It is very important for pavement engineers to know which factors are the main reasons for the damage of the paving around manholes. Based on the investigation on the damage of paving around manholes, a vibration model with multidegree of freedom for the vehicle-manhole cover was established and analyzed. After that, the Matlab software was used to obtain the variation law of impact load over time, and the 95% fourth power of the aggregate force was used as the index to evaluate the pavement damage. Finally, many influencing factors on pavement damage were analyzed by the method of grey correlation entropy. The results indicated that the impact load reached the maximum for the first time when the vehicle reached the top of the manhole cover, which was 1.29 times that of the static load, and the pavement damage coefficient was 2.12 times that of the static load. The influencing factors had different degrees of influence on the pavement damage; from large to small, they were change of road longitudinal slope > driving speed > damping of tire > stiffness of tire > height difference from the pavement damage > height difference from the manhole settlement > stiffness of the manhole cover.

1. Introduction

Manholes play an important role in the installation, inspection, and maintenance of urban facilities. Many manholes are located on urban roads, and they are weak parts. Under repeated vehicle load, the paving around manholes easily sustain serious damage, such as settlement, cracks, and pits [1]. Surveys were conducted on 300 paving around manholes in Guangzhou [2] and 212 in Tianjin [3]. It was found that there were different types of damage, including settlement, cracks, spalling, and pits (Figure 1) [4]. When the paving around manhole sustains damage, it not only affects the beauty of the pavement but also worsens pavement roughness. When a vehicle passes over uneven pavement, a significant “bump” occurs. At the same time, as a rigid plate with limited thickness, the manhole cover undergoes obvious deformation and vibration under the vehicle load, which would lead to increased vibration of the vehicle, resulting in greater vehicle impact load, accelerating the destruction of the pavement, which would in turn increase the vibration of the vehicle, forming a vicious circle.

In the maintenance of urban roads, the cost of repairing the paving around manholes is very high each year, but there remains the problem of further destruction very soon [5].

At present, research on manholes and the paving around manholes mostly focuses on manhole settlement mechanisms [6], new manhole structures [7–9], damage analysis of the paving around manholes [10], and treatment technology for pavement damage [11, 12], and the control of damage to paving around manholes has improved to some extent.

In the above studies, the dynamic load of a vehicle was a key factor. There were three main ways to obtain the dynamic load of a vehicle: software analysis, mathematical modeling, and the field test. Liu et al. [13], Chen et al. [14], and Liu et al. [15] used a multibody dynamics software SIMPACK to build a heavy-duty vehicle model and studied the dynamic load characteristics of vehicles under random excitation of pavement unevenness. The 1/4 vehicle model [16, 17], 1/2 vehicle model [18], and full car model [19, 20] were, respectively, established based on the mathematical method, and the dynamic load characteristics, driving comfort, and their influencing factors were studied. Liu et al.
used an accelerometer to monitor the acceleration of the front and rear axle and obtained the dynamic load.

When the vehicle passed over the paving around the manhole, the vibration characteristics of the vehicle were significantly different from those when passing over the general pavement. This was because the vehicle and the pavement were a weakly coupled system [22], and the deformation and vibration of the pavement were often neglected. But, when the vehicle passed over the manhole, there was obvious deformation and vibration of the manhole cover, which could not be ignored. However, a static load was often used in the study of the failure mechanism for the paving around manholes, while dynamic load was often ignored, meaning the failure mechanism of the paving around manholes is not yet comprehensively understood.

Therefore, based on the investigation on the damage of paving around manholes, this paper studies the dynamic characteristics of a vehicle when it passes over a manhole and lays the foundation for research on the failure mechanism of the paving around manholes. In the research, the deformation and vibration of the manhole cover is considered, a vibration model with multidegree of freedom for the vehicle-manhole cover is established, and the 95% fourth power of the aggregate force is used to evaluate the pavement damage. At the same time, the variation law of impact load over time is studied, and many influencing factors on pavement damage are analyzed with the method of grey correlation entropy, the key factors are identified, and provide reference for maintenance and design of paving around manholes.

2. Investigation

From March 10 to 25, 2019, investigations including on damage type to the paving around manholes and settlement of manholes were carried out on four roads—Jingshidong (300 manholes), Xinluo (100 manholes), Tianchen (100 manholes), and Xueshan (100 manholes)—in Jinan, Shandong Province, China. During the investigations, the damage was divided into four categories: manhole settlement, pavement cracks, pavement damage, and pavement deformation. Pavement damage included pit slot, looseness, and repaired areas. The deformation included settlement, rutting, and waves.

During the investigations, it was found that the settlement in the “Up” point was often less than that in the “Down” point (Figure 2), resulting in a change of road longitudinal slope, and had great influence on the impact load of passing vehicles. The investigation data of pavement damage and manhole settlement are shown in Table 1. The settlement of manholes and the changes of road longitudinal slope ($\Delta i$) are shown in Table 2. In Table 1, the region of the damage is equivalent to a circular region, represented by radius $r$.

As shown in Table 1, when the road had been used for a short time (Tianchen and Xinluo road had been used for 3 years; Xueshan road had been used for 5 years), the radius of the damaged region was small, mainly concentrated within the range 0.4–0.8 m. As the time increased (Jingshidong road had been used for 15 years), the radius of the damaged region gradually increased (range 0.7–1.2 m), and the proportion of the large radius of the damaged region gradually increased. Since the Jingshidong road had been used for 15 years and had reached the maximum design service life, it could be considered that the radius of the damaged region had reached the maximum of 1.2 m. Therefore, the paving around the manhole was defined as a circular area, with the circle center being the manhole center with a radius of 1.2 m.

It can be seen from Table 1 that 98% of the paving around manholes on Xueshan road had crack damage, and 56% had pavement damage; 100% of that in Jingshidong road had pavement damage (all had been repaired); 91% of that on Tianchen road had manhole settlement, and 51% had pavement damage; and 92% of that on Xinluo road had manhole settlement. Combined with the time that the road had been used, it was found that the probability of damage occurrence for manholes and the paving around manholes was 100%. The occurrence order of damage was manhole settlement $\rightarrow$ pavement cracks $\rightarrow$ pavement deformation $\rightarrow$ pavement damage (in need of repair).

As shown in Table 2, the settlement of manholes was generally small and concentrated in the range of 0–10 mm, mainly because the larger settlement had been treated, but there was still a small amount of settlement (>20 mm) that had not been treated. The value of $\Delta i$ was mainly distributed between $-1\%$ and $1\%$: the maximum value was 1.8% and the minimum value was $-2.1\%$. 
3. Vehicle-Manhole Cover Vibration Model with Multidegree of Freedom

3.1. Model Building.

As a complex system of multimass vibration, a vehicle is generally considered to have 18 degrees of freedom (DOF). It is very complicated to build a model according to the actual situation; so, it needed to be simplified. The current simplified models are the 1/2 vehicle vibration model with 5 DOF [23] and the 1/4 vehicle vibration model with 3 or 2 DOF [24]. In this paper, when the vehicle passed over the paving around manhole, a 1/4 vehicle vibration model with 3 DOF was built; when the vehicle passed over the manhole cover, the vibration and deformation of the manhole cover were considered to build the 1/4 vehicle vibration model with 4 DOF (Figure 3).

As shown in Figure 3, the process of a vehicle passing over manhole covers and the paving around manholes was divided into four stages: (1) on manhole paving → (2) on the manhole cover → (3) on manhole paving → (4) on normal pavement. In stage 2, considering the deformation and vibration of the manhole cover, a 4 DOF vehicle vibration model was established, and a 3 DOF vehicle vibration model was established in the other stages. In Figure 3, $m_1$, $m_2$, $m_3$, and $m_4$ are the weights of the vehicle seat, frame, wheel, and manhole cover; $y_1$, $y_2$, $y_3$, and $y_4$ are the displacements; $k_1$, $k_2$, $k_3$, and $k_4$ are the stiffness coefficients; $c_1$, $c_2$, $c_3$, and $c_4$ are the damp coefficients; $\xi(t)$ is the pavement unevenness; and $v$ is the vehicle speed.

It was assumed that the pavement roughness was good except for the manhole settlement and any damage to the paving around the manhole. Considering the damage as an unevenness incentive in the calculation process, the 3-DOF vibration model was established:

$$
m_1 \ddot{y}_1 + k_1 (y_1 - y_2) + c_1 (\dot{y}_1 - \dot{y}_2) = 0,\quad m_2 \ddot{y}_2 + k_2 (y_2 - y_3) + c_2 (\dot{y}_2 - \dot{y}_3) + k_1 (y_2 - y_1) + c_1 (\dot{y}_2 - \dot{y}_1) = 0,\quad m_3 \ddot{y}_3 + k_3 y_3 + c_3 \dot{y}_3 + k_2 (y_3 - y_2) + c_2 (\dot{y}_3 - \dot{y}_2) = 0,\quad m_4 \ddot{y}_4 + k_4 (y_4 - y_3) + c_4 \dot{y}_4 = 0.
$$

Table 1: Investigation data of pavement damage and manhole settlement.

| Road names | Time of road construction | Damage region (m) | Damage number |
|------------|---------------------------|-------------------|---------------|
|            |                           | Radius of damaged region (m) | Mean radius (m) | Manhole settlement | Pavement cracks | Pavement damage | Pavement deformation |
| Xinluo     | 2016.7                    | 0.5–0.7            | 0.66           | 92               | 40             | 32             | 2               |
| Tianchen   | 2016.7                    | 0.4–0.8            | 0.64           | 91               | 33             | 51             | 2               |
| Xueshan    | 2014.5                    | 0.4–0.8            | 0.61           | 44               | 98             | 56             | 3               |
| Jingshidong| 2004.9                    | 0.7–1.2            | 0.84           | 50               | 140            | 300            | 0               |

Table 2: Settlement of manholes and changes of road longitudinal slope.

| Investigation item | Tianchen | Jingshidong |
|-------------------|----------|-------------|
| Settlement        |          |             |
| 0–5 mm            | 62       | 54          |
| 5–10 mm           | 11       | 11          |
| 10–15 mm          | 2        | 1           |
| 15–20 mm          | 5        | 7           |
| >20 mm            | 0        | 7           |
| Δi                |          |             |
| –3%–1%            | 0        | 7           |
| –1%–0%            | 77       | 32          |
| 0%–1%             | 3        | 31          |
| 1%–2%             | 0        | 10          |
| >2%               | 0        | 0           |
still used equation (3) but the vehicle was driving on other areas, the calculation of $f$ impact load factor was calculated by equation (3). When the manhole was manhole, we assumed that the maximum 3.2. Calculation Example. We assumed that the maximum height difference caused by the damage to paving around the manhole was $H_1 = 1$ cm, and the position was 0.6 m from the edge of the manhole cover; the diameter of the manhole cover was 0.7 m, and its settlement was $H_2 = 1$ cm; if $\Delta t = 4\%$ and $v = 10$ m/s, the driving direction was uphill. In stage (1), the initial conditions of equation (1) were $\dot{y}_1 = -0.4, \dot{y}_2 = -0.4, \dot{y}_3 = -0.4, y_1 = 0.01, y_2 = 0.01,$ and $y_3 = 0.01$. In stage (2), the initial conditions of equation (2) were $\dot{y}_1 = \dot{y}_1(t_1), \dot{y}_2 = \dot{y}_2(t_1), \dot{y}_3 = \dot{y}_3(t_1), y_1 = y_1(t_1) + 0.01, y_2 = y_2(t_1) + 0.01, y_3 = y_3(t_1) + 0.01, y_4 = 0$ ($t_1$ was the duration of the vehicle driving on the paving around the manhole), and so on for the remaining stages. The transfer matrix method [25] was used to solve equations (1) and (2). Combined with equation (3), equation (4), and the initial conditions and the programmed Matlab software, the change of $f$ with time was obtained (Figure 4).

It can be seen from Figure 4 that under the excitation of pavement roughness, the vehicle load was a simple harmonic vibration of amplitude attenuation. When there was a new unevenness excitation, the vehicle dynamic load changed obviously. The $f$ was 1.12 at 0.06 s when the vehicle was on the “Up” point, 1.29 at 0.13 s when the vehicle was on the “Down” point, and reached a maximum value of 1.33 at 0.64 s. This was the reason why the settlement of the “Down” point was bigger than the “Up” point. Considering the subgrade around the manhole is difficult to compact, and the paving around the manhole was most likely to be damaged.

4. Evaluation of Pavement Damage and Influencing Factors

4.1. Evaluation of Pavement Damage. At present, there are three main indexes for the evaluation of pavement damage: dynamic load coefficient ($D$), road stress factor ($\theta$), and 95% fourth power of the aggregate force ($J$) [26]. In $D$, the relation between pavement damage loads is linear, but the repeatability of the vehicle dynamic load in the spatial distribution is not considered, which was quite different from the actual situation. Later, through many experiments, it was proved that the fatigue damage of a semirigid base asphalt pavement was directly proportional to the fourth power of vehicle load. Therefore, Potter et al. proposed $\theta$ [27] but still did not consider the spatial distribution of the vehicle dynamic load.
Based on this, Cole and Cebon [28] put forward $J$ (equation (5)). In $J$, the repeatability of the vehicle dynamic load in spatial distribution is considered and greatly improves the accuracy of pavement damage evaluation. Therefore, $J$ was used as the pavement damage evaluation index in this paper. Under a static load, the index was equal to 1, and the larger the value, the greater the damage to the pavement:

$$J \approx 1 + 1.65 \sigma_{A^4}$$

where $A^4$ is the fourth power of the aggregate force, $\sigma_{A^4}$ is the standard deviation of $A^4$, and $m_{A^4}$ is the average of $A^4$.

Since the vibration caused by the vehicle passing over the manhole was transient vibration, referring to the literature [23], we calculated $J$ within 1 s and started timing when the vehicle entered the paving around the manhole area. With the basic parameters described in Table 3 and Section 3.2, $J = 2.12 > 1$ calculated by equations (3) and (5). When the vehicle passed over the paving around the manhole and the manhole cover, the damage of the vehicle load to the pavement was significantly greater than that of a static load.

4.2. Influencing Factors. There are many factors affecting the dynamic load and pavement damage [25]. Seven factors, the vehicle speed ($v$), the height difference caused by pavement damage ($H_1$), the manhole settlement ($H_2$), the changes of road longitudinal slope ($\Delta i$), the stiffness coefficient of the manhole cover ($k_4$), the tire stiffness coefficient ($k_3$), and the tire damping coefficient ($c_3$), were analyzed. For each factor, $v$ was determined by the design speed of the urban road, $H_1$ was determined by the pavement damage, $H_2$ was determined by the manhole settlement, $\Delta i$ was determined by the uneven settlement of the manhole, $k_4$ was determined by the material type of the manhole cover, and $k_3$ and $c_3$ were determined by the tire model and material. By equations (1)–(4), the time history curves for $f$ under different influencing factors were calculated (Figure 5). By equation (5), $J$ under different influencing factors was calculated (Table 4):

(1) As can be seen from Figure 5(a) and Table 4, with the increase of vehicle speed, the maximum $f$ and $J$ increased gradually. When the vehicle speed increased from 10 km/h to 80 km/h, $J$ increased by 52.6%, which was obvious.

(2) As can be seen from Figures 5(b) and 5(c) and Table 4, with the increase of $H_1$ and $H_2$, the maximum $f$ and $J$ were significantly increased. When $H_1$ increased from 0.5 cm to 8 cm, $J$ increased by 48.5%; When $H_2$ increased from 0.5 cm to 8 cm, $J$ increased by 36.5%. Although the two factors of $H_1$ and $H_2$ were the same as the unevenness of the pavement, their influences on $J$ were different. Especially, when $H$ was larger than 1 cm, the influence of $H_1$ was

| Parameters | Value |
|-----------|-------|
| $m_1$ (kg) | 70    |
| $m_2$ (kg) | 4500  |
| $m_3$ (kg) | 430   |
| $m_4$ (kg) | 56    |
| $c_1$ (N·s/m) | 1800  |
| $c_2$ (N·s/m) | 7000  |
| $k_1$ (N/m) | 2100  |
| $k_2$ (N/m) | $9.5 \times 10^5$ |
| $k_3$ (N/m) | $4.8 \times 10^5$ |
| $k_4$ (N/m) | $1 \times 10^6$ |
| $c_3$ (N·s/m) | 5000  |
| $c_4$ (N·s/m) | 0     |

Figure 4: Impact factor of load variations over time.
Figure 5: Continued.
Figure 5: Time history curves for impact load coefficients \( (f) \) under different influencing factors. (a) Factor of \( v \). (b) Factor of \( H_1 \). (c) Factor of \( H_2 \). (d) Factor of \( k_4 \). (e) Factor of \( \Delta i \). (f) Factor of \( c_3 \). (g) Factor of \( k_3 \).

Table 4: Pavement damage coefficients \( (J) \) under different influencing factors.

| Influencing factors | \( J \) |
|---------------------|--------|
| \( v \) (km/h)      |        |
| 10                  | 1.73   |
| 20                  | 1.87   |
| 30                  | 2.03   |
| 40                  | 2.18   |
| 50                  | 2.32   |
| 60                  | 2.44   |
| 70                  | 2.55   |
| 80                  | 2.64   |
| \( \Delta i \) (%)  |        |
| 1                   | 1.72   |
| 2                   | 1.84   |
| 3                   | 1.98   |
| 4                   | 2.12   |
| 5                   | 2.25   |
| 6                   | 2.37   |
| 7                   | 2.47   |
| 8                   | 2.57   |
| \( k_3 \) (10^5 N/m)|        |
| 1                   | 1.64   |
| 2                   | 1.92   |
| 4                   | 2.02   |
| 5                   | 2.15   |
| \( H_1 \) (cm)      |        |
| 0.5                 | 2.07   |
| 1                   | 2.12   |
| 2                   | 2.27   |
| 3                   | 2.44   |
| 4                   | 2.60   |
| 5                   | 2.74   |
| 6                   | 2.87   |
| 8                   | 3.07   |
| \( H_2 \) (cm)      |        |
| 0.5                 | 2.08   |
| 1                   | 2.12   |
| 2                   | 2.22   |
| 3                   | 2.34   |
| 4                   | 2.45   |
| 6                   | 2.67   |
| 8                   | 2.84   |
| 10                  | 2.97   |
greater than the influence of $H_2$. At this time, the presence of the manhole cover with elastic characteristics buffered the vehicle vibration and reduced $J$ under the vehicle load.

(3) As can be seen from Figure 5(d) and Table 4, with $k_4$ increased, the maximum $f$ decreased gradually and $J$ decreased slightly; when $k_4$ increased from $10^2$ N/m to $10^9$ N/m, $J$ only decreased by 15.3%. Therefore, $k_4$ had little influence on $J$.

(4) As can be seen from Figure 5(e) and Table 4, with the increase of $\Delta i$, the maximum $f$ and $J$ increased significantly. When $\Delta i$ increased from 1% to 8%, $J$ increased by 33.1%. In fact, $\Delta i$ also belonged to the "unevenness" of pavement. Under the same excitation of pavement roughness, the larger $\Delta i$, the bigger $J$, but this factor was often ignored.

(5) As can be seen from Figures 5(f) and 5(g) and Table 4, with the increase of $c_3$, the maximum $f$ and $J$ decreased gradually. When $c_3$ increased from $10^3$ to $10^4$, $J$ decreased by 13.2%. As $k_3$ increased, the maximum $f$ increased significantly, the vehicle vibration period shortened, and $J$ increased first and then decreased. When $k_3$ was about $8 \times 10^5$, $J$ reached the maximum value of 2.31. It can be seen that $k_3$ and $c_3$ had a certain degree of influence on the pavement damage, but in fact, $k_3$ and $c_3$ were mainly affected by the tire pressure, and as the tire pressure was basically stable, $k_3$ and $c_3$ varied little; therefore, $J$ changed little.

Through the above analysis, it is clear that all the above factors had a certain degree of influence on $J$. However, among these factors, which factors were more important, played a major role, and which factors played a secondary role? As the units of the above factors were different, comparing the change of $J$ with the change of each factor was not significant. It was necessary to select a suitable evaluation method to compare the influence degree of each factor.

5. Grey Correlation Entropy Method to Compare the Degree of Influence of Each Factor on $J$

5.1. Grey Correlation Entropy Method. Grey correlation refers to the uncertain relationship between different things. It is a systematic analysis method to measure the degree of correlation between factors and systems and to compare the influence degree between each factor. However, this method can easily generate the problem that the local point correlation value controls the overall point correlation value, causing loss. To solve this problem, the grey correlation entropy method was proposed [29].

For grey correlation entropy analysis, let $X$ be the grey correlation factor set. Take $J$ as the reference set ($X_0 = \{X_0(k) | k = 1, 2, \ldots, n\}$), and take the 7 influencing factors as the comparison set ($X_i = \{X_i(k) | k = 1, 2, \ldots, n\}$, $i = 1, 2, \ldots, 7$). In the calculation process, the magnitude and unit of each factor were different. Therefore, in order to eliminate the influence on the calculation result, the data needed to be processed to obtain the dimensionless set $X_i$ and the reference set $X_0$, which was $X'_i = \{X'_i(k) | k = 1, 2, \ldots, n\}$, $i = 0, 1, 2, \ldots, 7$.

The process of grey correlation entropy analysis is summarized into the following 5 steps:

Step 1. The grey correlation coefficient of $X_i - X_0$ was obtained from the following equation:

| Influencing factors | $J$ |
|---------------------|-----|
| $k_3 \ (10^5 \text{N/m})$ |     |
| 6  | 2.24 |
| 8  | 2.31 |
| 10 | 2.26 |
| 15 | 2.22 |
| $k_4 \ (\text{N/m})$ |     |
| $10^2$ | 2.49 |
| $10^3$ | 2.48 |
| $10^4$ | 2.47 |
| $10^5$ | 2.39 |
| $10^6$ | 2.19 |
| $10^7$ | 2.12 |
| $10^8$ | 2.11 |
| $10^9$ | 2.11 |
| $c_3 \ (10^3 \text{N\cdot s/m})$ |     |
| 1  | 2.27 |
| 2  | 2.23 |
| 4  | 2.16 |
| 5  | 2.12 |
| 6  | 2.09 |
| 7  | 2.06 |
| 8  | 2.02 |
| 10 | 1.97 |
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Table 5: Computed results and ordered correlation values of grey entropy.

| Factors | Grey correlation entropy | Grey entropy correlation degree | Ordered |
|---------|--------------------------|--------------------------------|---------|
| v       | 3.95118                  | 0.999984                       | 2       |
| $H_1$   | 3.95047                  | 0.999985                       | 5       |
| $\Delta i$ | 3.95120              | 0.999988                       | 1       |
| $c_3$   | 3.95117                  | 0.999980                       | 2       |
| $k_1$   | 3.95109                  | 0.999961                       | 4       |
| $H_2$   | 3.95015                  | 0.999723                       | 6       |
| $k_4$   | 3.94565                  | 0.998584                       | 7       |

where $\xi$ is the grey correlation coefficient, and $\rho$ is the resolution coefficient ($\rho \in [0, 1]$ and is 0.5 generally).

Step 2. The distribution density of grey correlation entropy was obtained according to equation (7).

Let $R_i = \{x_0(k), x_i(k)\}$, and the defined distribution density of grey correlation entropy is as follows:

$$P_h = \frac{\xi \left( x_0(h), x_i(h) \right)}{\sum_{k=1}^{n} \xi \left( x_0(k), x_i(k) \right)}$$  \(\text{ (7)}\)

where $P_h \in P_i \ (h = 1, 2, \ldots, n)$, and $P_h \geq 0, \sum P_h = 1$.

Step 3. The grey correlation entropy was obtained from equations (8) and (9).

Let $X = (x_1, x_2, \ldots, x_n)$, $\forall x_i \geq 0$, and $\sum x_i = 1$, and grey correlation entropy is as follows:

$$H \otimes (x) \triangleq -\sum_{i=1}^{n} x_i \ln x_i$$  \(\text{ (8)}\)

where $x_i$ is attribute information.

The grey correlation entropy of $X_i$ is

$$H(R_i) \triangleq -\sum_{h=1}^{n} P_h \ln P_h$$  \(\text{ (9)}\)

Step 4. The grey entropy correlation degree of $X_i$ was obtained from the following equation:

$$E(X_i) \triangleq \frac{H(R_i)}{H_{\text{max}}}$$  \(\text{ (10)}\)

where $H_{\text{max}} = \ln n$ is the maximum value of the grey entropy and represents the maximum value of the difference information column composed of $n$ elements.

Step 5. According to the magnitude of the grey entropy correlation degree, which factor was more important was determined. The larger the value, the more important the factor.

5.2. Results. Grey correlation entropy analysis for the 7 factors shown in Table 5 was performed, and the computed results and ordered correlation values of grey entropy are shown in Table 5.

As can be seen from Table 5, the order of degree of influence of each factor on $J$ was $\Delta i > v > c_3 > k_3 > H_1 > H_2 > k_4$. Among them, $c_3$ and $k_3$ were mainly determined by the tire pressure, but tire pressure was basically stable; so, the range of $c_3$ and $k_3$ was small and had little influence on $J$ [30]. Therefore, in the analysis of $J$, $\Delta i$, $v$, $H_1$, and $H_2$ were the 4 major factors that needed consideration.

6. Conclusions

Considering the deformation and vibration of the manhole cover, the coupled vibration model of the vehicle-manhole cover was established, and the road damage was evaluated by $J$. The research results provide the theoretical basis for the maintenance of the paving around manholes, and the following conclusions can be drawn:

(1) When there was a new unevenness excitation, the vehicle dynamic load changed obviously. With the basic parameters, $f$ reached the maximum value of 1.33 at 0.64 s, and $J$ was 2.12. The unevenness of the pavement made the paving around the manhole easier to damage.

(2) When there was damage in the paving around the manhole and the manhole cover, which made the pavement roughness worse, the impact load of the vehicle was greatly increased, and the damage to the pavement was accelerated, and the repair of this pavement should be timely. Although the two factors of $H_1$ and $H_2$ were the same as the unevenness of the pavement, their influences on $J$ were different. Especially, when $H$ was larger than 1 cm, the influence of $H_1$ was greater than the influence of $H_2$. At this time, the presence of the manhole cover with elastic characteristics buffered the vehicle vibration and reduced $J$ under the vehicle load.
(3) According to the analysis of grey correlation entropy, the order of degree of influence of each factor on $J$ was $\Delta t > v > c_3 > k_3 > H_1 > H_2 > k_4$. Among them, $c_3$ and $k_3$ were mainly determined by the tire pressure, but tire pressure was basically stable, so the range of $c_3$ and $k_3$ was small and had little influence on $J$. Therefore, $\Delta t$, $v$, $H_1$, and $H_2$ were the 4 major factors that had significant influence on the $J$.

However, during the analysis of pavement damage, the influence of load time was not considered, which affected the accuracy of the analysis results. It is suggested that in subsequent research, the influence of load magnitude and time on pavement damage should be considered, and the pavement damage problem should be studied in depth.

Data Availability

The test data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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