Simulation Analysis on Impacts on Existing Highway from Pipeline Underpassing Based on ANSYS

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Abstract. Pipeline construction underneath existing highway leads to settlement deformation of the existing highway thus bringing potential security risks to highway quality and traffic safety. Taking pipeline underpassing of G93 Highway as the research object, this thesis utilizes ANSYS Finite Element Simulation Software and Mol-coulomb Criterion to establish model and realizes burial depth simulation through equivalent gravity field. Results show that vertical displacement of earthing on the top of burial depth pipeline mainly appears as vertical settlement, whose maximum value reaches 15.3mm. The maximum shearing stress value of subgrade soil is 0.051MPa. Shearing stress of materials is within the range of shearing strength. Pipeline structure right below the highway is secure.

Introduction

Pipeline underpasses existing structures and results in the settlement deformation thus bringing potential security risks to the quality and safety [1-3]. Baoxin Jia [4] carries out research on subgrade settlement value of cross tunnel, whose conclusion is that subgrade settlement degree of existing highway tunnel is concerned with factors of width coefficient of settling tank, internal friction angle, gradient, approaching distance of tunnel, etc. Zhao Lu [5] does research on impacts of construction method on underpassing highway tunnel. The result shows that surrounding rock deformation control effect in the case of CRD Method is better than Benching Tunneling Method and CD Method. This thesis utilizes ANSYS Software to do simulation analysis on impacts of pipeline underpassing on existing highway, which provides theoretical references for project construction.

Overview of Engineering Project

The proposed pipeline would cross the position from AA273 to AA274 of G93 Highway. Stake number AA273 includes X be 3330849.82, Y be 35583051.87 and H be 278.17m. Stake number AA274 includes X be 3330926.17, Y be 35583072.06 and H be 290.05m. Investigation area belongs to inter-mountain valley with sea-level elevation from 278.17m to 290.05m where topographic relief and narrow field are. It is found from engineering geological investigation that the field and periphery exclude bad geological process and geologic disaster phenomenon like landslide, collapse, ground depression and active fracture on the phase of investigation. This field is stable and suitable for pipeline crossing engineering construction.

Establishment of ANSYS Analytical Model

This ANSYS calculation model utilizes Mol-coulomb Rule to do analog computation. For the
purpose of eliminating boundary effect, distance between left and right boundaries of pipeline model and pipeline boundary should be three times longer than inner diameter. The length from upper and lower boundaries to pipeline boundary should be three times bigger than headroom. This calculation model includes 56981 unit nodes and 51788 units, which would realize high-precision numerical simulation. Fig.1 shows the ANSYS Finite Element Model.

In the ANSYS finite element calculation, all of soil mass, pipeline structure and highway engineering computing element utilize solid element. Asphalt pavement structure in finite element model is a multi-layer system which is simplified to be four layers including surface layer, base layer, sub-base layer and upper base layer. It applies linear elastic multi-layer system mechanics model. Fig.2 shows the spatial relationship between pipeline and earthing.

Model Parameters

Pipeline type is DRCPIII1500×2000 (GB/T11836). The proposed highway is YuSui Highway with Stake AA273 and Stake AA274. The crossed stratum is mainly composed of Quaternary Holocene residual deluvial clay $Q^{hel+dl}$ and middle Jurassic Shaximiao Formation argillaceous sandstone $J_{2s}$.

For the purpose of leading finite element calculation result to be accurate, take rock sample to do indoor test. Tab.1 shows the test result.

| Test index            | Statistical item               | frequency | Minimum value | Maximum value | Average value |
|-----------------------|--------------------------------|-----------|---------------|---------------|---------------|
| Argillaceous sandstone| Natural compressive strength   | 9         | 20.50         | 29.60         | 23.84         |
|                       | Saturated compressive strength | 9         | 3.05          | 4.74          | 3.70          |

According to integrated factors like formation lithology of the crossed fracture surface, structural features and groundwater conditions, middle Jurassic Shaximiao Formation argillaceous sandstone $J_{2s}$, layer is suggested to be chosen as crossing layer to build stake AA273. Middle Jurassic Shaximiao Formation argillaceous sandstone $J_{2s}$, layer is suggested to be chosen as crossing layer to build stake AA274.

In accordance with composite factors of engineering geological conditions and groundwater distribution conditions of the proposed field, it is suggested that trench excavation depth keeps within 5.0m and there exists no load on the top of slope. Tab.2 shows earth-rock engineering classifications of each stratum and excavation gradient proposed values.

| stratum                      | earth-rock engineering classification | Excavation gradient value |
|------------------------------|--------------------------------------|---------------------------|
| Silty clay ($Q^{hel+dl}$) 1  | II                                   | 1:1.0 (above groundwater level) |
| argillaceous sandstone ($J_{2s}$) 2 | V                                    | 1:0.50                     |
| argillaceous sandstone ($J_{2s}$) 3 | V~VI                                | 1:0.20                     |
Retaining measures should be taken while foundation pit excavation depth becomes higher than 1.5m. Temporary spoil disposal should keep certain distance with edge of foundation pit whose ratio to pit depth is not less than 1:1 thus preventing top of pit wall from collapsing.

Simulation Analyses

Calculation Result of Settlement Amount of Earthing Top Surface

Fig.3 shows vertical settlement of earthing. It is seen from Fig.3 that earthing on the top of pipeline longitudinally and symmetrically distributes along the pipeline in which settlement amount reaches the maximum value 15.3mm right above the pipeline. With increasing of transverse distance with pipeline and longitudinal distance with highway, vertical settlement amount becomes smaller and smaller. Vertical displacement of top earthing gradually decreases along driving direction of G93 highway. Fig.4 shows the settlement graph of subgrade soil.

![Figure 3. Diagram of vertical settlement of earthing.](image)

![Figure 4. Longitudinal and vertical settlement graph of subgrade soil along highway.](image)

Calculation Result of Shearing Stress of Subgrade Soil

Shear the stress in structural calculation. Object deforms on account of external causes such as load, temperature variation and so on, inside which interaction force comes into being between both sides of any shearing surface which is called internal force. Internal force intensity namely internal force acted on unit area is called stress. Stress could be divided into both components. One is perpendicular to shearing surface called normal stress. The other is tangent to shearing surface called shearing stress.

This ANSYS finite element utilizes shearing stress to decide security state of subgrade soil. Fig.5 shows the shearing stress distribution of subgrade soil.

It is seen from Fig.5 that shearing stress concentration appears on slope surface above pipeline. The buried pipelines symmetrically distribute in the shape of butterfly along longitudinal direction of G93 highway in which the maximum value of shearing stress of subgrade soil is 0.051MPa. Shearing stress of all materials keeps within the range of shearing strength.
Calculation Result of Force Safety of Buried Pipeline

Analysis on the principal stress of buried pipeline structure could do evaluation on its force safety. Fig. 6 shows the major principal stress of buried pipeline.

It is seen from fig. 6 that major principal stress of buried pipeline symmetrically distributes along longitudinal direction. Stress of pipeline structure concentrates right under G93 highway. The maximum value of principal stress is 1.76 MPa, which shows to be tensile and lower than ultimate tensile strength of concrete. It shows that the structure is secure. Fig. 7 shows the third principal stress of buried pipeline.
It is seen from fig. 7 that third principal stress of buried pipeline also presents symmetrical distribution along longitudinal direction. Stress of pipeline structure concentrates right under G93 highway. The maximum value of principal stress is 20.5MPa, which shows to be compressed and lowers than ultimate compression strength of concrete. It shows that the structure is secure.

Conclusions

This thesis utilizes ANSYS calculation software to do simulation analysis on pipeline underpassing of G93 Highway, which effectively reflects settlement and force characteristics of soil and pipeline structure. Main calculation results are shown as follows.

(1) Settlement of track center line along driving direction reaches the maximum value right above the pipeline, which gradually decreases in the shape of funnel along longitudinal direction of highway namely car driving direction. Therefore influencing range of buried pipeline on highway is within 25m away from both sides centering on transverse section of buried pipeline and within 25m in front and back of highway centering on transverse section of buried pipeline. The range adds up to 50m. Vertical displacement of earthing on the top of buried pipeline mainly appears as vertical settlement whose values are negative. The maximum settlement value reaches 15.3mm.

(2) Shearing stress concentration appears on slope surface above pipeline. The buried pipelines symmetrically distribute in the shape of butterfly along longitudinal direction of G93 highway in which the maximum value of shearing stress of subgrade soil is 0.051MPa. Shearing stress of all materials keeps within the range of shearing strength.

(3) Major Principal stress and third principal stress of buried pipeline symmetrically distribute along longitudinal direction. Stress of pipeline structure concentrates right under G93 highway, in which the maximum value of principal tensile stress is 1.76MPa and the maximum value of principal compression stress is 20.5MPa, which are lower than ultimate tensile strength and ultimate compression strength of concrete. Therefore the structure is secure.
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References

[1] Li Fang-yang. Construction technology of Separate frame bridge Jacking in Multi-strand metro line[J]. Journal of Highway and Transportation Research and Development (Applied Technology Edition), 2019, 15(05): 260-262+279.

[2] Lai Hong-Peng, Zhao Xin, Kang Zuo. Settlement control standard of existing metro line undercrossed by new metro tunnel in loess area[J]. Journal of Traffic and Transportation Engineering, 2018, 18(04): 63-71.

[3] Lai Hong-Peng, Zheng Hai-Wei, He Qiu-Min, Liu Hai-Yang. Investigation into Parameter Optimization of Existing Metro Tunnel for Shield Tunnel Closely Undercrossing It at Small Angle in Sand Stratum[J]. China J. Highw. Transp. 2018, 31(10): 130-140.

[4] Jia Bao-Xin, Sun Ao, Chen Hao, Wang He. Analysis of the Regularity of Subgrade Settlement due to Railway Tunnel Underpass of Existing Highway Tunnel Based on Peck Formula[J]. HIGHWAY, 2018, 63(07): 318-323.

[5] Dan Luzhao, Wang Dongying, Chen Wei, Guo Qionghua. Influence of Three Different Construction Methods on Shallow Tunnel Under-crossing Existing Highway[J]. Journal of Water Resources and Architectural Engineering, 2018, 16(02): 60-65.