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HYDRODYNAMIC PROBLEM OF CLOSED CHANNEL IN THE GORGE OF THE RIVER VERE

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Summary: *It is obvious that the project of the section of the high-speed highway in the gorge of the river Vere could not contain an analysis of probable negative consequences of this construction. It was miscount assumed that the closed channel, in addition to the transport problem, could also solve the flood problem in the lower part of the Vere gorge. It seems that mistakes were made during the design process, the reason of which is disregard of the factor of the hydraulic resistance in the tunnels having corrugated inner surfaces. As a result, the closed riverbed turned into an even greater danger than the historically known river Vere. Proceeding from such a vision of the reason for the development of the events, we cannot agree with the widely spread opinion that the devastating flood on 13.06.2015 was caused by anomalously heavy precipitation.*

Key Words:*. Vere river, floods, Stagnant zones, tunnels.*

Introduction.

The typical mountain river Vere is considered as one of the most dangerous in East Georgia due to frequent recurrent floods characterized by two orders of magnitude greater water flow than the average yearly value $Q | 1m^{3} s^{-1}$. Usually, floods used to occur in the lower part of the Vere gorge near the boundary of Tbilisi city. In the case of intense precipitations the lower, part of the Vere gorge turns into a fairly large catchment basin.. After constructing the part of the high-speed highway in 2010 in the lower part of the gorge, the river Vere appeared partially contained in the artificial closed bed consisting of several tunnels joined by open sectors. The new closed bed of the river Vere, instead of two, has seven tunnels with general length of 2100 m. The two tunnels, which had been constructed earlier, were partially elongated and as a result, nowadays the first tunnel is $l|$ 360 m and the other is $l|$ 1200 m long. Therefore, the geometrical properties of the natural bed corresponding the orography of the gorge, was significantly changed. In the Soviet period the flood zone was the area between the two tunnels (underground tubes) constructed in the first half of the last century. The first tube, which is nowadays situated under the Tamarashvili Highway, was 108 m long. The other tube was significantly longer, $l|$ 700 m. It occupied the natural bed of the river Vere before the junction with the river Mtkvari. Before 13.06.2015 night, for a long time, the flood taking place on 04.07.1960 was considered as the heaviest one. According to various assessments the flood was caused by the $h|$100 mm precipitations, which fell during two and half an hour. According to approximate assessments, during this time period, According to our assessments the water flow in the closed bed of the river Vere during the night of 13.06.2015 was probably was not more the one of the 04.07.1960 flood, when the maximum water flow in the Vere bed could be $Q|$260 $m^{3} s^{-1}$ [1]. However, the result of the last flood appeared much disastrous due to human life losses and enormous material damage.

The security problem of the closed channel.

The structure of the closed and sufficiently long arched tunnels of the river Vere was made of corrugated steel sheets. In particular, the total length of the tunnels of the closed channel was 46% of the original length of the natural river bed between the Tamarashvili highway and the river Mtkvari.The theory of the construction of water supply canals states that arched tunnels and bridges constructed from corrugated steel have a sufficiently high seismic stability. Therefore, according to their technical and economic characteristics, they are almost as stable as structures made of stone, reinforced concrete or metal. Moreover, large water pipes made of corrugated steel have some advantages over concrete ones due to technological simplicity and less labour-intensiveness for construction and installation works. It is known that one of the advantages of arched tunnels and bridges made of corrugated steel is their ability to gradually fracture, i.e. soft bedding in case of considerably strong and prolonged tremors. However, they should not be used for hydrotechnical objects in regard to mountain rivers with fairly long closed riverbed. Therefore, when designing a closed channel in the Vere gorge, it was necessary to a priori consider the dangers that could arise in case of severe weather conditions. Due to the constant threat of flooding, it was obviously not reasonable to use such constructions that could reduce the capacity of the closed channel. It would be quite likely that there would be retrospective data on the 04.07.1960 flood in order to assess the degree of danger potentially threatening the urbanized gorge of the river Vere. There were also valuable data on series of floods that occurred in the subsequent period of time. First of all, it was quite possible to estimate how much the capacity of the new tunnels of the closed channel corresponded to the full load of the modernized first tunnel. As it is shown below, most likely the damming occurred not only before the first tunnel, but also in front of other tunnels. An important proof in favour of such an assertion is the fact that the water from the dam formed on Svanidze Street did not flow over the Tamarashvili highway. Consequently, this highway was a watershed, dividing the gorge into two parts. Therefore, we can assume that the flooding beyond the watershed began independently from the reason of damming of the first tunnel. For this, e. g, it was sufficient that water flow in any of the tunnels was reduced due to the increase in hydraulic resistance, and also because of the drain of urban storm water in the lower part of the gorge. As it is known, on 04.07.1960, flooding occurred in front of both tunnels, where had formed the stagnation zones. It should be assumed that in emergency situations floods in a closed channel in the future can be caused not only by factors of roughness and curvature, but also other negative mechanisms. Obviously, roughness, under harsh conditions, in all sufficiently long tunnels of the closed channel will always contribute to the intensification of the turbulence and initiation of return flows. Therefore, we assume that the increase in hydraulic resistance to the critical level in the tunnels of the closed channel was one of the reasons that led to the disaster on 13.07. 2015. In particular, at the initial stage the flood zone formed in front of the first tunnel, the reason of which, in addition to the hydraulic resistance, was also partial overlapping of the inlet of the tunnel by various household objects and trees brought by the water flow. As a result, the flood zone gradually expanded and, according to oure estimates, a reservoir of volume $/3.1\text{-}4.4/10^5\ m^3$ rapidly formed and was kept long enough along the entire length of Svanidze Street. Such a factor of mechanical damping, but to a lesser extent than before the first tunnel, was observed for a certain time also in front of the second tunnel. However, in our opinion, it is necessary to pay special attention to the fact that the section of the gorge between the first and second tunnel was dammed while the water flow in the first tunnel was diminishing.

Hydraulic resistance in the tunnels of the closed channel.

It seems that during the design process of the sector of the high-speed highway in the Vere gorge, increase in the hydraulic resistance of tunnels of the closed channel under severe conditions was underestimated. According to the prevailing opinion, the cause of the devastating flood was precipitation of exceptional intensity, as well as trees, brought by the water flow and accumulated in front of the inlet of the first tunnel. However, it seems that such an explanation is insufficiently substantiated. Undoubtedly, the inlet of the first tunnel for some time was actually partially blocked that contributed to the flooding in Svanidze Street. However, it is especially noteworthy that from here the water did not flow over the Tamarashvili Highway, which turned out to be a watershed. After some time, the inlet of the first tunnel was released. Therefore, the previously partially blocked tunnel could not operate at its maximum throughput. Besides, there was a flood also in the area between the outlet of the first tunnel and the inlet of the last one. In design calculations the maximum value of the water flow in a closed channel was $Q \mid 260\ m^{3} s^{-1}$ (according our estimations 200 m□ ^{3} s^{-1}), which fully corresponds to emergency situations. However, we need additional facts for proving our opinion. Thus, below is a brief qualitative analysis, the basis of which is the hydrodynamic theory of turbulent water flow in rough pipes.

As far as the first tunnel was partially blocked, this could hardly have been caused only by the additional flow of water from urban drains and precipitation in the area of this part of the Vere gorge. Indeed, according to rough estimates, an additional volume of water in the area beetwin first two tunnels, beyond the watershed, could be V≈ 2.5*10^{5}м^3. Such an amount could accumulated during 2.5-3 hours. This corresponds approximately to the flow rate of water $Q\approx$ 25-30 m^3 s^{-1}, which is about (8-10)% of the estimated throughput of the first tunnel. However, the first tunnel was partially blocked for some time, and consequently its capacity was lower than the design one. Therefore, in spite of the additional volume of water received from the gutter, in the case of sufficiently effective operation of other tunnels (especially the last one), floods in the lower part of the gorge were unlikely to have occurred.

Modelling of the closed tunnels.

It is well known that the coefficient of hydraulic resistance in a circular pipe depends on the characteristic value of the Reynolds number and also on the curvature and roughness of the inner surface of the pipe. There must be a similar dependence for all natural and artificial channels, including tunnel water pipelines. Therefore, using the hydrodynamic similarity method, it is possible to correctly model the hydraulic resistance of a water channel of any shape. Consequently, it is possible to accurately determine the characteristic value of the coefficient of hydraulic resistance of the tunnels of the closed bed of the river Vere. To do this, it is necessary to approximate the closed channel (i.e., any of the tunnels) with a circular cross-section curved rough pipe. Obviously, such an analogy, both for a separate tunnel and for a closed channel as a whole, is physically fully justified. The analogy between a tunnel with a corrugated inner surface and a rough pipe is also evident. It enables to determine the coefficient of hydraulic resistance, the key parameter on which the flow of water in any water pipe depends. The main determinant of the degree of turbulence in the water flowing in the pipe is the dimensionless parameter, the Reynolds number $R_e = \frac{\bar{u}D}{\nu}$, where $\bar{u}$ is average water flow velocity, D is the pipe diameter, ν is kinematic viscosity of water. Therefore, for the closed channel of the Vere, the linear characteristics of which is the constant hydraulic radius of the tunnels, the speed of the river flow determines the characteristic value of the Reynolds number. It is known that for different hydrotechnical objects the permissible relative roughness can vary within the limits of 0.2%-7% [2].This parameter is the relation of the characteristic height of roughness to the radius of a pipe, or to the characteristic linear dimension of the cross-section of a water channel of any other shape. The longer the roughened tube, the lower the upper limit of the interval of subcritical values of the relative roughness. However, in case the throughput of a smooth analogue of a pipe approximating the water supply considerably exceeds the volume of incoming water, the upper limit of the permissible relative roughness of the inner surface of the water pipe can be increased to 7% and more. According our model estimates, the characteristic value of the coefficient of total hydraulic resistance of the closed channel of the river Vere was equal to 0.14 Consequently, the relative roughness of the inner surface of the river Vere closed channel actually amounted to $\approx$4% [3]. We assume that the increase in hydraulic resistance to the critical level in the tunnels of the closed channel was one of the reasons that led to the disaster on 13.07. 2015. Another reason maybe problems associated with the formation of stagnant zones or, zones of liquid stagnation, which are well known in the hydrodynamic theory [4]. In particular, at the initial stage the flood zone formed in front of the first tunnel, the reason of which, in addition to the hydraulic resistance, was also partial overlapping of the inlet of the tunnel by various household objects and trees brought by the water flow. As a result, the flood zone gradually expanded and, according to oure estimates, a reservoir of volume /3.1-4.4/10^5 m^3 rapidly formed and was kept long enough along the entire length of Svanidze Street. Such a factor of mechanical damping, but to a lesser extent than before the first tunnel, was observed for a certain time also in front of the second tunnel. However, in our opinion, it is necessary to pay special attention to the fact that the section of the gorge between the first and second tunnel was dammed while the water flow in the first tunnel was diminishing. Thus, it becomes obvious that the initial flood in the lower part of the Vere gorge occurred before inlet of the first tunnel. Then, regardless of the rapidly formed reservoir along the Svanidze Street, the areas in front of other tunnels were apparently also flooding. For example, after the first tunnel such a place could be the inlet of the second tunnel, or the inlet of the longest, the last tunnel connecting the Vere to the main river Mtkvari. Probably, it was the joint action of all local flood zones that resulted in heavy flooding. However, regarding the probability of possible repetition of severe meteorological conditions in the future, it seems that the discussion of the technical causes of the devastating 13.06.2015 flood should be supplemented with the fact that the river Vere has a sharp bend in front of the second tunnel. Therefore, it can be assumed that together with the negative effect of the hydraulic resistance of the tunnel, this place inevitably became one of the initial flood areas during the devastating flood. Thus, it becomes obvious that the initial flood in the lower part of the Vere gorge occurred before inlet of the first tunnel. Then, regardless of the rapidly formed reservoir along the Svanidze Street, the areas in front of other tunnels were apparently also flooding. For example, after the first tunnel such a place could be the inlet of the second tunnel, or the inlet of the longest, the last tunnel connecting the Vere to the main river Mtkvari. Probably, it was the joint action of all local flood zones that resulted in heavy flooding. However, regarding the probability of possible repetition of severe meteorological conditions in the future, it seems that the discussion of the technical causes of the devastating 13.06.2015 flood should be supplemented with the fact that the river Vere has a sharp bend in front of the second tunnel.

Conclusion.

1. The reason for the devastating flood on 13.07.2015 in the gorge of the river Vere was both natural and artificial causes. It seems that an anomalous natural phenomenon was added to a technical factor associated with structural deficiencies in a closed river channel, which is an integral part of the project of a high-speed highway section in the lower part of the Vere gorge. Therefore, in conditions of frequently repeated intense precipitation, the gorge remains a real threat for Tbilisi city in the future.

2. The analysis of the possible technical reasons that contributed to the disastrous results of the flood on the river Vere on 13.06.2015 may become the basis for preventive actions in case of a repeat of such a phenomenon in the future. For this purpose, simultaneous observation of the water level at critical locations of the closed channel, in particular, before the first and second tunnels, is quite effective. In these places, so-called stagnant zones, which serve as an indicator of the formation of recurrent currents, may appear. Stagnant zones can form even in case of medium intensity precipitation. As to the factor of hydraulic resistance, it will fully manifest itself in the case of extremely intense precipitation, i.e. under the condition of the maximum load of the tunnels of the closed channel. Consequently, until a certain moment, the zone of stagnation will not cause the decrease in the flow of water in the tunnels. Moreover, local water stagnation in front of the first and second tunnels can reduce, or simply prevent flooding in the area between the second and the following tunnels.

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