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Analysis for Application of Spreadable Structures in Civil Engineering

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Abstract:

Spreadable structures have a long history of development, with the earliest examples dating back to folding umbrellas and simple folding mechanisms, the design of which was based on geometrical principles and accomplished by hand techniques. With the development of materials science and computational technology in the 19th and early 20th centuries, complex spreadable structures gradually appeared in fields such as architecture and aerospace. Contemporarily, spreadable structures have been increasingly used in the field of civil engineering, especially in house building and bridge engineering, because of their foldable, easy to transport and rapid deployment characteristics. This research is to explore the application of spreadable structures in civil engineering, focusing on their potential in house building and bridge construction. The study analyses the important role of spreadable structures in post-disaster emergency buildings and bridges, especially shear spreadable bridges incorporating a chordal support system, which significantly improves the stiffness and load carrying capacity of the structure. The significance of the study is that it provides new ideas for the application of spreadable structures in civil engineering, and the performance of spreadable structures will be further improved in the future by combining new materials, intelligent systems and parametric design. This not only contributes to the rapid response in post-disaster reconstruction and emergency rescue, but also provides innovative technical paths and more efficient solutions for future civil engineering design.

Keywords: Expandable structures; civil engineering; building construction; road and bridge.

1. Introduction

Spreadable structures have a long history of development, with the earliest spreadable structures including ancient folding umbrellas and simple folding mechanisms. These structures were largely based on basic geometric principles and handcrafted techniques. During the 19th - early 20th centuries, the theoretical foundations were gradually developed and the study of geometry and mechanics provided the scientific basis for the design of spreadable structures. The work of early scholars such as Hermann Hermann laid the foundations for the mathematical modelling of structures. After the 1960s of the 20th century, with the development of material science and computer technology, engineers began to design more complex spreadable structures, and spreadable structures formally appeared and developed [1]. For example, architectural membrane structures and deployable antenna systems are gradually applied in practical engineering. They generally have two stable forms, closed and unfolded [2, 3]. Until the end of the 1980s, the theory and technology of deployable structure application research level in the aerospace field increased rapidly, including NASA, ESA, Cambridge University, Massachusetts Institute of Technology (MIT), Oxford University, etc., which put forward a variety of concepts of deployable structure system. In the late 1990s, China gradually started the related research and exploration, in which many research units, Zhejiang University, Harbin Institute of Technology, Tsinghua University, Tianjin University, Tongji University, etc., carried out a large number of studies on the design principle, structural configuration, and mechanism motion analysis of the spreadable structure, and achieved a great deal of results [4]. Since the beginning of the 21st century, extensible structures have been widely used in modern design in the fields of architecture, robotics, and emergency response. Expandable structures are conceptually divided into four categories: folding structures, open-close structures, tensile monolithic structures, inflatable structures, and cable-membrane structures [5].

In contemporary society, spreadable structures are widely used, especially in the civil engineering industry. In the civil engineering industry the main focus is on the stiffness and stability of the structure after spreading, not caring much about the shape [6]. Spreadable structures are used in the design of modern building facades, such as folding and unfolding curtain wall systems [7]. These systems can regulate the light and ventilation of a building in different weather conditions. Spreadable membrane structures are widely used in exhibition halls, stadiums and event venues [8]. They can be quickly deployed or contracted when needed to adapt to different usage requirements. Spreadable structures are used as temporary shelters during natural disasters and emergencies [9]. These structures offer the advantages of rapid deployment, scalability and high adaptability. Spreadable bridges are used as temporary access routes in a number of special situations [10]. These bridges can be quickly deployed and dismantled to meet temporary traffic needs. Spreadable structures play an important role in dynamic architectural design, e.g., building facades can automatically adjust to sunlight, wind, or other environmental factors to optimise the building‘s energy efficiency and comfort [11].

Overall, the application of spreadable structures in civil engineering has become more and more widespread in recent years, not only playing an important role in construction and temporary facilities, but also showing its unique advantages in innovative design and public art. With the gradual improvement of the theory in recent years, spreadable structures are more and more widely used in civil engineering industry. This research makes a summary of the application of spreadable structures in civil engineering in recent years. This study will be in the spreadable structure today‘s development, housing construction, bridge engineering three aspects to tell.

2. Basic Introduction to Spreadable Structures

The concept of expandable structures originated in the early days of mankind for everyday use, such as foldable tents for outdoor activities, temporary shelters, and storage umbrellas. These structures were designed to be easily transformed from a compact state to a usable state by folding and unfolding, to save space and at the same time meet the needs of daily life. In the 20th century, with the development of material science and mechanical design disciplines, complex expandable structures became available for architectural, aerospace, and engineering applications. Expandable structures are structural systems that are capable of changes in form through movement, folding or other forms of transformation. They are compact in their folded state and provide the required function or space when unfolded. Their distinctive features are portability and efficient use of space, which makes them highly useful and convenient in scenarios that require rapid deployment or reusability [12].

Spreadable structures can be divided into the following four categories, namely folding structures, open and close structures, tensioned monolithic structures, inflatable structures and cable membrane structures. The following will be a specific description of these four types of structures. Folding structure: Folding structure is based on the geometric folding principle, usually through the plane or surface folding movement to achieve the purpose of compact storage and expansion. It is characterised by the ability to fold the structure through precisely designed creases or articulation points, and to return to its original form when unfolded. Folding structures are commonly used in space-limited applications, such as spacecraft antennas,

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solar panels, etc., and when unfolded, they can quickly provide a large area of space for use. Folding roofs and movable booths are also common applications in the construction field.

An open-close structure is a spreadable system formed by multiple members through hinges or joints that can open and close like scissors. The unfolding of this type of structure is usually achieved by the relative motion between the members, and the common form is the scissor structure [13].Such structures are widely used in the architectural field for temporary exhibition facilities, movable stages, retractable roofs, etc., and have the property of rapid unfolding and contraction. Classic examples include retractable awnings, scissor-type bridge structures, etc. Tensioned monolithic structure is a structural system that relies on tensile and compressive stresses to balance each other. It consists of compressed rods and tensile cables. The rods are not in direct contact with each other, and the tensile cables form an overall stable structure while maintaining tension. Tensioned structures are commonly used in lightweight buildings, bridges, temporary structures and other fields. Famous examples include the Getty Centre in the USA and many modern lightweight scaffolding designs.

Inflatable Structure and Rope and Membrane Structure: Inflatable structure is filled with air or gas into a flexible material (e.g., membrane material or fabric), using air pressure to maintain the shape and rigidity of the structure. It is a form of structure with the advantages of rapid deployment and large area coverage. A cable membrane structure is a spatial structure formed by the combined action of a flexible membrane material and steel cables or other flexible materials. The steel cables or steel cables provide the tensile force, and the membrane material forms the pre-stress under the action of the cables to maintain the stability of the structure. Inflatable structures and cable-membrane structures are mainly used in rescue, temporary shelters, air-membrane stadiums, temporary exhibition halls and other scenarios are very common, but also commonly used in large-span buildings, such as sports stadiums, airport terminals, large exhibition halls. Classic examples include the cable membrane roof structure of the Munich Olympic Stadium. It is especially widely used in situations where rapid erection and dismantling is required.

3. Experiments and Discussion

3.1 Application of Spreadable Structures in House Construction

In recent years, there have been frequent natural disasters worldwide, such as floods, earthquakes and hurricanes. Frequent natural disasters have led to massive population displacement and property damage. Man-made disasters (e.g., wars, explosions) cannot be ignored, and have likewise caused large-scale destruction of infrastructure, especially housing construction. While tents for temporary accommodation can alleviate some of the housing problems of the affected population, they are usually designed for short-term use, whereas in real-life situations it can take years for people to return to normal-use housing, so temporary shelters are often not durable and prone to health problems. Spreadable structures, on the other hand, are lightweight, easy to transport and deploy, and are able to unfold from a compact form to a functional one in a short period of time, with the capacity to withstand high loads. These structures can be used as temporary shelters for communities in the aftermath of a disaster, providing a quick housing solution, mitigating the impact on affected communities and helping to restore infrastructure.

One of the main types of scissor structures used is the scissor structure, which can be adapted to different application scenarios through the use of simple mechanical principles to achieve geometric changes. Fig. 1 shows a very typical scissor model. Because of their simplicity, these structures are widely used for temporary construction in disaster-affected areas.

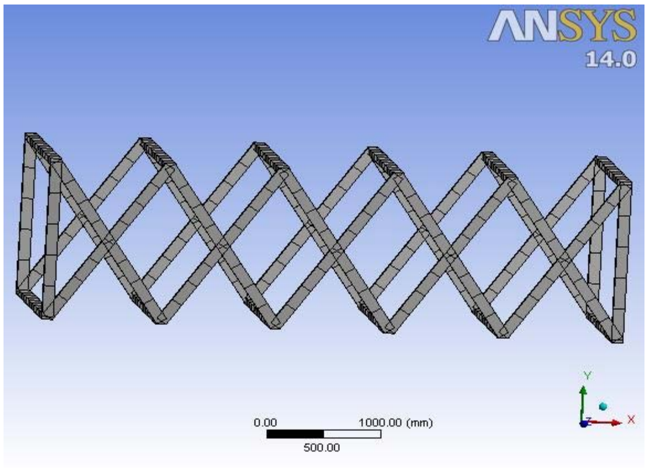

Fig. 1 3-D model of Bridge model [14].

The structure made of this structure (as in Fig. 2) can take up less space in compact form and hold up more space in functional mode for easy access. Secondly the materials of the spreadable structure are recyclable and easy to build and use with low skilled labour. The design also considers the flexibility, expandability and durability of the structure to meet long-term needs.

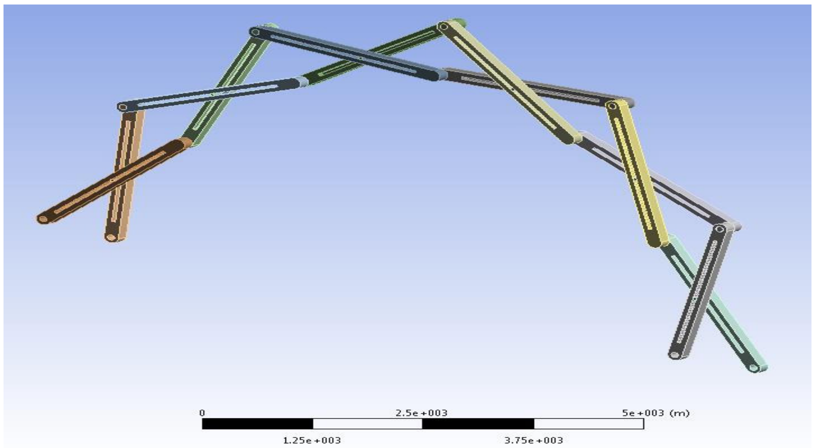

Fig. 2 Deployable Shelter model [14].

3.2 Application of Spreadable Structures in Bridge Engineering

Because it is more convenient to use, spreadable structure is also widely used in bridges. Especially in the construction of post-disaster emergency rescue channel, due to its simple production and easy to use, it is respected by rescuers. Abroad, Ario et al. proposed a shear spreadable bridge through the topology optimisation of solidly supported beams at both ends under the action of uniform load in the span [15], carried out the theoretical analysis of the static performance of the shear spreadable structure [16], the finite element simulation and experimental study [17] and the vibration modal analysis [18]. However conventional shear mechanisms generally suffer from poor stiffness and low material utilisation. The new string-supported shear spreadable bridge formed by slightly improving the shear structure and combining the string-supported system aims to improve the structural load carrying capacity and bending performance, e.g., the deflection of the shear mechanism is reduced by using the cable pre-stressing and the structural stress is improved □ so as to realise a kind of high-mobility, high-load-bearing emergency rescue equipment.

The optimised design of the new chord-supported shear spreadable bridge structure significantly improves the stiffness and load-bearing performance of the bridge, which makes its application in emergency rescue more advantageous. The dynamic characteristics of the bridge and its wide application in military and civil applications can be further investigated in the future. It can be seen that spreadable structures are also widely used in bridge engineering, but the performance of spreadable structures under dynamic loading has not yet been widely studied, such as the effect of travelling loads on bridge shear structures, etc., which requires further development and research [18].

4. Limitations and Prospects

Although the spreadable structure is very convenient to use, there are also many problems in the process of use. Firstly, the shear spreadable structure mainly relies on the bending resistance of the shear rods in the stressing process, which leads to its poor stiffness. This structure is prone to large deflection under high load conditions, which reduces its load-bearing performance. Secondly, the low utilisation of materials is also a major limitation, especially in areas such as post-disaster emergency bridges, where the lack of material strength and stiffness can affect their safety. Despite the lightweight and mobility of spreadable structures, their complex geometry and high-precision fabrication requirements result in high design and construction costs. In post-disaster applications, the deployment of spreadable structures requires precise mechanical components, especially when high stress environments are involved, and the additional cost and technical requirements become a bottleneck for implementation. The performance of spreadable structures under dynamic loading has not been extensively studied, such as the effect of travelling loads on bridge shear structures. The adaptability of such structures to cope with complex terrain and dynamic environments needs to be further improved.

Even though there are some problems with the current use of spreadable structures in civil engineering, the outlook is still favourable. In the future, spreadable structures are expected to improve strength and stiffness while reducing weight through the application of new materials (e.g. composites, fibre-reinforced plastics). These materials can improve the performance of existing structures, especially for applications in extreme environments. Meanwhile, the intelligent development of spreadable structures is an important direction, which in the future can integrate sensors and automatic control systems to enable them to au-

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tomatically adjust to external conditions. This will greatly enhance its ability to cope with complex environments, especially in disaster rescue and emergency engineering applications. Overall, despite the current limitations of spreadable structures in terms of material, stiffness and cost, through technological innovation and optimal design, their application in civil engineering is promising, especially in post-disaster reconstruction and emergency rescue.

5. Conclusion

To sum up, this research focuses on the application of spreadable structures in civil engineering, and explores their wide range of applications in areas such as housing construction and bridge engineering. Spreadable structures are particularly suitable for application in scenarios such as post-disaster emergency relief due to their lightweight, easy transport and rapid deployment characteristics. However, studies have shown that the existing spreadable structures still have some limitations in terms of material utilisation, stiffness and load resistance performance, especially under dynamic loading environments with less than satisfactory performance. By optimising the design of the new chord-supported shear spreadable bridge, the stiffness and load carrying capacity of the structure have been significantly improved, providing a more efficient solution for future emergency engineering. The research significance of this paper lies in the systematic summary of the advantages and shortcomings of spreadable structures in civil engineering, and through specific case studies, it proposes the future development direction of improving the performance of spreadable structures through material and technological innovations, intelligent development, parametric design and other means. This not only provides new ideas for post-disaster reconstruction and emergency rescue, but also brings important insights for the future structural design of civil engineering.

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