Construction technologies for flood-proofing buildings and infrastructures

Concepts and Technologies for flood-proof Road Infrastructure

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Title	Flood –proof Road Infrastructure – Technologies
Lead Author	Bladimir Osorio
Contributors	Ines Gallo, Pawel Poneta, Jerzy Jurczuk
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Summary

This report documents the research and participation performed by ACCIONA Infrastructure R&D, in partnership with MOSTOSTAL R&D, and describes the main findings and research steps necessaries to conclude the task. In FloodProbe project, both companies have been involved in task 4.2 *Concepts and technologies for damage mitigation in the urban built environment* and more specific in the *development of technologies for flood-proofing road infrastructure*.

Since the beginning of the project, three stages have been developed, so far. In the first stage, the limits in the application of floating technology for flood-proofing infrastructure in circumstances of flooding and post-flooding were defined. The second stage had consisted in a deep search of floating technology applied to infrastructure state of the art, a first approach analysis of multi-benefits, flexibility/compatibility, traditional/new materials application were also performed. Finally, the third stage had consisting in the development of concepts design of floating technology, applied to infrastructure as a quick response to maintain connection during a flood emergency event and in connection with shelters and hotspot buildings. All three stages have been incorporating the requirements made in connection with the others work packages activities, possible pilot's necessities and partners/stakeholders suggestions. A specific focus had been established on floating and lightweight bridge research.

For the final stages of this research activity, the work to be done consist in: a) the design and elaboration of select concepts, for this purpose, a floating pedestrian bridge will be developing according the necessities of the possible place of application, b) a scale prototype will be fabricate, according to designs defined on previous point, and c). based on the above points make a final report on the integration of technology applied to floating emergency attention by flooding in vulnerable areas.

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1 Scope of the Research

As has been mention before, ACCIONA R&D is involved in task 4.2 *Concepts and technologies for damage mitigation in the urban built environment* and more specific in the *development of technologies for flood-proofing road infrastructure*.

2 Principal Results

During the research carried out in this activity, so far, the following findings had been accomplished:

- An analysis approach to understand the flood effects caused on infrastructure.
- An identification of floating and lightweight technologies applied to road infrastructure.
- A development concepts proposal for flood proof road infrastructure, specifically to be used on flood emergency support attending.
- A catalogue proposal for the application of floating technology according to the flood emergency situation including an example of application
- Materials test results of some components of the prototype

2.1 Flood effects on road infrastructure

In order to understand the effects caused by a flood event on infrastructure and how this impacts people lives (economically and moral), especially in Europe and in the flood occurence, it is found that countries bordering the North Sea like the Netherlands, Germany, Belgium, Denmark, and UK share a long history in fighting against flooding threats from the sea. The need to protect these flooded vulnerable areas which cover 40.000 km2 and home of 16 million people has been rising since the tendency of increasing natural catastrophe threats and the important role of the threatened areas among those countries.

The South Holland and the North Holland provinces which are also the most populous province in the Netherlands, the engine of country's economy, and home of important cities are in risk of flooding. The north coast of Lower Saxony State, the west coast of Schleswig-Holstein State, and the biggest seaport in Germany, Hamburg are potentially flooded during storm seasons. The south east coast of UK, the Flanders coastline, and the west coast of Denmark are also potentially affected by flooding.

Floodwater interacts differently with the various elements in the flooded area because each element has its specific sensitivity to any of the parameters that characterize the flood event. The amount of damage will probably depend on the maximum height of the water, the duration of the presence of the floodwater, the flow velocity of the water, the season in which the flooding occurred and the transported materials. For humans especially, the period between dyke failure and the arrival time of the water in their houses may be of importance for evacuation purposes. Floods have an enormous potential impact, especially in areas where people are not prepared. (Alkema at al. 2001)

Finally, as it is know, road infrastructure forms a lifeline for inhabitants in a flood prone area, allowing evacuation as well as access to emergency response services to affected areas, and the continuation of the provision of essential services such as supply of food, bottled water and maintenance of comunications, and therefore, here it is where this impact suggest the importance of a backup solution. Flood proof structures are therefore propoused in circumstances of flooding and post-flooding, for interoperability and connection.

2.2 Floating Bridge Technology

It is denominated floating bridge those bridges that rest on the surface of water instead of saving it, as is usual. The fact that these bridges do not have roots in mainland makes its global stability depending of its buoyancy and it isn’t due to resistance and characteristics of their supports and foundations.

One of the main characteristics of these types of bridges is that it doesn’t represent a barrier to the passage of water; it could be pedestrian bridge or vehicular bridge, see Figure 1.

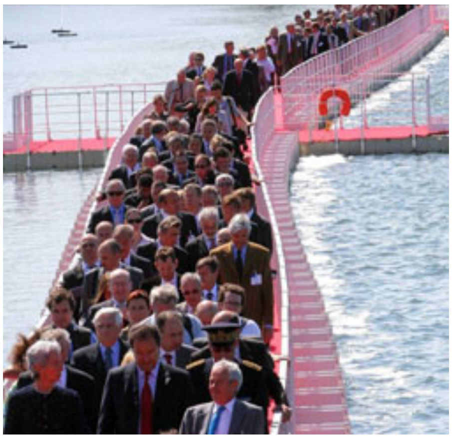


Figure 1 Pedestrian floating bridge by Eco-Dock Inc.

2.3 Lightweight Bridge Technology

This technology consists of extremely light sections that are assembled on site. The load-bering parts consist of fiberglass beams that are reinforced with carbon fibers on the underside. The bridge interacts with a thin bridge deck that is prefabricated out of composite-fiber-reinforced concrete with extremely high strength. Since these materials are very durable, they are advantageous in a life-cycle perspective, and they are highly suitable for industrial construction, see Figure 2.

Figure 2 Lightweight bridge placements by ACCIONA, Asturias - Spain, 2004.

The implementation of this technology follows a series of analysis and decision making process, that are in hands of the competent authorities involved in planning and design of buildings, infrastructure, disaster management and maintenance of key infrastructure (central, provincial, and local government agencies sharing the responsibilities with local stakeholders).

2.4 Other types of floating structures

Another kind of floating elements serving as an infrastructure support are show below:

2.4.1 Floating Storage Facilities

Very large floating structures have been used for storing fuel. Constructed like flat tankers (box-shaped) parked side by side, they form an ideal oil storage facility, keeping the explosive, inflammable fluid from populated areas on land. Japan has two major floating oil storage systems. One oil storage facility is located in Shirashima with a capacity of 5.6 million kilolitres while the other is at Kamigoto (see Figure 3) with a capacity of 4.4 million kilolitres. (Wantanabe at al. 2004).

Figure 3 On the left Shirashima Floating Oil Storage Base, and on the right Kamigoto Floating Oil Storage, Japan.

2.4.2 Floating emergency Bases

As floating structures are inherently base isolated from earthquakes, they are ideal for applications as floating emergency rescue bases in earthquake prone countries. Japan has a number of such floating rescue bases parked in the Tokyo Bay, Ise Bay and Osaka Bay, see Figure 4.

Figure 4 On the left Emergency Rescue Base in Tokyo Bay and on the right Emergency Rescue Base in Osaka Bay.

2.4.3 Floating docks, piers, berths and containers terminals.

There are in existence many floating docks, piers and wharves. For example, the 124 m x 109 m floating dock in Texas Shipyard built by Bethlehem Marine Construction Group in 1985. Floating structures are ideal for piers and wharves as the ships can come alongside them since their positions are constant with respect to the waterline. An example of a floating pier is the one located at Ujina Port, Hiroshima (see Figure 5). The floating pier is 150 m x 30 m x 4 m. Vancouver has also a floating pier designed for car ferries. Car ferry piers must allow smooth loading and unloading of cars and the equal tidal rise and fall of the pier and ferries is indeed advantageous for this purpose. A floating type pier was also designed for berthing the 50000 ton container ships at Valdez, Alaska. The floating structure was adopted due to the great water depth. (Wantanabe at al. 2004)

Figure 5 Floating Pier at Ujina, Japan.

2.4.4 Floating barriers (caissons)

The principle is to use a floating element, thus brought by water, closing the entire pass and introduced by ballast. Ballast may or may not pivot the cofferdam. There are different variations in this kind of elements, requiring pivoting; and are often composed of a watertight and bordered ensuring gate block the following image shows the operating principle.

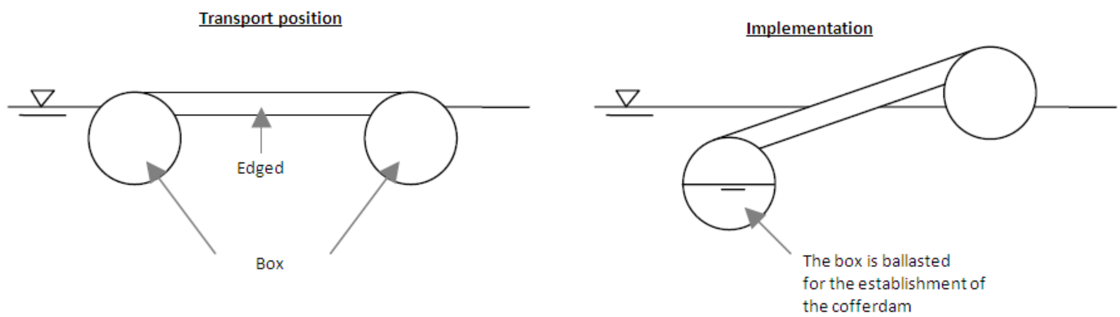


Figure 6 Schematization of a floating caisson

In this case, the installation requires a swiveling of the cofferdam (horizontal position to a vertical position), and it must therefore be equipped with two bridges, one for the position unemployment (floating), the other for position cofferdam. The boxes are fitted with valves operated from the bridge to fill them with water. Axes allow the positioning and maintaining in blocking reservations made in the batteries of the dam.

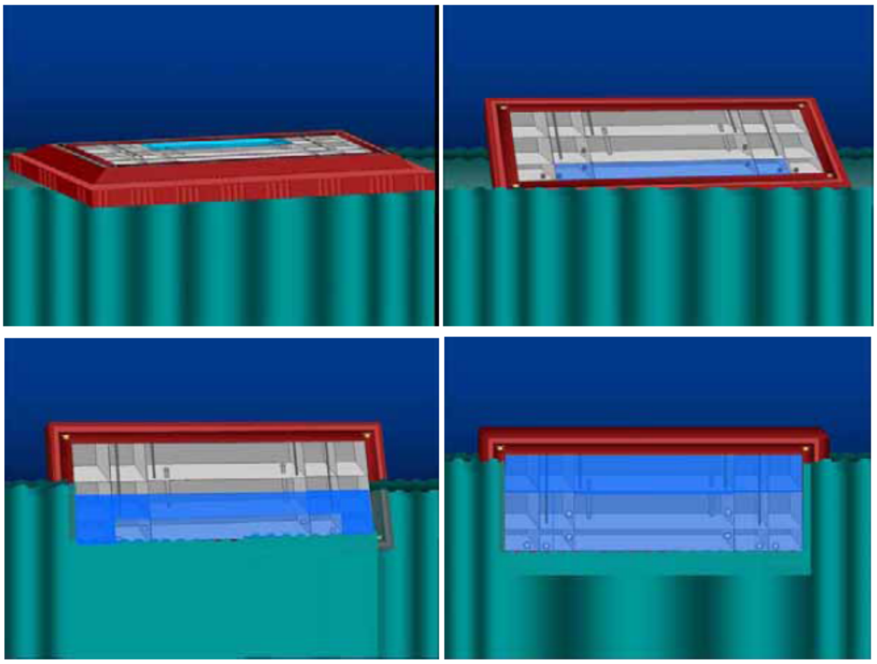


Figure 7 Floating barrier disposition, they have valves to fill the pass.

Their shape is usually not very suitable for navigation, therefore during the phase in which this is not used they are stored in the immediate vicinity of the work.

2.4.5 Floating columns

Floating hexagonal columns used as barriers for levee repairs consisting of reinforced concrete/composites hollow elements. This is a relatively recent development; so far it is more conceptual and consists of positioned of the floating column near the repair area, which final disposition could be as a lateral barrier to the outside / inside of water face or between the filling soils. The level of solution can be as temporary or permanent.

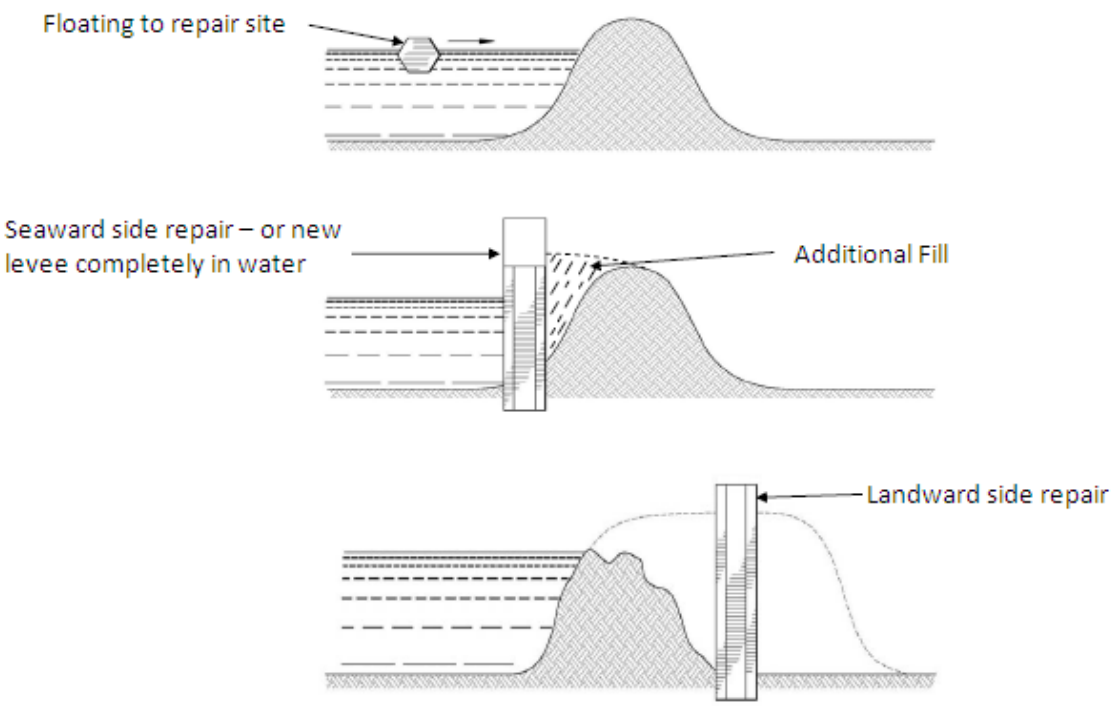


Figure 8 Schematic example of floating column application

2.4.6 Other floating applications

There is other range of minor floating infrastructure for a diverse series of temporary application, and of course no less important, as e.g. to support emergency response activities, maintenance and logistics, such as:

- Infrastructure systems for floating pipes and ducts.

Figure 9 Examples of floating pipes application

- For aquatic/flood emergency response

Figure 10 Examples of small floating bases application for emergency

- And as support for repairs and maintenance of other kind of infrastructure

Figure 11 Examples of floating bases application

3 Design concepts of multifunctional flood defense structures – Flood Proofing Road Technology

3.1 Introduction

Bridges in municipal infrastructure play a very important role; they are key elements throughout the entire transportation system of urban metropolitan areas. Due to their location during floods they are exposed to activity and impact of very strong forces caused by moving masses of water. Because of exceptional loads, greater than designed, load-bearing construction of a bridge becomes damaged. In many cases those damages are serious enough that they prevent safe use of the crossing.

On the other hand, during a flood event in urban areas, most cases often present which create breaks between communication points, e.g. between two buildings or between a building and their access road, etc. That is, do not necessarily have to be a damage bridge to the creation of a disruption in an urban area, a lack of temporary infrastructure is born.

In order to prevent such critical situations, a new solution should be adopted, consisting in the application of composite bridges. Their main advantages are easy, fast, safe and effective erection of the crossing at any place, using light construction equipment. Application of the composite technology will contribute to improvement in safety of people living in flood areas and will enable organization of efficient evacuation of such areas during floods.

3.2 Description of concepts for floating infrastructure

Three different concepts of floating infrastructure had been proposed, one of the main applications is related with road composite bridges, and inside this category two types of constructions are distinguished: lightweight bridges and promptly assembled bridges, another category is related to float bases, which can be used as support elements during a flood even, due to its versatility and quickly response. Each of them is intended for different operational loads and is characterized by other features.

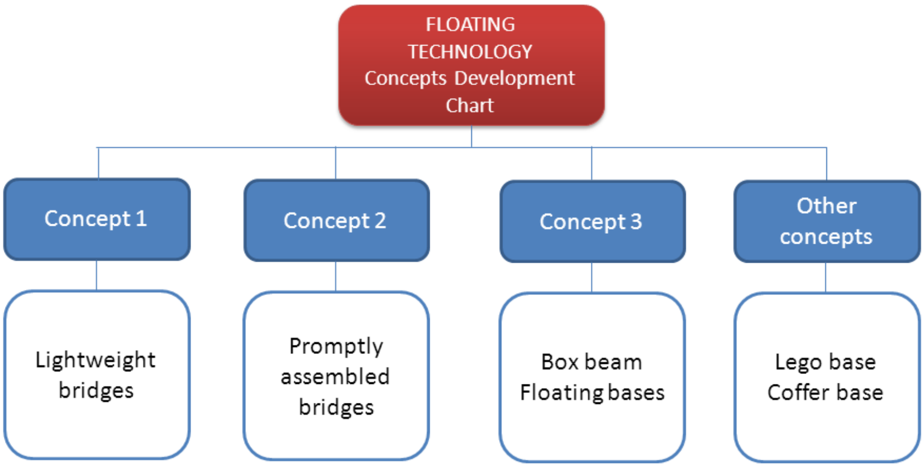


Figure 12 Concept development chart

3.2.1 Lightweight bridges

These bridges are installed as a temporary structure during a flood event and then disassembled and stored until used again as a temporary structure. They are adapted for pedestrian, bicycle and light vehicles traffic with total acceptable weight up to 3.5 tons.

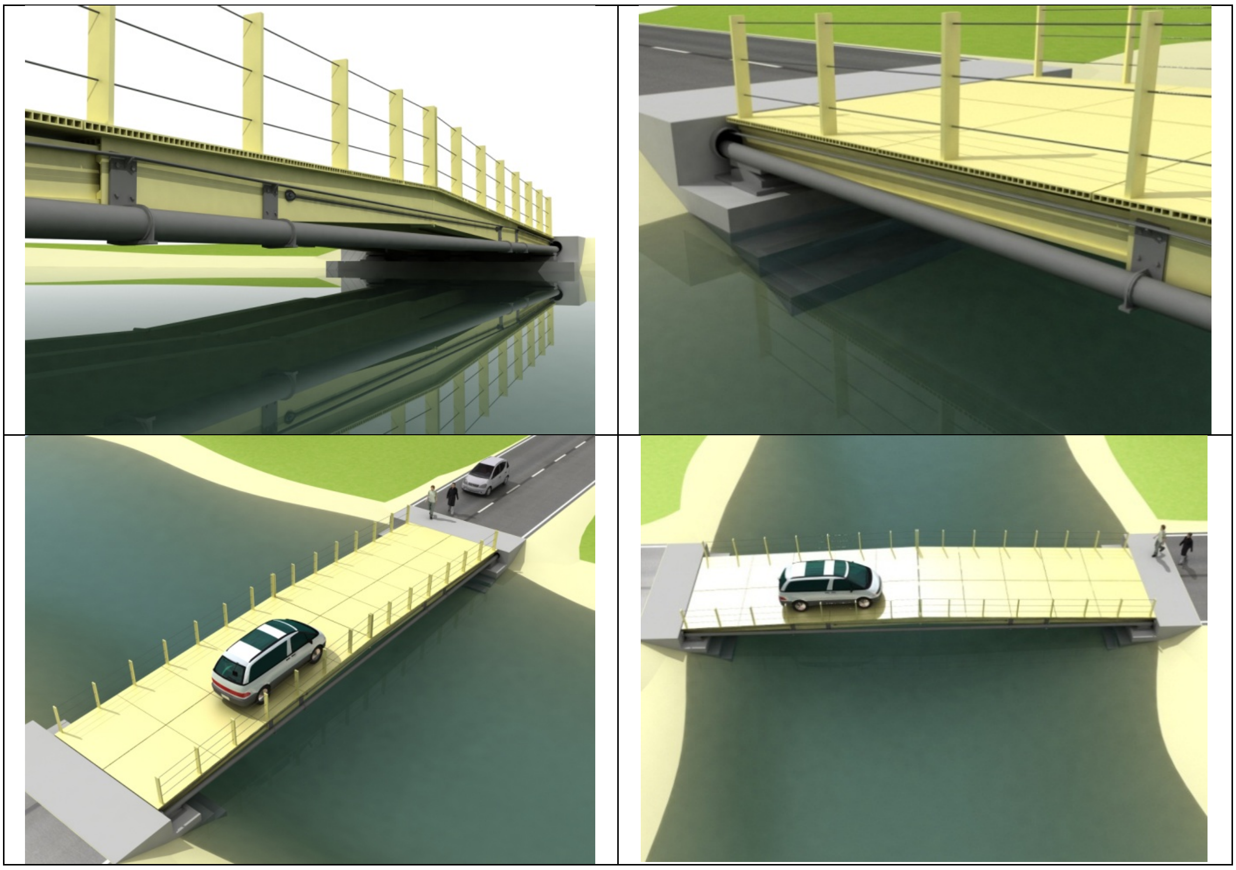


Figure 13 Lightweight composite bridges.

Their structure is composed of telescopic composite beams on which a light platform is placed.

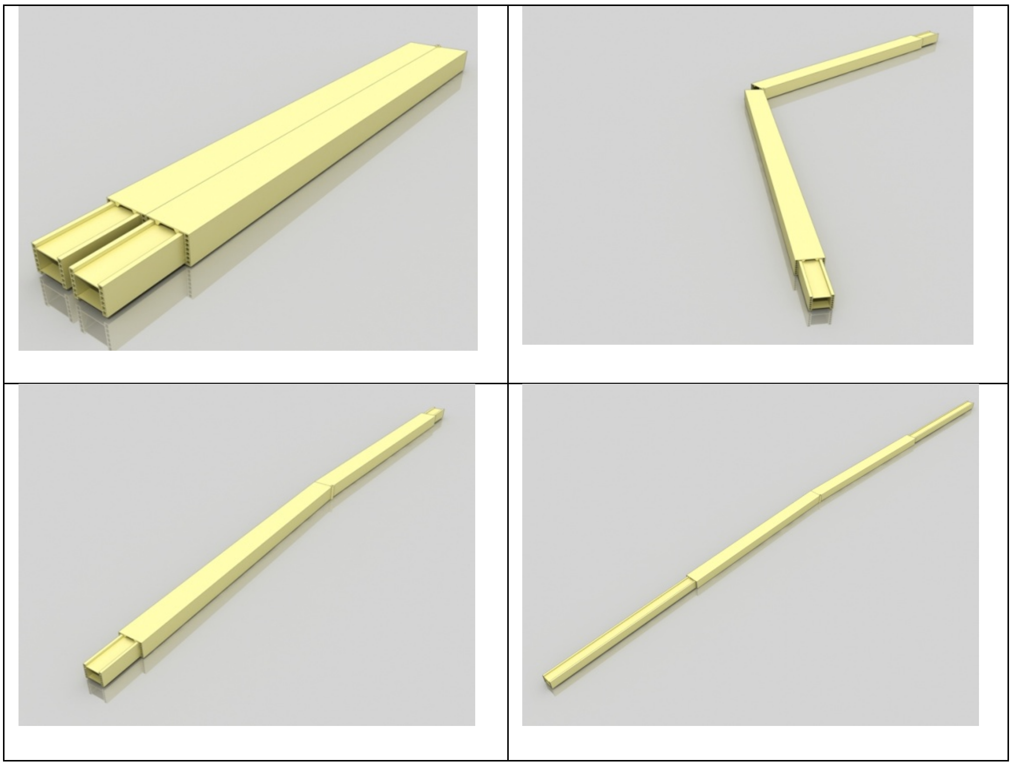


Figure 14 Telescopic beam assemblages

Beams have a joint placed in the middle of their span, enabling one to shape the slope of the bridge by regulating length of the bowstring. The bowstring, in the form of a composite rope, with adjusted length, connects ends of each beam. Outermost beams of the bridge are additionally equipped with brackets allowing an installation to be slung that delivers e.g. water, electricity, etc. All connections between structural elements of the bridge are mechanical.

Figure 15 Lightweight bridge assemblage processes

Before assembly of the bridge structure, bearings should be prepared or existing bearings should be used. Due to small loads from the bridge structure, light prefabricated materials, e.g. styrodur blocks, can be used for building bridgeheads.

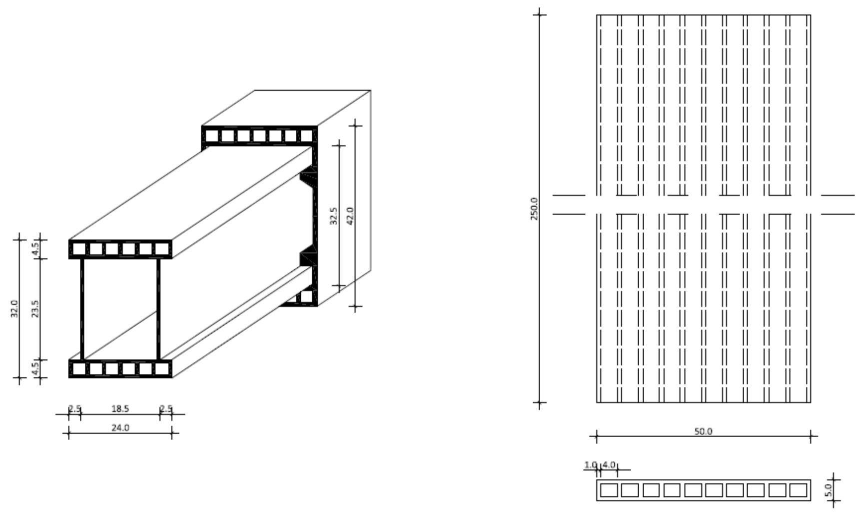


Figure 16 Typical section for a telescopic beam and deck for lightweight bridge

The presented solution of the bridge structure can be used as a permanent or temporary crossing, of course when periodical inspections and maintenance activities are performed. Visualization of a lightweight bridge is presented in Fig. 13.

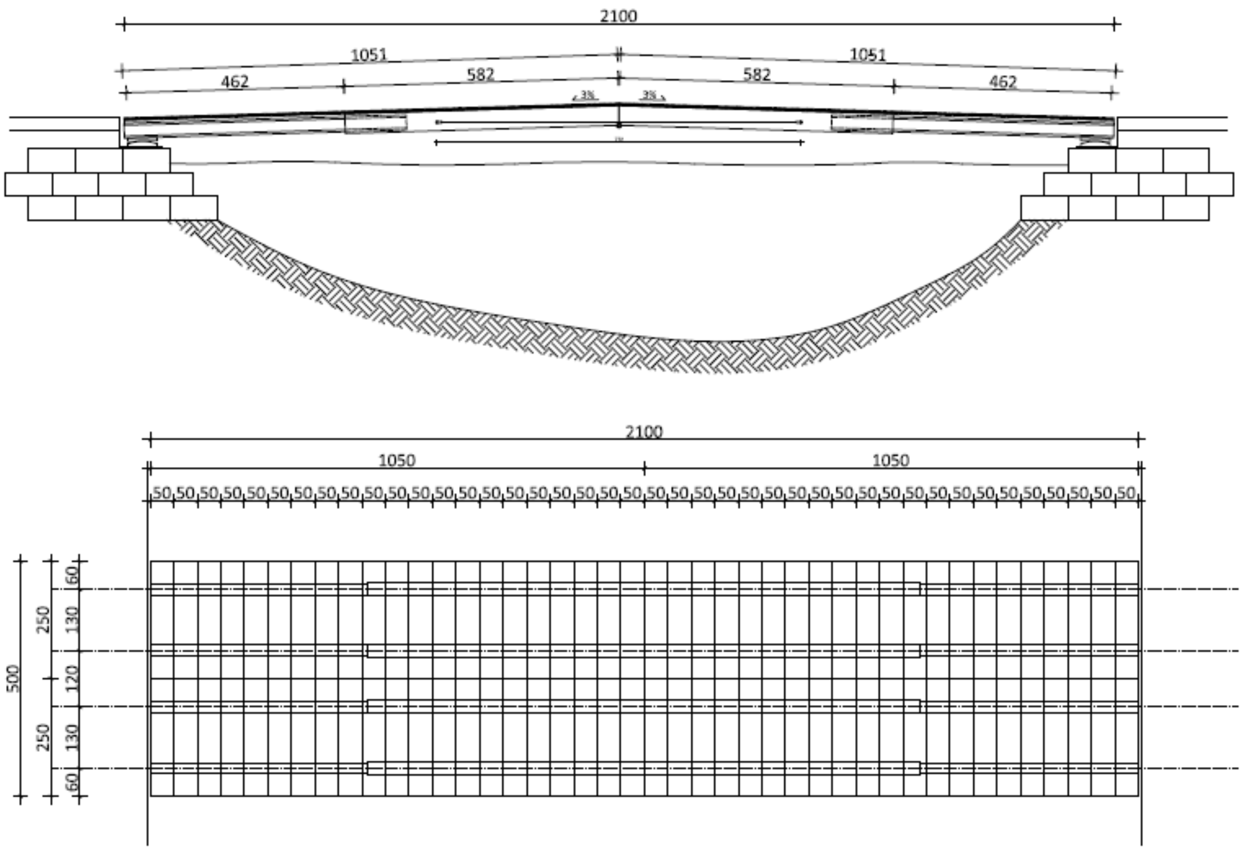


Figure 17 An example for a 21 m long x 5 m width Bridge, side and plan view.

Available sizes

Length	20 <L<30 m
maximum number of items	No limit
Width	5 m
Possible slope	3 %
Number of vertical joints	10
Number of horizontal joints	30 approx. (Slab connectors)
base structure Thickness	< 0.01 m

Structural aspects

Failure mode	Compression
Maximum height of water feature	0.5 m
Infiltration behaviour	N/A
Height	possible to increase in service
Resistance to damage and repair	The structure is rigid and has good resistance

Operational aspects

Installation time (30 m long)	6 person crew in 8 hours
Installation Method	Installation manual for the panels are light enough
Possibility of improper installation	No
Storage and transport	Can be stored outside without protection. The panels have a size of 2.5 x 0.50 x 0.05 m, and the beams 5.8 x 0.4 m, a van is sufficient
Adaptability to field conditions	Appropriate supports are necessary
Attachments / Sensitivity vandalism	Possibility of fastening / low vandalism exposure.
Location	Many applications but preferable for

	lengths not too important

Financial aspects

Maintenance / reuse / sustainability	Elements should be checked every year. The system is sustainable but proper maintenance increases the duration of life
Installation costs	30 m long and 5 m width above) Composite materials = € 85,000 Wood = 55 000 € Aluminium = € 99 000
Resources for the installation	View of the importance of the elements, a team installation and a lifting system required
Additional costs	Costs do not include experience teams and labour

Other aspects

Aesthetic	No unsightly (different colours available)
Environment	Non-polluting

Experience Feedback

These kinds of elements are frequently used as military bridges. This bridge was designed as a solution to the increased weight of the new tanks that were being developed in the early stages of the war, can be constructed from a variety of materials, including, modular aluminium, steel, and galvanized steel.

Figure 18 Military bridge assemblage

Needs

- For urban emergency response are required bridges to be smaller and easy to handle for assemblage / storing.

Fact sheet

Lightweight bridge	
	
Advantages	**Disadvantages**
Easy to implement if accessible by foot	requires adaptation of the support base (deposits can be difficult to remove)

No length limitation (adding elements to keep beams lengths acceptable) Proven system No diver is required Sustainable system No heavy equipment for installation (elements of reasonable size, installation manual)	The large number of elements increases the time of implementation of the cofferdam Lifting equipment is required if the items are too large
Range of use and recommendations	
Operational load of pedestrian and vehicular traffic up to 3.5 t Time of use: permanent or temporary bridge Span up to 30 m between bearings Width of the bridge 4 m Mechanical connectors for connecting elements of the bridge Elements of the bridge prefabricated and prepared for assembly Equipped with protecting barriers	

3.2.2 Promptly assembled bridges

Consist of prefabricated cubic composite elements. A connection of a dozen or so elements using mechanical connectors will become the floating base.

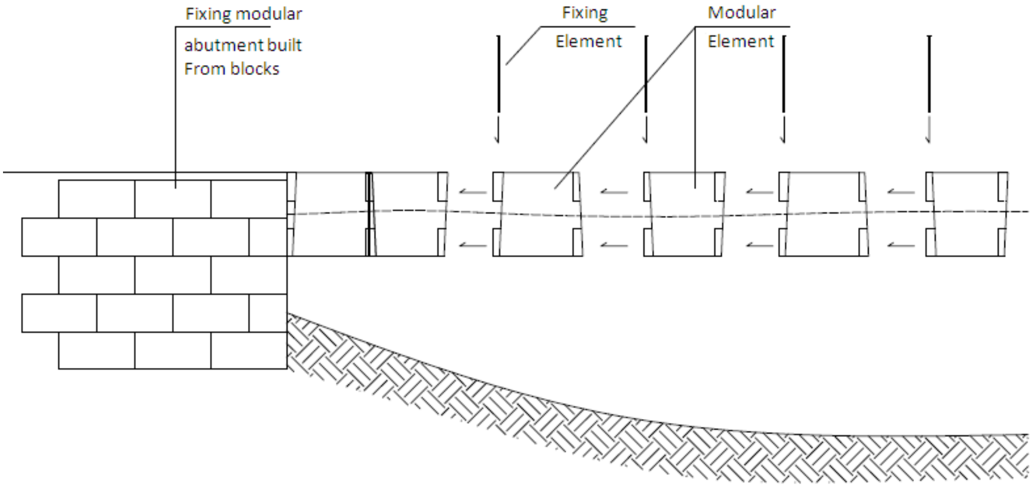


Figure 19 Floating box assemblage, lateral view.

In order to stabilize the bridge structure, it should be anchored using stays in the quay.

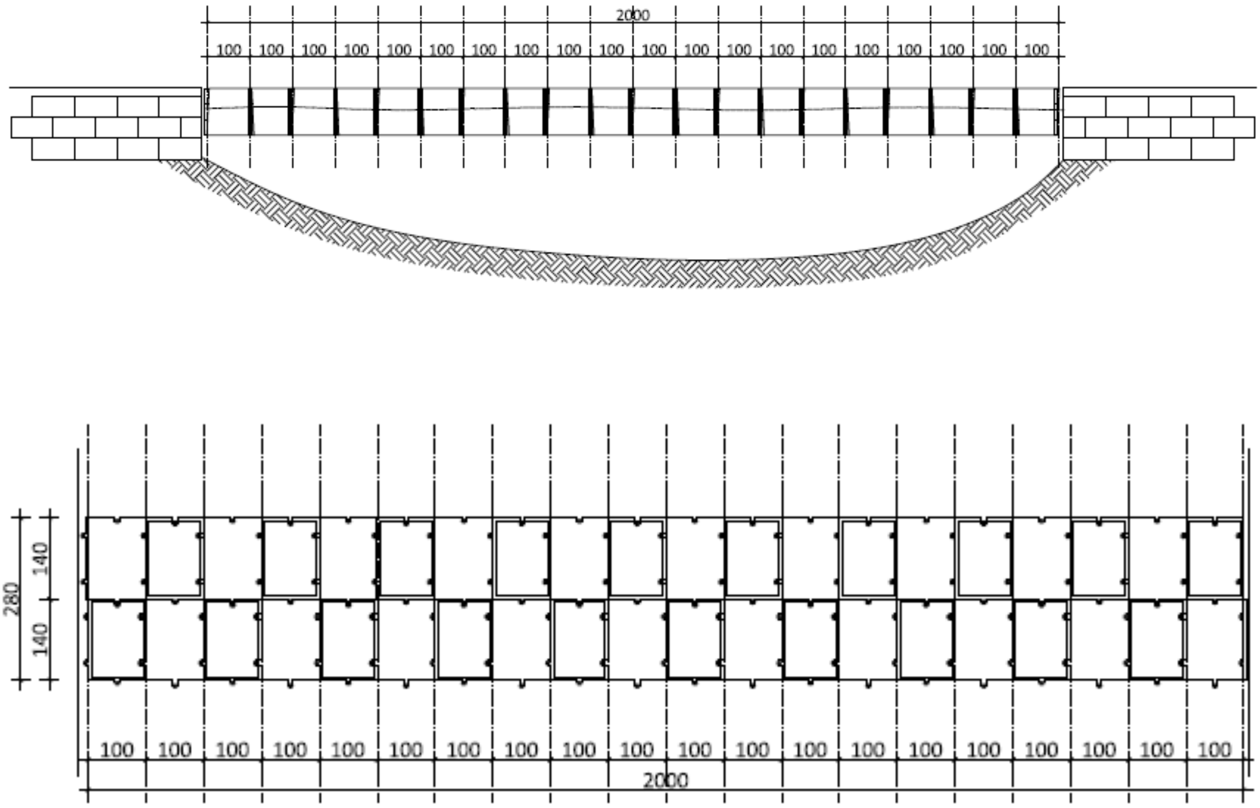


Figure 20 Bridge example, 20 m long x 2.8 m width, side and plan view.

For compensation of fluctuations in the water level and to facilitate movement from bank to the bridge, deflection constructions should be placed on its ends. On side surfaces of the bridge there are handles for slinging installations with various types of utilities.

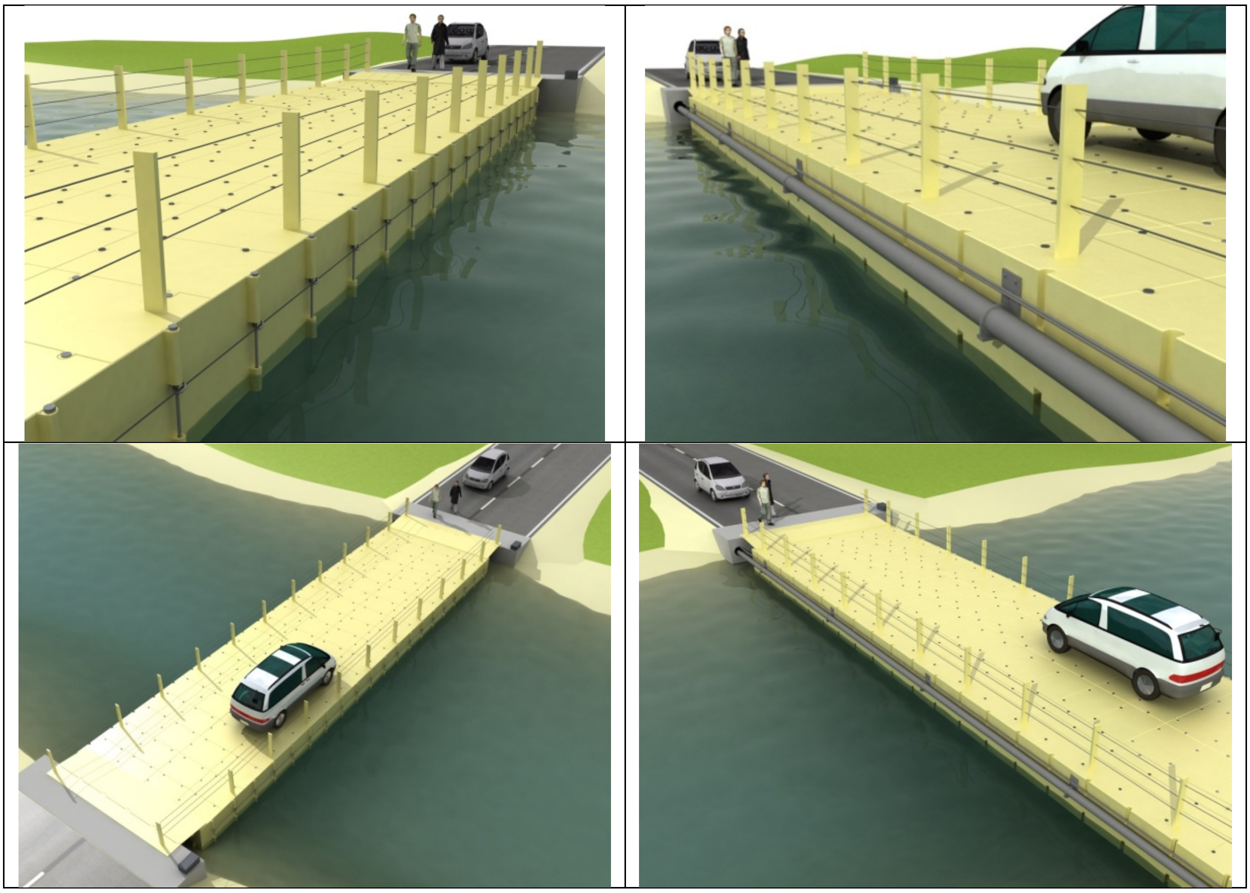


Figure 21 Promptly assembled composite bridge.

Depending on displacement, bridge can be used for movement of various kinds of vehicles, from motorcars even up to trucks and heavy equipment. Visualization of promptly assembled bridge is presented in Fig. 31.

Available sizes

Dimensions	1.1 x 1.1 m
Maximum number of items	No limit
Available height	1.5 m
Possible angles horizontally	angles of 90 ° are possible
Number of vertical joints	4 - 2
Number of horizontal joints	0 or 1 if the structures are stacked height

base structure Thickness	< 0.01 m

Structural aspects

Failure mode	No major damage
Maximum height of water feature	0.7 m
Infiltration behaviour	Depending on the type of conformation material
Behaviour in response to breaches	The collapse of the structure should not be seen induced stability and the weight of the floating box
Height	possible to increase in service
Resistance to damage and repair	The structure is rigid and has good resistance

Operational aspects

Installation time (120 m2)	Six person crew in 10 hours
Installation Method	Installation with assistance of 15 t crane
Possibility of improper installation	No
Storage and transport	Can be stored outside without protection. The floating box have a size of 1.5 x 1.1 x 1.1 m, a van is sufficient.
Adaptability to field conditions	Resilient to the boundary conditions of urban furniture, requires concrete anchors.
Attachments / Sensitivity vandalism	It is a submerged element, its supposed low risk, exposed face must be protected.
Location	Many applications but preferable for lengths not too important.

Financial aspects

Maintenance / reuse / sustainability	Elements should be checked every year. The system is sustainable but proper

	maintenance increases the duration of life
Installation costs	1 m2 above) Comp. mat.(plastic) = € 650 Galvanized steel = 435 € Aluminium = € 790
Resources for the installation	Team installation and a lifting system required
Additional costs	Costs do not include emergency experience teams and labour

Other aspects

Aesthetic	No unsightly (different colours available)
Environment	Non-polluting

Experience Feedback

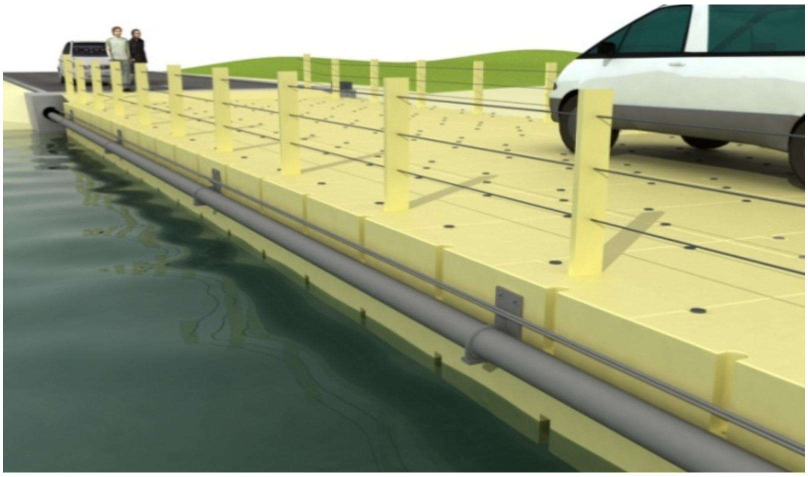
This kind of elements are frequently used in private docks and marinas, swimming areas, and landing piers, floating box can be constructed from a variety of materials, including lumber and Styrofoam/polyethylene combinations, modular aluminium, stainless steel, and galvanized steel.

Figure 22 Floating box applied in a private marina

Needs

- For emergency response elements are required to be easy to handle for storing in addition to withstand dry conditions.

Fact Sheet

Floating Box bridge and bases for shelters	
	
Advantages	**Disadvantages**
Inexpensive Easy to implement if accessible by foot No length limitation (adding elements to keep beams lengths acceptable) Proven system Sustainable system No heavy equipment for installation (elements of reasonable size, installation manual)	Reservations in the floor must be cleaned (deposits can be difficult to remove) Need to diver if holding more than 1m The large number of elements increases the time of implementation of the system Lifting equipment is required if the items are too large.
Range of use and recommendations	
Operational load of pedestrian and vehicular traffic above 3,5 t Time of use: temporary, excluding winter period Quays equipped with deflection compensating elements Stabilizing stays anchored in the quay Mechanical connectors for connecting elements of the bridge Speed of water flowing stream between 0.07 up to 0.1 m/s	

Protection of the bridge element against elements carried by the stream Possibility of fastening an installation Equipped with protecting barriers Elements of the bridge prefabricated and prepared for assembly

3.2.3 Composite Materials Box Beams

Is a floating base whose foundation consists of large hollow beams, made of fiber-reinforced sandwich and lightweight core polymer, which can be used as water storage tank. This concept, unlike the previous two, is a permanent solution, that is to say, it does not require the assembly and disassembly process for a flood event, but it responds according to boundary conditions

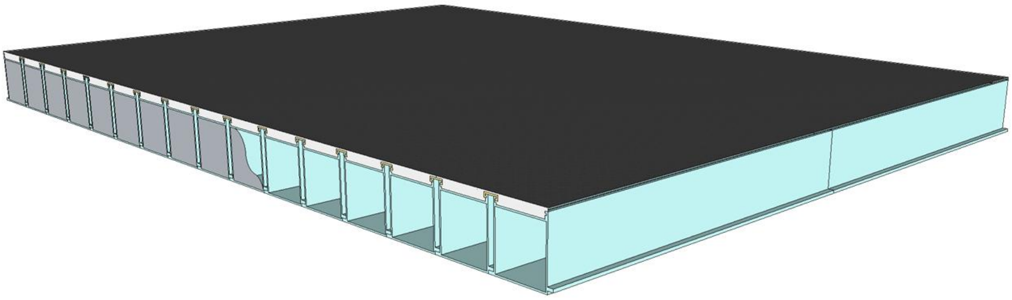


Figure 23 Schematic box beam configuration.

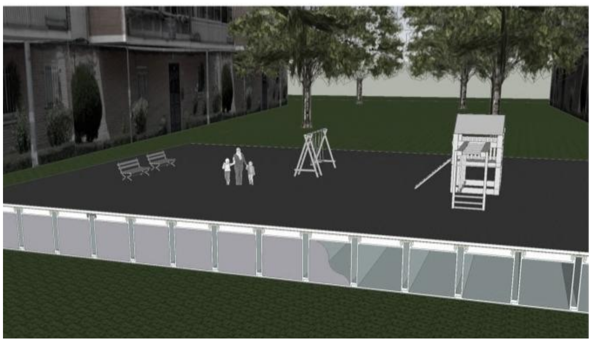
This concept includes the following elements:

- Beams of rectangular section (closed), of dimensions 1.7 x 1.5 x 30 m (canto x W x L)

- Composites internal stiffeners. - Composite connectors.

- Reinforced concrete plate with fiber rods reinforced polymer.

- Concrete skirt with fiber rods reinforced polymer.



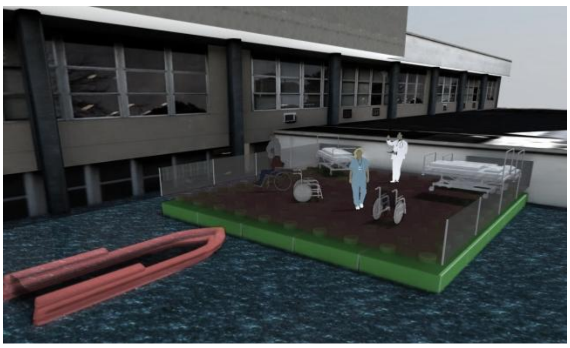


Figure 24 Schematic box beam application.

These elements are embedded in urban environments and may be part of the furniture as recreational areas for playgrounds, pedestrian zones, etc.

3.2.3.1 Beam Box Proposed construction system.

A brief description of how beam box system would be implemented is presented in four steps as follows:

1. Beams are placed directly in the moat and are united together by means of mechanical connectors (contemplates the possibility of mounting on a submersible platform, this serves as formwork for the base, facilitating their conformation).

2. Reinforcement and concrete are placed conforming the beams.

3. Placing the polymer fiber mesh, for the reinforced concrete, that forms the support plate and the skirt.

4. Finally installed building and / or structure is required on the support plate.

Available sizes

Length	10 m
Maximum number of items	No limit
Available height	1.4 m
Number of vertical joints	8
Number of horizontal joints	4 / m2
Base structure Thickness	0.05 m (including core)

Structural aspects

Failure mode	Lateral Buckling
Maximum height of water -	2.0 – 3.0 m
Infiltration behaviour	The element is completely waterproof
Resistance to damage and repair	The structure is rigid and has good resistance

Operational aspects

Installation time (20 m2)	Four person in 15 hours
Installation Method	Lifting equipment is required
Possibility of improper installation	No
Storage and transport	Stored is not necessary. The beam box have a size of 1.5 x 1.4 x 8 m, a truck is required
Adaptability to field conditions	Requires special adaptation for implementation
Attachments / Sensitivity vandalism	A moat system protect the box beams
Location	Many applications but preferable for lengths not too important

Financial aspects

Maintenance / reuse / sustainability	Elements should be checked/inspected every year. The system is sustainable but proper maintenance increases the duration of life
Installation costs	20 m2 above) Reinforced concrete = € 18.000 Composite materials = € 22.000 Aluminium = € 25.000
Resources for the installation	A team installation and a lifting system required
Additional costs	Costs do not include experience teams and labour

Other aspects

Aesthetic	No unsightly (different colours available)
Environment	Non-polluting

3.2.3.2 Experience Feedback

This type of box beam is usually used as modular system resulting platforms that are capable of supporting all types of heavy equipment loads in areas that are practically or economically inaccessible to conventional deck barges. This modular system used to be heavy, but can be quickly connected into larger assemblies of various sizes and shapes by ordinary work crews without the need for special tools or equipment.

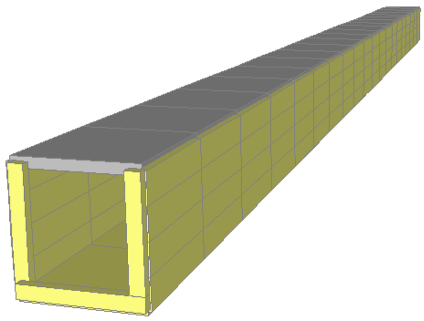
Figure 25 Example of box beam application, *Flexifloat Inc.*

Needs

- Box beams system needs to be protected against penetration, punches, etc.

3.2.3.3 Fact sheet

Composite Materials box beams



Advantages	**Disadvantages**
Easy to implement No length limitation (adding elements to keep beams lengths acceptable) Proven system Sustainable system Permanent solution	Reservations in the floor must be cleaned (deposits can be difficult to remove) Need to be implemented in dry conditions The large number of elements increases the time of implementation of the system Lifting equipment is required if the items are too large

Range of use and recommendations
Floating base maintenance The used of the floating base is limited by the depth of water (maximum of 2 to 3m) To increase the safety, the floating base must be configure in a moat The float base could be used as clean water storage unit

3.2.4 Other concepts

Initially were developed and presented a series of concepts which star point has been the lightweight bridges technology developed by ACCIONA for both, vehicles and pedestrian applications. By the other hand, on previews concepts had been discussed some pros and cons that can be analyzed in the future, these concepts are presented below

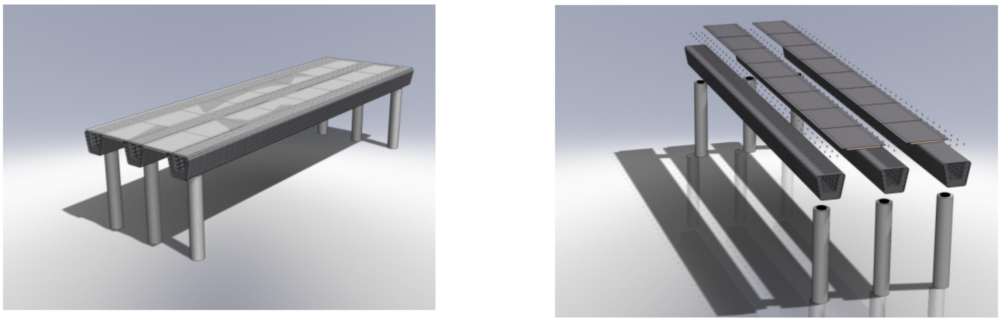


Figure 26 Schematic assemblage process for a lightweight bridge.

Figure 27 Construction of a composite materials lightweight bridge.

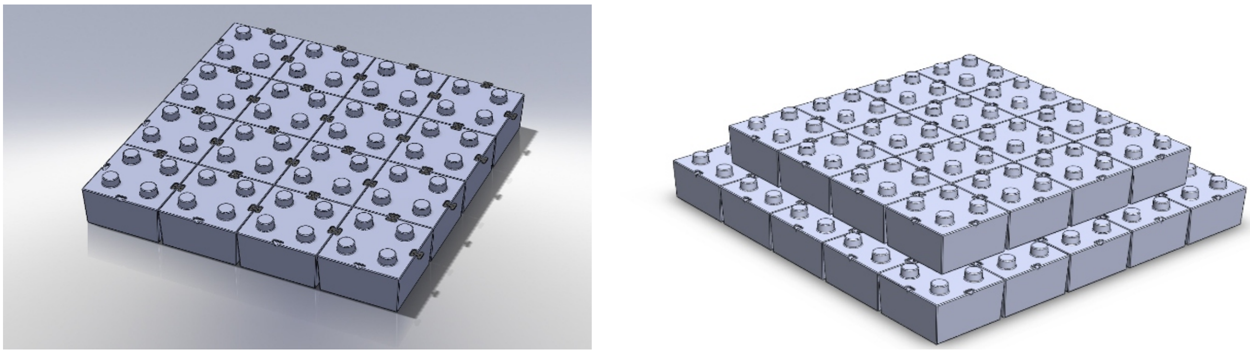


Figure 28 Schematic Lego concept.

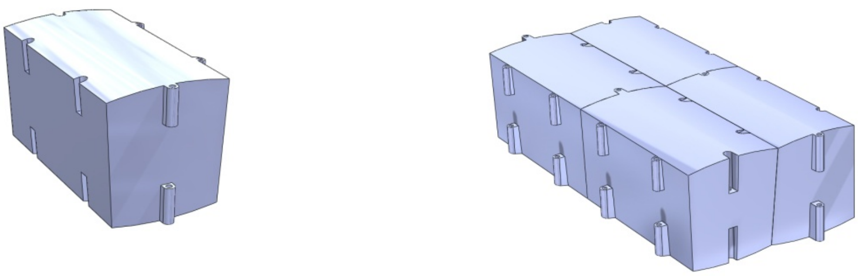


Figure 29 Schematic coffer concept.

3.3 Alternative Applications for Temporary Floating Infrastructure.

Apart from basic functions for which bridges are used, namely crossing of people, vehicles through a water obstacle, the suggested composite structures can be also used for other purposes. During floods they may serve as a connected network of platforms adapted for shelter and first aid. Visualization of facilities used as shelter is presented in Fig. 3.

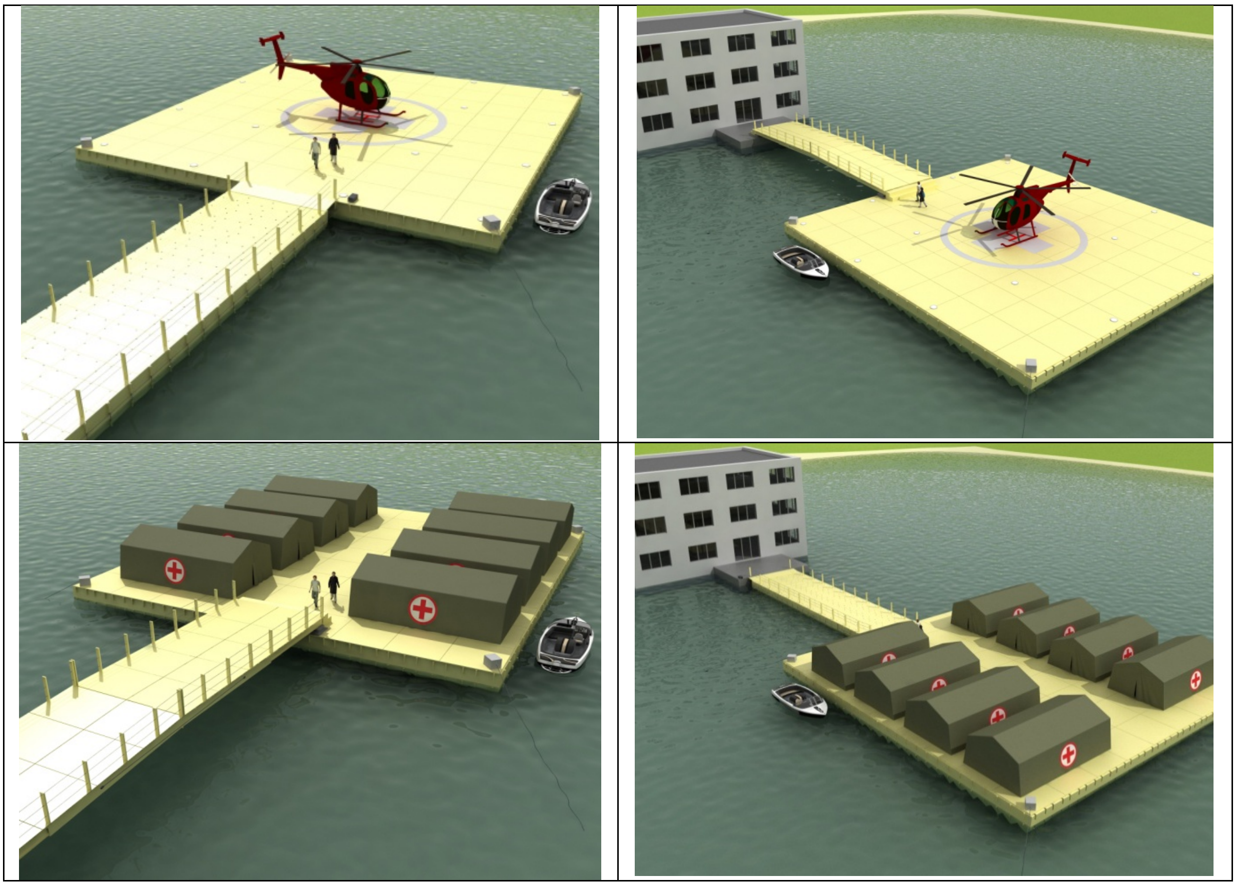


Figure 30 Examples of shelters using composite bridges.

3.4 Materials and equipment needed for the assembly of the bridge.

Elements of the presented composite bridges solutions should be prefabricated in a workshop, and prepared for transportation. Construction of the bridge elements should be prepared in advance and, when complete, the unit should be deposited in a storehouse, where it will await installation. The best solution is to place storehouses with prepared composite bridges near the place of their use, in order to eliminate burdensome and long-term transportation. Fixed bridges and selected public utility facilities could be equipped with backup composite bridges, constituting protection in the event of flood. This would contribute to quick restoration of a damaged bridge with its composite backup and would eliminate transportation interferences in the road network.

In order to efficiently assemble a composite bridge, it is necessary to train assembly crews, which would be prepared for assembly of a composite bridge. Each crew should be equipped with light construction equipment used for preparation of quays and assembly of the construction. Scope of ground works before assembly of the bridge will depend on type of the bridge structure and on the way of its support or anchoring to the quay. In the case of lightweight bridges where composite beams will be supported on the bridgeheads, respective bearing structures should be made. It is most recommended to use already existing bearings for supporting spans of a composite bridge. If it is impossible, bridgeheads in the traditional technology, such as reinforced concrete ones, should be prepared, or more innovative solutions should be implemented.

An important issue, which needs be considered during assembly of the bridge structure, is to equip it with elements for utilities transfer installation, if necessary. Of course, everything must be designed and executed in accordance with the specification prepared for the specific bridge facility. Fig. 4 and 5 present detailed stages for assembly of composite bridges.

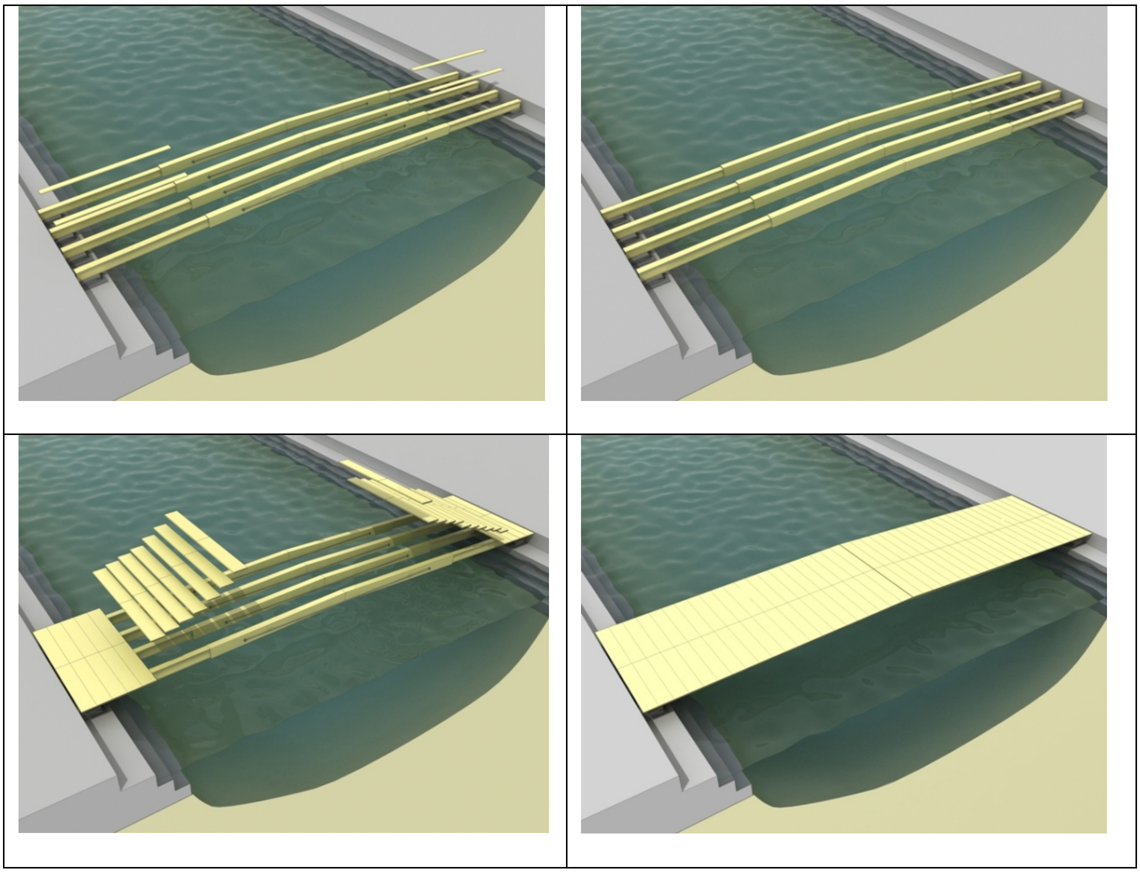


Figure 31 The assembly stages of lightweight bridge.

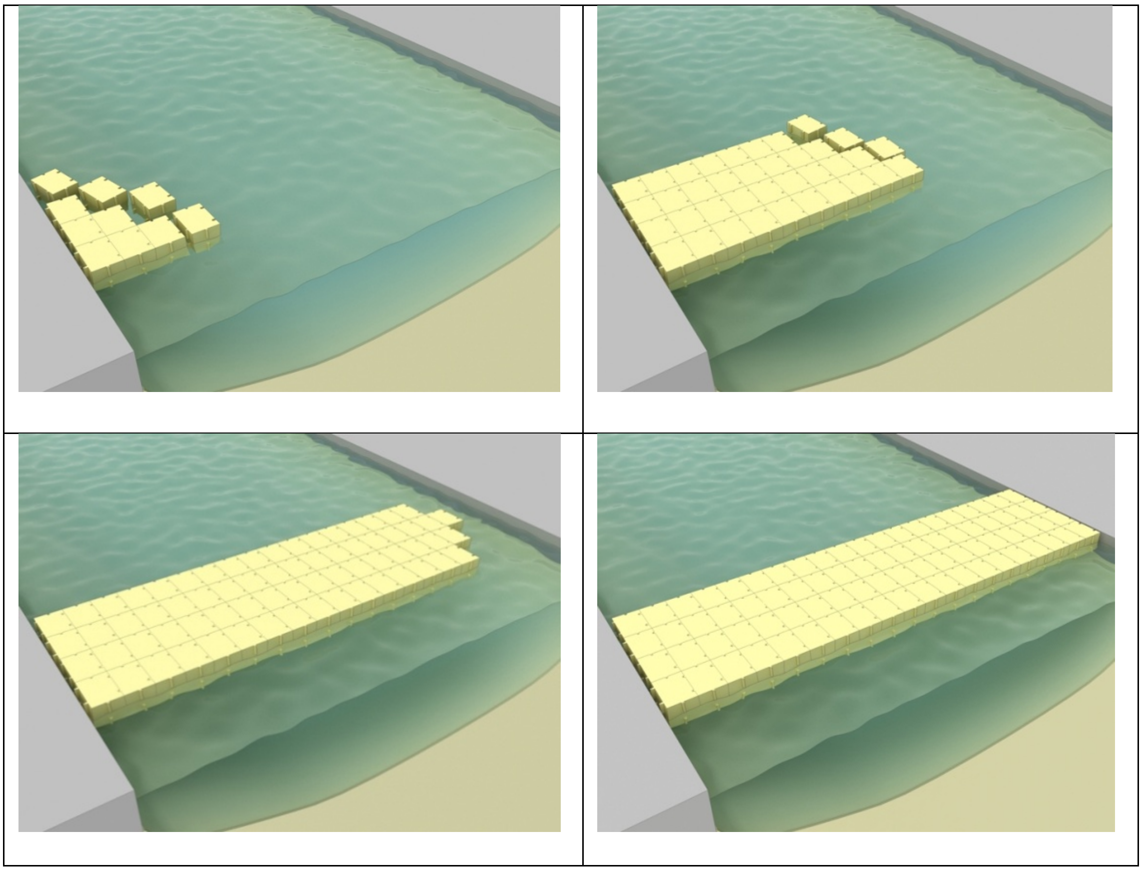
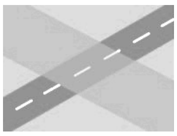
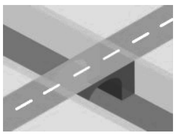
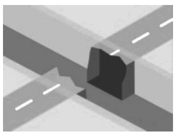
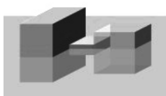
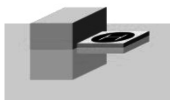
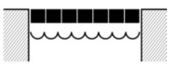
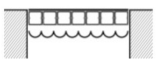
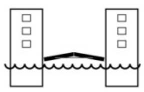
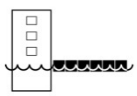


Figure 32 Assembly stages of a promptly assembled bridge.

3.5 Catalogue of composite bridges

In the proposed catalogue, composite bridge structures with the corresponding manner of usage have been suggested for five possible situations during floods: footbridge for pedestrians, vehicular bridges and two types of composite bridges: lightweight bridges and promptly assembled bridges. Included construction suggestions apply to facilities completed using composite materials.

Flood event / Tech. Solution					
 Pedestrian bridge					

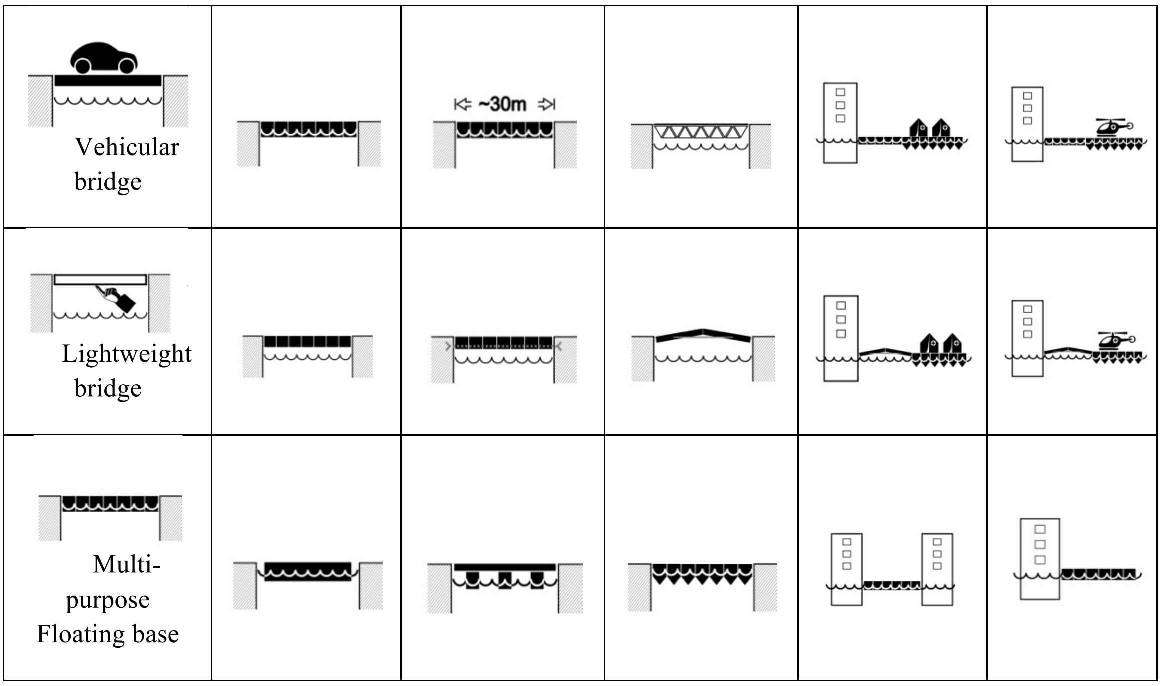


Figure 33 Propose catalogue, different use of floating technology according to the situation

4 Selection criteria and requirements

4.1 Connecting critical infrastructures

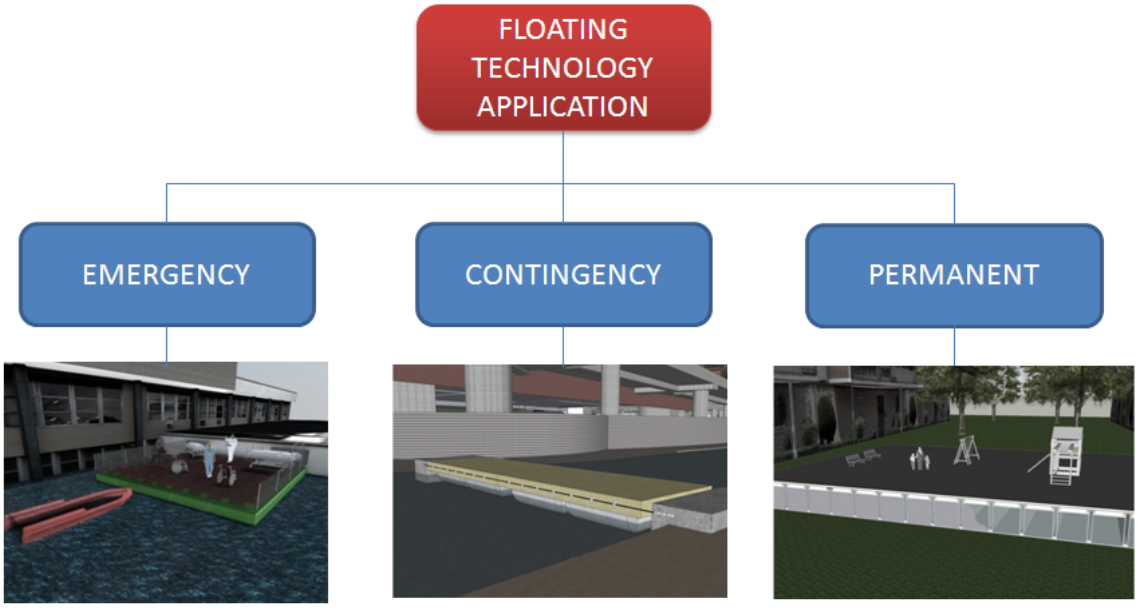
Connecting critical infrastructures during a flood is an important part of emergency services. If a critical facility is flooded, personnel and resources will be diverted from protecting the general community. In some places critical facilities may be under the jurisdiction of private, and state, county or district authority.

To give connectivity, floating technology could give support to critical facilities, like buildings or locations vital to the flood response effort:

a. Emergency operation centres
b. Police and fire stations
c. Hospitals
d. Highways garages
e. Selected roads and bridges
f. Suppliers of needed materials
g. Evacuation routes

4.2 Adjustments

This technology is appropriate for responses from a risk of which comprehension is adequate. Any large area designated for housing development, and specially one in a region with a history of flooding, creates the need and the opportunity for comprehensive program of adjustments to take appropriate account of current and future risk. All this in connection with the mentioned before regarding to which solution level will be applied, that it’s to say floating technology as emergency solution, contingency or permanent solution.



The new applications for floating technology require integral analysis of flood histories while factoring in predicted increases in the incidence of storms, torrential rain fall and sea level rise.

4.3 Where to apply this technology

There are few examples of infrastructure designed to be resistant for flood. Floating and amphibious infrastructure are ready to move beyond experimental stages.

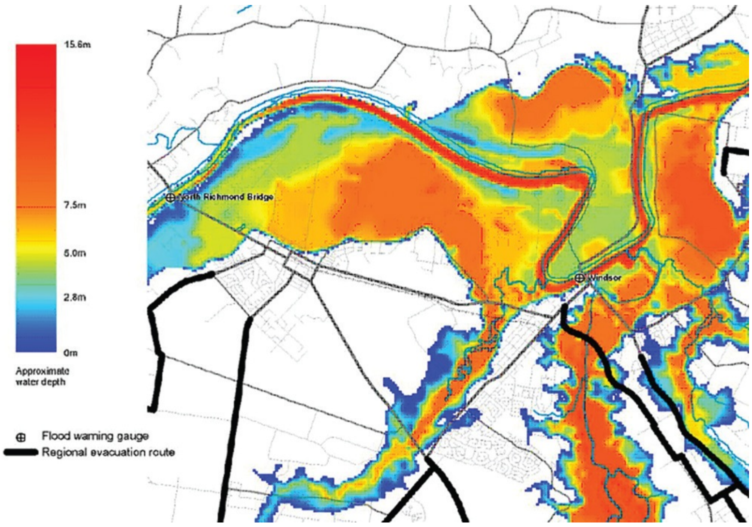


Figure 34 Flood risk analysis

Topographical analysis, for example, would provide a preliminary outline for more detailed land-use planning by identifying the lowest and highest land and its extend and propensity to flooding.

4.4 Risk

As it is well known once a flood incident occurred, it used to stop the whole economic activity; this implies that the disruption impacts the productivity of a community (industry, business and service)

Figure 35 Details of the effect of floods in industrial infrastructure zones, Asia - 2011

In the infrastructure, the effects caused by water and their retention time, cause huge damages to the physical infrastructure, which is a determining factor, given the direct relationship between economic and social. The proposed approach, of floating technology, do not gives a flood defence itself, but support displeased of emergency attendance.

4.5 Flood depth

The depth of flooding associated with the required use is one of the primary factors that influence floating design. The estimation of the depth for a particular site can be inferred from flood studies or hydrologic reports or from a flood profile and historical information.

4.6 Flood duration

The duration of a flood is an important fact for floating infrastructure because the implementation and the amount of time the facility might be use. Floating infrastructures that will be subjected to long periods of flooding must be carefully designed to reduce the risk of failure.

4.7 Frequency

The frequency of flooding is defined as the probability (in percentage) that a random flood event will be equal or exceed a specified magnitude in a given time period, usually one year. The frequency of flooding can be statistically determined using historical records of flooding at the location under consideration.

4.8 Site specific factors

In addition to the collection of information that defines the extent and characteristics of flood waters side specific features that must be investigated as part of a predesign analysis of floating infrastructure alternatives.

Existing road and utility systems can influence the selection and design of various floating measures. This information may be obtained from local and provincial planning agencies and utility companies.

4.9 Physiography characteristics of the area

An analysis of the various physiographic features of a proposed floating site is an important step in the identification of the best location for a new floating infrastructure. Characteristics that should be considered include the size and shape of the land areas, site elevations, slope, and existing drainage patterns.

The physiographic characteristics, of an area, may have a significant impact on the feasibility of the floating infrastructure element that requires a substantial amount of space. Physiographic futures can be determined from topographic maps, flood plain studies, and on-site investigations.

5 Case of study: Arriondas building – Asturias, Spain

Spanish territory, despite not having a very abundant precipitation rate, there are strong rainfall in a few hours, reaching average values over the year. As shown in the map of maximum daily rainfall in mainland Spain for a return period of 100 years of the figure below, more torrential rainfall develops along the coastal Mediterranean and Cantabrian, Pyrenees, and dividing the Duero and Tajo, the two plateaus occur in a generally more uniform rain.

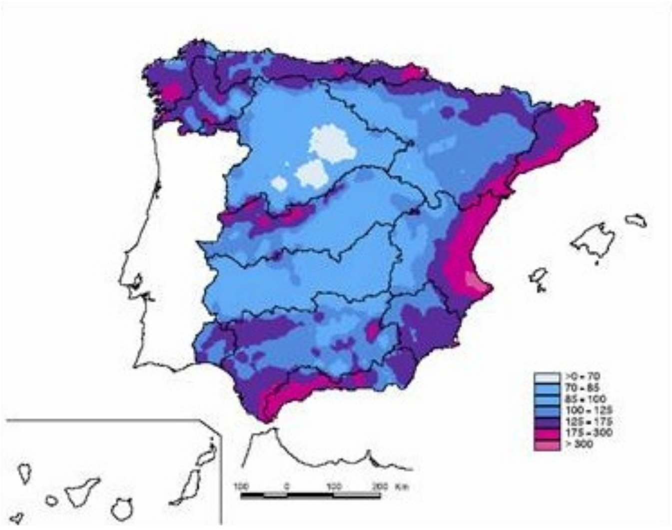


Figure 36 Map of maximum daily rainfall (mm) in mainland Spain for a return period of 100 years (*Source: White Paper on Water in Spain 1998, CEDEX*)

Some of these occurrences used to cause Floods that also cause destruction not only of goods but often cause fatalities. According to the Insurance Compensation Consortium, nearly 81% of the payment of claims for extraordinary risks corresponds to flooding.

The case of study is located in Arriondas town. Arriondas is in the Region of Asturias, and it is situated in northern Spain at the junction of the river Sella and the river Piloña, both are an important part of its natural heritage.

Figure 37 Case study location, Arriondas - Spain

Arriondas, at the east of Asturias is the town that has been most affected by flooding from the rising river Sella, this kind of even is more frequently since ten years. Among the most affected by flooding are farms, homes, streets, roads, highways, and other infrastructure that are forced to cut services. Many people have to be evacuated from their homes, schools, hotels and including a mental health unit (Covián Large Regional Hospital), which will be the propose place to be studied through five different schemes.

Figure 38 Arriondas emergency evacuation by a flood even, 2010

For analysis of the proposed exercise, it has that the Sella River has a mean annual flow of 42.79 m^3/s a minimum flow of 1.65 m^3/s and a maximum flow of 882.75 m^3/s. As can be seen the maximum flow rate is 20 times higher than the average flow. It is also noteworthy that the occurrence of floods occurs more frequently, in part due to climate change.

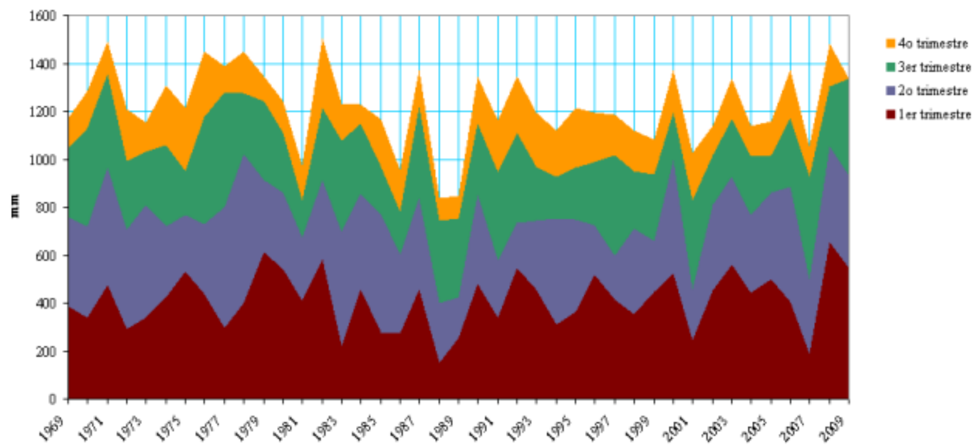
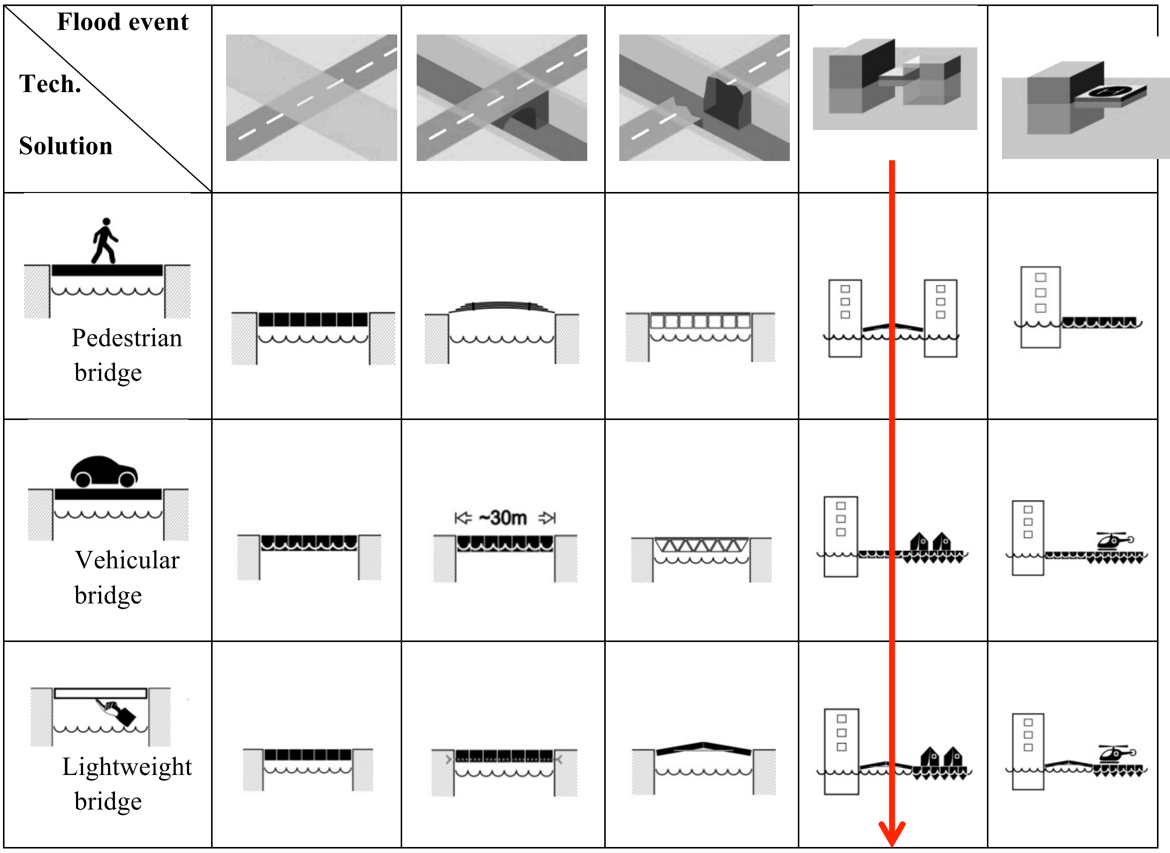


Figure 39 Quarterly evolution of precipitation, north side of Spain

According to this data and taking into account that the disruption occurs between buildings and the exit path that connects with the road. So, in the propose catalogue a selection of the appropriate floating technology is made.



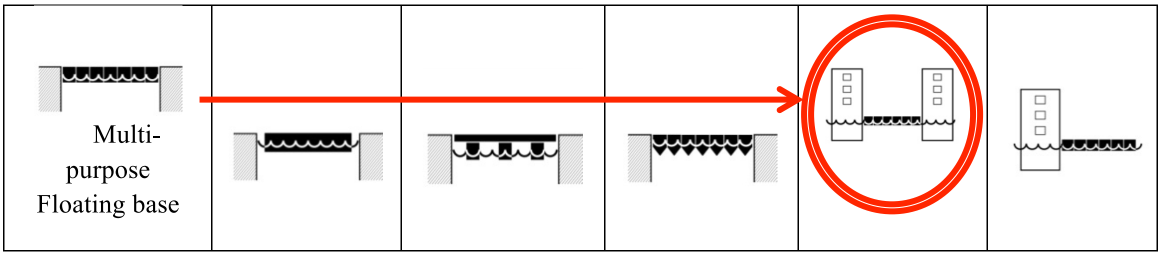


Figure 40 Selection of the appropriate technology

5.1 Cost / Benefit Analysis: Which solution fits best?

As a result of the 2010 floods, a solution needed to be found. Several Government Agencies propose different solution and levels of solutions plans. In this analysis will be consider a series of solutions for evacuation only. In this document a plan is propose with base on an analysis of 5 different options according to a return period (TR) and on the application of the concepts previously presented.

The fallowing options were considered:

5.1.1 ***Option 1 - Do nothing:*** Once sudden flooding has occurred and emergency evacuation crew helps to move personnel and patients trapped in the building. For this task different equipment, e.g zodiacs, helicopter and training external crew are employ.

Total costs	0 €
Value of benefit	0 €

5.1.2 ***Option 2 – Do minimum:*** The building has been fitted with some elements to the attention of the flood event and the staff has the basic knowledge to start an evacuation, return times are faster. The building still receives external support.

Total costs	2,500 €
Value of benefit	0 €

5.1.3 ***Option 3 – Emergency solution:*** The building has auxiliary facilities that store floating cubes which are displayed when the flood event occurred, staff has the basic knowledge to start an evacuation, return times are faster. The building receives external support but in smaller amounts. This would be a small project solution with a T_R = 15 years.

Total costs	37,500 €
Value of benefit	153,750 €

5.1.4 ***Option 4 – Contingent solution:*** This solution features a swing floating bridge annex to the building, which is displayed when the flood event occurred, staff has the basic knowledge to start an evacuation, and return times are faster. The upper floors are entitled to continue their operation, the building receives external support but in smaller amounts. This would be a medium project solution with a T_R = 40 years.

Total costs	97,500 €
Value of benefit	360,750 €

5.1.5 ***Option 5 – Permanent solution:*** The building features a floating pedestrian bridge located in a moat, which works in dry conditions as the typical route while under the bridge flood rises and connects the points on the evacuation route, staff have the basic knowledge to start an evacuation, and return times are faster. The upper floors are entitled to continue their operation, the building receives external support but in smaller amounts. This would be a medium project solution with a T_R = 100 years.

Total costs	165,000 €
Value of benefit	181,500 €

According to the analysis of the proposed scheme options, option 3 and 4 present the best cost / benefit ratio (see Table 1), but for a better solution it is important to include other aspects, eg solutions ranging from the strengthening of affected buildings, in order to be resilient to flood among others. So, this exercise just covers a partial aspect of a more comprehensive solution. The following table show a resume of the most relevant findings for the proposed solutions.

Table 1 Resume of options analysis

Floating Solution - Cost and Benefit Analysis (€)					
	Option 1	**Option 2**	**Option 3**	**Option 4**	**Option 5**
	Do nothing	Do minimum	Small project Emergency solution	Medium project Contingency solution	Large project Permanent solution
Standard of protection [T_R]			15 years	40 years	100 years
Total Solution costs [€]	0	2,500	37,500	97,500	165,000
Value of evacuation [€]	45,000	24,000	13,000	6,000	5,000
Value of benefit [€]			153,750	360,750	181,500
Net present value (benefit - cost) [€]			116,250	263,250	16,500
Benefit/total cost ratio [€]			4.1	3.7	1.1

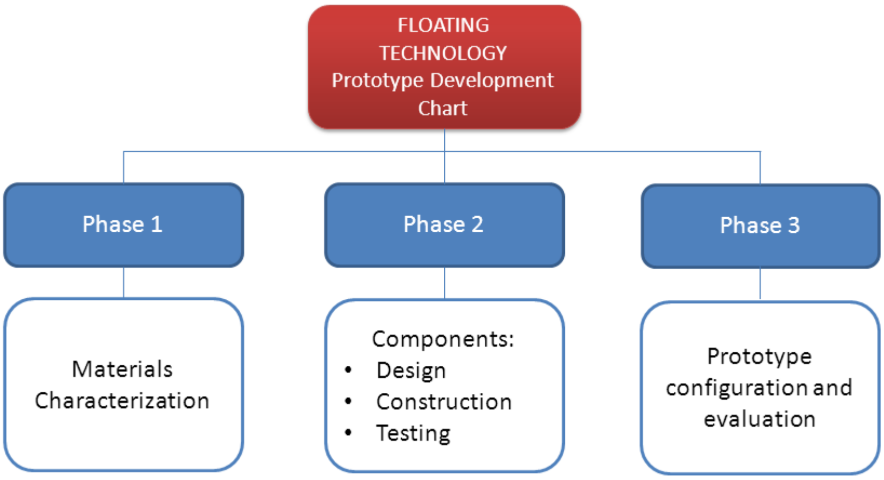
Within the global options provided by the different involved Agencies for the flooding's control from Sella River, has been considered the construction of a dam upstream for regulating the flow, although it is an expensive option, it has proved impractical for environmental reasons as there protected animal species, so this option has been discarded.

Figure 41 Marking the areas to implement the proposed solution

6 Prototype

Acciona and Mostostal had planned and executed a scale prototype, which consists on a floating bridge made by composite materials, according to proposed concepts for flood-proof infrastructure to be used as connecting support tool in flood emergencies.

To carry out these activities, the project has been divided into three distinct phases: the first phase will be a characterization of the materials used for the manufacture of the floating base, in the second phase will be the design, construction and testing of components, and the third phase will be a test of the prototype. In this document is only achieved to cover the first phase; the two remaining phases will be developed later.



6.1 Material characterization

For the analysis of the prototype it is important to define the suitable materials for their conformation, for this it is proposing a material characterization with special attention to polymeric materials reinforced with fiberglass and carbon, due their extraordinary mechanical properties, low weight and high durability, especially in humid environments.

6.1.1 Expected results

Get the mechanical properties of different materials (fibers, resins and cores) to be obtained from the drawings necessary values to be applied in the proposed new floating base.

Characterization of the materials to be use

The design values are obtained by characterizing the mechanical properties of the materials that are more appropriated to constitute structural elements, therefore these values are fundamental since it influences the final configuration of the proposals.

For the implementation of this activity has been defined three basic lines for the characterization of composite materials using a test program, the lines were as follows:

Characterization of the components of composite materials,

- Cores

- Resins

- Fibers

6.1.2 Results

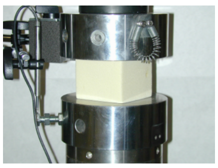
The results obtained were as follows

6.1.2.1 Cores

Polyurethane

This material has very good characteristics due to the increase of temperature which would be usable as a core in sandwich laminates of polymer fibers which are high curing temperatures (> 90 ° C).

Table 2 Polyurethane test results

Test	Description	Material	Compression Strength (MPa)	ε (%)	E(MPa)
	Core Compression test. The compression testing device essentially consists of two rigid plates.	PUR foam 70kg/m3	0.53±0.01	6.5±0.3	19.2±0.4
		Espuma de PUR 40kg/m3	0.25±0.01	3.8±0.1	6.7±0.6

Polystyrene

It is a very light, low cost, low compressive strength and from temperatures up to 50 ° C (see chart), it lost its mechanical properties, it is inconvenient for use as core with laminates of polymer fibers, since these are cured at temperatures near 100 ° C. This could be solved by using reinforcements that curing at temperatures much lower.

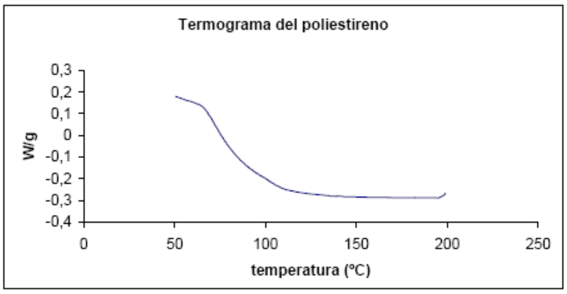


Figure 42 Degradation of the mechanical properties of polystyrene with increasing temperature.

Table 3 Polystyrene test results

Test	Description	Material	Compression Strength (MPa)	ε (%)	E(MPa)
	Compressive test (σ10) - UNE-EN-826	POL foam 70kg/m3	0.53±0.01	10±0.1	5.3±0.3
		POL foam 40kg/m3	0.32±0.01	10±0.1	3.2±0.3

6.1.2.2 Resins

The types of resins selected for characterization were as follows: Polyurethane, Polyester, Epoxy, Vinylester.

Results obtained for resins characterization tests.

Table 4 Resins test results

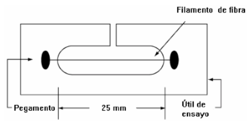
	Matrix Materials properties						
	Iso-Polyester	Orto-Polyester	Vinylester	Epoxy	PU	PP	Polymide (Nylon 6)
E(GPa)	4	4	8	12	4	1,7	1
ρ (Kg/m3)	1100	1100	1100	1100	1400	900	1070
σ(MPa)	40	40	50	60	65	35	60

Figure 43 Flexural strength test - ASTM D 175.

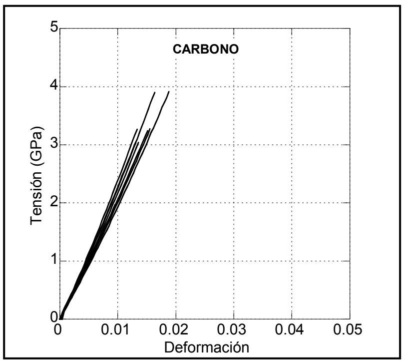
6.1.2.3 Fibers

Were tested two kinds of fiber: Carbon and Glass

Table 5 Fibers test results

Test	Description	Material	σ(MPa)	ε (%)	E(GPa)
	Simple tensile filaments test	Carbon Filaments 50k	**3150**±0.55	**1.40**±0.20	**223**±14
		Glass Filaments type-E	**1520**±0.12	**2.10**±0.30	**73.0**±3.5

Fibers characterization test results:



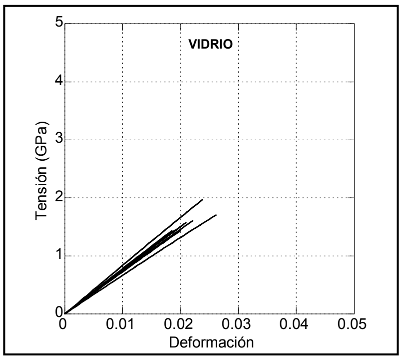


Figure 44 Fibers for Concrete Reinforcement:

In a floating base with concrete cover, concrete is subjected to shrinkage and tensile loads flexion. These conditions generate the appearance of cracks. For the control of concrete cracking, short fibers are proposed (Fig. 44).

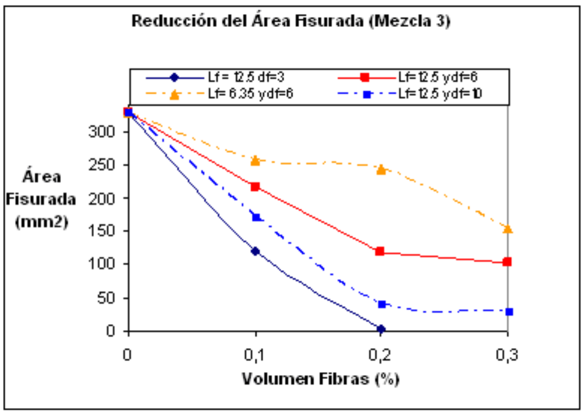


Figure 45 Test specimens of concrete and short fibers.

The graph shows that increasing the volume of fibers in concrete, cracked area substantially decreases. The following image shows 4 concrete specimens with different percentages of fiber (Fig. 45).

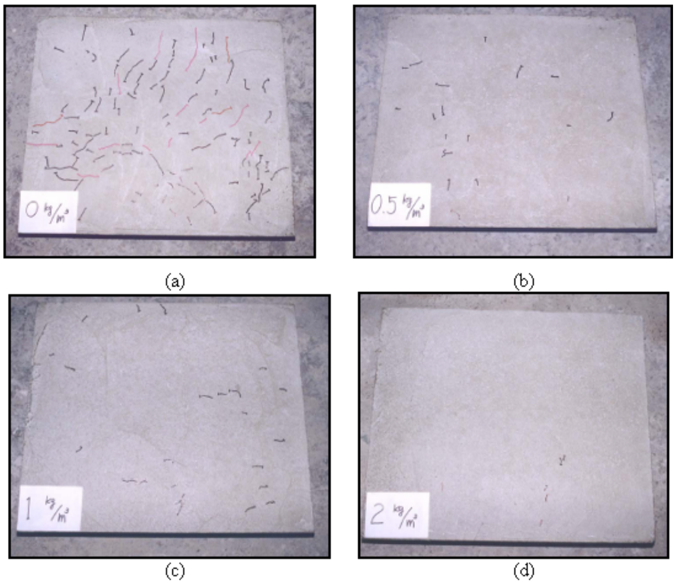


Figure 46 Figs., b, c and d; Map of cracking of the slab reinforced with different amounts of fiber.

6.2 Components fabrication

The elements to be manufactured for the formation of the floating base in composite materials consisted of the following:

- Longitudinal beams fiberglass lightened with polystyrene
- Crossbars fiberglass lightened with polystyrene
- Rebar fiberglass

Below a description will be made of the manufacturing process of the pieces mentioned above. The process has been divided into two groups of different production because they are pieces that will be produced by different techniques. The first group is related to the manufacture of parts of the beams of composite materials, and the second group of production, is related to the manufacture of composite materials bars (GFRP).

Prior to begin the manufacturing process has made the preparation of materials, tools, machinery and fiberglass fabric turned down due to the dimensions specified in the design (Fig. 46).

Figure 47 Materials ready for the manufacturing process.

In the first process, the tissues for the laminates of the beams have been impregnated with resin by the manual method, by means of the application roller on the tissue (Fig. 47), supported on a table.

Figure 48 Glass fiber impregnation process.

Once impregnated tissues, polystyrene foam cores are placed, which have been previously cut to the dimensions defined in the design (Fig. 48).

Figure 49 Composite materials manufacturing process.

For the second manufacturing process used, which is performed by injecting resin, a bag has been used on which induces a negative pressure to impregnate different layers of the laminate resin, through the suction generated.

Assembly of the beams

The beams are major elements for the floating base, which are those that give rigidity to the system and will provide stability. These beams are designed to work collaboratively with the concrete. Prior to his location, a "bed" is build or lower base of support on which is assembled together.


Figure 50 Box beam components adaptation.

Once attached and put in place, place the polystyrene blocks that act as the foundation, which given its compatibility with the fiberglass laminate can be well integrated with the set, plus its low density (90 kg/m3) will give the necessary buoyancy to the base. These are waterproof polystyrene blocks to prevent water ingress into the core of the base (Fig. 50), this activity will take place prior to placement of the modules on water (construction phase of field).

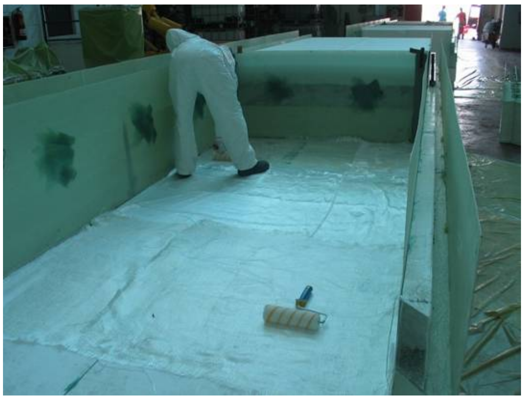



Figure 51 Mounting parts process

During the location of the beams and placement of the polystyrene blocks, these are joined together by adhesives (Fig. 51), this process also helps to create a barrier to the passage of water.

To give the necessary rigidity of the connections between the longitudinal and transverse beams, is placed a reinforcing fiberglass bars to be cast with concrete, in this way we obtain a monolithic connection with a too high degree of rigidity.

After assembly between the beams and the foundation blocks of polystyrene has proceeded to the placement of the glass fiber connectors, which allow a binding joint between pieces of composite material and the concrete.

After fitting the connectors, and has completed assembly of main structural system. Finally, the mesh is assembled and placed the protective barriers, the first was made with fiberglass rods, to be installed during pouring of the concrete top plate and serve as reinforcement, this task will be performed on site and the second barriers are installed as a perimeter protection. These barriers can be made by recycled tire rubber and are very light and thus help to gain buoyancy to the system.

Figure 52 Final disposition of the composite materials components of prototype

In this activity has been built the main part of the prototype to be used as floating infrastructure base. The technic used for its fabrication consists of a foundation block of polystyrene foam which supports a set of elements such as beams and a reinforced concrete slab. In this proposal is optimized section elements through the use of composite materials, which by being lighter, allowing among other things, increase the payload, gain buoyancy and resistance to corrosion.

6.3 Prototype development conclusion

As was previously said, there has been the development of the prototype based on three phases; phase 1: material characterization, phase 2: components design, construction and testing, and phase 3: prototype conformation and evaluation. In this task has only got part of phase two, construction. In phase 1, have been characterized most suitable materials for use in the prototype, based on a selection of lightweight, high mechanic capacity and environmentally resistant (e.g. exposure to moisture). As a result of this, glass fiber, polyester resin and polystyrene foam have been selected as main materials. In phase two, has been made the manufacturing of components based on the concept 3, box beams.

7 Dissemination

In 2011 a paper entitle "Application of Innovate Floating Technology for Flood Emergency Attendance" was prepared and approved as a poster for the FloodRisk Conference (flood risk management session) to be done in Rotterdam, The Netherlands, 20-22 November 2012.

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