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Development of the structure, survey and design of the equatorial overpass of the General Planetary Vehicle

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Abstract. The runway for the General Planetary Vehicle is a unique in scale and complexity infrastructural construction — an overpass with a length of 40 000 km, covering the planet along the equator and combined with a string-rail transport of the “second level”. This high-tech structure is a supporting structure for the General Planetary Vehicle and a communication artery that ensures the movement of passengers and goods, as well as the transfer of large amounts of energy and information. The article discusses the location of the overpass in the plan, indicates the most difficult sections and ways to overcome them. The options for the layout of the General Planetary Vehicle overpass are proposed, the main functional areas and structural elements are described. Significant factors affecting the implementation of the project, the problems inevitable in the development of the main elements, as well as solutions to optimize this transport and infrastructure complex have been identified. Solutions were proposed to optimize the overpass routing to overcome mountainous areas of the earth’s surface, considering the required takeoff and landing characteristics of the General Planetary Vehicle.

Keywords: space exploration, General Planetary Vehicle, equatorial overpass, floating tunnel, space industrialization, hyperspeed transport

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Разработка конструкции, изыскания и проектирование экваториальной эстакады общепланетарного транспортного средства

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Аннотация. Взлетно-посадочной полосой для общепланетарного транспортного средства служит уникальное по масштабам и сложности инфраструктурное сооружение – эстакада протяженностью 40 тыс. км, охватывающая планету по экватору и совмещенная с рельсострунным транспортом «второго уровня». Данное сооружение является опорной конструкцией для общепланетарного транспортного средства и коммуникационной артерией, обеспечивающей перемещение пассажиров и грузов, а также передачу больших объемов энергии и информации. Для обеспечения равномерного старта общепланетарного транспортного средства необходимо минимизировать возмущения, вызванные вертикальными и горизонтальными кривыми эстакады. При этом проектирование данного сооружения должно быть выполнено с учетом географических и природно-климатических особенностей тропиков как на сухопутных, так и морских участках. В статье рассмотрено расположение эстакады общепланетарного транспортного средства в плане, обозначены наиболее сложные участки и способы их преодоления. Предложены варианты компоновки эстакады общепланетарного транспортного средства, описаны основные функциональные зоны и конструктивные элементы. Определены факторы, влияющие на реализацию проекта, проблемы, неизбежные при разработке основных элементов, а также решения по оптимизации транспортно-инфраструктурного комплекса. Кроме того, предложены решения по оптимизации трассировки эстакады для преодоления горных участков земной поверхности с учетом требуемых взлетно-посадочных характеристик общепланетарного транспортного средства. Также проведена оценка влияния подвижного состава рельсострунного транспорта «второго уровня» на волновые колебания погруженного в воду транспортного тоннеля-поплавка, с целью обеспечения стабильной ровности пути для перемещения гиперскоростного транспорта и ленточных маховиков общепланетарного транспортного средства, имеющих космические скорости движения.

Ключевые слова: освоение космоса, общепланетарное транспортное средство, экваториальная эстакада, плавучий тоннель, индустриализация космоса, гиперскоростной транспорт

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Introduction

One of the fundamental trends in modern world development is the globalization of economic, political, and social processes, affecting almost all spheres of public life. In these conditions, the economy of any country is closely connected with the world economy; therefore, economic development within the national framework and foreign economic relations become links in one chain.

Further stable economic development of the world's countries is characterized by an increase in its dependence on sources of energy and raw materials due to their limitedness and strong influence on world price dynamics. Based on the main trends in effective development, transport and infrastructure complexes can be considered one of the most important factors of the world economy, as well as the foundation of the economic and industrial prosperity of the regions. Currently, a unified transport system is being intensively formed, based on the geographical location and resource potential of countries with the unification of networks of transport flows connecting different continents to ensure trade and international transit. Based on the foregoing, we can conclude that transport systems at the same level as financial, political, and social issues are becoming one of the most important bases that guarantee and ensure sustainable development of the world community.

At the same time, despite the fact that the history of transport development clearly demonstrates its key role in the development of society and formation of our technogenic civilization [1], according to the authors, the moment has come when it is necessary to give the word “transport” a new meaning — the savior of the Earth’s biosphere. This is possible if it becomes geocosmic and separates the technosphere and the biosphere in space, moving dangerous and harmful industries into near space. The solution to how to do this was developed by the inventor and engineer A. Unitsky [2], who proposed to create the General Planetary Vehicle (GPV), the first publications about which appeared back in 1982 in the all-Union popular science magazines Inventor and Rationalizer No. 4 and Technics for Youth No. 6. The carrying capacity of such a system (10 million tons), encircling the planet along the equator, makes it possible to raise entire factories in one start, in contrast to modern rocket technology, the low carrying capacity of which, along with the extremely high cost of geospace transportation, are the main constraining factors for the industrialization of space.

An overpass structure located along the equator line acts as a launching pad for the GPV. It combines various functions, the main of which are passenger and cargo distribution, the creation of a take-off and landing site, arrival/departure stations, as well as transport and logistics hubs. In a global sense, the equatorial overpass is a world road communication and infrastructure complex that unites states, continents and islands located in the equator zone.

Roads at all times have been connecting arteries between cities, along which new settlements were formed. When they were erected, at the dawn of time, humans adjusted to the existing relief, and later learned to change it. Such works have been carried out for many thousands of years. The equatorial overpass is no exception. The equator crosses plains, mountains and oceans. The complexity and uniqueness of this object lies in its extremely large length (40 075 km) and the alternation along the length of the solutions of land overpasses and oceanic sections of floating tunnels. The main obstacles on land are mountains: The East African Highlands (Kilimanjaro) in Africa and the Andes (Chimborazo) in South America. In water areas, it is possible to conventionally accept a constant surface level and a horizon line, but many kilometers of the depth of the bottom act as an encumbrance.

Since the placement of such a structure on the surface of the earth and water will divide the planet by an obstacle into two hemispheres, almost completely cutting off all existing communications (except air), a requirement arises to place a structure on supports above ground level on land and deepen below water level in the oceans.

The ideal trajectory of the overpass is a regular circle centered at the center of mass of Earth. Unfortunately, this is impossible to implement. But, due to the correct selection of the geometric parameters of the supporting elements, it is possible to get as close as possible to such an arrangement. The characteristics of the trajectory of the passage of mountainous sections affect the height of the supports and the depth of the overpass foundations, and the shape affects the operating conditions of the linear rotors inside the hull. Any deviation of the longitudinal axis of the GPV from the ideal circle leads to a complication of the design of this grandiose in size self-supporting aircraft and requires additional measures to stabilize it after takeoff. Vertical and horizontal curves create an additional load from centrifugal forces when the belt flywheels move at speeds of up to 12 km/s, upsetting the balance and exceeding the nominal forces per each running meter of the system in dynamic equilibrium.

1. Overpass Location Trajectory

Initial data for choosing the trajectory of the overpass

The following are taken as geometric boundary conditions:

- the minimum vertical radius of the route is 100 km;
- the optimal vertical radius of the route is 6371 km (the radius of the Earth);
- the optimum height of the overpass is 20—25 m (provides a minimum impact on the growth of forests and the migration of animals);
- the optimal depth for floating tunnels is 40—50 m.

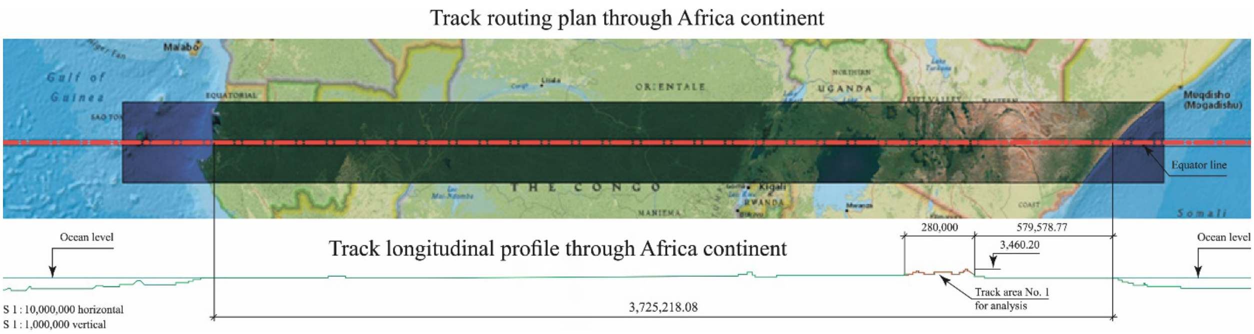

Figure 1. Scheme of the passage of the GPV overpass across the continent of Africa

Location of the overpass in the plan

The longitudinal profile is built according to the heights of the relief along the equator line[1]. The reference point is taken from the Greenwich meridian. Typical sections of the route in the profile across Africa are mountains up to 3.5 km in height, in front of and behind Lake Victoria (Figure 1).

At about 43° east longitude, the track runs through the Indian Ocean. The maximum ocean depth is 5.5 km, a decrease in depth to 50 m is observed in the Maldives (73° east longitude), off the coast and east of Sumatra, about 420 km long, where the depths are 9—50 m. Further, 109° east longitude, the western coast of Kalimantan Island, then the Makassar Strait 180 km wide, having an average depth of 2.2 km with 60 km of continental shallows (12 m depth) east of Kalimantan Island. Further, the route crosses the island of Sulawesi (120° east longitude), Tomini Bay, the Moluccan Sea, Halmahera Island and goes to the Pacific Ocean. The maximum ocean depth along the route is about 6 km (147° east longitude). There are 3 outlets of the continental bottom:

— the Gilbert Islands, 173° east longitude;

— Line Islands, 160° west longitude;

— the island of the Galapagos, 92° west longitude.

Mainland South America begins at 80° west longitude (Figure 2).

The highest point of the mainland profile, the Cordillera Mountains, 5 km high, rises at about 77° west longitude. Further along the mainland, the profile is calm up to the Atlantic Ocean — 47° west longitude. The maximum ocean depth is 7.6 km — 17° west longitude.

The total length of the route is 40,075 km, including:

— by water (oceans, seas, bays, lakes, rivers) — 31,170 km;

— by land (continents, islands) — 8,905 km.

2. Specifics of Passage of the Equatorial Overpass Overland

The most difficult sections of the route in the profile of Africa are mountains east of Lake Victoria within 36—38° east longitude. In South America, the most difficult area is the Cordillera Mountains — 77—78° west longitude.

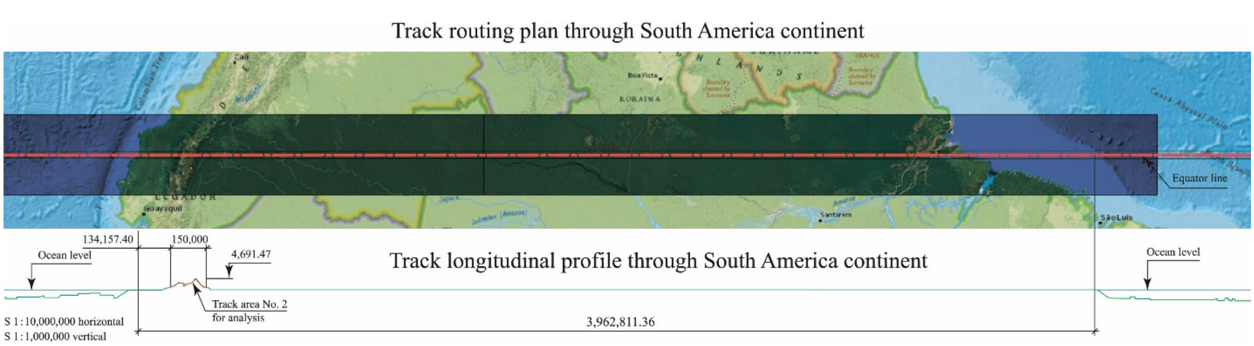

Figure 2. Scheme of the passage of the GPV overpass across the continent of South America

[1] Google Earth [Electronic resource]. Mode of access: https://earth.google.com (accessed: 06.04.2021).

When designing the trajectory of the overpass location through these sections, it is required to determine the parameters for constructing the radius and transition curves, based on the limitation of the magnitude of centrifugal forces with the following characteristics of the GPV:

— the linear speed of the rotor along the vacuum channel is up to 12 km/s with a dead weight of up to 450 kg/lin m;

— the mass of a running meter of the GPV together with the load is up to 1,150 kg/lin m.

The smaller the permissible radius of curvature of the overpass, the better it repeats the ground relief and the lower the maximum height of the supports will be. At the same time, the passage of Kilimanjaro with large radii (1,000 km and more) will require more work than when laying through the Andes, which are much higher than the African mountains, but have a more gentle relief.

The overpass supports are proposed to be made of reinforced concrete, with a height of up to 300 m (an indicator of the highest supports of modern bridges). If it is necessary to use a greater height, the required size can be compensated by using local embankments from the rock extracted during the excavation (Figure 3).

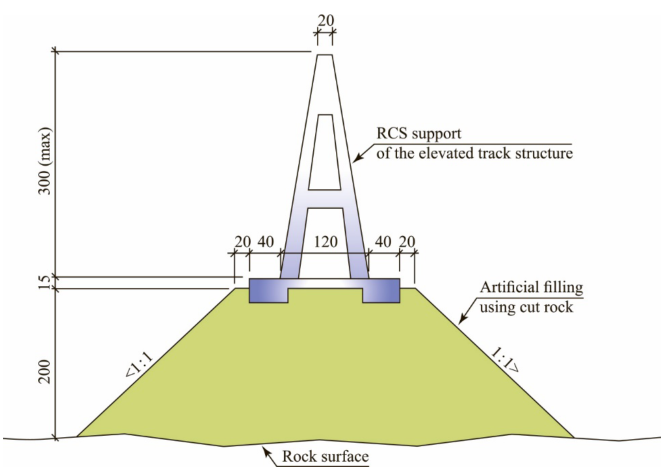

Figure 3. An example of a reinforced concrete support (option)

With an average pitch of 100 m supports, their number will be:

N = 8905000/100 = 89,050 pcs.

In this case, we obtain the percentage distribution of the categories of supports by height as follows:

up to 15 m — 50 % — 44,525 pcs.;

15 to 30 m — 25 % — 22,262 pcs.;

30 to 50 m — 15 % — 13358 pcs.;

50 to 100 m — 10 % — 8,905 pcs.

The highest peaks, characterized by sharp changes in heights, are more profitable to go through. At the same time, a feature of the construction of the equatorial launch platform is the need for an open space above the structure for lifting the GPV, which excludes the passage of mountain ranges through tunnels. This leads to the use of recesses, an example of such a design is shown in Figure 4.

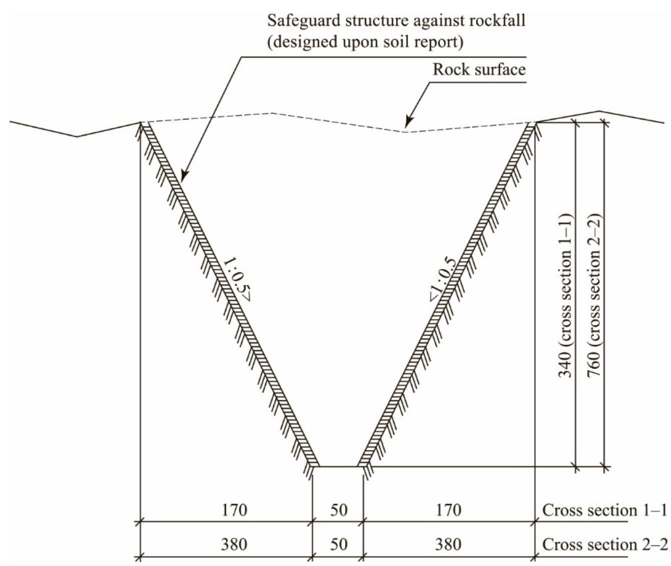

Figure 4. Cutting scheme (option) (all dimensions are given in meters)

Such characteristics of excavations, such as depth, minimum slope, protective and safety elements, are calculated individually for each mountain area, depending on the composition and strength of the rock, seismic activity, amount of precipitation, etc.

3. Specifics of Passage of the Equatorial Overpass Through Water Areas

As shown by previous studies, it can be concluded that the underwater location of the oceanic sections of the GPV take-off and landing structure is less material-intensive, more technologically advanced and, as a result, more economically profitable. Consequently, a floating overpass is the best option for the design of spans when passing deep-water sections. It is a tunnel submerged to a depth of 50 m. This concept, proposed by the author of the GPV more than 40 years ago [3], is currently being developed by scientists from Norway, Italy, and China [4]. A floating overpass must be designed to withstand external influences, operational and accidental loads, with sufficient strength and longitudinal bending stiffness. Given the length of the structure, a versatile and economical design is required.

The main components of the floating overpass are:

— anchoring elements — anchors, pontoons, supports;

— fastening and tensioning elements;

— vacuum cargo-passenger transport tunnels;

— pick-up/drop-off zones for passengers and service personnel;

— industrial and utility tunnels;

— freight transport tunnels to ensure cargo distribution;

— passenger and freight vehicles;

— supporting elements of the General Planetary Vehicle.

Due to the longitudinal direction of currents at the equator and the provision of zero buoyancy of the tunnel, the structure of the overpass ensures the maximum span length — the inter-support distances reach 500—800 m. These gaps will provide the required rigidity and strength of the load-bearing part of the structure.

Since the tunnel is located at a depth of about 50 m, it is important that it is absolutely waterproof and resistant to the effects of salt sea water. In addition, the tunnel must be reliably protected from hydrostatic and hydrodynamic forces directed at it.

Layout solutions for the floating tunnel

For maximum unification, the profile of the overpass itself, passing on land, corresponds to the profile of the oceanic sections with lower requirements for tightness and taking into account thermal deformation from temperature

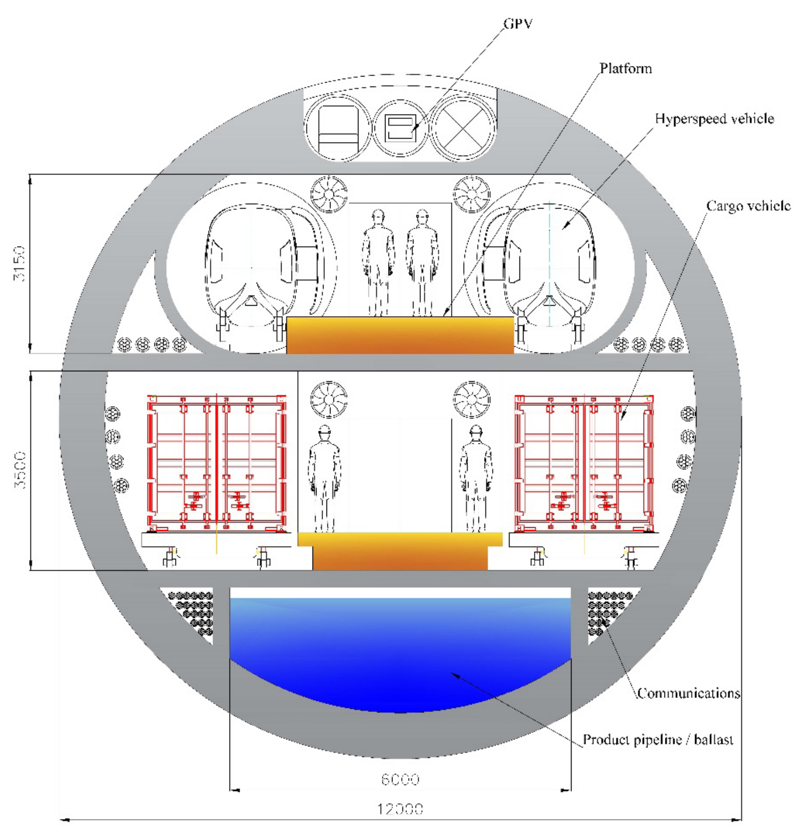

Figure 5. Option of the layout solution for the oceanic section of the floating overpass in the area of the landing station

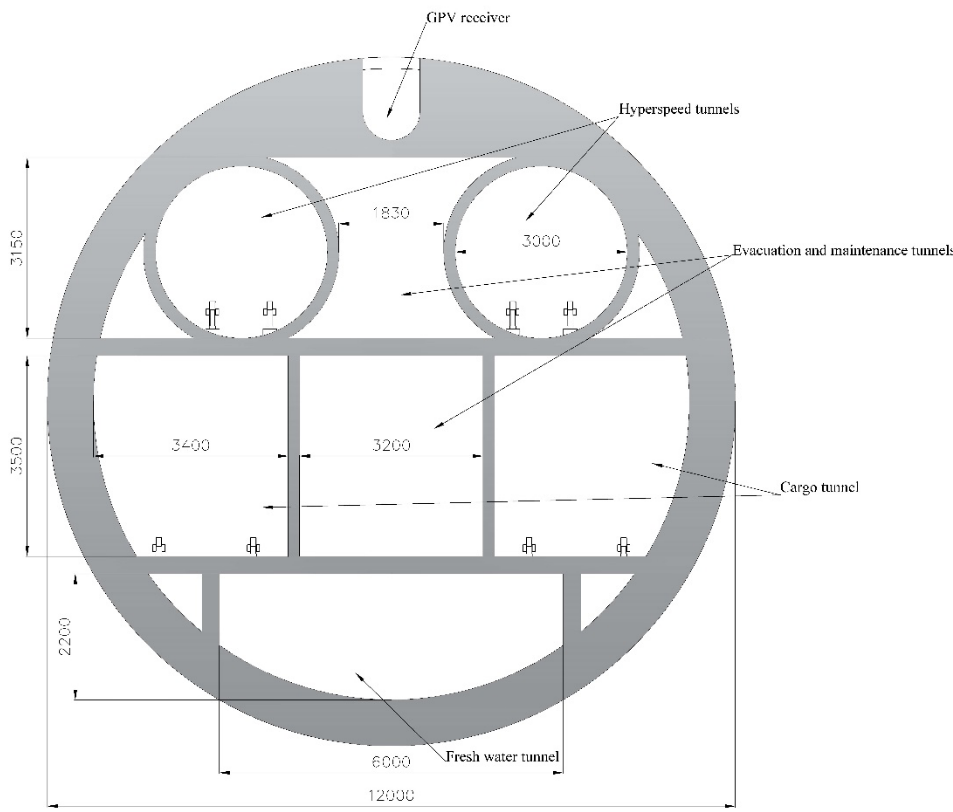

Figure 6. Option of the layout solution for the oceanic section of the floating overpass in the inter-span section

fluctuations. Figure 5 shows the recommended layout in the area of the landing station.

Geometrically, it is divided into four functional zones — in the central lower zone there is a product pipeline-ballast to regulate the buoyancy of the structure and deliver fresh water from the mouth of the river Amazon along the equator (including Africa and the Malay Archipelago), the cross-section has an area of 11 m^2 across. There are communication compartments along the edges of the ballast compartment. Above is the area of cargo vehicles with loading/unloading terminals. Above the cargo compartments, tunnels are based for the movement of vacuum hyperspeed vehicles in different directions, and underwater stations for the embarkation/disembarkation of passengers. In the upper part there is a cradle for receiving and launching the GPV with a landing and loading area for transport compartments.

The outer concrete pipe has an outer diameter of 12 m and a total wall thickness of 0,6 m (Figure 6). Inside, the pipe is divided by concrete partitions. The space behind the aprons and boarding areas, in the longitudinal direction, is used as a corridor for evacuation and maintenance of the structure. Free spaces at the edges of hyperspeed tunnels can be used for ventilation ducts and power supply.

The depicted option, with an average density of seawater in the equatorial zone (1,020 kg/m^3), has a mass of 1 lin m of the structure of 115,3 tons. When used as the main structural material of concrete, with a density of 2,500 kg/m^3, its reduced area, to ensure zero buoyancy, will be 46 m^2 (excluding compensation by liquid ballast).

Reinforced concrete is the main structural element of the internal components, which gives the required strength and weight to the tunnel. A diagram of the tunnel body is shown in Figure 7. To protect the concrete from external influences, the shell is supplemented with three layers.

The outer layer is made of corrosion-resistant copper alloys [5] to resist salt water and shellfish fouling. The second and third layers are made of foam materials that provide an elastic deformation zone of the tunnel from external shock loads.

For pipes, it is proposed to use a special high-strength concrete with a fibrous filler, having a Young's modulus of 30 GPa. The shell should be crimped with longitudinal reinforcement to prevent cracking, while the structure as a whole should be stretched to ensure stability and resistance to transverse loads and bending moments. This is achieved by segmenting the pipe and using string elements of different functionality in the structure.

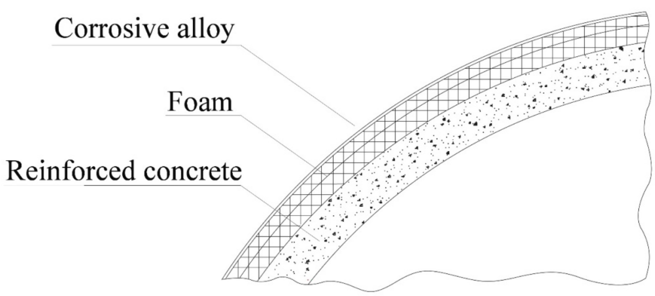

Figure 7. Tunnel body diagram

Excess buoyancy must be ensured at the points of attachment of the fixation (anchoring) systems of the floating overpass to the seabed. The design is based on the principle of an inverted pendulum — the pipe in such places has a special float that tends to float, but is held in place by rods; with such anchoring, the weakening of these rods is not allowed (Figure 8). Bindings can be placed vertically or combined vertically and/or obliquely.

Periodically, in order to provide the tunnels with fresh air and the possibility of evacuation, it is necessary to include vertical shafts, exits to the ocean surface, in the design (Figure 9) [7].

Pontoons are proposed as floating elements. They are susceptible to collisions with floating objects and vessels, therefore, to prevent the transfer of shock loads from the pontoon to the tunnel in the event of an accidental collision of the vessel, the following preventive measures are taken:

— the floating overpass is structurally independent, has a separate anchoring, the loss of the pontoon does not affect its geometry and structural integrity;

— the air chambers of the pontoons have a cellular structure — even if the tightness of half of the chambers is damaged, it will stay afloat;

— the use of multilayer sandwich structures — if the outer layers are damaged, the overall tightness will not be broken;

— dividing the pontoon into two elements to ensure the takeoff/landing of the GPV in the center of the pipe —

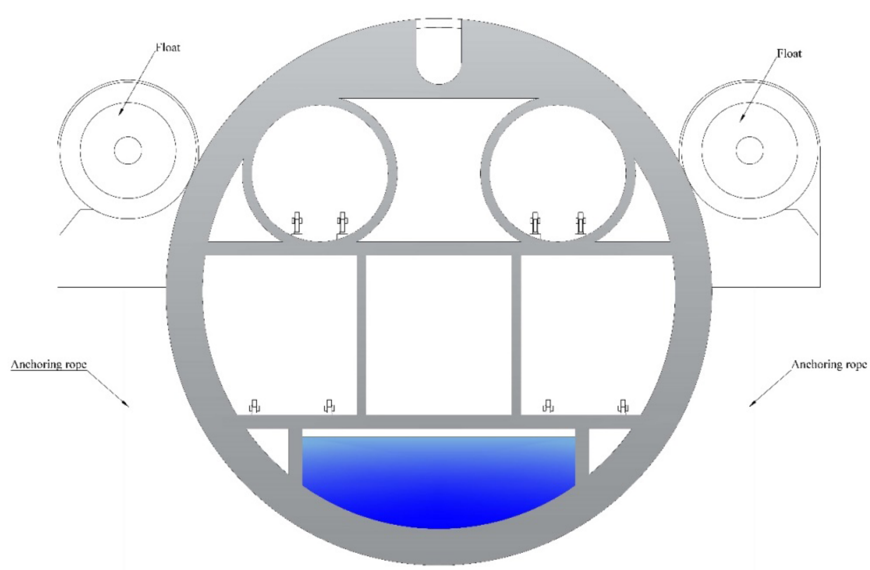

Figure 8. Option of the layout solution for the oceanic section of the floating overpass, section at the point of anchoring systems fastening

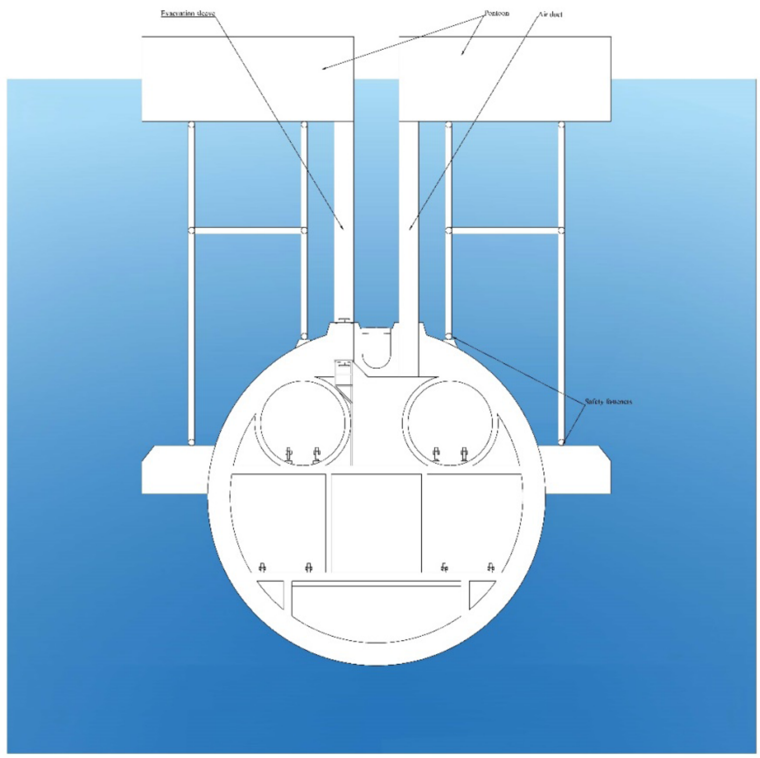

Figure 9. Option of the layout solution for the oceanic section of the floating overpass, section at the pontoon fastening point

acts as a duplication of the evacuation and air intake system, reducing the risk of losses;

— introduction of fuses into the structure of fastening the pontoon to the overpass, which are destroyed in case of exceeding the shock or wave load;

— the use of streamlined pontoons, which reduce the hydro- and aerodynamic drag coefficient and deflect the ship's hull as a result of tangential sliding impacts.

As preventive measures in order to prevent collisions, signal sound and light beacons are installed on the pontoons.

4. Analysis of the Impact of a Moving Vehicle on the Tunnel

To ensure comfortable conditions for the movement of hyperspeed vehicles, it is necessary to guarantee high evenness and stability of the track in the tunnel, and given the presence of external and internal disturbing factors in the form of currents, waves, passing ships and moving inside cargo vehicles, this becomes a difficult task. Each of the listed disturbances requires deep analysis, both separately and together to take into account synergy. In this article, the authors propose to briefly consider a predictable and controllable factor — the influence of a passing vehicle on a floating tunnel.

Initial data:

— the concrete used has a Young's modulus of 30 GPa;
— tunnel with a diameter of 12 m;
— wall thickness is 0.6 m;
— fixed section length is 800 m;
— estimated weight is 115,300 kg/lin m;
— density of the aquatic environment is 1.020 kg/m^3;
— design bending stiffness is 1.50 × 1010 kN×m;
— submersion depth of the tunnel is 50 m;
— form resistance coefficient is 0.55 (long cylinder);
— weight of a single loaded cargo vehicle is 25,000 kg;
— length of a single cargo vehicle is 22 m;
— frequency of traffic is 90 s;
— design speeds is 10 m/s, 30 m/s, 50 m/s.

Assumptions:

— the bending properties of the tunnel are the same in all directions;

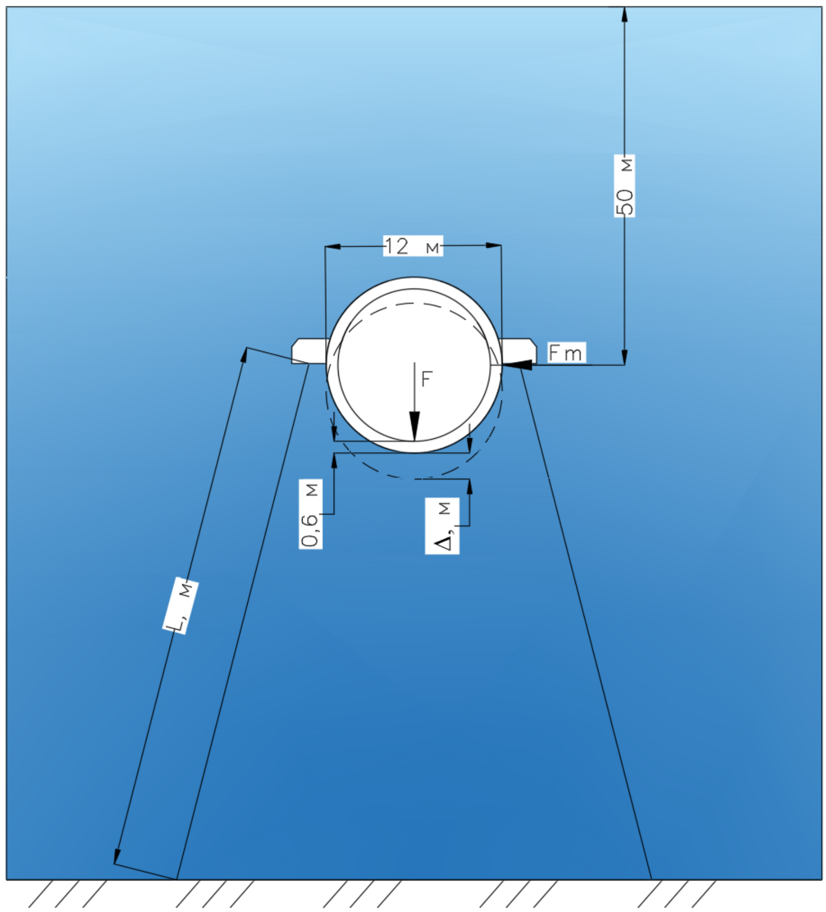

Figure 10. 2D diagram of the loads received by the floating tunnel

— the direction of the waves is perpendicular to the longitudinal direction of the pipe;

— the vehicle moves symmetrically in the center of the tunnel;

— the load from the vehicle is evenly distributed along the length;

— the vehicle is moving at a constant speed.

A 2D diagram of the loads received by the floating tunnel is shown in Figure 10.

A cargo vehicle during movement generates additional gravitational and inertial forces in both vertical and horizontal directions. The gravitational and inertial forces acting on the span can be expressed by the following equation:

$$F = -(Pk + ma) \sum_{E=ei}^{el} \delta(Ex - E)$$

where P is the gravitational force; m is the mass of a moving vehicle; δ is a function of two variables or the Kronecker delta function; Ex is a section subject to load; E is all sections from ei (initial) to el (last) subject to a moving load at a certain time interval, a is the acceleration vector.

The effects of wave excitations associated with a moving vehicle and vertical responses of a floating tunnel in the middle of the span (400 m from the anchorage point) for various transport speeds are investigated. Calculations have shown that the maximum vertical displacement (deflection) is less than 1 mm (Figure 11).

This is significantly less than wave excitations caused by a storm or an underwater earthquake. This is confirmed by other studies [6; 7]. The duration of the span deflection in case of a vehicle passage decreases with an increase in speed, while its value remains practically

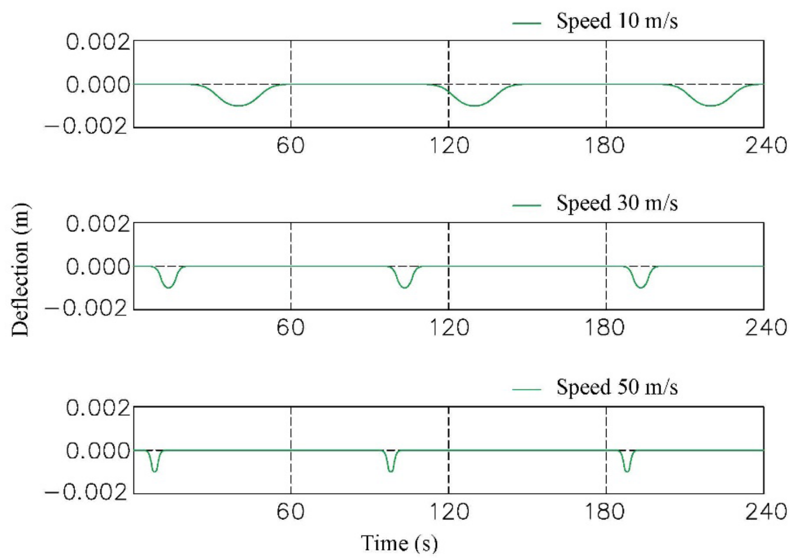

Figure 11. Graphs of the dependence of the vertical displacement of the tunnel on the speed in case of cargo transport passage

the same regardless of the speed of movement (within 3 % of the error).

Conclusions

The main technical solutions given in the article, taken in the design of the equatorial overpass of the General Planetary Vehicle, can be implemented at the modern technological level of transport construction. This indicates the technical feasibility of this project. At the same time, full consideration of all factors that affect the equatorial overpass throughout its life cycle is possible using mathematical modeling at the stages of construction, operation, modernization, and disposal. This model will allow for a more detailed study of both individual elements and the entire overpass in interaction with transport, natural and man-made loads, which will make it possible to develop the most optimal technical and technological solutions for its creation.

An option of the layout of the GPV overpass with a description of the functionality of individual zones and structural elements has been put forward. All solutions require continued technical and economic analysis.

The influence of a passing cargo vehicle on wave oscillations of a tunnel immersed in water was also calculated to ensure a smooth and comfortable movement of hyperspeed vehicles. This study requires a deeper research, taking into account all external and internal disturbing factors and mutual synergy.

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