

Study on Geometric Composition Analysis Method of Plane Bar Structure

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Abstract. The analysis of the geometric composition of planar bar structures is of great importance to both civil engineering students and scholars. In this paper, the basic method of the geometrical composition of the planar member structure is described, and the geometric composition method of the system standard is given by combining the common method with a single method. Firstly, the methods and techniques involved in the existing literature are summarized, and these methods are comprehensively evaluated. Then, the analysis method of plane geometry composition and the standardization application flow are presented, including the analysis of difficulties and the solutions. Finally, the application of Equivalent Replacement method to solve the problem is illustrated by examples. This paper can help the relevant industry and scholars to solve the geometric composition of the planar bar structure more effectively and avoid some mistakes. It can also provide a standard process for beginners to solve problems such as ignoring rigid bodies.

Keywords: Plane bar structure; Structural mechanics; Systematic normative.

1. Introduction

With the gradual development of modern civil engineering, the field of structural mechanics has also made great progress. Among them, the geometric composition analysis of plane bar structures, as the basic knowledge of structural mechanics, has been continuously reasoned, practiced, summarized and improved by countless scholars in the past [1]. A large number of analysis methods of the geometric composition of plane bar structures have been continuously improved in the process of practice. These methods have great academic and practical value for students and for those engaged in related industries in civil engineering and construction. For example, the method of ignoring the basis of providing exactly three constraints in geometric analysis effectively simplifies the cumbersome and complex plane bar structure, and provides great help for the design and construction of infrastructure of many large truss structures and steel frame structures at home and abroad. At present, this method has developed many branches, including the hinged triangle rule, instantaneous hinge, infinite hinge, binary body removal and expansion basis. However, there is no standardized application process for the various types of plane bar structure geometric composition analysis methods that have been widely used, which leads to information gaps between workers and scholars in different civil engineering and construction industries, and causes obstacles in academic exchanges and engineering exchanges. This article will provide a standardized application process by describing, explaining and evaluating the existing geometric composition analysis methods.

2. Evaluation of Existing Methods

2.1. Articulated Triangle Rule

In middle school mathematics teaching content, triangles have strong stability, and the static determination of planar rod structures mainly relies on this law. In the analysis of the geometric composition of the truss, it is most important to find the triangle composed of rigid bodies. In the geometric analysis process of plane bar structures, if a rigid body is combined with other rigid bodies to form a triangle through the constraints of a chain or hinge, the geometry of the structure will be unchanged [2]. If the geometrically invariant body is connected to the earth through three constraints,



the structure is a statically determinate structure with the configurational freedom of 0. If the earth provides redundant constraints, the structure is an over-static structure. To achieve an articulated triangle, the number of rigid bodies is different and the way of articulation is also different, as shown in Fig. 1~Fig.3.

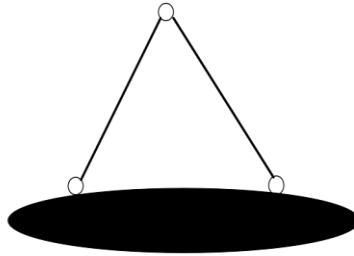


Figure 1. Articulated triangle with single rigid body



Figure 2. Articulated triangle with three rigid body

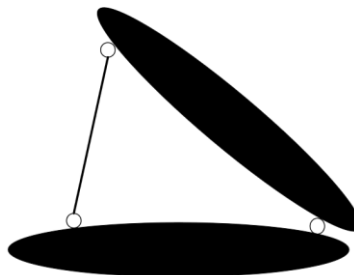


Figure 3. Articulated triangle with double rigid body

2.2. Instantaneous Hinge and Infinite Hinge

In geometric analysis, the hinge is a very important means of providing constraints. There are two special hinges, which called the instantaneous hinge and the infinite hinge, both of which are composed of double links to the structure. The logic is that each link can provide only one constraint to the structure, and each hinge provides two constraints, as shown in Fig. 4.

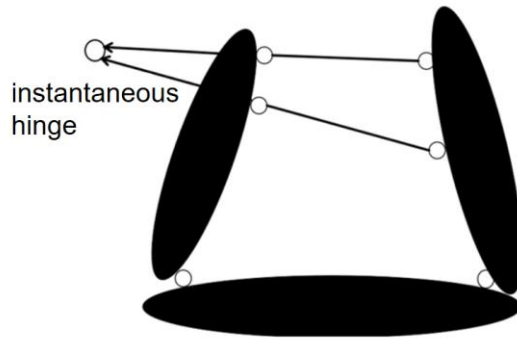


Figure 4. The instantaneous hinge

The reason why the instant hinge is called an instant hinge is mainly because the position of the virtual hinge point where the extension lines of the two links intersect will change. It is fixed in a certain position for only a moment, but it can still provide two constraints for the structure, and the function is the same as a hinge, so the two links can be regarded as a hinge. The concept of the infinite hinge is similar to the instant hinge. The difference from the instant hinge is that the two links that fix the rigid body are parallel to each other, as shown in Fig. 5. From a geometric point of view, two parallel straight lines will have an intersection at infinity, so the virtual hinge is at infinity and is called an infinity hinge.

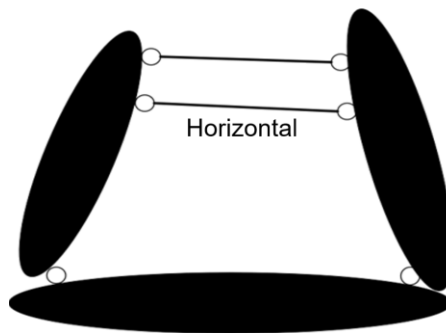


Figure 5. The infinity hinge

2.3. The Techniques of Binary Body Removal and Basic Rigid Sheet Expansion

In the field of structural mechanics, there are many ways to simplify plane geometric structures. The most commonly used methods are to remove the binary body and expand the basic rigid plate. The method of removing the binary body is the most common, but before explaining this method, the concept of the binary body should be understood first. As the name suggests, the binary body is a structure formed by combining two rods with a hinge and then hinged the ends of the two rods on the rigid plate. Such a structure has a characteristic, that is, "it will not interfere with the selection and expansion combination of the rigid plate". The specific logic is as follows: the sum of the degrees of freedom of the two rods themselves is 6, through the hinge connection, the degree of freedom is negative 2, and through two independent hinges connected to the rigid body, the degree of freedom is negative 4, which makes it have no effect on the degree of freedom of the entire plane bar structure; and it itself constitutes a local geometrically invariant system, so adding or reducing the binary body will not change the geometric structural characteristics of the original plane bar structure. The simplified plane geometric system by binary extraction and removal is shown in Fig. 6.

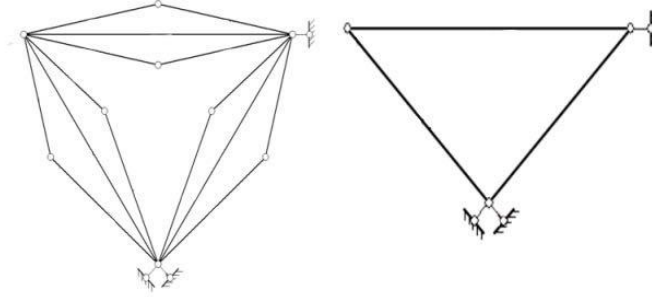


Figure 6. Schematic diagram of the structure before and after remove of binary body

After simplification, the properties of the original geometric structure have not changed at all, the front and rear freedom of structure are both 0, and both are statically determinate structures. However, it is obviously much simpler, making it easier to analyze static of structure and other issues.

Another method is the basic rigid sheet expansion method, which is only applicable when the foundation provides more than or equal to four constraints. Because the foundation provides more than three constraints at this time, it can be regarded as a rigid sheet, called the basic rigid sheet. If the basic rigid sheet is connected to other rods or rigid sheets through the articulated triangle rule at this time, the basic rigid sheet and the triangle formed by the articulation will be merged to form a larger rigid sheet, so that the basic rigid sheet is expanded, so there is no need to analyze the original articulated triangle, which greatly reduces the workload of geometric analysis, so that it will be able to avoid wasting time on cumbersome steps.

2.4. Evaluation of Existed Methods

Although the above methods can greatly improve the efficiency of geometric analysis, can deal with a variety of complex structures, and have been logically demonstrated, they have also provided great help in solving various structural mechanics problems and civil engineering structure design. However, due to the irregular time of invention of these methods and their excessive reliance on experience, there is still no systematic analysis method for the geometric analysis of planar bar structures, and there is a lack of standardized application.

3. Method Analysis and Standardized Application Process

3.1. Difficulty Analysis

When using the above methods to analyze planar bar structures, especially beginners of structural mechanics, who lack practical experience, often encounter many difficulties. There are roughly three difficulties worth discussing.

(1) The selection of rigid plates will be a difficulty [3]. This is the most difficult point in my opinion, because the rigid plates that the problem solver needs to find can completely cover all the nodes of the geometric system, and at the same time, it is necessary to ensure that the outer nodes of the rigid plates are connected to each other, and this is easy to be misled by the internal structure and the connection position of the foundation. In many cases, if the simplification is not in place, it is easy to misjudge the rigid plates, resulting in analysis errors.

(2) Whether the foundation is ignored or not is also a difficulty. At first glance, whether to regard the foundation as a rigid plate is just to judge whether the number of constraints provided by the foundation is greater than 3, but the judgment of redundant constraints has also become a major difficulty. At the same time, because the shape of the foundation is often special, many beginners tend to regard different parts of the foundation rigid plate as different rigid plates, resulting in the subsequent wrong selection of rigid plates.

(3) It is the problem of selecting the number of rigid plates. In the geometric analysis of a planar bar structure, a maximum of three rigid plates can be selected. Part of the redundant structure is expanded and swallowed up by the rigid plates, while the other part such as a binary body is ignored or replaced by another equivalent structure. When performing geometric analysis, it is easy to mistakenly select too many rigid plates.

3.2. The Solution of Difficulties

There are also some methods could solve these difficulties.

(1) The best solution to the difficulty in selecting rigid plates is to make sure the correctness of the choice of whether to ignore the foundation or not, and at the same time confirm that the plane bar structure has been completely simplified, so as to effectively reduce misleading factors.

(2) There are also good solutions for whether to ignore the foundation or not. For example, the method of expanding the foundation plate is preferred to simplify the geometry of the structure, which can effectively avoid misjudgment caused by the special shape of the foundation rigid plate.

(3) The number of rigid plates is selected, and the method is the same as the first item in this paragraph.

3.3. The Standardized Application Process

In view of the above three difficulties and their solutions, the standardized application of simplified methods for geometric analysis of planar bar structures has taken shape. The method sequence is as follows:

(1) The foundation is analyzed, ignoring the foundation or expanding the foundation rigid plate.

(2) The binary body is removed to maximize the simplification of the structure.

(3) The rigid sheet of the structure is selected according to the articulated triangle rule.

4. The Examples of Application: Equivalent Replacement

In the geometric composition analysis of planar bar structures, equivalent substitution is the core idea of the above methods [4, 5]. For example, treating the foundation that provides more than three constraints as a rigid sheet is an equivalent substitution idea. As shown in Fig. 6, the complex planar bar structure unit is simplified into a chain rod, and the overall geometric properties do not change. In addition, instantaneous hinges and infinite hinges are also a manifestation of an equivalent substitution idea, that is, using simple hinges to replace complex multiple chain rods, which belongs to the equivalent substitution idea of constraints.

For two other examples, as shown in Fig. 7 and Fig. 8, the structure after simplifying process will become an single rigid plates formed by a single rod or a single triangle with three rod.

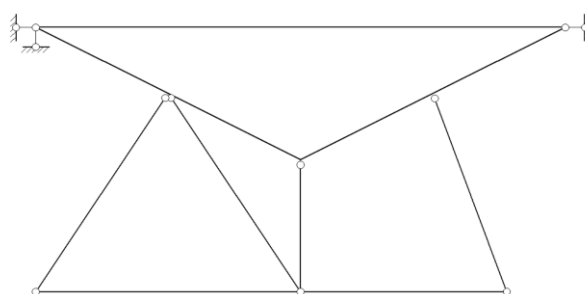


Figure 7. A complex Plane bar structure based on a triangle

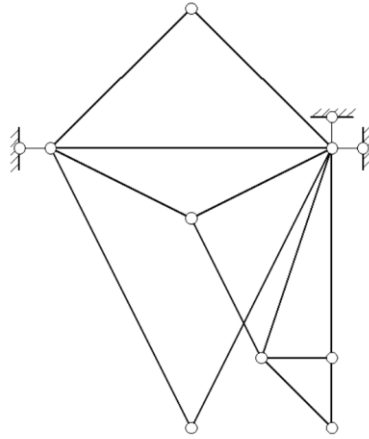


Figure 8. A complex Plane bar structure based on a single rod

5. Conclusion

In summary, the logical reasoning and application of the above methods can draw the following conclusions:

- (1) After in-depth logical reasoning and practical operation of the problem, it is proved from both experience and logic that the above methods are extremely suitable for solving the geometric analysis of plane bar structures.
- (2) The process of first determining whether the basic rigid plate is selected, then selecting and eliminating the binary body, and finally selecting the rigid plate to form an articulated triangle is more reasonable and efficient than the previous problem-solving methods. It can largely avoid various mistakes that civil engineering scholars and related industries are prone to in the structural mechanics sector, and can effectively improve the efficiency of problem solving and work. At the same time, it also provides a reasonable and effective option for communication between scholars and knowledge transfer between teachers and students.
- (3) The given standardized geometric analysis process has certain shortcomings in some special cases and actual use, such as the failure to solve the interference of the superposition of rods on the problem-solving process.

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