Ecological construction method by the deployable bridge

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Abstract. Global warming is a result of greenhouse gas emission from various sources, such as industrial manufacturing, transportation, and construction activities. Among these, construction activities further involve the destruction of the natural environment, which should be protected for ecological balance. During construction, the natural environment should be protected by preserving the natural scenery while ensuring safe and rapid construction. To achieve this, the construction structure needs to be designed with the features of light weight, high efficiency, and safety using deployable structures. Deployable structures are superior over general structures because they can be extended in any area within a few hours and have less impact on the natural environment of the construction site, thus providing an alternative choice for environmental protection and conservation. In a deployable structure model, deployment and truss structures are combined using the scissor mechanism concept. However, the structure is required to remain in a stationary condition. Therefore, this study investigates the equilibrium theory of the scissor structure and presents the methodology of a new bridge construction method.

Keywords: Scissor Mechanism, Deployable Structure, Ecology Protection, Combined Deployable and Truss Structures.

1. Introduction

Greenhouse gas emission from various sectors, such as industrial manufacturing, vehicle mobilization, and construction activities, is the major contributor to global warming. Currently, construction activities are associated with environmental issues, particularly in developing countries because they are concentrating on quantity and rapidity rather than quality, considering the existing era of high economic competition.

In this paper, the authors would like to present the concept of constructing a pedestrian footbridge (hereinafter skywalk) in a national park without endangering the environment. People walking through the skywalk would experience the sense of a real forest on a small scale, and they can release stress and obtain fresh air for health recovery with good hospitality. Many construction projects are faced with the deterioration of the natural view during construction. Hence, to achieve the goal of construction and retain the original natural conditions, building an elevated pathway without affecting the natural environment is necessary. The authors anticipate the skywalk to be an alternative construction procedure in the future.
Moreover, this study would be focused on the stationary condition of the structure and the construction procedures by considering the free-body diagram (hereinafter FBD) on equilibrium equations of single-unit and double-unit structures. Figure 1 explains the basic concept of this study.

![Figure 1. Folding (a) and deploying (b) condition of the structure [1, 2].](image)

2. Structural design concept
The structure would be deployed using a hydraulic damper combined with the scissor mechanism. The structural members remain in a stationary condition during the structure deployment. Furthermore, the basement of the structure should be fixed with support material and the deploying capacity should be controllable using special methods (figure 1).

2.1. Deployable structure
A deployable structure is a structure whose shape can be transformed by increasing or decreasing the length in the horizontal or vertical direction [3-5]. A deployable structure is easy to store and transport as well as easily expandable for connecting between the two sides of a river or connecting different structures. Deployable structures are always deployed with mechanisms, such as rotation, folding, and sliding, as shown as figure 2 [6].

![Figure 2. Example of deployable structures in various forms [6].](image)

2.2. Scissor structures
The scissors structure has two members connected by a pivot joint (single pattern) and many patterns connected by connection points (completed set); the centre of the member has a pivot (rotating point) and hinge (connection at the end of the member). Normally, the members of the structure are assembled in an "X" shape for a single structure [3-5]. It is a mechanical system bridge for storage and transportation with the folding mechanism, offering easy installation through transformation or expansion.
2.3. Fundamental balance of structure concept

A deployable structure should be balanced during deployment and it should be kept under control. Otherwise, the structure will become unstable and prone to accidents during construction. The weight at the fixed member should be more than the deployable members, as shown in figure 3. The corresponding equation can be expressed as follows:

\[ \sum M_B = 0 \]

The condition of moment at supported point B = 0 (\( \sum M_B = 0 \)). Thus, we obtain the equation as follows:

\[ -R\lambda = (P_{i+1} - P_i) \frac{\lambda}{2} - \sum_{i=2}^{n} P_i \left( n - \frac{1}{2} \right) \lambda \]  

(1)

Here, \( R \) is the control load for balance; \( P_1, P_2, \ldots, P_i \) and \( P_{i+1}, \ldots, P_n \) are the distributed load; \( \lambda \) is the length of a unit scissor; and \( n \) is the number of patterns that can be increased according to requirements. Regarding the balanced condition of the structure of this equation, we suppose the balance point of the structure is Point B, the weight control is AB beam and the weight of AB beam is determined by the weight of BC beam, as shown in figure 3. Thus, the equation can be shown and described as follows:

2.3.1. Reaction of the structure

In equation (1), we suppose the balance point of the structure is point B. Thus, the reaction force will be equal to the sum load of \( R \) and \( P_i \).

We obtain the reaction force \( R \) from equation (1):

\[ R = \left( P_{i+1} - P_i \right) \frac{1}{2} + \sum_{i=2}^{n} P_i \left( n - \frac{1}{2} \right) \]  

(2)

In case of \( P_1 = P_{i+1} \), we obtain reaction \( R \) from the following equation:

\[ R = \sum_{i=2}^{n} P_i \left( n - \frac{1}{2} \right) \]  

(3)

2.3.2. Bending moment of the structure

We suppose \( P_1 = 1 \) kN, \( q = 0.32 \) kN/m, \( \lambda = 1 \) m; the moment analysis is separated into two parts of the member as 1st part: \( (0 \leq x < \lambda) \) and 2nd part: \( (0 \leq x < n\lambda) \). In the analysis, the structure is assumed to be in a stable condition by controlling the weights of \( P_1 \) and \( q \), controlling the \( n \) value using the equation, \n= \sqrt{\frac{2P_1}{q\lambda}} \), where \( \lambda \) is a constant, as shown in figure 4.
3. Mechanics of scissors structure

3.1. Mechanics of one-unit scissor structure

![Diagram of scissors structure](image)

**Figure 5.** FBD of scissors structure (a) and continuous condition of each member for AE and BD (b).

In this section, the mechanics of the scissors structure are reviewed [1, 2, 7-11]. FBD of a unit scissors structure is shown in figure 5a. When the length of the members is \( L_0 \) and the expanding angle of inclination is \( \theta \), the sectional length \( \lambda \) and height \( 2h \) are \( L_0 \sin \theta = \lambda \) and \( L_0 \cos \theta = 2h \), respectively. Thus, the construction and storage of such a structure can be shown by the angle \( \theta \). This unit scissors structure can be designed using the following equilibrium equations:

\[
\sum H = H_A - H_B + H_D - H_E = 0 \quad (4)
\]

\[
\sum V = V_A - V_B + V_D - V_E = 0 \quad (5)
\]

\[
\sum M_{at\ A} = (H_D - H_E) 2h + (V_B + V_E) \lambda = 0 \quad (6)
\]

\[
\sum M_{at\ B} = (H_D - H_E) 2h + (V_A + V_D) \lambda = 0 \quad (7)
\]

\[
\sum M_{at\ D} = (H_A + H_B) 2h + (V_B + V_E) \lambda = 0 \quad (8)
\]

\[
\sum M_{at\ E} = (H_A + H_B) 2h + (V_A + V_D) \lambda = 0 \quad (9)
\]

The equilibrium equation corresponding to each external force \( V_A, H_A \) and \( V_E, H_E \) is given as two expressions, and the equilibrium equations of the moment concerning each nodal point from A to D are set up with four expressions.

Regarding members AE and BD that intersect as shown in figure 5b, it is apparent that the equilibrium equations of a couple of moments occur at Point C.


According to equation 4 to equation 11, we can be presented as the following matrix by arranging the eight calculated equilibrium equations.

\[
\begin{bmatrix}
1 & 0 & -1 & 0 & 1 & 0 & -1 & 0 \\
0 & 1 & 0 & -1 & 0 & 1 & 0 & -1 \\
0 & 0 & \lambda & \lambda & 0 & -2h & \lambda & 0 \\
0 & \lambda & 0 & 0 & 2h & \lambda & -2h & 0 \\
-2h & 0 & 2h & \lambda & 0 & 0 & \lambda & 0 \\
-2h & \lambda & 2h & 0 & 0 & \lambda & 0 & 0 \\
-2h & \lambda & 0 & 0 & 0 & -2h & \lambda & 0 \\
0 & 0 & 2h & \lambda & 2h & \lambda & 0 & 0
\end{bmatrix}
\begin{bmatrix}
H_A \\
V_A \\
H_B \\
V_B \\
H_D \\
V_D \\
H_E \\
V_E
\end{bmatrix}
= \begin{bmatrix}
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0 \\
0
\end{bmatrix}
\]

However, the pivot of each scissor member is set up under the condition of continuity of the member. The horizontal and vertical lengths of scissor will be obtained by these calculations, \(2h = L_0 \cos \theta\) and \(\lambda = \frac{L_0}{\sin \theta}\). An unknown reaction force can be solved by considering the loading condition and the boundary condition for the equations of equilibrium.

3.2. Mechanics of two-unit scissors structure

This paper summarises the research and development of a Mobile Bridge (MB) and presents the fundamental, numerical, and experimental results based on the experimental MB4.0. Eigenvalue analysis revealed the basic vibration modes of MB4.0 and indicated that the major vibration of the scissor bridge depends on its boundary condition. Thus, it is more likely to vibrate in the horizontal direction rather than the vertical direction after installation. In addition, the experimental testing revealed logarithmic decrement of MB4.0. These results imply that, although MB4.0 is prone to vibration due to its flexible structure, it is not required to remain in a stable state. The conducted research allows for a better and safer design of MBs. More details of the experimental testing and numerical analysis will be presented at the conference [1, 2, 7-11].

A two-unit scissor structure under the cantilever condition, which includes pinned support at points \(B_{1}^l\) and \(A_{1}^l\) and a load \(P\) at point \(A_{2}^l\), as shown in figure 6, is considered as an example.

![Figure 6. Two-unit scissors structure of a cantilever model.](image)
In this problem, it is possible to treat the external forces as the left and right sides of internal forces operating on the hinges at points B_{1,2} and A_{1,2}. Hence, these relationships are expressed as,

\[
\begin{bmatrix}
B_{1,2}^x \\
B_{1,2}^y \\
A_{1,2}^x \\
A_{1,2}^y
\end{bmatrix} = \begin{bmatrix}
B_1^x \\
B_1^y \\
A_1^x \\
A_1^y
\end{bmatrix} + \begin{bmatrix}
B_2^x \\
B_2^y \\
A_2^x \\
A_2^y
\end{bmatrix}
\]  

(12)

\[
\{(B_{1,2},A_{1,2})\}^T = \{(B_1,A_1)^T\}^T + \{(B_2,A_2)^T\}^T
\]  

(13)

The matrix form for each scissor unit in the two-unit scissor problem can also be obtained by following a procedure similar to the one described for the unit scissor model. The equilibrium equation for the first unit can be expressed as

\[
L\{(B_1,A_1)^T\} = -R\{(B_1,A_1)^T\} - \{(C_{1,0})\}^T
\]  

(14)

Similarly, the equilibrium equation for the second unit can be expressed as

\[
L\{(A_2)^T\} = -R\{(A_2)^T\} - \{(C_{2,0})\}^T
\]  

(15)

Substituting equation (14) and equation (15) into equation (13) and rearranging them, the matrix form for the two-unit scissors problem under the cantilever condition is obtained:

\[
\{(B_{1,2}),A_{1,2}\}^T = -(L^{-1}R)^2 \{(B_2,A_2)^T\} - L^{-1}R\{(B_{1,2},A_{1,2})\}^T
\]  

(16)

By substituting the initial condition of \((A_{2,0})^y = P\) and the other nodal forces \(= 0\) into equation (14), the unknown reaction forces for the two-unit scissors structure can be expressed as \((A_{1,0})^x = -(B_1^1)_x = -2P\tan\theta\) and \((A_1^1)_y = P, (B_1^1)_y = 0\). Comparing the theoretical results for the one-unit and two-unit scissors structures, the vertical reaction forces are the same, but the horizontal reaction forces are doubled. Therefore, it is clear that the horizontal reaction forces may become very large if the number of scissor units is increased.

4. Construction procedure

Building a skywalk in a forest without deteriorating the environment is quite difficult. Furthermore, the construction should be completed within a limited time. Therefore, the scissor bridge model is an attractive alternative for achieving this goal. In this study, the authors consider the skywalk construction in two different types of areas in the national park (figure 7) by applying different techniques and types of machinery appropriately. The designed skywalk has a pentagonal shape elevated above the trees for natural scenery observation in the national park. The basement and upper structures are constructed using scissor mechanism concepts.
4.1. Construction procedure using machinery and hydraulic system

For a construction site in a high-mountain area, where access to normal machinery is limited and electricity is available, the construction procedure will include alternative machinery such as a helicopter for transport and a hydraulic system for deployment, as shown in figure 8 and figure 9.

Figure 7. Skywalk construction in a national park model.

Figure 8. Preparing procedure in folding condition by helicopter.
4.2. Construction procedure using only machinery
For construction in large, flat areas or small hills, where else the electricity has not available, only machinery, such as cranes or excavators, will be used for deployment, as shown in figure 10.

5. Conclusion
This development project investigated the scissors structure to propose the design concept for skywalk construction in a national park. The fundamental mechanism of one-unit and two-unit scissor structures were studied, and their corresponding matrix equilibrium equations were derived. Furthermore, alternative ideas of construction procedures under two construction scenarios were explored. The main conclusions of this study are as follows:

- The fundamental mechanism of the scissor structures for safe construction is to maintain balance by controlling the weight of the core and sub-structures.
- The fundamental mechanism of the scissor structures (one-unit and two-unit scissors structures) were investigated and their equilibrium equation forms were transformed into the matrix form.
- For building the skywalk in the national park, two types of construction procedures could be proposed under two scenarios. In the case of mountainous areas, using helicopters for transportation, and in case of small hill areas, using small crane trucks for transportation and assembly of the structure members.
- However, this expandable structure (rotatable form) has a limitation in that its horizontal vibration resistance is weak. Therefore, future studies should consider this limitation and other necessary factors.
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