Numerical Analysis of Force and Deformation Characteristics of Reinforced Steel Corrugated Sheet Retaining Wall

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Abstract. Reinforced corrugated Steel retaining wall is a kind of retaining wall structure that can realize rapid construction. It has the characteristics of large strength, high rigidity, fast construction speed and small environmental disturbance. In this paper, the finite element model is established by using ABAQUS software. With the load of 80Kpa and 120Kpa at the top of the fill, the mechanical and deformation characteristics of the steel corrugated board are studied under the coupling of steel corrugated board and fill soil. The Horizontal deformation of corrugated panel and soil of different depths are analysed. Then the stability of the retaining wall structure are analysed. The research shows that the steel corrugated retaining wall presents a reverse "S" shape under the action of filling, the upper part presents an outward deformation, and the lower part presents an inward deformation extrusion soil; under the up load, the middle part of the retaining wall produces protrusions. As the load increases, the bulge increases with the tendency of the outward inclination. The stability analysis shows that the safety factor of the retaining wall structure under the load meets the requirements of relevant specifications.

1. Introduction
Gravity retaining walls have a large amount of masonry work and high requirements for the foundation's bearing capacity; grid-beam prestressed anchor cables (anchors) retaining walls have a little mass, good adaptability, complex construction, long cycles, and high cost (Wang B. et al.,2017); Reinforced retaining wall is construction convenient, economical, and environmentally friendly, but the wall deformation is large, cannot to meet the deformation control requirements of high-grade highways (Qiu W.Z. 2015; Wang R.F. et al., 2017; Ge Y.L. et al., 2008; Zhang Z.C. et al., 2017). In the actual engineering, restricted by mountainous environment conditions, the construction of supporting structures seriously restricts the construction period. A convenient and efficient method for widening and supporting subgrades should be adopt. The steel corrugated plate retaining wall is a new support form based on the ideas of steel corrugated plate, the reinforced retaining wall and the bridge nails. The retaining wall has the characteristics of strong panel strength, high rigidity, rapid construction speed and small environmental disturbance.

2. Structure and technology of steel corrugated board reinforced retaining wall
The steel corrugated plate retaining wall is composed of steel corrugated plate, shear bar, tensile band and anchor tensile plate. The construction method can be seen in figure 1. The retaining wall panel are
assembled by overlapped and overlapped, as shown in figure 2. The upper part is steel corrugated board panel, and the lower part is steel corrugated board foundation with the same model. Retaining wall panels are reserved pre-stretched hole for every 700mm from top to bottom and the troughs near the anchor plate side. The foundation is are reserved shear reinforcement holes for every 200mm from top to bottom and Peaks and troughs.

3. Parameters and models
The model size with 20m × 10m × 1.2m is set to research the effectiveness of the structure. In this model, the width of the backfill is 10m, the fill depth is 4.2, the foundation burial depth is at 1.5m, and the panel width is 1.2m. as shown in figure 3 and figure 4.

| material        | Bulk density (kN m⁻³) | Modulus elasticity (Mpa) | Yield Strength (Mpa) | Poisson's ratio | Internal friction angle (Kpa) | Cohesion angle (Kpa) | Dilatancy angle |
|-----------------|-----------------------|--------------------------|----------------------|-----------------|-----------------------------|----------------------|-----------------|

Figure 1. Structural of steel corrugated board retaining wall.
Figure 2. Structural of steel corrugated board assembled.
Figure 3. Structural model of steel corrugated board retaining wall.
Figure 4. Geometric model of steel corrugated board retaining wall.

Mohr-Coulomb (Zhao G.H. et al., 2017; Gu R.G. et al., 2016; Li C. et al., 2015) strength criterion is applied to analyse the foundation soil and backfill soil, and the steel corrugated plate, shear reinforcement, and steel-plastic composite tension bands are analysed using an elastic body model. Some assumed in the model. The fill is compacted by weight; the steel-plastic composite tension bands do not bear the pressure and bending moment; and no mutual sliding between the tension bands, anchor plates and the soil.
3.1. Establishment of finite element model
C3D8R and S4R units are applied to soil and steel corrugated board, B31 unit is applied to Shear reinforcement, and T3D2 unit is applied to tension bar. The relationship between these components in the model is as follows: The embed restraints are used between the retaining wall foundation, the soil and shear reinforcement. The face-to-face contact restraints is used between the Steel corrugated plate and the fill soil. The tie restraints are used between the Steel-plastic composite tensile band and the Steel corrugated plate. The embed constraints are used between the fill and the Steel-plastic composite tensile band. The bottom boundary of the model is fully constrained, and the top is not constrained, the remaining boundaries only constrain the normal displacement. The finite element model are shown in figure 5 and figure 6.

3.2. Data monitoring
The measurement points are selected along the Z direction on the peaks and troughs of the steel corrugated plate, and the measurement point distribution is 0.0m, 0.6m, 1.2m, 1.8m, 2.4m, 3.0m, 3.6m, 4.2m, 4.8m and 5.4m from the top; Set the horizontal displacement measurement points inside the soil along the X-direction 0m, 1m, 2m, 3m, 4m, 5m and 6m to troughs. The arrangement of measuring points is shown in Figure 7.
4. Analysis of calculation results

4.1. The filling effect

The Mises stress and deformation of the steel corrugated plate and the steel-plastic composite band are shown in figure 8 and figure 9. The figure that the steel corrugated plate and the steel-plastic composite band are in a good state of stress, the maximum deformation is 1.53mm, which is within the range of elastic deformation. The maximum stress of the shear steel bar reaches 197.5Mpa.

As shown in figure 10, the peak and trough stresses in the negative Z-axis direction are approximately anti-symmetrical "S" shapes. The trough is dominated by compression, which decreases firstly then increases, and then gradually decreases; the peaks is dominated by tension, which shows a trend of increasing first, then decreasing, and then increasing and then decreasing; The maximum principal stress value in the peak is about 17Mpa, the maximum value of the trough principal stress is about 6.5Mpa, and the difference between the two parts is about 23.5Mpa. The values are much smaller than the material strength values.
Figure 10. Steel corrugated plate peak and trough stress values in the negative Z axis direction

Figure 11. Horizontal displacement of Steel corrugated plate in the Z axis direction

Figure 11 reflects the horizontal displacement of the steel corrugated plate under the action of filling. As the figure shows that the steel corrugated plate presents an "S" shape deformation; the maximum displacement is at \( Z = -5.4 \text{m} \) and the horizontal displacement is \(-2.04\text{mm}\); the maximum displacement of the above part is at \( Z = -3.6\text{m} \), the displacement is \(-1.78\text{mm}\); the zero displacement is at \( Z = -1\text{m} \) of the steel corrugated plate retaining wall.

Figure 12-III shows a proportional deformation of the steel corrugated board retaining wall. Under the interaction of the filling pressure behind the wall and the rigidity of the steel corrugated board wall, the steel corrugated board rotates around the "A" point, forming a "leverage" effect, which generates passive earth pressure at the lower part of the foundation. As the increasing of filling, the outward rotation trend of the upper part of the retaining wall constrained by the composite band is obvious, causes the turning point to gradually increase to the point "B", and the area of passive earth pressure in the lower part increases. As which shown in figure 12-I.

Figure 12. Deformation process of steel corrugated board retaining wall

Figure 13 shows the horizontal displacement of the inside soil at a distance of 0m, 1m, 2m, 3m, 4m, 5m, 6m from the corrugated steel plate. The figure intuitively reflects the squeezing effect of the lower part of the retaining wall, which is most obvious at the toe of the retaining wall. Figure 14 shows the horizontal displacements of the fill body at distances of 1.8m, 3.6m and 5.4m from the top of the corrugated steel plate. According to the figure, the maximum displacement of the lower part of the corrugated steel plate is \(-2.04\text{mm}\) at the toe of the retaining wall. As the fill body increases, the squeezing effect gradually decreases, and the further away from the corrugated plate, the weaker the effect.
4.2. The load effect

The vertical even load of 80Kpa and 120Kpa was applied to the top of the model at a distance of 1m from the trough. Figure 15 shows the Mises stress distribution of the steel corrugated plate retaining wall and steel-steel-plastic composite belt under the uniform load of 120Kpa. The maximum stress is 147Mpa, which is located at the end of the belt, which is far less than its breaking design value.

The figure 16 shows the deformation value of the steel corrugated board retaining wall with the even load of 80Kpa and 120Kpa. With the even load of 80Kpa, the maximum horizontal displacement of the steel corrugated plate in the X direction is -6.35mm, located at the peak of 3.2m from the top of the corrugated plate. The displacements at the top and 5.4m from the top of the corrugated plate are -3.74mm and -3.99mm, respectively. With the vertical load of 120Kpa, the maximum displacement of the steel corrugated plate in the X direction is -10.34mm, which is located at the peak of 2.8m from the top of the corrugated plate; the displacement of the top of the corrugated plate and 5.4m is 8.18mm and 5.18mm, respectively. The displacements at the top and 5.4m from the top of the corrugated plate are-8.18mm and-8.18mm, respectively. Comparing the deformation of steel corrugated plate under two even distribution loads, it can be found that the "bulge" in the middle of the steel corrugated plate in the Z direction is backward-facing to the filling soil. With the increase of load, the position of the convex part increases gradually, and the slope of the back to the soil is inclined.

4.3. Stability analysis

The additional load changes the deformation characteristics of the steel corrugated plate retaining wall. The stability of the steel corrugated plate retaining wall under 120Kpa even load is analysed using the
strength reduction method (You G. et al., 2017; Li Y. et al., 2017). As shown in figure 17, the results show that the safety factor of the steel corrugated retaining wall is 1.35 under the 120Kpa even load, which means the safety factor of the retaining wall meets the requirements of design codes.

Figure 17. Steel corrugated retaining wall stability coefficient

5. conclusion
(1) Under the combined action of fill soil and steel-plastic composite belt, as the fill increases, the steel corrugated plate presents a reverse bulge, which produces a certain squeezing effect on the middle and lower fill soil, then produces an outward-facing deformation. At this time, the Foundation shear reinforcement is in a high stress state, the steel-plastic composite belt is in an elastic deformation state. Therefore, it is necessary to change the foundation form and increase the anchoring effect of the upper steel-plastic composite belt.
(2) Under the even load, the “bulge” facing away from the soil appeared in the middle of the Z-axis direction of the steel corrugated board. As the load increases, the deformation of the “bulge” part increases, and the steel corrugated board produce an inclination away from the fill. So It is necessary to increase the tensile strength and anchoring strength of the central steel-plastic composite belt.
(3) The corrugated plate enhances the stiffness of the steel plate, and the stability of the steel corrugated plate retaining wall is guaranteed under the joint action of the steel-plastic composite belt.

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