A REVIEW ON LIGHTWEIGHT MOBILE FLOOD WALL BARRIER: WAY FORWARD FOR MALAYSIA

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ABSTRACT

Flooding remains a persistent and ongoing challenge in Malaysia, posing continuous difficulties and hardships; therefore, combating flood risk has become a main priority for sustainable development in this country. The application of sophisticated engineering in hard structure approaches and flood control systems are often incongruous to the public. Therefore, there is a need to integrate soft engineering approaches and best practices of flood management to mitigate flood risk. There is also a need to integrate the concept of sustainable development into its planning policies towards flood hazard reduction. Mobile flood protection measures are useful as an alternative solution in flood protection and mitigation purposes. Mobile protective systems serve as a temporary solution to enhance the height of permanent flood defence structures during extreme events. They can also be deployed as emergency measures to mitigate flooding in vulnerable low-lying regions. As the available mobile systems differ in the type of material, method of installation and available protection height, a description of their features, and potential application are examined including their respective opportunities and drawbacks. This paper presents a review on different types of lightweight mobile flood wall barrier (MFWB) that were implemented to cope with floods in Malaysia with examples of application in other countries such as United Kingdom, Slovakia, and Netherlands. The MFWB products are reviewed and compared to each other according to the types, characteristics, mechanisms, drawbacks, and how these measures are integrated into spatial planning. Based on the findings, several recommendations are provided regarding enhancing flood risk management in areas prone to flooding and the way forward for Malaysia.

Keywords: Flood Protection System, Lightweight, Malaysia, Mobile Flood Wall Barrier

1.0 INTRODUCTION

Severe and increasing number of flood events continue to imperil communities globally (Munich, 2017; Shah *et al.*, 2020; Rentschler *et al.*, 2023; Rezvani *et al.*, 2023). In Malaysia, this remains a persisting issue, exemplified by significant historical incidents such as the devastating floods in Kuala Lumpur in 1971, which resulted in tragic loss of life and inflicted widespread damages, serving as poignant reminders of the vulnerability of the region to such natural calamities (Shaari *et al.*, 2016; Rosmadi *et al.*, 2023). Moreover, recent flood events have further underscored this vulnerability. These recent occurrences highlight the persistent threat posed by flooding in Malaysia and the urgent need for effective mitigation and preparedness measures to mitigate its impact on communities and infrastructure. Recent flood occurrences, such as those in Selangor in December 2021, are estimated to have potential damages surpassing RM 20 billion (Aiman, 2021). It arose due to irregular rainfall patterns and sudden heavy downpours in a confined area. The rapid urbanisation in the Klang Valley floodplain, intensified the flood damages by obstructing the natural drainage system. Additionally, in March 2023, at least 16 locations in Johor, Malaysia experienced rivers surpassing the danger mark, leading to the evacuation of thousands due to nearly 630 mm of rain in under 48 hours, aggravating the flood scenario (Davies, 2023). According to the United States Department of Agriculture (USDA; 2015), the gravity of this flood risk in Malaysia was vividly demonstrated in 2014 when an event led to the loss of 21 lives and caused economic damages estimated to exceed USD$500 million.

Combating flood risk has become a recognised prerequisite and national priority for sustainable development in Malaysia (Caddis *et al.*, 2012). With the acceleration of urban growth, the population, level of prosperity and urban area have all escalated significantly. In turn, the economic assets, the number of people, and properties that are at risk of flooding, have also increased and these trends are likely to continue. As a result, the likelihood of flooding in Kuala Lumpur and similar coastal cities have risen due to factors such as the elevation in relative sea levels and the effects of climate change. This is compounded by the expansion of impermeable surfaces and deficiencies in the drainage infrastructure (Tang *et al.*, 2018; Cheah *et al.*, 2019).

In the beginning of the 1990s, the Department of Irrigation and Drainage (DID) has embraced the Integrated River Basin Management and the Integrated Flood Management strategies in its flood control initiatives. These approaches aim to achieve a harmonious blend of structural and non-structural measures while fostering greater public involvement (DID, 2009). A novel flood management solution introduced by the Malaysian government is the Mobile Flood Wall Barrier (MFWB). The MFWB is an artificial vertical barrier engineered to temporarily restrain the rising waters of a river or waterway during seasonal or extreme weather events (Kádár, 2015). The MFWB is a flood protection system designed to protect a region from flood risks. It stands apart from permanent flood protection systems like dikes due to its mobility and swift installation capabilities, making it suitable for congested or high-traffic areas. It can serve as an emergency solution for areas with limited flood protection. MFWB can be categorised into two types: heavy-duty and lightweight products; and it can be designed in two ways-either as a partially pre-installed stationary mobile system or a fully mobile system (Koppe and Brinkmann, 2010).

The heavy-duty MFWB products have found extensive application in numerous developed nations, mainly for flood protection and enhancing resilience in the face of natural disasters. However, the utilisation of lightweight MFWB is still uncommon and has yet to be recognised as a prevalent preventive measure against flooding in Malaysia, distinguishing it from the practices adopted in numerous European countries (Liem and Köngeter, 1999). Indeed, the diverse geographic locations across different continents significantly impact the design and implementation of flood barriers. These variations in geography, including topography, climate patterns, and hydrological characteristics, necessitate the adaptation of flood barriers to suit local conditions (Gralepois *et al.,* 2016). For instance, in European countries, where some lightweight mobile flood wall barriers have been implemented, considerations might prioritise densely populated urban areas, historical sites, and intricate river networks (Ciampa *et al.,* 2021). In regions prone to heavy rainfall or rapid snowmelt, flood barriers might need to accommodate high-water volumes and fast-flowing currents (Wiskow and van der Ploeg, 2003). Conversely, in areas with lower annual precipitation or smaller water bodies, flood barriers could focus more on rapid deployment and ease of installation. Therefore, this review bears significant importance as it aims to shed light on the advantages, potential, and feasibility of implementing lightweight mobile floodwall barriers in Malaysia, offering insights into a novel approach that could revolutionise flood mitigation strategies and contribute to the nation's resilience against inundation risks.

The aim of this paper is to elucidate the practicality of lightweight MFWB during flooding in Malaysia. This paper includes the literature review relating to the lightweight MFWB from different countries and provides the information on the products that are feasible to be applied in the context of Malaysia. This paper also focuses on the review according to the type, characteristics, mechanism, drawbacks, and how these measures are integrated into spatial planning. Several recommendations are provided on how to improve the flood risk management in flood-prone areas and the way forward for Malaysia.

2.0 LIGHTWEIGHT MOBILE FLOOD WALL BARRIER (MFWB)

Generally, lightweight MFWB can be classified into two sub-categories namely partly pre-installed stationary mobile systems and completely mobile systems, as shown in Figure 1. These two systems are further described in the following sections. Examples of these commercial products can be found in the next section.

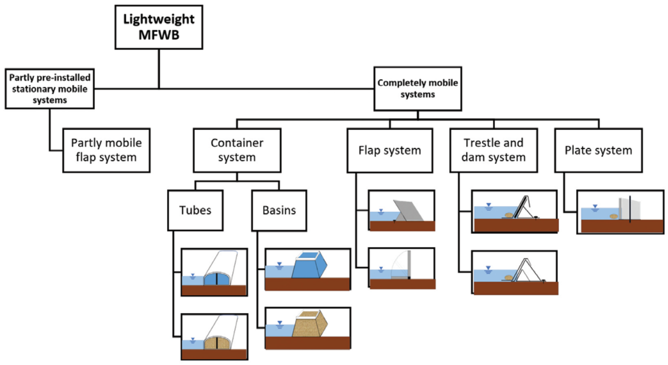


Figure 1: Classification of the lightweight MFWB based on the systemisation (Koppe and Brinkmann, 2010)

2.1 Partly Pre-Installed Stationary Mobile System

Usually, a partly pre-installed stationary mobile system is outfitted with concrete foundations and mechanical systems designed to transition the mobile component of the system from its inactive state to the protective position. Some have pre-installed load transfer points. These systems typically involve substantial investment costs. An example of a lightweight MFWB product is the partly mobile flap systems which comprises reinforced plastic liners or plates that are secured along a pre-installed foundation line and interconnected using either zip fasteners or sealing tapes (e.g. AquaFence Inc., 2021). Table 1 summarises the material, characteristics, mechanism, height, and drawbacks of the partly pre-installed stationary mobile system.

2.2 Completely Mobile System

Completely mobile systems are commonly applied as emergency system without prior planning (Koppe and Brinkmann, 2010; Chen *et al.,* 2018). There are several types of lightweight completely mobile system, i.e. container, mobile flaps, plates, trestle and dam systems. The following sections (Sections 2.2 and 2.3) describe the details of these four types of system.

Flexible tubes and basins are classified under the category of container system. Flexible tubes can be filled with sand or water (e.g. Beaver® System, NOAQ tube walls). Challenges might arise when trying to secure water-filled tubes, especially under dynamic loads like wave forces where cylindrical components could potentially shift and alter their position unpredictably. This can be solved by, for instance, using one cylindrical outer tube and two cylindrical inner tubes. The resistance between two inner tubes together with the inner and the outer tubes minimise the motion of the construction (Massolle *et al.,* 2018).

Alternative solutions include using special shape forming by incorporating inner reinforcements or joining two cylindrical tubes together (Koppe and Brinkmann, 2010). The NOAQ tube wall comprises tube-shape segments inflated using an air pump and organised in a chain-like configuration, along with a skirt that remains secured by floodwater. The tube wall has been recognised as the best solution and it's implemented worldwide (Chandra Mouli *et al.,* 2018). Their design allows for relatively quick deployment compared to many other flood barrier systems available. While some logistics, manpower, and time are required, the NOAQ walls offer a balance between speed and efficacy in emergencies. Their classification as one of the best solutions also stems from their adaptability and versatility. These walls are designed to be modular and scalable, enabling them to fit various terrains and flood scenarios. Their ability to offer a reasonably quick response during emergencies, coupled with their capacity to cover larger areas, makes them highly regarded. Moreover, NOAQ walls are often constructed from lightweight and portable materials, facilitating easier transportation and setup in different locations (Kim *et al.,* 2004). Basin systems can also be filled with solid matters or water (e.g. Box Barrier). Nevertheless, when early warning times are brief, the use of sand or other solid materials for filling is less probable due to the transportation time needed.

The mobile flap systems are mainly applied to dam frontal flow of waters. To date, such systems are commonly applied in United Kingdom to safeguard properties against flash floods (Rapidam, 2010). Between the actual rise of floodwater levels and the installation of the system, the system lies flat on the ground, allowing open access to the protected areas (Koppe and Brinkmann, 2010). An example of mobile flap system is the Rapidam product.

The trestle and dam systems are mobile means of flood prevention in which any preparative structural work is not required. This adaptable system is adequate for a notably diverse array of settings. Its unique trait is that it harnesses the force of water acting upon it to naturally create a restraining (i.e. frictional) force, thereby providing stability to the structure. The IBS® K- type product is an example of this system (IBS Technics GMBH, 2021)

Plate systems have the potential for utilisation as emergency systems (e.g. flood barrier shield). A similar product type is the Box Wall/ NOAQ Flood Barrier. These flood barriers are self-supporting, using the flood water's weight to stay in position. Both consist of easily transportable block sections and can be assembled by an individual (Koppe and Brinkmann, 2010). Table 1 summarises the material, characteristics, mechanism, height, and drawbacks of the various types of completely mobile systems mentioned above.

2.3 Available Lightweight MFWB Commercial Products

There are many lightweight MFWB commercial products that are commonly used for flood protection. Table 2 shows examples of lightweight MFWB commercial product including their advantages and mechanisms.

Box Wall is an independent, quickly deployable temporary flood barrier engineered for swift reaction to flood hazards in urban settings, appropriate for use on level and solid surfaces, for instance, asphalt, sidewalks, and concrete. Although the weight of each box section is light, the Box Wall stands firm without any external fastening, even when damming water reaches its full height. The Box Wall flood barrier is secured by the weight of the flood water itself. Figure 2 shows the Box Wall in pre-assembled state.

Table 1: Partly pre-installed stationary and completely mobile system (Koppe and Brinkmann, 2010)

Types	Materials/ Characteristics	Mechanism	Height (m)	Drawback(s)
Partly Mobile Flap Systems *(Pre-installed Stationary)*	Reinforced plastic liners or plates.	Raised manually with spacer or automatically by water.	0.5 to 2 meters	The preinstalled foundation may be an obstacle to daily activities, and it requires proper maintenance to avoid malfunction.
Flexible Tubes *(Completely Mobile)*	Reinforced plastic liner length ranging from 5 to 6 meters.	It needs to be filled with air for structure alignment. No need for supplementary anchoring. The stability of the structure is depending solely on their weight.	2 meters	The filling material has the same density as the load source. Buoyancy becomes a challenge when copping with significant storage heights that could lead to the risk of abrupt failure.
Basins *(Completely Mobile)*	A frame construction that uses a fixed plastic material or fitted textile.	Filling with water enables a fast installation.	Varies	Water filling with a low density.
Mobile Flaps *(Completely Mobile)*	Solid plastic sheets or flexible plastic material could be 100 meters long.	The flap is orientated to open towards the water, permitting the structure to be naturally filled with water.	0.5 to 0.7 meters	Cannot protect against flood that is higher than 0.7 meters.
Trestle and Dam *(Completely Mobile)*	Consists of wall units, load elements, supporting elements, and plastic liner.	The wall units are installed upon the supporting elements and secured using a plastic liner, which is anchored by sandbags along the waterside base. Often, ground anchors are deployed to ensure they do not slide or shift.	up to 1.3 meters	Often ground anchors are required to impede from sliding.
Plate *(Completely Mobile)*	Basic components can be obtained from construction stock grounds.	Casings are orientated in an upright position and anchored by hammering reinforcing steel into the ground.	Varies	Constructions lacking permanent installations provide low protection heights.

The Box Wall is especially beneficial during flash floods, this system efficiently manages fast moving water, redirecting it from vulnerable entry points. The Box Wall sections adhere to the asphalt and efficiently divert water. It can be constructed by interlocking as many box sections as required. After a flood, dismantling the Box Wall is straightforward, and cleaning can be achieved using a garden hose. These box sections can be piled up, requiring minimal storage space, and allowing them to be easily transported (Humid Tropics Cenre, Kuala Lumpur (HTC KL) and National Water Research Institute of Malaysia (NAHRIM), 2020).

Similar to the Box Wall, the NOAQ flood fighting system consists of two separate barriers that provide swift protection with minimal manpower demands. This self-supporting flood barrier utilises the water's weight to sustain its position. It includes lightweight, conveniently transportable block sections and can be assembled by a single individual. The NOAQ tube wall is made of tube-shaped sections filled using an air pump and arranged in a chain-like formation, together with a skirt anchored by floodwater. The tube wall variant is notably effective and is implemented worldwide (Chandra Mouli *et al.,* 2018).

Figure 2: Pre-assembled Box Wall/BW 50 Mobile Flood Barrier (Flood Defense Group, 2021)

Aquafence flood protection system consists of fences composed of a number of inter-linked, foldable elements and is already proven to work. It is built for simple and fast handling, installation and dismantling of its respective elements. The two lengths of boarding are locked together by a system of bracket to strengthen its which is shown in Figure 3. The fences are also formed in such a way that the forces of the water will strengthen it rather than weakening it.

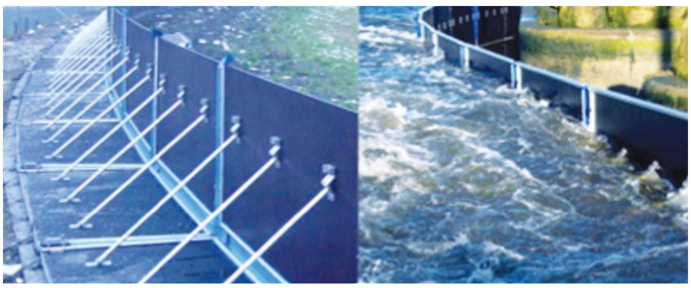


Figure 3: The Aquafence Mobile Flood Wall Barrier (AquaFence Inc., 2021)

Box Barrier is a product from Bataafsche Aanneming Maatschappij (BAM) Infraconsult Besloten Vennootschap (BV), Netherlands. It adapts the concept of sandbag, but instead of using sand which is heavier and needs to be transported from another place, the Box Barrier uses water itself as their strength and this requires less manpower and time needed for the setup of the flood wall. After the placement of the Box Barrier on the frontline, water needs to be pumped into the box through the hole on top so the weight of the water would anchor the box to the ground. Figure 4 shows how box barrier is installed when flood occurs.

Figure 4: The Box Barrier Mobile Flood Wall Barrier (Box Barrier, 2021)

Flood Barrier Shield is a product from Zero International from Indianapolis, United States of America (USA). Flood Barrier Shield is used on doors and windows on any premises to safe keep it from the floods (Figure 5). This barrier is assembled by slotting in an aluminium panel to a mount and sealed with rubber seal on the sides and bottom of the aluminium panel. The aluminium panel is made up of marine grade steel to prevent corrosion or rusting from occurring. The panels are removable when they are not needed and can be stored in a secure place for future use. The sizes are available from 10 inches up until 36 inches of height. Flood Barrier Shield conforms to the regulations established by the Federal Emergency Management Agency (FEMA) and Federal Insurance Administration (FIA) for the application of flood-resistant doors in flood-prone regions. Apart from the rubber neoprene seal, the aluminium panels are also secured by locks on both end sides.

Figure 5: The Flood Barrier Shield (Absupply.net, 2021)

Rapidam is a flood protection method that can be deployed quickly. It is constructed from a customised PVC fabric and can be efficiently rolled up by just two or three individuals. The freestanding models consist of individual 10-meter sections that can be effortlessly expanded by connecting them, facilitating the setup of a 20-meter section in approximately 15 minutes. (Figure 6). The height of this setup can differ between 18 to 180 cm.

Figure 6: The Rapidam Mobile Flood Wall Barrier (Chandra Mouli et al., 2018)

Following the raising of the upper barrier section, the weeding edge is solidly secured using specialised screw anchors. When floodwater hits, the weight of the water sustains the barrier in position. In the case of the Rapidam version, it needs to be attached to a concrete beam with stainless steel bolts. These bolts are pre-installed in the concrete, then removed and reattached when rolling up the Rapidam. This system can effectively retain a ton of water per meter (Chandra Mouli *et al*., 2018).

The Beaver® Storm and Flood Protection System comprises of two polyvinyl chloride (PVC) tubes placed adjacent permanently, connected to create a twin element (Figure 7). The components of the flood barrier are first inflated, easily repositioned into the preferred location, and then filled with water from a neighbouring water source or hydrant. These individual elements are joined together through a patented linking system, allowing the construction of flood barriers of varying lengths

Figure 7: The Beaver® Storm and Flood Protection System Mobile Flood Wall Barrier (Beaver® Protection Systems, 2019)

Table 2: Examples of lightweight MFWB product

Lightweight MFWB	Advantages	Mechanisms
Box Wall/ NOAQ Flood Barrier (BW 50) (Flood Defense Group, 2021)	• Friction and water pressure ensure barrier is stable • Can be used in curves and corners • Little storage space, faster defense, less manpower	• Anchored by the weight of the water • Built by slotting together any number of box sections • Stick with the asphalt and divert the water
Aquafence (AquaFence Inc, 2021)	• Simple and fast handling, installation, and dismantling • Little storage space • Cheap, can cover a wide area	• Locked together by a system of bracket • Water force strengthens the structure
Box Barrier (Box Barrier, 2021)	• Require less manpower and time to setup • Robust, flexible, stackable • Can be worked out in any length and in any direction • Can form various shapes	• Water force strengthens the structure • Water needs to be pumped through the hole on top so the weight of the water would anchor the box to the ground. • Can automatically fill with rising flood water
Flood Barrier Shield (Absupply.net, 2021)	• Panels are removable and can be reused • User friendly, fast deploy • Uses rubber neoprene sealant for water tightness	• Used on doors and windows • Acts by slotting in aluminum panel to a mount and sealed with rubber seal on sides and bottom of the aluminum panel
Rapidam (Chandra Mouli *et al.,* 2018)	• Time savvy	• Barrier is secured by the weight of water • Affixed to the base using stainless steel bolts that requires setup of a concrete beam. Initially installed into the concrete, the bolts are subsequently detached and reconnected when rolling up the Rapidam.
Beaver ® System (Beaver® Protection Systems, 2019)	• Rapid installation, versatile • Can be dismantled quickly • Take minimal storage	• The tube can be inflated for setting up position, then water from nearby source can be pumped in to stabilise the tube. • Multiple tube can be attached together with sleeve system.
IBS® K-System (IBS Engineered Products Ltd., 2019)	• Rapid and easy installation • Lightweight aluminum construction • Minimum manpower needed • Location independent • No discarding of any parts after use • Limited training required for operators	• Trestle which is the main support system that installed vertically with some angle. • Ground seals placed on the ground before dam beam. • Dam beam is slotted in between trestles. • Pressing tool is used to press down the dam beams for creating water seal.

that can adapt to distinct types of terrain (Beaver® Protection Systems, 2019).

The IBS Engineered Products Ltd Katastrophe (IBS® K-) requires no permanent installations for establishing on tarmac, even up to a flood height of 1.3 meters. This versatility permits it to be easily set up in different locations based on flood conditions. (Figure 8). According to IBS Engineered Products Ltd. (2019), in principle, this system consists of only 4 components ensuring that installation is quick and easy: K-trestles, dam beams, pressing tools and the special ground seal. The K-system functions through utilising the force exerted by floodwater, generating a downward force on the beams to ensure the stability and flood protection competencies of the barrier (IBS Engineered Products Ltd, 2019).

Figure 8: The IBS® K-System Mobile Flood Wall Barrier (IBS Engineered Products Ltd., 2019)

3.0 LIGHTWEIGHT MFWB CASE STUDIES

Four case studies have been extracted from the literature to compare the types of lightweight MFWB used in Malaysia and other western countries (i.e. Netherlands, Slovakia, United Kingdom).

3.1 Malaysia

Studies were carried out in a few areas in Malaysia to develop MFWBs that are suitable for flood protection of individual residences and government premises such as health clinics, police stations and schools (HTC KL & NAHRIM, 2020). MFWBs for individual residences were built in a smaller scale compared to a MFWB for government premises, where these government premises such as schools can also act as temporary retention camps for the flood victims. Table 3 lists the three types of flood wall barrier developed by HTC KL & NAHRIM (2020). Figure 9 shows the technical drawings for all 3 products.

Table 3: Applications of various MFWB NAHRIM-DID (NADI) types for specific targets

Type	Target
MFWB NADI 1	Residential area, opening space at doors
MFWB NADI 2	Wall-fenced area, opened gates
MFWB NADI 3	Government premises

MFWB NADI 1

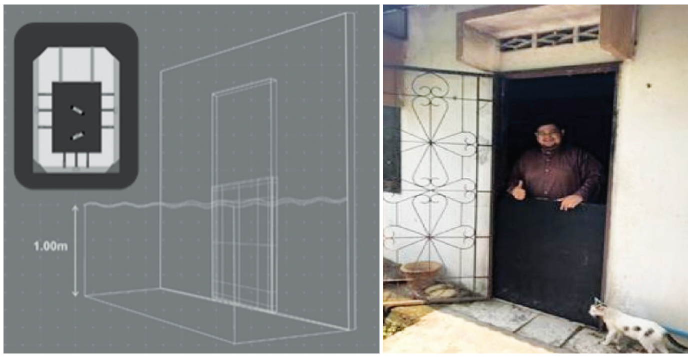
MFWB NADI 1 is specially designed to block water from entering buildings through opening space at doors. The design comprises a strong and rigid stainless-steel frame shaped like a wall, with a turning lever that enables it to expand accordingly to different door sizes. Neoprene rubber is wrapped to the frame used to ensure that the barrier stays watertight, and stainless-steel frames ensure that the structure does not corrode and maintains durability and reliability. It can hold excess water up to a meter high for flash flood protection and is able to withstand and bear water pressure without leakage attributed to its handle and knob locking system. It is easy to assemble and dismantle, and it is lightweight and easy to store during non-flooding season, making it very user-friendly (HTC KL & NAHRIM, 2020).

MFWB NADI 2

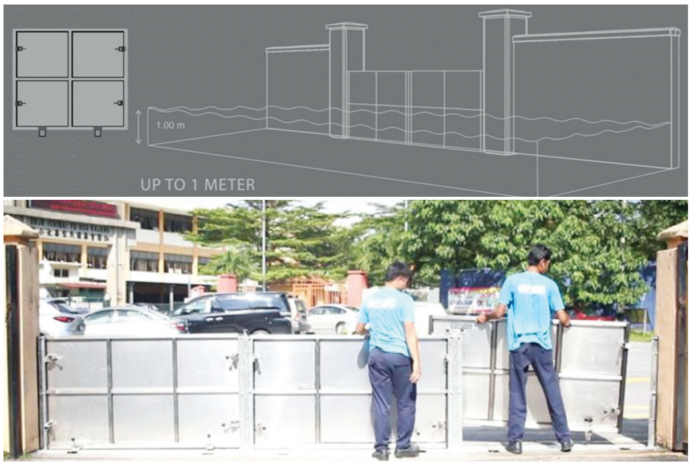
MFWB NADI 2 is designed mainly to block water from coming into the wall-fenced area through the opened gates. MFWB NADI 2 comprises of steel frame shaped like a gate, several steel poles and toggle clamps for ensuring watertight purpose. Other than steel frames used for structural rigidity, EPDM Sponge Rubber is also used to ensure MFWB NADI 2 is watertight, preventing water from coming to the other side of the wall. Stainless steel frames are used to ensure that the structure does not corrode, whilst maintaining its durability and reliability. Its function is to hold excess water for flash flood protection up to 1-meter high. It is able to withstand and bear water pressure without leakage using special clamps locking system. Awing to its slim and light design, MFWB NADI 2 is easy to carry and store during non-flooding season (HTC KL & NAHRIM, 2020).

MFWB NADI 3

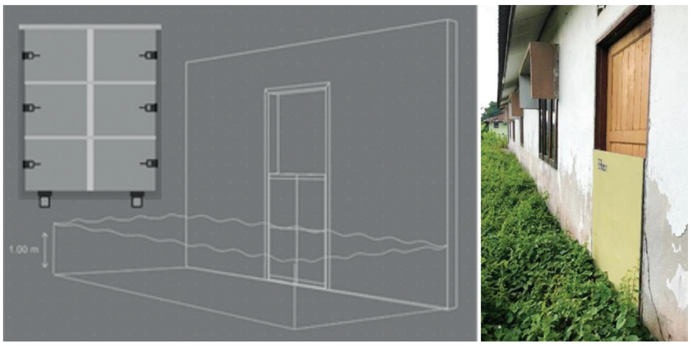
MFWB NADI 3 serves as a quick and simple barrier system, and it could provide floodwater protection of up to 1-meter-high for individual residence. It is able to withstand and bear water pressure without leakage using toggle clamp locking system. MFWB NADI 3 comprises of steel wall shaped frame and toggle clamps to ensure watertight purpose accordingly to the door size (HTC KL & NAHRIM, 2020).



(a) MFWB NADI 1 and its application



(b) MFWB NADI 2 and its application



(c) MFWB NADI 3 and its application

Figure 9: MFWB NADI 1, 2 and 3 (HTC KL & NAHRIM, 2020)

3.2 Slovakia

The Danube River located in Bratislava, stretches 65 kilometers from Bratislava to Vienna, creating particular zones of Bratislava prone to flooding. These areas have a lengthy past of flood vulnerability, mainly associated to storm rainfall events, especially during the snowmelt season (Kryzanowski *et al.,* 2013).

The principal protective measures were carried out to rectify the gaps in the current Danube flood protection system and to address areas in Slovakia, especially in the Bratislava region, that deprived sufficient protection. The Danube River can encounter incredibly high flows during extreme flood events, presenting a substantial danger to around 490,000 individuals. These flood mitigation measures incorporate the enhancement of existing flood control structures and the construction of new ones on both banks of the Danube River (Figure 10). The designated buffer zone along the Danube River is fixed at 0.5 meters above the stipulated floodwater level. The "Bratislava - Flood protection" initiative was implemented by the Slovakian government (Kryzanowski *et al.,* 2013).

Figure 10: MFWB built in Bratislava, Slovakia (Kryzanowski et al., 2013)

3.3 Netherlands

The Pitt review, guided by Sir Michael Pitt in the consequences following the widespread floods in England during June and July 2007, highlights the essentiality to give adequate safeguard for significant infrastructure within the utility sector, identified as "at risk." It reinforces that floods can lead to vital indirect implications, such as harm to critical energy, water, communication, and transportation facilities. Moreover, they can hinder essential public services like schools and hospitals. For example, the floods in 2007 significantly impacted infrastructure in Gloucestershire. Flooding at Tewkesbury's Mythe water treatment plant deserted 140,000 residences deprived to clean water for as many as 17 days. Furthermore, it was necessary to close the Castle Meads electricity substation, leading to a 24-hour power outage for 42,000 residents in Gloucester. Flooding on the M5 motorway isolated 10,000 individuals, with many others stuck on the railway network. Temporary flood defenses at the Walham electricity substation were credited with safeguarding the power supply for 500,000 people in South Wales and Gloucestershire. Other susceptible infrastructure involves emergency service stations and their main headquarters, which are integral to the response efforts, as well as critical public services like hospitals, schools, and care homes (Corrie, 2012).

The Alteau Mobile Barrier was used in the Netherlands flood protection case study. Figure 11 shows the Alteau mobile barrier after it is deployed. The Alteau Barrier is made from polyethylene fabric weighing 450 g and 610 g. This barrier automatically elevates to a maximum height of 1 meter and extends over several hundred meters by harnessing the water's force. It has been deliberately crafted for rapid emergency response operations. This self-inflating, portable water barrier is sustainable and operates without needing pre-inflation or an external power source. The setup procedure is rapid, and it can be easily repacked and reused for different intentions by simply rinsing it down and rolling it up.

The portable barrier can be conveniently carried using small vehicles to the intended destination and then transported by two individuals. It comes in different height and length configurations, with options attainable for water levels of up to 1000 mm. Multiple connections can be swiftly connected using the Velcro fastening system. Furthermore, it can be connected to a corner element to create a 90-degree turn, improving its flexibility for enclosing buildings (AET Flood Defence Limited, 2021).

Figure 11: The Alteau Flood Barrier (AET Flood Defence Limited, 2021)

3.4 United Kingdom

The town of Northwich has an extended duration of coping with flooding, notably in 1946, and more recently in 2000 and 2012. These flooding events not only brought anguish to residents and businesses but also led to substantial financial losses for enterprises and homes. Recognising this ongoing risk, the Environment Agency (EA), jointly with Cheshire West and Chester Council, formulated a flood alleviation plan with the aim to mitigate the risk of future flooding.

The Northwich project comprises of 1.7 kilometers of flood protection facilities, integrating a mixture of embankments and flood walls in place along the banks of the River Weaver and River Dane. With the aim to preserve the town's historic appearance, the initiative has utilised outstanding materials for the walls and incorporated cutting-edge technologies, for instance, glass panels and floating ecosystems to minimise the aesthetic impression of these defenses. Besides permanent flood barriers, the plan also incorporates removable defenses and flood gates strategically positioned along crucial roadways and footpaths (IBS Engineered Products Ltd, 2019).

The IBS® K system was used in the UK flood protection case study as shown in Figure 12. No preparatory structural work is required for the "K" system (from the German "Katastrophe"). It can provide a barrier height of as much as 1.3 meters. This versatile system is appropriate for use in a wide variety of

Figure 12: The IBS® K-System (IBS Engineered Products Ltd, 2019)

locations. Particularly, it has a distinctive feature where the force exerted by the water spontaneously creates a frictional retention force, thus stabilising the structure (IBS Engineered Products Ltd, 2019).

4.0 INSIGHTS FOR ENHANCED FLOOD MANAGEMENT STRATEGIES IN MALAYSIA

In addressing the multifaceted challenges of flood risk management in Malaysia, the country has traditionally relied upon top-down, government-controlled approaches primarily spearheaded by the Department of Irrigation and Drainage (DID). These strategies have involved a comprehensive range of measures, including the establishment of flood control commissions, structural interventions such as the development of the Stormwater Management and Road Tunnel (SMART) in Kuala Lumpur and the flood reservoir in Batu Jinjang, and the implementation of non-structural measures like flood forecasting and warning systems.

However, the emergence of lightweight mobile flood walls presents a promising addition to Malaysia's flood management arsenal. Notably, advancements in flood protection systems, exemplified by NAHRIM and DID's Mobile Flood Wall Barrier (MFWB) NADI series (1, 2, and 3), signify a shift towards more adaptable and efficient flood protection mechanisms. Comparative studies between these mobile barriers and European flood walls have shown the NADI systems' increased coverage, with NADI 1 capable of defending against up to 1 meter of floodwater, surpassing certain European equivalents. Moreover, each iteration within the MFWB NADI series is meticulously engineered to cater to distinct targets, encompassing varied settings such as residential areas, fortified spaces such as hospitals or educational institutions, and governmental premises. This strategic design approach aims to optimize flood prevention measures by tailoring the barriers to suit the unique requirements and vulnerabilities of each specific location, ensuring a more targeted and effective flood defense system.

The lightweight and versatile nature of these temporary flood protection systems renders them particularly suitable for regions lacking permanent flood defenses or experiencing infrequent flooding episodes that can be forecasted. Specifically designed for swift installation during flood warnings, these barriers are strategically placed at vulnerable points like doorways, window openings, and garage entrances. However, challenges such as storage requirements and deployment logistics have been noted, as the barriers can be bulky and may require two individuals for installation, hindering rapid deployment in adverse weather or constrained spaces.

Despite these challenges, the temporary flood walls offer a cost-effective and adaptable solution for mitigating floods up to 0.9 meters in depth, making them an initial choice for safeguarding properties. Nevertheless, a comprehensive flood management strategy in Malaysia necessitates a balanced integration of both structural and non-structural measures. Effective flood management should incorporate community participation, long-term policy planning, and the integration of innovative solutions like lightweight mobile flood walls. Emphasizing community involvement, improving coordination among agencies, and enforcing standard operating procedures are critical steps toward enhancing flood management efficiency and resilience in Malaysia.

5.0 CONCLUSION

From the case studies reported, the application of MFWB have been commonly used in most developed countries and they are proven to be useful and effective. A variety of lightweight MFWB products are satisfying different security and manageability levels for the application in Malaysia. Therefore, it is essential to carefully analyse the site conditions and requirements in every application. Founded on such comprehensive investigations, lightweight MFWB systems might be the fitting remedy for both, emergency use and planned flood protection. Typically, the following opportunities of lightweight MFWB systems can be summarised: 1) room-saving in densely populated areas, 2) provides benefits to urban planning due to open access to water body, and 3) mobile protective constructions that are completely movable provide advantages as emergency systems, particularly when compared to labour and time-intensive sandbag systems. On the other hand, the drawbacks are: 1) they may result in higher costs compared to permanent solutions providing an equivalent level of safety, 2) these structures provide limited height protection due to the lack of permanent installations, 3) susceptible to sudden failure when overloaded beyond their capacity.

Advancing research on lightweight mobile flood walls holds significant promise for addressing the persistent challenge of flooding. Future investigations should prioritise the exploration of innovative materials and design strategies tailored to the Malaysia's diverse geographical landscapes and climatic variations. Emphasising extensive field trials and simulations under varying flood scenarios is crucial to evaluate their performance accurately. Moreover, assessing the socio-economic implications of implementing these flood defences is essential to ascertain their practicality and acceptance within Malaysian communities. Collaborative efforts involving diverse expertise from engineers, urban planners, policymakers, and local communities will be pivotal in developing resilient and adaptable lightweight mobile flood wall solutions tailored to Malaysia's unique flood risk management needs.

Eventually, the notion of flood defence systems will have to be grounded on current world trends (e.g. living with floods and application of mobile flood protection measures), which are to be introduced by acknowledging the current best practices throughout the world. However, the actualisation of this idea is limited by the economic capabilities of the communities inhabiting in flood-prone regions. Therefore, it is important that Malaysia integrate this concept in mitigating floods as we advance towards the future of achieving floodwater resilience at the property level, both residential properties and government premises. ■

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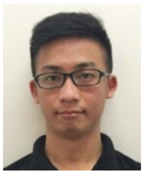

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