DESIGN OF THE UNDERWATER STRUCTURES

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Summary: *More and more often we can hear about the natural and ecological problems that our planet faces. Global warming and the rapid growth of population condition that we have to think about settling people on water surfaces in the future. The main theme of this paper is to present the new environment and setting basic guidelines for designers who are faced with underwater structures. After getting acquainted with the environment, we must face the challenges and represents the selection of construction and its materials. When we talk about construction, we can distinguish four basic types. And finally, we need to provide systems that will allow the chosen construction works, and provide needed comfort to users of space. Although there are no great need for underwater objects, we must strive for progress and the realization of those things that we considered impossible, but it will be necessary in the future.*

Keywords: *Natural and environmental problems; underwater environment; structures and materials; installations.*

1. INTRODUCTION

„A machine should not be destroyed, but it should be learnt what to do. Everything we do today will one day be done by robots. They will do everything slaves used to do before."

This is how Nikola Tesla foresaw the 21st century, in the thirties of the last century, and was not far from the truth. Technology today is advancing at almost unimaginable speed, and every day we hear about new developments, which we couldnot have even imagined in the past. The deeds that we consider science fiction today serve as an inspiration to architects. As early as 1870, Jules Verne in his work " Twenty thousand leagues under the sea, " tickles the imagination of people about the underwater world. It has been more than a hundred years since a man started traveling under water, with the discovery of the submarine, but human ambition did not stop there. The desire to move the boundaries of possibilities has led to the creation of new and unusual underwater objects. It all started with small projects of floating structures, many of which were implemented. Projects would predict a part of an object that is submerged in water, which would be part of the user's integration into the underwater world wide vistas. Ambitions lead architects further, so that it came to the first projects of large underwater objects for holidays (which we will discuss as it follows). Projects of underwater hotels allow holidays in a completely different way, where a man, over large glass surfaces, is

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integrated into the marine world. A place where we can peek into the world of which Jules Verne fantasized. This way, all that we could only imagine became a reality. [1]

Welcome to a new, underwater world.

2. NEED FOR UNDERWATER OBJECTS

Are the underwater objects necessity or just a caprice of society? Every day we listen more often about the natural and environmental problems that our planet faces. The first in a series of major problems certainly is global warming, which leads to sea level rise, melting of the glaciers and warming of the soil. The second in a series of major environmental problems is the rapid growth of the population, which leads to inhumane living conditions, lack of food and overpopulation of the planet. All these changes directly affect the entire ecosystem of the planet.

Regarding the fact that it is not possible to fully cope with all current natural and ecological problems, we need to think about objects in/on the water which in the future may be necessary as a way to combat overcrowding and rising sea levels. In order to be ready for the design of underwater (or floating) object, as the goal of this paper we will study the basic problems that engineers can encounter in projecting. The main problems that the designers have to face are certainly: the location and positioning of the object itself; construction of the facility and its protection; sustainable systems; space organization and design.

3. LOCATION AND POSITIONING

The first problem in designing underwater constructions is the choice of location of the object setting. For the positioning of objects it is best to provide for: warm seas, or parts of warm ocean currents; seas with clean, transparent water; locations full of colorful landscapes with rich flora and fauna; sea floors that are not too deep...

In order to achieve better thermal energy efficiency of the facility, it is better to choose warmer water for setting. This choice of location would significantly reduce energy consumption. The natural properties of water that affect the body in it give off heat much faster than in the air. This means that an effective isolation of underwater object needs much better characteristics than isolation of terrestrial objects. Warm seas, with clear water, are certainly good locations for the construction of tourist facilities for rest and recreation. Wide vistas through large glass surface area allow the space users to enjoy the marine world, so in relation to that an object needs to be positioned in a transparent water sea with rich flora and fauna. The bigger issue when choosing a location is to determine soil suitable for anchoring of the facility in order to prevent the force of waves and tides to take the facility away. When anchoring, there must be paid attention to environmental protection for which mutual work with bioecologists is required. Problem of waves can be partly solved by choosing a location protected from the open sea, with low sea waves. Tides can also pose a problem and therefore a location with minimal influence of the tides should be chosen. Preferably, the marine soil has as small slope as possible so that the facility can be placed away from the coast in order not to endanger users of the beach and at as little depth. When it comes to depth, it is auspicious to be 20 m. Construction of facilities that do not meet these parameters is possible, but if the designer adheres to the previously mentioned parameters, the facility will be much easier to design and maintain, and therefore the construction will be cheaper.

4. CONSTRUCTION OF THE FACILITY

Hydrostatic pressure has the least effect on regular spherical structure, but due to space organization and stability is more suitable construction of spheroidal shape.
The thrust that such a construction creates is much higher than in the spherical object because of the greater surface area to which the force of thrust has influence, making it more stable.
The forces acting on the body immersed in a fluid were explained by Pascal. The law explaining the influence of the pressure reads as follows: ,,Pressure to a closed fluid is transmitted equally to all walls", which means that the value of the pressure at one point of the fluid, that is at the same angles, is same regardless of the direction of the force. Hydrostatic pressure acting on the body is greater at the bottom, because the bottom side is on greater depth, which means that the force acting on the lower surface up has a larger intensity of the force acting on the upper side in the direction downwards, which creates downforce of thrust. [2] The pressure that occurs on the surface is 0,1MPa (1 bar) and increases with the depth constant for 0,1MPa (1 bar) at every 10 m height of the water column. Ellipsoid structure can be constructed in several ways, one of which is to build a three-piece construction, fastened with two identical rings. Three-level structure would consist of spherical cut-outs, one belt part and two identical cut-outs that make the floor and ceiling of the facility. It is possible to connect cut-outs by welding or bolts.

Solving the problem of construction is not really the end of all the problems. Depending on the requirements of investors, facility can be set in four different ways. The first method of affixing is by lending construction on the ground itself, such as the project ,,Poseidon Undersea Resort". Structures leaning along the ground are easiest to calculate, which makes them easy to design. Such structures are usually made of concrete in combination with glass and belong to the group of less expensive constructions.

The disadvantage of such facilities is endangering the ecosystem by positioning them on the ground, making this type of construction installation very unfavorable. Positioning the facility on the ground itself, does not allow the construction of the facility at a great depth. The problem that occurs when there is a large distance from the object to the surface is that it is very difficult design communication core, because the facility (regardless of the type of structure and the method of mounting) must be connected with part of the object that is on the surface.

Conditionality by communication makes this type of construction possible only in shallow areas. It is suitable to build this type of structure to a depth of 15m.
Building height (H) can be easily calculated if we determine the radius of the circle of intersection (R) and angle lines departing from the center of the circle of which one vertical and the other is connected with the edge of the crop (α), using the formula:

$$H=R(1-\cos\alpha) \text{ or } H=R_0(1-\cos\alpha)/\sin\alpha \tag{1}$$

Using the determined height of the building, the thickness of the shell (h_0) can be determined which is necessary for the construction of:

$$h_0 = \frac{p*R+\gamma w*R(D-H)}{2\sigma-R*\gamma s} \qquad (2)$$

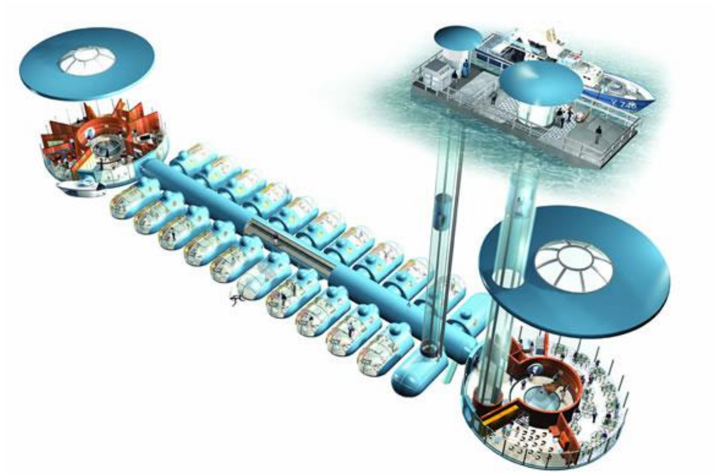

Figure 11: Construction on the ground ,,Poseidon Undersea Resort"

Where: (p) stands for force acting on the structure (excluding its own load); (R) radius of the circle cross section (γw) bulk density of water; (γs) bulk density of the material of construction; (σ) allowed voltage for materials; (D) water depth; (H) the height of the structure. [3]

Despite numerous disadvantages of the structure fitting to the soil, low price of its building and simplicity of design can lead to frequent construction of such facilities in the future.

Negative floating structure, except for the aforementioned, is the construction placed on the pillars. The project ,,Water Discus Underwater Hotel", the construction on the pillars was calculated on. Location benefits, set in a protected part from the waves and at shallow depth, enabled designers to predict the disk-shaped objects. Development of technical project for the disc-shaped structure is much simpler than for spherical objects. With the above-mentioned project it is planned that the building consists of two parts, one on the surface and the other of underwater that are attached to the ground with the three pillars and massive communication core.

Underwater structure has the possibility of launching and recovering thanks to the mechanism attached to the pillars. The load is passed on through the pillars to the foundation that is put on the sea floor. This type of construction requires a deep foundation for what should be solid ground with a low coefficient of settlement in the area of moderate seismic zones. Complicated funding plans and special soil testing further increase the cost of the project which is a major disadvantage of this method of setting up the facility. The structure with pillars is the most propitious for gulf cities and lakes, where there is little water movement. Impacts of the movement of water, such as waves and tides, largely influence this type of construction, due to the impact of horizontal forces. As a result of the operation of unforeseen transversal forces may be pulling out pillars and communication part (if the facility consists of two parts). Benefits of such construction with pillars are quick installation and the possibility of dismantling the building.

Figure 12: Construction placed on the pillars „Water Discus Underwater Hotel"

Probably the most functional type of facility are „suspended constructions". Although still under-explored because of their very costly and difficult preparation of the technical design of this type of structure, they are the most functional. Objects can be constructed of aluminum or steel with special protection dictated by the type of material. High construction price and complexity of design for such a facility might have been the only drawback and the reason for avoiding this way of construction. A number of systems that facility possesses help it become resistant to all the difficulties which underwater construction might face. Unlike other types of constructions, where we have made for the construction of two buildings one of which is on the surface, this is not the case. Complete mobility of the facility allows the design down into the water during the stay of people and rising to the surface in order to access the visitors. The possibility of a rapid ascent to the surface of the whole structure allows for quick evacuation of users in case of emergency. By ventilation systems that would submerge from the water providing of fresh air to the atmospheric pressure would be possible so as to avoid decompression illness, which can cause the air pressure. The building is also possible to predict as it is the two-set, with a part that floats on the surface and core of communication, as in the aforementioned ways of designing underwater structures. Ballast systems, which usually provide for the lower part of the building, regulating the airworthiness and thus can be regulated according to the needs that you will object to sink to surface or stand in place. Such systems allow the moving object from one place to another in case of need. The dynamic influences of water would still greatly influence the position of the object to its operation, so that it could be relocated. Suspension design of the site designated for its positioning, is prevented by anchoring and fastening wires adjustable in length. Anchoring must be carried out in at least three places (there is no need for more than four) for stability. Benefits of embedded systems provide that such facilities can be built, and in the seas with more complex external influences. Despite their high functionality, projects of'' suspended "underwater structures still do not exist.

The simplest projects of underwater objects are certainly floating structures, many of which have already been realized. The project is commonly overlooking the part which is immersed in water and contains a large glass surface over which vistas are enabled. During the drafting of the plan it is the most important to insulate the part which is immersed in the water and determine the focus of the construction which must be above the water, that construction would not sunk. Simplicity of design has led to the fact that presently only this type of design was realized.

Figure 13: Floating structure

Additional reinforcement structures for transport and securing the facility are a small part of the design, but they can be a big problem if not anticipated in advance. Increased power in fixing points to the attachment of structure may lead to a break or damage in that area, which can cause a lot of problems.

5. MATERIAL SELECTION

The choice of structure will directly affect the selection of materials. If we look at projects'' Water Discus Underwater Hotel " and ''Poseidon Undersea Resort " (none of which has yet been implemented) you will see that the designers chose a steel construction. In addition to steel, the construction can be made even in aluminum and concrete. The construction material will largely depend upon attaching the object to the ground. Each structure has its own characteristics with strengths and weaknesses.

Steel structures is most suitable for objects that are mounted on pillars. The low price of steel is one of the advantages of this method of construction. Easy creation of steel, or factory making quick and easy installation of steel elements give priority to this construction if needed for a short time to set up the facility. Opposite the benefits offered by this type of construction, steel as the material has a lot of shortcomings. Probably the biggest problem of steel is its oxidative action in contact with water. This feature causes the necessity to treat steel with separately protective devices or replace some parts with new ones after some time, which is reflected in the high cost of maintenance. In addition to corrosion of steel another shortcoming is low pressure resistance. If we consider that the water pressure increases by 1 bar (0,1MPa) every 10m height of the water column is a growing problem as the depth is greater.

Although it has a much shorter application through history, we can say that aluminum fully competes with steel. Aluminium structures can replace any steel structure. Perhaps the only reason for the construction of buildings of steel is the high price of aluminum, which is almost double. If we ignore, for now, the high price of aluminum, we will notice that according to all the other characteristics it is more suitable than steel for making underwater structures. Thanks to its characteristics, aluminum is very resistant to corrosion in contact with water, which is a great advantage over a steel structure. When it comes to the protection structure has the most favorable properties of aluminum because it is not necessary to further protect it, which is not the case with steel and concrete.
Transportation of aluminum construction is much lighter than the transport of steel and concrete structures. Aluminium as a material is almost three times lighter than steel (ρ_{al} = 2700kg/m3; $\rho_{č}$ = 7850kg m3). By comparison of aluminum and concrete (ρ_b = 2500kg/m3), we recognize that aluminum is something heavier than concrete, but if we consider the immensity of reinforcing concrete structure, we come to the conclusion that aluminum constructionis much lighter. The advantage of aluminum compared to steel is also a much lesser deformability during buckling, which shows the Young's modulus of elasticity for the aluminum which is: Eal = 69GPa, in contrast to the modulus of elasticity of steel that is: $E_{č}$ = 200MPa. Although packed with handy features, designers still largely avoid applying aluminum beaucouse complexity of technical documentation and its high prices in the market.

Concrete, a material with the longest tradition of these materials, may be considered the least appropriate material for underwater constructions. The large mass of concrete structures leads to much more difficult carrying out of the construction of a non-negative float. Such a construction can be carried out only on the pillars or directly on the ground. Both types of building concrete structures have a lot of shortcomings, so it is best to avoid concrete construction. Big problem when setting up concrete construction on pillars are the horizontal forces that have much larger impacts on the concrete structure, compared to the steel and aluminum, the rigidity of the concrete construction. In addition to the negative impact that horizontal forces create, a huge problem is made by net weight of the concrete structure, which is reflected in the difficulty of the budget of the foundation. The resistance of concrete to chemical effects of salt water is very bad, and for that purpose there shall be special protection of concrete. One of the fundamental legal safeguards for the aggressive environment is to add a protective layer of concrete a_0 = 3.5 cm. [4] Adding special additives in the concrete is another protective measure. The aforementioned protective measures, although meeting regulations, are not sufficient to protect the concrete from the high aggressiveness of the environment, so in order to have additional protection, waterproofing isolations are made. The simplest type of waterproofing are multilayer coatings of bitumen and placing protective layers of PVC film. Apart from multi-layer bituminous waterproofing, nowadays are increasingly used different types of high quality factory waterproofing. Despite its flaws, the concrete is very suitable because of its low price. Concrete structures need not be pre-fabricated, although the installation of prefabricated elements is much easier, using the caissons or drying must be part of the work carried out on the spot. It is most preferable to make of concrete small and simple constructions due to the low price and easier preparation of the technical part of the project.

Apart from the basic material of which structure is made, an important role in the design has the glass. It is suitable for projects that provide a broader perspective on the underwater world, and for this purpose often predicts glass ring around the entire facility. The construction of the glass ring, like in projects ,,Water Discus Underwater Hotel" and ,,Poseidon Undersea Resort", we come to the facade made of 10-35% of glass, which makes it a very important material in the preparation of the project. To create a ring there will be used toughened glass, because of its features. Toughened glass is physically and thermally much stronger than ordinary glass.

6. SUSTAINABLE SYSTEMS

Increasing urbanization of our planet leads to high power consumption. Due to the identification of non-renewable energy sources that are now commonly used, everything leads to environmental pollution and global warming. Hazard use of non-renewable energy sources and global developments have led to this kind of production and use of energy is becoming unsustainable. The project itself must be made for systems that use renewable energy sources and tend to the protectthe environment.

Position of facility stipulates designer for finding solutions for getting power away from the city's electrical wiring. The first option is certainly the cable routing along the sea and the ground connection. Connecting the city of electro-economic network is possible for objects that are close to the coast, but not for those on a larger distance. The best solution is certainly designing self-sustainable facility that has its own systems.

Installation of solar panels on the roof of the vessel leads to energy savings and another advantage of this system is that its installation time is becoming cheaper. Percentage of satisfying the entire demand of energy, solar energy depends on the size of the object and purposes of energy consumption, depending on the purpose of the facility. The strength of the panels available on the market is up to 250 kW/h, and the dimensions of one panel is 150 * 100 cm. The amount of energy produced, if we consider an area with a large number of sunny days, will depend on the number of panels. The laying of the panels on the additional platform laid directly on the water in large numbers, can meet the needs of 100% or such aspects of setting up the panels is not rational in terms of taking up space.

Due to the impossibility of satisfying all the needs of solar energy, for aesthetic reasons or because of the inability to mount the platform in areas of high waves, there is a possibility of a breakwater. Converting wave energy into electricity is enabled by a breakwater that also can serve as a protection facility from waves.

The great advantage of flooding the construction is thermal stability of water environment without large temperature differences during the year. The center with small change and stable temperature leads to almost unnecessary isolation of additional facility and ample room is additionally heated by heated air ventilation systems. The ventilation systems play a very important role in the design of underwater objects by the fact that the entire amount of air inside the building depends on the work of the ventilation system. The air used must be provided from sea surface due to the hydrostatic pressure acting on the depth. Due to the use of compressed air, there may occur decompression illness by the users of the space after exiting on the surface. Given that consumption of air per man is 30-40m3/h, and for high class hotels is projected 100m3/h it turns out that budget ventilation is not an easy job. Another problem the designers of ventilation face is supplying air at great depth. The air at great depths due to the reduction of pressure in the air ducts may be delivered only if we increase the pressure in the channels. Increasing the air pressure can be carried out by gradual narrowing of ventilation ducts, from the surface to the premises, or by pumping air. Air pumps are avoided due to the consumption of energy and their applications to resort to only in case it is not possible to deliver sufficient amount of air in the room.

As a component of „floating construction", are mentioned ballasts by which the airworthiness of the building is regulated. Ballasts, which have systems similar to those on submarines, comprise of chambers in the lower part of the structure and regulate the airworthiness of the building.

Pumps that are part of the ballast are connected to the water environment and air environment via a ventilation duct. Buoyancy facility regulates the pumping of water or air in the ballast tanks. By pumping air facility will be positively buoyant and keep emerging to the surface, and pumping water obtained the opposite effect due to much higher bulk density of water compared to air. [5]

When we talk about sustainability of the facility, it must be added that the project has to be made for systems for wastewater treatment in the gray water, which would reduce the consumption of water itself. Also, although nowaday such systems are very expensive to install, that would provide for a system for the treatment of sea water and converting the same into drinking water, leading to savings of funds for the purchase and transport of water or a water supply system in the building that has been connected.

7.CONCLUSION

Based on the analysis of the design of underwater objects, we can say that this kind of design opens up a new chapter in the history of architecture. The very importance of underwater objects is reflected both in the prosperity of the architecture and the solution to the environmental problems that our planet every day increasingly faces. The construction of buildings on water solves the problem of overpopulation of our planet, but also the problem of rising sea levels. Despite the very expensive construction of such buildings nowadays, it can be said that the construction of underwater objects is an investment for the future, because of its ability to function independently. Systems that may possess such facilities could lead to the production of electricity to meet the needs of municipal and drinking water and the treatment of municipal water, which would mean that the facility can operate completely independently. In contrast to the advantages of this type of design, we have to face with many disadvantages of underwater objects, such as primarily a huge price system which is necessary for the operation of such facilities and the complexity of project development. Despite the fact that this kind of design today is still ungrateful, and still is not necessary, we must be aware of the importance of underwater structures for the future

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ПРОЈЕКТОВАЊЕ ПОДВОДНИХ КОНСТРУКЦИЈА

Резиме: *Све чешће можемо чути о природно-еколошким проблемима са којима се наша планета суочава. Глобално загревање и убрзан раст броја становника условљавају нас да морамо размишљати о насељавању људи на воденим површинама у будућности. Главна тема овог рада јесте упознавање са новом средином и постављањем основних смерница пројектантима који се сусрећу са подводним конструкцијама. Након упознавања са средином, морамо се суочити са изазовима које чини сам одабир конструкције и њеног материјала. Када говоримо о конструкцији, можемо разликовати четири основна типа. И на послетку морамо предвидети системе који ће омогућити да изабрана конструкција функционише, и омогућити потребан конфор корисницима простора. Иако још увек нема великих потреба за подводним објектима, ми морамо тежити прогресу и остваривању оних ствари које смо сматрали немогућим, а биће нам неопходне у будућности.*

Кључне речи: *Природно-еколошки проблеми; подводна средина; конструкција и материјали; уградња система.*