Enhancing Rockfall Impact Test Standards: A Novel Approach for Accurate Velocity Measurement and Structural Optimization of Test Platforms

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Abstract. Rock Fall Impact Test Method and Evaluation of Railway Slope Flexible Passive Protection Products" TB/T3449-2016 is one of the most important test standards for slope flexible protection network systems more attention. However, there have been some problems in the implementation of the standard. In this paper, a method of calculating the velocity of falling rock hitting the net and determining the impact height when the average velocity of the test block within the last 1m distance from the impact point of falling rock is ≥25m/s is proposed by using Newton's second law and conservation of energy considering the air resistance, which solves the problem of difficult and inaccurate measurement of falling rock velocity in the standard. Then, it is pointed out that the buffer distance energy, which has been neglected for a long time in the calculation of shock energy, can be solved by setting the deviation of the test energy level. Finally, through the investigation and analysis of different structural forms of rockfall impact test platforms, it is proposed that the steel structure rockfall impact test platform is better, and it is suggested that the next revision of the standard should increase the requirement of the structural form of the test platform.

Keywords: Rockfall impact; Velocity measurement; Impact energy; Test platform.

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1. Introduction

The slope flexible protective mesh system was developed in the 1950s and has played a good protective effect against natural disasters such as rock fall, weathering, and avalanches on various slopes, and has been widely used at home and abroad[1]. Currently, 3 rock impact test platforms have been built in China to conduct rock impact test detection and research of slope flexible protective mesh systems [2][3]. As shown in Figure 1, it is a vertical rock fall impact test platform. The problems discussed in this paper are related to the platform. TB/T3449-2016 "Railway slope flexible passive protection products rock fall impact.

As one of the most important test standards for slope flexible protective mesh systems [4].Test Methods and Evaluation have contributed to the development of China's slope protection industry in the past six years [5]. Making the rock fall impact test of the slope flexible protective mesh system the most intuitive test to verify the performance of the protective mesh system [6] and more and more accepted by the relevant engineering and production enterprises [7]. However, there are also some controversies in applying the standard to the actual test.

Due to the high construction cost of the test platform and the long test period [8] the single test cost is high, and the test results may be unacceptable in case of disputes, resulting in greater economic losses. Based on the results of many rock fall impact tests and related studies [9].and some of my practice and understanding, we put forward some suggestions for reference in the next revision of this standard.

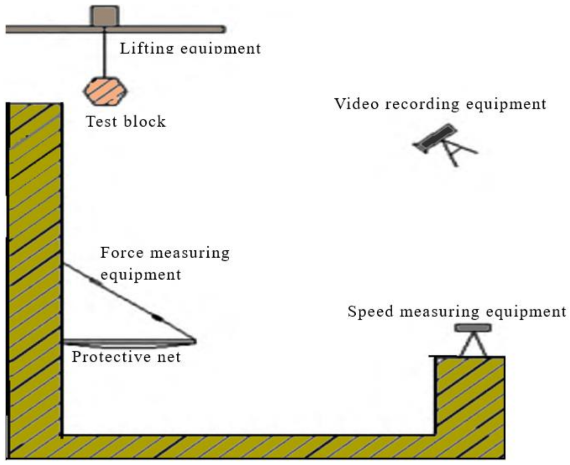

Figure 1: The vertical impact test platform's schematic diagram

2. Methodology

2.1 Speed measurement problems in the standard

During the passive protective net test, the average speed of the test block within the last 1m distance from the impact point shall not be less than 25m/s; During the flexible grid test, the average speed of the test block within the last 1m distance from the impact point should not be less than 15m/s the speed of the test block may be measured by laser velocimeter or radar velocimeter, or by image recording analysis method, with an accuracy of not less than 0.1m/s". Due to the high price of laser and radar speed measuring instruments that meet the measurement accuracy [10] and the uncontrollable landing point of rockfall impact, the randomness of the landing point deviating from the center of the network is high, and the manoeuvrability of using these two instruments is not strong. In practice, most of the high-speed cameras are used to record images, and then the speed is measured by image analysis[11].The standard stipulates that the parameters of high-speed cameras are not less than 5 million pixels, and the frame rate is not less than 100 frames /s. To meet the standards specified in the passive protective net test, at the distance from the impact point last.

The average speed of the test block within 1m should not be less than 25m/s, it is known that the rock fall movement time should not be less than 0.04s, if the use of 100 frames /s camera, the number of image frames in the last 1m range should not be less than 4 frames. If the number of image frames in the last 1m range is 3, the average speed is about 33.3m/s. If the number of frames is 5, the average speed is 20m/s. The speed measurement accuracy of the camera using 100 frames /s simply cannot meet the speed accuracy (0.1m/s) requirements specified in this standard. After calculation, to meet the speed measurement accuracy of 0.1m/s, at least 5000 frames /s high-speed camera should be used. At the same time meet this standard pixel is not less than 5 million, frame rate is not less than 5000 frames /s high-speed cameras are expensive, more than four hundred and five million, obviously not economical. Moreover, if a high-speed camera measuring speed of 5000 frames /s is used, the number of image frames in the last 1m range is about 200 frames, which greatly increases the difficulty of image analysis. In addition, due to the rock fall impact test, the steel column and the horizontal plane have an Angle θ, the standard stipulates $\theta \leq 30°$, as shown in Figure 2, θ is generally between 10° and 20° during the test installation.

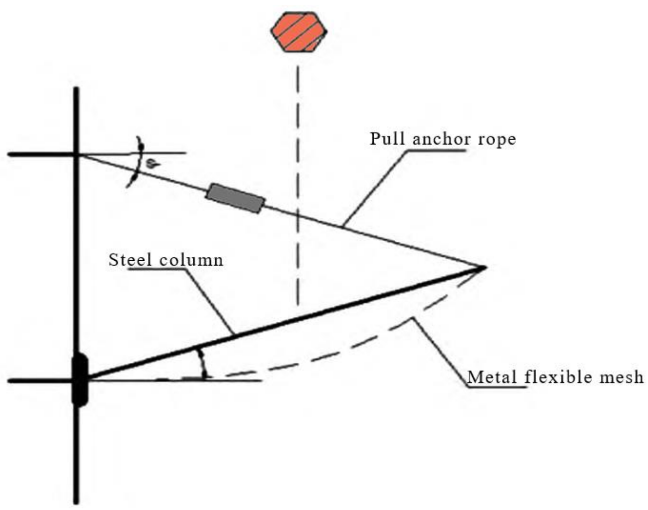

Figure 2: Diagram of vertical impact test platform protective net

This leads to the uncertainty of the center height of the mesh surface, which increases the difficulty of identifying the last 1m range in front of the drop hammer contact line during image analysis. Therefore, it is difficult to measure the average velocity of the last 1m distance from the impact point by image analysis.

2.2 Speed measurement solution

Given the above problems, the author proposes a method to calculate the average velocity of the test block and determine the impact height within the last 1m distance from the impact point by Newton's second law and conservation of energy considering the air resistance. The standard stipulates that during the passive shield test, the average speed of the test block within the last 1m from the impact point should not be less than 25m/s. In general, the air resistance f is proportional to the square of the relative speed of the object and the air [12] then the air resistance can be expressed as

$$f=-kv^2 \tag{1.1}$$

The f direction is the opposite of the velocity direction, and k is a constant determined by the density of the air, the shape and volume of the object. According to the calculation and analysis of air resistance in ball games by [13] the empirical formula of air resistance is as follows

$$f=\frac{1}{2}c\rho Av^2 \tag{1.2}$$

$$k=\frac{1}{2}C\rho A \tag{1.3}$$

Where ρ is the air density, A is the windward area of the object, k is the proportional coefficient, C is the air resistance coefficient, and C is generally taken as C=0.5[14]. The rock fall test block specified in this standard is a regular 26-heron, which can be approximated as a spherical object. The external force on the falling test block is

$$F=mg-kv^2 \tag{1.4}$$

According to Newton's second law

$$mg-kv2=ma \tag{1.5}$$

Where a is the acceleration, the gravitational acceleration considering the air resistance can be obtained as

$$a=g-\frac{kv2}{m} \tag{1.6}$$

This standard stipulates that the average speed of the test block within the last 1m distance from the impact point should not be less than 25m/s, and the average speed is 25m/s in this paper. It can be obtained by setting the velocity of falling rock at the contact line surface as v, the velocity of falling rock at 1m in front of the contact line as v1, the movement time of falling rock at the last 1m in front of the contact line as t=1/25=0.04s, the movement distance as h=1m, the impact height as H, and the impact kinetic energy of falling rock at the contact line surface as Ek.

$$v=v1+(g-\frac{kv2}{m})\,t \tag{1.7}$$

$$h=\frac{1}{2}(v1+v)\,t \tag{1.8}$$

Substituting (1.7) into (1.8) yields a quadratic equation concerning v in one variable

$$\frac{kt2}{m}v2+2tv-(gt2+2h)=0 \tag{1.9}$$

This equation can be solved

$$v=\frac{-2t\pm\sqrt{4t^2+4\frac{kt^2}{m}(gt^2+2h)}}{2\frac{kt^2}{m}} \tag{2.0}$$

According to the law of conservation of energy in free-falling motion

$$E_k=\frac{1}{2}mv^2=maH \tag{1.11}$$

Will (1.6) to bring in (1.11) gain

$$H=\frac{v^2}{2(g-\frac{kv^2}{m})} \tag{1.12}$$

Since all the parameters in (1.10) and (1.12) are known, it is easy to calculate the velocity v and the impact height H at the falling contact line surface, and further calculate the impact kinetic energy Ek at the falling contact line surface. In practical tests, the impact height is generally determined by the energy conservation equation of free-falling motion, which ignores the air resistance, when the impact velocity is guaranteed to be 25m/s. Then the weight of the rock fall test block is determined by different impact energy levels specified in the standard. Combined with formula (1.10) -(1.12), the author provides a set of data of impact test block weight, impact height, impact velocity, impact potential energy, and impact kinetic energy of the rock fall impact test, as shown in Table 1.

Table 1: Test parameters of rock fall impact

E (kJ)	g (m/s2)	m (kg)	H (m)	Ep (kJ)	Ek (kJ)	1m (m/s)	v (m/s)
85	9.79	262	33.07	84.8	83.1	25.0	25.19
170	9.79	540	32.93	174.1	171.4	25.0	25.19
250	9.79	794	32.87	255.5	252.0	25.0	25.19
340	9.79	1075	32.82	345.5	341.2	25.0	25.19
500	9.79	1585	32.78	508.6	503.0	25.0	25.19
670	9.79	2118	32.74	678.9	672.2	25.0	25.19
750	9.79	2118	36.77	762.5	754.0	26.5	26.68
1000	9.79	3122	33.23	1015.5	1006.5	25.2	25.39
1500	9.79	4770	32.67	1525.4	1513.9	25.0	25.19
1700	9.79	4770	36.95	1725.5	1710.8	26.6	26.78
2000	9.79	6310	32.64	2016.6	2002.7	25.0	25.19
3000	9.79	9450	32.87	3041.4	3023.0	25.1	25.29
5000	9.79	15750	32.84	5064.3	5038.3	25.1	25.29

Through practice, this set of parameters can guide the rock fall impact test. It solves the difficult and inaccurate problem of using the existing speed-measuring equipment. It is suggested that such table parameters should be included in the next revision of the standard to guide the test.

3. Impact energy problem

TB/T3449-2016 specifies the test procedure and gives the SEL (normal working level) and MEL (maximum test level) test levels of different passive protection products. In the real test, the impact energy level of falling rock is generally determined by the impact kinetic energy (that is, the kinetic energy of the falling rock test block at the contact network surface). However, the energy absorbed by the protective mesh system also includes the potential energy of the l3 buffer distance from the surface of the overhead contact line to the time when the falling rock is stopped, as shown in Figure 3. Therefore, the energy absorbed by the protective net should also include this section of potential energy Ep', if the buffer distance is calculated by 3m, the section of potential energy is about 10% of the impact kinetic energy, so the total energy absorbed by the protective net is about Ek×110%.

At the same time, the deviation range of the impact energy in the test is not clear in the standard, which brings questions to the actual test work. In the actual test, the energy is generally selected slightly higher than the specified level but not more than 5% of the specified level. Combined with the additional potential energy absorbed by the protective net behind the contact line surface of the rock fall test block, it is suggested to add the test energy level deviation of ±5% in the next revision of the standard.

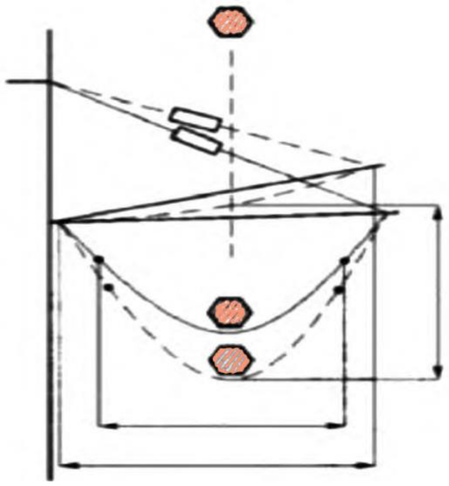

Figure 3: The vertical impact test platform's buffer distance

4. The structural form of the test platform

TB/T3449-2016 standard has no clear requirements for the construction material and structural form of the test platform. According to the author's investigation, three stone impact test platforms are in China, two of which are in the form of concrete retaining walls, and one is in the form of steel structure. The concrete retaining wall test platform is shown in Figure 4. When falling rocks impact the mesh surface, the retaining wall will bear greater force.

The moment, subjected to a large moment for a long time, is easy to cause micro-cracks in the concrete, and then expands into cracks or cracks, which may lead to the collapse of the concrete retaining wall during the rockfall impact test in extreme cases. According to the author's investigation, among the two rock-fall impact test platforms of concrete retaining walls that have been in service, cracks and cracks have appeared in one, as shown in Figure 5. Once this kind of crack or cracking occurs, it is extremely difficult to repair, and there is a great safety risk.

Figure 3: Rock impact test platform of a concrete retaining wall

Figure 5 Cracks on a concrete retaining wall falling rock impact test platform

Another type of rock fall impact test platform in the form of a steel structure, its main structure is H700×300×13×24mm, material Q355B H-type steel, first fixed by high-strength fastener connection pair and then welded construction, the structural stiffness is large enough (the author has a detailed analysis of this article), fully meet the requirements of rock fall impact test, its three-dimensional structure The type resembles an elongated pyramid structure, as shown in Figure 6. Due to its structural characteristics, the rock impact point is almost in the impact test platform elevation projection, so the torque is small, the overall structure is stable, and it is not easy to tip over. In addition, the steel structure test platform also has the advantages of not easy to damage, convenient maintenance, easy modification, low construction cost, and environmental protection of construction materials. ·73· Phase 5 Sichuan Metallurgy

In summary, the steel structure rock fall impact test platform is better, it is suggested to increase the requirements for the structure of the test platform in the next revision of the standard.

Figure 6 A steel structure rock fall impact test platform

5. Conclusion

A method proposed in this paper, which considers the air resistance and calculates the rock fall net velocity and impact height when the average velocity of the test block within the last 1m distance from the rock fall impact point is ≥25m/s by Newton's second law and conservation of energy, can well solve the problem of difficult and inaccurate measurement of rock fall velocity in the standard. This paper points out the buffer distance energy which has been neglected for a long time in the calculation of shock energy and proposes that the problem can be solved by setting the deviation of the test energy level to ±5%. Through the investigation and analysis of rock fall impact test platforms of different structural forms, it is proposed that the steel structure rock fall impact test platform is better, and it is suggested that the requirements for the structural form of the test platform should be added in the next revision of the standard. Test Procedures and Assessment have contributed to the growth of China's slope protection sector over the previous six years, making the slope flexible protective mesh system's rock fall impact test the most user-friendly method for assessing the system's effectiveness and increasingly acknowledged by the pertinent engineering and production companies; nevertheless, there are certain disputes when it comes to implementing the standard to the real test. The single test cost is high due to the high cost of building the test platform and the extended testing period. In the event of a dispute, the test results may not be accepted, leading to larger financial losses based on the findings of numerous studies and rock fall impact tests using some of my expertise, we proposed a few recommendations for further reading.

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