Research on impact performance of prestressed steel strand

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Abstract. As a common prestressed member, the steel strand has a wide range of applications. Its bearing capacity affects the safety of the whole structure. Once it is damaged, the whole structure will be damaged or even collapsed. As a single tension bearing member, the transverse behavior of steel strand is often ignored. However, in recent years, the impact fracture accidents of steel strand occur frequently, and the research on transverse impact resistance of steel strand is very important. At present, there is no reliable evaluation standard for the mechanical properties of steel strand subjected to impact. The strand is made of several independent wires. Under the action of external load, the stress of each strand is different, and the stress distribution inside the strand is more complex. Under the action of transverse impact, the fracture position and quantity of strands are different, and the failure modes caused by different impact conditions are also different. In order to understand the mechanical performance of steel strand under transverse impact and provide evaluation basis to improve the structural safety, this paper carried out relevant research through test and finite element simulation method.

1. Test on impact performance of prestressed steel strand

1.1 Experimental scheme
The low-speed impact test of steel strand with high-quality drop hammer is carried out to explore its impact resistance performance, and the deformation, strain and failure mode of steel strand under different impact height and prestressing grade are studied.

1.2 Prestress application mode
The overall prestressing force is applied by the tool combination of oil pump and Jack, and the prestress value can be measured through the matching data of through core sensor.

1.3 Impact under different prestress
In this test, single wire coated epoxy coated steel strand with the same size and specification is used. The impact condition is only to change the size of prestressing force on the steel strand, and other impact conditions are the same. The specific test impact scheme is shown in Table 1, and the corresponding failure mode is shown in Figure 1.
Table 1. Stranded wire impact conditions

| Height (m) | Impact energy (kJ) | Prestress (N) |
|------------|--------------------|---------------|
| 0.35       | 4630.5             | 100           |
| 0.35       | 4630.5             | 200           |
| 0.35       | 4630.5             | 300           |
| 0.35       | 4630.5             | 400           |

Figure 1. Failure patterns of different prestressed steel strands

It can be seen from the figure that the lower the prestressing force is, the more obvious the damage will be. When 100N prestressing force is applied, all seven strands of steel strand are broken, accompanied by loud noise; when 200N prestress is applied, individual strands are broken, and they are connected as a whole and still have corresponding bearing capacity; when 300N prestressing force is applied, there is no obvious damage to the strand and the whole strand is bent; when 400N prestress is applied, the steel strand is bent and there is no obvious damage to the strand.

1.4 Impact failure at different heights

In this test, single wire coated epoxy coated steel strand with the same size and specification is used. The impact condition is only to change the impact height of drop hammer, and other impact conditions are the same. The specific test impact scheme is shown in Table 2, and the experimental results are shown in Figure 2.
Table 2. Stranded wire impact conditions

| Height (m) | Impact energy (kJ) | Prestress (N) |
|------------|--------------------|---------------|
| 0.15       | 1984.5             | 300           |
| 0.25       | 3307.5             | 300           |
| 0.35       | 4630.5             | 300           |
| 0.45       | 5953.5             | 300           |

Figure 2. Destruction modes of steel strands with different impact heights

(a) Failure mode at 0.15m  
(b) Failure mode at 0.25m  
(c) Failure mode at 0.35m  
(d) Failure mode at 0.45m

It can be seen from the figure that with the increase of the impact height, the damage of the steel strand is more obvious. When the impact height is 0.15m, only bending occurs; when the impact height is 0.25m, only the single wire breaks; when the impact height is 0.35m, the single wire fracture phenomenon is obvious; when the impact height is 0.45m, almost all the strands fracture with loud noise.

2. Analysis of test results

It can be seen from the experiment that the steel strand member under the same impact condition only changes the prestress. With the increase of prestress, the impact deflection decreases, which can improve the impact energy of steel strand. If the initial pretension is properly applied to the member,
the stiffness of the member can be effectively increased. However, if the pretension is too large, the longitudinal tensile force of the component may be too large, which may lead to the failure process of the specimen.

Using the same impact condition, only the impact height is changed, that is, the impact energy. With the increase of impact energy, the impact deflection increases, and the strain value of some strands is larger. Therefore, the higher the impact height is, the faster the failure and fracture of the specimen is.

3. Simulation analysis of impact performance of steel strand

ANSYS software LS DYNA module is used to establish the finite element model to simulate the impact performance of steel strand, and further understand the deformation and stress-strain distribution of steel strand under different impact energy; through the movement of steel strand and impact hammer, the transverse bearing capacity of steel strand, energy conversion and consumption in the process of impact are studied.

LS DYNA is the most comprehensive nonlinear analysis software, which is suitable for the analysis of dynamic nonlinear problems such as impact and explosion. Its algorithm is mainly based on Lagrange. It has rich 2D and 3D solid elements, shell elements and other elements for different purposes. However, different kinds of elements have different analysis and calculation methods to meet the needs of different types of materials\[1\]. In terms of material model, LS DYNA has hundreds of definitions of metal and nonmetal materials, and can also define its own material constitutive model according to different requirements\[2\].

The steel strand component model mainly adopts solid164 solid element. Equidistant line is selected to set the distance division and reasonable grid division density is adopted. Considering that each strand of steel strand is in contact through twisting, the contact mode is defined as automatic single-sided contact type (ASCC), which is applicable to the study of various collisions, that is, the contact surface will automatically select and set between the two definitions of contact.

In the process of establishing the model, considering that the weight of the falling hammer is a fixed value, the principle of conservation of momentum\[3\] can be used to make the drop hammer have the initial velocity instead of the impact energy produced by falling. The drop hammer is placed directly at the impact point of the steel strand center. In this way, the conversion of gravitational potential energy and dynamic energy should be considered, that is, the initial velocity of the falling hammer can be obtained that:
\[ mgh = \frac{1}{2}mv^2 \]  
\[ v = \sqrt{2gh} \]  
(1)

That is, by changing the initial velocity of the drop hammer, the height of the impact can be correspondingly changed, which is to study the impact energy on the impact resistance of steel strand [4]. In order to save calculation time effectively, we directly define the instant of falling hammer impact as a cycle time, and convert the corresponding drop weight height into the initial impact velocity of drop hammer, that is, the impact height of 0.15m, 0.25m, 0.35m and 0.45M is substituted into equation 2, and the corresponding initial velocities are 1.71m/s, 2.21m/s, 2.62m/s and 2.97m/s, respectively.

3.1 Time history curve of different prestress
In the finite element simulation model, when the prestressing force is 100N, part of the strand breaks; when the prestressing force is 200N, the elements at the impact point of the strand are damaged, and the strand has fracture marks; when the prestressing force is 300N, the strand only bends, but it is obvious; when the prestressing force is 400N, the strand will be bent. The results show that only bending occurs. According to the impact phenomenon, it can be found that the impact energy of the finite element simulation steel strand is smaller than that of the test.

3.2 Stress time history curves of different heights
ReferenceIn the finite element simulation model, when the impact height is 0.15m and 0.25m, the steel strand only bends; when the impact height is 0.35m, the strand begins to produce unit damage; when the impact height is 0.45M, the strand wire has partial fracture. According to the impact phenomenon, it can be found that the impact energy of finite element simulation of steel strand is smaller than that of test, and the phenomenon of steel strand in simulation is not more severe than that of test.

4. Conclusion
Under the impact of falling hammer, changing the impact height without prestressing force means changing the initial velocity of the falling hammer. With the increase of the velocity, the impact resistance of the model decreases and the component damage is obvious. When the component is not fractured, the change rule of strain curve under impact is basically consistent with the strain curve measured by test, and the steel strand bends and produces plastic deformation; when the strand breaks, the strain value increases rapidly and the curve changes abruptly, and the impact position of the restraint end and the center of the strand produces large plastic deformation. The fracture position is consistent. As the impact continues, the strain value of strand will continue to increase, and the process will repeat when the strand breaks. With the increase of impact height, the number of fracture of model strand is different from that of test.

In a certain range, with the increase of prestressing force, with the increase of prestressing force, the stiffness of the model is enhanced, that is to say, the impact resistance is also improved. When the component is not fractured, the change rule of strain curve under impact is basically consistent with the change of strain curve measured by test, and the bending phenomenon of steel strand occurs; when the strand of model component breaks, the strain value increases rapidly and the curve changes abruptly, and the impact position of restraint end and steel strand center produces large plastic deformation. For the test, the fracture phenomenon at the impact position is more obvious; for the whole steel strand component, the strain value of steel strand wire decreases during the simulation process.
References
[1] Pan, H.Q., Gong, H.L. (2008) Application of rigid body elastomer conversion technology in ANSYS / LS DYNA [J]. Sichuan military engineering journal, 2008 (05): 38-39
[2] Zhang, J., Tian, Z.X., Song, Q.H., Yuan, J.T. (2018) Application and practice of LS-DYNA in Engineering Mechanics Teaching [J]. University laboratory work research, 2018 (04): 4-6
[3] Tang, G.T. (2008) Fundamentals of elastoplastic dynamics, 1st edition.
[4] Wang, Y.H., Huang, K.M. (2017) High speed warhead impact simulation based on ANSYS / LS-DYNA [J]. Computer measurement and control, 25 (10): 112-11