Improve the stability of the rolling bridge by changing the shape of the internal mechanism

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Abstract. The London-designed Rolling Bridge inspired this study by Thomas Heatherwick to add stability to this bridge. This study aims to analyze what structures can increase the bridge's overall stability and determine the basic parameters. Finally, it revealed the structural type of this structure. This study uses force analysis, Pythagorean theorem and calculation of degrees of freedom to determine that the new structure is more stable than the original structure. In the study, the total length and number of segments were assumed to be constant to study the effect on geometry and static height during deployment. The study concluded that when the bridge's internal structure is triangular, the bridge is more stable than the original design in the folded state—the internal structure changes from triangular to trapezoidal when the bridge is extended to a horizontal position. When the bridge changes from the horizontal position to the folded state, the internal structure changes from trapezoidal to triangular. Meanwhile, hydraulic columns are mainly used to lift and bend bridges. Each structure has five nodes and five segments. Despite the increasing number and complexity of computations, the variable triangular structure is more stable than the fixed trapezoidal structure.

Keywords: bridge's overall stability, force analysis, Pythagorean theorem, calculation of degrees of freedom.

1. Introduction

A *foldable bridge* is a movable bridge designed to fold to accommodate passing ship traffic that needs to pass through the waterway that the bridge spans. Folding bridges are available in many countries, with many variations of folding designs; some are very creative. This type of bridge design requires some complex and meticulous engineering; as designed, the bridge must handle the strains of daily life use and the stresses involved in folding and raising the folding bridge can to allow ships to pass under the bridge. The folding bridge can be used to accommodate pedestrians or vehicles. Metal is the standard construction material for such bridges because it is durable and very stable, and the bridge's movement is usually performed by hydraulic systems [1]. In some designs, the bridge remains mostly down except when it needs to be lifted. The decision about where to keep the bridge depends on the traffic needs in the area.

In a primary folding bridge, the hinged sections are folded together and pulled to one side to allow vehicles to pass. Other folding bridges are curled, and in another interesting variation on the traditional design, curled bridges are made up of several hinged segments that can be curled into a roughly circular shape from one side of the bridge. Start until the curved bridge reaches the shore. This visually exciting design is popular among pedestrian folding bridges. The predecessor is already researching increasing the lastingness of a rolling bridge [2]. Optimizing the main beam for the resistance structure of an oversized rolling bridge [3]. Parametric Study on the Rolling Truss Typology [4] road maps for motion planning [5] In this design: When the bridge is extended to the horizontal position, the internal structure changes from a triangle to a trapezoid. When folded from a horizontal position into a hexagon, the internal structure changes from a trapezoid to a triangle. Hydraulic columns lift each structure and unfold the whole bridge to bend or fold the whole bridge. According to the essay Design and analysis of a hydraulic system for opening and closing bridges [6]. The deformation of the internal structure when the bridge is unfolded or folded from triangular to trapezoidal and trapezoidal to triangular is controlled by gears [7] installed in the hydraulic column [8]. The research aims to increase the rolling bridge's stability in the folded situation.

The remainder of this report is divided into four sections. Section 2 summaries previous summarizes the previous research on the main beam of the rolling bridge and the research on its durability. Section 3 presents a basic unit to improve the design of rolling bridges. The basic concept of the connection structure is presented. The degree of freedom and the unfolding mechanism of the designed fundamental element are also analyzed. In addition, this section also carries out the force analysis of the proposed new deployable structure. Section 4 will calculate the displacement distance of some nodes of the basic unit during the folding process.

2. Methodology

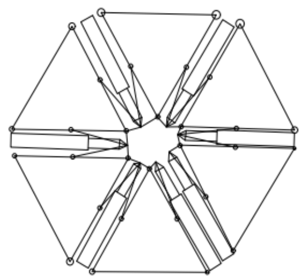

Figure 1. The folded bridge

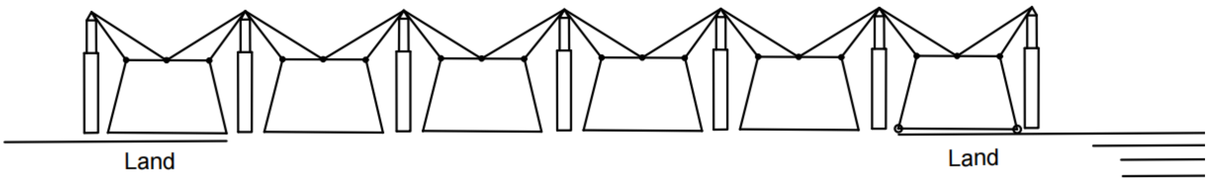

Figure 2. Horizontal unfolded Bridge

2.1. The overall structure of the bridge

First, we need to confirm the bridge's state when it is folded and unfolded. Figure 1 shows the bridge's state when folded, like a hexagonal sculpture. Moreover, Figure 2 shows the bridge's appearance after its horizontally unfolding. When not unfolded, the bridge consists of six internal structures, as shown in Figure 3, with a triangular structure, two hydraulic columns, and two chains.

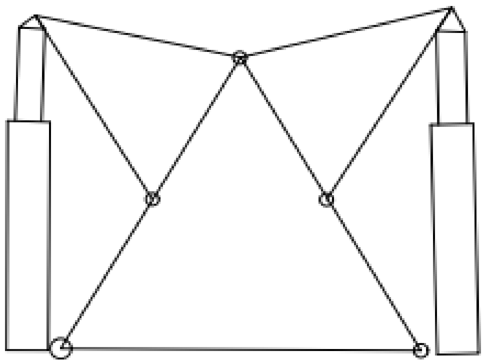

Figure 3. Separate basic unit

2.1.1. Basic unit design

The middle triangular part is composed of five joints and five bars. Each similar structure is the same construction to determine the number of independent motion parameters that must be given when the mechanism has a determined motion. We need to calculate the degrees of freedom of this structure. The diagram used is shown in Figure 4, and the calculated degrees of freedom are in Figure 4.

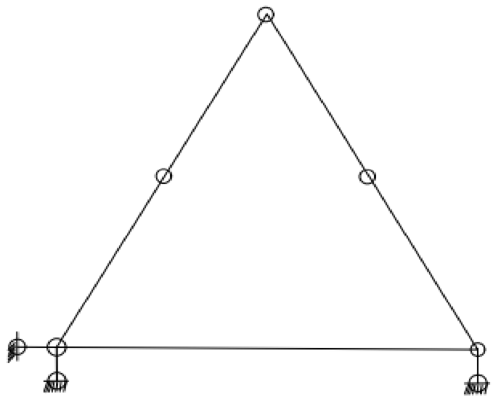

Figure 4. Simplified basic unit

Calculate the degrees of freedom from figure 4. Figure 4 shows that hinges connect the five bars, and the bottom two points are fixed hinge supports, as shown in Figure 4. We can choose the best support position through the optimization study of the overall joint design [9]. Because Figure 4 is 2d. So this is a plane mechanism so use the formula for calculating plane degrees of freedom.

$$M = 3(N - J - 1) + \sum_{i=1}^{J} f_i \tag{1}$$

Where N is the total of Links in the unit.Where J is the total of Joints in the unit

According to the above formula, in order to make the mechanism have a definite movement trajectory. So how to ensure that the internal structure can be smoothly deformed as we wish? Gears housed in hydraulic columns can do it. When pulled the gears at the same speed on both sides, the same amount of force can be provided so that the deformation of the entire internal structure can be controlled within a controllable range.

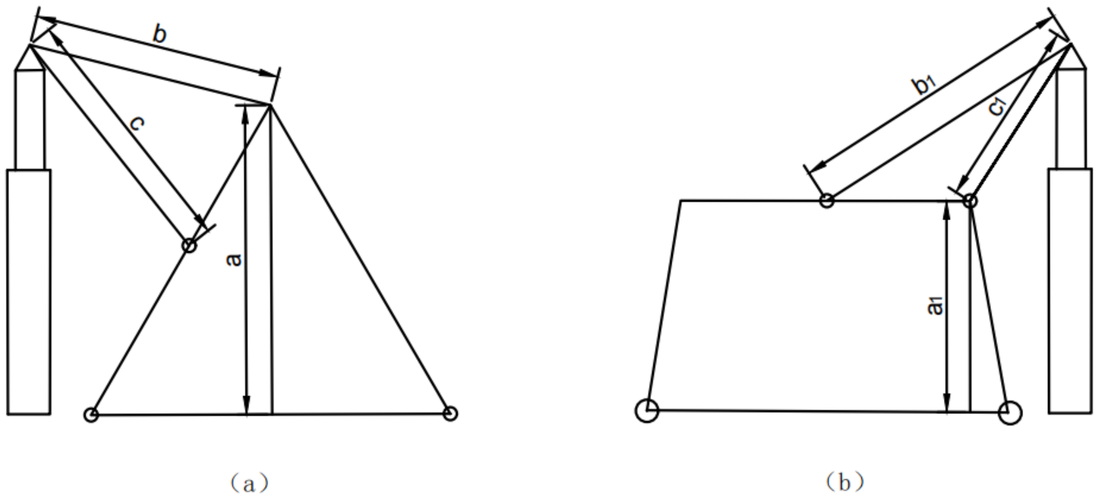

Figure 5. Length of section with fixed beam length(a)bridge folded(b)bridge horizontally expand

Through the length data of each part provided in Figure 5, the direction and distance that each joint moves in a small unit can be calculated, whether the whole bridge is unfolded horizontally or curled up.

3. Results

3.1. Calculate the degree of freedom

According to figure 4 and use the formula for calculating the degrees of freedom. It can be known that the degree of freedom of the unit is 2. Therefore, it is necessary to control two parts to make the mechanism can have a definite movement trajectory.

$$M = 3(N - J - 1) + \sum_{i=1}^{J} f_i = 2 \tag{2}$$

3.2. The force analysis of the basic units

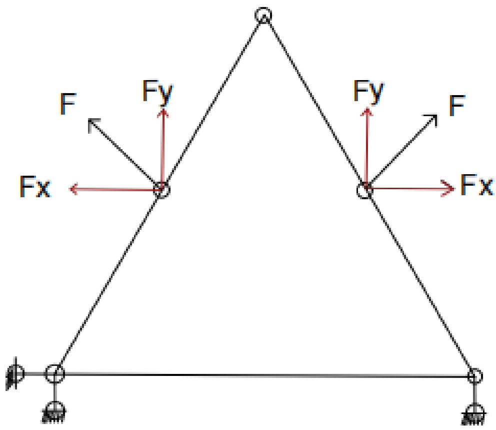

Figure 6. Force analysis in the horizontally expanded state

3.2.1. The force analysis of basic units when the bridge folded

When the entire bridge is unfolded horizontally, the force analysis of the internal structure under tension is shown in Figure 6. Under the pulling of the gear, two forces *F* will be provided to the internal structure. Ideally, the magnitude of the force is the same as the included angle of the joint. Each force *F* will have two component forces: the force f_y in the vertical direction and the force *fx* in the horizontal direction. As mentioned above, the magnitude of the force *F* is the same as the included angle of the joint, so the force in the horizontal direction is equal, and the distance of the horizontal movement of the two joints is equal. Therefore, the joint in the middle will not move in the horizontal direction but only in the vertical direction because the vertical components of the two *F* are in the same direction and will not cancel out.

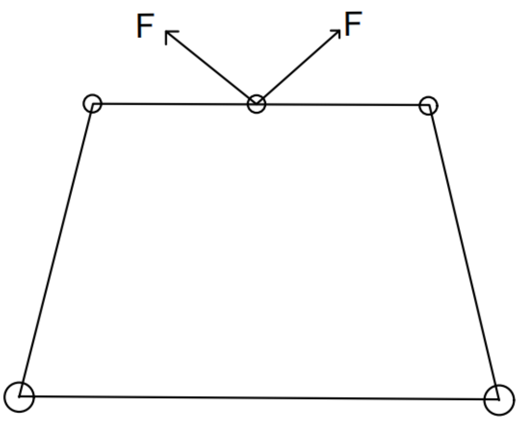

Figure 7. Force analysis when preparing to retract from a horizontal position

3.2.2. The force analysis of basic units when the bridge horizontal unfolded

The force analysis method in Figure 7 is similar to that in Figure 6. Under the pulling of the gear, two forces *F* will be provided to the internal structure. Ideally, the magnitude of the force is the same as the included angle of the joint. Each force *F* will have two components. One is the vertical force *fy*, and the other is the horizontal force *fx*. As mentioned above, the magnitude of the force *F* and included joint angle are the same and act on the same joint. Therefore, the force in the horizontal direction is equal, but the direction is opposite, so the distance of the horizontal movement of the joint receiving the force is 0. It will not perform any horizontal movement but will only move in the vertical direction because the vertical components of the two *F* are in the same direction, so it will not offset.

3.3. Calculate the moving distance of joint

Based on the figure5, we can calculate the moving distance of any joint when the bridge is unfolded or folded. Let the vertical distance between the top of the hydraulic column and the joint at the top of the triangle be x. The distance between the hydraulic column and the triangle is x_1. The side length of the triangle is d.b_1 is the distance between the center point of the internal structure and the top point of the hydraulic column when the bridge is unfolded, as shown in Figure 5.

$$b_1 = \sqrt{(x + a - x_1) + (x_1 + d / 2)} \tag{3}$$

c_1 can be obtained using the same method as b_1

3.4. Advantages of Hexagonal and Triangular Combination Structures

The combination of hexagon and triangle has better performance in terms of stability, stiffness, strength, and whatever the thicknesses were. If a structure with a specific load is required and there is no special requirement for the size, select triangular and hexagonal groups with smaller sizes can achieve the purpose. The composite structure can achieve the purpose of a lightweight design of the structure [10]. The new design has certain advantages in terms of stability and weight.

4. Conclusion

The current study did not determine the stress situation of each joint, and future research should determine the force situation of each joint and bar force. This paper's research shows that each small unit has five hinges and five bars and uses a fixed hinge connection at the bottom. The internal structure of the complete bridge changes from a triangle to a trapezoid when it is laterally unfolded. The internal structure changes from a trapezoid to a triangle when the entire bridge is folded laterally. Through the force analysis of two cases, the calculation of the degrees of freedom of the small unit and hydraulic column provides an analysis of the force given to each joint by deployment and expansion of the entire bridge and the placement of gears in the hydraulic column. This design can be shown to work, and each combination of triangles and hexagons is generally stable. It has better performance in terms of strength and strength. Using a combination of triangles and hexagons can achieve the same performance with less material for the same load. Therefore, using a combination of triangles and hexagons has advantages over conventional designs.

Through the calculation, this paper can know the moving distance of each joint and the change in the geometric state of the internal structure in the case of a fixed-length full beam and a fixed-length bar.

The main contribution of this paper is to improve the stability and strength of the internal structure of the rolling axle and reduce the weight. The above is conducive to improving the bridge's safe service life and load-bearing capacity and can reduce the consumption of specific non-essential resources.

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