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ROMAN AQUEDUCTS ON THE ISLAND OF PAG

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In the time of the Roman Republic the northern and most fertile part of what was then the island of Cissa was the private agricultural latifundium considered that of the Calpurnia family. Since there was a lack of fresh, running water an aqueduct was constructed. The sudden and destructive bora in the channel below Velebit forced increasing numbers of vessels to find new bays further south. Among these was Novaljska draga which had an excellent position but no running water. To remedy this the Škopalj – Novaljska draga aqueduct was built, one of the most ambitious and expensive Roman hydraulic constructions in this part of the Adriatic. It is considered that it was built during the time of the Antonine imperial dynasty.

Key words: aqueduct, Roman period, Pag, Croatia
Ključne riječi: akvedukt, rimsko doba, Pag, Hrvatska

The island of Pag differs from all other Croatian Adriatic islands in that during Roman times two aqueducts were built on it.

ROMAN – LIBURNIAN AQUEDUCT KOLAN-*CISSA*
ROUTE OF THE AQUEDUCT

The source of the aqueduct was 66 m above sea level (*figs* 1 and 2). In a drought, about 100 m below the source, it is possible to see the position of the narrow course of the channel which was not dug very deeply (*fig* 3). The route of the aqueduct cut across the ancient road from **Bunar** through Kaštel to Novalja ending at **Japnjača** (*fig* 1: 3). An ancient reservoir was once sited here which did not only serve as a reservoir but also allowed sediment to drain out. So that the gravitation aqueduct should maintain its calculated height from Japnjača onwards it was carried increasingly high above ground level. (*fig* 4).

The route cut across today's asphalt road and into the **Slatina** area where as much as 2 metres high remains of the substruction of the aqueduct channel are still visible (*fig 5)*. After leaving Slatina the route went across **Banjadolac** (*fig* 1: 7–8). It crossed the valley with the aid of arches almost 5 metres high (*fig*. 6). From the south, but only from the south, the construction was shored up by buttresses as protection against the fierce winds of the *bora* (*fig* 7).

The route went around the **Špital** region. It now no longer took an isohyptic course and cut across **Punta Zrče** (*fig* 1: 11). Only here is the whole construction of the aqueduct preserved. As can

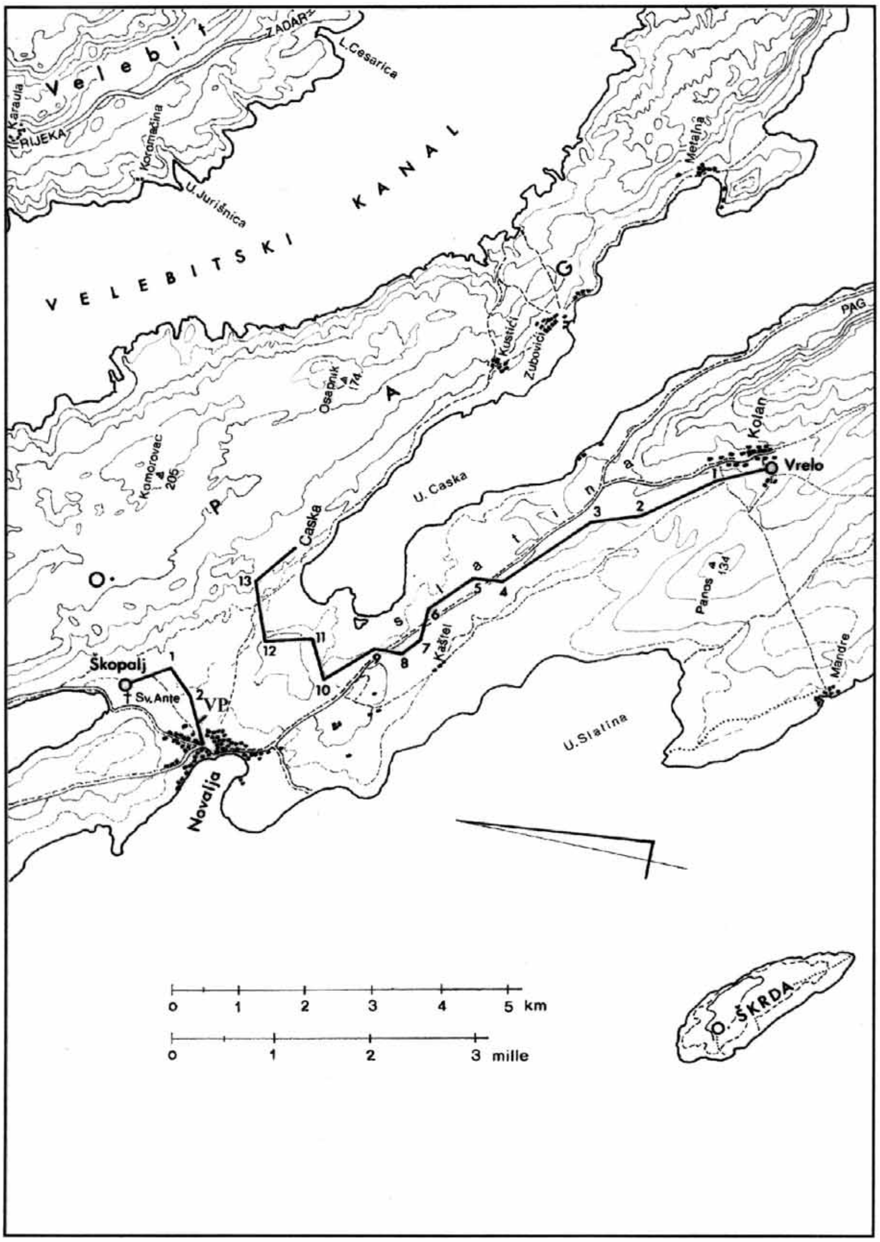

Fig 1 – The course of the aqueducts (B. Ilakovac).

Sl. 1 – Trase akvedukata (B. Ilakovac).

be seen on ground plan and cross section 1–2 on *fig* 8, after making its way through a 130 metre long cutting the first stonework path A is found with walls on either side B. The inside of the channel was covered with three layers of a special water resistant cement (*opus caementitium*). The channel was 15 cm wide *(fig* 9). and covered with Roman bricks 42.5 cm x 29.6 cm and 7.4 cm thick the cutting was at the end filled in and covered with the excavated stone.

Fig 2 – The Bunar source (B. Ilakovac).

Sl. 2 – Vrelo Bunar (B. Ilakovac).

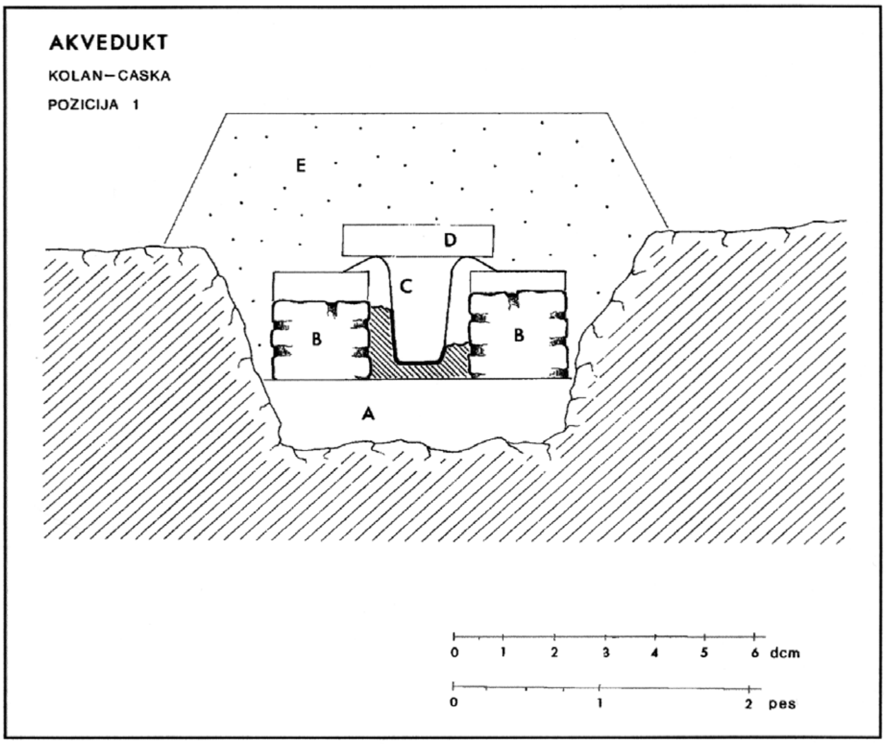

Fig 3 – Cross-section at he position 1 (B. Ilakovac).

Sl. 3 –Položaj trase 1 (B. Ilakovac).

Fig 4 – Remains of the aqueduct substruction, position 3–4 (B. Ilakovac).

Sl. 4 – Ostaci visokog nosača, položaj 3–4 (B. Ilakovac).

After the cutting at Zrče the route followed the configuration of the terrain and ended at the point marked 12 (*fig* 1). There is a watershed across Novaljsko polje, known locally as **Anđelka**, which divides the north of Novaljsko polje from the Caska bay. We may suppose that the route came to this point where the valley is at its highest and narrowest point and crossing it would be most easily be possible with an expensive short lead piped siphon (*fig* 1: 12–13). Anton Šanko found here the remains of the lead piping of what had been a siphon (ILAKOVAC 1981a :278; 1978: 445; 1982: 175). From point 13 (*fig* 1) to Caska no more remnants of the aqueduct have been found except for scattered constructions for the channel beside the path from Škopalj to Caska.

CAPACITY (ILAKOVAC 1982: 96)

L (length from Bunar to point 12) = 8209 metres

H (height difference between Bunar, 66 metres, and point 12, 23.6 metres) = 42.40 metres.

I (incline of gravitational channel from Bunar to point 12)

H / L = 42.4 m / 8209 m = 0.00516 = 1 / 139.6

U (length of wet cross-section of the channel) = 0.48 m

F (surface of a section of the watercourse) = 0.041 m^2

R (hydraulic radius) = F / U = 0.041 m^2 / 0.48 m = 0.085 m

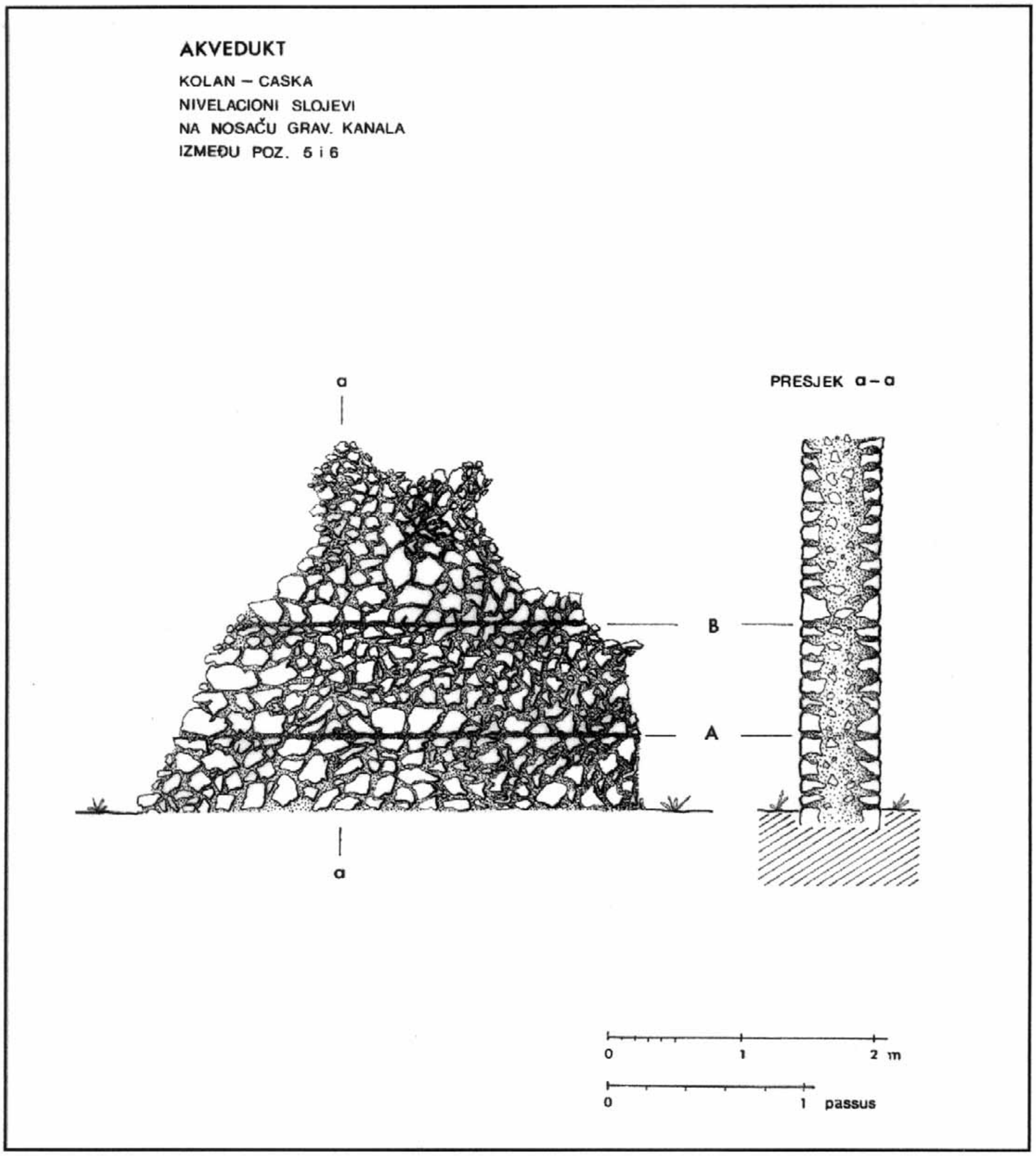

Fig 5 – Slatina, position 5–6 (B. Ilakovac).

Sl. 5 – Slatina, položaj 5–6 (B. Ilakovac).

b (coefficient of friction) = 0.35

v (speed of flow of water) = 100 x R x vI / b + vR = 100 x 0.085 x v0.00516 / 0.36 + v0.085 =

v = 0.92m/s

Q (capacity) = v x F = 0.92 m/s x 0.041 m² = 0.038m³

Q = 38 litres per second (maximum)

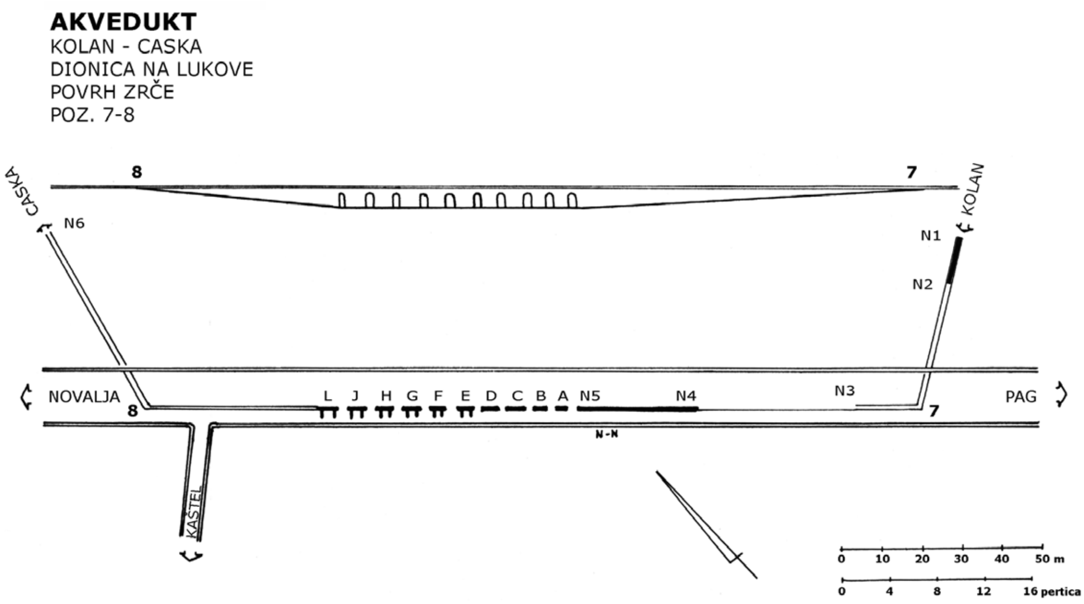

Fig 6 – Banjadolac, position 7–8 (B. Ilakovac).

Sl. 6 – Banjadolac, položaj 7–8 (B. Ilakovac).

DATING

The only evidence for dating is provided by the single find of a piece of roofing tile (*tegula)* which was built into a section of the arch construction in the Slatina region, this bears the factory mark SEX APPVLEIO C (*fig* 10). Such factory marks on the edge of tiles are found only on the oldest Roman tiles. R. Matijašić, the leading expert on Roman tiles in Croatia, does not know of any brickworks with this mark.

ROMAN AQUEDUCT ŠKOPALJ – NOVALJA

Trading vessels using the channel below Velebit were at risk from the terrible strength of the bora or north-westerly wind which unexpectedly swept down from Velebit. If ships were to avoid the Velebit channel, taking a route around the southern coast of Pag, bays and anchorages were needed where mariners could stock up on supplies, avoid bad weather and get drinking water.

One of these was **Novaljska draga** (Novalja Bay) which had not kept its Liburnian name. It had a number of advantages. It was protected from the east wind (*levant*), from strong southerly winds and from the *bora* from the north. It was open only to the west from which came the gentlest and most refreshing wind, the *maestral* (*fig* 1). Another advantage was that the shore was not rocky but gently shelving which meant that if need be even somewhat larger boats might be driven on shore without great damage.

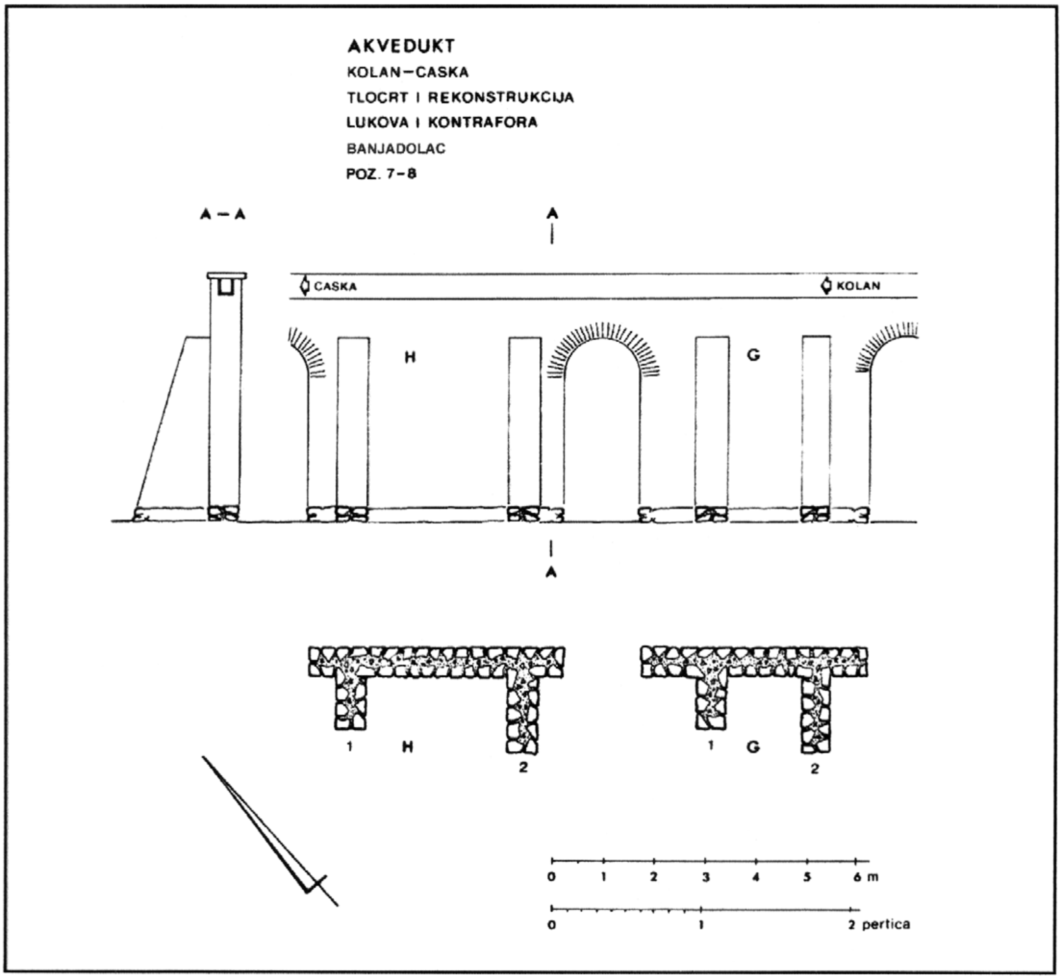

Fig 7 – Banjadolac, reconstruction (B. Ilakovac).

Sl. 7 – Banjadolac, rekonstrukcija (B. Ilakovac).

BUNAR SPRING – NOVALJSKA DRAGA

Not 12 kilometres east of Novaljska draga there is still a well known spring that has not retained its Liburnian name and is known by local people simply as **Bunar**.[1] It is 66 metres above today's sea level and between it and Novaljska draga there are no land obstacles that would require the excavation of a deep cutting, the construction of a gravitation canal on high supports or the making of a tunnel. (*fig* 1). These advantages would have allowed simpler, faster and cheaper construction of a new aqueduct for Novaljska draga. But there was one insurmountable obstacle. The Bunar spring was on an estate, perhaps belonging to the Calpurnii, as there is an inscription mentioning *Calpurnia L. Pisonis auguris filia* (STICOTTI 1940: 177–178; ŠONJE 1958; ŠAŠEL 1962; KURILIĆ 2004: 7). One might speculate that in early times they had built for themselves their private aquedu-

1 The toponym *bunar* is the only word on Pag derived from Turkish (SKOK 1950:73)

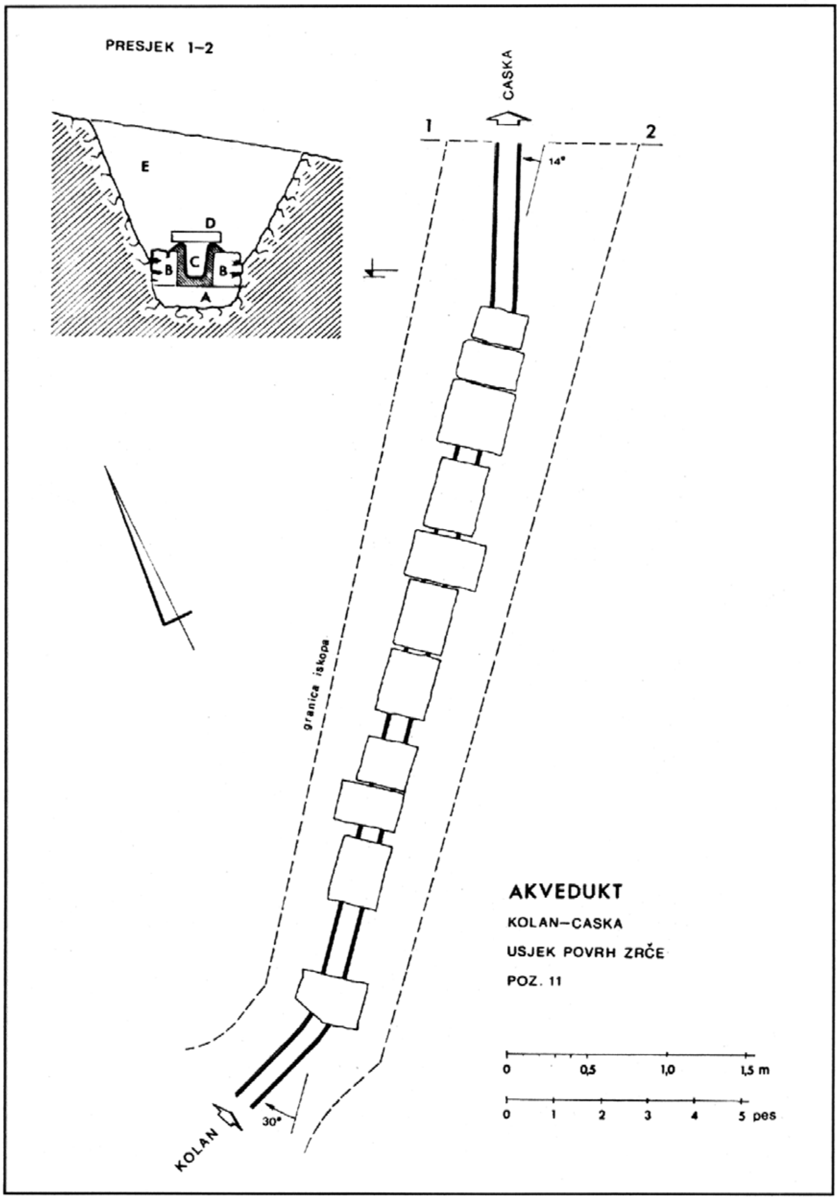

Fig 8 – Punta Zrče, position 11 (B. Ilakovac).

Sl. 8 – Punta Zrče, položaj 11 (B. Ilakovac).

ct to *Cissa*. If the Bunar spring were used to provide water for the Novaljska draga aqueduct, then the local population of *Cissa*, then the largest settlement on the island, would be left without drinking water.

During the time of the Roman Republic before the formation of Octavian's principate (27 BC) one of the richest families in Rome was the aristocratic Calpurnia family (*cf*, RE V, 1365–1408 s.v. Calpurnius; Tac. *Ann.* I.39, IV.36, 62; Suet. *Caes.* 21). The fourth wife of Gaius Iulius Caesar

Fig 9 – Punta Zrče (B. Ilakovac).

Sl. 9 – Punta Zrče (B. Ilakovac).

(100–44 BC) was Cornelia, the daughter of Lucius Piso. Gneus Calpurnius Piso, consul in 23 BC, was in opposition to Octavian, Emperor Augustus (27 BC –14 AD). He was succeeded by his son the priest (*augur*) Lucius Calpurnius Piso. The tragedy that during the time of Octavian and later overcame this once powerful patrician Roman family can be discerned in the artistically composed inscription of Calpurnia, niece of Gaius Lucius Piso and daughter of Lucius Piso (ŠONJE 1958: 311; ŠAŠEL 1963: 387; KURILIĆ 2004: 7).

ŠKOPALJ –TRINČEL BAY

The square network of stone walls that once protected the fertile, supposedly Calpurnian (STICOTTI 1940: 177–178; ŠONJE 1958; ŠAŠEL 1962) fields is best seen in the Novalja valley. There is a well known spring there called **Škopalj** which is still visible, and is only a few hundred metres from Trinčel bay (*fig* 11). If a pier had been built for ships in Trinčel bay and water brought to it from Škopalj ships moored there would have had access to plenty of fresh water, and it would have been a short aqueduct, no longer than 500 meters, and built without any construction obstacles. But Trinčel bay had one great and insurmountable drawback which prevented ships from using it. It did

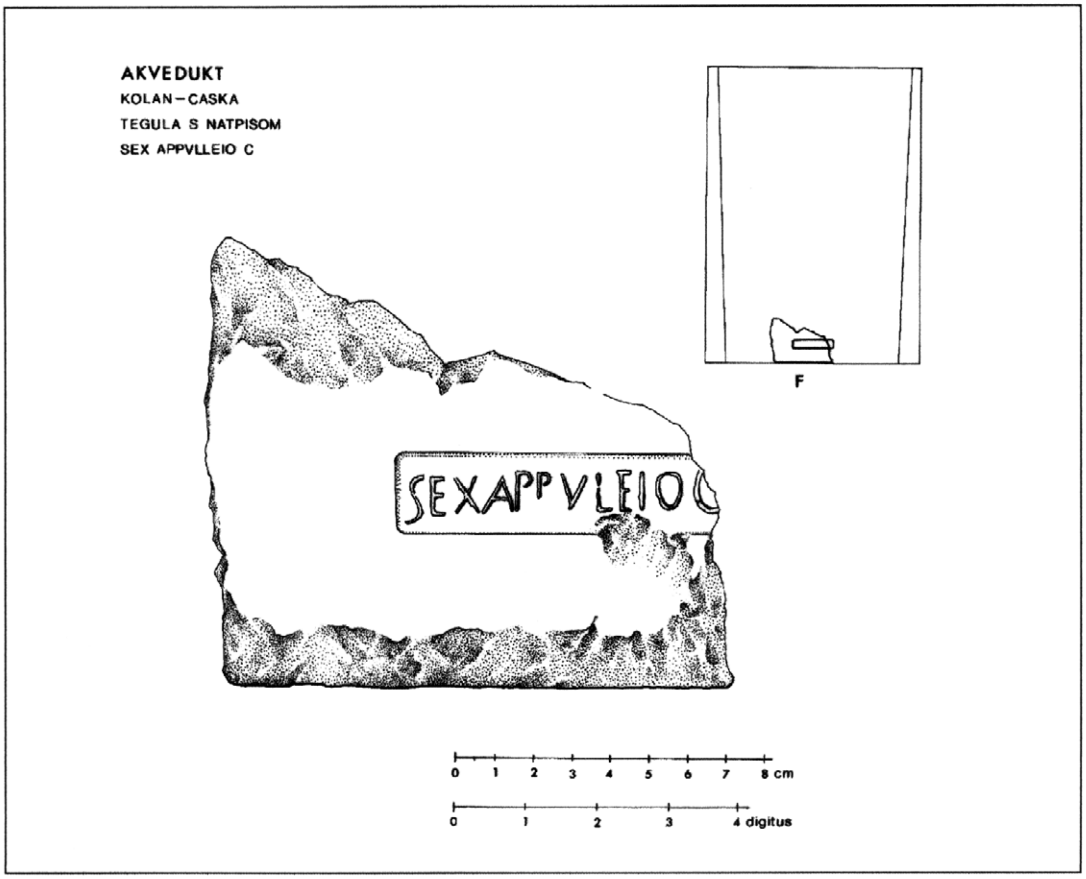

Fig 10 – The SEX APPVLEIO C stamp (B. Ilakovac).

Sl. 10 – Žig SEX APPVLEIO C (B. Ilakovac).

not escape the Velebit channel. Ships sailing from Rab (*Arba*) direct to Trinčel would have to pass along the coast of the Lun headland which would mean navigating more than 20 km open sea on the north side of Pag (*fig* 11).

The Bunar spring below Kolan was already in use but the Škopalj spring was not. However between it and Novaljska draga was the barrier of Mount **Figurica** which made a simple overland gravitational aqueduct impossible (*fig* 12). There was only one solution – to excavate a tunnel (Vitr. VIII.6.3; ASHBY 1935: 34; FAHLBUSCH 1982: 93; ILAKOVAC 1982: 12 and notes 6). But when the Roman surveyors drew up the plans for such an aqueduct they had an unpleasant surprise.

To realise it they would have to excavate a gravitational tunnel for the canal of a length of at least 1,400 metres through Figurica hill. In spite of the cost and the many construction problems that the route through Figurica hill would entail it was accepted since the cheaper and easier Škopalj – Trinčel bay alternative would not overcome the main maritime danger, the Velebit *bora*. Before any work could begin the whole route of the aqueduct from Škopalj to Novaljska draga where the main distribution point would be located had to be levelled. Because of the rocky and uneven terrain the route was divided into three sections.

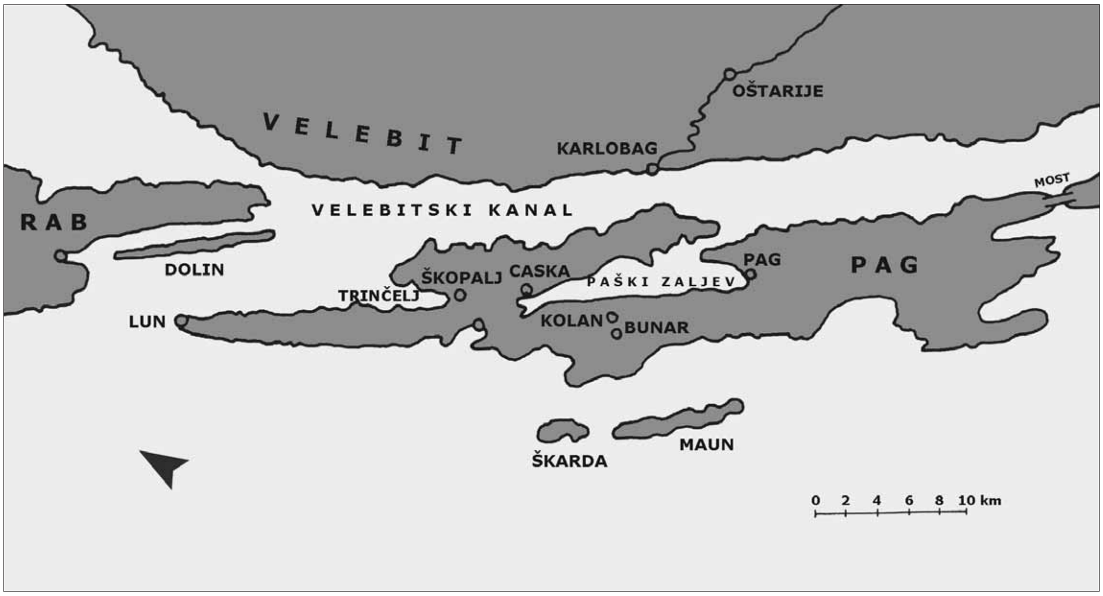

Fig 11 – The Island of Pag (B. Ilakovac).

Sl. 11 – Otok Pag (B. Ilakovac).

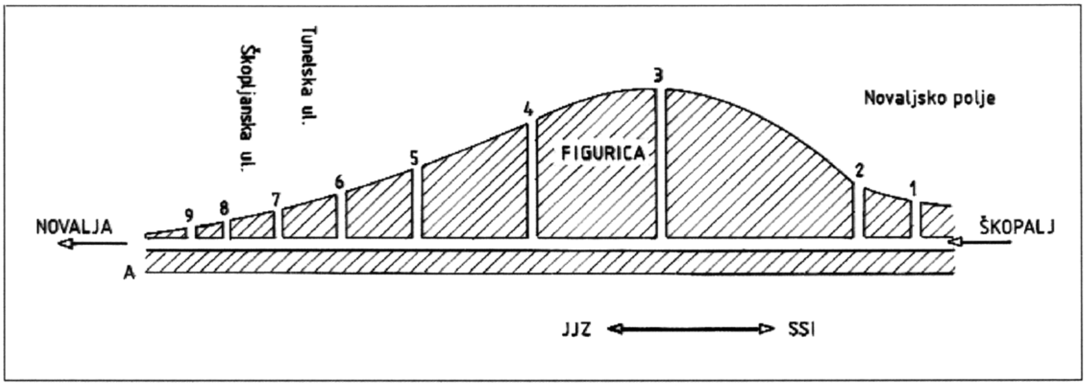

Fig 12 – Vertical cross-section through the Figurica Hill (B. Ilakovac).

Sl. 12– Vertikalni presjek brda Figurica (B. Ilakovac).

SECTION ONE – ŠKOPALJ SPRING – TUNNEL

When in 1912 the Austrian administration restored the old Roman aqueduct they came upon its source in the walled and well preserved spring of Škopalj (*caput aquae*), but we have no record of this (ILAKOVAC 1969: 275; 1982: 109, sl. 30). The Novaljska draga parish records show that only part of the overland construction was protected, between the tunnel and the spring in the direction of Baran bridge (CRNKOVIĆ 1985: 89; ILAKOVAC 1990: 201). The records also mention a water channel connection VP which came from the east from a as yet unidentified spring, VP is marked on

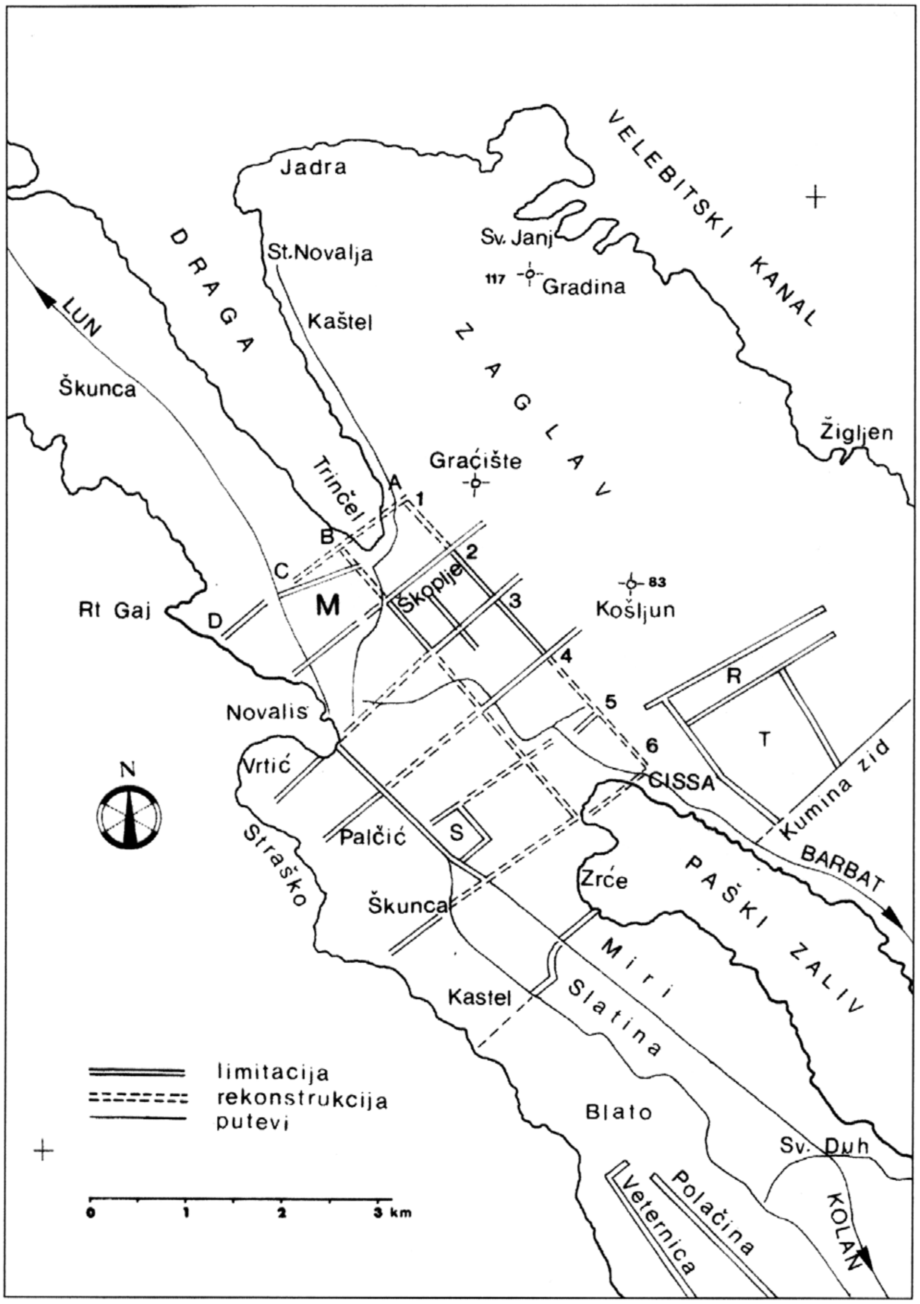

Fig 13 – Land division (B. Ilakovac).

Sl. 13 – Limitacija agera (B. Ilakovac).

fig 1. This makes it very likely that the overland construction of the new Austrian aqueduct from Škopalj to the tunnel, a length of about 700 metres, followed the route of the old Roman aqueduct. If we study the contour lines on a map we see that the route of the Roman aqueduct from Škopalj

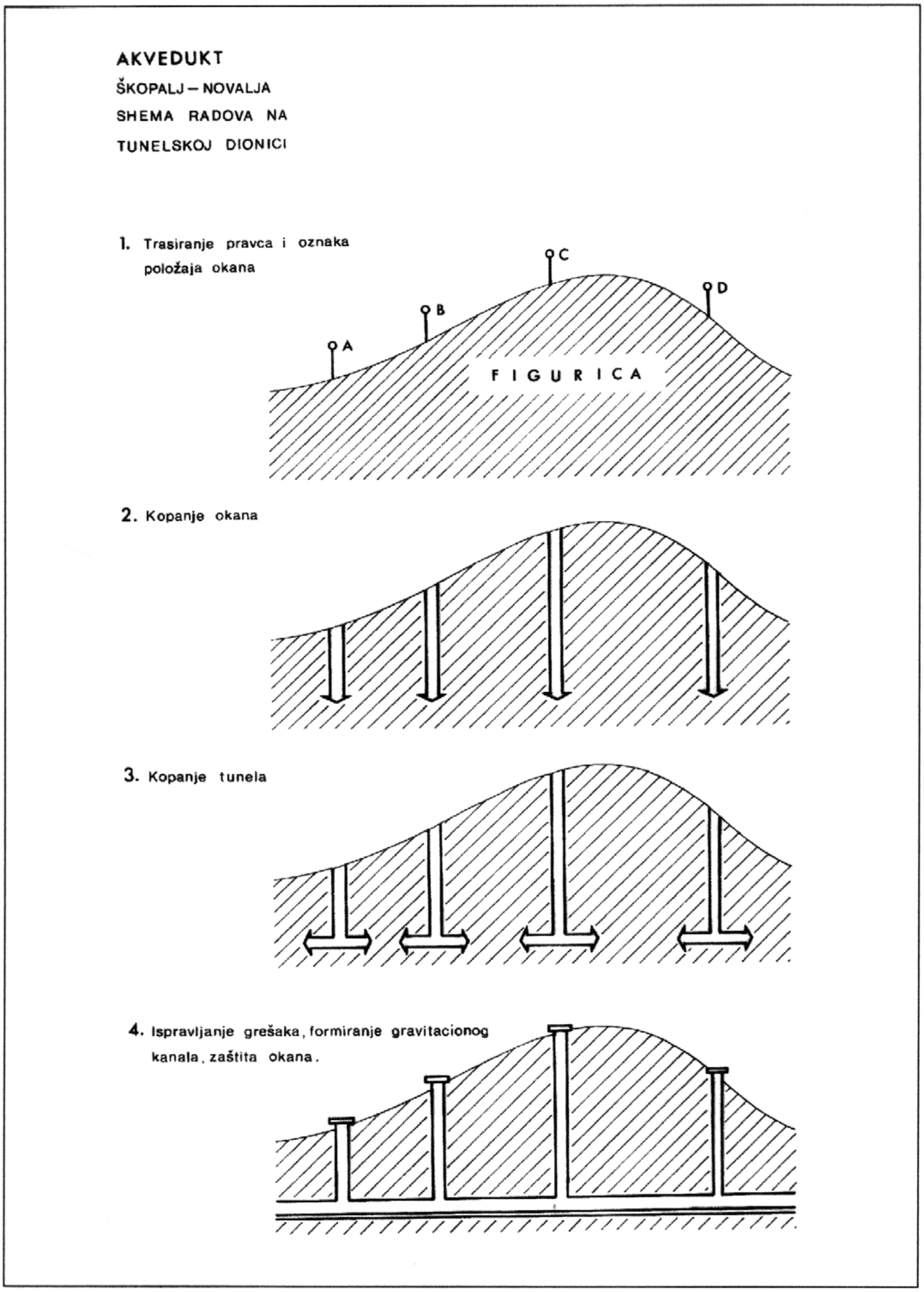

Fig 14 – The method the excavation of the tunnel (B. Ilakovac).

Sl. 14 – Način kopanja tunela (B. Ilakovac).

Fig 15 – Wall around the shaft O-7 (B. Ilakovac).

Sl. 15 – Ograđeno okno O-7 (B. Ilakovac).

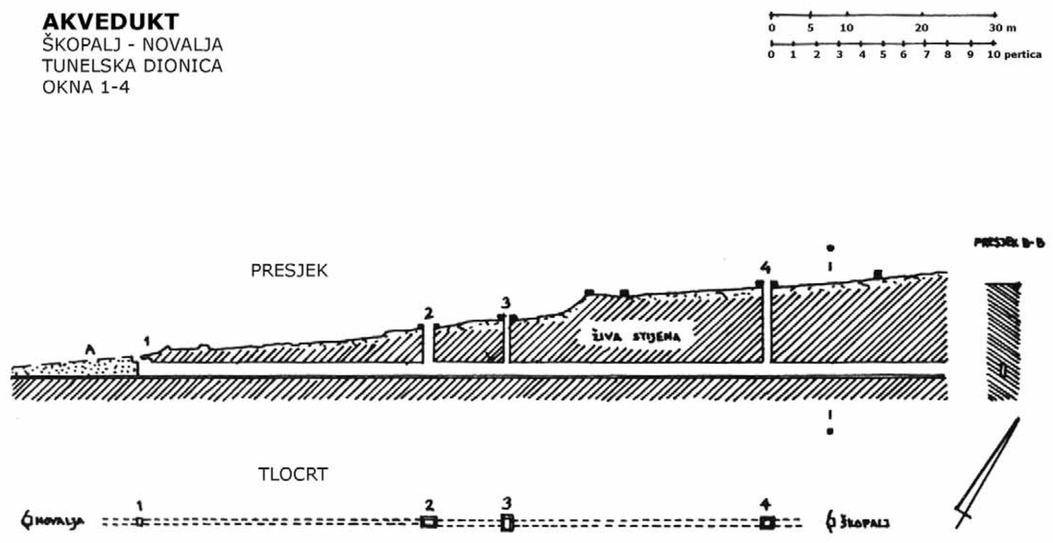

Fig 16 – The end of the tunnel (B. Ilakovac).

Sl. 16 – Završetak tunela (B. Ilakovac).

follows them to form a gentle curve making a detour around the Novalja valley. This is the so called »isohyptic« tracing of Roman aqueducts which avoids obstacles but means a longer aqueduct (ILAKOVAC 1982: 31).

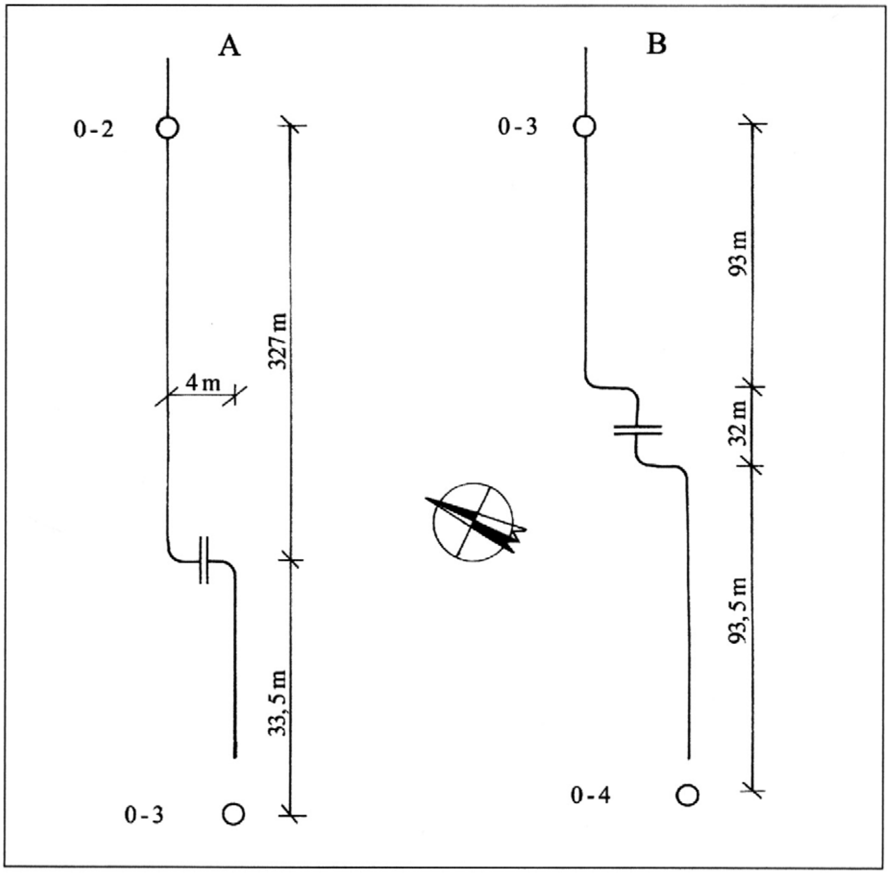

Fig 17 – Deviations during the tunnel excavation (B. Ilakovac).

Sl. 17 – Krivo kopanje tunela (B. Ilakovac).

When the first section had been completed the dam at the Škopalj spring was opened and the water allowed to flow as far as the tunnel. This was to check the first part of the construction and at the same time to gain information about the water capacity of the new aqueduct.

SECOND SECTION – THE TUNNEL

The completion of the overland construction from Škopalj to the tunnel marked the beginning and the point of greatest height of the gravitational channel in the tunnel. At that time there were no surveying instruments accurate enough to make it possible to start excavation from both ends with the certainty that they would meet in the middle, not only at the right height but in the right place. Problems of this kind had for instance already occurred with the construction of the aqueduct for the town of Samos in the sixth century BC (ILAKOVAC 1982: 12, note 6) in a length of about 1000 metres; and also with erroneous tunnelling directions in the aqueduct tunnel for the town of *Saldae* in Mauretania in the second century AD (ILAKOVAC 1982: 24) The imperial builders on the island of *Cissa* introduced the following innovation. From the end of the first section right down to Novaljska draga where the public well was to be placed, right through Mt **Figurica** nine marker points

Fig 18 – Roof-tile with the stamp AFAESONIAF.

Sl. 18 – Tegula s natpisom AFAESONIAF.

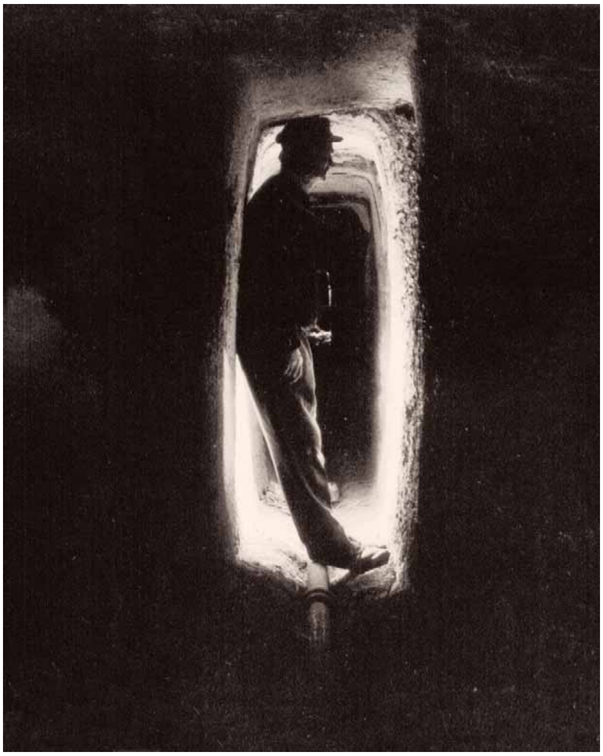

Fig 19 – Tunnel at the shaft O-8 (B. Ilakovac).

Sl. 19 – Tunel kod okna O-8 (B. Ilakovac).

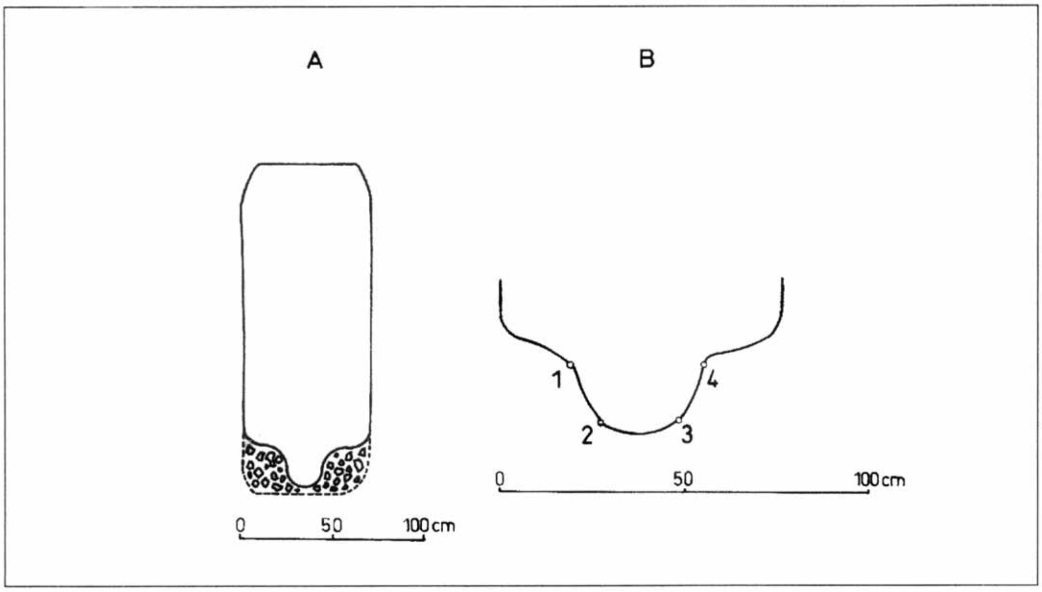

Fig 20 – Cross-section through the tunnel A and the gravitational channel B (B. Ilakovac).

Sl. 20 – Presjek tunela A i gravitacionog kanala B (B. Ilakovac).

were selected (*fig* 15, 1) to mark the position of nine shafts (*fig* 12; cf. LÓPEZ-BOADO 2004: 67). These would be the vertical points of the tunnel through Figurica and their depth and the distance between them was shown. The first shaft was found on the land of Frano Markan and was filled in. The positions of the other eight can still today be seen. Almost all the shafts were square but not all the same size. The smallest, O-6, at Gvozdenica measures 100 x 50 cm. The largest is O-3, and measures 128 x 76 cm. Only O-7 is circular and in size is 90 cm in diameter. The Austrian engineers after restoring the old Roman aqueduct built a low wall round the entrance to each shaft and covered them with stone slabs. (*fig* 15). Only shaft O-4 has no wall and was filled in.

Work began at the same time on the tunnel entrance and exit points and in excavating the tunnel from all nine shafts (*fig* 14). Each had a marker of relative height in relation to the water level at Škopalj spring. When each shaft had been excavated to the depth determined for the water level of the gravitational channel, excavation began simultaneously in two directions in all shafts (*fig* 14). This new approach required two excavators for the entrance and exit and 18 in the shafts all working simultaneously. The short distance between the shafts reduced the likelihood of excavations taking a wrong direction and also speeded up the work.

Work went fastest at the entrance and exit points for by daylight any mistake of direction was easily checked. The echo of the work of cutting through solid rock helped to roughly fix the position especially as the sections of the tunnels got closer and closer but errors of direction continually occurred. Figurica is not a compact mountain, in many places there are tectonic faults which wrongly echoed the sound of the excavators. The first serious misdirection was found Immediately beyond shaft O-2 and only 36 m before shaft O-3. The were connected by excavating on both sides towards the left until they met (*fig* 17A). The point where they met is marked with two parallel lines.

The greatest misdirection came between shafts 0-3 and O-4. The direction of the tunnel was changed four times at a depth of 30 m before a joining was achieved (*fig* 17B). Between shafts O-4

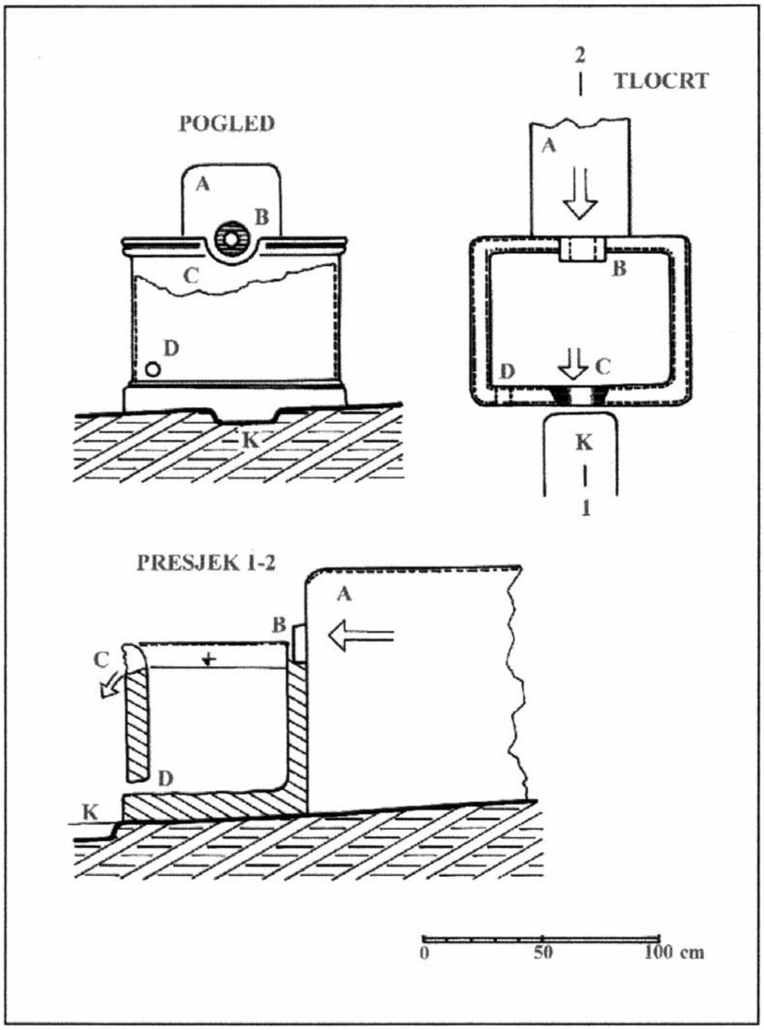

Fig 21 – The public well (lacus) (B. Ilakovac).

Sl. 21 – Javni zdenac (lacus) (B. Ilakovac).

and O-5 a large underground **cave** was discovered about 7 m long and almost 7 m high. This called for complex building techniques. First the floor of the cave had to be strengthened and sealed so that both sides could be built up and finally it had to be arched over above. This was necessary so that the friable sides of the cave did not crumble and bury the gravitational channel. Roman bricks and roof tiles (*tegulae*) were used), one of them bears the remains of the mark of the Roman brickworks AFAESONIAF (*Auli Faesoni Africani*) (*fig* 18).

Examining the tunnel in a very poor light vertical cuts about 70 cm long could be seen on the sides, these were the Roman builders' measurement of length. The first pair was found 58 m before shaft O-3, and the second 61 m before shaft O-5. At the exit from the tunnel on the Novalja side a circular recess about 22 cm deep was found on the bottom of the gravitational channel (a sediment drain; *fig* 16).

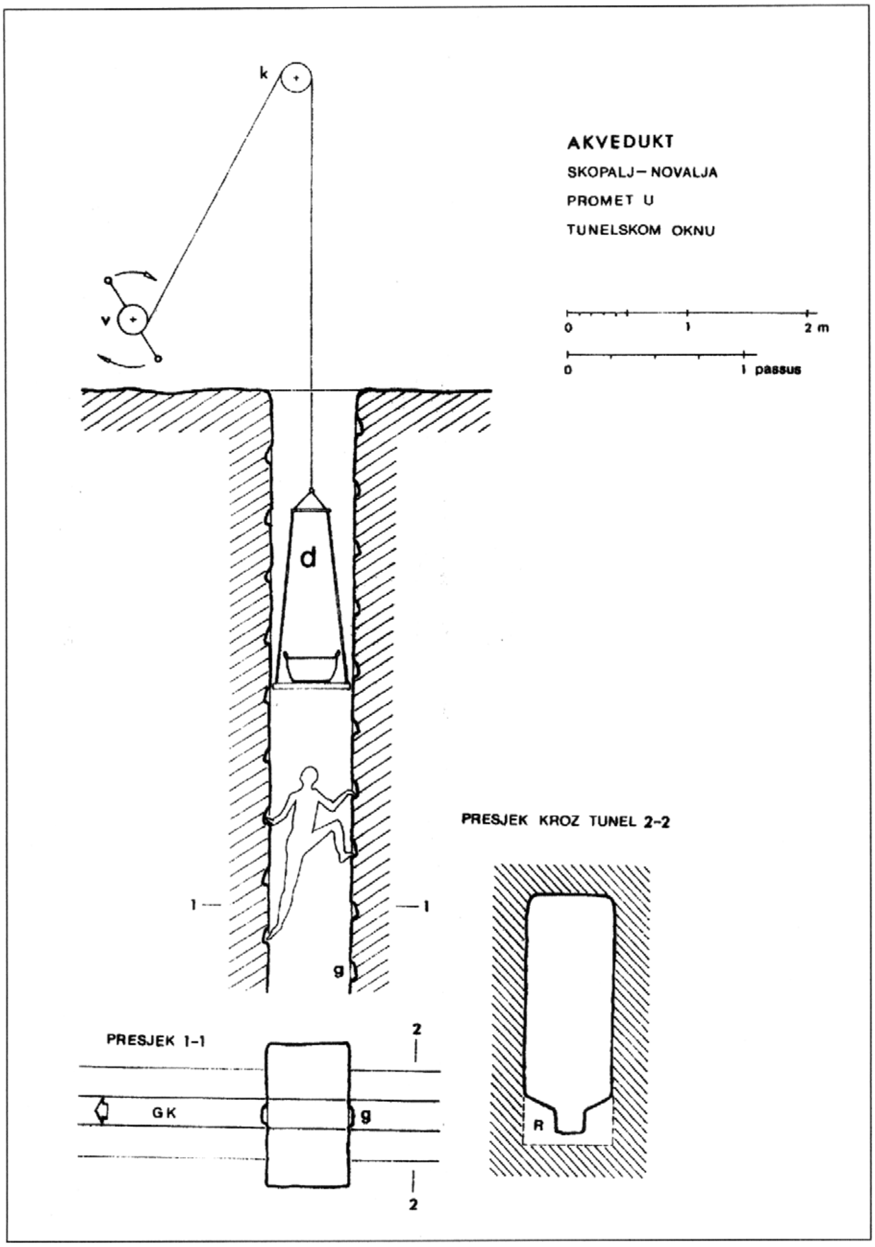

Fig 22 – Circulation in the tunnel (B. Ilakovac).

Sl. 22 – Promet u tunelu (B. Ilakovac).

The workers for excavation through bedrock were probably selected slaves and prisoners who already had experience of this kind of work. Experienced miners, who normally followed the position of the ore, during the construction of gravitational aqueducts, would have checked the position of the tunnel during excavation for it had to be controlled not only for position but for the gradient required by the plans.

Fig 23 – Novalja port.

Sl. 23 – Luka Novalja.

When the tunnel had been roughly excavated high quality stone-masons widened and smoothed the sides of the tunnel to allow easier movement (*fig* 19). In some places there are circular marks left by some instrument used for finishing work on the sides. After this had been done a surveyor (*librator*) would establish the gradient of the tunnel base. Vitruvius records that the most reliable tool for the surface tracing of urban aqueducts was the *chorobates* (Vitr. VIII.5; ILAKOVAC 1990a: 237). This bulky instrument 6 m long and more than 3 m high was certainly not used here. Besides a plumb-line for measuring gradient the *chorobates* had a spirit-level (*libra aquaria*). The *librator* in this narrow and uncomfortable tunnel had to use a spirit-level which was light, not more than 150 cm long and about 10 cm high.

Not until the *librator* had finished the required measurements of the gravity channel from entrance to exit could the final construction of the channel begin. In order to save money on expensive water-resistant mortar a considerable amount of stone was used (*fig* 20A). First the gravity channel was roughly built. The water was allowed to flow from Škopalj through the first section as far as the

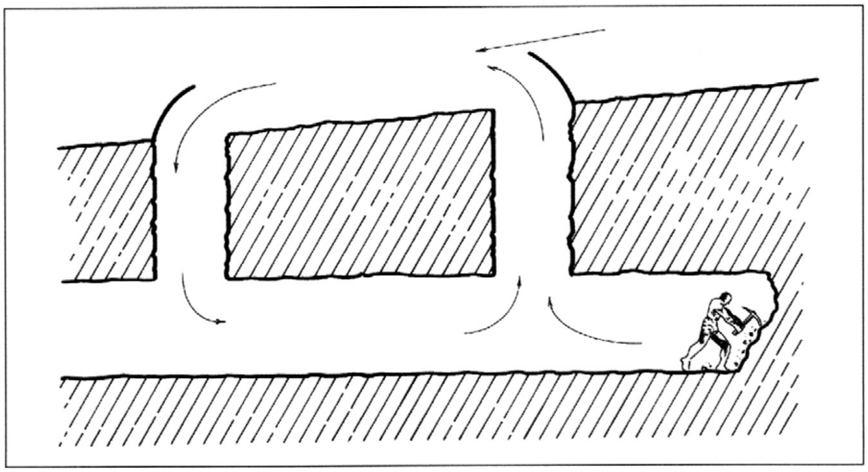

Fig 24 – The airing of the tunnel (B. Ilakovac).

Sl. 24 – Zračenje tunela (B. Ilakovac).

tunnel, then it was allowed further and to the great satisfaction of builders and workmen it emerged on the other side of Figurica. After full checking, and if necessary making corrections, the builders applied special water resistant cement (*opus signinum*) in order to complete the base of the channel.

The height of the tunnel was adapted to the height of a grown man, about 176 cm. In width it varied from about 50 to at most 68 cm. Two adults could hardly pass each other in it (*fig* 19).

THIRD SECTION: TUNNEL – PUBLIC WELL (*LACUS*)

The last 600 m long, third section was the easiest to build. At Škopalj a sluice was made to stop the flow of water and a place was selected for the final public fountain (*fig* 21) which was not put too near to the shore (marked Z on *fig* 23). It was made of local breccia stone 95.5 cm long, 77 cm wide and 74 cm high. The fountain basin had a capacity of about 300 l of water. It was discovered some way away from its original position, by Ivan Škunca, known as Šimera, when he was digging foundations for a new building (ILAKOVAC 1994: 1). The front and sides were the thickest, about 9 cm. The back was not so thick (marked A on *fig* 21) since the end of the aqueduct was built onto it. The upper accessible parts of the basin are smooth on the inside so as not to scratch the hands of those taking water. On the outside they have decorative moulding.

In the centre of the back the circular recess (marked B, *fig* 21) is shown where a ceramic pipe entered the basin carrying water from the aqueduct. On the front and most damaged side is an oval recess marked C through which excess water flowed into an open channel K. On the left side at the bottom of the front there is a circular opening D about 4 cm, which could be closed with an oiled wooden plug, when there was a lot of sediment at the bottom, as a result of a long rainy period which muddied the source water. This plug could be taken out and the well cleaned itself. It needed about 25 seconds to fill up again (see above under capacity).

According to Ivan Škunca there was a channel construction joined to the basin in the direction of the »Italian's hole« (*Talijanova buža*) which is what the local people called the aqueduct tunnel. He said it was covered by red stone slabs, he also said that about 3 metres from it there had been another smaller basin all trace of which had been lost (ILAKOVAC 1994: 3).

Fig 25 – View into the tunnel of the Roman aqueduct (Croatian Conservation Institute – University of Zadar, 2007).

Sl. 25 – Pogled u kanal antičkog vodovoda (Hrvatski restauratorski zavod – Sveučilište u Zadru, 2007).

Fig 26 – View into the tunnel of the Roman aqueduct (Croatian Conservation Institute – University of Zadar, 2007).

Sl. 26 – Pogled u kanal antičkog vodovoda (Hrvatski restauratorski zavod – Sveučilište u Zadru, 2007).

When the building of the newly completed aqueduct Škopalj-Novalja was complete the entire water construction was enclosed to prevent the entrance of snakes, frogs and snails. All vertical shafts were closed and for inspection and maintenance purposes one or more places were designated which would allow entrance to the channel to carry out any necessary work.

CAPACITY

We do not have the Austrian levelling documents of 1910 which were the basis for renovation of the old Roman aqueduct. In 1948 there was fresh interest in reconstruction Austrian waterworks and a new geodetic vertical profile from Škopalj to the end of the tunnel was made. On it is noted the elevation of the bottom of the Roman gravity channel from shaft O-2 to the end of the tunnel. This is our only basis for calculating the capacity of the Roman aqueduct Škopalj – Novaljska draga (ILAKOVAC 1982: 96).

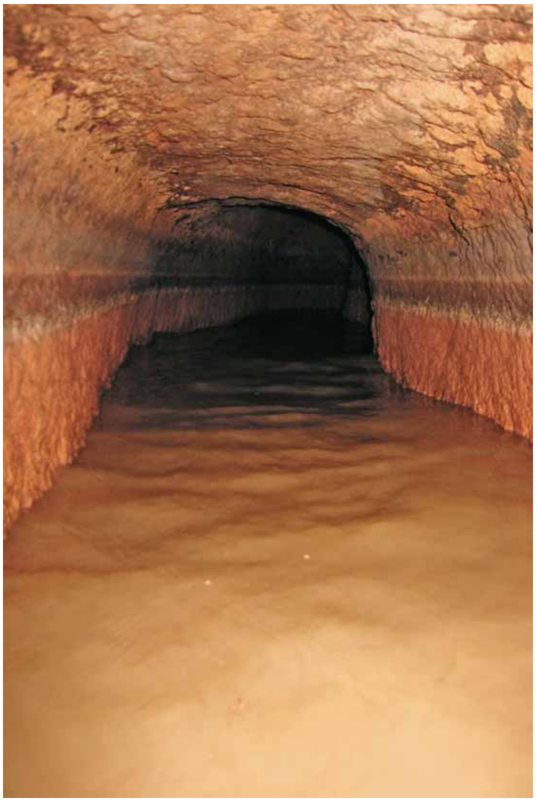

Fig 27 – View into the tunnel beyond the retention (Croatian Conservation Institute – University of Zadar, 2007).

Sl. 27 – Pregled kanala iza brana (Hrvatski restauratorski zavod – Sveučilište u Zadru, 2007).

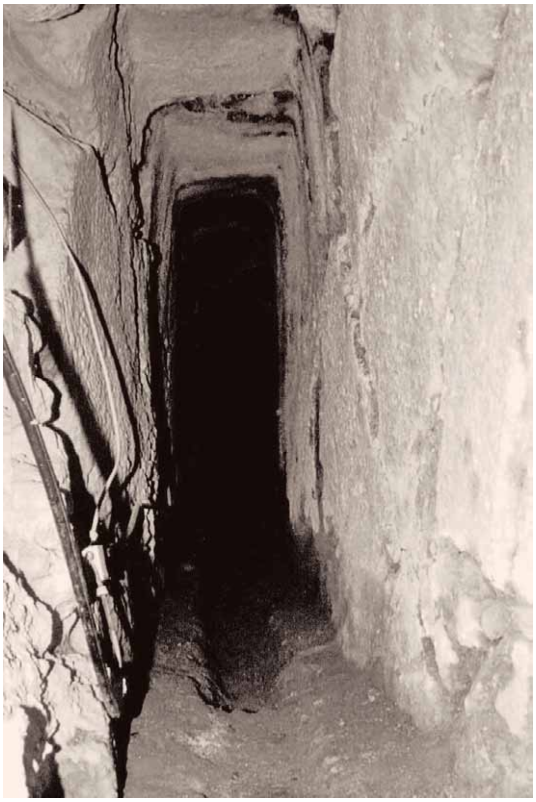

Fig 28 – View of the tunnel of the Roman aqueduct (B. Ilakovac).

Sl. 28 – Pogled u kanal antičkog vodovoda (B. Ilakovac).

L (length of route from shaft O-2 to end of tunnel 900 m)

L = 900 m

H (difference in height from the bottom of the gravitational channel) 4,88 m at shaft O-2 and 3.54 m at the end of the tunnel. Difference 1.34 m

H = 1.34 m

I (incline of gravitation channel H/L = 1,34m/900m = 0,00149 = 1/671

I = 0,00149

U (length of the water cross-section, on *fig* 21B open polygon 1–4)

U = 0,46 m

F (surface of the section of the water flow, on *fig* 21B closed polygon 1–4)

F = 0,0278 m²

R (hydraulic radius) = F/U = 0,0278 m²/0,46 m = 0,0604 m

R = 0,0604 m

b (friction coefficient) = 0,35

v (speed of flow of water) = 100 x R x I/b +vR = 100 x 0,0604 x 0,0386/0,35 + 0,0246

v = 0,391 m/s

Q (capacity) = v x F = 0,391 m x 0,0278 m^2 = 0,0108 m^3/s

Q = 10,8 litres/second

The survey of 1948 explains why the Austrian administration already had to place a windmill at Škopalj with a pump to bring the water up to the 22 m high water reservoir at Roman shaft O-2 (ILAKOVAC 1990: 203). In 1948 the water level at Škopalj was already 48 cm lower than the base of the gravitation channel at shaft O-2 and direct access to water by the original channel was no longer possible (Škopalj +4.40 m, bottom of gravitational channel at shaft O-2, +4.88). Such alterations to water level were often found where the rock was porous or had been subject to change of position.

In 1879 the Austrians reconstructed Diocletian's aqueduct in Split. They were not only able to use the same route but, with repairs, the same gravitational canal because the powerful headspring of the Jader river which is forced from the bedrock, had remained on the same level from Diocletian's time (BELAMARIĆ 1999: 9).

The Roman aqueduct Boljkovac– Nin is a different case. The water level was from the first too low and so strong walls were built and the level was raised to 88 cm (ILAKOVAC 1969: 258; 1982: 139).

There are no written sources to show how the many construction problems involved in a tunnel 1,400 m long were tackled. We can only surmise.

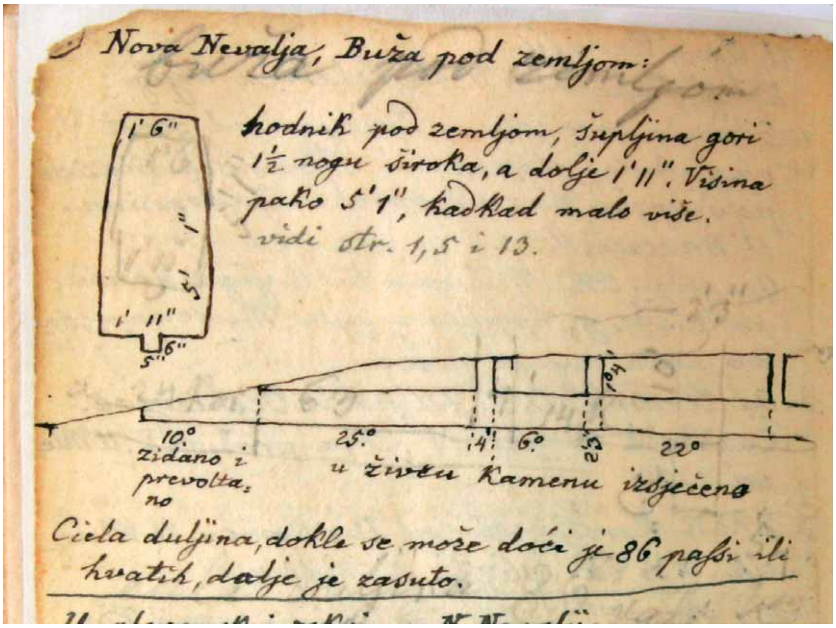

Fig 29 – Mijat Sabljar, notes on the tunnel, sketch-book, September 1852 (Ministry of Culture, Republic of Croatia).

Sl. 29 – Mijat Sabljar, bilješke o tunelu, putna bilježnica, rujan 1852 (Ministarstvo kulture Republike Hrvatske).

TRAFFIC AND REMOVAL OF EXCAVATED MATERIAL

In shafts O-3 and O-5 the footholds for climbing up and down and manoeuvring without a pulley are still extant on both sides of the narrower part (*fig*. 22). The total volume of 9 vertical shafts and about 1,400 metres of tunnel amounts to 1,500 cubic meters of excavated stone. The excavated material could be pulled up through the shaft, as shown on *fig* 22. Around shaft O-3, the deepest shaft of 46 meters, remains of the excavated stone are still visible. For the Novalja anchorage a new pier was needed and most of the excavated stone was used for this purpose. It was transported to the shore and used to achieve a level surface (*fig* 23). This is why the areas round today's petrol station is strikingly level. Another part of the excavated material was used to make the new pier, shown on *fig* 23 marked P. In a similar way in the second century AD when extensive new vineyards were planted in Kumenat near Biograd na moru, stone from excavations was used to build two piers (ILAKOVAC 1992a: 282).

LIGHTING

At the entrance and exit to the tunnel daylight could be used. But as the tunnel became longer it became darker. At first the workers used lamps. Between shafts O-8 and O-9 on both sides of the tunnel can be seen natural and artificial niches for oil lamps (ILAKOVAC 1960: 141; 1973: 365; 1976: 29). That they were used for that purpose is shown by the blackened rock face above these hollows which cannot be wiped off.

VENTILATION

While the tunnel was under construction, especially in the shafts, there was a continual danger of life threatening concentrations of carbon dioxide (CO2). Pure air is a mixture of 20.94% oxygen and 79.03% nitrogen. Stale air contains 5.6% carbon dioxide, a poisonous gas without colour, taste or smell. For workers in vertical shafts or trenches it is particularly dangerous as it is heavier than air. The dangers it presented were well known in the ancient world. Vitruvius warned that before entering underground works a lighted torch should be lowered. If it did not go out then the shaft was safe. If it did then it was dangerous (Vitr. VIII.6.13). The oil lamps already mentioned were also dangerous polluters of the air and the lungs of workers creating carbon dioxide in the tunnels and shafts.

DATING

There are no historical records of the construction of the Škopalj – Novaljska draga aqueduct. The Roman roof tile built into the tunnel with the stamp FAESONIAF (*Auli Faesoni Africani*) suggests that the aqueduct was built sometime between the end of the first century AD and the third century AD, when these brickworks were active. Besides the tile with the mark AFAESONIAF built into the vault of the tunnel, a tile with the same mark was found in the Roman channel in Novalja (GLUŠČEVIĆ 1985: 82).

Comparative evidence may support the idea of a construction date not before the second century AD. Aqueducts were not built in colonial urban centres such as **Pula** (*Pola*) (ILAKOVAC 1982: 24), **Zadar** (*Iader*) (ILAKOVAC 1982: 236) and **Solin** (*Salona*) (ILAKOVAC 1982: 27, notes 18 and 19), until the second century. Aqueducts for the two island municipal centres **Rab** (*Arba*) (ILAKOVAC 1982: 26; note 13) and **Omišalj** (*Fulfinum*) on the island of Krk (ILAKOVAC 1982: 25; note 11 i 12) were built at the end of the first and during the second century. **Podgrađe** (*Asseria*) near Benkovac did not get running water until the end of the second century. **Nin** (*Aenona*) got water a little earlier (ILAKOVAC 1969: 289; 1982: 138).

Two aqueducts were built for military camps. ***Burnum*** (ILAKOVAC 1984: 44) near Ivoševci got one at the beginning of the first century, and the military camp of **Gardun** (*Tilurium*) near Sinj after 150 although the camp was located on the Cetina (ABRAMIĆ 1940: 225).

CONCLUSION

The Škopalj – Novaljska draga aqueduct was an ambitious hydraulic engineering undertaking. About 200 years later a similarly complex construction was undertaken by the Emperor Diocletian (248–305) to bring water to his Palace in Split from the 33 meter high source of the river Jadro. Of the 9 km long route of the aqueduct in the section across Ravne Njive, a 1,395 tunnel was constructed (BULIĆ 1929: 67; BELAMARIĆ 1999: 11). Vertical shafts were used for the construction of this tunnel also but they have never been either studied or documented.

One result of the aqueduct, the public well and pier was that Novaljska draga became increasingly well known as a new port even though a new and modern pier was also built at Cissa, the main settlement on the island. The Croatian word **Novalja** may have developed either from the Latin noun *novalis, -is*, f., meaning cleared or cultivated land (SKOK 1950: 68), or from *navale* or *navalia*, n., meaning a dockyard or slipway. Thus Novalja like Zadar is etymologically a pre-Croatian name. Not until the twelfth century is the name Novalja (*Navalla*) mentioned in the place where it is today.

The aqueduct, fountain and piers were vital for the development and future of Novalja.[2] It is a rare historical example of how the emergence of a new coastal settlement owed its position not only to a bay but to the availability of drinking water.

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FIGURE CAPTIONS
POPIS ILUSTRACIJA

Fig 1 – The course of the aqueducts (B. Ilakovac);

Sl. 1 – Trase akvedukata (B. Ilakovac);

Fig 2 – The Bunar source (B. Ilakovac);

Sl. 2 – Vrelo Bunar (B. Ilakovac);

Fig 3 – Cross-section at he position 1 (B. Ilakovac);

Sl. 3 –Položaj trase 1 (B. Ilakovac);

Fig 4 – Remains of the aqueduct substruction, position 3–4 (B. Ilakovac);

Sl. 4 – Ostaci visokog nosača, položaj 3–4 (B. Ilakovac);

Fig 5 – Slatina, position 5–6 (B. Ilakovac);

Sl. 5 – Slatina, položaj 5–6 (B. Ilakovac);

Fig 6 – Banjadolac, position 7–8 (B. Ilakovac);
Sl. 6 – Banjadolac, položaj 7–8 (B. Ilakovac);
Fig 7 – Banjadolac, reconstruction (B. Ilakovac);
Sl. 7 – Banjadolac, rekonstrukcija (B. Ilakovac);
Fig 8 – Punta Zrče, position 11 (B. Ilakovac);
Sl. 8 – Punta Zrče, položaj 11 (B. Ilakovac);
Fig 9 – Punta Zrče (B. Ilakovac);
Sl. 9 – Punta Zrče (B. Ilakovac);
Fig 10 – The SEX APPVLEIO C stamp (B. Ilakovac);
Sl. 10 – Žig SEX APPVLEIO C (B. Ilakovac);
Fig 11 – The Island of Pag (B. Ilakovac);
Sl. 11 – Otok Pag (B. Ilakovac);
Fig 12 – Vertical cross-section through the Figurica Hill (B. Ilakovac);
Sl. 12– Vertikalni presjek brda Figurica (B. Ilakovac);
Fig 13 – Land division (B. Ilakovac);
Sl. 13 – Limitacija agera (B. Ilakovac);
Fig 14 – The method the excavation of the tunnel (B. Ilakovac);
Sl. 14 – Način kopanja tunela (B. Ilakovac);
Fig 15 – Wall around the shaft O-7 (B. Ilakovac);
Sl. 15 – Ograđeno okno O-7 (B. Ilakovac);
Fig 16 – The end of the tunnel (B. Ilakovac);
Sl. 16 – Završetak tunela (B. Ilakovac);
Fig 17 – Deviations during the tunnel excavation (B. Ilakovac);
Sl. 17 – Krivo kopanje tunela (B. Ilakovac);
Fig 18 – Roof-tile with the stamp AFAESONIAF;
Sl. 18 – Tegula s natpisom AFAESONIAF;
Fig 19 – Tunnel at the shaft O-8 (B. Ilakovac);
Sl. 19 – Tunel kod okna O-8 (B. Ilakovac);
Fig 20 – Cross-section through the tunnel A and the gravitational channel B (B. Ilakovac);
Sl. 20 – Presjek tunela A i gravitacionog kanala B (B. Ilakovac);
Fig 21 – The public well (lacus) (B. Ilakovac);
Sl. 21 – Javni zdenac (lacus) (B. Ilakovac);
Fig 22 – Circulation in the tunnel (B. Ilakovac);
Sl. 22 – Promet u tunelu (B. Ilakovac);
Fig 23 – Novalja port;
Sl. 23 – Luka Novalja;
Fig 24 – The airing of the tunnel (B. Ilakovac);
Sl. 24 – Zračenje tunela (B. Ilakovac);
Fig 25 – View into the tunnel of the Roman aqueduct (Croatian Conservation Institute – University of Zadar, 2007);

Sl. 25 – Pogled u kanal antičkog vodovoda (Hrvatski restauratorski zavod – Sveučilište u Zadru, 2007);

Fig 26 – View into the tunnel of the Roman aqueduct (Croatian Conservation Institute – University of Zadar, 2007);

Sl. 26 – Pogled u kanal antičkog vodovoda (Hrvatski restauratorski zavod – Sveučilište u Zadru, 2007);

Fig 27 – View into the tunnel beyond the retention (Croatian Conservation Institute – University of Zadar, 2007);

Sl. 27 – Pregled kanala iza brana (Hrvatski restauratorski zavod – Sveučilište u Zadru, 2007);

Fig 28 – View of the tunnel of the Roman aqueduct (B. Ilakovac);

Sl. 28 – Pogled u kanal antičkog vodovoda (B. Ilakovac);

Fig 29 – Mijat Sabljar, notes on the tunnel, sketch-book, September 1852 (Ministry of Culture, Republic of Croatia);

Sl. 29 – Mijat Sabljar, bilješke o tunelu, putna bilježnica, rujan 1852 (Ministarstvo kulture Republike Hrvatske).

SAŽETAK

RIMSKI AKVEDUKTI NA OTOKU PAGU

Jedinstveni otok Pag izdvaja se među našim jadranskim otocima i po tome što su na otoku Pagu u doba antike bila sagrađena sljedeća dva akvedukta.

LIBURNSKO-RIMSKI AKVEDUKT KOLAN – KISA (*CISSA*)
TRASA AKVEDUKTA

Izvorište bivšeg akvedukta (*caput aquae*) nalazi se na 66 metara iznad mora, (sl. 1 i 2). Stotinjak metara niže izvorišta **Bunara** moguće je za vrijeme velikih suša zamijetiti položaj plitko ukopanog kanala (sl. 3). Trasa presijeca prastari put od Bunara preko Kaštela do Novalje te izbija na **Japnjaču** (sl. 3, poz. 1.) Tu se nekoć nalazio *castellum aquae* koji nije služio samo kao vodosprema, već kao i taložnica. Da bi se održala izračunata visina gravitacijskog kanala, od Japnjače je nosač gravitacijskog kanale sve viši u odnosu na tlo (sl. 4).

Trasa presijeca sadadašnji asfaltni put i prolazi područjem **Slatina,** gdje su i sada vidljivi i do dva metra visoki ostaci nosača akvedukta (sl. 5). Napuštajući područje Slatina, trasa presijeca **Banjadolac** (7–8). Dolina je bila premoštena nosačem na lukove, gotovo 5 metara visokim (sl. 6). Konstrukcija je bila, ali samo s južne strane, poduprta kontraforima radi zaštite od udara silovite bure (sl. 7).

Obilazeći područje **Špital**, trasa napušta izohipsno trasiranje i presijeca **Puntu Zrče** (11). Jedino je na tome mjestu u cijelosti sačuvana čitava vodovodna kunstrukcija. Kako prikazuje tlocrt i presjek 1–2 na sl. 8, nakon probijenog, 130 metara dugačkog usjeka, prvo je sagrađena zidana staza A i na njoj dva bočna zidića B. Unutarnje stijene kanala bile su premazane u tri sloja posebnom hidrauličkom žbukom (*opus caementitium*) i oblikovale su žlijeb kanala širok 15 centimetara (sl. 9). Kanal je bio pokriven rimskim ciglama veličine 42,5 cm x 29,6 cm 7,4 cm debljine i na kraju je usjek zasut i zaštićen iskopanim kamenom.

Od usjeka Zrče trasa prati terensku slojnicu i zaustavlja se na položaju onačen brojem 12. Na tom je mjestu preko Novaljskog polja vododjelnica, koju je narod nazvao **Anđelka**, koja Novaljsko polje dijeli na sjeverno prema Škoplju i južno prema uvali Caske. Lako je bilo zamijetiti da je trasa bila planski dovedena do te točke, jer je na tom dijelu dolina najviša i najuža pa je prelaz preko doline bilo moguće riješiti najkraćim i veoma skupim olovnim sifonom (12–13). Na tom je položaju Anton Šanko bio zatekao ostatak olovne cijevi nedgdašnjeg sifona. Od položaja 13 pa sve do Caske više se ne nalaze sačuvani ostaci vodovodne konstrukcije, jedino izvaljeni dijelovi zidanog nosača gravitacijskog kanala pored puta što od Škoplja vodi u Casku.

KAPACITET (ILAKOVAC 1982: 96)

L (dužina trase od Bunara do točke 12) = 8209 metara

H (visinska razlika između Bunara, 66 metara, i točke 12, 23,6 metara) = 42,40 metara.

I (strmina gravitacijskog kanala na potezu od Bunara do točke 12)

H : L = 42,4 m : 8209 m = 0,00516 = 1 : 139,6

U (dužina omočenog opsega kanala) = 0,48 m

F (površina presjeka vodenog toka) = 0,041 m^2

R (hidraulični radius) = F : U = 0,041 m^2 : 0,48 m = 0,085 m

b (koeficijent trenja) = 0,35

v (brzina vodenog toka) = (100 x R x vI) : (b + vR) =

(100 x 0,085 x v0,00516) : (0,35 + v0,085) = 0.92metra na sek.

Q (kapacitet) = v x F = 0,92 m/s x 0,041 m^2 = 0,038m^3

Q = 38 litara na sekundu (maksimalno)

DATIRANJE

Pretpostavljamo da je akvedukt bio sagrađen na prijelazu iz stare u novu eru. U prilog tomu je i unikatni nalaz ulomka krovne cigle (*tegula*) koji je bio uzidan u konstrukciju luka na području Slatine, a na kojem je otisak tvorničkog žiga SEX APPVLEIO C (sl. 10). Utiskivanje tvorničkog žiga uz rub tegule nalazimo samo na najstarijim rimskim tegulama. Naš uvaženi stručnjak za žigove na rimskim tegulama, R. Matijašić ne poznaje rimsku ciglanu pod tim nazivom.

RIMSKI AKVEDUKT ŠKOPALJ – NOVALJA

Zbog veće sigurnosti pomorski je promet od davnina bio usmjeren uz obalu. To staro iskustvo slijedili su i sve brojniji brodovlasnici na glavnom pomorskom putu od Ravene i Akvileje prema Istoku. Spore teretne lađe sve su češće počele ploviti podevelevitskim kanalom. Neke su zagonetno nestale i nikad nisu stigle u svoja odredišta. Neiskusni mornari i strani brodovlasnici nisu u početku pomišljali na strašan učinak neočekivane i razorne podvelebitske bure, već na poznate liburnske gusare koji su bili najvještiji u pljački stranih brodova na području Jadranskog mora. Ali je neumoljiva romanizacija i rimska ratna mornarica koja je imala svoje baze u Raveni i Mizenu već u toku 1. stoljeća poslije Krista s uspjehom suzbila liburnsko gusarenje.

Velike teretne lađe i nadalje su nestajale. Oni mornari i putnici koji su se u olujnom nevremenu uspjeli spasiti prenosili su istinu o razornom djelovanju velebitske bure ističući da je tijekom plovidbe Velebitski kanal postao grobnicom mnogim brodovima. Sve se više napuštala plovidba podvelebitskim kanalom. Južni plovidbeni put bio je otprije poznat, ali je povećani pomorski promet i napuštanje podvelebitskog plovnog pravca zahtijevalo otkrivanje novih uvala i draga u kojima bi posade brodova mogle nabaviti namirnice, zaštititi se od nevremena i opskrbiti pitkom vodom.

Jedna od tih bila je i **Novaljska draga** kojoj se nije sačuvalo liburnsko ime i koja je imala nekoliko prednosti. Zaštićena je od istočnog vjetra (levant), s južne strane od valovite južine, a sa sjevera od bure. Otvorena je prema zapadu odakle dolazi najblaži i osvježavajući maestral (sl. 1). Novaljska je draga imala i tu prednost što obala nije stjenovita već blago ponire što je omogućilo da se iz nužde i s manje oštećenja mogu nasukati i veći brodovi. Stoga su u Novaljsku dragu sve češće stizale strane lađe radi noćenja ili da se sklone od nevremena. Dok je u Novaljskoj dragi bilo svega nekoliko lađa mogli su se putnici uz pomoć mještana i mornara nekako opskrbiti pitkom vodom. Strane su se lađe sve češće sidrile u Novaljskoj dragi pa su i teškoće oko opskrbe vodom postale sve veće.

VRELO BUNAR – NOVALJSKA DRAGA

Ni 12 kilometara istočno od Novaljske drage nalazi se i danas poznato izvorište kojem se nije sačuvalo liburnsko ime a danas ga mještani nazivaju **Bunar**. Prema konfiguraciji terena izvorište Bunar nalazi se 66 metara iznad sadašnje razine mora te između njega i Novaljske drage ne postoje nikakve terenske prepreke koje bi iziskivale kopanje dubokih usjeka, podizanje gravitacijskog kanala na visoke nosače ili bušenje tunela (sl. 1). Takve bi prednosti znatno pojednostavile, ubrzale i pojeftinile izgradnju novog akvedukta do Novaljske drage. Ali bila je jedna nepremostiva poteškoća, izvorište Bunar nalazilo se tada na privatnom posjedu Kalpurnija. S tog su izvora još u staro doba Kalpurnijevci izgradili svoj privatni akvedukt za liburnsko–rimsku Kisu. Ako bi se izvorište Bunar iskoristilo za izgradnju akvedukta za Novaljsku dragu, mještani liburnsko–rimske Kise, tada glavnog naselja istoimenog otoka, ostali bi bez pitke vode.

ŠKOPALJ –UVALA TRINČEL

U dolini Novaljskog polja, gdje su se i najbolje sačuvali ostaci pravokutne mreže kamenih ograda koje su štitile najplodniji dio velikog Kalpurnijeva posjeda, i sada se nalazi poznato vrelo **Škopalj**, od uvale Trinčel udaljeno svega nekoliko stotina metara (sl. 14). Ako bi se na području uvale Trinčel sagradilo pristanište za brodove i do njega dovela tekuća voda od Škoplja, bio bi to u cijelome Rimskom Carstvu najkraći, ni 500 metara dugačak akvedukt sagrađen bez ijedne terenske prepreke. Da je taj plan ostvaren, od toga bi najveću korist imala obitelj velevlasnika Kalpurnija. Novosagrađeno pristanište za brodove bilo bi u sredini njihova najplodnijeg posjeda i nadomak Kisi (sl. 14). Kalpurnijevci ne bi trebali više zaobilazno putovati morem kroz opasan podvelebitski kanal do ulaska u Paški zaljev i dalje sve do Kise (sl. 12). Da je taj plan bio ostvaren, danas zasigurno ne bi bilo ni današnje u svijetu poznate i sve uspješnije Novalje. Ali je i uvala Trinčel imala i jednu veliku i nezaobilaznu manu tako da je skretala brodove da napuste plovidbu podvelebitskim kanalom. Da bi se iz smjera Raba (*Arba*) uplovilo u uvalu Trinčel trebalo je od paškog rta Lun uploviti u Paški kanal te preko 20 kilometara nezaštićeno ploviti uz sjevernu stranu otoka Paga do uvale Trinčel (sl. 12).

ŠKOPALJ – NOVALJSKA DRAGA

Dok je izvorište Bunar ispod Kolana bilo zauzeto, **Škopalj** je bio slobodan, ali se između vrela i Novaljske drage ispriječilo nezaobilazno brdo **Figurica,** što je omogućilo da se nadzemnim gravitacijskim kanalom dopremi tekuća voda u Novaljsku dragu (sl. 13). Za ostvarenje tog plana bilo je samo jedno rješenje – kopanje tunela. Kad su rimski geodeti (*agrimensores*) obavili premjer pretpostavljene trase budućeg akvedukta i geodetski snimili zatečeno stanje.

Za ostvarenje tog plana trebalo je kroz brdo Figuricu iskopati gravitacijski kanal (tunel) u dužini od najmanje 1400 metara. Prije svih građevinskih radova geodeti su morali izmjeriti i iznivelirati cijelu trasu budućeg akvedukta, od vrela Škopalj do odabranog položaja nadomak Novaljskoj dragi, gdje bi se trebao nalaziti javni zdenac. Zbog veoma teškog i neujednačenog terena cijela je trasa budućeg akvedukta bila podijeljena u tri dijela.

PRVA DIONICA – VRELO ŠKOPALJ – TUNEL

Kad je austrijska uprava obnavljala stari rimski akvedukt (1912. g.), morala je zateći početak rimskog akvedukta, građevinske ostatke obzidanog i zaštićenog vrela Škopalj (*caput aquae*), ali o tome nema spomena. Iz Ljetopisa Novaljske župe doznajemo da je bio zaštićen samo dio nadzemne konstukcije od tunela prema vrelu Škopalj u pravcu Baranova mosta. Ljetopis spominje i vodovodni tunelski priključak VP koji je dolazio sa istoka iz još neutvrđenog izvora (na sl. 1 označeno VP). Stoga je vjerovati da je nadzemna konstrukcija novog austrijskog vodovoda od Škoplja do tunela, u dužini od oko 700 metara, slijedila trasu starog rimskog akvedukta. Ako se osmatraju vodoravne slojnice na zemljovidu (izohipse), uočljivo je da trasa rimskog akvedukta od Škoplja prati visinsku slojnicu koja u blagom luku obilazi Novaljsko polje. To je tzv. »izohipsno« trasiranje rimskih akvedukata koje izbjegava terensko prepreke ali produljuje trasu akvedukta.

Kad je prva dionica do tunela bila izgrađena, na Škoplju je otvorena ustava i voda je potekla sve do tunela. Bila je to provjera ispravnosti prve dionice, ujedno i podatak o kapacitetu budućeg akvedukta.

DRUGA DIONICA – TUNEL

Završetak nadzemne izgradnje akvedukta od Škoplja do tunela odredio je početak i najvišu razinu dna gravitacijskog kanala u tunelu. U to doba još nije bilo preciznih geodetskih instrumenata pomoću kojih bi bilo moguće pouzdano probijanje tunela samo s obje vanjske strane a da se suprotni smjerovi poklope ne samo po visini već i po pravcu. Od kraja prve dionice pa sve do Novaljske drage, gdje će biti postavljen i sagrađen javni zdenac akvedukta, bile su preko brda **Figurice** postavljene označene trasirke (sl. 25). Na tom je pravcu bilo odabrano devet mjesta koja su označila položaj devet okana (odiha, zračnica, šaht; sl. 13). Vertikalni presjek kroz brdo Figuricu prikazuje njihov međusobni položaj i dubinu. Prvo i zatrpano okno O-1 nalazi se na zemljištu Frane Markana. Ostalih osam okana i sada su zamjetni na površini. Okna (*spiracula*) u poprečnom su presjeku četvrtasta ali različita. Najuže okno O-6 nalazi se na položaju Gvozdenica i u presjeku mjeri 100 cm x 50 cm. Najprostranije je okno O-3, u presjeku mjeri 128 cm x 76 cm. Samo je okno O-7 kružnog presjeka, s promjerom od oko 90 cm. Po uzoru na zatečeno stanje, austrijska je uprava, nakon što je obnovila stari rimski akvedukt, svako okno ogradila niskim zidićem i s gornje ga strane zatvorila kamenim pločama (sl. 16). Nezaštićeno je ostalo samo okno O-4 koje je sve do tunela ostalo otprije zatrpano.

Istovremeno s probijanjem tunela na ulaznom i izlaznom dijelu počelo je kopanje svih devet vertikalnih okana (sl. 15). Na rubu svakog okna bija je označena relativna visina u odnosu na razinu vode na Škoplju. Kad je okno bilo iskopano do dubine na kojoj će se nalaziti geodetski izračunata visina gravitacijskog kanala, otpočelo je istovremeno kopanje u dva suprotna smjera (sl. 15). S tim novim postupkom uz dva kopača na ulazu i izlazu iz tunela bilo je istovremeno uposleno još 18 novih radnika kopača. Poradi kratkih razmaka između okana novom su metodom smanjena krivo usmjerena kopanja, a radovi na probijanju tunela ubrzani.

Lakše je bilo napredovati na ulaznom i izlaznom dijelu tunela jer je danje svjetlo otkrivalo pogrešan smjer kopanja. Odjeci alata kojima su probijali živu stijenu pomogli su da približno odrede položaj i približavanje susjednog rova, ali je uvijek dolazilo do odstupanja. Brdo Figurica nije kompaktna stijena, na mnogim su mjestima u tunelu vidljiva tektonska poremećenja koja su pogrešno reflektirala zvukove kopača. Idući od okna O-2 i svega 36 m prije okna O-3 nalazi se prvo veće odstupanje. Spajanje je bilo izvedeno obostranim kopanjem ulijevo sve dok se nakon 4 m nisu spojili (sl. 18 A). Mjesto sastanka označeno je dvjema paralelnim crtama.

Najveće odstupanje od pravca nalazi se između okna O-3 i okna O-4. Na dužini od oko 30 m četiri su puta mijenjali pravac kopanja dok se konačno nisu sastali (sl. 18 B). Između okna O-4 i O-5 naišli su na veliku podzemnu **špilju** dugačku oko 7 metara i približno toliko i visoku. Na tom dijelu tunela učinjeni su i najveći građevinski radovi. Prvo je trebalo popuniti, utvrditi i zazidati donji dio špilje da bi se mogle nadozidati obje bočne strane tunela i na kraju uzidati svod. To je učinjeno da bi se na dijelu nekompaktne i zdrobljene stijene stijene spriječilo rušenje i zatrpavanje gravitacijskog kanala. U radovima je korištena rimska opeka i krovni crijep (tegula), a na je jednoj je ostanak žiga rimske ciglane AFAESONIA (Auli Faesoni Africani; sl. 19).

Osmatrajući tunel pri veoma slabom svjetlu na bočnim su stranama 70 cm dugačke vertikalne usjekline, rimskim graditeljima oznaka dužine. Prvi se par usjeklina nalazi nalazi na 58 m prije okna O-3, a drugi 61 m prije okna O-5. Na izlasku iz tunela, na strani Novalje, u dnu gravitacijskog kanala sačuvalo se kružno udubljenje promjera svega oko 22 cm (taložnica; sl. 17).

Pri probijanju žive stijene glavnu radnu snagu vjerojatno su činili odabrani robovi i kažnjenici već otprije iskusni u rudarskim oknima. Rudari su pratili položaj rudače, a pri izgradnji vodovodnih (gravitacijskih) tunela morao se pratiti ne samo smjer već i otprije izračunat nagib gravitacijskog kanala.

Kad je tunel bio ugrubo probijen, vješti su klesari širili i dotjeravali bočne strane tunela radi udobnijeg kretanja (sl. 20). Na nekim se mjestima zapažaju kružni tragovi od alata kojima su bočne stijene bile dotjerivane klesanjem. Nakon toga bi vještak za gradnju kosih, gravitacijskih kanala (*librator*) na dnu tunela postavio oznake visina dna kanala. Vitruvije (VIII.5) spominje da je kod površinskog trasiranja gradskih akvedukata najpouzdanija geodetska sprava bio **horobat**. Taj glomazni geodetski instrument dugačak 6 i više od 3 m visok u ovom tunelu sigurno nije bio korišten. Pored viska za određivanje nagiba horobat je bio opremljen otvorenom razuljom (*libra aquaria*). Stoga se librator u tijesnom i neudobnom tunelu morao služiti razuljom koja je bila lagana, svega 150 cm dugačka i oko 10 cm visoka.

Kad je librator označio visinske položaje gravitacijskog kanala od ulaska do izlaska, moglo je početi zidanje gravitacijskog kanala u tunelu. Radi uštede na skupoj hidrauličkoj malti, kod zidanja je mnogo korišteno kamenje (sl. 21 A). Prvo je ugrubo uzidan gravitacijski kanal. Na Škoplju je otvorena ustava i voda je potekla prvom dionicom do tunela i onda na veliko zadovoljstvo graditelja i radnika izbila na suprotnoj strani brda Figurice. Nakon provjere i eventualnih korekcija zidari su posebnom hidrauličkom žbukom (*opus caementicium*) konačno oblikovali žlijeb gravitacijskog kanala u tunelu (sl. 21 B).

U poprečnom presjeku visina je tunela prilagođena visini odraslog muškarca, oko 176 cm. Širina iznosi od 50 do najviše 68 cm, jedva da se dvije odrasle osobe mogu mimoići (sl. 20).

TREĆA DIONICA: TUNEL – JAVNI ZDENAC (*LACUS*)

Oko 600 m dugačka treća dionica bila je graditeljima i najlakša. Da bi se mogla i sagraditi, na Škoplju je pomoću ustave bio prekinut dotok vode. Na odabranome mjestu, ali ne i preblizu obale, bio je postavljen javni zdenac (na sl. 24 označen slovom Z). Kako prikazuje slika 22, to je kamenica isklesana od domaće breče, dugačka 95,5 cm, široka 77 cm i 74 cm visoka. Zapremina kamenog zdenca je oko 300 l. U dislociranom položaju kamenicu je otkrio Ivan Škunca, zvan Šimera, kad je kopao temelj za novogradnju. Najdeblje su dvije bočne strane i prednja strana, oko 9 cm. Stražnja je strana tanja jer je do nje bio dozidan završetak gravitacionog kanala akvedukta (na sl. 22 označeno slovom A). Gornje pristupne strane kamenice blago su prema unutra zaobljene da ne bi ozlijedile ruke dok se grabila voda.Sva su tri gornja ruba zdenca s vanjske strane ukrašene profilacijom.

U sredini stražnje strane sačuvalo se kružno udubljenje B, ležište za keramičku cijev kroz koju se voda iz akvedukta ulijevala u zdenac (sl. 22). Na prednjoj strani kamenice, koja je i najviše oštećena, nalazilo se i ovalno udubljenje C preko kojeg je neiskorištena voda istjecala u otvoreni kanal K. S lijeve strane dna nalazi se kružni otvor D promjera oko 4 cm, koji je bio zatvoren nauljenim drvenim čepom. Kad bi talog prekrio dno zdenca, nakon dugotrajnih kiša koje bi zamuljile izvorsku vodu, izvadio bi se čep i očistio zdenac. Da se ponovno napuni trebalo je oko 25 sekundi (vidi ovdje pod »kapacitet»).

Prema navodu I. Škunce, na ovaj je zdenac dolazio zidani kanal od smjera Talijanove buže, kako mještani nazivaju tunelsku dionicu akvedukta, i bio je pokriven kamenim pločama crvene boje. Navodi se da je na udaljenosti od nekih 3 m bila zatečena još jedna ali manja kamenica kojoj se zagubio svaki trag.

Kad je izgradnja akvedukta bila u cijelosti dovršena prema rimskim propisima, sva je vodovodna konstrukcija bila zazidana da bi se spriječio ulazak zmija, žaba i puževa. Bila su zatvorena sva vertikalna okna, a radi pregleda i popravaka određeno je jedno ili više mjesta preko kojih je bilo moguće ući u tunel i obaviti potrebne građevinske radove. Briga oko nadzora i održavanja novosagrađenog akvedukta Škopalj – Novaljska draga bila je povjerena stručnoj osobi (*curator aquae*). Treća dionica i položaj javnog zdenca uvjetovali su i budući položaj javnog trga (*forum*) u kasnorimskoj Novalji.

KAPACITET

Ne raspolažemo s austrijskim nivelmanskim zapisnikom iz 1910. godine koji je bio osnova za izgradnju projekta za obnovu starog rimskog akvedukta. Radi kasnije obnove austrijskog vodovoda za Novalju, godine 1948. god. izrađen je novi geodetski vertikalni profil od Škoplja do kraja tunelske dionice. Na tom planu upisane su nivelete dna rimskoga gravitacijskog kanala od okna O-2 do kraja tunela, što je ovdje i jedina geodetska podloga za proračun kapaciteta rimskog akvedukta Škopalj – Novaljska draga.

L (dužina trase od okna O-2 do kraja tunela iznosi 900 m)

L = 900 m

H (visinska razlika od dna gravitacijskog kanala) 4,88 m kod okna O-2 i 3,54 m na kraju tunela. Razlika je 1,34 m

H = 1,34 m

I (strmina, nagib gravitacijskog kanala) H : L = 1,34m : 900m = 0,00149 = 1 : 671

I = 0,00149

U (dužina omočenog opsega, na sl. 21B otvoreni poligon 1–4)

U = 0,46 m

F (površina presjeka vodenog toka, na sl. 21B zatvoreni poligon 1–4)

F = 0,0278 m^2

R (hidraulični radius) = F : U = 0,0278 m^2 : 0,46 m = 0,0604 m

R = 0,0604 metra

b (koeficijent trenja) = 0,35

v (brzina vodenog toka) = (100 x R x I) : (b +vR) =

(100 x 0,0604 x 0,0386) : (0,35 + 0,246)

v = 0,391 metar na sekundu

Q (kapacitet) = v x F = 0,391 m x 0,0278 m^2 = 0,0108 m^3 na sekundu

Q = 10,8 litara na sekundu

Nivelman Škopalj – Novalja iz 1948. godine objašnjava zašto je već austrijska uprava bila prisiljena na Škoplju postaviti vjetrenjaču koja je pomoću crpke tlačila vodu sa Škoplja u 22 m visoku vodospremu pored okna O-2. Te 1948. godine razina vode na Škoplju već je bila za 48 cm niža od dna gravitacijskog kanala kod okna O-2 pa direkno dovođenje vode jednim gravitacijskim kanalom nije više bilo moguće (Škopalj +4,40 m, dno gravitacijskog kanala kod okna O-2, +4,88). Takve su hidrološke pojave bile česte na izvorištima gdje su geološki slojevi bili rastresiti i vodopropusni.

Obnavljajući Dioklecijanov akvedukt, austrijska je uprava 1879. godine dovela vodu u Split ne samo istom rimskom trasom već pretežito istim ali obnovljenim gravitacijskim kanalom, jer je snažno vrelo Jadra koje istječe iz žive stijene ostalo na istoj nadmorskoj visini kao u doba izgradnje Dioklecijanovog akvedukta.

Poseban je slučaj s rimskim akveduktom Boljkovac – Nin. Prirodno prenisko izvorište obzidali su snažnim zidanim bedemom i na umjetan način podigli razinu vode na izvorištu za oko 88 cm.

Nema pisanih izvora koji bi objasnili kako su bile rješavane mnoge građevinske teškoće kod izgradnje oko 1400 m dugačke tunelske dionice. Ostaju nam samo pretpostavke.

PROMET I ODLAGANJE ISKOPA

U oknima O-3 i O-5 sačuvali su se **usjeci za noge** s obje uže strane okna, što je omogućilo penjanje i kretanje kroz vertikalno okno bez pomoći neke dizalice (sl. 23). Devet vertikalnih okana i oko 1400 m dugačke tunelske dionice zauzimaju prostor od oko 1500 kubičnih metara iskopanog kamena. Dio izvađenog kamena bio je izvučen kroz okno, kako prikazuje sl. 23, a glavnina iskopa bila je uklonjena provizornim drvenim sanducima kroz već iskopani dio tunela. Uokolo najdubljeg, 46 m dubokog okna O-3, nalaze se s vanjske strane manji ostaci iskopanog kamena. Za opskrbu brodova u Novaljskoj dragi tekućom vodom trebalo je izgraditi i novo pristanište za brodove. Stoga je većina iskopa bila dopremljena do obale i upotrebljena za nasipavanje priobalnog dijela, da bi se izgradila za promet prikladna vodoravna površina (sl. 24). Stoga je i dio današnje Novalje uokolo benzinske crpke napadno ravan što je posljedica rimskodobnog nasipavanja. Drugi dio nasipanog kamena bio je iskorišten za izgradnju novog pristaništa (na sl. 24 označeno slovom P). Na sličan je način u 2. stoljeću poslije Krista, kad je zasađivan novi i veliki plantažni vinograd na položaju Kumenat kod Biograda na Moru, iskopani kamen iskorišten za izgradnju dvaju pristaništa.

OSVJETLJENJE

Na ulaznom i izalaznom dijelu tunela koristili su u početku danje svjetlo. Kako su probijanjem tunela napredovali, tako je tama postajala sve veća. U početku su se pomagali upaljenim svjetiljkama. Između okna O-8 i O-9 na bočnim se stijenama tunela nalaze prirodna ali i umjetno isklesana ležišta za uljanice. Da su na tim mjestima gorjele uljanice, dokazuju crni tragovi povrh tih udubina koji se ne brišu.

PROVJETRAVANJE

Za vrijeme provjetravanja tunela, a još više vertikalnih okana, bila je stalna i za život opasna koncentracija ugljičnog dioksida (CO_2). Udišemo čisti zrak (smjesa od 20,94 % kisika i 79,03 % dušika). Potrošeni zrak koji izdišemo sadržava oko 5,6% ugljičnog dioksida. Taj otrovni plin nema boju, miris pa ni okus. Za radnike koji rade u vertikalnim oknima i rovovima (bunari) posebno je opasan jer je teži od zraka i taloži se u najnižim djelovima smanjujući postotak kisika u zraku. Već je stari svijet poznavao tu opasnu pojavu. Vitruvije upozorava da se prije ulaska u podzemne rovove spusti upaljena svjetiljka. Ako se ne ugasi uvjeti za rad su povoljni; ako se ugasi, opasno je za život (Vitr. VIII.6.13). I već spomenute uljane svjetiljke a još više pluća radnika, stvarali su u tunelu i u oknima otrovni ugljični dioksid. Smišljenom ventilacijom to se moglo djelomice riješiti. Područje Novalje naglašeno je vjetrovito. Postavljanjem skošene vjetrolovke A do ulaska u okno vjetar je bio usmjeren u okno, a skošena vjetrolovka B pomogla bi pri isisavanju i boljoj ventilaciji (sl. 27).

DATIRANJE

Povijesnih podataka o izgradnji akvedukta Škopalj – Novaljska draga nema, a poredbene činjenice upućuju da nije mogao biti sagrađen prije cara Trajana (98–117. g.). Rimski krovni crijep (*tegula*) uzidan u svodu tunela s natpisom FAESONIA (Auli Faesoni Africani) ne pomaže za uže datiranje, jer je serijska proizvodnja ciglane Faesonia trajala od kraja 1. stoljeća pa sve do u 3. stoljeće. Pored tegule sa žigom AFAESONIA koja je uzidana u svodu tunela, tegula s jednakim žigom otkrivena je u rimskom kanalu u Novalji.

Kolonijalna središta Pula (*Pola*), Zadar (*Iader*) i Solin (*Salona*), dobili su svoje gradske akvedukte tek tijekom 2. stoljeća. Za dva municipalna središta na našim otocima, za Rab (*Arba*) i Omišalj (*Fulfinum*) na otoku Krku bili su sagrađeni akvedukti potkraj 1. i tijekom 2. stoljeća. Podgrađe (*Asseria*) kod Benkovca dobilo je tekuću vodu tek potkraj 2. stoljeća. Nešto je prije bio sagrađen gradski akvedukt za municipij *Aenona* (Nin).

Dva su akvedukta bila sagrađena za rimske vojne logore. *Burnum* pokraj Ivoševaca dobio je akvedukt početkom 1. stoljeća, a drugi vojni logor Gardun (*Tilurium*) pokraj Sinja dobio je tekuću vodu poslije 150. godine, iako je logor bio sagrađen na rijeci Cetini. Samo je za liburnsko–rimsku Kisu (Caska) bio sagrađen privatni akvedukt na prijelazu iz stare u novu eru.

OSVRT

Izgradnjom akvedukta, javnog zdenca i pristaništa ondašnja je Novaljska draga postala sve poznatija kao nova luka, a stara je Kisa kao glavno naselje istoimenog otoka dobila još jedno ali suvremeno i opskrbljeno pristanište. Od latinskih imenica *novalis*, *-is*, f., u značenju *iskrčeno i agrikultivirano zemljište*; *navales*, *-ium*, m., u značenju *pristanište* i *navalia*, *-ium*, m., *brodogradilište*, djelovanjem sličnozvučnosti (homofonija) tek je kasnije nastao hrvatski naziv **Novalja**. Stoga su Novalja kao i Zadar etimološki prethrvatski toponimi. Tek se u 12. stoljeći prvi put spominje ime Novalja (*Navalla*) na mjestu gdje je i danas.

Rivanj, April 26, 2005

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