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A novel deployable tied arch bridge

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ABSTRACT

This paper presents a novel type of vehicle launched deployable bridge for military or relief operations. Most existing vehicle launched deployable bridges (also known as assault bridges or mobile bridges) take the form of a simply supported beam and require mechanically complex deployment sequences. This bridge has, first, an innovative deployment sequence based on a single actuator and a tied arch form; second, a stackable cross-section to reduce the package size during transport; and third, vertical suspenders which allow for "smart" redistribution of load as the bridge deflects. Analysis of the bridge is presented along with experimental results from a three-meter long scale physical model. Load cells and fiber optic strain sensors are used to monitor the physical model, and the results are shown in relation to a statics analysis. Our results suggest this novel design would have lower forces and moments than existing deployable bridges, making it lighter and potentially advancing the current state of the art.

1. Introduction

Vehicle launched deployable bridges were first invented in World War I to aid with tank logistics in areas with damaged or inadequate infrastructure. Today, these bridges play a variety of roles in both military and relief operations. Although there are numerous temporary bridging solutions [1], this paper will focus on the vehicle based solutions which are among the most mobile.

With increasing urbanization and aging infrastructure, there is a need for new mobile bridges to increase mobility after natural disasters or military conflicts. In particular, for bridging short spans across localized failures as identified by the US Army's Future Force plan [2].

We consider a vehicle launched deployable bridge as a crossing that can be deployed rapidly from one side of a gap without access to the far side. In military literature, this type of bridge is referred to as an "assault bridge." An excellent history of assault bridges in the UK during WWI and WWII can be found in [3,4]. Below, we provide a brief overview of previous bridging concepts highlighting novel structural forms.

The first vehicle launched deployable bridge was a 6.4 m steel beam that could be lowered using cables from the front of the Mark V tank designed by Charles Inglis (Fig. 1a). The bridge would have enabled cavalry units to cross narrow canals in WWI although it did not see action [3]. Other bridging concepts were proposed in WWII including the Churchill ARK MKII where the tank itself serves as a support (Fig. 1b) and the Churchill Bridgelayer (Fig. 1c) which places the bridge with a mechanical arm.

Currently, the US military employs two assault bridges, each capable of supporting Military Load Class (MLC) 70 loads: the M60A1 Armored Vehicle Launched Bridge which has a scissor deployment and spans 18.3 m (Fig. 1d), and the M104 Wolverine which has a horizontal deployment and spans 24 m (Fig. 1e) [5]. Relatively little has been published about the design process behind these military funded bridges; some exceptions include a paper on the design of the Korean K1 Armored Vehicle Bridge Launcher [6] and a study on using composites to span short gaps [7]. In the latter study, Robinson and Kosmatka use an innovative carbon/epoxy sandwich core to achieve a bridge profile of just 100 mm which can support MLC 30 loads. While this paper details a novel structural form, Robinson and Kosmatka use a novel material to improve a traditional form.

One of most innovative recent designs is from Hanus et al. [2]; they propose deploying a pantograph as the bridge's structure, locking the pantograph in place with metal formwork, then casting in-place a concrete deck. They test the sections of the concrete deck but never appear to have built a prototype of the entire bridge. Their research, done in conjunction with the US Army

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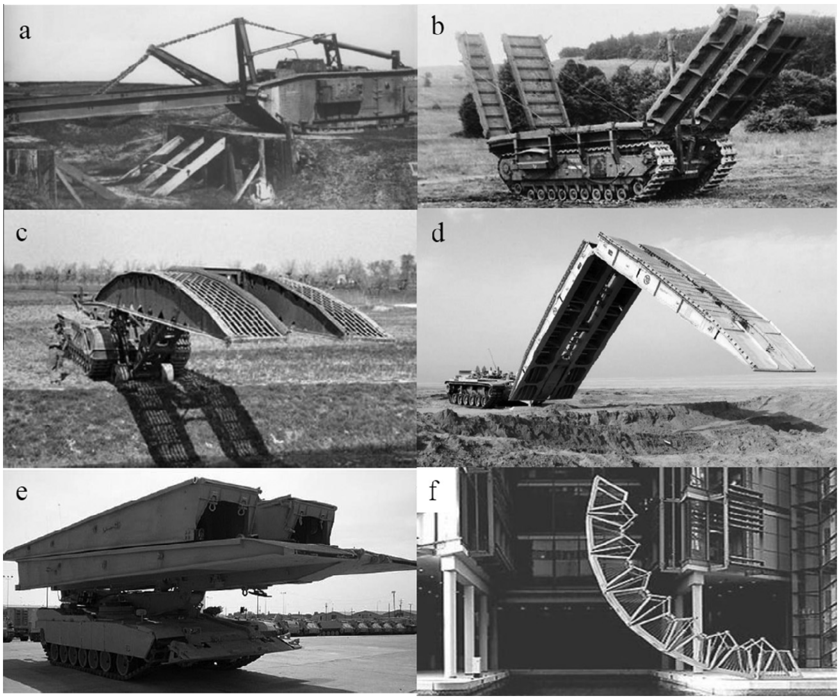

Fig. 1. Previous deployable bridging concepts. (a) Mark V Canal Bridge (b) Churchill MRK AKII (c) Churchill Bridgelayer (d) M60A1 AVLB (e) M104 Wolverine (f) Heatherswick's Rolling Bridge. (Source: Leonard G). a–e are in the public domain; f is used with permission.

Engineer Research and Development Center, demonstrates the military's continued need for novel bridging solutions.

The longest deployable bridge is the Dry Support Bridge made by WFEL which can span up to 46 m [8]. A four truck convoy is required to build the bridge: a launcher truck extends a telescopic beam over the area that the bridge will span, and then segments from the three support trucks form the final bridge below the telescopic beam.

Some non-military deployable bridges have experimented with structural forms relevant to this paper. Rolling Bridge designed by Thomas Heatherswick (Fig. 1f) takes on an arch form but it requires 14 actuators [9]; its complexity and weight make it poorly suited for larger spans or heavier loads. Work by Thrall presents several novel structural forms, along with a method for determining new forms [10]. This novel method includes both physical shape finding and computational optimization, for pareto-optimal solutions.

The aim of this paper is to introduce a new structural form and deployment technique, as a potential future model for deployable bridges. Construction details, dynamic analysis during deployment, and material selection is outside the scope of this paper. This paper will focus on the structure itself. We present an analytical model of the bridge, validate this model using a scaled physical model, then generalizing the findings from the analytical model for more loading scenarios.

2. Concept of novel tied arch deployable bridge

We propose a 15 m long deployable bridge that could be mounted on non-dedicated military and relief vehicles as a utility attachment. A rendering of the full scale bridge is shown in Fig. 2, a 40 cm long model built to examine the deployment sequence is shown in Fig. 3, and a 3 m long model to study the structural properties of the bridge is shown in Fig. 4.

During deployment, a winch tightens the horizontal cables in Fig. 2a so that the retracted bridge unrolls into its final shape. Each of the bridge segments are attached to adjacent segments by hinges along the top of the arch. Three vertical suspenders hang from each side of the bridge (six in total) connected to the horizontal cables with a pulley, allowing the tension to be adjusted without affecting the position of the suspenders. These suspenders, which will be discussed further in Section 5, reduce the hogging moment in the bridge when there is no applied load.

To retract the bridge, spools are connected to the last segment; the cables from this spool are connected to a winch on the vehicle allowing the bridge to be rolled up (Fig. 2b). Some tension must be applied in the deployment cable during retraction to keep the bridge from collapsing, but not so much as to prevent retraction.

Power for both the deployment and the retraction would be provided by the vehicle, similar to the powered joint of the M60A1 Vehicle Launched Bridge.

This simple physical model in Fig. 3 was made by connecting wooden segments with a piece of duct tape running along top of the arch. A single cable or string was required to "un-spool" the bridge and adjusts tension in the tied arch; this is labeled the bottom cable in Fig. 3.

The bridge could then be retracted by pulling on the top cables labeled in Fig. 3 which were wrapped around the spool. Pulling caused the cables to unspool, turning the spool counter-clockwise whereby rolling up the bridge.

It should be noted that the rough prototype in Fig. 3 uses solid blocks as the bridge segments, but we found significantly smaller package sizes could be achieved by using a stackable cross-section. Fig. 2c shows the stackable cross-section on a final version, while the inset in Fig. 4a shows the stackable cross section used in our structural model. The diameter of the bridge's package in Fig. 3 is roughly twice the height of the deployed bridge, but using the improved cross section in Fig. 4a, the diameter of the retracted bridge is roughly equal to the height of the deployed bridge (i.e. a 2× reduction in package size).

Fig. 4b and c show the structural model with and without vertical suspenders, respectively. This model consisted of 14, 120-mm