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APPLICATION OF THE BAILEY BRIDGES IN POST-EARTHQUAKE INTERVENTIONS

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Abstract

After an earthquake, the availability of transport corridors must be guaranteed to allow the evacuation of the population and the unhindered passage of rescue vehicles. Bridges are crucial in any transport network and can be damaged, partially or completely collapsed during an earthquake. On the other hand, in such circumstances, it is important to ensure fast and safe passage of people and goods over obstacles. Bailey bridges are prefabricated systems that enable quick and temporary passage and are used by many armies around the world, including the Croatian army. Possible applications of Bailey bridges after the strong earthquake presented in this paper are: (i) construction of Bailey bridge at the site of an existing bridge that collapsed during the earthquake; (ii) construction of Bailey bridge at an unprepared crossing, (iii) partial bridging of one or more spans of a destroyed bridge, (iv) strengthening of an existing bridge pier with Bailey truss elements, (v) construction of a new support (pier) for the superstructure with Bailey truss elements, (vi) Bailey bridges on barges. In addition to the theoretical possibilities, several case studies – Bailey bridges recently constructed by Armed Forces of the Republic of Croatia will be presented: Bailey bridge in Donja Stubica, Bailey bridge over Korana River near Karlovac, Bailey bridge near Marija Bistrica in Croatia, and Bailey Bridge over Dreta River in Slovenia.

Keywords: Bailey bridge, steel truss, post-earthquake intervention, army.

1. Introduction

The consequences of strong earthquakes are often partially or completely destroyed infrastructures, which ultimately leads to communities being isolated and in urgent need of help. Bailey structures are characterised by their ease of assembly and maintenance, allowing them to be set up and dismantled quickly, making it much easier to provide relief to those at risk, support rescue operations and reconnect communities. Bailey structures were first used on a large scale during the Second World War, where they proved invaluable in situations that required rapid assembly of bridging structures [1, 2].

Bailey structures were invented in the 1940s by Sir Donald Bailey and were primarily intended for military use. The modular design of the Bailey constructions made it possible to quickly and easily build bridges, which allowed the army to quickly cross various types of obstacles. Over time, civilian structures also recognized the advantages of Bailey bridges, therefore their use exceeded only military applications, and they became an indispensable tool in bridging various types of obstacles, especially in dealing with disasters and crises [2, 3].

Bailey bridges are made of prefabricated steel components that can be easily transported and quickly assembled on-site using only manpower, without the need for special tools or heavy machinery. The bridge sections can be connected to each other, allowing the length and load capacity of the bridge to be adjusted to any obstacle. The installation of a Bailey bridge requires minimal or even no preparatory work or site modification for crossing an obstacle, making Bailey bridges ideal for use in emergency and urgent situations [2, 4].

Due to their simplicity and speed of assembly, easy maintenance, and relatively affordable cost, Bailey bridges are used worldwide for both military and civil purposes. They are especially valuable

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in disaster relief efforts following natural catastrophes such as earthquakes, floods, and hurricanes, where rapid infrastructure construction is necessary. Their versatility, durability, and strength make them ideal for both temporary and long-term bridges in both rural and urban areas [2, 5].

2. Possibilities of Bailey bridge

2.1. Purpose of the structure

Bailey structures consist of standardized folding elements, tools, and accessories. The primary function of panel bridge equipment is to assemble fixed bridges, panel crib piers, and towers. Other specialized structures, such as floating bridges, suspension bridges, retractable bridges, and mobile bridges, can be constructed using specialized components. The use of these materials is governed by standard guidelines outlined in the Regulations on the Assembly of Bridges and Scaffolding Made of Bailey Material M-S6 (M-2 and M-1). Beyond their primary function, Bailey materials can also be used to construct a wide range of other structures, including suspension bridges, railway bridges, temporary docks, loading and unloading ramps, auxiliary scaffolding, cable car and electricity pylons, antenna masts, roof structures, and more. Since no standardized solutions exist for these applications, a custom technical solution is developed for each specific case, leveraging the expertise and adaptability of Bailey materials. With minor non-standard modifications, the potential applications of Bailey bridge components are limited only by the user's imagination [5, 6].

2.2. Description of the structure

A Bailey bridge is a type of portable, prefabricated, truss bridge (Fig. 1). Due to the multiple uses and temporary nature of structures made from Bailey material, a key feature of the design is its assembly and disassembly capability. Parts of the same type are identical to ensure interchangeability and possess high strength and durability, allowing for multiple assemblies and disassemblies. Damaged parts can be replaced quickly and easily. The structural design of the elements is based on their primary purpose but also has sufficient properties for a much broader universal application across different types of structures, with or without minor modifications and the addition of new elements. The bridge structure can be easily adapted to the width and depth of an obstacle, required load-bearing capacity and the static system of the designed bridge by adding or removing sections of the superstructure [5, 6].

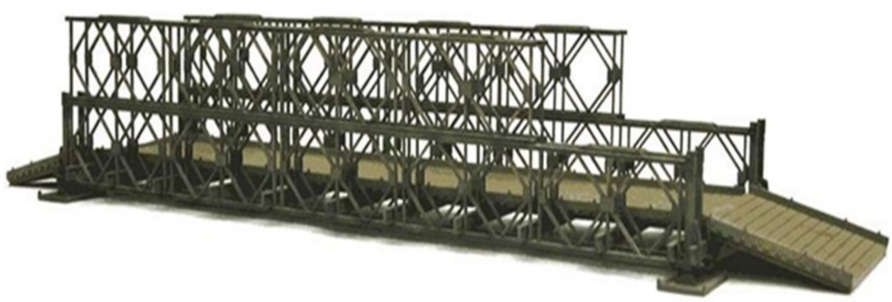

Figure 1. Model of Bailey bridge

The construction is simple to assemble, and the elements are relatively lightweight, allowing them to be transported and assembled manually without the need for heavy machinery. Of course, a crane can be used during assembly to speed up the installation process. No special scaffolding or machinery is required to install the bridge, as it is launched over the obstacle using a launching nose, which is attached to the front of the bridge, and a counterweight,

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which is essentially the mass of the bridge itself. The bridge can be launched manually, with the required number of personnel depending on the bridge dimensions [5, 6].

As a technical system, Bailey material is not used as individual elements but is assembled into specific sets, including: a set for a launching bridge, a set for a pontoon bridge, and a set with additional components for a suspension bridge. Each kit contains the appropriate number of elements to achieve the required load-bearing capacity and bridge length. Additionally, various types of scaffolding can be constructed using elements from the pontoon bridge set [5, 6].

The main components of the bridge structure include (Fig. 2):

- Main girders made of panels,

- Transoms (cross griders),

- Stingers (longitudinal griders) [5, 6 ,7].

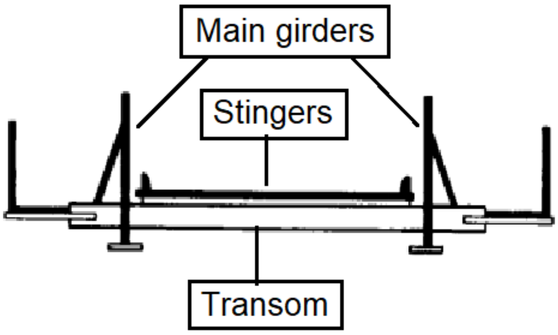

Figure 2. Main parts of Bailey bridge [5, 7]

The main girders are assembled by connecting the trusses to each other, forming walls and stories. The bridge has two main girders. They are interconnected by transoms. The constructions of the main girders allow for different lengths and load-bearing capacities of bridges and spans. They are distinguished by the number of truss walls and stories. The number of truss walls and stories mainly determines the type of main girders, and thus the type of bridge. The prescribed types of main girders are:

- single-truss single-story (SS),
- double- truss single-story (DS),
- triple- truss single-story (TS),
- double- truss double-story (DD),
- double- truss triple- story (DT),
- triple- truss double-story (TD),
- triple- truss triple- story (TT) [5, 6].

Figure 3. Bailey Bridges: single-truss single-story (SS), double-truss double-story (DD) and triple-truss triple-story (TT)

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In addition to the seven types mentioned, it is possible to create other variants of main girders (for example, with 4 stories), but they are rarely used. Instead of adding a wall or story, the main girders can be strengthened by placing additional flanges on the trusses [5, 6].

The transoms connect and stiffen the main girders, support the roadway and transfer the loads received from the roadway to the main girders. In three-story bridges, the transoms are also used to stiffen the upper chords of the main girders, forming the upper part. The transoms determine the distance between the main girders, and thus the fixed width of the bridge and the roadway. The bridge roadway and pedestrian walkways are directly supported on the transoms [5, 6].

The roadway is assembled from stingers, decks and buffers and serves as a surface for vehicle traffic. The basic position of the roadway is on the transoms at the level of the lower chord of the main girders, and the positions of the roadway on the second and third floors are also possible, or above the level of the main girders. The roadway directly receives moving loads and transfers them to the transoms. Unlike the variability of the main girders, the roadway is unchangeable regardless of the length and load capacity of the bridge. It is only possible to add traffic lanes to protect the floors from premature wear [5, 6].

In addition, footpaths can be constructed on the sides of the main girders and ramps are built at the entrances to the bridge [5, 6]. All elements other than the supports (main girders, transoms, carriageway, ramp and footpaths) are referred to as the bridge's superstructure and the supports as the substructure. A superstructure consists of main girders, cross girders and carriageways and the substructure of floating supports.

The bridge rests on the land via supports. Supports are shore or intermediate supports. Shore supports are assembled directly on the shores and the ends of the bridge rest on them. Coastal support consists of two bearing slabs with bearings placed on beams and planks, or other wooden supports, transverse and longitudinal supports or similar in order to increase the bearing capacity of the soil and transfer forces to a larger surface [5, 6].

Inter-support landings are used in multi-span bridges to support the upper part on several supports in an obstacle that cannot or is not optimally bridged in one span. The landings between the supports can be made from Bailey elements of various types or from other types of construction materials, and the existing supports of collapsed bridges are also used [5, 6].

Floating supports are built from pontoons, freighters and logs (Fig. 4). They are only used in scaffolding and pontoon bridges. Bailey pontoons can only be used as three-part supports. Floating supports can consist of one or more three-part pontoons. The ramp consists of special elements that make it possible to enter and leave the bridge. Depending on the purpose of the crossing, the ramp can be one or more bays long. Pedestrian walkways can be installed on the outside of the main girders, regardless of the type of girder. They are supported directly on the ends of the transoms.

The bridge elements are designed so that they can be transported within the construction site and assembled without the use of machines using only human labour. Moreover, single truss in the length of a 3.048 m and corresponding elements create a separate structural unit – one truss field. The ramp at the entrance to the bridge in the length of a 3.048 m ramp is referred to as the ramp field.

Bridges with abutments are built over dry and water obstacles. They are manufactured in all seven types. They are quite stable as they are not dependent on the water level. The fewest types of Bailey elements are installed in them, i.e. only the basic elements of the upper part and coastal supports and, if necessary, additional elements for landing Bailey supports, and the use of pontoons, navigation accessories and anchorages is excluded. The assembly of these bridges is slower than that of pontoon bridges, especially when building between the supports of a larger span bridge.

Bridges with standing supports can be single-span or multi-span. The span is part of the bridge construction between two supports, regardless of whether these supports are on the bank or in the obstacle. A single-span bridge spans the obstacle by supporting the structure of the upper part only at its ends on bank supports. Single-span bridges are built over narrow obstacles where no intermediate

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supports are required due to the short length of the bridge. Due to their short length, such bridges have a simple construction of the main supports and are quickly assembled and placed over the obstacle. A single-span bridge can also be built over a wider obstacle (up to 64 metres) if it is deep and the construction between the supports is not possible or would be very complex (over ravines, in canyons, over deep riverbeds, etc.). In these cases, a larger the width of the barrier requires the use of heavier types of multi-wall and multi-story structures, which are more complex and take longer to build.

A multi-span bridge is assembled on wide barriers and relies not only on the bank supports (like a single-span bridge), but also on intermediate supports in the barrier, creating several spans of the structure between the supports. The bank supports of a multi-span bridge are the same as the bank supports of a single-span bridge. Existing supports from demolished bridges can be used as intermediate supports, or new supports can be built from Bailey elements or local materials, or a combination of these. Multi-span bridges can be permanent or with separate spans.

Bridges with separated spans are such superstructure structures, in which the main girders above the supports are completely separated or connected only in the lower part via external span verticals or directly to the lower truss flanges, forming separate functions of each span or a hinge function of the structure above. between the columns.

The greater or lesser complexity of the construction of a multi-span bridge depends primarily on the complexity of the construction between the supports, and only then on the types of main supports.

In the case of obstacles whose width is within the limits of a single-span bridge, but with a more complex construction, the more optimal solution is to choose between a multi-span bridge with abutments, piers and superstructure of a simpler type, rather than a single-span bridge with a more complex superstructure.

Figure 4. Floating Bailey Bridge

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3. Role of Bailey structures in the post-earthquake period

One of the most vital functions of Bailey bridges following an earthquake is to restore access to areas cut off due to damaged infrastructure. These temporary crossings over rivers, valleys, or collapsed roads provide crucial mobility for people, vehicles, and supplies. In the chaotic aftermath of an earthquake, the priority is to quickly supply the affected population, and Bailey bridges play a critical role in facilitating the transport of essential items like food, water, medical aid, and equipment. By ensuring relief efforts are not impeded by impassable terrain, they are pivotal in the recovery process.

The social and economic impact of an earthquake can be devastating, but Bailey bridges contribute significantly to the rebuilding process. They reconnect isolated communities, allowing residents to reunite with their families, access vital services, and participate in the broader recovery efforts.

Bailey bridges have been applied in post-earthquake interventions worldwide, some example are:

- Japan, 2011: Following the Tōhoku earthquake and tsunami, Bailey bridges were quickly installed to enable access to isolated regions, facilitating relief efforts and aiding the rebuilding process.
- Nepal, 2015: Following the earthquake in Gorkha, Bailey bridges proved crucial in connecting remote mountainous regions to larger urban centres to ensure the timely delivery of aid and support.

4. Case studies – Bailey bridges assembled by Croatian army

4.1. Bailey bridge in Donja Stubica, Croatia

In 2023, the Engineering Regiment of the Croatian Army constructed a "Bailey M-1" bridge in the settlement of Gornja Podgora in the town of Donja Stubica. The bridge was installed to allow the passage of heavy construction machinery and vehicles for the purpose of rebuilding a family house that was severely damaged during the earthquake in March 2020. The bridge construction type is single-truss single-story. The total length of the bridge is 12.19 meters, and the mass of the structure is 7.12 tons. The bridge has a maximum load capacity of 26 tons for tracked vehicles and 30 tons for wheeled vehicles. The installation work lasted for 3 days [8].

Figure 5. Bailey bridge in Donja Stubica, Croatia [9]

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4.2. Bailey bridge over Korana River near Karlovac, Croatia

In June 2020, the Engineering Regiment of the Croatian Army installed the largest "Bailey M-1" bridge in Croatia to date. This bridge is located over the Korana River in the settlement of Turanjski Poloj in the city of Karlovac. The bridge was installed to provide assistance in flood control efforts, specifically to allow the passage of construction machinery and vehicles necessary for building a flood protection embankment along the Korana River. Construction type of the bridge is triple- truss double-story. It is 42.67 meters long, and the structure weighs 74.9 tons. The maximum load capacity of the bridge for tracked vehicles is 40 tons, and for wheeled vehicles, it is 48 tons. The construction of this bridge took 7 days [10]. After the embankment was built, the bridge was disassembled.

Figure 6. Bailey bridge over Korana River near Karlovac, Croatia [10]

4.3. Bailey bridge near Marija Bistrica, Croatia

Over the Krapina River in the settlement of Selnica in the Municipality of Marija Bistrica, the Engineering Regiment of the Croatian Army rebuilt the "Bailey M-2" bridge in September 2024, which was handed over for permanent use to the local community. This bridge was constructed because the original bridge, installed in 1999 by the former "33rd Engineering Brigade of the Croatian Army," was severely damaged in April 2023 when a vehicle much heavier than the allowed weight crossed it This bridge is crucial for the area's transportation connectivity as it facilitates access to agricultural land and the Croatian National Shrine of Our Lady of Bistrica. The bridge features a single-truss single-story construction type. Its total length is 27.43 meters, and the total mass of the structure is 23.58 tons. The bridge's maximum load capacity is 12 tons for tracked vehicles and 14 tons for wheeled vehicles. The bridge structure was installed in two days [11].

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Figure 7. Bailey bridge near Marija Bistrica, Croatia [12]

4.4.Bailey Bridge over Dreta River in Slovenia

In September 2023, the Engineering Regiment of the Croatian Army set up the "Bailey M-1" bridge for the first time outside the borders of Croatia, at the site where a bridge over the Dreta River in the village of Lačja Vas, in the Municipality of Nazarje, Slovenia, collapsed due to severe flooding.The bridge was installed to restore connectivity between Lačja Vas and other parts of Slovenia. The bridge features a double- truss single-story type of construction. It has a maximum load capacity of 36 tons for tracked vehicles and 42 tons for wheeled vehicles. The installation of the bridge was completed in just 4 days [13].

Figure 8. Bailey bridge over Dreta River in Slovenia [13]

5. Conclusion

Bailey bridges are a fascinating engineering invention. Thanks to their modularity, portability, and ease of assembly, Bailey bridges have saved countless lives and facilitated the reconstruction of numerous communities after natural disasters and war. They are a true example of how innovation can have a long-lasting positive impact on the world.

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In order to maximize and properly use Bailey bridges, it is necessary to focus on assessing the affected terrain to define the key points where bridges are urgently needed. Bailey bridges should be installed at the locations we initially selected, such as collapsed road links, key river and stream crossings, or various other types of obstacles, to facilitate the transport of people and aid.

At the very beginning of a crisis event, it is necessary to ensure that bridges of this type are primarily in the service of helping rescue teams and emergency services in order to access the affected areas as easily as possible with the aim of quick evacuation of the injured. Although Bailey bridges are a temporary solution, they need to be included in long-term reconstruction plans to stabilize the situation and begin permanent reconstruction. This approach in an emergency situation ensures that the affected areas get the help they need quickly and that lives return to normal as quickly as possible. As earthquakes continue to pose significant challenges around the world, further development and use of Bailey bridges will be critical in mitigating the effects of such disasters.

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