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Experimental study on the compactness of assembled bridge sleeve grouting

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Abstract
In order to study the effect of grout defects of assembled bridge sleeves on the tensile performance of sleeve connections, 36 grouted sleeve specimens with different defects were designed and produced with grout defects as variables, and the connection performance of the specimens after maintenance was tested by static one-way tensile test, and the quantitative relationship between different rates of grout defects and sleeve connection performance was established. The results show that: at a yield strength of about 435 MPa, the grouting defect rate is within 16% of the specimen steel pull-out damage, and the safety of the specimen can be satisfied within 36% of the grouting defect rate; at a yield strength of about 405 MPa, the grouting defect rate is within 28.75% of the specimen steel pull-out damage, but as the ultimate strength of the steel is close to 621 MPa, the specimen is susceptible to Dangerous damage; steel yield strength of about 445MPa, due to their own steel material strength is too large, even if no defective specimens are easy to produce slip damage, although the grouting defect rate of 30.5% or less, the safety performance of the specimen is guaranteed, but the performance of the material can not be effectively played, easy to cause material waste.

Keywords: *Assembled bridges, Grouted sleeves, Grout defects, Single-way tensile test.*

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I. INTRODUCTION

With the development of China's economy and urban construction, the adaptability of the traditional cast-in-place construction method, which relies on cheap labor and high requirements for closed traffic, is decreasing. Assembly bridge construction using factory prefabrication and on-site assembly construction is gradually replacing cast-in-place construction as a new method of urban bridge construction in China[1].

In the actual construction process of assembled bridges connected by grouted sleeves, grouting defects may occur due to changes in grout liquidity, unsteady grouting pressure, poor grouting and grout leakage, which may lead to the formation of grouting defects in the sleeve, which will reduce the stability of the components and structure and cause different degrees of damage to the structure and components.Chinese scholars have conducted various studies on sleeve connections with grouting defects.Zheng Qinglin et al [2] examined the effect of sleeve grouting defects on the seismic performance of assembled concrete columns through a proposed static test of assembled concrete columns, and the test results found that the asymmetry of the hysteresis curve and the pinch effect became more pronounced as the grouting defects and horizontal displacement of the specimens increased.Gao Rundong et al [3] analyzed the effect of grouting defects in different locations on the strength of steel sleeve grouted joints and found that the middle sleeve defects had a more negative effect on the joint performance.In a study of the effect of grouting defects on the tensile properties of the sleeve connection, this paper takes a 40mm diameter grouting sleeve specimen as the object of study to investigate the effect of different degrees of defects on the tensile properties of the connection joint and to compare and analyse its load bearing capacity, damaging form and deformation capacity, with a view to providing reference for the safety evaluation of the grouting quality of the nodes between prefabricated elements and the quality control of sleeve grouting construction.

II. OVERVIEW OF THE TRIAL

2.1Test Piece Design

The construction dimensions of the grouting sleeves for the steel connections used in the tests are shown in Figure 1, and the defective specimens were designed by controlling the height of the pressure grout defects l_2. A total of 36 specimens in 12 groups were designed to study the effect of defect degree on the performance of the connection, as shown in Table l. The specimen numbering rules are shown in Figure 2.

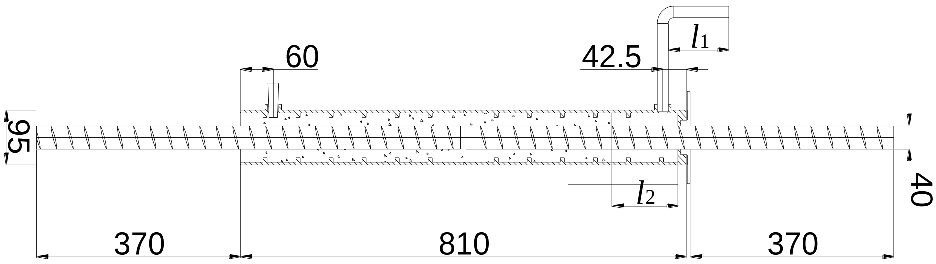

Figure 1: Schematic diagram of specimen dimensions

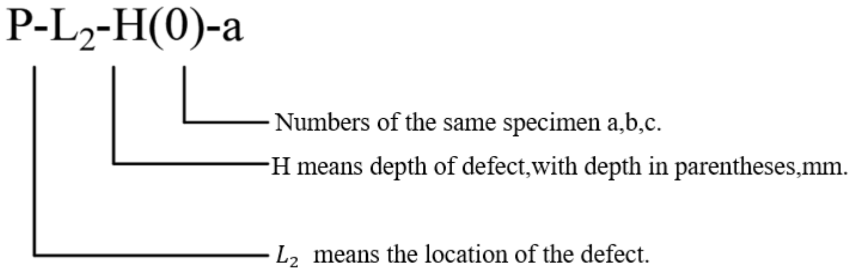

Figure 2:Specimen numbering rules

Table 1:Specimen design

Specimen Group Number	Specimen Number	Defect Length /l_2 （Mm）	Number Of Specimens	Remarks
Group 1	P-L_2 -H(0)-a/b/c	0	3	0 × Diameter Of Rebar
Group 2	P-L_2 -H(10)-a/b/c	10	3	0.25 × Diameter Of Rebar
Group3	P-L_2 -H(20)-a/b/c	20	3	0.50 × Diameter Of Rebar
Group4	P-L_2 -H(30)-a/b/c	30	3	0.75 × Diameter Of Rebar
Group5	P-L_2 -H(40)-a/b/c	40	3	1 × Diameter Of Rebar
Group6	P-L_2 -H(60)-a/b/c	60	3	1.5 × Diameter Of Rebar
Group7	P-L_2 -H(80)-a/b/c	80	3	2 × Diameter Of Rebar
Group8	P-L_2 -H(100)-a/b/c	100	3	2.5 × Diameter Of Rebar
Group 9	P-L_2 -H(120)-a/b/c	120	3	3 × Diameter Of Rebar
Group 10	P-L_2 -H(140)-a/b/c	140	3	3.5 × Diameter Of Rebar
Group 11	P-L_2 -H(160)-a/b/c	160	3	4 × Diameter Of Rebar
Group 12	P-L_2 -H(200)-a/b/c	200	3	5 × Diameter Of Rebar

The defect length of the specimen is controlled by a pre-buried foam ring with machined dimensions of 75mm x 95mm x 20mm and 75mm x 95mm x 10mm (inner diameter x outer diameter x thickness), the two foam rings are freely combined and strung together with cotton rope so that their thickness meets the requirements of design defect l2, and an air outlet hose is set in the combined foam ring to ensure that the air in the sleeve can be properly The air is discharged. When pre-burying the combined foam ring, bury the foam ring through the top of the sleeve, correct the position of the air outlet hose, put the air outlet hose through the position of the grout hole of the sleeve, then pull the cotton rope tightly and tie it to the end of the sleeve, so that the foam ring is fixed in the sleeve.

2.2 Mechanical Properties of Materials

Grout test blocks (40mm x 40mm x 160mm) were made according to specification [4], maintained in the same environment as the sleeve grout connection specimens, and the strength of the grout test blocks was measured before stretching the sleeve specimens. The test block was measured to have a compressive strength of 102.6 Mpa in accordance with the test method of the code. 40mm diameter HRB400 reinforcement used in the actual project was used for the reinforcement, and the yield strength of the reinforcement was measured to be 427 Mpa and the tensile strength was 645.6 Mpa in accordance with the test method of the code. GTZQ440 model sleeve produced by Hunan Ji Xing New Material Technology Co. Made of ductile iron, its performance meets the requirements of the current standard [5].

2.3Loading Device and Loading System

The test was carried out using an electronic universal machine (range 2000KN) produced by Shenzhen Wanxiao Test Equipment Co. The loading regime is set according to the requirements of the specification [6]: the first stage is stress-controlled 10MPa/s, 0→0.6fsk→0 to measure the residual deformation; the second stage is strain-controlled 20mm/min, loaded from 0 to specimen damage, and the total elongation is measured. After the test is completed, the displacement and tensile forces at each time point can be exported from the data acquisition instrument.

（a）（b）

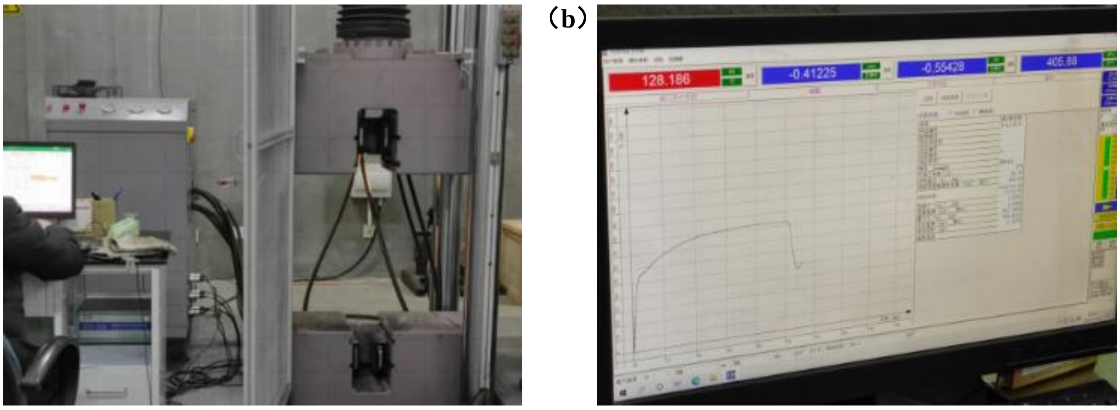

Figure 3: Specimen loading device and acquisition system,（a）Testing machines and data acquisition,（b）Load-displacement curves generated by the acquisition system

2.4 Measurement Content and Measurement Method

The measurement distance of the specimen is shown in Figure 4. The length of the sleeve in the figure is 810mm, the middle of each 5mm position set at both ends of the rebar limit valve, grouting holes and slurry holes on both sides of the buried length of the rebar is 400mm; nominal diameter of the rebar d for 40mm, Lc take 2d, before the test with a marker in the end of the rebar mark, for the installation of extensometer to measure the residual deformation of the test piece; total elongation measurement distance L_{01} take 100mm, rebar clamping and surplus length L_d take 190mm. The load and displacement can be automatically recorded by the loading device data acquisition system.

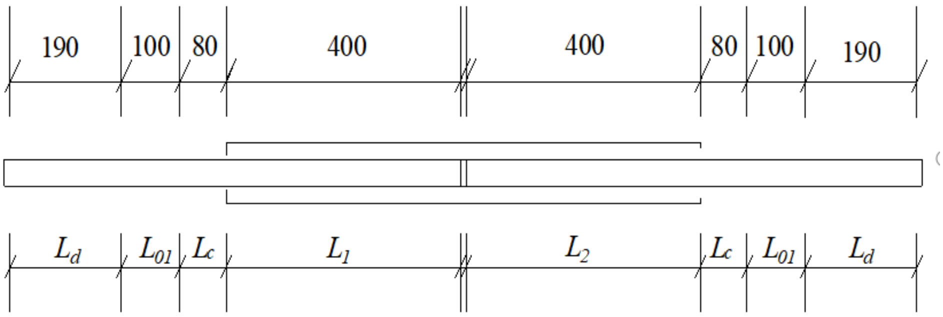

Figure 4: Specimen measurement gauge (unit/mm)

III. TEST PHENOMENA AND DAMAGE PATTERNS

According to the regulation [7], if the connection occurs when the reinforcement pulls out, it is a reasonable damage mode; if the connection occurs when the reinforcement pulls out and the ultimate tensile strength is greater than 1.15 f_{stk}, it is defined as a slip qualified damage mode; if the ultimate tensile strength is less than 1.15 f_{stk} when the reinforcement pulls out, it is defined as a slip unqualified damage mode. In addition, the defect rate is defined as the ratio of the actual defect length to the depth of insertion of the reinforcement into the sleeve on one side.

Table 2:Test results and damage to grout defective specimens

Group number	Specimen number	Yield strength f_y /Mpa	Tensile strength f_u /Mpa	Destruction patterns
1	P-L_2 -H(0)-a	440	658	Connection damage
	P-L_2 -H(0)-b	435	649	Rebar pull-off
	P-L_2 -H(0)-c	440	644	Connection damage
2	P-L_2 -H(10)-a	441	656	Rebar pull-off
	P-L_2 -H(10)-b	428	643	Rebar pull-off
	P-L_2 -H(10)-c	430	647	Rebar pull-off
3	P-L_2 -H(20)-a	445	674	Rebar pull-off
	P-L_2 -H(20)-b	434	647	Rebar pull-off
	P-L_2 -H(20)-c	407	621	Rebar pull-off
4	P-L_2 -H(30)-a	427	649	Rebar pull-off
	P-L_2 -H(30)-b	420	632	Connection damage
	P-L_2 -H(30)-c	439	656	Rebar pull-off
5	P-L_2 -H(40)-a	406	611	Connection damage
	P-L_2 -H(40)-b	409	618	Rebar pull-off
	P-L_2 -H(40)-c	442	653	Connection damage
6	P-L_2 -H(60)-a	410	627	Rebar pull-off
	P-L_2 -H(60)-b	436	650	Rebar pull-off
	P-L_2 -H(60)-c	407	619	Rebar pull-off
7	P-L_2 -H(80)-a	455	620	Rebar pull-off
	P-L_2 -H(80)-b	436	652	Rebar pull-off
	P-L_2 -H(80)-c	400	618	Rebar pull-off
8	P-L_2 -H(100)-a	436	645	Connection damage
	P-L_2 -H(100)-b	446	649	Connection damage
	P-L_2 -H(100)-c	433	646	Connection damage
9	P-L_2 -H(120)-a	406	594	Connection damage
	P-L_2 -H(120)-b	409	604	Connection damage
	P-L_2 -H(120)-c	434	641	Connection damage
10	P-L_2 -H(140)-a	437	631	Connection damage
	P-L_2 -H(140)-b	439	642	Connection damage
	P-L_2 -H(140)-c	431	623	Connection damage
11	P-L_2 -H(160)-a	432	608	Connection damage
	P-L_2 -H(160)-b	402	617	Rebar pull-off
	P-L_2 -H(160)-c	439	651	Connection damage
12	P-L_2 -H(200)-a	435	598	Connection damage
	P-L_2 -H(200)-b	407	582	Connection damage
	P-L_2 -H(200)-c	428	618	Connection damage

According to the regulation [7], if the connection occurs when the reinforcement pulls out, it is a reasonable damage mode; if the connection occurs when the reinforcement pulls out and the ultimate tensile strength is greater than 1.15 f_{stk}, it is defined as a slip qualified damage mode; if the ultimate tensile strength is less than 1.15 f_{stk} when the reinforcement pulls out, it is defined as a slip unqualified damage mode. In addition, the defect rate is defined as the ratio of the actual defect length to the depth of insertion of the reinforcement into the sleeve on one side.

The tests recorded the yield strength, ultimate tensile strength, damage morphology, elongation of some specimens and residual deformation of large diameter grouted sleeves at different grouting defect rates. The damage morphology of the specimens was divided into reinforcement pull-out and joint damage (reinforcement slippage). The experimental results and damage of the specimens are shown in Table 2.

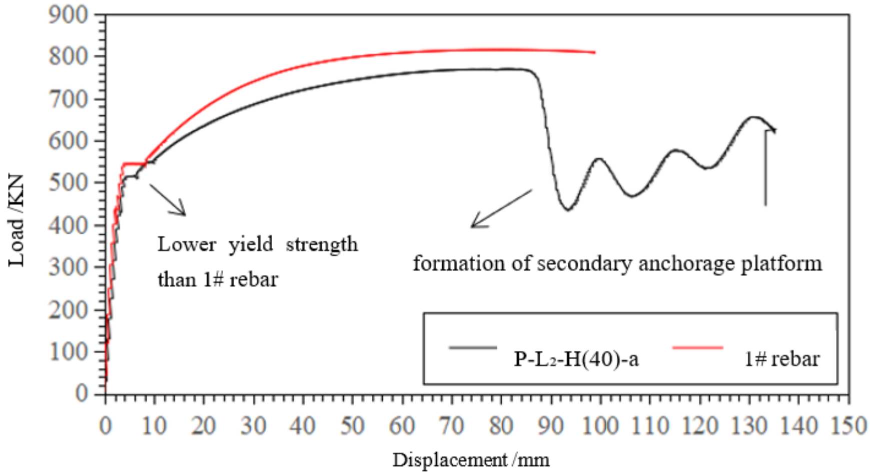

Figure 5:Rebar slip of test piece P-L2-H(40)-a

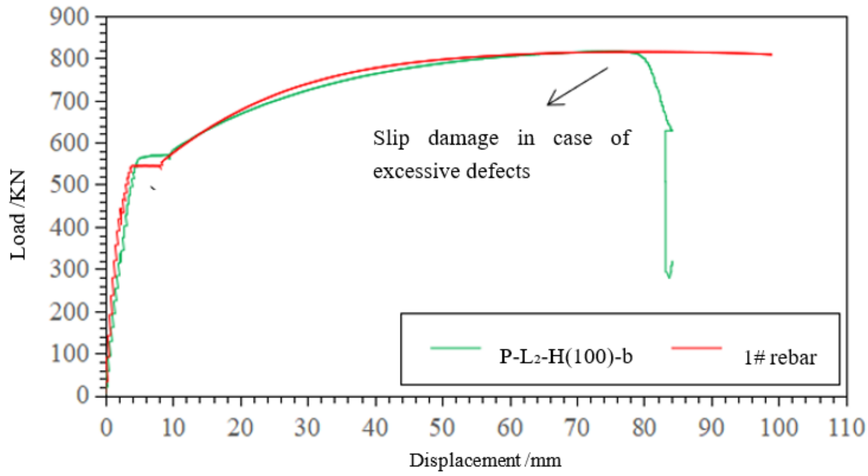

Figure 6: Rebar slip of test piece P-L2-H(100)-b

The test piece in the tensile process exists in the elastic stage, yield stage, strengthening stage, damage stage, the test piece in the reinforcement pulling damage stage shows the reinforcement pulling off. The axial force of the specimen in the slip damage stage decreases with the increase of the loading displacement, the axial force of the specimen decreases in a precipitous manner, at this time the reinforcement slips and breaks, continue loading, the axial force of the specimen will rise and oscillate back and forth in a certain interval, as shown in Figure5. If the defect of the specimen is too large, in the slip damage stage, the grout will lose its secondary anchoring effect on the reinforcement and the reinforcement will slip directly, accompanied by a dull sound, as shown in Figure6.

IV. COMPARISON OF LOAD-DISPLACEMENT RELATIONSHIPS

4.1 Comparative analysis of defect-free specimens and reinforcing steel parent material

The reinforcement parent material was compared with the defect-free specimens P-L_2 -H(0)-a, b and c. The experimental results are shown in Table 3 and the load-displacement curves are shown in Figure 7. The load-displacement relationship curves for the three grout-defect-free specimens basically overlapped in the first three stages; the difference was that when the specimens were damaged, the load forces of specimens a and c decreased sharply with increasing load displacement, producing slip damage, while the toughness of specimen b was significantly higher than that of specimens a and c due to the strength of the reinforcement in specimens a and c. This was because the strength of the reinforcement in specimens a and c was greater than the bonding capacity between the reinforcement and the grout, while the strength of the reinforcement in specimen b was less than the bonding capacity between the reinforcement and the grout.

Table 3:Rebar base material and defect-free specimens

Test piece name	Specimen number	Yield strength f_y/MPa	Tensile strength f_u/MPa	Destruction mode
Rebar base material	Rebar 1#	427	648	Rebar pull-off
Defect-free specimens	P-L_2 -H(0)-a	440	658	Qualified slip damage
	P-L_2 -H(0)-b	435	649	Rebar pull-off
	P-L_2 -H(0)-c	440	644	Qualified slip damage

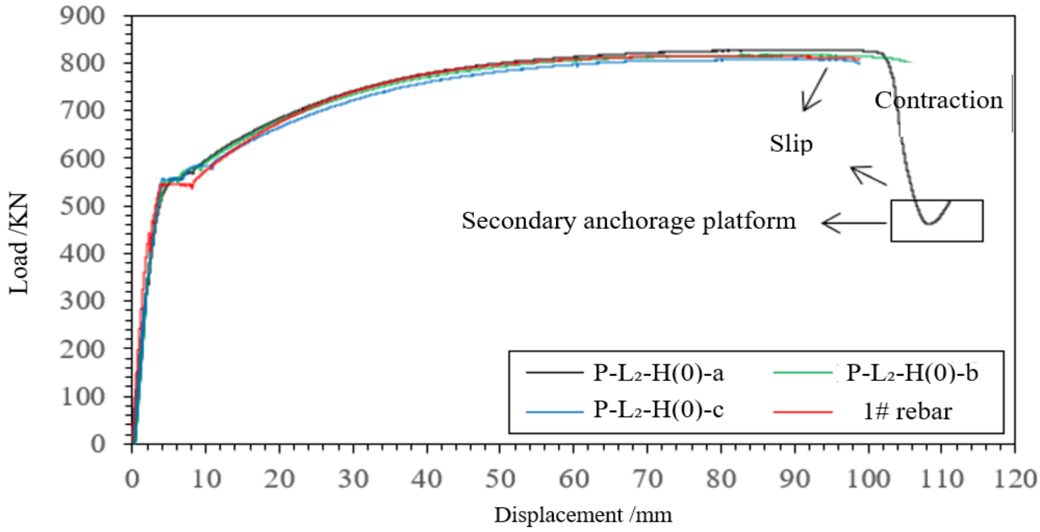

Figure 7:Load-displacement curves of defect-free specimens and rebar base metal

4.2 Comparative analysis of yield strength 435±5 MP specimens

Among the specimens with yield strength of 435±5MPa, specimens with about 10% defect rate gradient were selected (in Table 4), and the load-displacement curve was plotted as shown in Figure 8, and the relationship between grout defect rate and tensile strength of the specimens was shown in Figure 9.

For specimens with similar yield strength of reinforcement, the load-displacement curves basically coincide with the standard specimens as the loading displacement increases. When the grouting defect rate is below 15.5%, the load-displacement curves basically overlap, indicating that the defects have no effect on the specimen performance at this time. When the defect increases to 26.25%, the specimen P-L_2 -H(120)-c slips at about 100mm, the load capacity and deformation performance is slightly reduced compared to the standard specimen, but the tensile strength meets the requirements of safety, and the specimen is in a qualified state of reinforcement slip. When the defect increases to 36.75%, the specimen L_2 -H(160)-a slips at about 60mm, the deformation performance and load bearing capacity continues to decrease, at the same time, because the defect is too large the grout cannot play the role of secondary anchorage, the tensile strength does not meet the safety requirements, the specimen is in a state of unqualified reinforcement slip.

Table 4 Yield strength 435±5MPa test piece

Specimen name	Specimen number	Defect rate/%	Yield strength f_y/MPa	Tensile strength f_u/MPa	Destruction mode
Standard specimens	P-L_2 -H(0)-b	0.00	435	649	Rebar pull-off
Test piece	P-L_2 -H(20)-b	3.75	434	647	Rebar pull-off

	P-L2-H(80)-b	15.50	436	652	Rebar pull-off
	P-L_2 -H(120)-c	26.25	434	641	Qualified slip damage
	P-L_2 -H(160)-a	36.75	432	608	Unqualified slip damage
	P-L_2 -H(200)-a	46.25	435	598	Unqualified slip damage

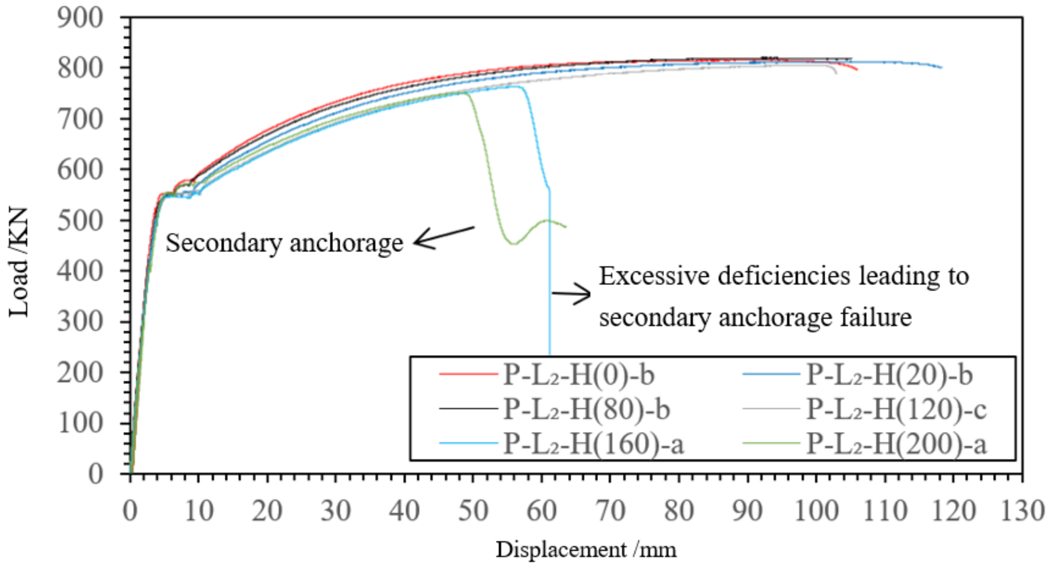

Figure 8: Load-displacement curve of specimen yield strength 435±5MPa

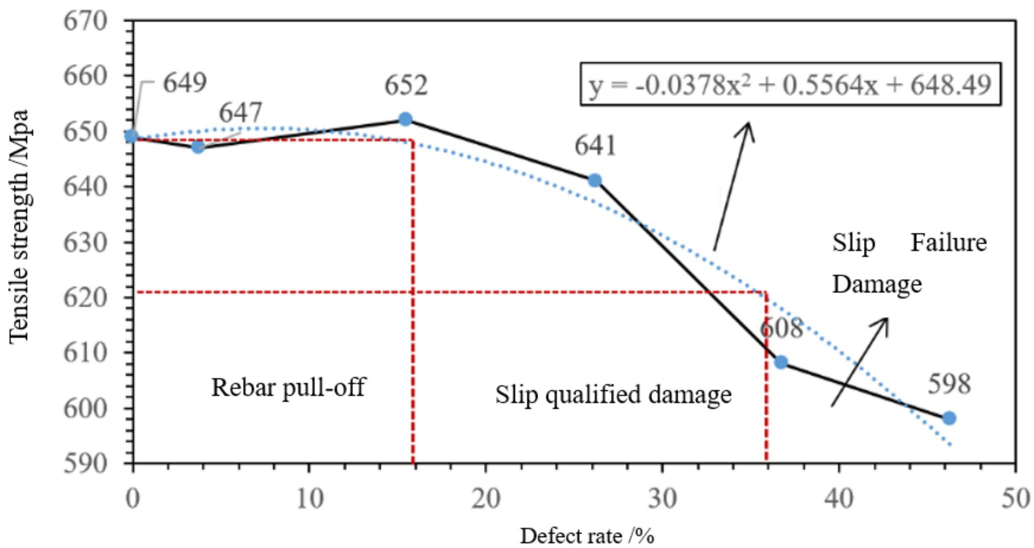

Figure 9:Relationship between defect rate and tensile strength (yield strength 435±5MPa)

When the defect continued to increase to 46.25%, the specimen L_2 -H(200)-a slipped at a loading displacement of about 50mm, and the deformation performance and load carrying capacity further declined, but the grout after slipping was sufficient to withstand the load after slipping, and the seismic trend of secondary anchorage appeared.

The curve relationship between the defect rate and tensile strength of the specimen was obtained by fitting the data, as shown in Figure 9. From Figure 9, it can be seen that: grout defect rate <16%, with the increase of defects, the tensile strength of the specimen did not change much, the specimens were broken by reinforcement pulling; 16%< grout defect rate <36%, with the increase of defects the tensile strength of the specimen showed a decreasing trend, but met the safety requirements; grout defect rate >36%, the specimen Grouting defect rate > 36%, the tensile strength of the specimen decreases with the increase of defects, and the safety requirements are not met.

4.3 Comparative analysis of specimens with a yield strength of 405±5MPa

Among the specimens with yield strength of 405±5MPa, about 10% defect gradient was selected (refer toTable 5), the load-displacement curve is shown in Figure 10, and the relationship between grout defect rate and tensile strength of the specimens is shown in Figure 11.

Table 5 Yield strength 405±5MPa test piece

Specimen name	Specimen number	Defect rate/%	Yield strengthf_y/MPa	Tensile strengthf_u/MPa	Destruction mode
Standard specimens	L_2 -H(20)-c	3.75	407	621	Rebar pull-off
Test piece	L_2 -H(60)-c	12.50	407	619	Rebar pull-off
	L_2 -H(80)-c	17.00	400	618	Rebar pull-off
	L_2 -H(160)-c	28.75	402	617	Rebar pull-off
	L_2 -H(120)-a	30. 50	406	594	Unqualified slip damage
	L_2 -H(200)-b	45.00	407	582	Unqualified slip damage

When the grouting defect rate is below 28.75%, the specimen performance is basically the same, indicating that the defect has basically no effect on the specimen performance under this condition. When the defect increases to 30.5%, the specimen P-L_2 -H(120)-a shows slip damage, the bearing capacity is slightly reduced compared to the standard specimen, the safety no longer meets the specification requirements, the deformation performance is only half of the standard specimen, which means that as the defect rate of grouting continues to increase, once the loading displacement is too large, the grout cannot play the role of anchorage, damage will occur instantly and the danger is great. As the defect continued to increase to 45%, specimen P-L_2 -H(200)-b slipped and the deformation performance and load capacity continued to decrease, but the grout after slipping was sufficient to withstand the load after slipping and a secondary anchorage oscillation trend occurred.

The relationship between specimen grout defect rate and tensile strength, as shown in Figure 11, grout defect rate of 28.75% or less, with the increase of defects, the tensile strength of the specimens did not change much, the specimens are basically the reinforcement pull-off damage, grout defect rate of 28.75% or more, with the increase of defects specimens tensile strength The specimens are basically slip damaged and the safety does not meet the 1.15f_{stk} (621MPa) requirement.

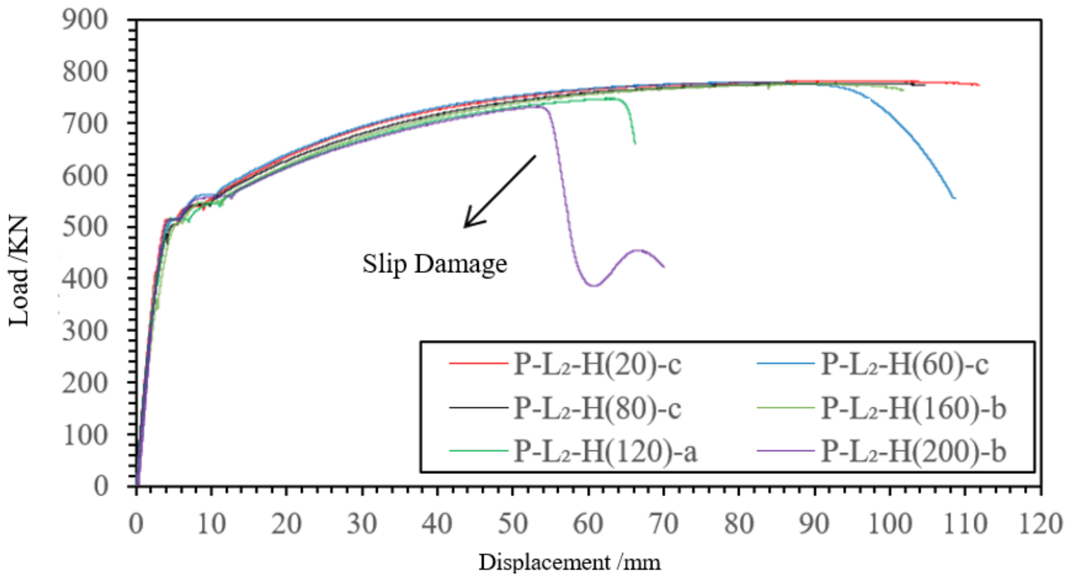

Figure 10:Load-displacement curve of specimen yield strength 405±5MPa

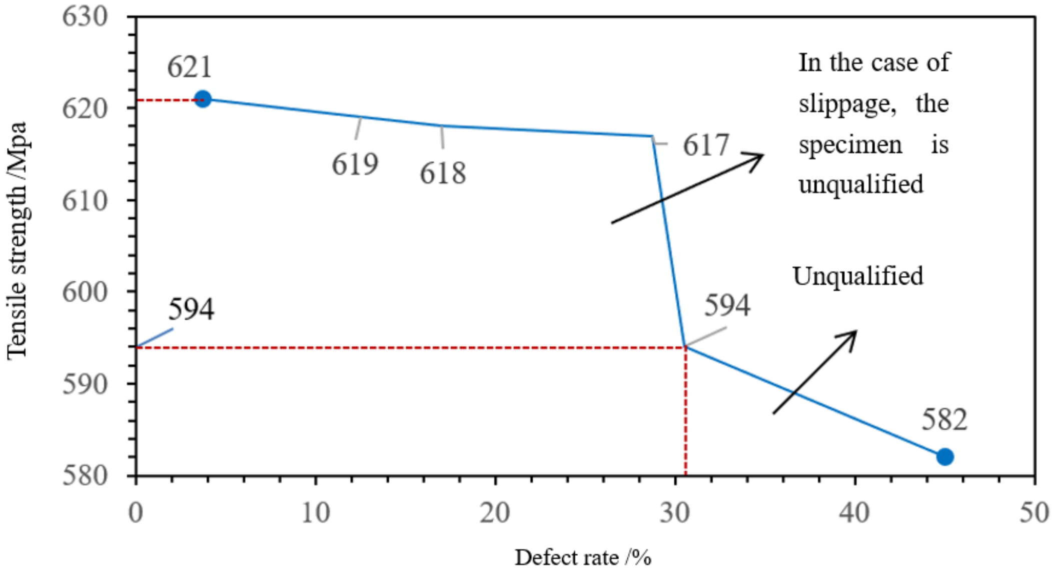

Figure 11: Relationship between defect rate and tensile strength (yield strength 405±5MPa)

4.4 Comparative analysis of specimens with yield strength 445±5MPa

Among the specimens with yield strength of 445±5MPa, those with about 10% defect gradient were selected (refer to Table 6), the load-displacement curve is shown in Figure 12, and the relationship between grout defect rate and tensile strength of the specimens is shown in Figure 13.

Table 6: Yield strength 445±5MPa test piece

Specimen name	Specimen number	Defect rate/%	Yield strengthf_y/MPa	Tensile strengthf_u/MPa	Destruction mode
Standard specimens	P-L_2 -H(10)-a	2.50	441	656	Rebar pull-off
Test piece	P-L_2 -H(0)-c	0.00	440	644	Qualified slip damage
	P-L_2 -H(40)-c	9.75	442	653	Qualified slip damage
	P-L_2 -H(100)-b	18.00	446	649	Qualified slip damage
	P-L_2 -H(140)-b	30.50	439	642	Qualified slip damage

For the specimen with yield strength of 445±5MPa, when the grouting defect is small, the P-L_2 -H(0)-c sliding damage occurs, meanwhile, the P-L_2 -H(10)-a reinforcement pull-out damage occurs, the load-displacement curves of P-L_2 -H(0)-c and PL_2 -H(10)-a specimens are basically bonded, and their bearing capacity and deformation performance are basically the same. With the increase of defect rate, the tensile strength and deformation performance of the specimen will gradually decrease, but the change is not significant, and the ultimate tensile strength is greater than 621MPa, and the safety meets the requirements, which indicates that the specimen with yield strength of 445±5Mpa has high safety reserve capacity.

The specimens with yield strength 445±5MPa a are easy to produce slip damage even without defects due to the excessive strength of their own reinforcement material; the grouting defect rate ≤30.5%, with the increase of defects deformation performance and tensile strength decreases in turn, although the safety performance of the grouting defect rate within 30.5% is guaranteed, but the performance of the material cannot be effectively played, which is easy to cause material waste

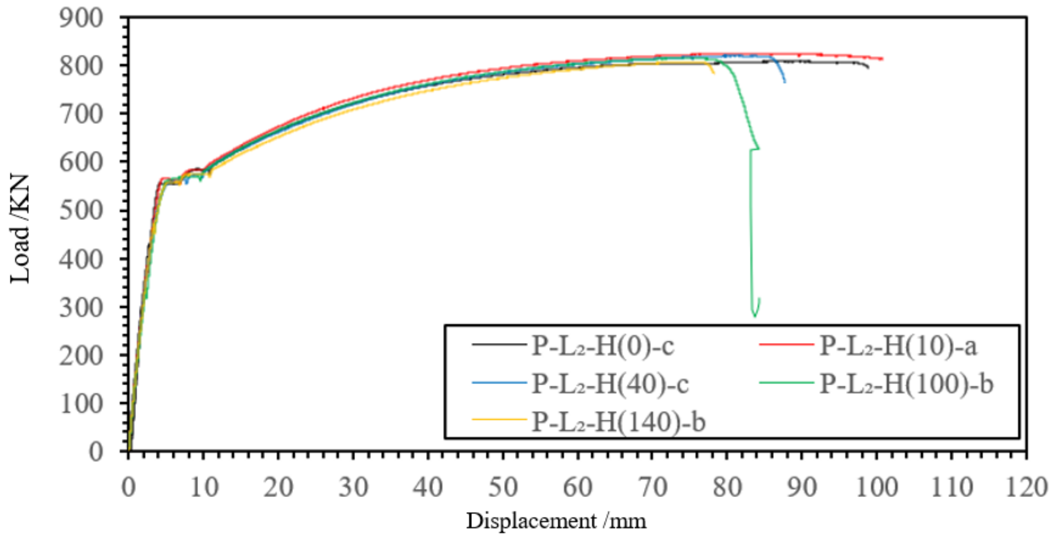

Figure 12:Load-displacement curve of specimen yield strength 445±5MPa

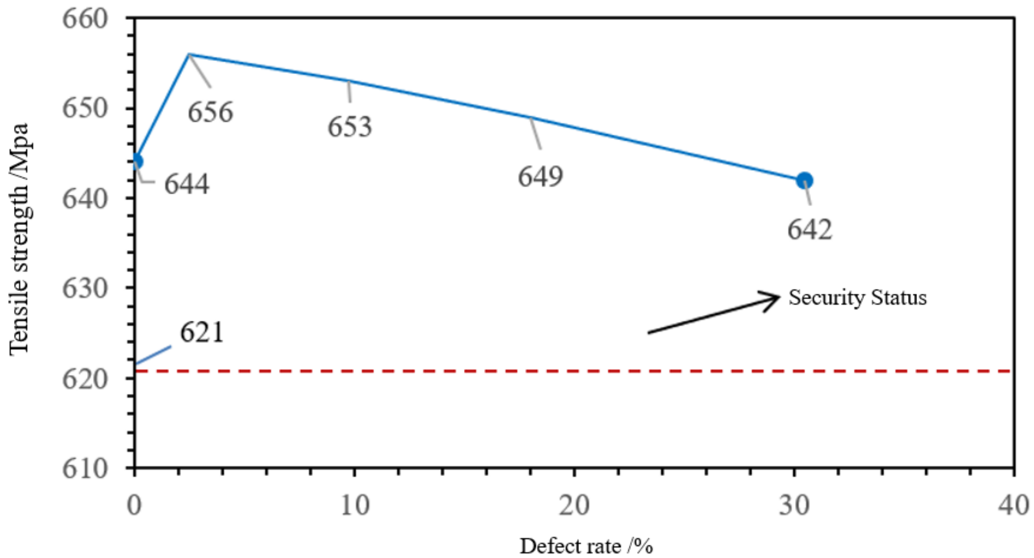

Figure 13: Relationship between defect rate and tensile strength (yield strength 445±5MPa)

V. CONCLUSION

(1) In the case of full grouting, the performance of the specimens with pulled-out reinforcement is given full play, while the load-bearing capacity and deformation performance of the specimens with slip damage are not effectively utilised; in the case of full grouting, when the strength of the elected reinforcement is greater than the corresponding grout bond, slip damage will occur, resulting in a waste of material.

(2) For specimens with yield strength of 435±5MPa, grouting defect rate ≤16%, the change of defect rate has little effect on the tensile strength of the specimens, and the specimens are broken by pulling the reinforcement; 16%＜grouting defect rate＜36%, the tensile strength of the specimens decreases with the increase of defects, but meets the safety requirements; grouting defect rate ≥36%, the tensile strength of the specimens decreases with the increase of defects, and the safety does not meet the requirements. and decreases with the increase of defects, safety does not meet the requirements.

(3) for the yield strength of 405 ± 5MPa test specimens, grouting defect rate ≤ 28.75%, the defect rate on the specimen performance basically no effect on the test specimen, are broken steel pulling damage, but because the test specimen using reinforcing steel parent material strength is relatively low, the ultimate strength is close to 621MPa, the test specimen is easy to occur dangerous damage; grouting defect rate >28.75%, the test specimen generally does not meet the requirements of safety. The ductility is only half of the standard specimen, once the damage occurs the danger is great, and when the defect further increases, the deformation performance

and bearing capacity of the member will be further reduced. Therefore, the actual project should try to use slightly higher yield strength reinforcement to enhance the safety reserve capacity of the specimen, so as not to affect the strength of the slurry due to factors such as water-cement ratio or temperature, resulting in the specimen being in an unsafe condition.

(4) The specimen with yield strength of 445±5Mpa of reinforcement, due to the excessive strength of its own reinforcement material, is easy to produce slip damage even without defective specimens, although the grouting defect rate ≤30.5%, the safety performance of the specimen is guaranteed, but the performance of the material cannot be effectively played, which is easy to cause material waste.

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