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THE MODELLING OF FLOW PHENOMENA IN THE POLYCENTRIC RIVER BEDS

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Abstract: The paper presents the modeling of free level flow phenomena in the polycentric riverbeds sections. The classical section of hydrotechnical galleries is modified in exploitation through phenomena of hydrodynamic erosion. The calculation model adopted considers a flow section formed of lines and circular curves. For the polycentric section specific to the case study analyzed, we determined the calculation relations of the hydraulic parameters.

Key words: gallery, hydrodynamic erosion, flow modeling, polycentric riverbeds

1. INTRODUCTION

An important place within a hydrotechnical system is represented by the adduction pipes. The flow in adductions can be characterized by free level under the pressure, or in certain situations in a mixed manner. The modification of design parameters and of the hydrodynamic regime in the adductions for water is developed in a continuous destructive process or variable in time. The multiple actions determine the modification of the constructive and functional parameters of the adduction, diminish the mechanic resistances, disturb the stability and decrease the safety in the construction exploitation. Most of the times, the remedy of destructive effects involves expensive works and which are executed in extremely difficult conditions.

2. THE CALCULATION MODEL

The calculation model was conceived for the characterization of the free-level flow in structurally modified sections in the exploitation process. The model answers the hydraulic requirements imposed to the adductions of the type of hydrotechnical galleries with free flow regime and affected by the phenomena of hydrodynamic erosion. The technologies for the galleries construction and the effects of the hydrodynamic erosion model the free-level flow section in a certain form. In some situations, there are also corrosion phenomena determined by the transport of the alluvium material and some chemical characteristics of water.

In some cases, a significant modification of the geometrical shape of the free-level flow section has resulted. The hydraulic, mechanical, chemical phenomena etc., acting together, have determined a new shape of the flow section. Knowing the evolution in time of the flow section imposes the determination of the hydraulic parameters with direct influences on the geometrical dimensions. Among these parameters, we notice speed, the load loss, the cavitation coefficient etc.

The calculation model has taken into account the following modifications of the flow section:

- the inferior part is achieved in a flat shape out of technological considerations;
- the wall in the flow area is modified differentially regarding length through the hydrodynamic erosion;

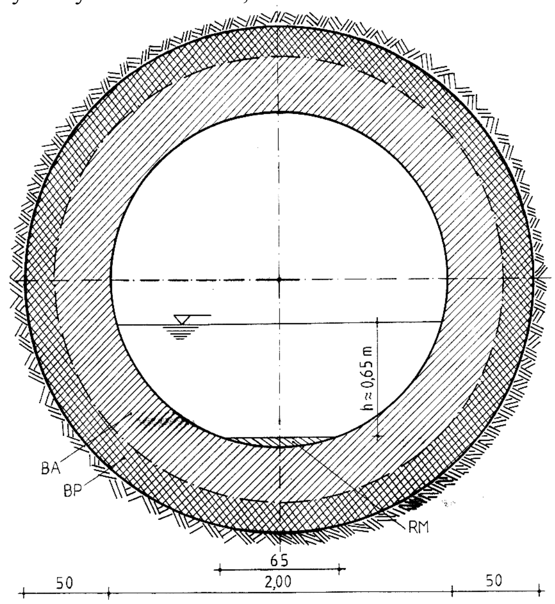

Fig.1 The hydraulic calculation scheme of the gallery.

- the hydrodynamic erosion, the abrasion, the chemical corrosion, in some cases the cavitations have determined modifications of the roughness per perimeter. The section of the calculation model is formed of lines and circular curves.

The erosion areas per perimeter can be approximated with circular curves of a certain radius. In the first stage, we determined the hydraulic parameters specific to the modified flow section.

The flow section perimeter (initially circular)

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was approximated with portions through $N_A=(N_M-1)/2$ line segments or circular curves (NM – number of measuring points, NA – number of segments). In the case analyzed, we admitted 6 circular curves and the flat foundation mat.

Fig. 2 View of the flow section of Strunga hydrotechnical gallery.

Geometric Parameters of the section flow are dependent on water depth:

$0 < h \le (z_{i+1} - z_{C0})$, $i = 1,\ldots,N_A$.

The geometrical parameters considered are: the free-level width of the liquid, $B_i(h)$;

- wet perimeter, $P_i(h)$;
- area of transversal section, $A_i(h)$;
- the ordinate of the centre of gravity of the section, $z_{Gi}(h)$.

The support circles are given by the equation:

$$(y-b_i)^2+(z-a_i)^2-R_i^2=0,(i=2,\ldots,N_A)$$

The expression of geometrical parameters for the calculation model is the following:

- width at the liquid free-level,

$$B_i(h)=2\cdot\left[b_i+\sqrt{R_i^2-(h-a_i)^2},(i=2,\cdots,N_A)\right]; \quad (1)$$

- wet perimeter,

$$\begin{cases} P_i(h)=\{P_i(z_{M0})=2\cdot B_{C0},\ for\to i=1 \\ P_{i-1}(z_{i-1})+2\cdot R_i\left|arccos\left|t_i(h)\right|-arcsin\dfrac{y_{i-1}-b_i}{R_i}\right|, \\ for\to(i=2,\cdots,N_A) \end{cases} \quad (2)$$

where:

$$t_i(h)=\frac{h-a_i}{R_i}, \text{ for } i = 2, \ ,Na; \quad (3)$$

- area of the transversal section,

$$A_i(h)=\begin{cases} A_i(z_{M0})=0,\ for\to i=1 \\ A_{i-1}(z_i)+2\cdot\left[F_i(h)-F_i(z_{i-1})\right], \\ for\to(i=2,\cdots,N_A) \end{cases} \quad (4)$$

where:

$$F_i(z)=b_i\cdot z+\frac{1}{2}\cdot R_i^2\cdot\left[t_i(z)\cdot\sqrt{1-t_i^2(z)}+arcsin(t_i(z))\right],$$
$$for\to(i=2,\cdots,N_A)$$
(5)

- the ordinate of the centre of gravity,

$$z_{Gi}(h)=\frac{I_{zGi}(h)}{A_i(h)}, \quad (6)$$

where:

$$I_{z_{Gi}}(h)=\begin{cases} I_{z_{Gi}}(z_{M0})=0,\ for\to i=1 \\ I_{z_{Gi}}(z_{i-1})+2\cdot\left[G_i(h)-G_i(z_{i-1})\right], \\ for\to(i=2,\cdots,N_A) \end{cases} \quad (7)$$

with:

$$G_i(z)=\frac{1}{2}\cdot b_i\cdot z^2+\frac{1}{2}\cdot R_i^2\cdot$$
$$\cdot\begin{Bmatrix} a_i\cdot\left[t_i(z)\cdot\sqrt{1-t_i^2(z)}+arcsin(t_i(z))\right]- \\ \frac{2}{3}\cdot R_i\cdot\left[\sqrt{1-t_i^2(z)}\right]^3 \end{Bmatrix} \quad (8)$$
$$for\to(i=2,\cdots,N_A)$$

With the relations above we determined the hydraulic parameters of the modified flow section: the hydraulic radius R_h, the speed module W, the rate of flow module, K, the hydrostatic force appropriate to the live section, F_h.

The mathematic model presented above was implemented in the computer program MATLAB Sect_Poli_Centr_Masurat.m. The program achieves the following operations based on some data known through measurements made in the field:

1. The shape of the channel section (included in the yOz, with Oz – vertical symmetry axis) is determined through the precision airborne survey of the coordinates (y_i, z_i) for $N_M=2\cdot N_A+1$ points.

2. Determining the equations for N_A circular curves or line segments that describe the flow section.

3. Determining the geometric and hydraulic parameters B, A, P, R_h, z_G, W and K for a transversal flow section made up of N_A circular curves or line segments connected , appropriate to the depth h imposed.

The program Sect_Poli_Centr_Masurat.m was run for the input data according to the case study "Strunga hydrotechnical gallery". The flow section is defined by a line and five circular curves.

The calculation model is based on the observations and measurements achieved in the flow section of pipe section 2 that ensures the adduction Timişeşti –Iaşi, line II. The flow section is modified due to the technological considerations regarding the gallery construction and as a result of the water hydrodynamic action during about 40 years of exploitation.

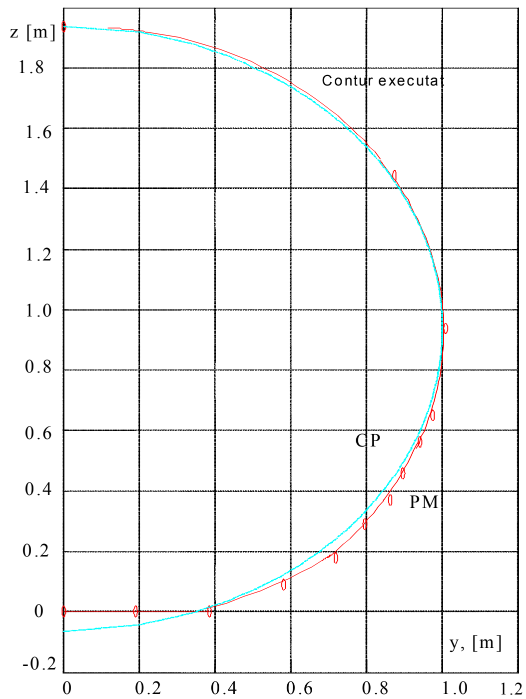

Fig. 3 Strunga hydrotechnical gallery: blue – designed contour; red: executed contour

The virtual circular section given through the design is replaced in the inferior part by a polycentric section. According to the field analyses and the measurements made, the following have resulted for the shape of the flow section: the inferior part is represented by a line.

3. EXPERIMENTAL RESULTS

The hydrotechnical Strunga Gallery is a part of the water feeding system of Iasi. The theoretical and experimental researches were carried out on the second pipe section of the adduction Timişeşti Iaşi. The pipe section is made up of a hydrotechnical gallery with the role of under-crossing of Strunga Hill. The gallery takes the rate of flows transported gravitationally by three pipes: two pipes PREMO Dn 1000 supplied from Timişeşti source; the third pipe Dn 600 from Verşeni source.

The total flow taken from the gallery is transferred in pipe section III under the adduction pressure (Dn 2000, steel, PREMO). The pipe section III is connected to the compensation reservoir of Iaşi city.

The hydrotechnical structure was built directly excavating the bedrock of the Strunga hill, excepting the extreme areas. Strunga hill is made up of shale and limestone. The structure of the gallery is made of reinforced monolith built-up concrete. There is a row of prefabricated blocks at the rock contact. To the interior on the arch bricks there is a lining of monolith reinforced concrete that was to be covered with jet Crete. The internal diameter is of 2.00 m and external diameter, 3.00 m (Fig. 1, 2).

The gallery supply is achieved through a loading chamber, with the rectangular shape section and the depth of 6.00 m. The gallery empties downhill into a cable chute where the pipe section III is connected. In the downhill cable chute, a weir is mounted for putting pressure in the gallery.

The gallery length is of 1324 m, and the medium downgrade has the value of 1.14 ‰ [4]. According to the longitudinal execution profile, on the first half of the length, the foundation mat downgrade is of 1.0 ‰. On the last gallery length, the foundation mat downgrade is of 1.28 ‰ [4].

Researches carried out to the interior of the flowing section showed significant changes in the micro-relief of the cut-off trench with influences on the roughness perimeter distribution pattern. The free flow running led to the hydrodynamic erosion of the apron. The differentiated roughness led the formation of four different areas. The cut-off trench of the gallery was carved under the action of the water current forming a cavity in the concrete and macro roughness in the hydraulic phenomenon. Also on the inferior third part of the perimeter one can note the decreasing effects of the erosion that continuously carves the roughness of the wall in the area of water contact.

The studies made within the flow section emphasized important modification in the hearth micro-relief, with influences on the manner of distribution of the perimeter of the roughness. The free-level flow determined a foundation mat conditioning through the hydrodynamic erosion phenomenon. The roughness differentiated in an obvious manner on the perimeter, forming four characteristic dimensional areas.

The gallery hearth was modeled under the action of the water flow, forming some cavities in the concrete mass, respectively a macro-roughness in the hydraulic phenomenon. In addition, on the inferior third of the perimeter we notice, in decreasing manner, the effects of the erosion phenomena, which continuously model the wall roughness in the area of water contact.

The checking of hydraulic parameters emphasized a modification of the transported rate of flow and of the speed.

Because of the non-compliance of geometrical parameters and the execution technology stipulated in the project for Strunga gallery (the current situation is presented in Figure 1), the following result in the current stage of exploitation of the analyzed pipe section:

- at the same depth of water in the gallery, the water speed is diminished with up to 19%;
- accordingly, the rate of flow is diminished with up to 12.5%;

- the increase of the gallery rate of flow must be achieved through works of the flow section rehabilitation.

The most unfavorable situation from the hydraulic point of view is registered on the first pipe section of the gallery (about 60…110 m). according to the investigations in the gallery, and the data obtained through simulation, it results that on a distance of 15…95 m after the entrance in the gallery, the water current evolves in a supercritical state of movement, this fact is proven by the state of the flow section, where we register a hydrodynamic continuous and significant erosion, with a intense transport of material of different dimensions.

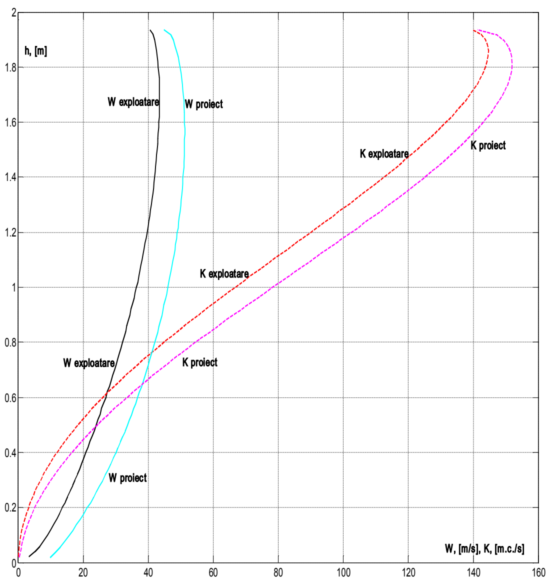

Fig. 4 Strunga hydrotechnical gallery-designed and effective characteristics

At the same time the degradation in the apron area can lead to the apparition of the cavitation phenomenon on the first 10…30 m of the input section. This phenomenon, combined with dynamic erosion, can accelerate the process of degradation of the gallery's apron in this area, a situation that was also emphasized at the time of the visualization of the flow sections. Research in this field has proved the existence of a continuous exchange of water between the gallery and the incorporating medium, through an infiltration - ex-filtration process. The quality of water in the rock massif (mineral water of a sulphurous nature) also determines chemical erosion upon the execution materials of the gallery.

The speeds registered in this area have values of 4.90…9.20 m/s in the entry section, according to the value of the control depth. In the final section of the supercritical movement area, the speeds reach values of 1.70…1.90 m/s. Thenceforth, the supercritical movement goes through a hydraulic bounce into an under-critical movement, and the bounce position is marked at different distances through the phenomenon of sedimentation of the alluvial material.

The water movement in the gallery is formed of a succession of non-uniform movements gradually varied and rapidly varied, which differently influence the functional state and the hydrodynamic stability. For calculating the non-uniform movement, we created the computer program MGVAT1_Strunga.m in the MATLAB.

4. CONCLUSIONS

The interpretation of data obtained allows the exposal of the following general conclusions:

-The gallery flow section presents a hydrodynamic erosion phenomenon differentiated according to length, more intensified on the entry pipe section and less active on the central and final pipe sections;

-The flow into the gallery is formed of a section of gradually varied and rapidly varied non-uniform movements, which differently influence the functional state and the hydrodynamic stability;

-For determining the hydraulic parameters in the modified flow sections, we drew up two calculation programs in MATLAB for the uniform movement and the non-uniform movement.

-The results regarding the modeling of the water movement in the gallery for the modified section indicates different values of the speed and the rate of flow compared to the designed values.

-Adopting some rehabilitation and re-technologizing measures must take into account the current state of the flow section and the modified value of the hydraulic parameters.

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