# DEVELOPMENT OF INNOVATIVE DRAINAGE PIPE DESIGNS THAT REDUCE THE RISKS OF LOSS OF STABILITY IN DIFFICULT CONDITIONS

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**Abstract**

*The article shows natural and architectural analogies in which triangular and arched arches are the most stable. A new design of a drainage pipe with a cross section in the form of a Reulot triangle with an angular arch, related to cycloidal structures and increased stability, has been developed. Based on model studies, it was revealed that the arches in the form of half an astroid are the most stable, in this regard, a new design of a drainage pipe with a vault in the form of intersecting hyperbolas has been developed, which practically corresponds to half an astroid.*

**Keywords:** drainage pipe, structure, stability, arch, Reulot triangle, arch.

## I. Introduction

Application in the practice of industrial, urban, transport and hydraulic engineering horizontal tubular drains are a combination of drainage pipes with loose filter sprinkles. The structural forms of tubular drains and their main elements are determined by the hydrogeological and hydrochemical features of the drained area, and also depend on the layout of the protected structures, their purpose and conditions of work.Ceramic, asbestos cement, polymer, concrete and reinforced concrete pipes are used as drainage pipes. The studies of A.Y.Tulaev [1], S.K.Abramov, B.M.Degtyarev and I.V.Korinchenko [2], S.I.Storozhuk [3], G.A.Razumov [4], F.G.Gabibov and H.B.Salaeva [5, 6] and others are devoted to the constructions of horizontal tubular drainage. The monographs of R.Prevo [7], L.A.Babin, L.I.Bykov and V.Ya.Volokhov [8], S.V.Vinogradov [9], P.P.Borodavkin and A.M.Sinyukov [10], L.A.Dimov and E.M.Bogushevskaya [11] are devoted to the calculation of horizontal pipeline (including closed drainage).] and others. Many computer programs have been developed to calculate horizontal pipelines [12, 13, 14, 15]. Currently, a very urgent task for engineers is to identify the most stable cross-sections of horizontal drainage pipes, which are often laid in difficult ground conditions.

## II. Investigation of natural and architectural analogies to identify the most stable drainage pipe sections

To identify the most rational and stable vaults for drainage and collector pipes, it is undoubtedly useful to use natural analogies found in mining and underground construction, as well as analogies from the experience of designing and constructing vaults, domes and arches of famous architectural structures.In mining and underground construction, one of the costly items is fixing the arch of the workings to prevent its collapse. In order to reduce the material costs associated with carrying out this kind of work, various forms of workings were proposed at different times, ensuring the formation of a "natural balance" vault.

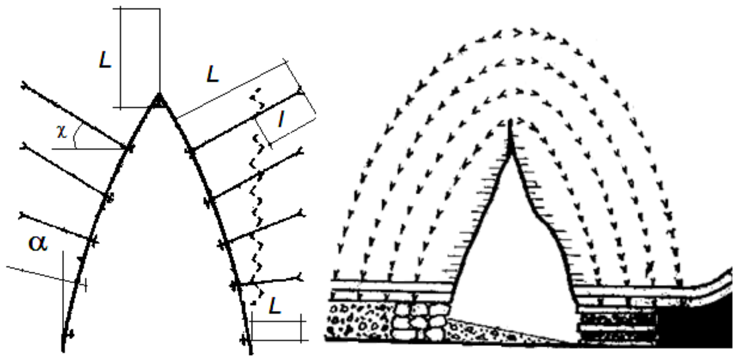
Thus, in the work of S.B.Stajevsky [16], the results of field and experimental studies of the stability of underground workings, depending on the shape of their cross-section, are presented. It has been established that workings with a cross-section close in shape to a triangle and with walls deviated from the vertical by an angle $\alpha \le 15 \div 30^{\circ}$ have their own high load-bearing capacity, and if necessary, they require insignificant costs to strengthen them.

A significant increase in the strength of soils and rocks in the vicinity of the triangular section is due to the fact that in the zones adjacent to the apex of the triangle, the vertical and horizontal stress components reach significant values that have very close numerical values (the effect of all-round compression).

M.M. Protodyakonov [17] notes: "Based on observations of old abandoned drifts, the fastening of which has long rotted and has not been renewed, and over which, with the appropriate lateral rocks, a natural vault is formed, which holds for years and decades without further fixing, it was decided to achieve directly obtaining the same vault." Further in the work [17] it is noted: "... the drifts have the form of a very high arch ..." and "... can stand for many years without repair."

S. K. Kilesso [18] cites the fact that there are triangular drifts, which are without any repairs from the IV century BC

To the conclusion that the production cross section close to the triangular are the most optimal for large depths, based on field data and results of calculations, came and the authors [19]. Figure 1 shows the arches of natural equilibrium.




*a)* *b)*

**Figure 1:** *Vaults of natural equilibrium: a) – a vault obtained experimentally; b) – a vault in an abandoned tunnel*

The history of the development of arched structures in the general history of construction reflects the process of changing the relationship between the growing material and cultural needs of people and the growing possibilities of meeting these needs.

The arch as a load-bearing structure, simultaneously perceiving and transmitting the load, has brought its unique charm to our days through millennia. As O. Buettner and E. Hampe [20] note: "It was already known to the architects of antiquity that if a stone beam was given an arched shape, then it acquires new bearing properties that can significantly increase the overlapped span with the same building material."

E.Torroja [21] gives the following characteristic of the arch as a bearing element of a building structure: "From the point of view of stress distribution, the arch is the biggest find in the history of classical architecture. Even today, it has not lost its significance, although humanity has been getting used to the idea for quite a long time that it is the arch that is the element that increases the strength of the structure."

In the era of ancient Greek civilization, "false arches" were mostly erected. The most famous and oldest arched structures are the gateway arch and the arched vault, preserved from the Mycenaean culture. We find these curved systems with a continuous arched line of protruding cantilever elements in almost all ancient cultures.

In numerous works on the history of construction equipment by scientists of the past and modern specialists, the evolution of arched structures is described in detail. L. Adler [22] points out that "even before the appearance of arched structures in ancient Greece, they were already known to the Etruscans living in the territory later conquered by Ancient Rome. Therefore, it is the Etruscan arches that can be considered the forerunners of Roman arches and vaults."

The desire of the masters of Gothic cathedrals to reduce the mass of structures and preserve the load-bearing capacity of arched structures led to the creation of giant lattice arched loops (figure 2). In the arched loops obtained by medieval architects, who at that time solved not only artistic but also design problems, empirically, in vertically interacting paired arches, elements of modern reloid structures are viewed.

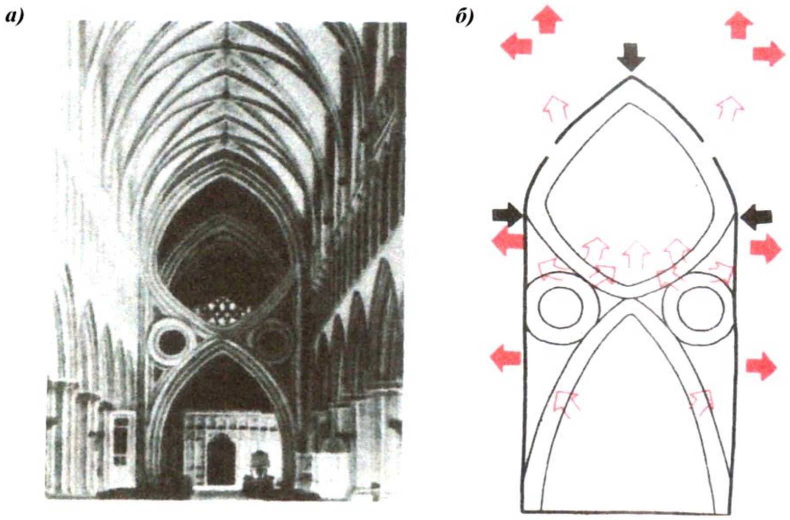



**Figure 2:** *Reinforced arched hinges of the Cathedral in Wales (Great Britain), the end of the XII century: a) – type of arched hinges of the cathedral; b) – the scheme of the arched loop*

## III. Development of drainage pipes with arches of increased stability

The design of the drainage pipe (figure 3) in cross-section in the form of a Reulot triangle, which has a bottom part 1 and side parts 2, has been developed. There is a perforation 3 along the entire surface of the drainage pipe. One of the corners 4 of the cross-section of the pipe is located in its upper consolidated part. Ground water passing through the protective drainage sprinkling, through the perforation of the bottom 1 and side parts 2 of the drainage pipe, enters its inner cavity and flows to the collector along a given slope. Compared to pipes with a circular cross-section, the considered design has higher indicators of stability, strength and water absorption capacity [23].

Model studies [24] show that the greatest stability is observed in the development with a vault in the form of half an astroid. A new design has been developed (figure 4) of the drainage pipe, in which the arch 1 with intersecting hyperbolas 2 practically corresponds to half of the astroid. At the same time, in the lower semicircular part 3 of the pipe section, due to perforation 4, during the period of elevated groundwater level, pressure micro-streams will occur, which will erode the formed silty deposits.

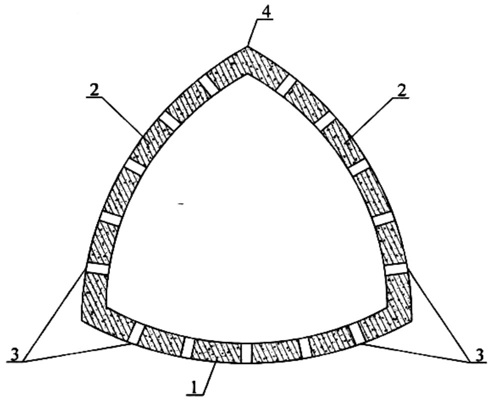



**Figure 3:** *Drainage pipe with a peppered cross section in the form of a Reulo triangle with an angular arch: 1 – bottom part of the pipe; 2 – side parts of the pipe; 3 – perforation; 4 – upper arch corner of the pipe*

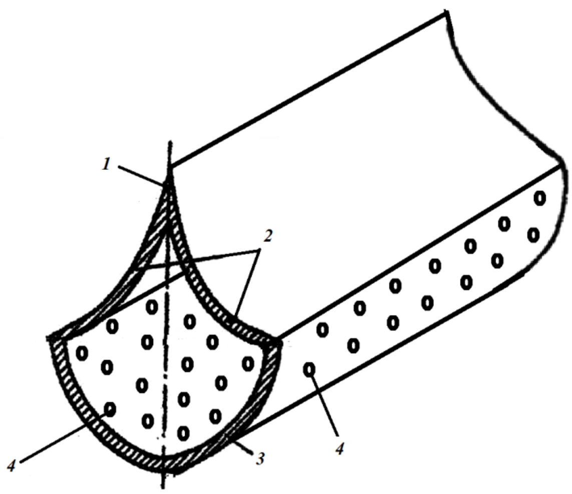



**Figure 4:** *Drainage pipe with a vault formed by the intersection of hyperbolas: 1 - vault; 2 - hyperbolas; 3- semicircular lower part of the pipe; 4- perforation*

## IV. Conclusions

1. Natural and architectural analogies have shown that triangular and arched arches are the most stable;

2. A new design of a drainage pipe with a cross-section in the form of a Reulot triangle with an angular arch has been developed, relating to cycloidal structures and increased stability;

3. Based on model studies, it was revealed that the arches in the form of half of the astroid are the most stable, in this regard, a new design of a drainage pipe with a vault in the form of intersecting hyperbolas has been developed, which practically corresponds to half of the astroid.

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