Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)

The move towards fully automated military bridging systems

R.C. Connor[1] & I.J. Dunn[1]
[1]*DERA, United Kingdom.*

Abstract

The evolution of mobile military bridging illustrates how operational considerations and material developments are leading to more sophisticated concepts. Modular military bridge structures have traditionally been assembled and dismantled by hand using large numbers of small components, but the requirement to bridge longer spans, coupled with the need to reduce construction times and manpower has led to increased mechanisation. Semi-automated construction techniques are now well accepted in the Field Army. Remote control, teleoperation and fully autonomous bridging systems all offer operational benefits and some examples are discussed.

1 Introduction

The ability to cross both natural and man-made obstacles has always been crucial for good mobility and is vitally important for successful battlefield operations. The earliest Roman bridges used to support military operations were massive structures constructed using stone and timber. Although cast iron improved structures in the 1870s, it was only the advent of steel with its good tensile properties that dramatically improved designs. In recent years military bridges have been developed to carry heavier loads over increasingly wide gaps. The military bridge system of today employs sophisticated structures made up of modular components, designed and fabricated using advanced materials and launched using a variety of different techniques.

The speed of deployment is vital in military operations. Requirements to reduce build times have led to fewer but larger modular components, typically weighing 1.5 tonne which has precluded manual construction. Vehicle mounted hydraulic cranes have proven valuable engineering assets in improving construction efficiency. At the same time, military bridges must be readily transportable and there is a need to minimise the logistic burden for storage, inspection and transportation.

2 Evolution of military bridging systems

Construction techniques for military bridges have evolved steadily over many years, largely due to the use of higher specific strength materials and the use of mechanisation. Early gap crossing techniques traditionally involved erecting structures by hand where manpower was plentiful. Over the last six decades there has been an exponential improvement in the efficiency of construction (Figure 1).

2.1 Bridge types

Military bridges are typically classified into three generic types depending on their role in the theatre of operations: Close Support Bridges (CSBs), General Support Bridges (GSBs) and Line Of Communication (LOC) bridges. The principles used for construction and launch/recovery of each system are generally different, dictated by their location and the operational scenario.

2.1.1 Close Support Bridges (CSBs)

These bridges are normally used in the forward combat zone where they can be subject to direct fire and such bridges must be launched rapidly from under armour without the exposure of crew. The No.10 CSB in service with the British

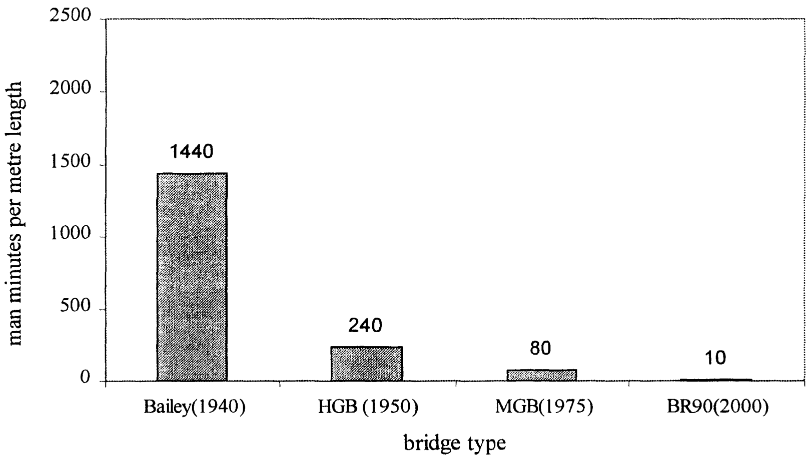

Figure 1: Improvements in construction efficiency for a 30m MLC70 bridge.

Figure 2: No.10 Close Support Bridge.

Army is carried and launched on a modified tracked chassis and the 3-stage hydraulic mechanism for launching this bridge is already almost fully automated. At a weight of 13 tonne the scissor launched bridge has a length of 26 m and can be launched within 3 minutes and recovered from either end in less than 5 minutes (Figure 2). The scissoring mechanism has proven very reliable over many years, and involves no hydraulics in the bridge itself. The same launcher vehicle can alternatively carry and deploy two shorter bridges (13.5m in length) each weighing approximately 5.4 tonne, this time using an up-and-over launch mechanism to deploy the bridges. These bridges are initially coupled together and launched as an integral pair, before disconnecting and recovering the uppermost bridge so that it can be deployed afterwards. Larger gaps up to 60 metres span and 5 metres deep can be bridged using a combination of two or three overlapping CSBs, with intermediate spans supported on the base of the gap or a floating pier. The development of a CSB Trestle (currently with Industry) will improve the trafficking profile of such bridges and allow increased speed of crossing.

2.1.2 General Support Bridges (GSBs)

These bridges are used for more deliberate operations in the indirect fire zone where it is acceptable to construct and launch bridges in somewhat slower time and with a building party out in the open. This group of bridges contains a great variety of types, including dry single span structures or multi-span bridges on fixed piers, and wet bridges built as continuous floating structures or multi-span bridges built on piers or discrete floating supports. Wet bridges also include ferries such as this amphibious floating equipment M3 (Figure 3). In its road-

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)
© 2000 WIT Press, www.witpress.com, ISBN 1-85312-817-1

Figure 3: M3 in road configuration.

running configuration this watertight hull carries a pair of hinged pontoons on its upper structure which are unfolded and outrigged on entering the water to provide a self-propelled floating unit. Two such rigs can be coupled together to form a ferry which can carry a Main Battle Tank (MBT) or multiple units can be connected to form a continuous floating bridge. This vehicle represents a 30% logistic saving in equipment and manpower over its predecessor M2.

Until recently, GSBs such as the Medium Girder Bridge (MGB) were built by hand on a roller frame with a modular launching nose, using the rear of the bridge as counterweight. The bridge is constructed by pinning panels together to form two structural girders, with infill decking laid between them to provide a 4m roadway. The double storey version built in 1.8m increments, carries a Challenger tank at 63.5 tonnes over a span of 30 metres. For wider gaps or to carry heavier loads, a system of metal reinforcing links can be fitted underneath the bridge to strengthen it. Alternatively, a pier system could be constructed which would allow longer multi-span bridges to be built over dry or wet gaps (Figure 4).

2.1.3 Line Of Communication (LOC) bridges

Finally, LOC bridges are normally constructed as logistic bridges on primary supply routes to carry more intensive traffic for longer periods of time and to free up expensive GSBs for use in more forward areas (Figure 5). These bridges have generally evolved from the original Bailey Bridge and Heavy Girder Bridge and the modern equivalents are galvanised to improve longevity and reduce maintenance.

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)

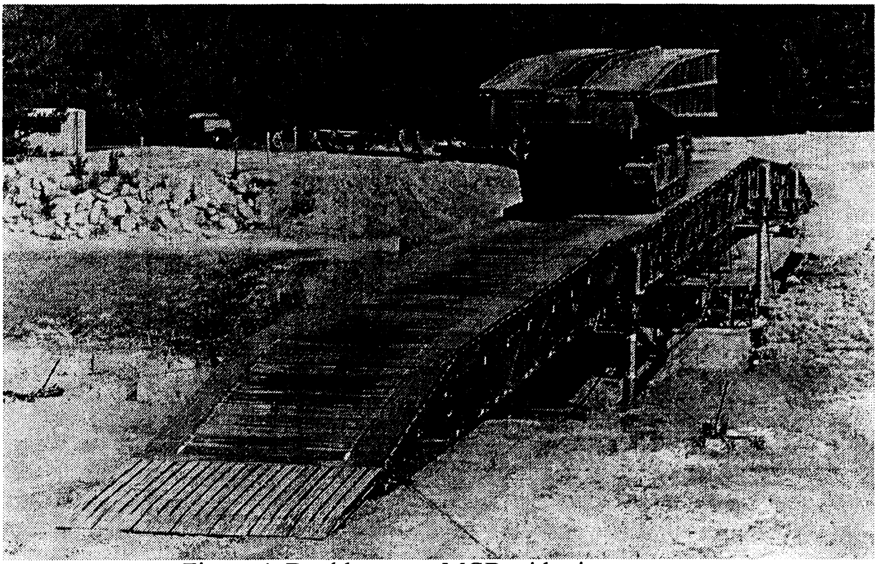

Figure 4: Double storey MGB with pier system.

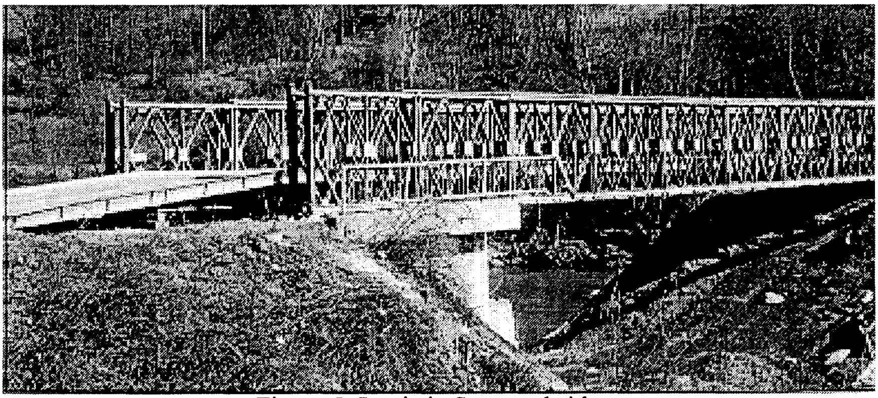

Figure 5: Logistic Support bridge.

2.2 Recent equipment developments

In the late 1970s, Mechanically Aided Construction by Hand (MACH) was devised as a method of building MGB in much larger sections with the same launching nose and roller frame, but using lorry mounted cranes and much reduced manpower. Further development of this concept led to the most recent GSB now in service with the British Army. Known as Bridging for the Nineties (BR90), this system is based on a standard 32 m bridge built with the Automotive Bridge Launching Equipment (ABLE) and two Bridging Vehicles (BVs). This system relies heavily on mechanisation to supplement manual

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)
© 2000 WIT Press, www.witpress.com, ISBN 1-85312-817-1

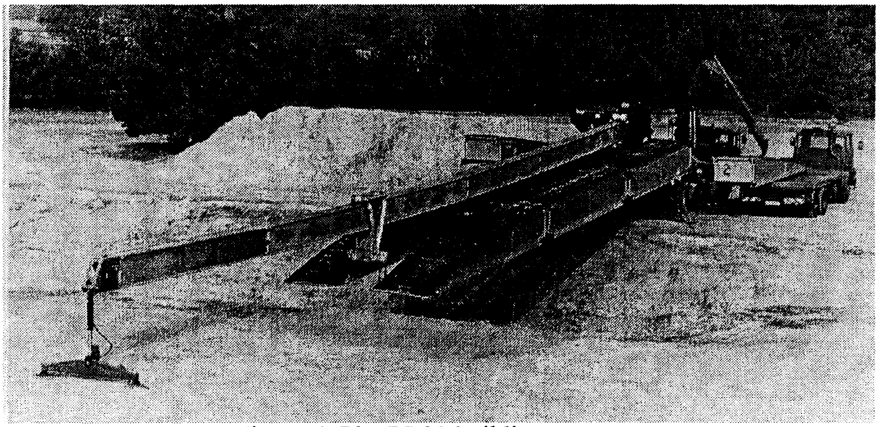

Figure 6: The BR90 building concept.

construction (Figure 6). The bridge itself comprises two interconnected trackways with an overall width of 4 metres and a girder depth of 1 metre. The 32m bridge can be built in less than 30 minutes, even at night, by a team of 10 men.

Panels of 2 m, 4 m and 8 m length are carried to the build site on flat bed trucks, and allows bridges to be constructed in 2 metre increments from 16 metres to 32 metres. Each BV is fitted with a 20 tonne metre hydraulic crane which is used to lift and sling panels onto rollers mounted within the ABLE launch vehicle, where they are pinned together by hand to form the two continuous trackways. ABLE is a special-to-role vehicle with excellent cross-country mobility and hydraulically powered mechanisms. An integral Launch Frame in 7020 alloy is used in the initial construction sequence to support and drive out an overhead lightweight Launching Rail (LR) across the gap. Also constructed of aluminium alloy (7019), modules of rail, each weighing about 0.5 tonne, are pinned together to form a cantilevered span of up to 38 metres. With the rail supported on the far bank by a bipod, the bridge is winched out beneath the simply supported beam, as sections of bridge are progressively added. When the bridge has been lowered to the ground using a system of pulleys and cables, the LR is recovered by the reverse operation and the bridge can be dressed for traffic. Infill deck panels are used to fill the gap between trackways and kerbs and edge markers define the extremities of the roadway. By combining 2 x 32 metre bridge sets with some special articulator panels with built-in hydraulics, it is possible to construct two span bridges using the same bridge panels and ABLE launch mechanism. Multi-span bridges can be supported on fixed or floating piers, and for fixed piers the home bank span can be reinforced. Two span bridges up to 62 metres can be built in this way.

The use of additional modules to construct a LR up to 50m in length allows long span bridges to be built from 34 metres up to 44 metres in length. These bridges

Figure 7: Long span bridge.

require special 4 metre panels fitted with a reinforcement king post system, as well as additional modules of bridge, reinforcement links, anchorage systems and tensioning devices. Single span structures such as these can carry a main battle tank (63.5 tonnes) and even a laden tank transporter train weighing 105 tonnes with some degree of caution. The structural capability of the Long Span Bridge (LSB) has been validated up to a length of up to 56m (Figure 7). However, the launch of such a bridge using the ABLE launch system already described is beyond the strength and stiffness capabilities of the aluminium LR, quite apart from considerations of vehicle counterweight. Technical performance therefore demands that advanced composite materials, specifically Carbon Fibre Reinforced Plastic (CFRP) must be researched to meet this objective.

2.3 Design and materials

2.3.1 Design criteria

The design of military bridges is obviously constrained by the same structural principles as civilian bridges, but it is important to appreciate the significant differences between them. Civilian bridges are designed with a large safety factor to carry light vehicle loads relative to their dead weight. In contrast, because of their well-defined load spectrum, military bridges use a nominal safety factor of only 1.33 on yield stress, although they can carry military loads typically 10 times heavier than their own dead weight. Some of the most important factors to be considered in design have been collected together in a Code specifically for military bridges [1]. Of course far larger live load deflection to span ratios are acceptable for military bridges. Apart from the structural strength requirements, durability and robustness feature high in design considerations, and fatigue life and failure modes are important parameters

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)
© 2000 WIT Press, www.witpress.com, ISBN 1-85312-817-1

which must be determined to define the techniques and frequencies of inspection in the service environment. Military bridges must also be constructed and dismantled repeatedly in the field, usually at night and often only with guaranteed access to one side of the gap. The simplicity of connecting modular components together rapidly and booming them across the gap within several minutes demands simple and reliable jointing techniques. The optimised structure must balance sophisticated design and the use of new materials against practical and robust equipment that can be produced at an affordable cost. Smart structures and the use of condition and health monitoring systems might help reduce support costs for future equipment.

2.3.2 New materials

Aluminium and Al/Li alloys are attractive materials for military bridges, combining good specific strength and stiffness with reasonable cost. The 7000 series of Al alloys have been exploited in several recent bridge structures, and DERA has developed special weldable alloys (DGFVE232B) with added Cu to minimise potential problems with Stress Corrosion Cracking (SCC). Techniques such as explosive bonding allow the joining of weldable and non-weldable alloys, and the prospect of joining aluminium and titanium offers exciting possibilities for future bridge structures.

For military bridges where weight is critical, specific strength and stiffness become important parameters in material selection (Figure 8). To minimise weight we must maximise material efficiency and hence specific properties, although most common structural materials have very similar specific Young's moduli [2]. This apparent limitation explains why new materials are actively being researched, despite their cost, where it is necessary to achieve a specific operational requirement.

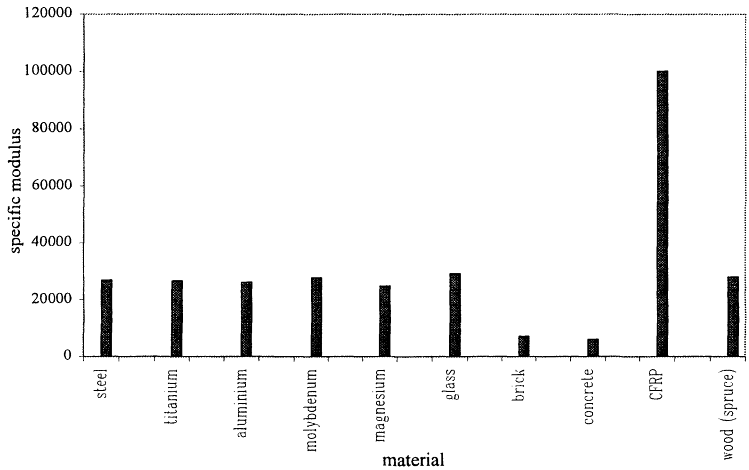

Figure 8: Specific Young's moduli of common structural materials.

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)
© 2000 WIT Press, www.witpress.com, ISBN 1-85312-817-1

2.3.3 Developments in materials

The original Bailey Bridge designed in the 1940s and its subsequent derivatives (Extra Wide Bailey Bridge and Heavy Girder Bridge) designed for larger loads, all involved heavy components designed in medium strength steel. Armoured vehicle launched bridges also involved the use of steels, including 18% Ni maraging steel (1500 MPa UTS). Chosen for its high specific strength this material requires heat treatment (3 – 6 hours at 480 degrees C) to develop its full mechanical properties and although expensive, it is readily repairable. Further materials research for military bridging led DERA to develop a new weldable alloy of Al-4%Zn-2%Mg known as DGFVE232B. Used extensively in the development of the MGB and BR90 this high strength alloy is available as forgings, plate or extrusion, with good fatigue and fracture characteristics.

With the limitations of DGFVE232B now in sight, increased performance targets require us to research advanced fibrous composites in various forms. Initial research with composites used CFRP to selectively stiffen metal sections, but it soon became apparent that optimum benefit for composites results from *ab initio* design. An example of CFRP structures is the Extended Launch Rail (ELR) of 62 metres length which we have researched as an enhancement for the ABLE system described above (Figure 9). This length of rail was technically not feasible in a conventional alloy because of limitations in material strength and vehicle countermoment. Fabrication using industrial pre-preg achieved aerospace properties at much lower cost and produced a weight saving of 40% compared with its metallic equivalent. Other research has addressed the new technical risks associated with this type of structure (eg concentrated loads, impact damage, repairability and environmental degradation).

Figure 9: CFRP Launch Rail undergoing structural testing.

3 The move to automated bridging systems

3.1 Automation

The first potential applications for increased automation in bridging operations involve gaining access to the bridging site. Remote guidance of a vehicle to a given site is particularly effective where the vehicle is a high priority target or in extremely hazardous operations eg minefield breaching and Close Support Bridging. Robotic techniques will be increasingly possible in route planning and reconnoitre activities, particularly in the selection of suitable bridging sites. The development of improved sensors, including video imagery and laser rangefinders has opened up new possibilities in surveying potential bridging sites and making critical measurements such as span. The use of lasers which do not require reflectors on the far bank allows remote surveying to determine gap dimensions, with a typical accuracy of 0.050 m from distances up to 1 kilometre. Rangefinders with horizontal and vertical encoders accurate to fractions of a degree also allow the bridge commander to assess longitudinal and transverse slopes of both home and far bankseats, thus optimising the location to build the bridge.

On adverse bridging sites it is sometimes important to control the attitude of the vehicle for bridge launch and recovery, and servo-mechanisms already used in active and semi-active vehicle suspension systems could be used to remotely control the attitude of the vehicle platform during bridge construction or recovery.

3.2 On site automation

Once the bridging site is reached, increased automation has further potential. Apart from simple automotive vehicle controls (e.g. engine, transmission, steering and brakes) it is relatively straightforward to control the action of hydraulic rams and mechanisms remotely. The UK/GE amphibious floating bridge equipment M3 has utilised pre-programmed hydraulic cranes to lift and deploy sections of bridge to designated locations. In the same way, a semi-automated crane could be used to reduce manpower and human fatigue in the construction of BR90. It is possible to perform certain unmanned operations using umbilical connections or microwaves to control connection and launching sequences to remove the man from the hazard. In the longer term full autonomy would reduce manpower. Future bridging concepts are likely to exploit the full potential of such technologies.

3.3 Automated crossing aids

In addition to controlling the construction of the bridge and its launch across the gap, there are several other related activities where automation and remote control devices can play a part.

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)
© 2000 WIT Press, www.witpress.com, ISBN 1-85312-817-1

Convoy spacing is an important parameter in military bridging, not only to achieve the necessary throughput of vehicles but also to ensure the bridge structures are not overloaded in use. This can be achieved using a camera and image processor on the convoy vehicles to follow a target on the lead vehicle, although such systems require line-of-sight contact. Other systems can be based on acoustic or radar and medium range proximity sensors. An automatic vehicle convoy capability also offers the potential for one operator to control multiple vehicles in the field, with convoy vehicles following a manned or teleoperated vehicle. Vehicle eccentricity on military bridges is also a critical parameter, physically controlled by kerbs and bridge edge markers. Automatic guidance systems, which keep vehicles on the centreline of the bridge, have the potential to reduce slewing loads and increase crossing speeds.

4 Bridge launching concepts

As examples of future concepts involving increased automation, we shall consider a Close Support Bridge launched from a tracked vehicle chassis using a propped cantilever [3], and a concept for a Light Close Support Bridge launched from a trailer or light vehicle using a mechanical crane [4].

4.1 Close Support Bridges (CSBs)

Most CSBs consist of twin trackways spaced apart to give a fixed bridge width, and there is generally a change in length involved for stowage on the vehicle.
Overall transport limitations generally restrict the number sections and girder dimensions, and more compact bridges involve more complex unfolding mechanisms. Irrespective of their capabilities in terms of span and load capacity, there are a limited number of bridge types and associated launch mechanisms. Some generic types are shown in Figure 10. The key difficulties are stowage of the bridge on the vehicle without compromising mobility, and converting the bridge to an operational configuration and deploying it across the gap.

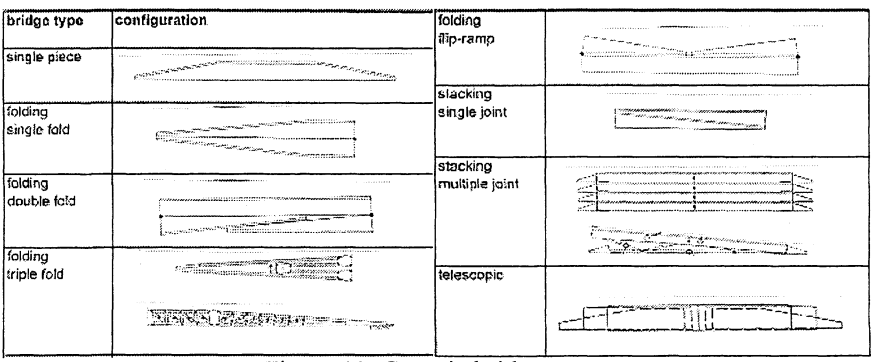

Figure 10: Generic bridge types.

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)
© 2000 WIT Press, www.witpress.com, ISBN 1-85312-817-1

The majority of launching systems utilise the space between the trackways to locate the launch mechanism, and it is usually a requirement that such bridges can be launched and recovered from either end without crew exposure. Launch times are typically around 5 minutes for launch and 10 minutes for recovery, irrespective of method. Stealthy launches are desirable, and ideally the launch silhouette and various signatures would be kept to a minimum. In this respect, horizontal launch or flip-ramp mechanisms are advantageous over scissors bridges if the system of connection is reliable.

The majority of launch methods support the bridge at two positions during launching. This allows good control for stability and rotation. A manipulator arm could be used to support the bridge at its centre of gravity, to lift it clear of the launcher and lower it across the gap. This is an extension of the swing-over method, but could be used to deploy folding flip-ramp or telescopic bridges. Alternatively, horizontal bridges can also be deployed using the cantilevered principle, the exact manipulations depending on bridge type. These systems require a forward supporting launching arm along which the bridge can be traversed. Once across the gap the launching arm is rotated to lower the far end of bridge and then further rotated to lower the home bank end. The horizontal cantilever method applies a significant overturning moment about the fulcrum pad and this must be reacted by the counterweight of the launch vehicle.

Introducing a prop underneath the launching arm can increase the resistance to overturning. DERA have pursued this concept based on a horizontally launched

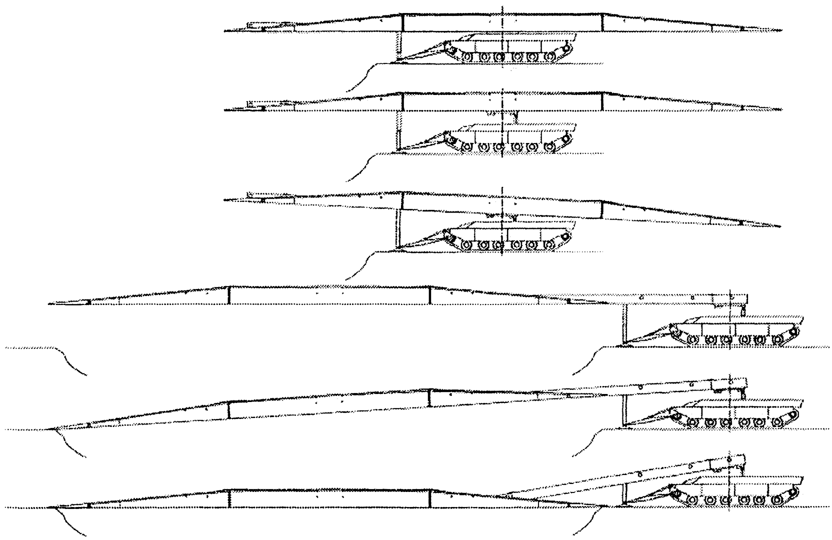

Figure 11: Horizontally launched bridge using a propped cantilever.

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)

folding bridge, using a propped cantilever to support the rail (Figure 11). In this concept both the bridge and rail involve flip-ramp mechanisms, although the principle could also be used for single piece bridges and telescopic bridges. The bridge itself is carried on a launching rail that can be extended and rotated about the front of the vehicle. The bridge is traversed along the rail across the gap, and the launch rail is withdrawn and restowed for further use. Virtual modelling has been used to simulate the principle of deployment. The form and construction of bridge structure has not yet been tested but would rely heavily on advanced composite materials. Outline designs suggests it would be feasible to achieve an operational bridge length of 32m to carry a load of 72.5 tonnes with a stowed length of 15 m on the vehicle. However there is currently no User requirement for such a system.

4.2 Light Close Support Bridge (LSCB)

There are already bridges either in service or developed with other countries which utilise trailers as an integral part of a bridge system. This DERA concept comprises a commercially available crane, a prime mover and a bridge. The principle behind the concept is to launch a bridge using a crane, which is either on a trailer or on the prime mover (Figure 12). The advantage of it being on a trailer is the flexibility of being able to use a number of prime movers to tow and launch a bridge, ie, having a non-specific launch vehicle. However, the disadvantage is the loss of manoeuvrability especially when reversing is required. The different components of the system are as follows:

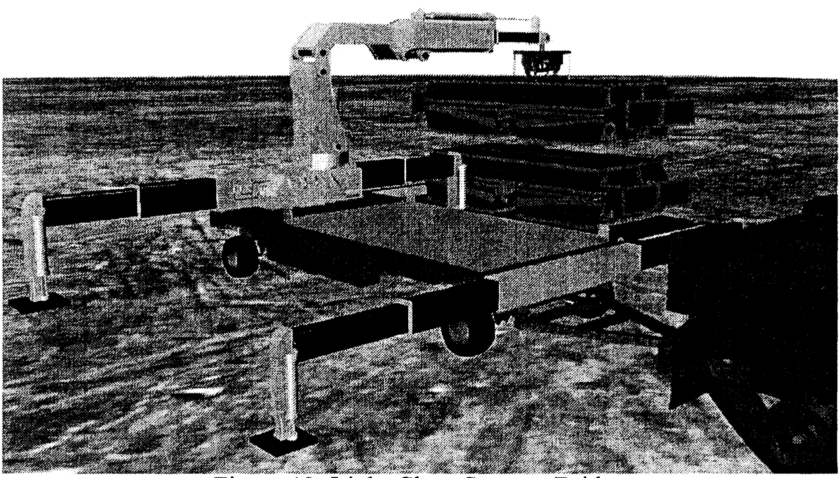

Figure 12: Light Close Support Bridge

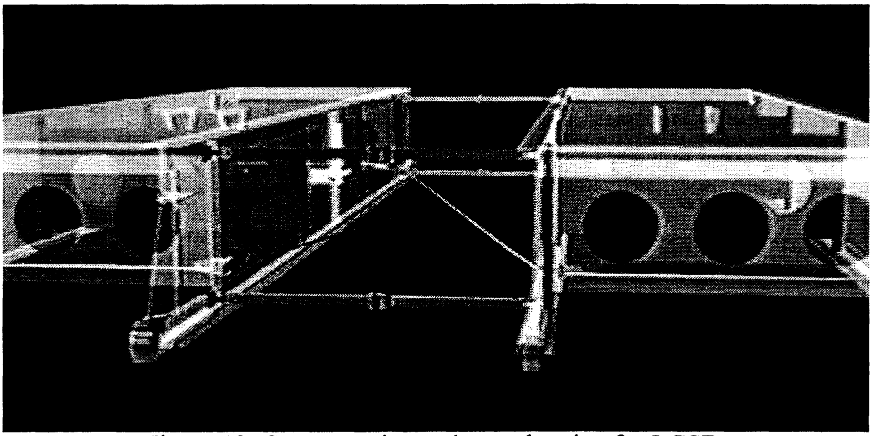

Figure 13: Centre section and cross bracing for LCSB.

4.2.1 Bridge

The bridge is a twin trackway bridge made from a weldable aluminium alloy (DGFVE 232B) with a proposed span of 13m to support a load of 35 tonnes. The bridge consists of either 3 sections per trackway or 5 sections per trackway, with self-cleaning deck and cross bracing (Figure 13). Two bridges can be stowed within a standard 6m ISO container making logistic supply easier. Once removed from the container the bridge can either be manually widened or placed on the trailer/prime mover and located on platens. These platens would then move apart widening the bridge to its full width. The cross bracing is made up of two elements, both of which automatically deploy when the bridge is opened to its full width. The first part is a sway brace that is made from flexible rope which locks out when the bridge is widened. The second part is a cross connector, which also locks out but requires pinning to keep it locked. The cross bracing allows movement in the vertical plane to compensate for slopes of 1 in 20. The bridge sections are connected together via a single pin hinge for the 3-section bridge and a double hinge pin for the 5-section bridge, both on the bottom chord. The top chord has a simple compression face abutment.

4.2.2 Deployment/Recovery

A lifting beam is attached to the end of the crane and is used to deploy and recover the bridge. The beam is craned into position between the trackways and locked in position by retracting a hydraulic cylinder located in the beam. Attached to the locating probes are hydraulic motors that drive the deployment/recovery mechanism for the bridge. The bridge itself contains no internal power. Once the probes are located the hydraulic motors drive shafts, via bevel gears and screw jacks allowing the bridge to fold or unfold (Figure 14).

Mobile and Rapidly Assembled Structures III, C.A. Brebbia & F.P. Escrig (Editors)
© 2000 WIT Press, www.witpress.com, ISBN 1-85312-817-1

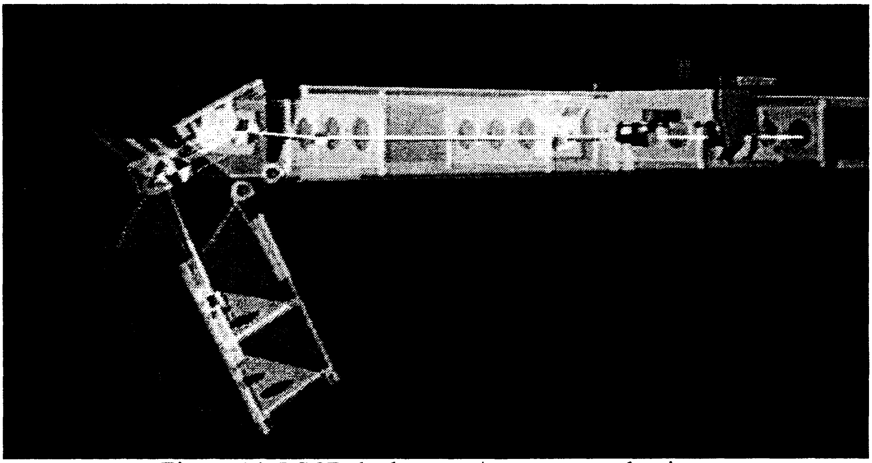

Figure 14: LSCB deployment/recovery mechanism.

4.2.3 General

The current concept allows the operation to be undertaken within the safety of the towing vehicle, via closed circuit TV. To aid the speedy deployment/recovery of the bridge the crane could be semi-automated, ie have pre-set positions. In the longer term it might be possible to make the system fully autonomous and remove the operator from the hazard.

5 Conclusions

Military bridges are essential for good mobility and the evolution of bridge structures and their launching mechanisms has shown a clear trend towards the increasing use of mechanical aids.

The selection of suitable materials has proved critical to efficient bridge structures and the need for high specific strength and stiffness will inevitably involve the use of advanced fibrous composites and exotic alloys in future bridge structures. Material selection also has a large impact on manufacture, robustness, durability and subsequent inspection and repair costs in service.

Robotic techniques offer operational benefits in hazardous areas. The increased use of automation in combat vehicles and sensor technologies involved in transportation systems both offer potential benefits for bridge launching mechanisms. Remote vehicle control and teleoperation of automotive functions is now possible, but fully autonomous construction techniques for future military bridge systems will require further research.

This paper represents the speculative views of the authors and does not necessarily reflect future operational trends.

Acknowledgements

The authors would wish to express their thanks to Vickers Bridging, Mabey & Johnson Ltd and Williams Fairey Engineering Ltd for permission to publish some of the photographs.

References

[1] Trilateral Design and Test Code for Military Bridging and Gap Crossing Equipment, January 1996 edition.
[2] Waterman, N.A. & Ashby, M.F. (eds). Elsevier Materials Selector, Elsevier Applied Science, 1991.
[3] Connor R.C., Novel Launch Techniques, DRA/LSF3/CR96/002/1.0, April 1996
[4] Taylor, R.M., & Dunn, I.J. Trailer launched Bridge Concept – Update, DERA/LS4/CR98010/1.0, Feb 1998