Construction of Typical Vehicle Use Environment based on Virtual Simulation Test

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Abstract. This paper puts forward the importance and advantage of using virtual simulation experiment to test the performance of vehicle environment. Through the construction of virtual pavement under different environments such as typical virtual test ground and wading test ground, the mobile performance experiment and capacity experiment of different types of heavy trucks were carried out, and the vehicle performance was evaluated as a whole. The virtual simulation test, by simulating the typical environment that may be encountered in the process of vehicle driving, collects the vehicle running state and driving parameters, studies and analyzes their performance, and provides an important basis for the improvement and improvement of vehicle design.

1. Introduction

Heavy trucks are mainly used for large cargo transportation, using complex and harsh environment. In order to grasp the performance of heavy truck under different conditions of use, it is of great significance to construct a virtual test site to carry out targeted virtual experiments to study and analyze the performance of heavy truck. The virtual simulation test can simulate the typical environment that may be encountered in the driving process of the vehicle. By collecting the driving state and driving parameters of the vehicle, the performance of the vehicle can be studied and analyzed, and the overall performance of the vehicle can be evaluated, which provide important basis for improving and perfecting the design.

2. Advantages of simulation experiments

2.1 The experiment meaning

Under different environmental conditions, the vehicle is affected by different pavement conditions, and the performance is very different. How to adapt to different environment and use conditions and give full play to its performance has become one of the important research problems of heavy vehicles at present. Through the experiment of environmental performance, it is of great significance to analyze the influence of different environmental conditions on the use of vehicles in order to optimize the design of heavy vehicles and improve their environmental adaptability.

2.2 Advantages of experimental methods

Real vehicle test is a common way of experiment, although it is directly effective, but there are poor economy, high risk, if not properly operated may cause car damage and death. With the development of computer technology, virtual simulation experiment has become a new way of experiment. According
to virtual simulation technology, virtual experiment field is constructed, and carrying out simulation experiment not only saves a lot of capital, but also has no danger.

The virtual experiment is not only low cost and safe, but also can simulate different environment and pavement conditions by adjusting the parameters, and the dangerous which can not be carried out by real car, and can be repeated. This paper uses the existing virtual simulation technology to construct the pavement conditions under different environments, and provides a platform and means for carrying out the experiment of environmental performance of heavy vehicles.

3. Simulation system construction

3.1 Subject of experiment

The construction of virtual test ground mainly includes typical site construction and wading site construction. Typical virtual test sites include four typical pavement environments: sand, gravel pavement, ice land, desert land, swamp road.

3.2 Typical site construction

The typical virtual test field consists of four typical environmental test fields, namely, sand and stone field, snow and ice field, desert field and swamp. Each test field is 2.5km×2.5km in size.

3.2.1 Sand and gravel pavement environment. For the gravel pavement, the plastic coefficient is introduced to characterize the elastic-plastic behavior of the ground surface under the action of vertical load. The mechanical model is as follows[1]:

When loading:

\[ p = k z^n \quad (z > z_{max}) \]  

When unloading:

\[ p = p_{max} - k_p n k (z_{max} - z) z_{max}^{n-1} \quad (z \leq z_{max}) \]  

The meanings of the parameters in the above formula are shown in the following table 1:

| para | meaning        | para | meaning        |
|------|----------------|------|----------------|
| p    | ground pressure| K_p  | plastic coefficient |
| z    | deformation depth| z_{max} | maximum deformation depth |
| k    | stiffness coefficient| p_{max} | maximum pressure |
| n    | soil deformation index |

3.2.2 Ice land, desert land, swamp road environment. When loading:

\[ p = \left( \frac{k_s}{b} + k_\theta \right) z^n \]  

When unloading:

\[ p = p_{max} - (k_0 + A_u z_{max}) (z_{max} - Z) \]  

The meanings of the parameters[1] in the above formula are shown in the following table 2:
The traction of the vehicle is achieved by the tangential reaction force provided by the ground. The supporting reaction of the ground is supported by the shear resistance of the ground material. The shear strength of the material is one of the important factors that determine how much traction the vehicle can exert when driving off-road, and it is a function of the physical and chemical properties of the material. It is usually characterized by the coulomb formula of ground material mechanics:

$$t_m = c + \sigma_n \tan\theta$$  \hspace{1cm} (5)

In the formula, $t_m$ represents the maximum shear stress, or shear strength, $\sigma_n$ represents the pressure on the cut surface of the soil, $\tan\theta$ represents friction coefficient.

Through a large number of physical tests, the parameter values of various soils were tested at home and abroad. Table 1 lists the $k_c$, $k_\varphi$ and $n$ values of various soils.

It can be seen that there is a close relationship between various parameters. It can be seen that there is a close relationship between various parameters. The dimensions of $k_c$ and $k_\varphi$ depend on the $n$ value, different values of $n$, the magnitude of the stiffness changes. It can be said that $k_\varphi$ of frictional soil is related to $n$ value and $\varphi$ value, and the frictional soil always has a high $k_\varphi$ and a low $k_c$. The cohesive soil is always $k_c$ high and $k_\varphi$ low. Similarly, the value of soil deformation index $n$ is always high for dry frictional soils, but low for cohesive and frictional soils with high humidity. It can be seen that the moisture content of soil has a significant effect on the mechanical properties of soil. The ground property parameters of the virtual test field are defined according to this definition. The values of ground parameters are shown in table 3.

| para | meaning                        |
|------|--------------------------------|
| $k_c$ | cohesive soil deformation modulus |
| $k_\varphi$ | friction soil deformation modulus |
| $k_\varphi$ | characteristic parameters of soil |
| $b$ | tire width |

Table 3. Travel ground parameter value

| ground          | water content | n   | $k_c$ [kN/(m$^2$)] | $k_\varphi$ [kN/(m$^2$)] | $c$ | $\varphi$ [°] |
|-----------------|---------------|-----|---------------------|--------------------------|-----|--------------|
| dry sand        | 0             | 1.1 | 0.95                | 1528.43                  | 1.04| 28           |
| sandy loam      | 15            | 0.7 | 5.27                | 1515.04                  | 1.27| 29           |
| 22              | 0.2           | 2.56| 43.12               | 1.38                      | 38  |
| 11              | 0.9           | 2.53| 3127.97             | 4.83                      | 20  |
| 28              | 0.3           | 2.79| 114.11              | 13.79                     | 22  |
| clay            | 55            | 0.5 | 13.19               | 602.25                    | 5.17| 13           |
| 55              | 0.7           | 5.03| 1262.53             | 4.14                      | 10  |
| heavy clay      | 25            | 0.33| 12.70               | 1555.95                   | 2.07| 34           |
| 40              | 0.11          | 1.84| 303.37              | 68.95                     | 6   |
| barren clay     | 22            | 0.2 | 1.64                | 1724.60                   | 20.69| 20           |
| snow sand       | 37            | 0.15| 1.52                | 119.63                    | 89.85| 11           |
|                 | 1.6           | 1.37| 1963.72             | 13.79                     | 19.7|

3.2.3 The setting of random road level. The test site contains random pavement A to H grade, each pavement length 200m. The modeling is based on the draft road roughness representation method proposed by ISO/TC108 / SC2N67[2]. A Pavement Power Spectral Density Function GP (n) can be fitted to:

$$G_p(n)=G_q(n_0)(n/n_0)^w \quad (n_1 \leq n \leq n_u)$$  \hspace{1cm} (6)

In the formula above, $n$ represents the spatial frequency, representing $n$ wavelengths per meter in length(m$^{-1}$); $n_l$, $n_u$ represent the upper and lower spatial frequencies of the pavement spectrum respectively; $n_0$ represents reference space frequency, $n_0=0.1m^{-1}$; $G_q(n_0)$ is the pavement spectral value.
under the reference space frequency $n_0$, which is called the road roughness coefficient ($m^2/m^1$); $w$ is the frequency exponent, is the absolute value of the slope of the slope on the logarithmic coordinate, which determines the frequency structure of the lake surface spectrum, $w=2$.

The standard deviation $\sigma_p$ of road roughness can be calculated by the following equation:

$$\sigma_q^2 = \int_0^\infty G_q(n) \, dn = \int_{n_u}^{n_l} G_q(n_0) \left(\frac{n}{n_0}\right)^{-w} \, dn = G_q(n_0) n_0^w (n_l^{-1} - n_u^{-1})$$

(7)

From this formula, the estimated formula of roughness coefficient of road surface can be obtained as follows:

$$G_p(n_0) = \sigma_q^2 n_0^w (\lambda_u + \lambda_l)^{-1}$$

(8)

In the formula, $\lambda_u$ and $\lambda_l$ represent the maximum and minimum wavelengths of the road surface. Therefore, according to the road roughness coefficient $G_p(n_0)$ and with reference to international standards, the road roughness is shown in the following table4:

**Table 4. Classification of road roughness coefficient**

| Ground Load | $G_p(n_0)/$mm $^2/m^1$ | $\sigma_p$/mm |
|-------------|-------------------------|---------------|
| A           | 8.16 32 | 2.69 3.81 5.38 |
| B           | 32 64 128 | 5.38 7.81 10.77 |
| C           | 128 256 512 | 10.77 15.23 21.53 |
| D           | 512 1024 2048 | 21.53 39.45 43.00 |
| E           | 2048 4096 8192 | 41.06 69.00 86.13 |
| F           | 8192 16384 32768 | 86.13 121.81 172.26 |
| G           | 32768 65536 131072 | 172.26 243.61 344.52 |
| H           | 131072 262144 524288 | 344.52 487.22 689.04 |

The test site contains sinusoidal roads of different wavelengths, pair-open roads, washboard roads, Belgium roads and other test roads that meet the requirements of the experiment. The length of each road surface is 200m. Random pavement A to H, each pavement length 200m.

There are 4 vertical walls with different heights, with heights of 0.5m, 0.6m, 0.7m and 0.8m respectively. There are 10 ramps with different angles. The slope angles of ramps in each test site are defined as: sand and stone field 20° to 32°, ice and snow field 12° to 22°, desert field 20° to 30°, swamp field 15° to 28°. There are 10 tilting slopes at different angles. According to the different capacity of the ultimate tilting slope of heavy trucks under different conditions of ground adhesion, the inner tilting slope Angle of each test site is defined as: sand and stone field 15° to 25°, ice and snow field 8° to 15°, desert field 15° to 27°, swamp field 10° to 22°[3].

There are also 5 test roads for deep snow in the ice and snow field test field, with snow depth of 0.1m, 0.2m, 0.3m, 0.4m and 0.5m respectively; 1 ice surface test road and 1 ice and snow composite test road, each test road has a length of 50m and a width of 10m; snow covered 5 mounds, each 50m in length, 40m in width and 8m, 9m, 10m, 11m and 12m in height, respectively. Typical virtual road test point effects are shown in figure 1 below.
3.3 Construction of wading test site
The wading test site consists of three parts: hard bottom pool with fixed inlet and outlet water angle, soft bottom pool with fixed inlet and outlet water angle and hard bottom pool with variable inlet and outlet water angle.

There are 4 hard bottom pools with fixed access water, each with 15° access angles, length 50m, width 10m, water depth 0.3m, 0.5m, 0.8m, 1.0m, respectively. There are 4 soft bottom pools with fixed access water, each with 15° access angles, length 50m, width 10m, water depth 0.3m, 0.5m, 0.8m, 1.0m, respectively. Subaqueous sludge adhesion coefficient is defined according to international standards. One hard bottom pool with variable access water angle, length 50m, width 10m, water depth adjustable, access water angle 10° to 20°[3,4].

The effect is shown in figure 2 below:

![Figure 2. Wading environmental test site](image)

4. Experimental expected efficiency
Through the construction of a typical virtual test site including sand, snow, desert, swamp four typical environmental test sites, can carry out different types of heavy truck motor performance experiments, which is capable of the mobility of different types of heavy trucks[5]. It can carry on the experiment of different type of heavy truck maneuver performance, the experiment content mainly includes different road surface, different load condition movement speed, movement resistance and so on, and discharge capacity test, which mainly includes the limited discharge capacity test of vehicles with different loads including snow depth, water depth, the limit of different pavement conditions through the slope angle, etc[3,4].

5. Conclusion
In this paper, by combing the typical use environment of heavy vehicles, analyzing the pavement conditions that may be encountered, using virtual simulation technology and combining different pavement parameters, the corresponding virtual pavement is constructed, which provides a means for heavy trucks to carry out virtual experiments on pavement conditions in different environments.

References
[1] Huming Duan, Ying Ma, Feng Shi “Feature extraction and statistical analysis of road surface survey data,” Vibration and Shock, vol.32, issue 1, pp.33-39,2013.
[2] Xiaotian Qu, Qiang Zhao, Jiye Zhao, “Analysis and evaluation of pavement grade based on measured unevenness,” Chinese and Foreign Highways, vol.39, issue 1, pp.52-59,2019.
[3] Ronghai Li, Yishun Lang, “Study on the driving road surface of heavy vehicles,” Road and Waterway Transport, 2014.
[4] Hui Li, “Development of simulation test set for automobile full operating condition,” University on The Mountain of Swallows,2016.
[5] Nina Liu,“Virtual simulation demonstration system platform construction,” Modern Information Technology,vol.9, issue 5, pp.31-35,2018.