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Roman sewer of Diocletian's palace in Split

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Subject review

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Diocletian's palace, built at the beginning of the 4th century, is the best preserved Late Roman palace in the world. The Palace, as all urbanized spaces, had its water supply and sewerage and, as an imperial building, the best one. All the former knowledge and findings of the sewage system, inside and outside of the Palace and new conclusions on project and realisation of this important, detaily planned and built roman infrastructural facilty are gathered in this article.

Key words:
Roman, Sewage, Aqueduct, Diocletian's Palace, Split

Pregledni rad

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Antička kanalizacija Dioklecijanove palače u Splitu

Dioklecijanova palača u Splitu, sagrađena početkom IV. stoljeća, najbolje je sačuvana kasnoantička palača u svijetu. Palača kao i svi drugi urbanizirani prostori u Rimskom Carstvu imala je sustav vodoopskrbe i odvodnje i to kao carska građevina vjerojatno najbolji. U ovom članku sabrana su sva dosadašnja znanja i svi nalazi sustava kanalizacije unutar cijele Palače i u njenoj neposrednoj blizini te su doneseni novi zaključci o projektu i realizaciji tog značajnog, detaljno planiranog i izvedenog antičkog infrastrukturnog objekta.

Ključne riječi:
antika, kanalizacija, vodovod, Dioklecijanova palača, Split

Übersichtsarbeit

Katja Marasović, Snježana Perojević, Jure Margeta

Die römische Abwasseranlage des Diokletianpalastes in Split

Der anfangs des 4. Jahrhunderts erbaute Diokletianpalast ist der am besten erhaltene spätrömische Palast der Welt. Der Palast war, wie alle urbanisierten Bereiche, mit Wasserversorgungs- und Abwasseranlagen ausgestattet, die erstklassig ausgelegt waren, da es sich um kaiserliche Bauten handelte. In dieser Arbeit sind die gesamten bisherigen Erkenntnisse bezüglich der Abwasseranlage innerhalb und außerhalb des Palastes, sowie neue Schlussfolgerungen hinsichtlich der Planung und Ausführung dieses bedeutenden und sorgfältig geplanten römischen Infrastrukturobjekts zusammengefasst.

Schlüsselwörter:
römisch, Abwasserkanal, Aquädukt, Diokletianpalast, Split

1. Introduction

In 305 the Roman emperor Diocletian left his throne in Nicomedia in order to spend the rest of his life in his native country, in a fortified palace close to Salona, which was at that time the capital of the Roman province of Dalmatia. He built the palace at the southernmost part of the Split peninsula in a well protected cove, at the place previously occupied by a monumental creation from the first century [1, 2] (Figure 1).

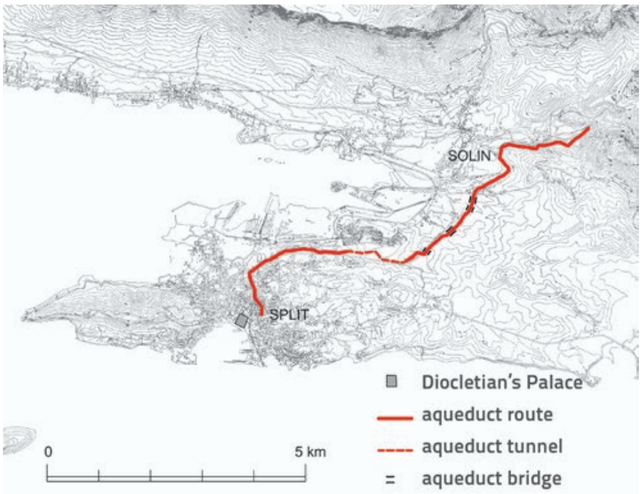


Figure 1. Palace's position in a wider region and the aqueduct route

After destruction of Salona in the seventh century, its residents found refuge within the safe walls of the Diocletian's Palace and initiated its transformation into the town of Split. Since these times, the life in the Palace has been going on without interruption, and the Palace itself is currently the oldest part of the city's historic core (Figure 2) which was included in 1979 into the UNESCO register of World Cultural Heritage.

Figure 2. Position of Diocletian's Palace within the historic core of Split

The Diocletian's Palace is rectangular in shape and measures 180 x 200 m in plan. It was built in form of a military camp with the emperor's residence facing south. It used to be fortified with sixteen towers on three inland sides, while it was rather opened toward the sea were it had a number of access points (Figure 3.). At each facade, the Palace had one gate, i.e. three inland gates and one facing south, with the gate position defined by the main streets of the Palace. In accordance with the traditional design of Roman towns, the Palace featured the *Decumanus* street about 12 meters in width, which ran from the eastern gate to the western gate, and the *Cadro* street, which extended from the northern gate to the *Decumanus* street. The square, known as Peristyle, was formed in the centre of the Palace. The Palace space was functionally divided into three basic parts, which can also be differentiated by their altitude (Figures 4 and 8):

- northern part (1.3 hectares in area), with the highest point at the north-eastern corner of the Palace (+ 8.20 m asl) and the lowest at the southwest, i.e. at the Western Gate (+ 5.50 m asl), accommodated the military and servants. The structures situated in this part of the Palace include dormitories, dining rooms, laundry rooms, kitchens, abattoirs, food and equipment storage rooms, etc. More than seventy smaller vaulted rooms were positioned along exterior walls, with the chemin-de-ronde right above them [2]. Two great structures with central courtyard were situated to the east and west of the *Cardo* street.
- central part, to the south of *Decumanus* (about 0.8 hectares in area), with the Peristyle in its centre, and with two sacral-funerary spaces (Themenos), bounded by a high wall (floor level at about + 6.40 m asl), to the east and west of the Peristyle. The Emperor's Mausoleum was built within the eastern Themenos, while three cult structures were erected within the western Themenos. Two baths, the so called eastern bath and western bath, were subsequently built (but still in ancient Roman times) in the space outside of the two Themenos zones (floor level at about +5 m asl) and they do not form a part of the original Palace design [2, 3].
- southern part where the emperor's residence was situated (about 0.7 hectares in area) was built on the substructure formed of more than 50 excellently preserved vaulted rooms about 8 meters in hieth, which are popularly known as *Cellars*. The emperor's residence was situated at a higher level compared to the central space of the Palace and the *Decumanus* street, at about +8.50 m asl. In this way, the emperor's quarters were to some extent physically separated from the other parts of the Palace (Figure 4).

Figure 3. Assumed appearance of the Palace (E. Hebrard)

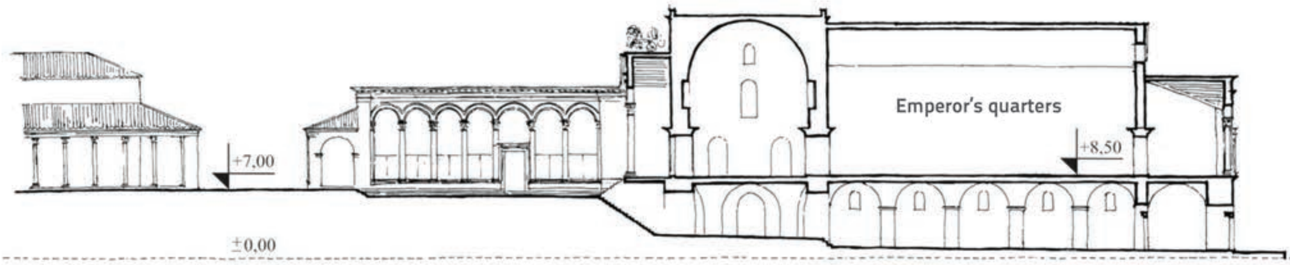


Figure 4. Diocletian's Palace, north-south cross section (J. Marasović)

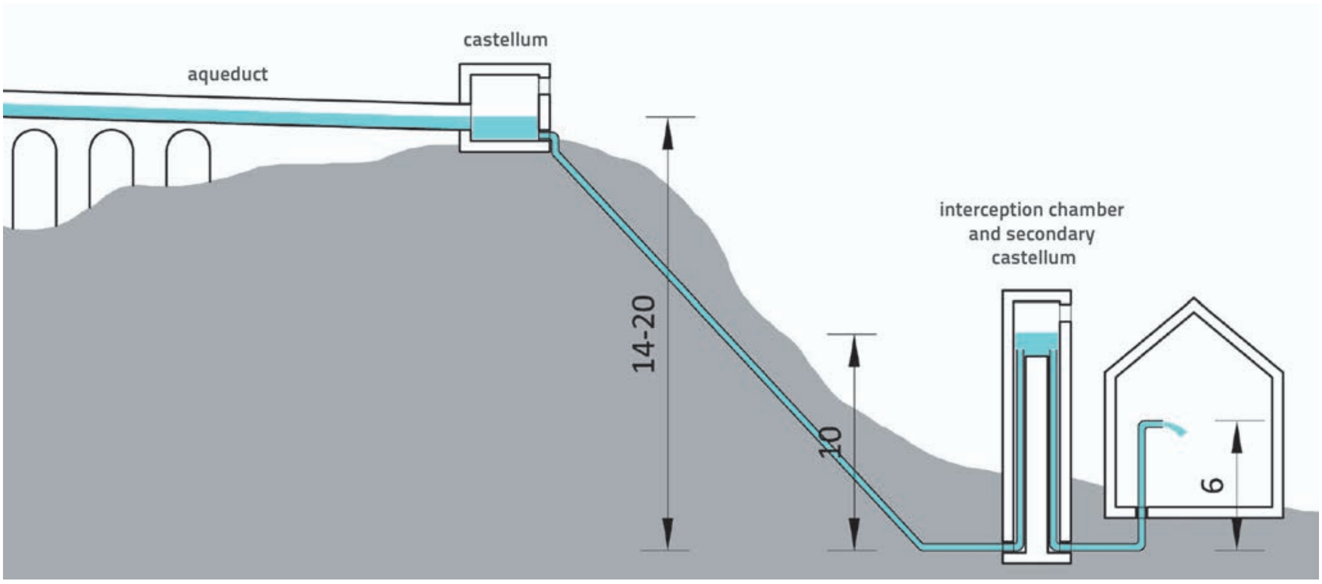


Figure 5. Typical functional elements of the water-supply system used in old Roman towns (according to Hodge, 1992)

The location of the Palace was carefully selected so as to meet all requirements for the emperor's residence and its defence, as well as all other requirements needed to ensure proper sustainability of the structure and its functions. Its altitude with respect to the source of water ensured water supply by gravity. Similarly, its vertical disposition and position at the sea coast enabled evacuation of all water from the Palace equally by gravity.

Romans knew that the good quality water and healthy surroundings are a precondition for safe and healthy life. This is especially significant for an isolated and fortified space, such as this Palace, in which a lot of people lived in close contact with animals. An aqueduct 9.5 km in length, starting at the Jadro rivulet source, was built in the 4th century to ensure water supply for the Diocletian's Palace (Figure 1). It was put out of use in the 7th century but was renovated and put to function in the late 19th century, and is even now in use. The water intake is at +33 m asl, and the longitudinal gradient of the channel varies from 0.65 to 2.66 ‰. The vaulted aqueduct channel measures 60/150 cm, and the maximum water depth in the channel is 120 cm. An average capacity of the water source is about 10 m^3/s, and the calculated capacity of the old Roman channel is approximately 715 l/s while 470 l/s is currently captured from this water source [4]. The aqueduct ended near the Palace with a distribution basin (*castellum divisorium*) whose exact location has never been established. It is however presumed that it used to stand somewhere on slopes of the Gripe Hill [5] about 250 meters to the northeast of the Palace at about +20 m asl. From the distribution basin, the water was carried to the Palace under pressure and by gravity and, within the Palace, it was distributed to several zones by lead pipes, to facilitate its usage. It may be assumed that the emperor's quarters had a separate water supply network, exclusively for the emperor and his entourage. Outfall points were of free flow type. The water-supply system used in the Palace did not have interception chambers which were common in greater agglomerations (Figure 5). In case of this Palace, The distribution basin – *Castellum* – ensured appropriate pressure of 6 m with respect to outfall points in the Palace.

The Palace also had its drainage system for the evacuation of water from bathrooms and fountains, and for rainwater disposal. It can be assumed that the faeces, food leftovers, and similar solid waste from animals were collected in separate pits which were emptied from time to time (dry procedure). However, the possibility that the wet process was also used in the Palace in addition to the dry process can not be excluded although the wet process is rarely encountered in ancient Rome.

Not much has been written to this day about ancient Roman sewerage systems. This is why an emphasis is placed in this paper precisely on the drainage system used in the Diocletian's Palace, which is an infrastructure system significant for maintaining health in urban agglomerations. The intention is to reconstruct the drainage system and to study in more detail its properties and construction method, as this effort has not so far been made.

District commissioner Mr. Ivan Burati found in 1857 an ancient Roman channel under the northern gate of the Diocletian's Palace [6]. Soon thereafter, in 1889, the idea was born to clean this system so that it can be used for municipal sewerage [7]. This proposal was however not realized. In his monograph about the Palace, Austrian architect Georg Niemann presented in 1910 his findings related to this ancient Roman sewerage [8].

In the scope of investigation and reconstruction works conducted after 1955, channels, original manholes, stone-made street drains, and cross channels that transported water from street drains into main channels, were discovered at several localities in the northern part of the Palace [9].

In 1981, conditions were finally put in place for clearing channels at the northern part of the Palace from the fill material and debris, and it is in this year that about 250 meters out the total of 560 meters of the main sewerage network were investigated [10-13]. Channels were filled with water as the sewerage outfall was backfilled and made dysfunctional already in the Middle Ages. To make the system functional, a design for the ancient channel extension to the sea was subsequently made [16]. The outfall section from Fruit Market to the sea was realized in 1996, and the remaining part has still not been realized.

The continued investigation of the sewerage system was enabled in 1995 by the Split based public utility company *Vodovod i kanalizacija.* This investigation revealed, in front of the northern gate to the Palace, the starting point of a big sewerage channel and the drainage system of the area to the north of the Palace [15, 16]. Several studies have been made in recent years to create preconditions for further investigations and revitalization of the ancient Roman sewerage system [17, 18]. All these investigations and findings, as well as the literature on the study of similar infrastructure facilities, were taken into account during rehabilitation of the Palace's drainage system.

2. Sanitation facilities and practices used in ancient Roman towns

The water drainage system used in ancient Roman towns and buildings largely depended on their use and significance. Each urban community had a rainwater and sewage drainage system which was mainly built in the centre of the town, while the so called decentralized system was used in suburban areas. All communities were supplied with running water from public fountains, and they also had appropriate sanitation facilities: public baths and toilets – *foricae* and urinals in every town district [19-21]. Only wealthier residents and persons of higher social ranking could afford private bathrooms and lavatories – *latrinae* – while other residents used public sanitation facilities. Palaces of wealthy citizens were equipped, next to sanitation facilities, with water tanks that were replenished either by water pipes or from palace roof, and with private fountains. Less privileged people, who often resided on building floors, had chamber pots which they emptied into special pits located near their place of residence, or they used common lavatories within the building. In some cases, the used water from higher parts of buildings was drained via verticals. Only rooms on the ground floor had pipe-based water supply [22]. Lavatories were not seldom built near the street and were accessible to public, but against payment. Residents of the lowest status and slaves were not allowed to use public sanitation facilities. In some communities, Romans collected urine and used it for processing textile and leather [19] and as a cleaning substance.

Archaeological findings have not been able to reveal how many public toilets provided running water both for personal hygiene and for flushing waste into sewerage. The sewerage system was not built for the sole purpose of collecting faeces. Nevertheless, according to relevant historical records, the waste and faeces were oftentimes discharged into street drains. Thus the waste arrived into the drainage system whose main purpose was to evacuate rainwater and used water [23]. The mixed disposal of rainwater and sewage facilitated creation of sludge and slimy accumulations in channels that were the dwelling place for rats and other animals, and the disintegration of organic matter resulted in the occurrence of hydrogen sulphide which, combined with water, formed acids that eroded the channels. The drainage system and outflow points did not have devices that would prevent propagation of stinking and poisonous gases that were formed in the sewerage. This is probably the reason why houses were very rarely linked to the street sewerage system, although this practice was allowed [19].

In addition to streets, some other public spaces such as squares, market places, etc., were also washed with water that was evacuated into the drainage system, which also accommodated water from public baths, fountains, public fountains and other places where water occurred in urban agglomerations. This means that the system was basically a mixed one and was used for the collection and disposal of all waters, but rarely of faeces.

In ancient Roman times, water was not purified before being discharged into the environment. As it constantly ran through the drainage system that was well aired, we may say that the water was partly treated through natural processes. The effect of such treatment depended on weather conditions and waste load. Most residents used decentralised, individual systems, i.e.

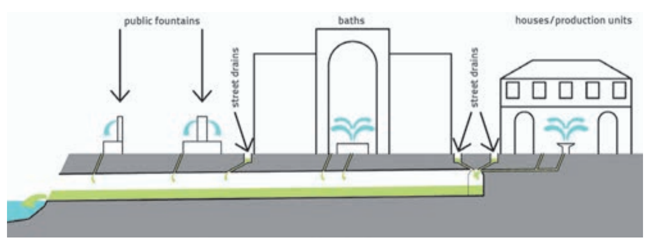


Figure 6. Functional elements of the water drainage system

septic tanks, and so it can be said that on-site sewage treatment systems were quite well represented. From time to time, the liquid part of the waste was extracted and discharged into environment or was used, according to some authors, in agriculture [24]. Similarly, solid waste was also often used in agriculture or was simply buried into the ground. In densely inhabited areas, such practices lead to contamination of environment, propagation of diseases, and spreading of illnesses. This was further aggravated by construction of toilets in the vicinity of kitchens, as the same pit was also used for the disposal of household waste. The situation was particularly difficult in warmer parts of the year. In order to reduce negative influences, waste disposal pits were built deeper, i.e. in parts of houses that were inaccessible to animals and less exposed to sun and heat. Thus the temperatures in pits were lower, and disintegration processes were slowed down. To prevent spreading of diseases, Romans paid great attention to the quality of water used in the water supply system, and they took care that water and water intake areas are protected from contamination. However, although Romans attempted to provide for good sanitary conditions, the health status of residents was often less than satisfactory due to the above mentioned deficiencies of sanitation systems used in urban communities.

3. Rehabilitation of drainage system used in Diocletian's Palace

Investigations of drainage system used in the Diocletian's Place in Split mostly confirm that the system was equipped with all of the above mentioned sanitation facilities that were available in these times, and that ensured comfortable and healthy life to the emperor and his entourage. Unlike the three currently known baths that existed in the Palace (out of which only one was included in the initial design of the Palace, while the remaining two were built at a later time) [2], the number and arrangement of other sanitation facilities (lavatories, fountains, public fountains, urinals, septic tanks) is still unknown. Although it is certain that such facilities did exist, their whereabouts and quantity have not as yet been determined. It can be assumed with a great level of certainty that the emperor's quarters had their own sanitation facilities which were inaccessible to the public, while the sanitation facilities for the military and servants were situated in the remaining parts of the Palace. Additional information about these facilities could be obtained by further study of the distribution of water evacuation channels and connections to these channels.

Channels and drains discovered so far provide a fairly accurate picture of the rainwater collection system. The entire Palace was provided with the surface water drainage system, which was also used for evacuation of all other waters that were supplied via aqueduct to the Palace. In fact, as in ancient Roman towns the water was constantly flowing in public and private buildings and houses, it had to be collected so as to avoid flooding and contamination of environment, and possible spreading of diseases in cases when water was polluted through its use. Such waters were therefore collected and evacuated by means of sewerage systems. The mixed sewage disposal system was used in the Palace, and the water drainage was operated by gravity.

The vertical and spatial disposition of the Palace required development of an appropriate water drainage system for the Palace and the surrounding area. In this respect, we may differentiate the drainage system and protection against external waters, drainage system for the northern part, central part around the Peristyle, and southern low-lying coastal part (Cellars), and the drainage system for the imperial part of the Palace above the Cellars. All these individual systems are united into a single integrated drainage system, which is in fact quite rarely encountered in the ancient Roman town drainage practice. However, as this is a fortified Palace of a high (imperial) ranking, the system was centralized to the maximum extent taking into account altitude differences within the Palace. Sea was the final recipient for all waters.

3.1. Water drainage for the Palace surroundings

The Diocletian's Palace was built right at the sea shore, at the end of a valley slightly sloping in the seaward direction, i.e. in the north-east south-west direction. Some smaller water streams, both under the ground and on the surface, are located in this area. The greatest surface stream is a creek situated in the present-day Manuš district (to the north of the Palace) (Figure 7). By analysing the original terrain configuration, it can be assumed that the creek most likely traversed the area in which the Palace was built, and was certainly diverted from that location to the east of the Palace toward the sea. Today this creek is channelized and runs under the town's open-air market (Pazar). The fact that a surface stream ran in the immediate vicinity of the Palace was quite favourable as it enable safe supply of water for various purposes.

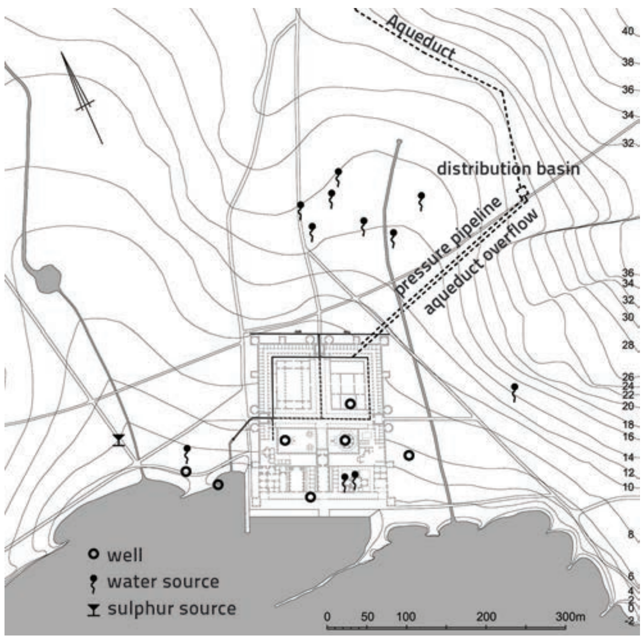


Figure 7. Area around Diocletian's Palace, assumed condition in the 4th century

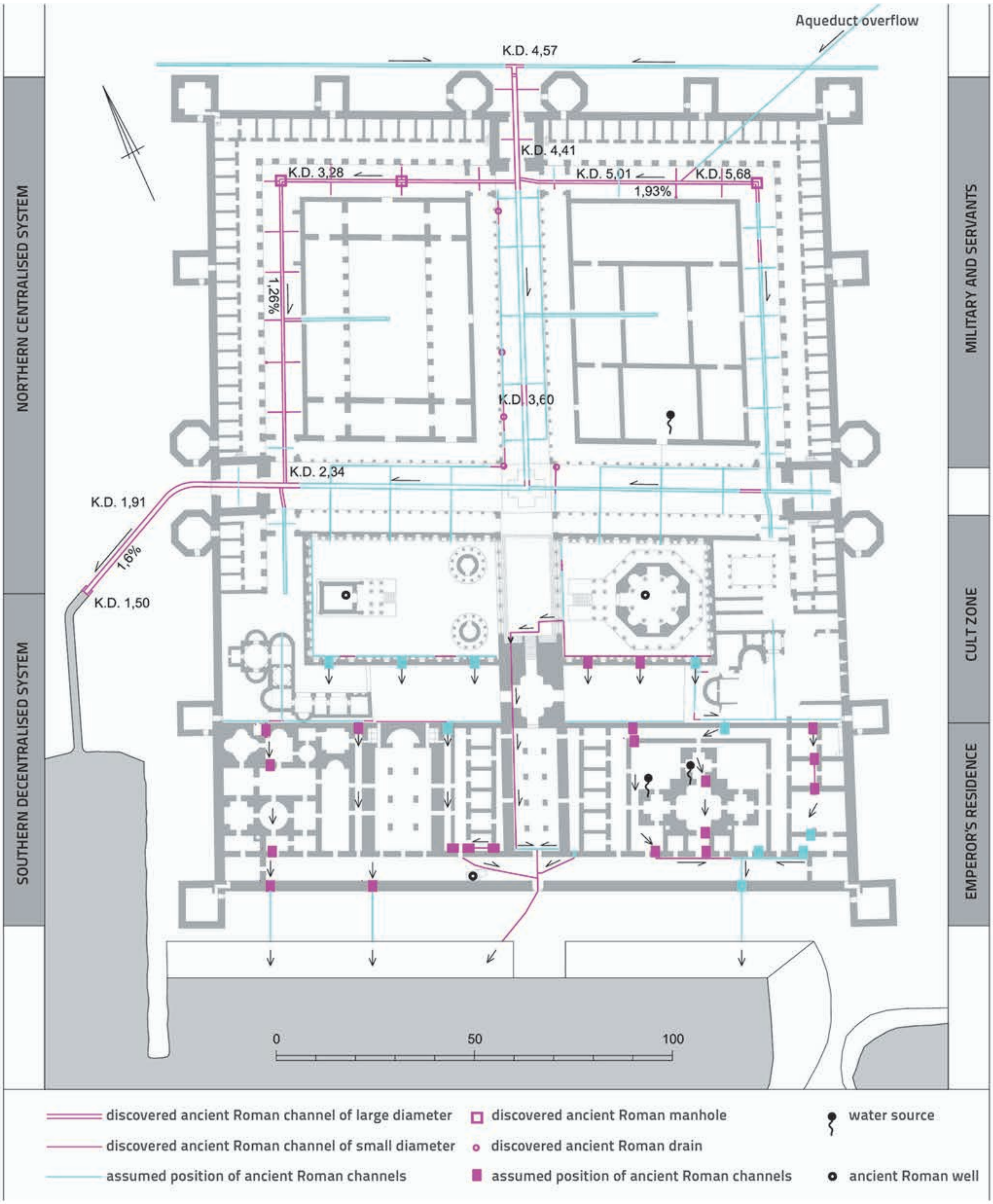


Figure 8. Schematic view of the Diocletian's Palace sewerage system

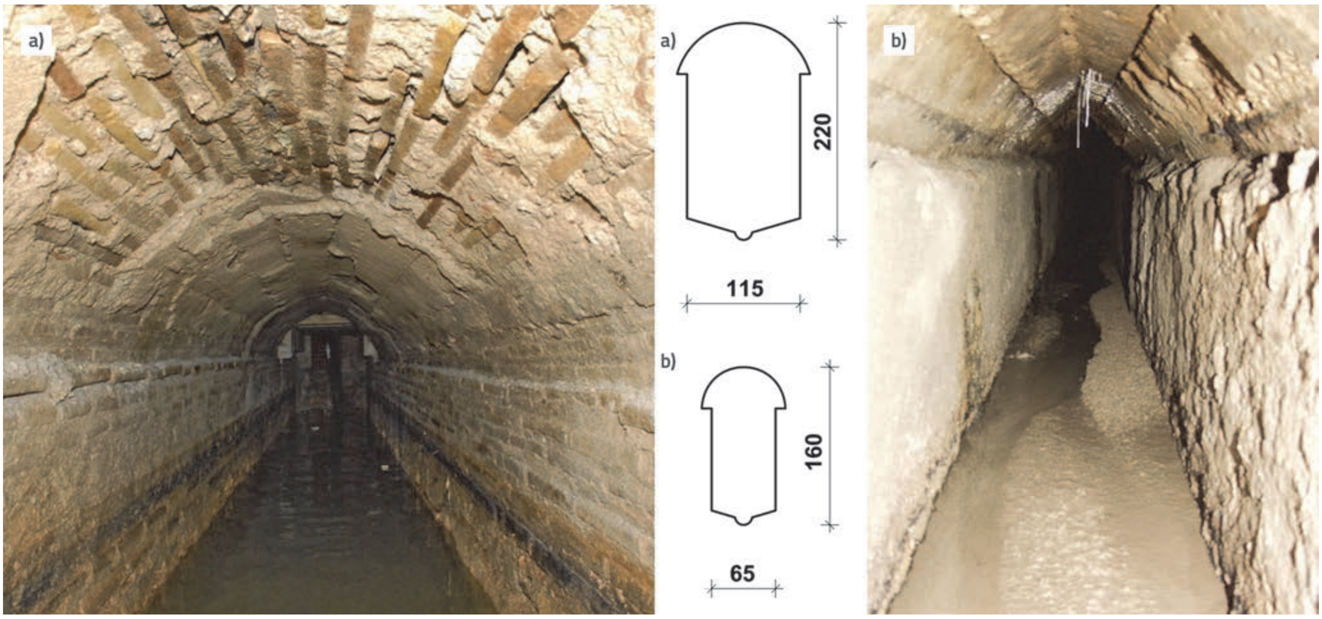


Figure 9. Large-section channels at the north part of the Palace (photos by: T. Bartulović)

The construction of this Palace constituted an obstacle to natural circulation of surface and ground waters, which ran from the north and discharged through the funnel like valley right in front of the northern facade of the Palace. Here they were collected in a peripheral drainage channel that ran parallel to the northern wall, almost touching the towers. Waters were evacuated in this way into the Palace's main sewer positioned in the Cardo street. This additionally ensured continuous rinsing of the main drainage channel. The drainage channel was made of small size semi-dressed stones measuring 45/50 cm, and its bottom was made of compacted earth [15].

3.2. Drainage system within the Palace

According to available data, it can be concluded that the Palace had two separate drainage systems (Figure 8):

- a uniform central drainage system by which the water was drained from the north and central parts of the Palace, from levels of more than + 5.50 m asl. All water collected in this way was evacuated via a single outfall situated outside of the west wall of the Palace.
- the south-side decentralized drainage system with several separate sub-systems and channels by which the water was evacuated directly into the sea from the south side. This system comprised emperors quarters situated at +8.50 m asl, and low-lying areas in the central part of the palace that could not be connected by gravity to the central drainage system.

3.2.1. North part of the Palace

Vaulted masonry channels are situated in the axis of streets situated in the northern part of the Palace, including *Decumanus*. The highest point of the channel bottom was at the north-east (+ 5.68 m asl), while the lowest was at the south-west (+ 1.50 m asl). These channels follow natural configuration of the terrain and their gradient varies from 1.26 to 2 % (Figure 9).

The main sewerage channel situated in this part of the Palace measures 230 m in length, and 115/220 cm in cross-section (Figure 9.a). It runs along the axes of *Cardo* and western part of *Decumanus* and leaves the Palace by passing under the western gate. At that point, it slightly turns towards the south-west and ends forty meters away from the gate with a portal-shaped outlet structure which was discovered in 2011 [25]. The portal measures 115/127 cm in diameter, and its bottom is at 1.50 m asl (Figure 10). From the outlet structure, the water was evacuated by open channel into the sea. Walls and vault of main channels were built using roman brick measuring 36x36 m 4 cm in thickness, lined with a thick layer of mortar. The water flow profile of the channel was 115 x 180 cm. According to the mentioned archaeological explorations undertaken in 1995, the portal shaped inlet structure of the channel measuring 115 x 160 cm, made of big dressed stone blocks, was discovered eleven meters to the north of the Palace's northern gate [15] (Figure 11). Two holes were found at the bottom side of the stone lintel. These holes provided seat for a rotating two-winged metal bar that prevented people and animals from entering the Palace's sewerage system (Figure 12). It is at this point that the already mentioned drainage channels from the east and west sides were connected with the main channel. The bottom of the starting point of the channel is at + 4.57 m asl.

The mentioned main sewerage channel situated in the northern part of the Palace is joined by smaller channels 65/160 cm in diameter (Figure 9.b), 333 m in total length. The maximum water height in channel amounted to 120 cm. A cascade was realized at the point where these channels join the main channel: their

Figure 10. Outlet structure discovered in 2011 at Hotel Central [25]

Figure 11. Inlet structure discovered in 1995 in front of the northern gate of the Palace

Figure 12. Holes for metal door in the stone lintel of the inlet structure [5]

bottom is higher than the bottom of the main channel and, viewed in plan, they are staggered with respect to one another at the crossing with the main channel. This was done in order to prevent backwater and return of water in case of a high water level in the main channel [17, 18]. These channels are made of semi-dressed stone, and their vault is built with ancient concrete. Traces of wooden formwork used to this effect are still visible. In explorations conducted in 1980s a connection was discovered with the channel of the same diameter in the western part of *Decumanus* (crossing point between the Krešimir and Adam streets). This channel collected water from the area to the south of *Decumanus*. Original manholes measuring 45 x 45 cm in size (Figure 13) were discovered at the north-eastern and north-western corners of the sewerage network and in the western part of the northern *Decumanus*.

Transverse channels evacuating water from street drains discharged this water into main and secondary channels, at the vault level. Streets were paved with big stone slates which were preserved to this day at a big surface in the eastern part of *Decumanus*. Streets had a big cross slope toward the curb of street porticos. The water discharged into stone drains placed along the edge of the street. In side streets, drains were directly connected with smaller channels with the main channel positioned along the street axis (Figure 14). In *Cardo*, drains were connected with each other by a longitudinal channel that followed the edge of the

Figure 13. Original manholes (Urban development institute of Dalmatia)

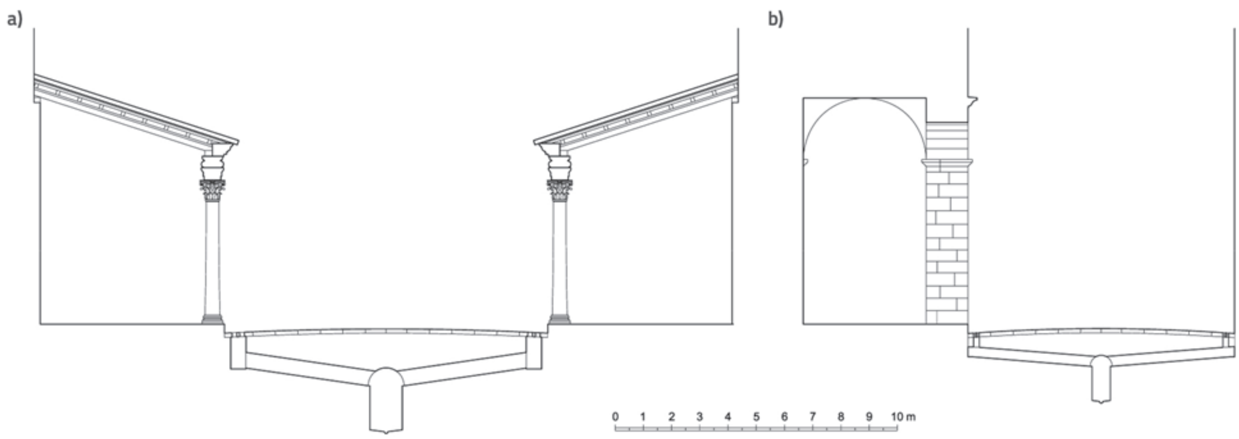


Figure 14. Cross-section through the main and western *Cardo*

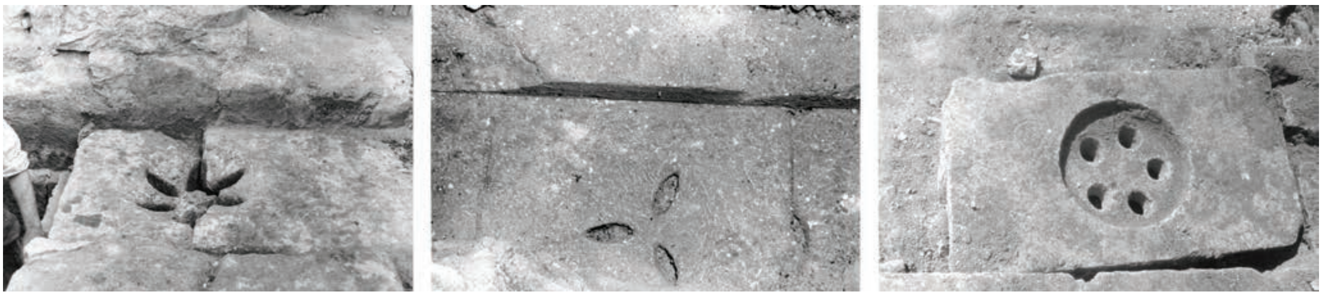


Figure 15. Stone drain types used in Diocletian's Palace (Urban development institute of Dalmatia)

street, and was then connected to the main street channel by a transverse channel.

Four stone drains shaped as six-petal rosettes, and an another one shaped as a three-petal rosette, have so far been discovered. Two simpler drains with five circular holes were discovered in the southern part of the Palace (Figure 15). It is interesting to note that no rosette-shaped drains were discovered at the southern edge of the eastern part of *Decumanus* where, as already mentioned, the initial paving has been almost completely preserved. It can now be assumed that the water was collected by means of water inlets placed in portico curbs in a way that is similar to drainage solutions that are currently in use.

The rain water from courtyards of two big construction blocks situated in the northern part of the Palace (western courtyard measuring 19 x 40 m, and eastern courtyard measuring 16 x 25 m) had to be collected and evacuated into big street channels. Fountain overflows, and water from bathrooms and lavatories, also had to be evacuated into big street channels. A larger profile channel which ran from the western block courtyard to the western Cardo channel was discovered in the scope of explorations conducted in 1950s [9].

The basic sewerage system is quite sizeable and so the aeration was good in dry season. Hence, it can be presumed that anaerobic processes of organic matter deterioration were not intensive in the channels. The ventilation was operated via street drains that were positioned as appropriate over the entire space of the Palace. The situation was even more favourable in the rainy season when the quantity of inflowing water was considerable, and so the effluent was greatly diluted. The combination of permanent outflow from sanitation facilities and fountains in the dry period, and abundant precipitation in the rainy season, ensured proper rinsing of the sewerage system. A transverse channel is linked to the street channel 65/160 mm in diameter in the eastern part of the north-side *Decumanus*, nineteen meters away from the highest point of the main sewerage network (which is situated at the north-eastern corner of the Palace). This transverse channel, unlike the other ones, is connected at an angle of about 45 degrees (viewed in plan), and it comes from the possible site of the distribution basin of the aqueduct. According to the normal Roman practice of rinsing sewerage using overflow water from the aqueduct, it can be assumed that this is the connection of the overflow channel from the aqueduct (distribution basin), which additionally ensured proper rinsing of the channel. Solutions used in this Palace clearly show that great efforts were made to ensure proper sanitation conditions in the Palace.

It would be difficult to believe that faeces were simply disposed of in the street, although this was sometimes a normal practice in Roman towns. However, a part of the waste from floor surfaces of the Palace, e.g. animal droppings and similar waste, was probably regularly cleaned with water that was then evacuated into the sewerage system. Kitchens for the military and servants had to be located in the northern part of the Palace, and so it can be assumed that pits for the disposal of food leftovers, probably linked with lavatories, were also located in this zone. It is not known whether public lavatories situated in the northern part of the Palace were continuously rinsed with water from the aqueduct, or from the overflow from fountains and baths or if, perhaps, only dry lavatories were used.

The cross-section of channels usually increased in the downstream direction to take into account an expected increase in water flow. However, standard channel dimensions (115/220 cm and 65/160 cm) were used in the Palace to simplify their realization. This approach is quite logical as total channel lengths were not excessive and so it would not be justified to change dimensions on such short sections. Channel dimensions enabled movement of people, and thus good maintenance of channels was ensured. This is yet another proof that Roman builders left nothing to chance.

The channel capacity was quite large (cf. Table 1). If we take that the surface water concentration time is ten minutes, and that the rainfall recurrence interval is one hundred years, then the reference rainfall intensity is about 370 l/s/ha [26]. If we take into account the drainage area of 4 hectares (northern and central parts of the Palace, and valley to the north of the Palace), and the runoff coefficient of 0.7, then the quantity of surface waters amounts to 1.03 m^3/s. Of course, the climate and hydraulic runoff parameters were probable different in the past and so the quantity of water was perhaps also different, but this difference should not have been great. If we add to this quantity the water from the water supply system (0.7 m^3/s) then the result is 1.7 m^3/s. Thus it is quite obvious that the existing channels had considerable capacities, i.e. their capacities were more than sufficient to accommodate all waters coming to the Palace and the rain water. Channels were also properly dimensioned to accommodate surface waters which ran from the surrounding area toward the Palace.

Table 1. Hydraulic features of channels (absolute roughness 20 mm)

Channel	Maximum water height in channel	Downward grade 1,26 %		Downward grade 2,0 %	
š/v [cm]	h [cm]	Q [m^3/s]	V [m/s]	Q [m^3/s]	V [m/s]
115/220	180	6,8	3,29	8,6	4,15
65/160	120	1,95	2,31	2,45	2,91

3.2.2. Southern part of the Palace

Three distinct sections can be differentiated in the southern part of the Palace: a) central space to the south of *Decumanus*, b) vaulted rooms (Cellars) that carry the emperor's quarters, and c) emperor's quarters above the Cellars (Figure 4).

Central space to the south of *Decumanus*

The central space to the south of *Decumanus* comprises: central square (Peristyle) , eastern *Temenos* with mausoleum, and western *Temenos* with three cult structures, all of them situated at an average level of + 6.40 m asl. The Peristyle drainage was solved with the southern channel leading to Cellars. Waters from the northern part of the eastern and western *Temenos* were probably discharged into the *Decumanus* channel, as the differences in levels are favourable for such arrangement. Because of the low level of the Mausoleum crypt (+ 4.40 m asl) and temple (+ 4.60 m asl), the water from the southern part of *Temenos* could not be evacuated into the *Decumanus* channel, and so the water from this space (mostly consisting of rainwater) was discharged via stone drains into channels and evacuated through several culverts in the southern walls of *Temenos*, and from there southward toward Cellars. The above information was confirmed by excavations conducted in 2013 (cf. Figure 8). Heated baths, probably with adjacent public lavatories, were subsequently built in the westernmost and easternmost parts of this central zone of the Palace. Baths used a great quantity of water for their pools and fountains, and this water had to be collected and evacuated via a drainage channel. Considering the differences in level between the baths and channels, it can be assumed that the eastern and western bath channels ran southwards into the Cellars and, through them, the water was evacuated into the sea. This leads us to the conclusion that possible lavatories were probably dry facilities with occasional rinsing only. This will additionally be explained through further investigations.

The emperor's quarters substructure: Cellars

Water culverts 41 - 56 cm in width were discovered in the northern wall of Cellars (Figure 16.a). These culverts provided passage for the earlier mentioned water coming from the public part of the Palace to the south of *Decumanus*, and for underground waters, and also probably for waters coming from subsequently built public baths.

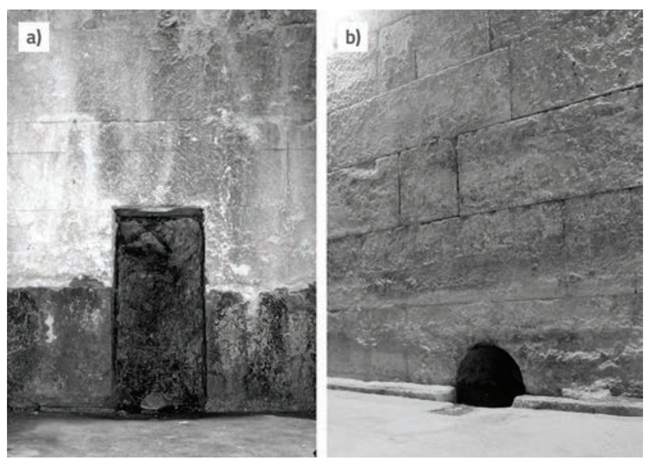
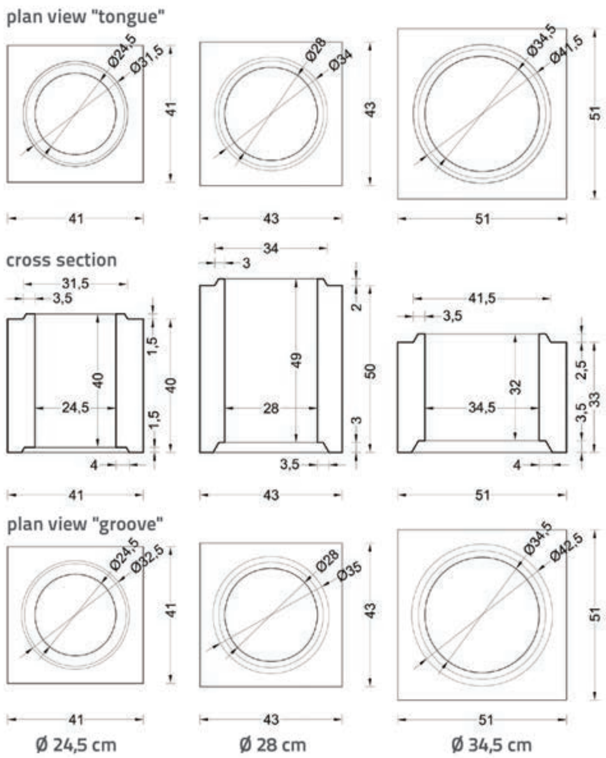


Figure 16. Culverts in cellar walls (authors)

As according to investigations the floor in Cellars was not improved by human action (except in the central hall and southern corridor) and it consisted of undeveloped space with local cliffy protrusions (stacks), it can reasonably be concluded that cellars were not used and that they served exclusively as a load bearing structure providing support for the emperor's

Figure 17. Stone pipes



Figue 18. Stone pipe types found in Cellars of the Diocletian's Palace

Figure 19. Ancient drainage vertical made of stone pipes, discovered in 2013 in the ancient wall of an eastern structure of the northern part of the Palace (No. 1 Julius Nepot Street)

quarters above them. In any case, the Cellar floor was inclined southwards so as to direct the waters reaching the Cellars toward outfalls situated in the southern Palace wall (Figure 16b) and this via several simple open channels realized for this purpose. It should be noted that in the fourth century the sea level was by about 1.7 m lower compared to the present situation, and so the water ran into the sea by gravity. The water from Peristyle was also evacuated toward the sea by a drainage channel which passed through the central cellar rom and under the southern door to the Palace and, from there, it continued for 12 meters to the point where it discharged into the sea.

Emperor's quarters

The emperor's apartment situated at the south side of the Palace is not much preserved and it is therefore quite difficult to reconstruct its drainage system. It is located at +8.50 m asl. The water coming from peripheral roofs of the emperor's quarters was evacuated directly outside of the Palace, while water coming from internal roofs ran down to Cellars through four long and narrow lightwells and four internal courtyards. However, considering the arrangement of rooms, additional verticals had to exist at some points. During explorations in the Cellars, over thirty pieces of stone tubes 24.5, 28, and 34.5 cm in diameter, were found in the centuries-old embankment which, according to treatment technique and mortar preserved at connection points, could be dated back to Roman times (Figures 17 and 18). In ancient Roman times such stone pipes were used for aqueduct siphons, but also as vertical shafts for water drainage (e.g. at the amphitheatre in Arles) [27]. Similar stone pipes measuring 20 cm in diameter were used in the 19th century Split as drainage verticals. According to a recently found drainage vertical made of stone pipes, discovered in an ancient wall of an eastern structure at the northern part of the Palace (at No. 1 Julius Nepot street) [28] (Figure 19), it can reasonably be assumed that some pipes found in Cellars were actually used for vertical drainage in the emperor's quarters. As to faeces disposal from the emperor's quarters, it can be assumed that this disposal was solved via individual chamber pots.

4. Experience, conclusions and recommendations

The Diocletian's Palace in Split is the world's best preserved late antiquity palace thanks to the fact that the town of Split was actually formed within its walls in the seventh century. Although the Palace transformed over time, many original ancient Roman structures were preserved to this day. One of them is an excellently preserved sewerage system that is presently for the most part backfilled.

The entire system used for evacuation of waste water and rainwater from the Palace, and the system used for the disposal of waste matter (human faeces, animal droppings, and waste waters from households and the Palace), is reconstructed in this paper. The technology used for water collection and transport, typical facilities forming the system, capacity of the system, and system maintenance conditions, are presented based on the data obtained through excavations, information from literature, and according to current knowledge about drainage systems. While the system formed of big channels situated in the northern part of the Palace has been known since 1980s, this paper presents for the first time the secondary network formed of smaller channels that are linked to the main system. Furthermore, the overall network enabling drainage of streets and structures in the northern part of the Palace is reconstructed based on the channels explored to this date. In addition, results of various archaeological explorations made in the southern part of the Palace are presented in a single document, and the entire channel network for this part of the Palace is reconstructed. On this basis, it can be concluded that the Palace had two separate drainage systems

- a uniform central system for the drainage of water from the northern and central parts of the Palace and for evacuation of this water to the west of the Palace and
- the south-side decentralized drainage system with several separate subsystems and channels through which water was discharged directly into the sea in front of the southern façade.

The waste water and rainwater drainage system used in the Palace, and the system for protection against external surface and ground waters, constitutes an excellent example of the ingenuity of engineering practices and solutions used in ancient Roman times. This detailed analysis enables us to conclude that, by selecting the best protected part of the cove for the location of this Palace, designers and builders of the Diocletian's Palace took into account not only the requirements aimed at ensuring safe mooring of the arriving ships, but also those concerning water supply and drainage. Thus the altitude of the Palace with respect to the water intake ensured an appropriate pressure in the water supply system, while the distribution of higher and lower parts within the Palace, as well as the distribution of channels, enabled an efficient drainage of all areas.

The concept, details and individual solutions were elaborated in accordance with standard sanitary engineering practices, which have not greatly changed since these times. Today, just like in ancient Roman times, the main task of the drainage is to evacuate waste water from the structure in the fastest and safest manner, with the smallest possible impact on residential zones and natural environment. It is completely clear that the sewerage system and the entire design of the Palace was thoroughly elaborated prior to the start of construction, especially as it is well known that construction of drainage systems, in these times and also today, is the first phase in the construction of any structure. All outstanding achievements of the Roman design and construction are in many ways visible in the Diocletian's Palace. This is quite understandable when we know that this Palace is an outstanding complex made for one of the most significant Roman emperors.

By defining the system built for the drainage of waste and rain water, and for disposal of waste substances from the Palace, conditions have been created for further closely targeted excavations aimed at checking validity of the currently accepted concept, and also for further explorations. According to long-term plans, the sewerage system of this Palace is to be for the most part renovated and made accessible to the general public.

Considering the scarce data on the exploration of ancient sewerage systems compared to other architectural achievements of these times, results of this research are expected to contribute to the study and understanding of other drainage systems used in the antiquity.

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