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Effect of spalling thickness on transverse axial bearing capacity of pile foundation under different corrosion depths

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Abstract: The transverse and axial bearing characteristics of bridge pile foundation in salt marsh area are studied by numerical simulation. This paper mainly analyses the change of transverse and axial bearing characteristics of pile foundation caused by the change of spalling thickness of bridge foundation. The results show that the transverse and axial bearing capacity and displacement of pile foundation will be affected by the change of concrete spalling thickness under the condition of pile corrosion. When the peeling thickness is above 9.0cm, the transverse and axial bearing characteristics of pile foundation are obviously different with the change of corrosion depth of pile body. When the peeling thickness increases and the corrosion depth of the pile body is different, the negative displacement below the zero point of the first displacement of the pile body is continuously reduced, and the displacement curve above the first displacement zero point in the direction of the pile body begins to shift. When the peeling thickness reaches 15.0cm, the pile top displacement increases to 3.75mm. The research results are of great significance to the establishment of safety evaluation system of highway bridge pile foundation in alpine salt marsh area, and provide a basis for the structural design of highway bridge pile foundation in alpine salt marsh area.

1 Introduction.

Bridge pile foundation is the most important bearing structure in the process of bridge use, in addition to being affected by vertical load, it will inevitably be affected by transverse and axial load. Under the influence of various unfavorable conditions, the study of its transverse and axial bearing characteristics is very important [1-5]. Zhang Kunyong uses the finite element method to carry out the numerical test on the loading process of the transverse and axial loaded rock-socketed pile, and obtains the load-displacement curve which is consistent with the loading range of the field test, and verifies the rationality of the numerical model [6]. Through the analysis of the transverse and axial working performance of the pile foundation of the steep slope bridge in Qinba Mountain area, He Jianjun uses the finite element analysis software to calculate the load transfer mechanism and bearing characteristics of the bridge pile foundation under different slope, pile length and pile diameter in the steep slope section. the variation law of the bearing capacity of the bridge pile foundation and the deformation law of the pile side soil in the steep slope section are obtained [7]. Feng Jun made an in-depth study on the transverse and axial bearing characteristics of bridge group pile foundation with high cap in soft soil [8] In recent years, the theoretical research on the transverse and axial bearing characteristics of pile foundation is also in-depth development [9-12]. At present, the infrastructure construction of highway transportation in China is developing continuously, and the construction is also widely used in special soil areas. With the progress of the western development strategy, the highway is also constantly advancing to a more complex environment, at the same time, pile foundation as an important part of highway construction, it is necessary to improve the ability of pile foundation to resist complex environment [13-17].

The salt marsh area in northwest China is rich in a variety of corrosive ions. With complex and harsh environmental conditions such as frost heave and carbonization, diseases such as fracture, peeling and peeling appear on the surface of concrete members, resulting in internal loosening of concrete members and reduction of strength, which affects the mechanical properties of concrete materials below the ground of highway bridge pile foundation in varying degrees, affecting the bearing capacity of the bridge. It even makes it impossible to use properly. In saline soil area, under the condition of pile corrosion, under the influence of different thickness of pile concrete spalling, the transverse axial bearing capacity and displacement of pile foundation will also be affected to a certain extent [18-20].

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Therefore, relying on the background of Dexiang Expressway, through numerical simulation, a large number of trial calculations and analysis are carried out on the single pile foundation with different thickness of concrete peeling off under the condition of different depth caused by pile foundation corrosion. The purpose of this paper is to explore the influence of spalling thickness on the transverse and axial bearing characteristics of pile foundation caused by bridge foundation.

2 Model Establishment and parameter selection.

2.1Geometric model.

Through the finite element analysis software to establish a finite element model to meet the needs of computing resources, and combined with the bearing characteristics of the pile foundation, after many trial calculations, according to the Saint Venan principle, for the simulation analysis of a single pile, the thickness of the soil at the bottom of the pile is 20m, and the thickness of the soil on the side of the pile is 8D (D is the diameter of the pile), which can reflect the geometric size and spatial position of the pile and soil, and the spalling thickness of the bridge foundation is selected as 3cm, 6cm, 9cm, 12cm, 15cm and so on.

2.2Selection of calculation parameters.

The difficulty of finite element calculation is to determine the constitutive model which accords with the actual situation and how to select the calculation parameters accurately. After the pile foundation is corroded, the concrete in the pile body will attenuate in quality, and the strength will also decrease accordingly. In the finite element calculation, the attenuation of elastic modulus is used to simulate the actual pile corrosion.

For the characteristic of relative dynamic elastic modulus of concrete, when the finite element parameters are selected, the finite element calculation parameters are selected according to the reduction of relative dynamic elastic modulus determined by indoor corrosion test as the standard. The data of laboratory tests show that when the specimen begins to peel off, the attenuation of its relative dynamic elastic modulus is 80%~70% of that of the beginning. Therefore, in the parameter selection of numerical simulation, the relative elastic modulus of pile foundation is 80%, 75%, 70% and 60% of that at the beginning, respectively, which is used to simulate the corrosion conditions of pile body. Tab.1 is the parameter selection.

Tab.1 Finite element calculation parameters

Name of material	Elastic Modulus E（MPa）	Poisson Ratio N	Cohesion c（kPa）	Angle of internal friction φ（°）	Bulk density γ（kN/m^3）
Pile	$3.0×10^4$	0.20	—	—	25.0
Fine sand	12.5	0.33	10.8	30	18.4
Silty clay	5.6	0.30	20	20	18.3
Spalling concrete	$2.4×10^4$	0.20	—	—	25.0
Exfoliation 9.0 cm	$2.3×10^4$	0.20	—	—	25.0
Exfoliation 12 cm	$2.1×10^4$	0.20	—	—	25.0
Exfoliation 15 cm	$1.8×10^4$	0.20	—	—	25.0

3 Calculated working condition.

The environment in the alpine saline soil area is bad, under the condition of dry-wet cycle and salt corrosion, the concrete members of the underground pile will fall off seriously, and even the reinforcement will be exposed. In order to further study the transverse and axial bearing characteristics of bridge pile foundation in saline soil area, relying on the Qinghai Dexiang highway project, and analyzing the research on the lower corrosion structure of bridges and culverts in Qinghai at the same time, it is found that the corrosion phenomenon mainly occurs between 1.0m above the ground and the groundwater level. The muddy silt and saturated fine sand in the road area where Dexiang Expressway is located are mainly concentrated in 8.0 m below the surface, so the corrosion depth (defined as the corrosion zone height of pile foundation below ground, represented by symbol H) can be considered in the design of working conditions. the corrosion depth can be 0.0m, 1.5m, 3.5m, 5.0m and 8.0m, respectively. Meanwhile, spalling thickness (decrease of force section of pile body, radius decrease with symbol δ) increases with corrosion period, concrete spalling thickness is 0.0cm, 3.0cm, 6.0cm, 9.0cm, 12cm, 15cm. Specific calculation conditions are shown in Tab.2.

Tab.2 Calculation conditions of spalling thickness change

Spalling thickness δ（cm）	Pile diameter D（m）	Pile length L（m）	Depth of decay H（m）

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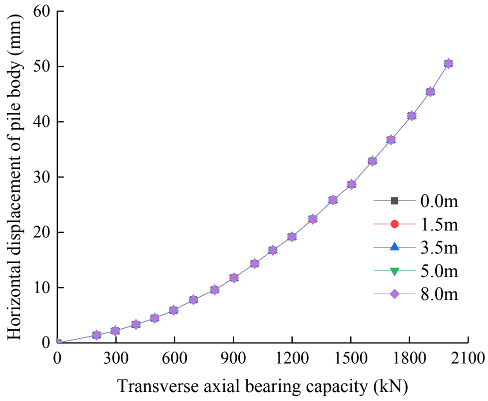
0、3、6、9、12、15	1.8	40	1.5、3.5、5.0、8.0

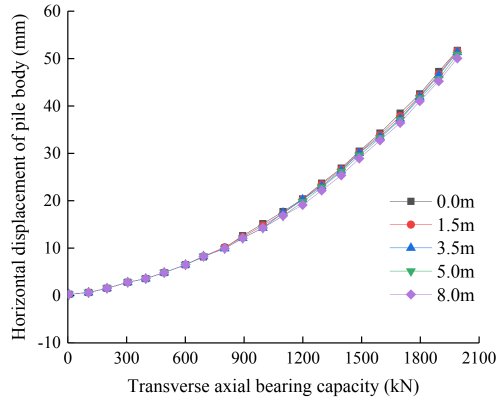
4 Results and analysis.

4.1Effect of thickness variation on transverse and axial bearing capacity of pile foundation under different corrosion depth.

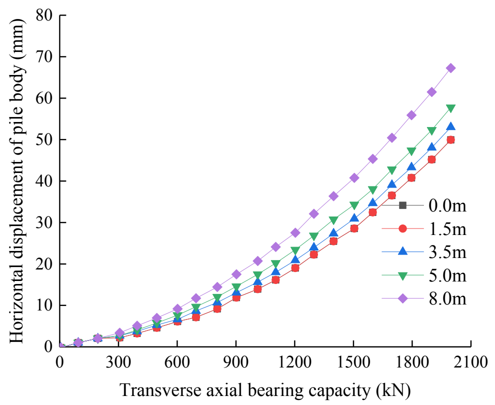
When pile length is 40m diameter of 1.8m pile diameter is invariable, the thickness change of pile foundation is changed. Using transverse and axial loading method, the influence of thickness variation of pile foundation on bearing characteristics of pile foundation is studied. The variation rule of pile foundation bearing capacity H-y curve is shown in Fig.1.



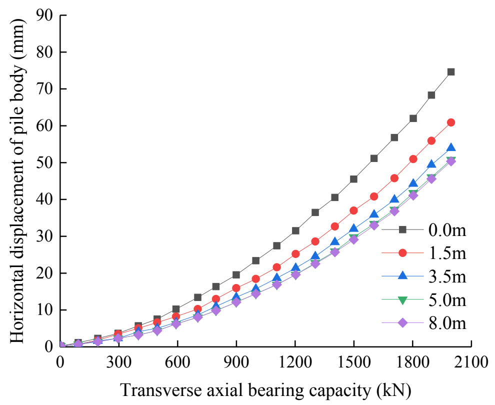
（a）δ3.0cm-D1.8-L40



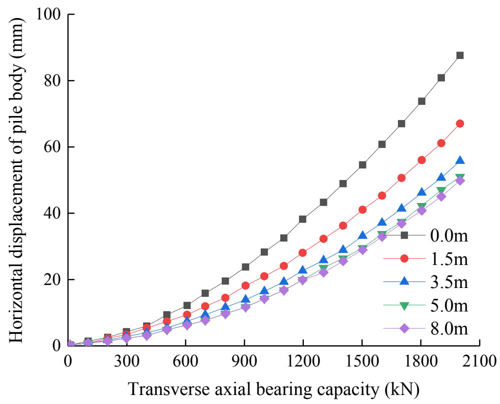
（b）δ6.0cm-D1.8-L40



（c）δ9.0cm-D1.8-L40



（d）δ12.0cm-D1.8-L40



（d）δ15.0cm-D1.8-L40

Fig.1 Effect of peeling thickness variation under different pile diameters on transverse and axial bearing capacity of pile foundation

According to curve analysis of graph a and graph b, it can be obtained that under the condition of thickness of

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3.0 cm and 6.0 cm, transverse and axial bearing capacity of pile body does not change obviously due to the change of depth of pile body corrosion. This is because when spalling thickness is relatively small concrete protective layer has not completely shed therefore pile body structure is relatively complete use safety. Comparing graphs c, figure d and figure e shows that when spalling thickness reaches more than 9.0 cm transverse and axial bearing capacity of pile body increases obviously with variation of corrosion depth of pile body. Taking spalling thickness of 9.0cm as an example, it can be found that transverse and axial displacement of pile foundation decreases with increasing corrosion depth when transverse and axial displacement of pile top is 60mm. When corrosion depth is 8.0m pile body, the lowest transverse and axial bearing capacity is only 1700 kN.

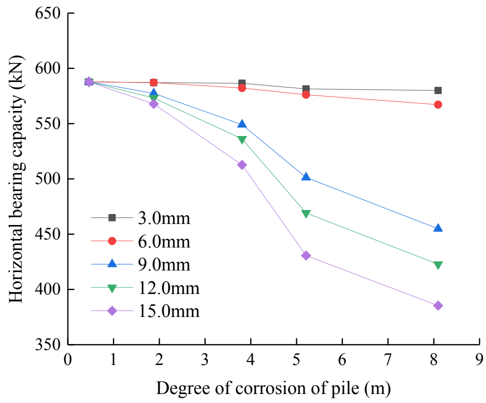


Fig.2 Variation of transverse and axial bearing capacity with different peeling thickness

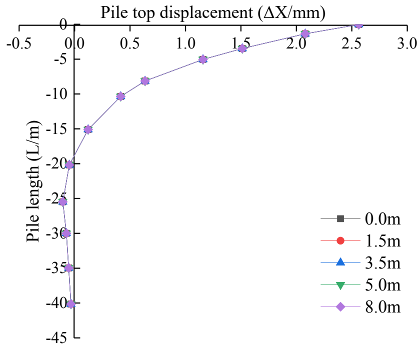
From Fig.2, it can be concluded that the change of spalling thickness affects transverse and axial bearing capacity under different corrosion depth, and there is obvious difference between transverse and axial bearing capacity of 9.0cm, 12.0cm and 15.0cm. When thickness of spalling thickness is 9.0cm and corrosion depth is 1.5m, transverse and axial bearing capacity decreased from 587.04kN to 586.06kN， decrease of 0.2%; When corrosion depth is 3.5m, transverse and axial bearing capacity decreased from 587.04kN to 548.95kN, decrease of 6.5%; When corrosion depth is 5.0m, transverse and axial bearing capacity decreased from 587.04kN to 500.44kN,decrease of 14.8%; When corrosion depth is 8.0m, transverse and axial bearing capacity decreased from 587.04kN to 453.37kN, decrease of 22.8%. When thickness of spalling thickness is 12m and corrosion depth is 1.5m, transverse and axial bearing capacity decreased from 587.04kN to 575.23kN, decrease of 2%; When corrosion depth is 3.5m, transverse and axial bearing capacity decreased from 587.04kN to 534.92kN, decrease of 8.9%; When corrosion depth is 5m, transverse and axial bearing capacity decreased from 587.04kN to 471.53kN, decrease of 19.7%; When corrosion depth is 8m, transverse and axial bearing capacity decreased from 587.04kN to 422.72kN, decrease of 28.0%. When thickness of spalling thickness is 15m and corrosion depth is 1.5m, transverse and axial bearing capacity decreased from 587.04kN to 569.01kN, decrease of 3.1%; When corrosion depth is 3.5m, transverse and axial bearing capacity decreased from 587.04kN to 511.20kN, decrease of 12.9%; When corrosion depth is 5.0m, transverse and axial bearing capacity decreased from 587.04kN to 430.86kN, decrease of 26.6%; When corrosion depth is 8m, transverse and axial bearing capacity decreased from 587.04kN to 385.12kN, decrease of 34.4%.

Tab 3. Allowable bearing capacity and reduction range

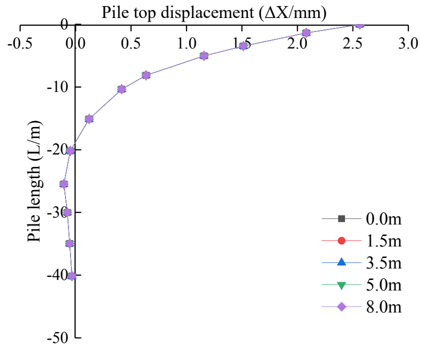
Depth of decay / Allowable bearing capacity / Reduction amplitude （%）			0.0m	1.5m	3.5m	5.0m	8.0m
Pile length （m）	Pile diameter （m）	Spalling thickness *δ* （cm）					
40	1.8	3.0	587.04/0.0	586.57/0.1	584.85/0.4	581.28/1.0	577.45/1.6
		6.0	587.04/0.0	586.06/0.2	582.36/0.8	575.5/2.0	567.5/3.3
		9.0	587.04/0.0	578.67/1.4	548.95/6.5	500.44/14.8	453.37/22.8
		12	587.04/0.0	575.23/2.0	534.92/8.9	471.53/19.7	422.72/28.0
		15	587.04/0.0	569.01/3.1	511.2/12.9	430.86/26.6	385.12/34.4

4.2 Effect of thickness variation on transverse and axial displacement of pile foundation under different corrosion depth.

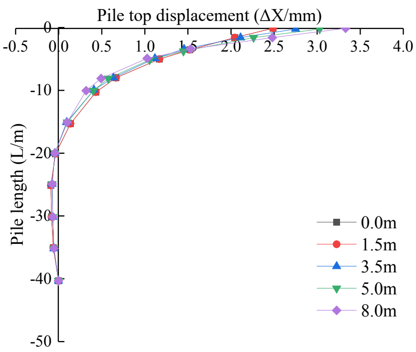
Under the condition that the pile length is 40m and the diameter is 1.8m, the spalling thickness of the bridge foundation changes. The influence of the spalling thickness of the pile foundation on the bearing characteristics of the pile foundation is studied by using the method of transverse axial graded loading. Under the condition that the corrosion depth of the pile body changes, the transverse axial displacement curve of the pile foundation along the pile direction is shown in Fig 3.



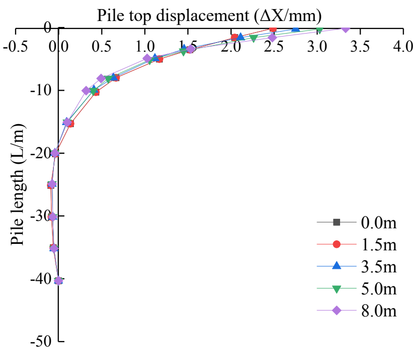
（a）δ3.0cm-D1.8-L40



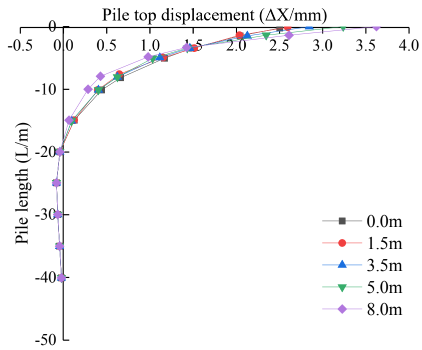
(b) δ6.0cm-D1.8-L40



(c) δ9.0cm-D1.8-L40



(d) δ12cm-D1.8-L40



(e) δ15cm-D1.8-L40

Fig 3. Transverse and axial displacement curve of pile body direction with variation of corrosion depth under different peeling thickness conditions

According to curve analysis of graph f and graph g, there is no obvious change in transverse and axial displacement of pile body when thickness of pile body changes when thickness of flake is 3.0cm and 6.0cm respectively. Because the thickness of spalling is not large enough, the protective layer of concrete is not completely exfoliated and reinforcement parts are not obvious, thus showing that when thickness of flake is

3.0cm and 6.0cm, it shows that the protective layer is not obvious. The depth of pile body corrosion has little influence on transverse and axial displacement and safety of pile foundation structure is relatively small.

The comparison shows that the negative displacement below the zero point of the first displacement of the pile decreases with the increase of the spalling thickness. Comparing graphs c diagram d and e, we can see clearly that when the thickness of spalling becomes larger the displacement curve of the first displacement of pile direction is shifted above zero point at different depth of pile body corrosion depth when spalling thickness becomes larger. Even when the thickness of spalling reaches 15cm, the pile top displacement reaches 4.2mm. This indicates that with increasing spalling thickness transverse and axial displacement of pile body will change with depth of pile body after exposed. Pile foundation stability has been greatly influenced.

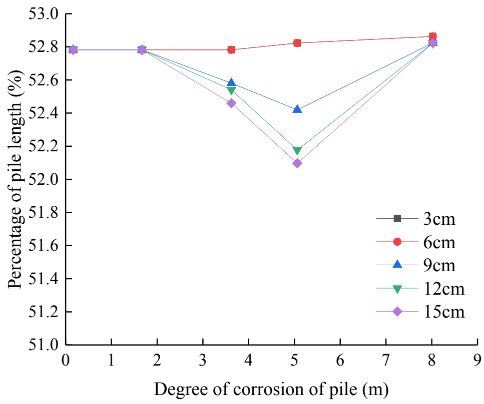


Fig 4. Percentage of pile length from zero point of transverse and axial displacement to pile bottom under different peeling thickness

Meanwhile, at the same time, it is of great significance to study the relative position change of the first displacement zero in the pile body. As can be seen from figure 4: taking the spalling thickness of 15cm as an example, when the corrosion depth of the pile is 0.0m, the position of the zero point of the first horizontal displacement is 18.888 m from the top of the pile, accounting for 47.2% of the length of the pile; When the corrosion depth of the pile is 1.5m, the position of the first horizontal zero is 18.900m from the top of the pile, accounting for 47.2% of the length of the pile; When the corrosion depth of the pile is 3.5m, the position of the first horizontal zero is 19.001m from the top of the pile, accounting for 47.5% of the length of the pile; When the corrosion depth of the pile body is 5.0m, the position of the first horizontal zero is 19.167m from the top of the pile, accounting for 47.9% of the pile length; when the corrosion depth of the pile body is 8.0m, the position of the first horizontal zero is 18.839m from the top of the pile, accounting for 47.1% of the pile length.

5 Conclusion.

(1) The thickness of spalling affects transverse and axial load characteristics under different depth under different depth of decay. When the thickness of pile body spalling is relatively small, transverse and axial load bearing characteristics of pile foundation does not change obviously because of corrosion depth of pile foundation; When spalling thickness reaches more than 9.0cm, transverse and axial load characteristics of pile foundation occur obviously with variation of corrosion depth of pile body.

(2) When the transverse and axial bearing capacity of pile foundation is at the same depth of decay, the decrease amplitude increases with increasing thickness of pile body spalling. When the thickness of spalling is above 9.0cm, its decrease amplitude increases obviously.

(3) With the increase of the spalling thickness, the negative displacement below the zero point of the first displacement of the pile body is decreasing, and the displacement of the pile top is increasing; under the same corrosion depth, different spalling thickness will also affect the position of the zero point of the first displacement, that is, the greater the spalling thickness, the farther the position of the first displacement zero from the top of the pile, especially when the corrosion depth is 5m.

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