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THE USE OF GEOSYNTHETICS IN HYDROTECHNICAL CONSTRUCTION

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ABSTRACT

A hydrotechnical structure is a structure with devices and technical installations related to them, used for water management and shaping and using water resources. Special attention should be paid to the properties of the used materials, but also to the impact of water and all accompanying processes. Over the years, geosynthetics are increasingly used as a material in construction, including hydrotechnics. The priority aspect when choosing a geosynthetic material is the approach to fulfilling a specific function, reducing investment costs, ensuring stability and strengthening the structure, as well as ease of installation. Due to their wide range of applications and economic advantages, they have gained the reputation of full-fledged building materials. The article presents the most important possibilities of using synthetic polymers in hydrotechnics. The functions and advantages of individual permeable and impermeable materials were taken into account. Most geosynthetics serve as reinforcement, these are geotextiles, triaxial geogrids, geogrids, geocomposites. These materials are used in strengthening the ground and slopes, separating land, as independent drainage and as protection of drainage systems.

Keywords: hydrotechnics, geosythetics, filtration, hydrology.

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INTRODUCTION

When implementing hydrotechnical investments, special attention should be paid to the properties of the materials used, but also to the impact of water [1] and all accompanying processes. According to the Polish-language standard PN-EN ISO 10318:2007, geosynthetic materials are defined as "a product whose at least one component is made of a polymer (polyester, polypropylene, polyethylene or polyamide), in the form of a sheet, strip or spatial form, used in contact with the ground (or other material) in geotechnics, foundations and civil engineering [2]. Hydrotechnical structures take into account different periods of use. They can be considered as temporary facilities for which the expected period of use is shorter than 5 years or, regardless of the period of use, they are used for the construction, repair or renovation of another hydrotechnical facility, and permanent facilities for which the expected period of use is longer than 5 years.

General information regarding construction and water structures is included in the relevant legal acts. These are primarily the Construction Law Act of March 10, 2023 [Journal of Laws 2023, item 682] and the Water Law Act of June 16, 2023 [Journal of Laws 2023, item 1478]. Supporting legal acts drawn up on the basis of the above-mentioned regulations are the Regulation of the Minister of the Environment of April 20, 2007 on the technical conditions to be met by hydrotechnical structures and their location, and the Regulation of the Minister of the Environment of August 21, 2019 on the scope of water management instructions [Journal of Laws of 2019, item .1725].

In addition to the previously mentioned standard defining geosynthetics, there are other standards related to hydrotechnical construction:

- PN-EN 13252:2002 Geotextiles and related products - Properties required for products used in drainage systems;
- PN-EN 13253:2002 Geotextiles and related products - Properties required for products used in anti-erosion protection (bank protection and strengthening);
- PN-EN 13254:2002 Geotextiles and related products - Properties required for products used for the construction of water reservoirs and dams;
- PN-EN 13255:2002 Geotextiles and related products - Properties required for products used for the construction of canals; and:
- PN-EN 13361 Geosynthetic barriers - Properties required for products used for the construction of reservoirs and dams;
- PN-EN 13362 Geosynthetic barriers - Properties required for products used for the construction of canals.

According to the legal definition, a hydrotechnical structure is a structure with devices and technical installations related to them, used for water management and shaping and using water resources [3], including: earth and concrete dams, weirs, discharge structures with overflows and outlets, embankment culverts and monks, navigation locks, flood embankments, hydroelectric power plants and power plants, inland surface water intakes, sewage outlets, water reservoir bowls with slopes and slopes, pumping stations, canals, adits, hydrotechnical pipelines, siphons, siphons, aqueducts, regulatory structures on rivers and streams, thresholds, bulkheads, above-level reservoirs collecting liquid and semi-liquid substances, ports, swimming pools, wintering areas, piers, piers, jetties, quays, boulevards, slipways and breakwaters on inland waters, fish ladders [4,5].

The definition of a hydrotechnical structure also includes a damming structure and is defined as a structure enabling the permanent or periodic damming of water or liquid or semi-liquid substances above the adjacent area or reservoir [6].

Over the years, geosynthetics are increasingly used as a material in environmental protection and construction, including hydrotechnics [7]. Due to their wide range of applications and economic advantages, they have been called full-fledged building materials [8]. Geomaterials are used to construct infrastructure operating under high load conditions [9,10,11]. However, the performance of geosynthetics is constantly monitored due to the constant action of destructive factors [12,13].

The aim of the article is to indicate the most important types of geosynthetics used in hydrotechnics and the functions they perform depending on their properties.

METHODOLOGY

THE ROLE OF GEOSYNTHETICS DEPENDING ON THEIR PARAMETERS

The priority aspect when choosing a geosynthetic material is the approach to fulfilling a specific function, reducing investment costs, ensuring stability and strengthening the structure, as well as ease of installation [14]. Geosynthetic materials are made of various types of polymers that differ in mechanical, hydraulic and chemical properties [15] but the basic parameter is permeability. Impermeable materials include: Geomembranes, Bentomats and Bentonite geomembranes, while permeable materials include: Geotextiles, Geotextiles, Geogrids, Geomats, Geogrids, Geocells, Geocomposites. The most commonly used are: polyethylene, polypropylene, polyamide, polyester, aramid, polyvinyl alcohol. When designing engineering facilities, including hydrotechnical facilities, the parameters of geosynthetics such as tensile strength, stiffness, water permeability and surface roughness should be taken into account [16]. Table 1 presents the importance of engineering parameters depending on the type of geosynthetic.

Tab. 1

Comparison of the importance of engineering features of selected geosynthetics [17].

Type of geosynthetic	Water permeability		Strength	Stiffness	Surface roughness
	in plane	perpendicular			
Geotextiles	D	D	D	D	S
Geomembranes	S	S	M	M	D
Geogrids	D	S	D	S	M
Geocomposites	S	D	D	S	M

Importance: D- significant, M- medium, S-small

Synthetic polymers are diverse and multifunctional, which is why they usually perform more than one function. The basic functions are divided into two groups. The first are mechanical functions such as: separation function, strengthening function, protective function and anti-erosion function. The second group are hydraulic functions, including: filtration function, sealing function, and drainage function [18, 19].

The separating function is to prevent adjacent soil layers from mixing, while water flows freely. The filtration function allows to stop the penetration of soil or particles into permeable layers. The sealing function is a barrier that prevents water from flowing between two layers, e.g. soil. The strengthening function enables the improvement of the mechanical properties of the soil, e.g. the load-bearing capacity of the substrate or the tensile strength of the surface. The protective function serves as additional mechanical or chemical protection for other building materials. The drainage function allows water, liquids and gases to flow in the plane of geosynthetics. The anti-erosion function is used to limit or prevent the movement of soil on the slope surface [20].

Tab. 2

Roles of geosynthetics [21].

Type of material	Role						
	Filtration	Sealing	Separation	Reinforcement	Anti-erosion	Protection	Dreinage
Geotextiles	+		+	+	+	+	+
Triaxial geogrids				+			
Geogrids			+	+	+		
Geomats					+		
Geodrains							+
Geocomposites				+	+		+
Geomembrane		+	+				
Bentomats		+					

APPLICATION OF GEOSYNTHETICS

In order to use geosynthetics when constructing hydrotechnical facilities, specific requirements must be met to maximize their service life [22]. The ground surface on which the layer of polymer material will be placed must be free of any elements that could damage the structure of the material, e.g. roots or stones with sharp edges, and must be level and have the same conditions of compaction and humidity [23]. It is also recommended that the geotextile be laid according to a previously prepared detailed design in an "uphill" direction, using special machines or manually. Geosynthetics should be attached using U-shaped steel pins with a diameter of 10 mm and a length of min. 500mm, the width of the overlap on the layers should be between 30cm and 60cm, and the extreme edges should be extended by 1.5m. The unfolded synthetic material should not have any creases but should be slightly stretched and quickly covered with a layer of primer to protect it from UV rays [24]. Geosynthetic materials, thanks to their different structure, type of weave or fiber arrangement, can play different roles in the structure used. In hydrotechnical construction, the materials used must have certain characteristics in order to be used in the construction of the facility [25]. Since renovation work in hydrotechnical facilities is particularly demanding, these materials must be characterized by high failure-free performance and high resistance to mechanical loads. Additionally, they should occupy a small space, because in such places it is usually impossible to create a large construction site.

The materials used must be resistant to various factors. These are mechanical, chemical, atmospheric and biological factors. These factors include:

- aging resistance,
- tensile resistance,
- frost resistance,
- flexibility,
- resistance to chemical degradation,
- moisture resistance,
- resistance to molds, fungi and other microorganisms,
- hydraulic parameters (e.g. water permeability, pore size),
- temperature resistance,
- resistance to solar radiation,
- water resistance [26].

Moreover, synthetic polymers cannot react with water, be toxic or cause water and environmental pollution [27]. Geotextiles can decompose into smaller particles (microplastics), which may pose a threat to water and the biosphere [28], however, due to low bioavailability, they generally do not pose a threat to the environment.

An important aspect of choosing polymer materials is the maximum use of their functionality, ease of installation and high availability, but also reducing investment costs [29]. Currently, there are no clear standards and guidelines that should be followed by people responsible for structures using geosynthetics [30].

The lack of unified standards or theoretical and empirical calculations results from differences in quality or working mechanism, which causes manufacturers of polymer materials to create design guidelines only for their products, making it difficult to compare them [24].

Hydrotechnics can be considered both in relation to surface and groundwater with various physicochemical and bacteriological properties [31].

Erosion is the process that has the greatest impact on the hydrographic network, and thus on the hydrotechnical structures within it. It causes the soil (usually sand and silty sand) located at the bottom and on the banks of streams to be washed away by the water flow. Long-term erosive action causes, among other things, landslides. To protect the watercourse against washing out, geosynthetics can be used in the construction of bank and bottom revetments. Geotextile materials will be best used in this case. Due to the weave of geotextiles, they serve as a filtration layer that protects the soil against washing out. Soil particles remain on the geotextile layer without causing any loss of the bottom and edge material. The soil does not penetrate water and does not contribute to the increase in pore pressure. In addition to the filtration function, the use of geotextiles to strengthen the bottom and slopes of watercourses constitutes a separation barrier, which prevents mixing of different fractions of soil used in the structure [32,33].

Spatial anti-erosion geomats can also be used to protect the banks. They are mainly used on slopes with an inclination greater than 1:3. Thanks to their structure, geomats retain the soil, which makes it easier for the planted plants to develop a root system, and they also help maintain soil moisture, protecting the slope from drying out or being exposed to sunlight. Moreover, the interaction of the geomat, the soil and the plant roots growing on it causes the geosynthetic to be attached to the ground, creating a layer that protects the ground against erosion [34].

In addition to supporting plant growth, anti-erosion mats contribute to increasing the stability of the slope, thus creating an overall (together with the overgrown vegetation) durable structure resistant to environmental factors [35].

Cellular geogrids will also work well to strengthen slopes, because their honeycomb-like structure allows them to be filled with appropriately selected filling material (e.g. sand, concrete, soil). The advantage of using geogrids is that they can be placed on a previous geotextile base, provided that the slope conditions and the selected method of filling or anchoring allow it [36]. Anti-erosion geosynthetic materials are intended, in addition to protecting the ground against erosion factors, to also support vegetation - facilitating the growth of the root system on slopes and the bottom [34]. Additionally, by sowing the slopes with vegetation, the stability of the banks increases [24].

The next group of hydrotechnical structures in the construction of which geosynthetic materials are used are linear drainages, which include, for example, drainages or ditches. In drainage, geosynthetics act as a filter between the existing soil and the water drainage system. Some materials may also have a typical drainage function. Examples of the use of geosynthetic products in linear drainage systems are French drainage, ribbed drainage, surface drainage and geosynthetic barrier. Geocomposites, geomembranes and geotextiles are most often used in such structures. The most popular option is when the geotextile covers/surrounds a layer of easily permeable soil filling the ditch [37].

A ribbed drain is based on a geotextile filter and a core in the form of, for example, a drainage geogrid supplying water to the drainage pipe. Unlike a French or surface drain, the drainage pipe is wrapped in a geocomposite that has water-permeable properties [38].

Geosynthetics (polymer barriers) are also used as geosynthetic barriers in linear drainage. They are used to seal the base of pavements, tanks or ditches. Additionally, due to their properties, geotextile products can be used to cover drainage systems to protect them against siltation with fine-grained soils and to protect geomembrane seals against mechanical damage [39].

Popular hydrotechnical structures are all water reservoirs, which, depending on the needs, fulfill various functions - from intercepting flood waves, through rainfall retention, to recreational purposes. The structures of reservoirs, especially slopes and bottoms, must be adapted to their tasks. Most often, geosynthetics are used in septic tanks and infiltration tanks [30].

Tight tanks are designed to collect water. Most often, they are fed by rainwater, surface runoff from adjacent areas and tributaries from the hydrographic network. To function properly, they need an appropriate structure, including paying special attention to sealing the bottom and slopes. For this purpose, it will be appropriate to use geosynthetics, among others: geotextile and geosynthetic barrier. The use of a geosynthetic seal prevents liquid from penetrating through the bottom and slopes and retains contaminants. An additional layer of geotextile material placed on the geosynthetic barrier supports puncture protection, making the entire structure stronger and more durable [40].

Infiltration tanks capture water from surface runoff and simultaneously discharge it into the ground. Geotextile fabric is also used in this type of tanks. It constitutes a separation layer between the native soil and the bottom of the tank made of gravel and sand in an appropriate fractional arrangement (filter layer). Its task is to capture pollutants and prevent the bottom from being washed out during water infiltration into the soil. The banks of such a reservoir are often planted with aquatic plants to support pre-treatment processes [18].

The high density of the hydrographic network requires protective measures in the areas adjacent to the rivers. One such way is to build flood embankments. Their task is to intercept and contain water in the event of a surge or flood. An earth embankment raised above the height of the river bed is called a flood embankment.

Earth embankments are made of various materials, including: from geosynthetics. Geosynthetic materials are used at various stages of embankment construction and modernization [41].

Geosynthetic materials, mainly geomembranes and bentomats, are used to seal the body of flood embankments, including as slope screens, and to seal the embankment body in the form of a vertical anti-filtration core [36].

The reconstruction of the flood embankment damaged by too long of flood water seepage (washout) is carried out by drainage at the bottom of the embankment, using geomembranes and bentonite mats in the structure to seal the ground under the embankment [42, 43].

Reinforcement of flood embankments can be done by using geotextile as a separation layer between the soil on the air side and the embankment body. Separating permeable layers from cohesive and non-cohesive interlayers strengthens the embankment structure, but also makes it possible to raise the embankments and protects it against washing out [18].

The use of geosynetics is also reflected in the protection of sea shores [44]. Shore protection structures are considered hydrotechnical structures that influence the shape of the sea shore while ensuring its protection. Such structures include: storm embankments, coastal strips, groynes, coastal breakwaters, underwater sills and surface reinforcements. The main type of polymer materials used for these structures is geotextile. In marine construction, it is mainly used to strengthen shores as a filter in lining reinforcements, to separate layers of different fractions, as bags for filling with sand and as mats that protect against washing out the bottom. [45].

Sea shore reinforcements, breakwaters and groynes are also made of geopipes (long cylindrical sleeves filled with liquid material, e.g. water and sand). Water flowing out by gravity leaves a compact block, which, due to compaction, becomes an anti-filtration cover and also a reinforcement. A geopipe can be the core of a protective structure or a starting structure, e.g. for a stone riprap. Moreover, local material (e.g. taken from the bottom) is perfect for filling, which reduces the costs of making such reinforcement. [46].

THE MOST INTERESTING CASE STUDIES

In northern Germany, a storm dam was built on the Eider River in 1973. Its task was to protect the North Sea coast against storm waves. Over the years, the barrier lost its stability due to washing away. Consequently, in 1993, a decision was made to increase the strength and stabilize the underwater slope. For this purpose, it was decided to use geotextile containers filled with sand (geobags). Thanks to stabilization, the barrier stops waves up to 4 m. The use of geosynthetics also allowed for cost reduction. [47].

In France, in 1974, the first building was built using a double layer of geomembrane. This is how the Pont-de-Claix reservoir was created, which was to collect water used to make snow on mountain slopes. The double layer of geosynthetic was to be additional protection against leakage and disturbance of slope stability. The layers were separated by drainage. Monitoring was carried out at the reservoir, which in 2004 showed a leak in the western part of the reservoir. The failure was removed by gluing a geomembrane patch. In 2011, a visual inspection of the condition of geomembranes was carried out. Visual inspection showed that the material was in good condition apart from one minor damage [48].

In Poland, the Białobrzegi dam was built in the Narew and Bug valley. The initial method of discharging water from the dam area was pipe drainage with outlets to a ditch next to the dam, which flowed into the equalization tank. The impact of hydrogeological conditions was unfavorable and resulted in flooding and silting of the entire system. As a result, the dam's drainage was repaired. In 1994, the old system was cleaned and additional protection was provided in the form of drainage in a geotextile cover. The geosynthetic was used as a filter and drainage protection. After 22 years, research was carried out on the impact of mechanical and chemical clogging on the water permeability of geotextiles. The results showed a 1.6-fold reduction in the water permeability coefficient compared to pure geotextile [49].

In San Diego, California, construction of the Olivenhaim Dam was completed in 2003. It creates an emergency water reservoir for the city. A geomembrane and geogrid were used in the construction of the front wall. An important aspect when choosing the seal was flexibility due to earthquakes occurring in this area. The geomembrane prevents leaks and the destruction of the dam. The geogrid increases drainage [50]. In 2004, an earthquake with a magnitude of 5.5 on the Richter scale occurred approximately 100 km from the reservoir. The dam was not damaged during the earthquake, guaranteeing safety [51].

In 2006, on the east coast of Malaysia, an innovative project was implemented on the beaches of Teluk Kalong, Kemaman and Terengganu to protect sea shores from erosion. For this purpose, geotextile pipes were immersed in the coastal zone to create underwater embankments (dikes). The geosynthetic used was a woven high-strength geotextile filled with sand. In 2008, a similar initiative was launched to protect the shoreline at Pantai Batu Buruk, covering a 5-kilometer stretch of beach. After completion of the project, improvement of the coastline and an increase in the foreshore area were observed [52].

Canals were constructed on the Pench River in central India to supply water to agricultural crops in the

Nagpur region. They are divided into two main channels - the right-bank canal and the left-bank canal. In the 1980s, the canals were sealed with concrete. Over the years, the concrete began to crack, causing water to seep through and the clay underneath the seal to swell. Stresses caused by ground movement caused cracking of the concrete, so in 2019 a decision was made to choose a bituminous geomembrane as the new material lining the canal. The geomembrane is characterized by high flexibility and durability, as well as resistance to high temperatures. After the geosynthetic proved effective in 2022, it was decided to improve the next section of the canal also using it [53].

As part of works aimed at improving flood protection on the Oder, along the German-Polish border, a 3 km long section of the flood embankment was reconstructed. The aim of the work was to strengthen the embankment to withstand more extreme flood conditions. Soil tests below the embankment section revealed relatively deep, soft layers of peat, organic silt and clay. These conditions made it difficult to stabilize the embankment and increased the risk of its damage during a flood. A high-strength geogrid was installed to ensure the stability of the embankment. The geogrid was placed on the ground and covered with soil [54].

SUMMARY AND CONCLUSIONS

The implementation of effective, quick and economical solutions in construction does not exclude the hydraulic engineering department. Making elements of security systems in hydrotechnical structures in the form of geosynthetic materials works perfectly. Geosynthetics have a wide range of applications thanks to durability, low manufacturing costs, the possibility of using local materials, but also improving the quality of constructed structures. They are used in strengthening the ground and slopes, separating land, as independent drainage (drainage), structural reinforcements and as protection of drainage and drainage systems.

Each type of geosynthetic material is characterized by specific properties. The great diversity and the possibility of performing several functions at the same time in this case make it difficult to select appropriate materials. The applicable legal standards make it somewhat easier, but the lack of specific schemes or the limited experience of designers may make it difficult to decide which material will work best. Nevertheless, the geosynthetic technologies used prove their effectiveness in various conditions.

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