Research Article

A Model-Based Unloaded Test Method for Analysis of Braking Capacity of Elevator Brake

Qifeng Peng,[1] **Zhongxing Li,**[2] **Hong Yuan** (iD),[1] **Guojian Huang,**[2] **Shanqing Li** (iD),[1] **and Xueli Sun**[2]

[1]*MOE Key Laboratory of Disaster Forecast and Control in Engineering, School of Mechanics and Construction Engineering, Jinan University, Guangzhou 510632, China*
[2]*Guangzhou Academy of Special Equipment Inspection and Testing, Guangzhou 510180, China*

Correspondence should be addressed to Hong Yuan; tyuanhong@jnu.edu.cn and Shanqing Li; lishanqing09@163.com

In order to improve the inspection efficiency and accuracy of the braking capacity of the elevator brake being used, a novel method for analyzing the full-loaded braking performance by using the unloaded braking performance is proposed, and a set of methods for measuring the braking torque is designed. Based on the analysis of the key factors that affect the mechanical performance of the elevator brake, the calculation model of the braking torque in the process of the emergency braking with the traction ratio of 2 : 1 is established, and the relationship between the braking torque and acceleration under different working conditions is analyzed. It is shown that, for the model assumed, the emergency braking torque is 1.56 times that of the static braking torque under 1.25 times the rated load. The braking torque increases linearly with the increase of braking acceleration. An elevator model being used is tested and calculated. The experimental results show that the braking acceleration measured by the experiment is 11.95% less than the theoretical value. And the analysis shows that, comparing with the traditional test method, the braking torque test method designed in this paper is more accurate and safe.

1. Introduction

As the vertical transportation in the building, the elevator is an indispensable electromechanical device, especially in modern high-rise buildings. It brings convenience to us and improves our working efficiency and living standards [1].

The elevator braking system is an important part of ensuring the safe operation of the elevator [2]. Most of the elevator's operation control and safety protection must ultimately be achieved through the brake system [3, 4]. Once safety function of the brake fails, it often leads to such serious accidents as falling, roofing, and shearing of the elevator car, which brings unacceptable risks and great threats to passengers' lives and property [5, 6].

The main reasons for failure of the brake include insufficient brake torque, jamming of the brake mechanism [7], electrical adhesion of the contact and low balance coefficient.

The evaluation to performance of brake has been in the qualitative stage, mainly through the loading test [8–10]. To judge the brake performance, the stopping distance of the elevator has been measured by emergency braking with specified load [11–14]. The difficulty of the test with load is not discussed here. The test load is generally required to exceed the rated load of the elevator (usually 1.25 times the rated load [8]). There are two problems in the test. First, it is difficult to transport the weight needed in the experiment, and the transportation cost is high. Second, many elevators, especially the older ones are difficult to meet the requirements of full-load test. It cannot reliably stop elevators with 1.25 times the rated load and brings high risks.

In the past, few scholars concerned about the braking performance test of the elevator braking process being used. Esteban et al. [15] presented a dynamic acceleration calculation model, which calculates the acceleration dynamic changes during the normal operation of the elevator.

Ungureanu et al. [16] analyzed the position change of the elevator under no-load and full-load conditions. Then they get a precise method for cage motion control for third-order trajectory planning. Skog et al. [4] tested elevator position, passenger quality, engine system, abnormal stop, and abnormal door by acceleration sensor and magnetic induction sensor. The relationship between the sensor signal and corresponding test condition is found through many tests. By contrast, more attention is paid to the material characteristics of brakes. Bao et al. [17] discussed the influences of the braking conditions on the friction coefficient and surface temperature. Longwic et al. [6] studied the test results of the influence of the guidance system pollution on the braking delay of involute gears in the friction lift. Hao Yan et al. [18] established a thermal-structural coupling model by friction thermodynamics analysis. The variation of temperature and friction co-efficient of the friction cone in the synchronization process was studied. These studies have great practical value for the analysis and improvement of elevator passenger quality and the design of elevator brake, but the emphasis of these studies is concentrated on the design and manufacture stage of the brake and cannot reflect the performance of the brake in the use stage. In order to improve the safety and efficiency of inspection for elevator brakes, the dynamic response of the brake in the process of elevator braking was specially studied in this paper, a practical method of testing the brake in use of the elevator was put forward, and the experimental verification was carried out.

2. Theoretical Calculation Model for Elevator Braking Torque

When the elevator stops normally, the drive main engine controls the elevator to decelerate to the quasi-static state, then the brake acts [19]. However, when it is abnormal, the elevator has been stopped in high speed. The car and the counterweight are urgently braked under gravity, friction, and braking force. Due to sudden deceleration, the traction system experiences an increase in moment, during sudden brake [20].

In order to calculate the brake torque provided by the brake under different working conditions, a 2 : 1 elevator model is taken as the research object in this paper. According to 3 typical elevator operating conditions, various factors affecting the brake torque are analyzed by using the torque balance principle, and the brake torque calculation models are established, respectively. The relationship between the no-load emergency-braking acceleration and the full-load braking capacity is found by analyzing the braking torque relationship under various working conditions.

The whole system composed of car, counterweight, and tractors has been studied (shown in Figure 1), and the force conditions during the braking of the elevator with a 2 : 1 traction ratio are analyzed, and the following assumptions are made:

(1) The friction between wire rope is not considered.
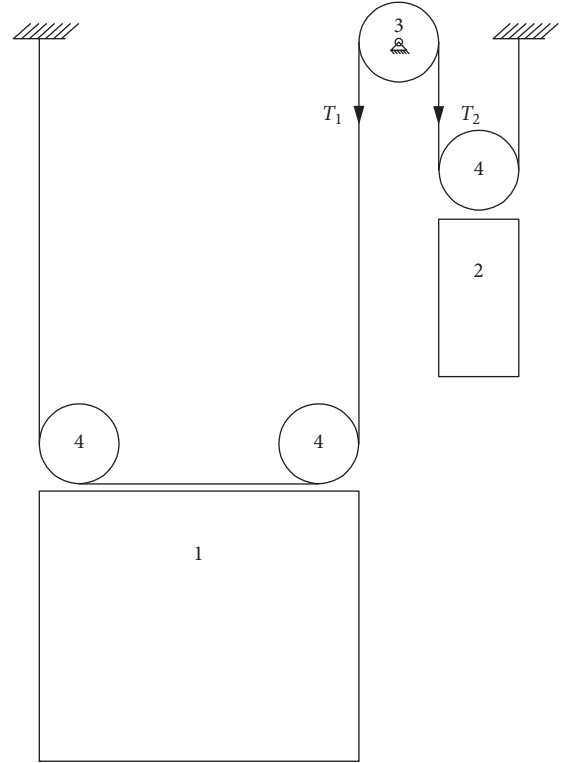
(2) The influence of wire rope vibration is neglected.

Figure 1: Diagram of traction system. (1) Car; (2) counterweight; (3) traction wheel; (4) pulley.

(3) The relative sliding between the traction wheel and the wire rope is neglected.

(4) It is assumed that the compensation rope is not installed.

(5) The potential energy of the bottom of the elevator is taken as 0.

For the elevator structure with a traction ratio of 2 : 1, according to the operation characteristics of the elevator, the braking torque of the elevator is analyzed and calculated under three different working conditions.

Condition 1. Static condition when the car loaded with a certain quality.

Condition 2. Emergency braking condition when the car running upward.

Condition 3. Emergency braking condition when the car running downward.

2.1. Analyzing Condition 1. Static condition when the car loaded with a certain quality: It is assumed that the tension of the car side traction rope is T_{s1}, and the tension of the counterweight side traction rope is T_{s2}. The whole traction system is in a state of equilibrium, so the static braking torque provided by the brake can be calculated by the

principle of moment balance. The braking torque calculated in case of the car is loaded with i times rated load.

The tension of the car side traction rope T_{s1} when the car loaded with i times rated load is

$$T_{s1} = \frac{(P + i * Q)}{2} \cdot g + m_{R1} \cdot g, \tag{1}$$

where P is the masses of the empty car and components supported by the car, Q is the rated load, g is the standard acceleration of free fall, define m_R as the actual mass of suspension ropes, and m_{R1} is the actual mass of suspension ropes on car side. m_{R1} can be written as

$$m_{R1} = \frac{(H - x) * m_R}{H}, \tag{2}$$

where H is the height of the hoistway and x is the height of the car.

The tension of the counterweight side traction rope T_{s2} when the car loaded with i times rated load is

$$T_{s2} = \frac{W}{2} \cdot g + m_{R2} \cdot g, \tag{3}$$

where W is the mass of counterweight including mass of pulleys, m_{R2} is the actual mass of suspension ropes on counterweight side. m_{R2} can be written as

$$m_{R2} = \frac{x * m_R}{H}. \tag{4}$$

It is known from the moment balance of the elevator system that the static braking torque when the car is loaded with i times rated load is

$$M_{fs} = -T_{s1} \cdot R + T_{s2} \cdot R$$

$$= \left[\frac{W}{2} \cdot g + \frac{(H - x) * m_R}{H} \cdot g \right]$$

$$\cdot R - \left[\frac{(P + i * Q)}{2} \cdot g + \frac{x * m_R}{H} \cdot g \right] \cdot R. \tag{5}$$

2.2. Analyzing Condition 2.
Emergency braking condition when the car car running upward: In emergency braking, the wire rope on both sides of the traction wheel is not only affected by the gravity, but also affected by the inertia force. The force situation of the elevator in the emergency braking is analyzed as follows.

The tension of the car side traction rope in emergency braking condition when the car running upward T_{u1} is

$$T_{u1} = \frac{P + iQ}{2} \cdot (g - a_u) + m_{r1} \cdot (g - 2 \cdot a_u)$$

$$- \frac{m_{P1} \cdot 2 \cdot a_u}{2} + \frac{FR_1}{2}. \tag{6}$$

The tension of the counterweight side traction rope in emergency braking condition when the car running upward T_{u2} is

$$T_{u2} = \frac{W}{2} \cdot (g + a_u) + m_{r2} \cdot (g + 2 \cdot a_u) + \frac{m_{P2} \cdot 1 \cdot a}{2} - \frac{FR_2}{2}. \tag{7}$$

It is known from the moment balance of the elevator system that the braking torque when the car running upward is

$$M_{fu} = -T_{u1} \cdot R + T_{u2} \cdot R$$

$$= -\left[\frac{P + i \cdot Q}{2} \cdot (g - a_u) + m_{r1} \cdot (g - 2 \cdot a_u) \right.$$

$$\left. - \frac{m_{P1} \cdot 2 \cdot a_u}{2} + \frac{FR_1}{2} \right] \cdot R + \left[\frac{W}{2} \cdot (g + a_u) + m_{r2} \right.$$

$$\left. \cdot (g + 2 \cdot a_u) + \frac{m_{P2} \cdot 1 \cdot a}{2} - \frac{FR_2}{2} \right] \cdot R. \tag{8}$$

2.3. Analyzing Condition 3.
In the same way, the tension of the car side traction rope in emergency braking condition when the car running downward T_{d1} is

$$T_{d1} = \frac{(P + i \cdot Q)}{2} \cdot (g + a_d) + m_{r1} \cdot (g + 2 \cdot a_d)$$

$$+ \frac{m_{P1} \cdot 2 \cdot a_d}{2} - \frac{FR_1}{2}. \tag{9}$$

The tension of the counterweight side traction rope in emergency braking condition when the car running downward T_{d2} is

$$T_{d2} = \frac{W}{2} \cdot (g - a_d) + m_{r2} \cdot (g - 2 \cdot a_d) - \frac{m_{P2} \cdot 1 \cdot a_d}{2} + \frac{FR_2}{2}. \tag{10}$$

It is known from the moment balance of the elevator system that the braking torque when the car running upward is

$$M_{fd} = -T_{d1} \cdot R + T_{d2} \cdot R$$

$$= -\left[\frac{(P + i \cdot Q)}{2} \cdot (g + a_d) + m_{r1} \cdot (g + 2 \cdot a_d) \right.$$

$$\left. + \frac{m_{P1} \cdot 2 \cdot a_d}{2} - \frac{FR_1}{2} \right] \cdot R + \left[\frac{W}{2} \cdot (g - a_d) + m_{r2} \right.$$

$$\left. \cdot (g - 2 \cdot a_d) - \frac{m_{P2} \cdot 1 \cdot a_d}{2} + \frac{FR_2}{2} \right] \cdot R. \tag{11}$$

3. Calculation and Analysis

The braking torque depends mainly on the braking pressure and the friction coefficient between the brake pad and the wheel. The braking pressure depends on the

compression of the spring, because the spring elongation is constant; the braking pressure can be considered unchanged; and the friction coefficient is mainly determined by the material and the surface roughness of the brake pad and brake wheel; it can be considered that the friction coefficient will not change in a short time. So it can be assumed that the braking performance of the elevator is stable, that is, the braking torque remains constant during each test, so $M_{frd} = M_{fer}$ can be obtained. Assuming that the elevator parameters are shown in Table 1, the changes of braking torque under different working conditions are analyzed.

3.1. Calculation and Analysis of Static Torque of Elevator Brake

3.1.1. Static Torque Variation When Loading Different Quality. According to the analysis of Condition 1, the static braking torque changes with the amount of the elevator loading. As the wire rope and pulley have little influence on the brake torque, in order to compare, only the elevator stopping in the middle of the trip is analyzed. In this case, the weight of the traction rope on each side is equal.

The formula of the static torque can be expressed as

$$M_{fs} = \frac{M_{cwt}}{2} \cdot g \cdot R - \frac{(P + i \cdot Q)}{2} \cdot g \cdot R. \qquad (12)$$

Let $M_{cwt} = P + k \cdot Q$ and k is the balance coefficient of elevator, then

$$M_{fs} = \frac{k - i}{2} \cdot Q \cdot g \cdot R. \qquad (13)$$

From equation (13), it is easy to know that the braking torque of the elevator under static load is related to 4 factors: elevator balance coefficient, elevator rated load, traction wheel radius and elevator loading quality. The relation between elevator loading mass ratio and braking torque is shown in Figure 2.

In this case, when the balance coefficient is 0.45, the braking torque of the elevator is 500 N·m from empty load ($i = 0$), and the M_{fs} decreases with the increase of i. At $i = 0.45$; the weight of the two sides of the traction wheel is equal. At this time, $M_{fs} = 0$, when $i > 0.45$, with the increase of i, the weight of the car side is greater than the counterweight side, the direction of braking torque is changed, the braking torque is constantly increasing, and the braking torque curve shows a linear change.

3.1.2. Influence of Car Quality on Static Brake Torque. On the basis of the analysis of the experimental cases, the rest of the parameters are assumed to be constant and only the quality of the elevator car is changed (namely, the balance coefficient k is changed).

The static braking torque M_{fs} of different car quality conditions when the car loaded with 1.25 times rated load can be calculated by Equation (5). The $i = 1.25$ is substituted into Equation (5), and the results obtained are shown in Table 2.

TABLE 1: Model parameter values.

| Parameter	Nomenclature	Value
The masses of the empty car and components supported by the car	P	1.2×10^3 kg
The rated load	Q	$1 \times 10^3 \, k < 0.5$ kg
The mass of counterweight including mass of pulleys	W	1.65×10^3 kg
The standard acceleration of free fall	g	9.8 m/s^2
The actual mass of suspension ropes	M_{SR}	52.8 kg
The reduced mass of pulleys on car side	m_{P1}	0.7 kg
The reduced mass of pulleys on counterweight side	m_{P2}	0.7 kg
The radius of the traction wheel	R	0.225 m
The height of the hoistway	H	24 m
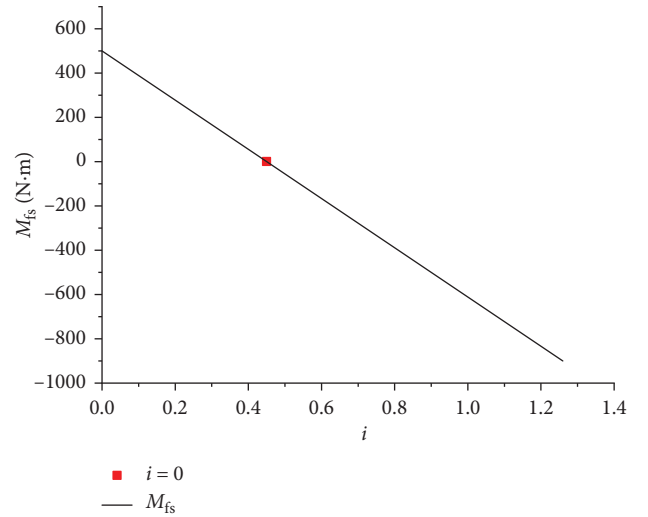
FIGURE 2: Relation between elevator loading mass ratio and braking torque.

TABLE 2: The influence of car quality on static brake torque.

P (kg)	$k = (P - W)/Q$	$M_{fs1.25}$ (N·m)
1150	0.5	943.2990
1200	0.45	998.4240
1250	0.4	1053.549
1300	0.35	1108.674
1350	0.3	1163.799

The analysis of the elevator traction system under 1.25 times the rated load under different balance coefficients can be found that the increase of the elevator car's quality will lead to the decrease of the balance coefficient and will also lead to a significant increase of the braking torque under 1.25 times the rated load. When the weight of the car is increased by 50 kg, the balance coefficient is reduced by 0.5. The braking torque required by the brake needs to be increased by 55.125 N·m.

3.2. Effect of Acceleration on Emergency Braking Torque. In the case of the same braking torque when the elevator balance coefficient is $k < 0.5$, the acceleration of emergency braking for different loads of the car is analyzed. When the elevator is fully loaded downward, the acceleration of emergency braking is the smallest, and when the elevator is fully loaded upward, the acceleration of emergency braking is the largest.

In the case shown in Table 2, it is assumed that the value of the emergency braking acceleration is from $1.96 \, \text{m/s}^2$ to $9.8 \, \text{m/s}^2$, and the braking torque and the full-load downward acceleration curve can be calculated by Equations (8) and (11).

When the acceleration of the unloaded acceleration a_{ue} is determined, the braking torque of the elevator M_f and the acceleration value under full-load downlink a_{dr} and uplink a_{ur} conditions can be calculated as shown in Table 3.

The greater the unloaded uplink acceleration, the greater the emergency braking torque provided by the elevator brakes, and the acceleration of full-load downlink and uplink will also increase accordingly. The relationship between the three kinds of acceleration and braking torque is shown in Figure 3.

4. Experiments

A dynamic braking torque test method that can be used in elevators has been developed to verify the feasibility of the abovementioned model. The test procedure is as follows:

(1) Measure the radius of the traction sheave R

(2) Measure car mass P and counterweight mass W

(3) Arrange the acceleration sensor and data acquisition device of SoMateDAQlite on the car, and set the sampling frequency to 100 HZ

(4) Run the elevator without load up to uniform velocity (middle stroke), then cut off the electricity, and measure the acceleration of the elevator car

4.1. Test Method of Elevator Quality. As the high quality suspension system, the actual quality of the elevator car is not consistent with the quality in factory in the process of use (the quality of the car given by the manufacturer is generally a range, not a fixed value). How to measure the quality of the car and the weight has always been a major problem for an elevator.

In order to test the quality of the car and the counterweight, a set of quality-testing device has been developed, the specific parameters as shown in Table 4. It considered the structural characteristics of the elevator, and measured the weight of the car and the counterweight by measuring the tension of the wire rope of the elevator.

The quality-testing device is composed of mechanical lifting structure and data display structure (as shown in Figure 4(a)). The mechanical lifting structure is made up of two symmetrical parts. When measuring, the left and right parts are fixed on the elevator traction rope through bolts and nuts. The unilateral side of the device (as shown in Figures 4(b) and 4(c)) consists of a servomotor, an upper

TABLE 3: Braking torque—acceleration relation

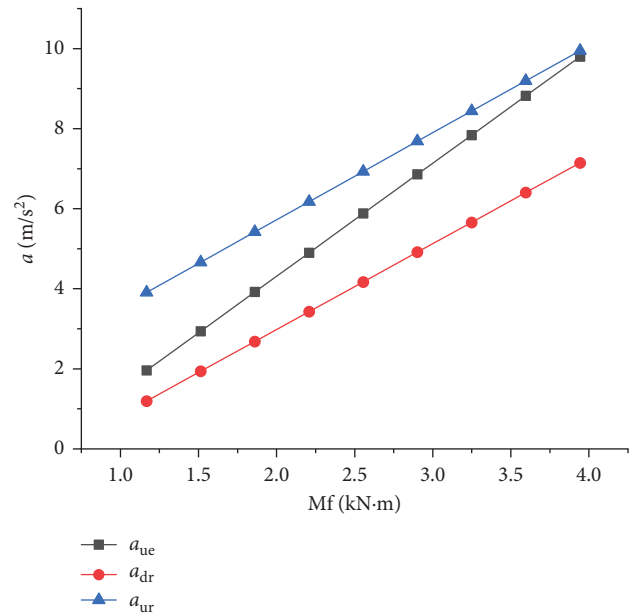| $a_{\text{ue}}(\text{m/s}^2)$	$M_f(\text{kN·m})$	$a_{\text{dr}}(\text{m/s}^2)$	$a_{\text{ur}}(\text{m/s}^2)$
1.96	1.167817	1.1979	3.9102
2.94	1.514689	1.9415	4.6653
3.92	1.861560	2.6851	5.4204
4.90	2.208431	3.4288	6.1755
5.88	2.555302	4.1724	6.9306
6.86	2.902174	4.9161	7.6857
7.84	3.249045	5.6597	8.4408
8.82	3.595916	6.4033	9.1959
9.8	3.942788	7.1470	9.9510

FIGURE 3: Braking torque—acceleration relation diagram.

TABLE 4: Parameters of elevator quality-testing device.

Measuring range	≤2000 kg
Measurable rope diameter	8 mm~16 mm
Error	≤5‰
Measurable rope number	≤8 root

clamping block (C1), a lining block, an S-type tension sensor, a connecting screw, and a lower clamping block. The motor is fixed on the upper clamping block (C2), the lining block is fixed in the clamping block, and directly contacts with the wire rope to ensure that the wire rope is clamped tightly during the test. And the data display component is mainly used to transform the sensor signal and display the measured quality data.

The car will be stopped at the same height with counterweight. The rope above the car/counterweight will be selected to fix clamps 1 and 2 (as shown in Figure 5(a)). With the support of clamp 1, clamp 2 is lifted so that the rope in the middle is relaxed and unstressed (as shown in Figure 5(b)). The tension between clamp 1 and clamp 2 is transferred to the device, which is measured by the S-type tension sensor, and the value is the weight of the car/counterweight.
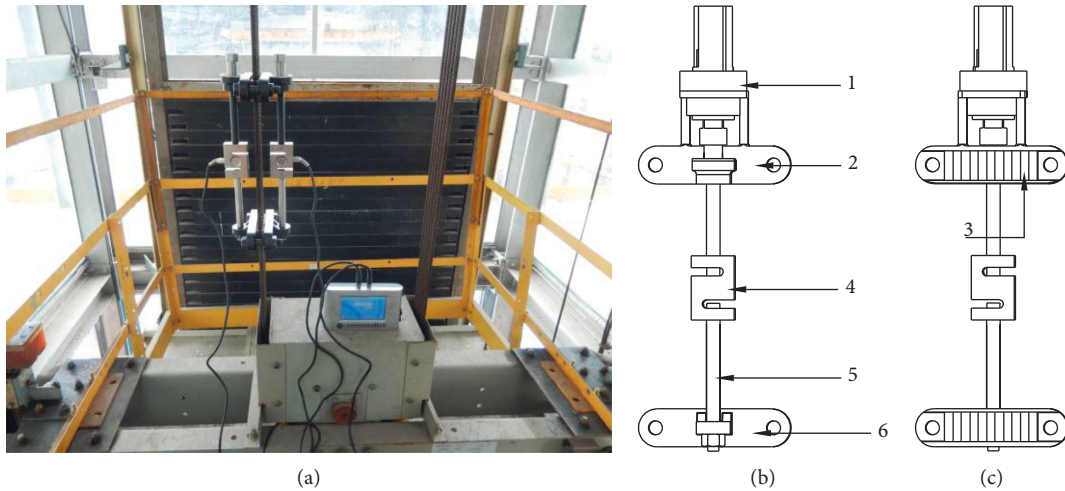
FIGURE 4: Quality test picture of elevator car. (1) Servomotor, (2) C1, (3) lining block, (4) tension sensor, (5) connecting screw, and (6) C2. (a) Assembly diagram. (b) Unilateral front view. (c) Unilateral back view.
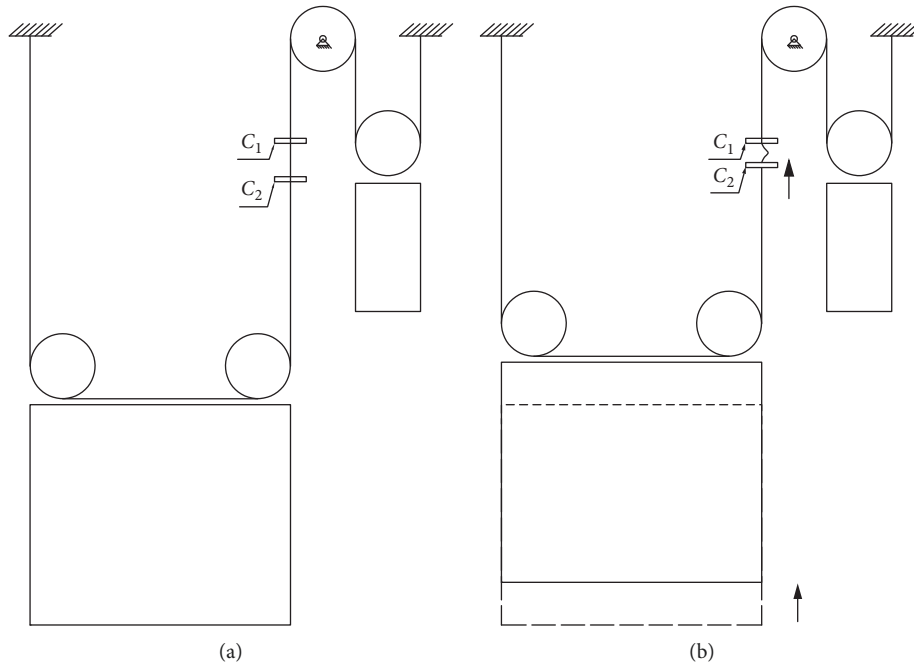

FIGURE 5: Schematic diagram of quality test. C1: clamp 1; C2: clamp 2. (a) Fixture installation. (b) Wire rope bending in test.

4.2. Acceleration Test and Calculation Method. The acceleration test is carried out on the top of the car. The experimental setup consists of an eDAQ data collector (shown in Figure 6(a)), an acceleration sensor (marked by the red circle in Figure 6(b)), and a notebook computer, which are connected by data lines. The eDAQ data collector (type: K-EDAQ-2) made in US is selected to measure acceleration in the process of braking. The parameters of the acceleration sensor used are shown in Table 5. Notebook computers are mainly used to store the collected experimental data.

After the installation of the experimental device, the tester leaves the top of the car, and the no-load uplink emergency braking test is carried out by the professional elevator maintenance personnel. When the car runs to the middle of the well, operate the emergency stop switch and test the acceleration in the process of stopping.

The braking acceleration curve of the elevator running up under unloaded condition is shown in Figure 7.

From Figure 7, we know that the acceleration first increases at $t1$ and then reverses after 0.15 s. Analysis of the acceleration with the time period changing from $t1$ to $t2$ shows that the elevator loses the traction force of the traction main engine under the emergency braking operation, because the counterweight is heavier than the empty car, and the brake does not lock so that the elevator car is speeding up under the effect of the gravity difference. At $t2$ time, the brake effect occurs, the car gradually slows down under the action of braking torque, and the car stops running at $t3$.
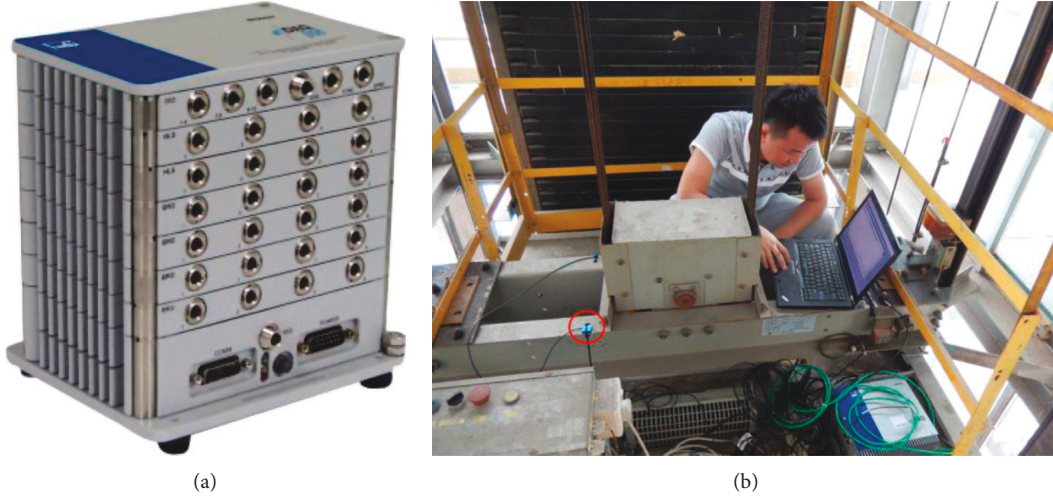
(a)

(b)

FIGURE 6: Acceleration test chart. (a) eDAQ data collector. (b) Acceleration test.

TABLE 5: ASC acceleration sensor.

Manufacturer	ASC GmbH
Type	ASC 4421-001-6A
Country	Germany
Serial number	16-23872

TABLE 6: Larger peak points.

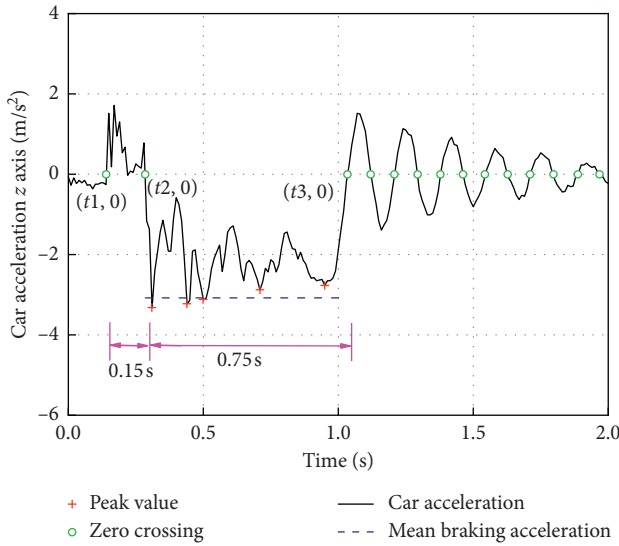| t	a
0.31	−3.323
0.44	−3.232
0.5	−3.124
0.71	−2.879
0.95	−2.772

FIGURE 7: Acceleration test results of unloaded uplink emergency braking.

The acceleration value fluctuates within a higher value range between $t2$ from $t3$. Considering the loosening of contact between the brake shoe and brake wheel during braking, the higher value has been seen as a test result at the ideal state of the elevator brake. 5 larger peak points (shown in Table 6) have been chosen to analyze. The average value of 3 median points is the braking acceleration.

The average acceleration peak value is $a_{ue} = -3.078$ (minus sign indicates the direction of acceleration).

5. Results and Discussion

5.1. Calculation of Braking Torque for Running up under Unloaded Condition. The car is in the middle of the well, so

$$m_{R1} = m_{R2} = \frac{m_R}{2}. \tag{14}$$

The parameters in Table 1 and the value of a_{ue} are substituted into

$$M_{fu} = 1.557 \times 10^3 \, \text{N·m}. \tag{15}$$

Compared with static load calculation and emergency braking results under the same load condition, it can be seen that the emergency braking torque is much larger than the static load torque. In this case, when $k = 0.45$, under 1.25 times rated load, static load torque $M_{fs1.25} = 998.42$ N·m. The emergency braking torque is constant when loading different weights. It can be considered that the emergency braking torque $M_{f1.25} = M_{fu}$ under 1.25 times load. The ratio of emergency braking moments is $M_{f1.25}/M_{fs1.25} = 1.56$.

5.2. Downlink Acceleration Analysis. Due to the constant pressure of the brake spring, the braking torque of the uplink and downlink processes can be considered equal. That is,

$$M_{fu} = M_{fd} = 1.557 \times 10^3 \, \text{N·m} \tag{16}$$

The value of M_{fd} is substituted by Equation (11), and the average stopping acceleration value of the elevator when loaded with rated load ($i = 1$) downward is

$$a_{dr} = 2.079 \, \text{m/s}^2. \tag{17}$$

Similarly, equation (11) can also get the average acceleration of the elevator when no load ($i = 0$) downward is

$$a_{de} = 5.957 \, \text{m/s}^2. \tag{18}$$

5.3. Experimental Verification and Error Analysis. In order to verify the accuracy of the established calculation model, the experiments of no-load downlink braking experiment were carried out, and the braking acceleration curve of the car is shown in Figure 8.

From Figure 8, we know that the acceleration first increases a small value at t1 and then increases rapidly after 0.12 s. This phenomenon is also due to the deceleration of the car under the action of counterweight before the brake acts. 5 larger peak points (shown in Table 7) have been chosen to analyze. The average value of 3 median points is the braking acceleration.

The experimental results show that the braking acceleration $a'_{de} = 5.261 \, \text{m/s}^2$ measured by the experiment is 11.95% less than the theoretical value $a_{de} = 5.957 \, \text{m/s}^2$. The main reasons are as follows:

(1) The experimental data-processing method which takes the average value of five peaks may cause errors, and the better data-processing method needs to be further studied later.

(2) Acceleration calculated theoretically is based on the assumption that the brake torque is equal in the process of up-going and down-going. In the actual use of the elevator, the brake torque in different directions may be different because of the different use conditions.

(3) In the calculation process, the resistance of the elevator-driven main engine acting on the car-counterweight system after power failure is not considered.

5.4. Comparison of Elevator Braking Performance Test Methods. At present, there are two kinds of test on the braking performance of the elevator in use: one is 1.25 times rated load braking test, the operation method is to apply 1.25 times rated load to the car first, then make the elevator run to the rated speed, cut off the power supply so that the elevator emergency braking, then test the running distance of the car from power failure to the time when the elevator stops. Another kind of motor rotation experiment, the operation method is to set a program so that the main engine at a certain time to output a certain amount of torque, see whether the brake wheel will rotate under the given torque. These two methods and the test methods proposed in this paper are compared and analyzed from five aspects: safety, convenience, static and dynamic braking torque test ability, intuition.

5.4.1. The Experimental Method Proposed in this Paper. The quality test instrument and the acceleration tester are used to carry out the no-load emergency stop test, and the safety is high. The operator only needs to carry a small
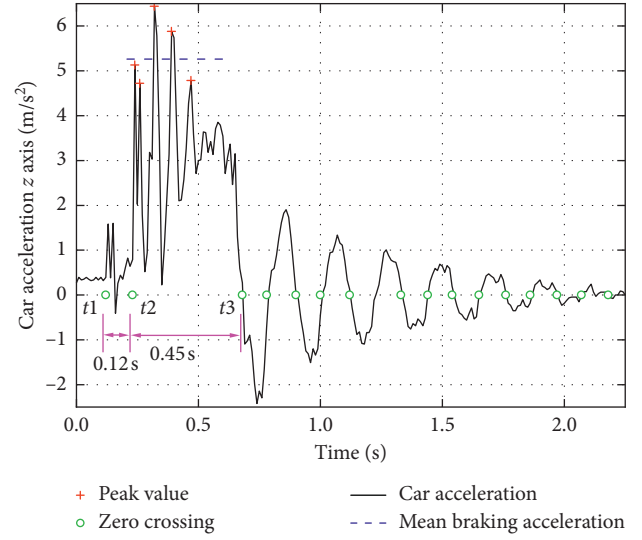

FIGURE 8: Acceleration test results of unloaded downlink emergency braking.

TABLE 7: Larger peak points.

t	a
0.24	5.129
0.26	4.718
0.32	6.438
0.39	5.875
0.47	4.779

The average acceleration peak value is $a'_{de} = 5.261 \, \text{m/s}^2$.

number of instruments, which is convenient for testing and easy to operate. The results can not only get accurate static braking torque, but also calculate the emergency braking torque of full load. The results are intuitive and easy to judge.

5.4.2. 1.25 Times Rated Load Braking Test Method. It is necessary to place 1.25 times the rated load on the elevator and carry out emergency stop test under overload condition. Once the braking capacity of the elevator is insufficient, great danger will occur. Generally, the rated load of the elevator is more than 1 ton, that is to say, it needs to carry more than 1.25 tons of load for the experiment, and the experimental process is time-consuming and laborious. It is difficult to distinguish the measured brake distance, which includes the operating distance in the brake response process and the operating distance after the brake action. The results can only indirectly estimate the braking capacity, with large error and not intuition.

5.4.3. Motor Rotation Experiment. Set up a program to operate at a specific time in advance, and there is no operator involved in this process. During the experiment, it is possible to trap passengers entering the elevator at this time. So there are certain risks in the experiment. The program can only measure whether the brake can satisfy the static braking ability under the action of the specific magnitude of the output torque, and the result is not intuitive.

The abovementioned analysis results are summarized in Table 8.

TABLE 8: Comparison of 3 test methods.

	Method in this paper	1.25 times rated load method	Motor rotation method
Safety	High	Low	Medium
Convenience	High	Low	Medium
Static torque	Measurable	Measurable	Specific value measurable
Dynamic torque	Accurately calculated	Estimated from braking distance	Unmeasurable
Intuition	Intuitionistic	Not intuitionistic	Not intuitionistic

6. Conclusions

In this paper, through the analysis of the force of the whole elevator system, the calculation method of the torque under the emergency braking condition of the elevator brake is studied. The torque of the brake in different working conditions is analyzed. A test method of emergency braking torque of elevator is also proposed. An elevator with a lifting height of 24 meters is tested by this method. Based on these works, the following conclusions are obtained:

(1) Braking capacity is related to the brake shoe pressure, the clearance of brake shoe, the performance of the friction pad, and the surface roughness of the brake wheel. In the case of emergency stop, the brake is locked when the brake wheel rotates, and this situation has raised a lot of requirements for brakes braking capacity. By calculation, it can be known that under the action of 1.25 times rated load, the emergency braking torque of the experimental elevator selected in this paper is 1.56 times the static braking torque.

(2) The influence of car quality on static braking torque is analyzed by using the established calculation model. The results show that the required braking torque increases by 55.125 Nm for each 50 kg increase in the mass of the elevator car under 1.25 times rated load. The relationship between the emergency braking acceleration under different working conditions is also analyzed. The results show that the greater the no-load braking acceleration tested by the experiment, the greater the braking torque. The braking acceleration will also increase under the full-load condition.

(3) A set of elevator quality tester is designed, which can accurately measure the quality of the elevator car and counterweight, and a new method of elevator braking torque testing is studied. Based on the calculation results of braking torque of no-load uplink braking, the acceleration of braking under full load is analyzed. The experimental results show that the braking acceleration measured by the experiment is 11.95% less than the theoretical value. 3 main causes of experimental errors are also analyzed.

(4) Comparing the braking torque measurement method proposed in this paper with the traditional method, it can be seen that the static and dynamic braking torque can be calculated by the method in this paper, and it has the advantages of high safety, convenient operation, intuition and accuracy. The experimental method can be used in the inspection of elevator brakes being used, and it is of great practical significance to improve the safety of elevators in use.

The resistance of the elevator-driven main engine acting on the car-counterweight system should be further investigated in the future.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

References

[1] T. Li, Y. Peng, Z. Zhu, Z. Yu, and Z. Yin, "Effect of the lifting velocity and container shape on angle of repose of iron ore particles," *Advances in Materials Science and Engineering*, vol. 2017, Article ID 3405432, 11 pages, 2017.

[2] E. Durak and H. A. Yurtseven, "Experimental study of the tribological properties of an elevator's brake linings," *Industrial Lubrication and Tribology*, vol. 68, no. 6, pp. 683–688, 2016.

[3] S. M. Kalikate, S. R. Patil, and S. M. Sawant, "Simulation-based estimation of an automotive magnetorheological brake system performance," *Journal of Advanced Research*, vol. 14, pp. 43–51, 2018.

[4] I. Skog, I. Karagiannis, A. B. Bergsten, J. Härdén, L. Gustafsson, and P. Händel, "A smart sensor node for the internet-of-elevators—non-invasive condition and fault monitoring," *IEEE Sensors Journal*, vol. 17, no. 16, pp. 5198–5208, 2017.

[5] B. Xu, M. Cheng, H. Yang, J. Zhang, and M. Yang, "Safety brake performance evaluation and optimization of hydraulic lifting systems in case of overspeed dropping," *Mechatronics*, vol. 23, no. 8, pp. 1180–1190, 2013.

[6] R. Longwic and K. Szydło, "The impact of the elevator guides contamination on the braking process delay for selected progressive gears," *Advances in Science and Technology Research Journal*, vol. 11, no. 2, pp. 1–7, 2017.

[7] K. Han, S. Choi, J. Lee, D. Hyun, and J. Lee, "Accurate brake torque estimation with adaptive uncertainty compensation using a brake force distribution characteristic," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 12, pp. 10830–10840, 2017.

[8] BSI, *EN 81–50:2014 Safety Rules for the Construction and Installation of Lifts—Examinations and Tests Part 50: Design Rules, Calculations, Examinations and Tests of Lift Components*, BSI Standards Publication, London, UK, 2014.

[9] Y. Li and Q. Wu, "Experimental study on friction sliding performance of rubber bearings in bridges," *Advances in Materials Science and Engineering*, vol. 2017, Article ID 5848149, 8 pages, 2017.

[10] N. Kobayashi, K. Kawase, S. Sato, and T. Nakagawa, "Experimental verification on effects in an emergency stop by installation of magneto rheological fluid damper to an elevator," *IEEE Transactions on Magnetics*, vol. 53, no. 11, pp. 1–4, 2017.

[11] H. Her, Y. Koh, E. Joa, and K. Yi, "An integrated control of differential braking, front/rear traction, and active roll moment for limit handling performance," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 6, pp. 4288–4300, 2016.

[12] H. Lu, Z. Cai, and Q. Feng, "An improved method for fuzzy-interval uncertainty analysis and its application in brake instability study," *Computer Methods in Applied Mechanics and Engineering*, vol. 342, pp. 142–160, 2018.

[13] N. Noguchi, A. Arakawa, T. Yoshimura, and Y. Sekiya, "Identification method of elevator rail deformation using operational acceleration data," *Transactions of the Japan Society of Mechanical Engineers*, vol. 78, no. 786, pp. 431–445, 2012.

[14] W. D. Zhu, W. Fan, Y. G. Mao, and G. X. Ren, "Three-dimensional dynamic modeling and analysis of moving elevator traveling cables," *Journal of Multi-body Dynamics*, vol. 231, no. 1, pp. 167–180, 2017.

[15] E. Esteban, O. Salgado, A. Iturrospe, and I. Isasa, "Model-based approach for elevator performance estimation," *Mechanical Systems and Signal Processing*, vol. 68-69, pp. 125–137, 2016.

[16] M. Ungureanu, I. Crăciun, M. Bănică, and A. Dăscălescu, "Study for elevator cage position during the braking period," *Materials Science and Engineering Conference Series*, vol. 144, article 012010, 2016.

[17] J. Bao, Z. Li, and D. Hu, "Frictional performance and temperature rise of a mining nonasbestos brake material during emergency braking," *Advances in Materials Science and Engineering*, vol. 2015, Article ID 867549, 7 pages, 2015.

[18] H. Yan, Z. Xu, J. Yuan, L. Liang, T. Cao, and W. Ge, "Friction characteristics of synchronization process based on tribo-thermodynamics," *Advances in Materials Science and Engineering*, vol. 2018, Article ID 8467921, 9 pages, 2018.

[19] G. Pan and L. Chen, "Impact analysis of brake pad backplate structure and friction lining material on disc-brake noise," *Advances in Materials Science and Engineering*, vol. 2018, Article ID 7093978, 9 pages, 2018.

[20] E. Esteban, O. Salgado, A. Iturrospe, and I. Isasa, "Model-based estimation of elevator rail friction forces," in *Advances in Condition Monitoring of Machinery in Non-Stationary Operations*, Springer International Publishing, New York City, NY, USA, 2016.

The Scientific
World Journal

Journal of
Applied Chemistry

Journal of
Nanomaterials

Scientifica

International Journal of
Polymer Science

Advances in
Chemistry

Advances in
Physical Chemistry

International Journal of
Analytical Chemistry

Hindawi

Submit your manuscripts at
www.hindawi.com

Advances in
Condensed Matter Physics

Journal of
Chemistry

International Journal of
Biomaterials

Advances in
High Energy Physics

Journal of
Engineering

Journal of
Nanotechnology

International Journal of
Corrosion

Journal of
Materials

BioMed
Research International

Advances in
Tribology

Advances in
Materials Science and Engineering