Research on Testing Equipment for Anti-impact Performance of Building Guardrails

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Abstract—The detection status and existing problems of the anti-soft and heavy object impact performance of glass and metal guardrails for buildings were briefly described in the article. A set of detection equipment was designed for the shortcomings, which mainly included guardrail installation devices, height positioning devices, and impact control systems. It has the advantages of small size, low cost, simple operation, high efficiency and low uncertainty, etc. In addition, the influence of factors such as installation quality and test environment on the test results can be excluded, which greatly improves the accuracy and fairness of the test results.

1. INTRODUCTION
As an important non-structural component of a building, the safety and durability of building guardrails directly affect the safety of people's lives and property[1]. With the rapid development of modern buildings in China, the number of accidents caused by fence quality problems increased by the increase of building height. Therefore, it is increasingly important to control the quality of building fences to ensure the safety and normal use of building fences[2]. The main standard for the detection of glass and metal guardrails for buildings is "JG / T 342-2012 Glass and metal guardrails for buildings", from which it is known that the impact test of guardrails on soft and heavy objects emphasizes the protection of guardrails against human impact, that is, after the human body hits the guardrail with a certain amount of impulse, the guardrail must not exhibit protection class failure such as excessive relative displacement, loosening or falling off of various components, etc[3]. The standard test of the impact resistance against soft heavy objects is performed with a 45kg impact object and an impact energy E of 300J. The impact is sequentially performed on the handrails and railings. The relative displacement of
the handrails after each impact measurement should not be greater than h/25, and the connecting part
does not appear slack or shedding\[4\].

At present, the detection of the impact resistance performance of guardrails against soft and heavy
objects in China is mostly conducted at temporary construction test sites. Fastening the guardrail by
burying the pillars in the concrete has a long time period and high cost\[5\]. The ground clearance can be
directly measured by a steel tape measure, so as to calculate the impact height. However, the ground
flatness of the temporary test site cannot be guaranteed, resulting in inaccurate impact heights. The
disadvantage of the pendulum impact method is that the equipment is too large and the operation is
complicated. In view of the above problems, a set of anti-soft and heavy object impact detection device
for building guardrails was designed. It consists of a guardrail installation device, a height positioning
device and an impact control device. The guardrail is fixed by a pad and a hoop. The impact height is
determined by a spirit level and a steel ruler. The impact method is free fall, and the next steps are:
lifting the weight by the motor, releasing the weight by the electromagnet, collecting the displacement
by the displacement sensor, and automatically calculating the data by the software. It has the
advantages of small equipment size, low cost, simple operation, high efficiency, high accuracy, low
uncertainty, etc. It can also exclude the influence of factors such as installation quality and test
environment on the test results, greatly improving the accuracy and fairness of the test results.

2. INTRODUCTION AND OPERATION OF GUARDRAIL INSTALLATION DEVICE
With consumers' requirements for building decoration increasing, building guardrails which is the
important part of the building's appearance, are becoming diverse in style. The shape, cross-section size,
height, and width of the guardrail pillars are different, which brings difficulties to the fixed installation
of the guardrail detection. In response to the above difficulties, a set of installation devices was
designed, as shown in Figure 1, including horizontally movable hoop 1, arc cushion 2, rectangular
cushion 3. First, adjust the hoop to match the distance between the columns, then put the arc cushion
and rectangular cushion into the hoop to match the shape and size of the armrest section, finally lock
the hoop to fasten the guardrail.

![Figure 1. Guardrail installation device](image)

3. INTRODUCTION AND OPERATION OF HEIGHT POSITIONING DEVICE
The temporary test field method generally uses a steel tape to measure the distance between the
handrail and the heavy object from the ground to calculate the impact height. Factors such as ground
flatness, steel tape perpendicularity, straightness, and reading angle of view all affect the accuracy of
the measurement data. In response to the above problems, designed a set of height positioning device
was designed, as shown in Figure 2, which mainly consists of a spirit level 1 and a fixed steel ruler 2.
After the guardrail is fixed, the horizontal line of the spirit level is adjusted to the center of the weight,
and read the height value of the horizontal line on the steel ruler as the initial height value. Next, the
height of the weight lifting can be calculated according to the impact energy. Adjust the level of the
spirit level to the target height value, then lift the weight until the center of the weight coincides with
the horizontal line, and the height positioning is completed.
4. IMPACT DEVICE

4.1. Introduction and operation of the device
In the temporary test field method, a pendulum impact is used. The device is large in size, unstable in a fixed manner, complicated in operation, and has a secondary impact. In addition, the heavy object is released manually, and the position of the heavy object moves during the release process, which will cause the impact position to deviate. In view of the above problems, a set of impact devices was designed, including a movable gantry, a lifting motor, an electromagnet, a displacement sensor and operating software (see Figure 4). Figure 3 shows the device details. After the guardrail is fixed, the gantry is first moved until the weight is above the impact point of the guardrail. At this time, the displacement sensor will record data S1. Then use the lifting motor to lift the weight to the target height, turn off the electromagnet, release the weight, and complete the impact. After the weight is removed, wait for the displacement data to be stable and the data S2 is recorded, then move the gantry to make the weight above the impact point of the armrest, and then use the lifting motor to lift the weight to the target height, turn off the electromagnet, release the weight and complete the impact. After removing the weight, wait for the displacement data to stabilize and record the data S3.
4.2. Correction processing of anti-soft and heavy object impact data

In the standards for impacts on railings and handrails respectively, the mass of soft and heavy objects is 45kg and the impact energy is 300J. After the impact, the guardrail will be deformed. Since the free-fall impact method is adopted in the device, it is necessary to modify the gravity potential energy of the soft weight with deformation. The revised formulas are as follows (formal 1-2), where S1, S2 and S3 are the same as in IV. A, S4 is the displacement of the handrail after impacting the railing, and S5 is the handrail’s displacement after impacting it, the unit of displacement is mm, m is the weight of 45 kg. Data correction is done automatically by the operating software.

\[
S_4 = \left( S_1 - S_2 \right) \times \frac{300}{300 + mg(s_1 - s_2) \div 1000} \\
S_5 = \left( S_1 - S_3 \right) \times \frac{600}{600 + mg(s_1 - s_3) \div 1000}
\] (1) (2)

5. UNCERTAINTY ANALYSIS

5.1. Mathematical model building

In the formula 1, E is the impact energy (N·m), m is the mass of the soft weight, and h is the effective fall height of the soft weight.

5.2. Sources of uncertainty

It can be known from the mathematical model that the main sources of uncertainty are weight error, falling height measurement error, standard error of tape measure and operation error of personnel, etc[6].

5.3. Uncertainty class A

There will be errors when different experimenters detect the results of anti-soft weight impact test. The two methods are tested and divided into two groups of two people each. Two people in each group repeatedly measured the effective falling height of soft weight objects four times. The results are statistically shown in Table 1. A method was used to evaluate [7]. The effect of repeatability is evaluated through multiple independent repeated measurements, and the uncertainty of repeatability \( u_{re,2} \) is introduced. The standard deviation \([S_\rho(h)]\) of two samples in each group is calculated as follows (formal 4-5), where m is the number of experiments and n is the number of repeated measurements per person.

After calculation, it is concluded that the first group of standard deviation \( S_\rho(h)_1 \) and \( S_\rho(h)_2 \) are 0.38mm and 7.99mm, respectively.
The formula for calculating the average deviation $\{S_P(\hat{h})\}$ is as follows. According to formula 5, the average deviations of the two groups were 0.155mm and 3.261mm, respectively.

$$S_p(h) = \sqrt{\frac{\sum_{i=1}^{n} \sum_{j=1}^{n}(h_{ij} - \bar{h})^2}{m(n-1)}}$$  \hspace{1cm} (4)

The average relative uncertainty is calculated as formula (6):

$$u_{ra} = u_a = S_P(\bar{h})$$  \hspace{1cm} (5)

$$u_a = \frac{S_P(\hat{h})}{\sqrt{mn}}$$  \hspace{1cm} (6)

Where $u_a$ is the average uncertainty. $\bar{h}$ is the average of the effective drop height measured by each group, as shown in Table 1. After calculation, the relative uncertainty of the first group of averages is 0.0233% and 0.491%, respectively.

5.4. Uncertainty Class B

The uncertainty of the weight of the soft weight, the uncertainty of the standard of the tape measure, and the uncertainty of the error of the tape measure reading are all evaluated by the type B method [6]. The soft weight and tape used in the two groups of tests are the same tool. In addition, the rules for measuring tape readings are all rounded to 50%, so the uncertainty of these three parts is the same. The weight error of the shotgun bag is 0.015% (the error value given by the Metrology Institute test certificate), and includes factors $k$ is $\sqrt{3}$ in evenly distributed condition, so according to the formal 8, the relative uncertainty $u_{rb}$ of the indication error is 0.009%. The calibration error of the tape measure is 0.01% which is given by the calibration certificate of the Metrology Institute, when the $k$ is $\sqrt{3}$, the relative uncertainty of the calibration of the testing machine $u_{rc}$ is 0.006%. Because of uncertainty of measuring tape reading error, the test data of the tape length used is only recorded to the whole number. The first digit after the decimal points processed by the principle of rounding to 50%. The $k$ value remains unchanged, then the uncertainty $u_{rd}$ is 0.02887, the relative uncertainty ($u_{rd}$) is as formal 9, after calculation, the relative uncertainties of the two groups are 0.0043% and 0.0043%.

| Group times | Person-times | Effective drop height $h$ / mm | Person Mean | Group mean |
|-------------|--------------|---------------------------------|-------------|-----------|
| 1           | 1            | 666.5, 666.2, 666.6, 666.3, 666.4 | 666.40      | 666.275   |
|             | 2            | 666.6, 666.2, 666.3, 665.5, 665.1 | 665.15      |           |
| 2           | 1            | 670.2, 660.2, 652.5, 659.3, 660.5 | 660.55      | 663.075   |
|             | 2            | 656.8, 661.7, 672.6, 671.3, 665.6 | 665.60      |           |

$$u_{rh} = \frac{0.015%}{K}$$  \hspace{1cm} (7)

$$u_{rd} = \frac{0.02887}{\bar{h}}$$  \hspace{1cm} (8)

5.5. Synthetic standard uncertainty

The above uncertain components are independent of each other, and the standard uncertainty $u_{rh}$ is synthesized. The calculation formula is as follows. After calculation, $u_{rh}$ is 0.025% and $u_{rd}$ is 0.482%.

$$u_{rh} = \sqrt{u_{ra}^2 + u_{rb}^2 + u_{rc}^2 + u_{rd}^2}$$  \hspace{1cm} (9)
5.6. Evaluation of extended uncertainty
Extended uncertainty $U$ is calculated as formal 11, according to GB / T 15481-2000 “General requirements for the capabilities of testing and calibration laboratories”, taking $k$ is 2 [8], the extended uncertainty of the two groups is 0.3332mm and 6.4217mm, respectively.

\[ U = k \times U_{\text{tr}} \]

5.7. Conclusion and analysis
Through the above analysis of the uncertainty, it was found that the main part of the uncertainty was derived from the error part of the personnel operation. Compared with the temporary test field method, the standard uncertainty of the equipment was reduced by 94.8%. In A group, the spirit level were used to measure height data with an steel ruler. Compared with the direct measurement by tape, the height of the Steel ruler is rigid and fixed, which means the light of the spirit level is struck on the tape so that reading is more accurate and stable, which effectively avoids errors caused by factors such as verticality, straightness and angle of reading during the tape measurement. And uncertainty is greatly reduced.

6. CONCLUSION
The equipment realizes the testing of the anti-soft weight performance items in the laboratory for building glass and metal guardrail, which has the advantages of reasonable design, simple operation, small volume, high efficiency and low uncertainty, etc. The problems of high time consuming, high cost and low efficiency of temporary experimental site detection are solved, and the efficiency of guardrail detection is increased by more than 10 times. Through comparative tests, it is proved that the equipment reduces the uncertainty by 94.8% compared with the traditional temporary test field method. At the same time, the influence of guardrail installation quality, test environment and human factors on guardrail test results can be eliminated, and the fairness and accuracy of guardrail test results can be greatly improved. The defect of this device is that the function is relatively single, and only the impact resistance test of the guardrail can be performed, so how to expand the function of the device needs to be further studied.

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