

An internal force solving method and its application in teaching of mechanics of materials

Wei-Wei Zhu

School of Urban and Rural Construction & Engineering Management, Kunming University, Kunming, China

Abstract. This paper presents an improved method of positive assumption for internal force solving, and the application process of this improved method is introduced by some examples, matters to be noted in teaching by this improved method are also analyzed. Teaching practice shows that using improved method of positive assumption to solve internal force, can effectively reduce the error rate, improve the students' ability to analyze the internal force, increase the confidence in *mechanics of materials* learning, and can produce positive transfer effect for subsequent rated courses learning.

1 The position of internal force analysis in the course of mechanics of materials

Mechanics of Materials is an important basic course for civil engineering major, which lays the foundation of the theory and method of the following courses. Internal force analysis of the engineering member is the basis of the strength and deformation research. Our teaching practice shows that, *Mechanics of Materials* is a difficult course for beginners; many students can not correctly understand and grasp the positive and negative rules of internal force, resulting in error of internal force calculating, thus weakening the enthusiasm of learning this course. Therefore, it is necessary to summarize the method of internal force solving, form effective teaching ways, to improve students' enthusiasm for learning, deepen and promote the understanding and application of relevant knowledge.

2 Problems existing in internal force solving by traditional method of positive assumption

Method of positive assumption has become a commonly used method in internal force solving. In [1-2], the basic idea of traditional method of positive assumption is: no matter what kind of deformation member occurs, when drawing free-body diagram, each internal force on the section is uniformly arranged in a direction consistent with the stipulated positive, then, establish the equilibrium equation of force system according to the reference coordinate system. In the equilibrium equation, a force is marked as positive if it is consistent with the positive direction of coordinates; on the contrary, it is marked as negative. If the solution value of the equation is positive, the internal force direction assumed is the same as the actual direction; if solution is negative, the internal force direction assumed is by the contrary to the actual direction. Here is an example to illustrate the process using traditional method of positive assumption to solve internal force.

Example 1: a straight rod is loaded by 6 axial external forces as shown in Figure.1 (a), determine the internal force on section m — m . (unit: kN)



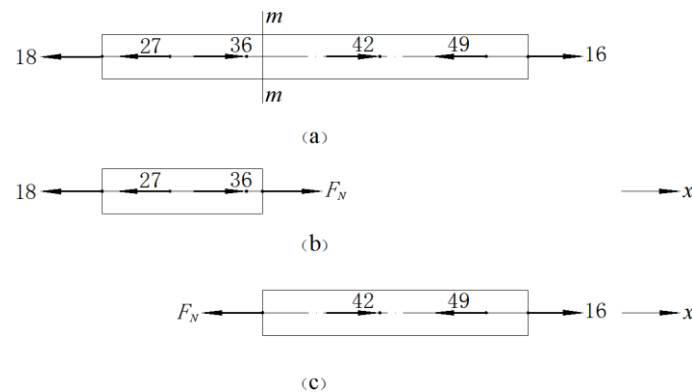


Figure 1. Force analysis of example 1

Solution:

It is assumed that the m — m section is used to cut off the rod, and the left side of the free-body is analyzed, free-body diagram is shown in Fig. 1 (b). Because the tension force is stipulated as positive in *Mechanics of Materials*, the internal force on the section is set to be positive (leaving the section), and an axis x is established (take horizontal—right as positive direction in this example).

Establish the equilibrium equation according to the direction of axis x : $\sum F_x = 0$,
 $-18 - 27 + 36 + F_N = 0$, $F_N = 9(kN)$.

The value of the solution is positive, indicating that the internal force on the section is also positive (leaving the section), that is, the actual internal force is tension force.

However, this traditional method is worth discussing: in the process of establishing the equilibrium equation, the establishment of the reference axis is arbitrary, and can be established according to the actual needs of the problem. In the solving process of this example, horizontal—right is taken as positive direction of x axis, so just make the axial force F_N stay positive in the equilibrium equation. However, even if the x axis is in the horizontal direction, it is not possible to ensure that the axial force which is consistent with the positive direction of the reference axis must be tension force. As shown in Fig. 1 (c), according to the traditional method of positive assumption, the m — m section is used to cut off the rod, and the right side of the free-body is analyzed, the internal force on the section is set to be positive (leaving the section), establish a x axis which horizontal—right is taken as positive direction. Then establish the equilibrium equation according to the x axis, we have $\sum F_x = 0$, that is $-F_N + 42 - 49 + 16 = 0$, $F_N = 9(kN)$, the value of the solution is positive, indicating that the internal force on the section is also positive (leaving the section), that is, the actual internal force is tension force. So far, many students will have questions: since it is method of positive assumption, why the internal force has been "assumed to be positive" is marked as negative in the equilibrium equation? In fact, it is because that the traditional method of positive assumption is easy to cause confusion between the positive and negative of reference axis direction and the positive and negative of internal force. In order to avoid the "chaos", the author proposes an improved method of positive assumption.

3 An improved method of positive assumption for solving internal force

3.1 The application steps of improved method of positive assumption

(1) No matter what kind of deformation member occurs, when drawing free-body diagram, each internal force on the section is uniformly arranged in a direction consistent with the stipulated positive.

(2) Do not need to draw the reference axis, write the equilibrium equation of force system directly. When writing equilibrium equation, first to write the internal force which is set as positive, if the directions of the other forces is the same as which is set as positive, it is marked as positive, on the contrary, it is marked as negative (here the "force" refers to the generalized force, including the moment).

(3) Solve the equilibrium equation of force system. If solution value of the equation is positive, the actual internal force is the internal force which is stipulated as positive; if solution value is negative, is the internal force which is stipulated as negative.

In step (2), we first to write the internal force which is set as positive because it is convenient to determine the positive or negative sign of forces other than the internal forces, teaching practice proves that this treatment can indeed greatly reduce the rate of students' mistakes.

3.2 Application examples

Example 2: the problem is the same as that of example 1; force analysis diagram is shown in figure 2.

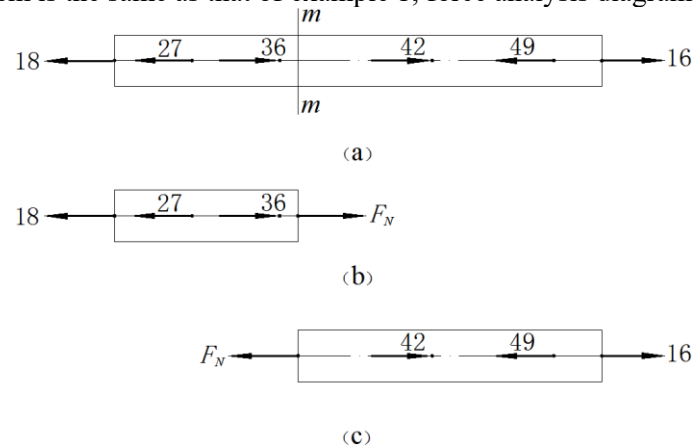


Figure 2. Force analysis of example 2

Solution:

It is assumed that the m — m section is used to cut off the rod, and the left side of the free-body is analyzed, free-body diagram is shown in Fig. 2 (b). Because the tension force is stipulated as positive in *Mechanics of Materials*, the internal force on the section is set to be positive (leaving the cross section). Do not need to draw the reference axis, write the equilibrium equation directly: $F_N + 36 - 27 - 18 = 0$, $F_N = 9(kN)$.

The value of the solution is positive, indicating that the internal force on the section is the internal force which is stipulated as positive in *Mechanics of Materials* (tension force).

If the right side of the free-body is analyzed, as shown in Figure.2 (c), set the internal force on the section to be positive (leaving the section), do not draw the reference axis, write the equilibrium equation directly: $F_N - 42 + 49 - 16 = 0$, $F_N = 9(kN)$.

The value of the solution is positive, indicating that the internal force on the section is the internal force which is stipulated as positive (tension force).

Example 3: determine the internal force on section m — m of the simply supported beam AB as shown in Figure.3 (a).

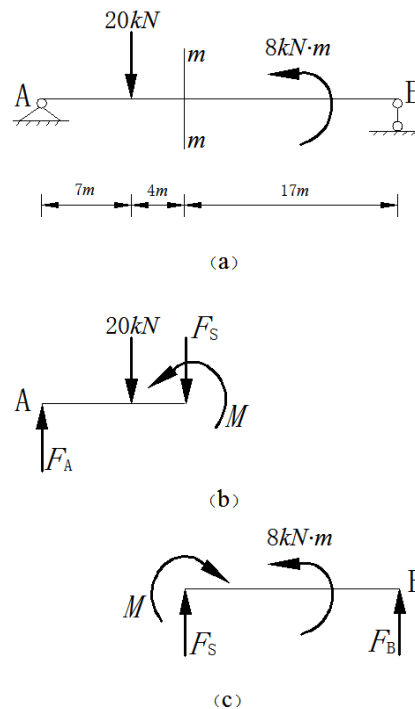


Figure 3. Force analysis of example 3

Solution:

Reactions at A and B can be determined from equation of static equilibrium: $F_A = 15.3\text{kN}(\uparrow)$, $F_B = 4.7\text{kN}(\uparrow)$, the solution procedure is omitted here.

It is assumed that the m — m section is used to cut off the beam, and the left side of the free-body is analyzed as shown in Fig. 3 (b). Because the shearing force that causes the beam segment to rotate clockwise is stipulated as positive, the shearing force on the section is set to be positive (downward); Because the bending moment that causes the underside of beam segment to be in tension is stipulated as positive, the bending moment on the section is set to be positive (counterclockwise). Do not need to draw the reference axis, write the equilibrium equation directly: $F_s + 20 - 15.3 = 0$, $M + 20 \times 4 - 15.3 \times (7 + 4) = 0$, Shearing force $F_s = -4.7(\text{kN})$, bending moment $M = 88.3(\text{kN} \cdot \text{m})$. The value of the solution is negative, indicating that the shearing force on the section is actually negative.

If the right side of the free-body is analyzed, as shown in Figure.3 (c), set the shearing force and the bending moment on the section to be positive (the shearing force is upward and the bending moment is clockwise), do not need to draw the reference axis, write the equilibrium equation directly: $F_s + 4.7 = 0$, $M - 8 - 4.7 \times 17 = 0$, Shearing force $F_s = -4.7(\text{kN})$, bending moment $M = 87.9(\text{kN} \cdot \text{m})$. The value of the solution is negative, indicating that the shearing force on the section is actually negative. (The difference between the two bending moments is $0.4\text{kN} \cdot \text{m}$, which is the error caused by keeping a decimal place.)

This improved method of positive assumption can also be used for solving torque, writing bending moment equation and shearing force equation, here is no longer for them.

It should be pointed out that in the general methods to solve the internal force, including the traditional method of positive assumption, when writing equilibrium equation, it is necessary to draw a positive axis to be used as a reference for the positive and negative sign of the force in the equilibrium equation, as shown in Fig. 1(the x axis). The improved method of positive assumption proposed in this paper does not need to draw the reference axis. It can be understood that the direction of the gen-

eralized internal force, which is defined as the positive direction of the "potential" reference axis, is not necessary to draw it.

4 Teaching application analysis

After several years of teaching practice, the author believes that the use of this method of positive assumption to solve the internal force has the following advantages:

(1) On the basis of being familiar with the nature of internal forces and their positive and negative rules, using the improved method of positive assumption to calculate the axial force, torque, shearing force and bending moment, is conducive to deepening the understanding of basic concept and relative knowledge of these internal forces, improving the accuracy of internal force analysis and solution, so as to improve the learning self-confidence and enthusiasm of *Mechanics of Materials*.

(2) When calculating the internal force on a section of a beam, the traditional method of positive assumption and the improved method of positive assumption proposed in this paper are not simpler than "the simplified method" which is presented on many textbooks. However, in calculating shear force and bending moment, compared with the simplified method, the improved method of positive assumption is helpful to improve the understanding of the basic concepts. ("The simplified method" here is: on the free-body, forces that rotate clockwise around the section produce positive shearing force, and forces that rotate counterclockwise around the section produce negative shearing force; upward forces produce positive bending moment, downward forces produce negative bending moment.)

(3) Learning and mastering the improved method of positive assumption for internal force solving can produce positive transfer effect on the learning of the following contents of *Mechanics of Materials*.

However, any kind of teaching method is not omnipotent; it can not be applied to all students. We should pay attention to the following matters when using improved method of positive assumption to solve the internal force in classroom teaching:

(1) Whether the students have formed the thinking mode of "solving the internal force must use the improved method of positive assumption", which makes the simple problem complex. In the daily teaching and homework marking, teachers should observe the students' ability of flexible use of the method.

(2) The cultivation of students' learning transfer ability should be strengthened consciously in teaching. We have found that in the first few years of teaching, many students can skillfully use the improved method of positive assumption for internal force solving after learning tension and compression, but in the study of torsion and bending deformation, students often do not think of or can't use this method correctly. The reason is that the characteristics of torsion and bending deformation, as well as the nature and the sign rules of torque, shearing force, bending moment and other internal forces are not understood accurately enough. In view of this, [3] puts forward "the discovery teaching mode", [4] puts forward "the research teaching mode", and [5] puts forward "the independent participation teaching mode with experiment as the guide", these are very meaningful exploration.

5 Conclusions

Internal force calculation and analysis is the basic content of *Mechanics of Materials*. As a teacher, it is necessary to summarize the daily teaching activities, and then sums up some ways to make students easy to master the internal force solving, so as to improve the learning efficiency. We have used the improved method of positive assumption proposed in this paper recent years in teaching and have achieved good effect. It should be noted that in the daily teaching and homework correcting, teachers should be fully aware of whether students can really use the method flexibly, and at the same time, should consciously use some innovative teaching methods to enhance students' ability of learning transfer.

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