Study on Dynamic Response of Buried Pipeline Rolled by Heavy Vehicle Based on Co-simulation by ADAMS and ABAQUS

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Abstract. At present, the rolling load of heavy vehicles has become one of the main ground loads threatening the safety of buried pipelines. In this paper, the vehicle simulation is carried out based on ADAMS to extract the wheel force. At the same time, the pipeline soil coupling model is established based on ABAQUS. The amplitude of the random moving load extracted by ADAMS is used for finite element simulation calculation, the dynamic response process of the pipeline is simulated, and the stress distribution of the buried pipeline under the vehicle rolling load is obtained. Aiming at the pipeline stress concentration area, that is, the most vulnerable area of the pipeline, the pipeline load reduction and prevention and control measures are proposed, and the four measures are compared, which provides theoretical support for the actual engineering prevention and control.

1. Introduction
In China, with more and more land being developed, the environment of many pipelines originally surrounded by farmland has changed greatly. Natural roads have been formed on the natural gas pipelines originally laid according to the requirements of farmland burial depth. Pipelines in farmland, wasteland and other places are still laid directly, and most pipelines have not been protected [1]. The pipeline crosses the temporary construction access road from time to time. One of the main loads borne by the pipeline buried under the road is the vehicle load [2]. Although the vehicle does not roll directly on the pipeline, the transmission of vehicle rolling load through the road and soil will still affect the operation of the pipeline. T. Bajcara [3] also proposed that the traffic at the intersection of pipeline transportation routes may have a significant impact on the structural integrity of the pipeline because the traffic induced vibration propagates from the pavement through the soil and excites the buried pipeline. Therefore, attention should be paid to the impact of vehicle rolling load on the safety of buried pipeline, and it is necessary to study the dynamic response of buried pipeline under heavy vehicle rolling load.

2. Multi Body Dynamics Simulation of Vehicle Rolling Pavement Based on ADAMS
In recent years, virtual prototype analysis software is widely used in the field of mechanical manufacturing, among which ADAMS is a representative virtual prototype analysis software. The
ADAMS/CAR module contained in ADAMS can establish a model on the computer to obtain the necessary performance parameters according to the needs of simulation analysis. At the same time, many common component templates in the automotive market are stored in its template database. Using these existing subsystem standard templates, users can conduct modeling operations faster [4].

2.1. Vehicle Model Establishment
The whole vehicle simulation test is carried out in ADAMS/CAR. The virtual whole vehicle assembly model is mainly composed of subsystems such as cab, steering device, vehicle body, leaf spring, drive shaft, wheel and engine. In the experiment, the existing large truck model is selected from the template library, and it is adjusted according to the actual working conditions. The model of the whole vehicle is changed by changing the weight of one part of the vehicle, where the weight of the carriage in the model is changed. When the simulation analysis results of assembly combination can not meet the requirements, the model can be modified by returning to the modeling interface, and then the required working conditions can be simulated and analyzed. After many modifications and debugging, the virtual vehicle model is finally established, as shown in figure 1.

![Vehicle model](image1.png)

**Figure 1.** Vehicle model.

2.2. Wheel Load Data Extraction
According to the field investigation experience, the driving speed of heavy vehicles under the condition of no grade highway is generally 20 ~ 40km / h. In this experiment, the vehicle speed is 36km / h and the vehicle weight is 5×10^4 kg, simplify the experimental site according to the actual working conditions, assume that a flat earth road is relatively flat, adjust the relevant parameters of the road generator, establish the motion event of vehicle uniform linear motion, set the running time as 2.1s and the output steps as 30 steps, and finally build the multi-body dynamic model of vehicle road coupling. Run the simulation in ADAMS and measure the wheel force of 10 wheels, as shown in figures 2, 3 and 4. The line from top to bottom are left rear wheel 1, left middle wheel 2, right middle wheel 2, right rear wheel 2, left rear wheel 1, left middle wheel 1, right middle wheel 1, right rear wheel 1, right front wheel, left front wheel.

![Wheel force](image2.png)

**Figure 2.** Wheel force (left rear wheel 1, left middle wheel 2, right middle wheel 2, right rear wheel 2).
3. Dynamic Response of Pipeline Under Heavy Truck Rolling Based on ABAQUS

3.1. Establishment of Soil Mass Model for Pipeline

3.1.1. Setting Soil Parameter. The constitutive model can reflect the basic properties of many kinds of soil, and objectively and truly reflect the deformation of pavement and subgrade. The soil model chosen in this paper is M-C model and D-P model. As an ideal elastoplastic model, the M-C model obeys Hug’s law before failure and obeys the Coulomb failure criterion after failure. However, as a kind of porous medium, the linear elastic model can not reflect the stress and strain of soil well before it reaches the yield limit, so the D-P model is used to supplement [5]. The D-P constitutive model takes into account the consolidation time and other factors, which is more comprehensive in theory. It is mainly used to simulate the soil mass with lower stiffness and greater cohesion, and the cohesive soil and soil-rock mixed filler with good gradation [6]. The soil parameters set are shown in tables 1 and 2.

Table 1. Soil mass Parameter table.

| Category | Elastic parameters | D-P model parameter |
|----------|--------------------|---------------------|
| Density (kg/m^3) / Elastic modulus (MPa) | Poisson’s ratio | Friction angle (°) | Flow stress ratio | Expansion angle (°) |
| Back fill | 1780 / 14.4 | 0.4 | 36 | 1 | 0 |

Table 2. D-P Model hardening parameters

| Yield stress (MPa) / Absolute plastic strain | 0.17 | 0.65 | 0.75 | 0.8 | 0.85 | 0.035 | 0.051 | 0.073 | 0.092 |

3.1.2. Pipe Parameter Setting. Pipeline uses M-C constitutive model, the pipeline selects X70 pipeline steel, further, dynamic response law is analyzed. See table 3 for specific parameters.
Table 3. Pipeline material parameter.

| Category | Density / (kg/m$^3$) | Elastic modulus /GPa | Poisson's ratio |
|----------|----------------------|----------------------|-----------------|
| X70      | 7850                 | 210                  | 0.3             |

3.1.3. Division of Finite Element Part. It is assumed that the soil is an isotropic and homogeneous continuum, The soil mass is 21m long, 12m wide and 5m thick along the driving direction of the vehicle; In the model, the buried depth of the pipeline is 1m, the pipe diameter is 813mm, the wall thickness is 11.9mm, and the gas transmission pressure is 6Mpa.

Set the outer surface of the pipe in face-to-face contact with the inner surface of the soil, The penalty function method is used to constrain the tangential upward direction of the contact surface, Set "hard contact" in the upward direction of method, the friction coefficient is set to 0.4. Use C3d8R element for grid division.

3.1.4. Addition of Vehicle Dynamic Load. In order to take into account the randomness and mobility of vehicle rolling load, According to the tire load extracted by ADAMS multi-body dynamics simulation, the VDLOAD subroutine is written. The contact area between vehicle load single wheel and soil is 0.35mx0.24m,The finite element calculation part in the driving direction of the vehicle is 60 times the contact length of a single wheel, In the meshing step, 120 meshes in the length direction are set, Namely, the vehicle travels through two grids in a time interval to create dynamic load. VDLOAD subroutine can realize the input of dynamic load. Extract the established amplitude for calculation in ABAQUS / explicit calculation, so as to achieve the purpose of random load, In this way, the actual working condition under rolling load is simulated more truly.

3.2. Result Analysis of Dynamic Response Law of Pipeline

According to the established soil pipe model, use ABAQUS for numerical calculation and obtain the dynamic response results of the pipeline under the conditions of vehicle weight of 50t and vehicle speed of 10m/s. See figure 5, 6, 7 and 8.

![Figure 5. Displacement contours](image)

![Figure 6. Vertical displacement curve](image)

![Figure 7. Von-mises stress contours](image)

![Figure 8. Von-mises stress vs. time](image)

Within 0 ~ 2s, The vehicle load pressure has not been transmitted to the pipeline through the soil, The pipeline is only subject to its own internal pressure, Under the interaction with soil constraints. The stress value and downward displacement of the pipeline have little change and are in a relatively
stable state. Within 2 ~ 4.1s, the stress of the pipe increases when the front wheel force is transmitted to the pipe, and then decreases. Increases and falls again when the second and third rows of wheels pass by, and reaches the maximum when the third row of wheel force is transmitted to the pipeline. The maximum stress is near the center line of the track, and the maximum stress value is 30.95MPa; The pipeline also produces vertical downward displacement in a downward parabola shape. The maximum vertical displacement is located near the middle of the wheel base, and the maximum displacement is 22.03mm. Within 4.1 ~ 5s, when the third wheel of the vehicle drives away from the soil above the buried pipeline, the stress and vertical displacement of the pipeline decrease. During rolling under vehicle load, Because the pipeline here is subject to the superposition of downward displacement of pipeline sections on both sides along the axial direction, the maximum stress of buried pipeline and the maximum vertical displacement of pipeline are located near the midpoint of vehicle wheelbase.

4. Pipeline Load Reduction and Prevention Measures

With the development of logistics transportation industry, it is inevitable that heavy vehicles will pass on the road surface with buried pipelines. But the early laid pipeline has some defects. If no load reduction measures are taken, the pipeline is likely to be damaged and broken, resulting in accident losses. At the same time, for the pipeline under planning or construction, it is necessary to ensure its safe operation and economic rationality. Therefore, it is indispensable to take appropriate pipeline load reduction and prevention measures according to the actual situation.

Different methods of load reduction have obvious differences in the protection effect of buried pipelines. For buried pipelines with high risk of heavy vehicles passing through and low early design standards, temporary load reduction measures are often taken include laying steel plates and concrete slabs. Laying steel plate has the advantages of fast construction speed, good performance, multiple use, high utilization rate, friendly environment and economy. And the method of forming cement concrete rigid pavement can directly bears and distributes vehicle load, can also effectively increase the stress hysteresis of soil and prevent the fatigue failure of pipeline, whose load reduction effect is better than laying steel plate.

In terms of permanent load shedding, there are usually two measures: laying geogrids and CLSM replacement materials. Laying geofence can effectively use its reinforcement, reduce vertical earth pressure, improve soil shear strength and increase the integrity of subgrade structure. This method has been widely used in the subgrade of buried underground pipeline. Controllable low strength material (CLSM) is a kind of alternative graded traditional backfill material, which can evenly transfer load, increase soil stress lag, reduce section deformation, and make the stress of pipeline more reasonable. It is mostly used in pipeline backfill engineering. Compared with the traditional sand and clay backfilling method, CLSM backfilling method has the advantages of convenient construction, green environmental protection and efficient load reduction [7].

5. Conclusion

The pipe soil coupling model is established by ABAQUS. The wheel load is extracted by multi-body dynamics software ADAMS, and the dynamic load is loaded by VDLOAD subroutine. It is found that the maximum stress of buried pipeline and the maximum vertical displacement of pipeline are near the midpoint of vehicle track during the rolling process of vehicle load. Aiming at the vulnerable area of pipeline, four load reduction measures are proposed and compared.

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