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REVIEW ARTICLE

Design criteria for the floating walkways and pontoons considering the extreme climatic conditions

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ABSTRACT

The study has addressed design criteria about how the industry of the floating reinforcement concrete precast (pontoons) is installed in the factory with the combinations of utility, electricity services, and internet service. The pontoon bridges are successfully installed on the road for transport. The installation process for pontoons is successfully attempted in a balanced situation above the surface of the sea to the resistance of floating precast (pontoons) to any ambient effects such as weather conditions, the movement of the waves, or any other effects. This study has found new inspirations to identify the pontoon bridges of the future in spite of the fact that several new ideas are already presented by the most imaginative designers. A detailed explanation regarding the procedures of mold preparation, reinforcement, and use of expanded polystyrene, casting, and the pontoon installation is presented. The findings of the study may help engineers in providing firm considerations to the technical details of the construction process while considering the significance of extreme climatic conditions in various regions.

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Introduction

Floating structures that are large-scale are majorly classified as either pontoons or semisubmersibles. Pontoons are basically floating slabs with low depth-to-width ratios that are placed in calm seas along the shore, inside a cove or lagoon, or where breakwaters and other protective structures may be built to shield the structure from high waves and surges (Wang & Wang, 2015) Moreover, in the history of floating structures, a prominent position is also enjoyed by the floating bridges. Floating walkways are a linear pontoon system formed from numerous hinged flotation modules and supported by a boat

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ramp lane during tides, according to the Queensland Government's Department of Transport and Major Highways (2015). It is usually without a gangway or access bridge and is immediately attached to a cast in situ concrete abutment. Floating bridges generally serve as a structure of last resort which can only be used for marshes, ponds, bogs, or other areas that are too damp to trail bridges that are traditional and less costly.

According to Wang & Wang (2015), the earliest floating bridges of notes were created in 480 BC during the invasion of Greece by the Persian king Xerxes. In addition, the history of floating bridges can go back up to 2000 BC, according to Watanabe & Utsunomiya (2003); however, only in recent decades where floating bridges are being used in modern infrastructures. According to Chandler (2021), there are currently twenty floating bridges around the world, and out of them, four are only present in Washington. Important trends in the development of floating bridges and other floating structures have been discussed by Wang & Wang (2015). The latest floating bridge constructed in 2007 is in Dubai, which is constructed across the Dubai creek and connected Bur Dubai with the Deira section of Dubai.

Neese (2002) mentioned that the best water-resistant material that can provide firm support to a floating structure is the one whose specific gravity is lower than water. Besides, a reliable floating structure is one that is developed from a small section of plywood fixed to floating logs which is reinforced through concrete pontoons. However, the complex structure and size of floating walkways majorly depend on the environment in which it is being placed. These types of bridges are rare and are generally found in a few locations. However, in the majority of locations, boardwalk, puncheon, and traditional bridge are often preferred.

Pontoons, on the other hand, serve as a temporary fixed floating structure and are used as a pathway for commuters to reach the surrounding water. It consists of a gangway ramp style that is developed and designed to match to shore. Floating pontoons are constructed focusing on the tropical waterways, which experience high and low floods (season). They are made to survive through severe loading conditions such as high and low floods while ensuring to meet unique requirements such as; function, safety, and structure. Such designs are further important in mitigating and protecting the tropical environment, which serves as a source of retaining the cultural heritage (Igwe & Ajoko, 2020). The manufacturing of pontoons is based on different materials, dimensions, and weights in marine construction to enable them to lift large weights. It has been broadly accepted that pontoon bridges are only available in the field of military engineering (Derewenko et al., 2011). However, these bridges are also seen for swamps and crossing rivers and, therefore, are considered as obsolete and folkloristic works.

Pontoons are widely used for different purposes, such as timber pontoons, concrete pontoons, and metal pontoons (steel and aluminum). It is a common dilemma that the theory and technique of the pontoon bridges are not taught in the universities (Zhang et al., 2010). Most structural designers do not think that they have an opportunity to tackle such situations. On the contrary, the pontoon bridges are of significant importance to installing new structural applications, whereas it presents a rapid, economical, and simple solution to cross water sheets (Tattoni, 2007).

According to Australian Standard Guidelines (2001) for design marinas, concrete pontoons are present in different dimensions, such as concourse pontoons up to (6 m wide, 1 m wide central service channel, 20 m long, and 1.5 m height), superyacht pontoons up to (4 m wide, 20 m long, 1.5 m height), premier pontoons (3 m wide, 15 m long, 1.2 m height), and superyacht fingers pontoons (2 m wide, 20 m long, 1.2 m height) (Australian Standard Guidelines, 2001). The quality assurance system ISO 9001:2000 is used in the fabrication of concrete pontoon, which is manufactured through preparing the mold, reinforcing installation, using expanded polystyrene, and casting of concrete (Planning and Design Guidelines for Small Craft Harbors, 2000). Several studies focused on the structures and construction of floating walkways, which include the evolutionary development of floating structures and pontoons. For instance, Morra (2012) conducted a study and provided details related to the processes involved in the construction of floating structures and pontoons. The study included information regarding the previous characteristics of floating structures, and technological developments, along with the need that brought about these changes. The study was central in outlining different issues that are significant in the advancement of the floating structures. Another study was conducted by Rapo (1981) and provided significant details in relation to the facilities and different types of floating structures. However, according to the study, different circumstances and possible damages are caused by severe damages in the docking. The study suggested block loading, ship strength, and dock stability as the major sources of preventing increased damage.

In general, floating bridges are balanced vertically by pontoons. A number of elements should be considered in the design of floating bridges. The structural eigen properties of floating bridges are influenced by several parameters, which include the cross-section properties, end connections, curvature of the curved bridges, pontoon types, and the number of pontoons. The environmental loads, including the wave current, wind, and tidal forces, excite the dynamic responses of the bridge under different types of loads. Fluid-structure interaction is certainly important in the case of a tsunami or extreme wave impact loads from the environment.

The idea of a self-floating reinforced concrete precast bridge is a novel idea to be installed in the shipyard based on tugging and assembling in the selected locations. Another important idea is to support a pontoon bridge by a railway line crossing the Bering Strait. Therefore, this study has presented the steps to manufacture and install the Floating Reinforcement Concrete Precast considering the extreme climatic conditions. The development of curved floating bridges considers conventional onshore arch bridges that are conceptualized as vertically curved and axially compressed structural systems. The elevation, as a curved structure, is as critical as the span length. In addition, the rise-to-span ratio is a fundamental indicator of the structural properties of a curved bridge. As a curved structure, the rise is a critical parameter that is as important as the span length.

Moreover, the rise-to-span ratio is a key indicator of the structural properties of a curved bridge. Theoretically, the elbow structure only forms a compressive force along the center of the mass line. Although it is virtually impossible due to complex load combinations, it is possible to study the perfect rate of increase to achieve a perfect internal power distribution. In the case of a floating bridge, due to local constraints, it is not possible to design the lift conversion ratio too much. On the other hand, shallow arches are believed to cause significant horizontal movement of the subsistence and have the disadvantages of high deformation and low rigidity. It is not yet known whether the horizontally curved floating bridge has such a disadvantage when it is centuries old. In this article, a relatively low rate of elevation and selection is chosen for a curved floating bridge, and the response and internal forces are investigated by changing the boundary conditions (BCs) and span. It is believed that the distribution of the pontoon is in the coastal sea of Singapore. The water depth is very shallow. Therefore, the waveform characteristics of deep-sea pontoons are also different. In addition, the cross-section of the bridge was developed to meet high traffic flow requirements (three lanes each way), and the span of the bridge was relatively short. In this case, the horizontal stiffness of the bridge is expected to be high. Therefore, a lower rate of increase is studied at an early stage to see if arc activity can be achieved. However, when compared to previous research, these new properties of floating bridges are relatively new; therefore, there is a need to explore these properties of floating bridges.

Experimental Investigation of Pontoon Bridges

Design Development

The design standard is that the structure of the reservoir must be stable and capable of carrying personnel and materials. The design should ensure stability and minimize the impact of registration because the pontoon bridge is supported by two concrete sinkers. The aim of the design is to maximize the cargo (that is, cargo space) that the floating ship can effectively carry. Finally, the project should strike a balance between this optimization and the construction cost of the pontoon, given the weight of the pontoon. The scope of the design is to develop and use ordinary carbon steel as a point for a landing dock. Gangway made of steel pipe with a wooden bottom/floor, with a mound base as an anchor on the shore and an offshore roll on the floor of the lagoon. The concept of design will be limited to floating rules and production descriptions. The design will mainly include the pontoon and the gangway (gangway), and the strength analysis of the material will only be done on the components of the pontoon. The material used in the construction of the pontoon pier shall be steel. Building components and non-building components must be cold-formed to meet the requirements of AISI S240 Chapter A3 and AISI S220 Chapter A4. Organizing members should be limited to category 33 (230) and category 50 (340), while non-structured members should be limited to category 33 (230). Corrosion protection should meet the same standards.

Preparing the Mold

Mold plates are made of smooth mold purpose steel as they are installed based on required tolerances to meet all structures measured. The fixing bolts are tightened, and all holes are plugged with welding and grounded smooth to clean the mold surfaces and treat them with oil (Figures 1 and 2).

Figure 1. Preparation of the mold

Figure 2. Phases of mold preparation

Reinforcing Installation

The reinforced concrete industry provides increased significance to use higher strength reinforcing steel for specific applications (Morra, 2012). Relief of congestion is the prime factor toward this interest, specifically in constructions assembled in a high seismic design category. Construction efficiencies or high-strength concrete enhance other areas where a high-strength bar enables reinforced concrete is required to be utilized for more inspiring applications. Today, Grade 60 steel is used within the concrete design and construction along with the occasional but increasing use of Grade 75. It has been notified that different grade of steel can be used for large projects with higher grades and a minimum grade for ordinary tasks for more inspiring structures. The increase in costs is generally observed for higher grades; therefore, the material is used in small quantities. In the actual scenario, small concrete members are usually permitted by higher grades that are associated with the space issues for reinforcement placement. The steel acts as a central supporting material, although the steel usually comprises merely a few percent of the total reinforced concrete volume. The cutting and bending, the cost of the steel, and the forming of the deformed bars are included in the form's installation. The general attempt is represented by the cost-saving factor of using the minimal reinforcement and the concrete, which reflects typical unit costs for the two materials.

All reinforcing mesh and steel bars of stainless steel to resist corrosion (side mesh, intermediate wall mesh, intermediate wall corner and vertical rebar, sidewall upper long rebar, deck mesh) are included in the pontoon installation. The minimum yield stress of steel bars is 500 MPa, which must be cleaned completely of lubricate and any dirt to use plastic spacers and checked all installed reinforcing. It is not allowed to mix stainless and galvanized when attaching seaflex to anchors.

The importance of Grade 500 steel allows for reinforcement bars in all international and national building codes and standards. All the current codes restrict the allowable design strength of reinforcement to 80 Ksi (MPa) from a design standpoint. An economy can also be accomplished using Grade 500 steel rather than commonly accessible Grade 415 bars in the market. One of the main advantages of using Grade 500 is to replace the steel congestion in the foundation mat and at the beam-column joints. On the contrary, the development length differs for Grade 500 steel as compared to Grade 415 steel. Higher-strength concrete and better engineering judgments are required for achieving maximum benefits from Grade 500 steel.

Using Expanded Polystyrene (EPS)

The manufacturing of buoys, floats, and pontoons is commonly observed through expanded polystyrene (EPS) due to its excellent physical properties as it has better resilience and buoyancy and is light in weight. Archimedes' principles are used for buoys, floats, and pontoons to displace their own fluid weight. There is no standard shape, pattern, or design for pontoons, floats, and buoys, whereas it is simply customized on the basis of the application nature. It is not essential that EPS is used to manufacture buoys, but pontoons are manufactured with high densities either with proof coating or without coating (Figure 3).

Center of buoyancy

A floating object creates a water displacement; the center of gravity of the displaced volume of water is called the center of buoyancy. The center of buoyancy is important because the resulting upward force engages here. The position of this center of buoyancy can be calculated for the different shapes, assuming a center or evenly distributed load on the floating body.

<u>Rectangular body</u>

The center of buoyancy for a rectangular body is:

$$B_{rec} = \frac{1}{2} d \quad (1)$$

B_{rec} = center of buoyancy measured from water surface [m]

<u>Triangular body</u>

The center of gravity for a triangular body is:

$$\mathcal{Z} = \frac{S_y}{A} \quad (2)$$

$\mathcal{Z}$ = position center of gravity [m]
S_y = static moment in the x-y area [m^3]
A = area [m^2]

$$A_{tri} = \frac{1}{2} w, h \quad (3)$$

A_{tri} = area triangle [m^2]
w = width of floating body (m)
h = height of floating body (m)

$$S_y = \frac{1}{3} w. h^2 \quad (4)$$

S_y= static moment in the x-y area [m^3]
w = width of floating body (m)
h = height of floating body (m)

Substituting these formulas into the formula of the center of gravity results in:

$$\mathcal{Z} = \frac{2}{3} h \quad (5)$$

The center of gravity of an equilateral triangular object is seen from the base, at one-third of the height.

The center of buoyancy for a triangular body is then:

$$B_{tri} = \frac{1}{3} d \quad (6)$$

B_{tri} = center of buoyancy measured from water surface [m]

<u>Cylindrical body</u>

The center of gravity for a half-cylindrical body is:

$$\mathcal{Z} = \frac{4.r}{3\pi} \quad (7)$$

$\mathcal{Z}$ = position center of gravity [m]
r = radius (m)

This is approximately 0,42 times the radius (0,42r).
The center of buoyancy for a half-cylindrical body is then:

$$B_{cyt} = \frac{4.r}{3\pi} \approx 0{,}42r \quad (8)$$

B_{cyt} Center of buoyancy measured from water surface [m]

This formula only applies to a cylindrical body that is half fully underwater. Otherwise, the Simpson method should be used to determine the center of gravity and buoyancy.

Figure 3. Use of expanded polystyrene

Features of EPS Pontoons

Stable

High-quality expanded polystyrene materials are used to form these products. The main reason for using these high-quality materials is that it floats on water and will not crumble once an individual board on them.

Durable

EPS is lightweight and durable to withstand any amount of weight, specifically for pontoons. Due to its stability, individuals in huge numbers can stand on it regardless of any fear of falling off.

High compressive strength

The manufacturing process of pontoons is meticulously attempted to ensure that it is tough and robust, to a certain extent, to withstand extreme climatic conditions. The manufacturing process of pontoon EPS is two-fold. Steam is used to expand the raw beads by creating pre-puff beads that are cured in large bags before mold preparation. The pre-puff beads are steamed to form a block that is anywhere from 37-1/2″ – 54″ x 49″ x 121-1/2″-220″ once in the mold. Afterward, the placement of blocks is made on the storage floor based on the adequate time length before being cut into assorted sizes and shapes. To meet specific project needs, blocks are manufactured and produced in several densities.

EPS size and density

There are different block sizes available for state-of-the-art Hirsch mold anywhere from 37-1/2″ – 54″ x 49″ x 121-1/2″ – 220″. The most common cut sizes available are 48 inches X 96 inches and 24 inches X 96 inches, even though pontoon does not stock any foam. Following specifications are used in the manufacturing process of pontoons.

Table 1. EPS requirements

Items	Dimensions
Thickness	1/4″ to 54″
Lengths	Up to 216″ (18′)
Widths	Up to 48″
Densities	75 lb to 2.85 lbs per cubic foot

During the pontoons manufacturing, all the ducts are needed for the installations of utility, electricity services, and Internet service. The EPS blocks were used as filling and casting molds inside the pontoon, and the bottom was treated to resist marine borers by using polyurea coating and after reinforcing installation, which allowed to lift off the readymade EPS into the mold.

Casting

Before proceeding to the casting process, the area of casting is examined since an equally leveled casting is required. Check the height position of deck mesh before casting is checked; the strength of concrete is durable (45 N/mm. s), containing cement, superplasticizer, Micro-Silica, and plastic fibers. Color pigment impregnation should be added to concrete, whereas water-resistant silicone impregnation is for further treatment. Casting must be done very carefully to prevent any risk considering the correct positioning of EPS upon completion of the casting process, which includes pouring the pontoon deck to the bottom of the service duct and lifting the service duct (Figure 4). The concrete is then compacted by using vibrating rods, linear and vibrating beam deck surface, and integrated air-operated side mold vibrators to increase the quality of pontoon sides. All side and deck structures of the pontoon are made uniform and continuous. Next anti-slip graining is being made by using mild brushing. The poured concrete is then protected with water curing and plastic covering, which supply the pontoons with seaflex mooring tubes.

Figure 4. Service duct lifting

Concrete Sinkers and Seaflex Mooring System

The system is effective as it solved many problems in pontoons design & installation, specifically the efforts made by the experienced divers. It used to moor the pontoons to the seabed to keep the pontoon in its place regardless of the wave's movement or the difference in water level consisting of seaflex and rope. Seaflex is regarded as an active part of the mooring, and it does not cover all the distance from anchor blocks to the pontoon. Always pre-tensioned at the lowest water level, adjusting for water level changes and taking care of forces. The number of seaflex is calculated by the attachment distance and the length of the pontoon (Figure 5).

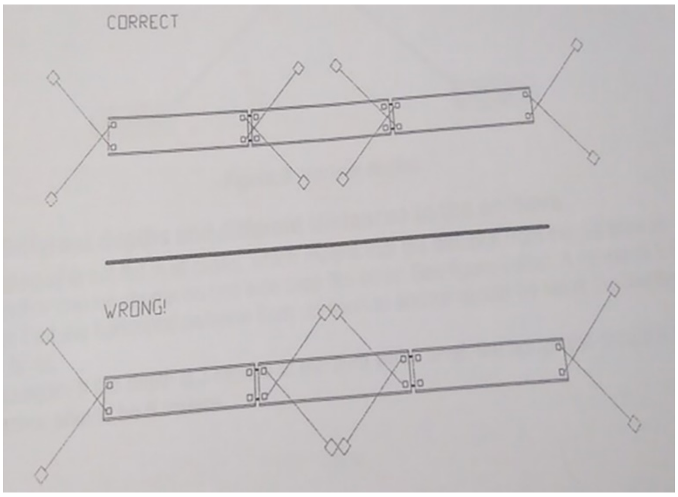

Figure 5. Placement of seaflex

The seaflex mooring is placed at a horizontal angle of 45 degrees, as this angle depends on the direction of the main force. The vertical angle between the mooring line and the seabed does not exceed 40° at the highest water level because if the angles increase the stability of pontoons, it will decrease (Figure 6).

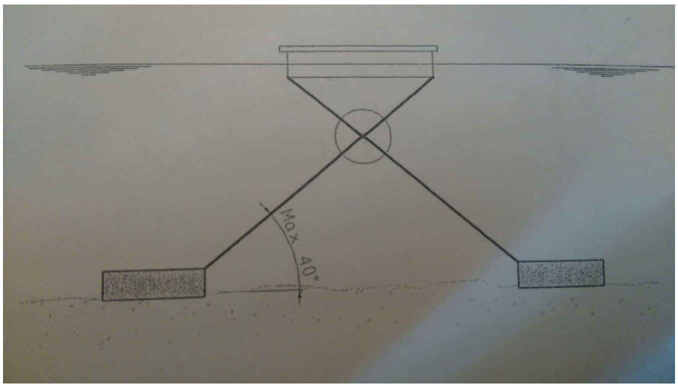

Figure 6. Right vertical angle between the mooring line and the seabed

When the depth increases further out from land, the distance between the pontoon and anchors will increase (Figure 7).

If the seabed is not flat, the horizontal distance between the pontoon and the anchor will be twice the medium water level. For instance, when the water depth was 3 m, the horizontal distance between the pontoon and the anchor was equal to 6 m.

From the Pythagoras theorem, the distance from the anchor is found to the rope, which was the hypotenuse of the depth, and the horizontal distance to the anchor equals the root of (3^2+6^2)=6.7 m (Figure 8).

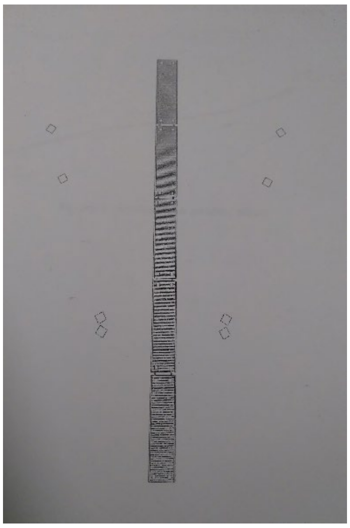

Figure 7. Deeper further out from the shore

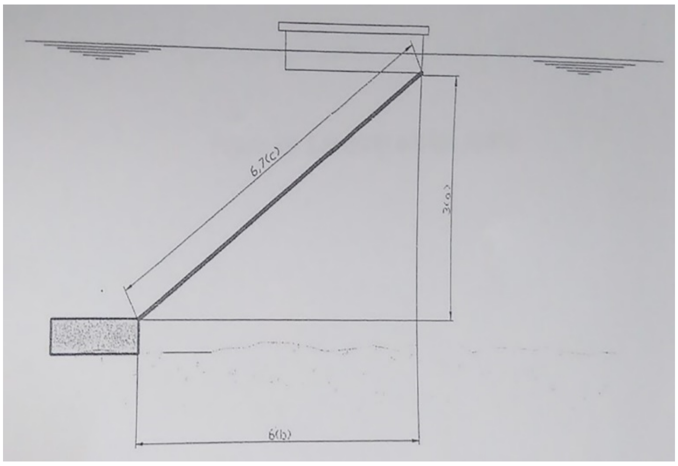

Figure 8. Hypotenuse calculation

The type of rope used is different according to the breaking load of rope and the number of seaflex rubber hawsers such as square plait polyester rope. Seaflex is always pre-tensioned 30% at the lowest water level even if the pontoon is moved (re-installed). The seaflex is pre-tensioned according to its length when left in the factory. This system is safe, strong, no effect on sea beds, easy to handle, low corrosion, simple to install, low maintenance, keeps the pontoon in the right place, handles any variation in water level, no bottom erosion, and no damage to the marine ecosystem.

Anchors

Anchors are normal dead weight from reinforced concrete on the land, expressed in tons, and it shall be the same number of rubber hawsers in the seaflex. Therefore, if a seaflex is used with 4 rubber hawsers, the weight of the anchor will be 4 tons or more. The weight of the anchor depends on the type of seabed; if the bottom is soft, it will be easier for the anchor to skin down, and a lighter anchor can be used. If there are small stones in the seabed and the friction is very low, a heavier anchor will be used. If the anchor is 10 tons, two 5 tons anchors can be connected together instead of 10 tons.

The Pontoon Installation

All pontoons contain service channels, an underwater lighting system, electricity and water outlets, illuminated stainless steel mooring bollards, led lighting, safety equipment, service buildings, and a sewage sanitation pump-out system. The chafing between the ropes is removed because they are crossing each other under the pontoon so that the ropes can be fixed by swapping. This shows that the rope that is under moves and lays over the other rope. Some pontoons, such as superyacht fingers, are fixed to walkways with flexible joints. When the moorings are moved, the free depth for boats is increased.

To install the pontoon, each one is lifted, pontoons and anchors (sinkers) are transported by trailers or barges, and sometimes by tag boats. The inner corners of the pontoon are moored to the land, and the pontoon is moored temporarily in its position with a lighter anchor. Permanent anchors are placed, and the anchor with seaflex attached to the rope is loaded on the boat. The anchor is lowered slowly down by a winch, and the diver checks if the anchor in the correct position. The rope is connected to the pontoon. The seaflex is pre-tensioned. This system is available for all the pontoon units.

In cross-border surveillance, fiber optic sensors were used to monitor possible damage. The bridge passed the above test. No voltage damage or excess buoyancy was found. A space scanner was also used to test the displacement of bridge elements under the load of the above-mentioned vehicle. As part of the reservoir's work, many other tests have been performed, such as the use of strain gauges to measure the load when testing on a pile of sand with the appropriate shape, various tests of technology for the production of other components, and strength testing of internal nodes. Current research shows that polymer composites and movable composite bridge structures can be used in the construction of military bridges. The use of composite materials in military and civilian bridges has unique advantages because these materials have a special strength compared to steel and aluminum and have the best corrosion resistance to atmospheric resistance during storage. Therefore, polymers have a bright future in bridge construction. The example of a new floating bridge confirms the usefulness of polymer composites in bridge construction. This also proves the positive impact of the collaboration between the Technical University and the Polish Army's design and research departments.

Conclusion

The study findings showed it is evident that the pontoon bridges are not just a military device or folkloristic curiosity, but they also represent the effective and economical solutions for crossing large sections of even deep water. The findings also suggested that the length of the pontoon bridges is not restricted by structural or technological problems. It is concluded that blocks of EPS comprise different dimensions. According to its original rubber length, seaflex is always pre-tensioned. Seaflex system shows better stability for pontoons as it is manufactured faster compared to any other system, is gentle to the environment, and is the most modern method for mooring a pontoon bridge. The weights for pontoons differ up to 75 tons, resulting in pontoons as strong and carrying large weights. There will be a substantial impact of inclusive access to the population and economy.

To implement such requirements to floating structures, there are still restrictions because of variable tide heights and dynamic motions, while there is clear guidance for buildings. Conflicting requirements are required for operating a terminal, such as minimal lighting levels regardless of glare so as not to intervene in the navigation platform. This review has sought to present some of the design tactics for using the improved accessibility for a waiting area and pontoon and lighting, stimulated by the input of a user group and an access consultant. On the contrary, it does not offer guidance about how to design to obey the pre-requisites mentioned within the regulatory standards.

Recommendations

The pontoons are designed for 50 years of service life. The area of casting must be checked. Fixing of mold and steel must be checked. The bottom of EPS blocks must be treated. The casting must be done very carefully. Cracks and holes must be repaired. Lifting the service duct must be careful in all pontoons-built services ducts. The curing operations must be done every day. Transportation of pontoons and anchors must be careful. The seaflex system is safer than other systems because it is an elastic and environmentally friendly mooring solution for any floating application such as docks/pontoons, floating wave attenuators, and buoys. It is unrivaled in its ability to keep it stable and secure even in locations exposed to extreme weather conditions.

From the construction response, it can be concluded that the flexible end connection will be better compared to the vertical and horizontal bending differences. In terms of axial force and horizontal bending moment, the short bridge is better, while the vertical bending moment of a long bridge is relatively small. In further design and optimization, it is recommended to increase the horizontal rigidity of long-term working conditions in the bridge, but vertical rigidity can be reduced. For the curved bridge, this is not an ideal load condition when the axial compression effect is still excellent. However, short bridges show more flexible effects than long bridges. Therefore, a higher rate of increase in peer-to-peer bonds should be considered to discuss the best rate of increase in curved floating bridges, and the related N-M effects will be further investigated.

Compliance With Ethical Standards

Conflict of Interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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