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New Conceptual Design of Portable Bamboo Bridge for Emergency Purposes

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Abstract. Portable bridges serve as routes for troops during the military operations and the disaster relief operation. Nowadays, bamboo has been regarded as one of the alternative construction materials for building and bridge structures. This paper presents the conceptual design of the portable bridge. Several types of portable bridges and bamboo bridges are reviewed in the current work. The characteristics, capability and method of construction of each bridge are discussed. Finally, the conceptual of the portable bamboo bridge for emergency purposes is presented. The idea of producing portable bridge is proposed in the current work as it is crucial for providing route for communities affected by natural disasters.

INTRODUCTION

During peacetime, rapid bridging construction is needed to temporarily replace a damaged bridge caused by natural disasters such as flood, landslide, earthquake or tsunami. In this situation, a portable bridge is usually utilized while the construction of the new bridge is carried out. For example, portable bridges such as Bailey bridge and Medium Girder bridge (MGB) had been deployed during the large-scale disasters such as the Indian Ocean Tsunami in 2004, the Hai Tang Typhoon occurred at Taiwan in 2005 and the Pakistan Earthquake in 2005. Portable bridging has been identified as the fastest and the most effective solution to open up the line of communication for Humanitarian Assistance and Disaster Relief (HADR) operation (Azrul & Norazman, 2016).

The concept of sustainable development and green technology has become the major theme of engineering in the 21st century, specifically in civil and structural engineering. New environmental-friendly materials such as composite polymer and bio-composite materials are developed to partially replace conventional construction materials such as steel and concrete (Xiao et al., 2010). On the other hand, bamboo has been identified as one of the alternative construction materials for building and bridge structures. Bamboo is abundance and well-known for its ability to withstand high bending stress, tensile stress and compressive stress according to Bahari and Krause (2016). Apart from exhibiting high strength to weight ratio, bamboo culm is fast growing where it becomes mature in three years and reaches the peak of its strength.

Utilization of bamboo as an alternative construction material for building and bridge structures has been widely known. Modern studies have proven the use of bamboo in construction of houses (Salzer et al., 2016), multistorey building (Li & Dong, 2012) and various type of bridges (Kaur et al., 2016). Bamboo culm can be used as the main construction elements (Van der Lugt et al., 2006). Attractive features of bamboo such as its lightweight and its abundance enable the rapid construction of a bridge (Jayanetti & Follett, 2008). American Bamboo Society has mentioned that the most appropriate bamboo species for bridge construction are Guada sp., Phyllostachys sp., Dendrocalamus sp. and Gigantochloa sp. (Laroque, 2007). This section compiles and reviews several types of portable bridge and bamboo bridge. The characteristics and capability of each bridge are discussed as well. Finally, the conceptual of the portable bamboo bridge for emergency purposes is presented clearly in this paper.

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REVIEW ON PORTABLE BRIDGE TECHNOLOGY

Compact 100 Bailey bridge

Inspired from the idea of Bailey bridge which was used during World War 2 in 1941, the Compact 100 Bailey Bridge was designed and developed by Mabey and Johnson Limited, UK to replace a bridge which was previously damaged during war or natural disaster. It is a portable bridge consisting of pre-fabricated trusses made of Grade 55 Steel, which is currently adopted by 31 armed forces worldwide including that in Malaysia (www.mabey.co.uk). Royal Engineer Regiment has been assigned to manage this bridge and recently, this bridge is also included in the inventory of the Public Work Department of Malaysia. Figure 1 shows the compact 100 Bailey bridge.

FIGURE 1. Installation of compact 100 Bailey bridge (Azrul & Norazman, 2016).

Cantilever launch method, a method that relies purely on manpower (~40 crew members) without the need of using any temporary intermediate supports, is used to construct the compact 100 Bailey bridge. This bridge can be built in multiples configuration, ranging from 5 - 20 bays (the length of each bay is 3.05m). The width for the walkway is 4.2m. Of course, its construction time depends on factors such as site condition, number of crews and availability of supporting equipment, etc.

Medium Track Bridge

Medium Track Bridge (MTB) was developed by General Dynamics European Land System (GDELS), Germany in 2011. This lightweight, modular bridge is fabricated of high strength aluminium specially made to cater for military and civilian vehicles up to MLC 40. The bridge consists of two parallel treadways. The bridge weight is 540 kg for a complete 4m MTB. Due to its lightweight, the bridge modules can be transported easily by light tactical/commercial vehicle and launched on the same vehicle by the crew members as shown in Fig. 2. It takes ~10 minutes to launch a 4m MTB with 4 crew members. It is interesting to note from (GDELS, 2011) that MTB is able to increase the tactical mobility of units (with no gap-crossing capability) without relying on engineer bridging unit.

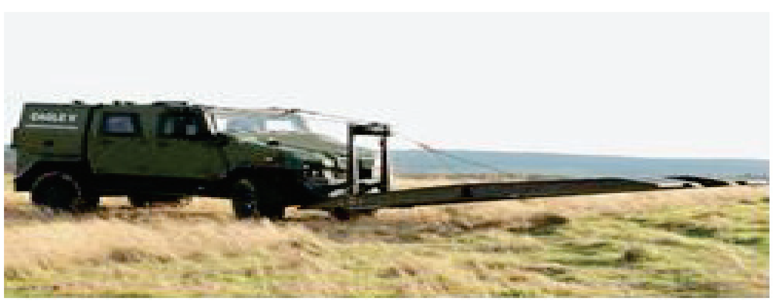


FIGURE 2. MTB during launching from light tactical vehicle (GDELS, 2011)

Hybrid FRP-Aluminum Modular Bridge

The modular hybrid fiber reinforced polymer (FRP)-aluminium modular bridge was developed by Zhang et al. (2013) to cater for emergency purposes. The length of width of a single-span simply supported one-lane bridge are 12 m and 3.2 m respectively. The cross-section of each rut is triangle in shape with 1.2m width and 0.85m depth, and transverse braches are adopted to link up the ruts. The bridge consists of a deck and multiple trussed members as illustrated in Fig. 3. It is interesting to note that the maximum load of this bridge is 10 tonnes.

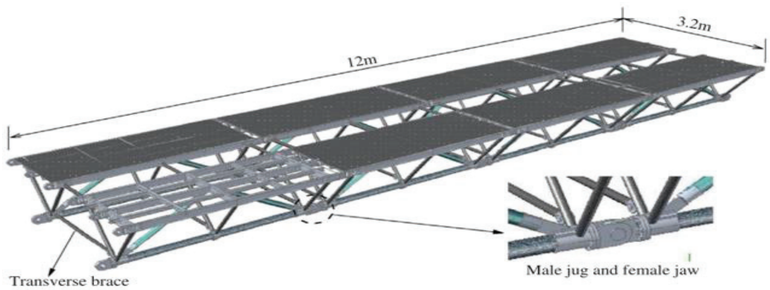


FIGURE 3. Illustration of hybrid FRP-aluminium modular bridge (Zhang et al., 2013)

Single Span Military Bridge

Azrul and Norazman (2014) have recently utilized the 6061-T6 aluminium alloy to develop a single span girder-type military bridge based on the operational requirements provided by the Malaysian Army and outlined in the Trilateral Design and Test Code (TDTC) for Military Bridging and Gap Crossing Equipment. Its length and width are 41.1 m and 4 m, respectively, and it is able to carry a Pendekar tank vehicle of MLC 70. Finite Element Analysis (via MSC PATRAN/NASTRAN simulation software) has been used to perform the stress analysis as shown in Fig. 4. On the other hand, structural testing has been performed on the scaled-down girder model by following the procedures outlined in the TDTC.

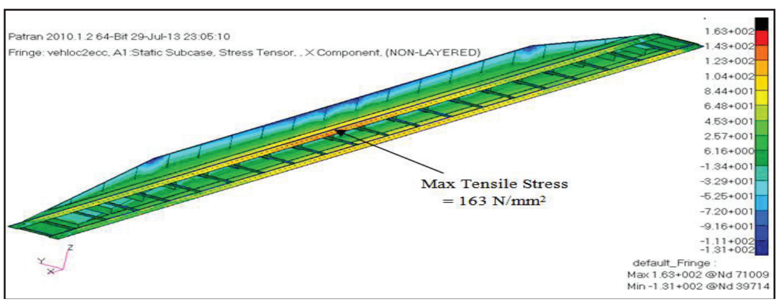


FIGURE 4. Stress contour plot of the single-span military bridge girder (Azrul, 2014)

REVIEW ON BAMBOO BRIDGE TECHNOLOGY

Cucuta Bridge

Figure 5 shows the Cucuta bridge in Colombia used as a pedestrian arch bridge. It was designed by Jörg Stamm and built in year 2008. The bridge weighs 130 tonnes and the bridge length is 31m, consisting of four camber pre-tensioned arches. Each arch comprises of 6 bamboo culms. The culms were connected by using steel dowel ranging from 1.5 m to 2 m. The strength of the connection area was enhanced by concrete mortar filling. In order to reduce bending, the main beam was connected in a parallel, vertical manner. The camber pre-tensioned arches placed at the side of the bridge act as the main support of the bridge.

FIGURE 5. Side view of Cucuta bridge (www.guaduabamboo.com)

The bridge foundation and the floor were built from reinforced concrete while the roof was covered with special canvas imported from France. 600 Guadua angustifolia bamboo culms of diameter ranging from 10 - 14 cm and length ranging from 6 - 10 m were used to build this bridge. According to Jörg Stamm, the bridge complied with the Colombian regulation and it was able to withstand a live load of 40 persons. It has been reported by (Carmiol-umaña, 2016) that 90% of the load can be absorbed by the camber arches.

Bamboo Truss Bridge

Morisco (1995) has developed and tested a truss bamboo bridge with length of 12 m and width of 2.5 m by using local bamboo known as *bamboo galah* (Gigantochloa heterostachya) of diameter 7-8 cm. From the testing report, the bridge was able to support three type *Kijang* vehicles with of each weighs 1655 kg (Fig. 6).

FIGURE 6. Bamboo truss bridge during field test (www.moriscobamboo.com)

The truss members were connected by using steel gusset plates, bolts and filling voids with wood or sand in the mortar joint as illustrated in Fig. 7.

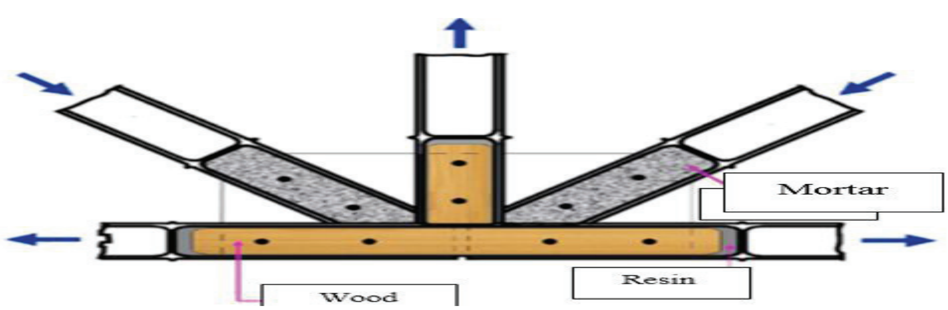


FIGURE 7. Connection system used by Morisco & Mardjono (1995)

Bamboo Floating Bridge

In the early of July 2013, the district of Ban Nongloo in Sangklaburi, Thailand was under unprecedented heavy downpour. The downpour had destructed the three decades old timber bridge. To ease transportation, the community leader had initiated the bamboo floating raft bridge project. The 450 m bamboo floating raft bridge was constructed by using bamboo culms as buoys to keep the raft bridge afloat as shown in Fig. 8 (Svamivastu, 2013).

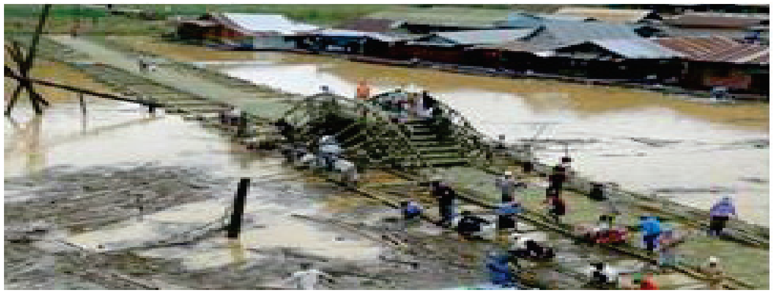


FIGURE 8. Bamboo floating raft bridge under construction (Svamivastu, 2013)

The main components of the floating bamboo raft bridge comprise of three elements: buoys, horizontal walkways and elevated crossway. Multiple species of local bamboo was used in this bridge construction namely Bambusa nutans, Bambusa bambos, Dendrocalamus membranaceus, Dendrocalamus asper and Gigantochloa densa. Modularity of the bridge section is one of the unique features of this bridge. In the dry season, the length of the bridge can be shortened by removing certain sections of the bridge. It took 6 days to complete the construction of the bridge, instead of the planned period of two weeks due to the ease of construction and abundance of bamboos in the region.

Matina Bridge

Matina Bridge, which is located in Davao City, Mindanao, Philippines was built in year 2011 (Fig. 9). The bridge was designed by Community Architect Network (CAN) based on the Howe truss concept with pre-tensioned arches recommended by Jörg Stamm. The bridge is 23 m in length, and it consists of camber compression arches and truss members. Steel bolts and pins strengthened by mortar filling are acting as joints at designated bamboo internodes as shown in Fig. 10. Here, the mortar filling is used to transfer loads between the bamboo walls and the steel components (e.g. threaded bars, bolts and pins). Reinforced concrete is used to construct the bridge floor and the foundation while *nipa* (Nypa fruticans) leaves are used as a roof cover. The giant bamboo known as *apos* (Dendrocalamus asper) has been used as the construction material of the bridge due to its abundance in Davao City (Fitrianto, 2010).

FIGURE 9. Side view of Matina bridge (Fitrianto, 2010)

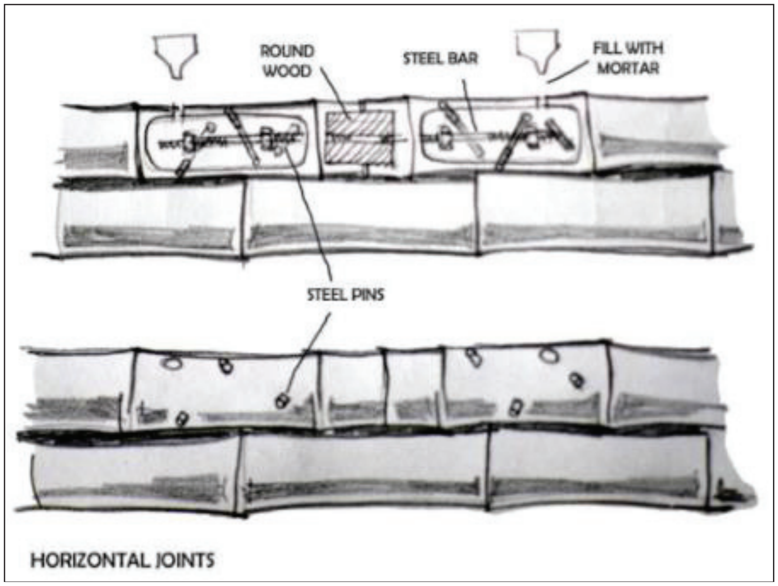


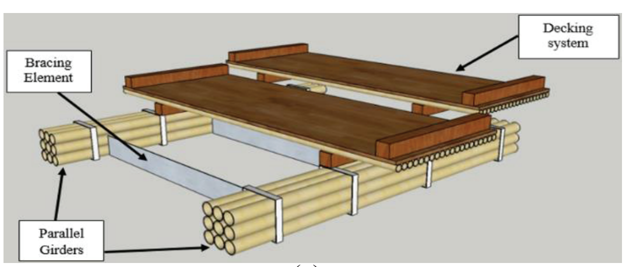
FIGURE 10. Example of the incorporated joint area (Fitrianto, 2010)

NEW CONCEPTUAL DESIGN OF BAMBOO PORTABLE BRIDGE

The idea of producing portable bridge by using bamboo culm is proposed as it is crucial for providing routes for communities affected by natural disasters. Usually, portable bridges are built up by modular systems consisting of one or more bridge segments dimensioned with the goal of minimum structural weight and for high mobility (Mazzolani, 1994). Bamboo culm is found to have potential in building a modular and a lightweight bridge structure. This section presents the conceptual design of the portable bamboo bridge intended for emergency purposes. It includes bridge characteristics, launching concept and structure concept of the proposed portable bamboo bridge.

The portable bamboo bridge is designed as a single span bridge which enables one to cross natural or manmade obstacle. The single carriageway bridge is used to cater for short gap, which can span up to 20 m. The bridge must be capable to support load up to 10 tonnes of loaded truck. The bridge is constructed mainly by manpower, which is assisted by on board crane placed on the carrier vehicle. Under this condition, it would take few hours to complete the bridge construction. Besides that, the bridge parts must be light enough to ease transportation. In a portable bridge system, design simplicity is crucial to avoid confusion during bridge erection and to save time. The use of standard parts (with identical dimension and capacity) are adapted to ease construction.

The portable bamboo bridge structure is designed as a modular girder bridge, comprising of at least two parallel girders, decking system, bracing element and connection part. A set of bridge consists of 5 modules. Each module is 4 m in length and 3 m in wide; therefore, the combination of 5 modules would produce a bridge of 20 meters long. Due to its modularity, the storage area of the bamboo portable bridge structure is manageable and it can be transported easily. The illustration and concept model of the portable bamboo bridge structure are shown in Fig. 11. Meanwhile, Fig. 12 shows scaled mockup developed in order to build understanding and improvement in future.



(a)


(b)

FIGURE 11. Illustration of portable bridge (a) module (b) complete

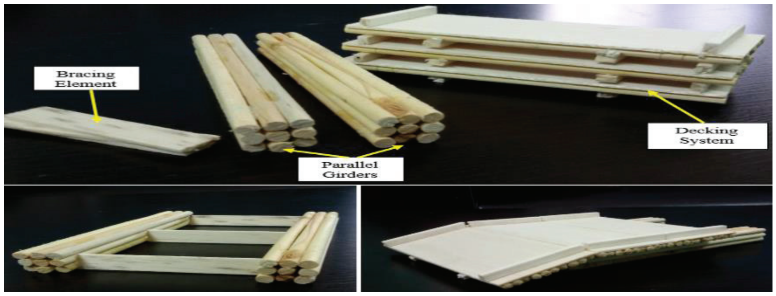


FIGURE 12. Scaled mockup using wood stick

The launching concept of the portable bamboo bridge mimics the cantilever launch method applied in the construction of Compact 100 Bailey Bridge. This method is economic and practical, by relying on manpower without the need of any machines or temporary intermediate supports. Adapting the counterweight concept, the launching will be done by erecting a temporary launching nose at the front of the bridge and pushing the bridge over the gap on rollers. Also, this method does not depend on the costly fully automation system. The launching sequence of the portable bamboo bridge is conceptually designed as shown in Fig. 13.

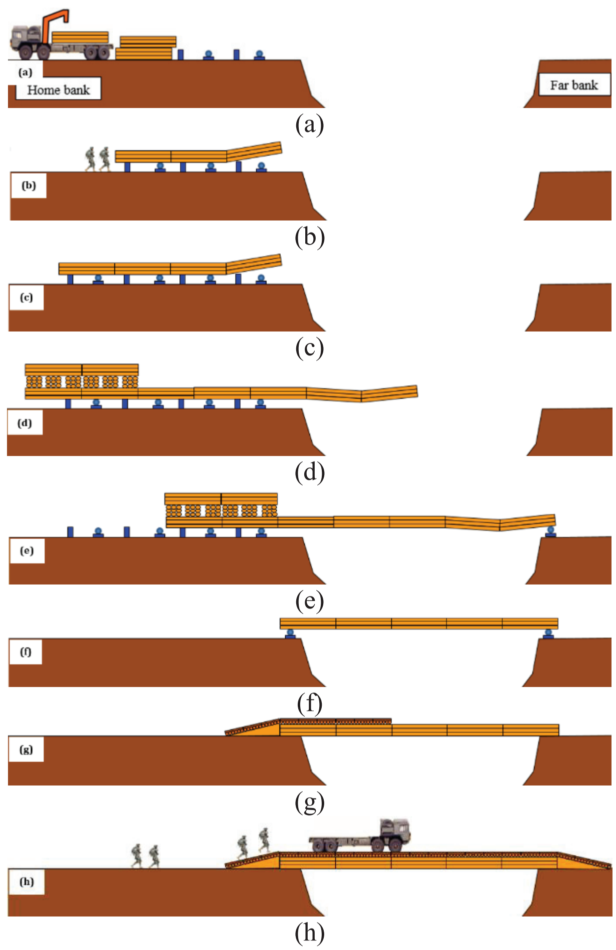


FIGURE 13. Conceptually launching sequence of the portable bamboo bridge (from a to h)

Further information based on Fig. 10 as follow:

(a) Carrier vehicle unload bridge components and setup launching equipment.
(b) Start construct nose girder (tilt up the most forward girder).
(c) Continue construct real girder.

(d) Push forward structure by step (construct real girder and attach counterweight at back).
(e) Push structure until far end touch the landing roller.
(f) Dismantle nose girder and counterweight, then lower the structure to ground using jack.
(g) Install deck and ramp.
(h) Complete portable bamboo bridge ready for crossing.

CONCLUSION

This paper has reviewed the portable bridge and bamboo bridge technology, which is dedicated for those who are interested in emergency application and bamboo technology. Adapting both technologies, the conceptual design of the portable bamboo bridge has been established including bridge characteristics, launching concept and structure concept. By establishing the conceptual design of the portable bamboo bridge, it is hope that it can spawn off other areas of research such as design standard, mechanical and physical properties, testing procedure, connection and fatigue issue pertaining to the bamboo bridge structures. The bamboo portable bridge can be commercialized since the portable bridge is an important communication support facility used for disaster relief works. Due to the technology advancements in civil and structural engineering, a lighter and stronger bridge can be designed. Also, local commercialization technology using bamboo can result in competitive price and saving for the nation.

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