Research on the Key Technology of Embedded Nylon Casing in Tunnel by Mining Method

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Abstract—The embedded nylon sleeve is a technology of embedding reinforced nylon sleeve in the concrete structure to install and fix the mechanical and electrical equipment system. This paper takes the first phase of Urumqi Metro Line 2 as an example, it introduces the design scheme of embedded nylon casing, and analyzes the stress state of the structure under the condition of embedded nylon casing and no embedded through numerical simulation. The theoretical calculation and pull-out test of nylon sleeve are carried out, It is concluded that the pull-out bearing capacity of the embedded nylon sleeve can reach 50kN, which can meet the requirements of later equipment installation. The successful application of this technology, It breaks through the technology of using expansion bolt to fix the equipment installation and reduces the impact of later installation on civil structure, Therefore, it is a great significance to promote the application in urban rail transit.

1. INTRODUCTION

Urban transit construction projects are surging in China in these years. In the common construction process, civil engineering projects come before equipment installation and furnishing. When the civil engineering project completes, the equipment installation team enters the scene to drill, plant and embed expansion bolts in reinforced concrete structures, install and fixate equipment and cables. This technique is universal in railway construction projects in China. As precision management of construction projects advances, more and more technical workers are exploring the reserving and embedding work in construction. If reserving and embedding work is performed for sites where equipment is to be installed in during civil engineering design and construction, it will not only improve the safety and durability of concrete structures, reduce construction noise and construction dust, but increase installation efficiency of electromechanical equipment, shorten the construction cycle and reduce the construction costs. At present, reserving and embedding techniques have seen wide adoption in developed countries; in China, the embedded chute technology has been used in the shield section of Line 9 in Shenzhen[1]. The development has made some progress, but there are still problems in the chute embedding technique and it is thus not promoted throughout the country. Liu Chuncheng[2] has studied mechanical and electrical reserving and embedding engineering in expressway tunnels; Liu Xin[3] has probed into the mechanical properties of embedded tunnels with shield tunnel segments and their impacts on structures. This paper draws on the experience of high-speed railway sleeper embedded nylon casings[4,5], and applies it to the metro mining
section through theoretical research and experimental verification to provide more favorable conditions for equipment installation.

2. DESIGN SCHEME OF THE EMBEDDED NYLON CASING (ENC)

2.1. Project introduction
The first phase of the Urumqi Metro Line 2 project is 11.8km in length, of which the primary support thickness is 250mm and the lining structure thickness is 300mm. As the stratum is corrosive, C45 high-performance concrete is used, and the rebar are HRB400 and HPB300. The standard section has a span of 5.68m and a structure height of 6.03m. Also, the thickness of the soil coverage is between 10.5m and 33m. The main stratum where the structure is located is mainly pebbles, which are dark gray with a thickness of $10 \sim 50m$. The composition of the pebbles is mostly rounded sandstone and limestone, whose roundness is good. The particle size is about 20% for $2 \sim 20mm$, 45% for $20 \sim 60mm$ and 15% for more than $60mm$. The rest is filled with miscellaneous sand gravel and silty clay, containing boulders locally, and the maximum particle size is greater than $110mm$. The physical and mechanical indexes of the stratum are shown in Table 1.

2.2. Location design of the embedded nylon casing
The equipment system distributed on the running tunnel includes evacuation platforms, overhead contact system (OCS), illumination, special leaky coaxial cables, communications, signals, civil leakage coaxial cables, fire protection and sewerage system.

The embedded nylon casing (ENC) is connected to the reinforced concrete structure, the cable support of which follows the traditional support to ensure the reliability of the structure. According to the operational conditions of the support and the professional requirements of the equipment, the

| Serial number | Layer | Age and origin | Density | Eigenvalue of Bearing Capacity of layers | Coefficient of earth pressure at rest | Coefficient of subgrade reaction | Shear test | Recommended value | Classification of soil | Rock Classification (revised) |
|---------------|-------|----------------|---------|----------------------------------------|-------------------------------------|---------------------------------|------------|-------------------|--------------------------|--------------------------------|
| 1-1           | Miscel laneous fill | Q\text{\textsuperscript{a}}\text{\textsuperscript{b}} | 1.89    | 0.60                                   | 0                                   | 17                              | Grade I normal soil | VI                |
| 4-4           | Silt | Q\text{\textsuperscript{a}}\text{\textsuperscript{b}} | 1.7     | 150                                     | 0.43                                | 19                              | 21                     | 20 18                  | Grade I normal soil | V                          |
| 4-9-1         | Roun d gravel | Q\text{\textsuperscript{a}}\text{\textsuperscript{b}} | 2.21    | Medi-um dense                           | 450                                 | 0.32                            | 65                     | 72 2 40                 | Grade I normal soil | V                          |
| 4-9-2         | Dens e | Q\text{\textsuperscript{a}}\text{\textsuperscript{b}} | 2.30    | Medi-um dense                           | 550                                 | 0.28                            | 28                     | 70 3 42                 | Grade III hard soil | V                          |
| 4-10-1        | Pebbl e | Q\text{\textsuperscript{a}}\text{\textsuperscript{b}} | 0.26    | 85                                      | 90                                  | 6                                | 44                     | Grade IV soft rock | V                          |
| 4-10-2        | Dens e | Q\text{\textsuperscript{a}}\text{\textsuperscript{b}} | 0.30    | 82                                      | 90                                  | 6                                | 44                     | Grade IV soft rock | V                          |
ENC is buried along the line longitudinally at a spacing of 1m and one casing at a time, taking the convenience of construction into comprehensive consideration. The vertical spacing of OCS support is required to be 4m, and two nylon casings per site. When the ENC is embedded in the circular direction, the independent mounted principle of each system shall be followed, and the installation and safety distance shall be met, as shown in Figure 1.

2.3. Force analysis of the lining structure

According to the load analysis of the installed equipment system, the maximum load is 3.9kN per linear meter of the evacuation platform, which is carried by two embedded bolts. Besides, the load of other embedded parts is less than 1kN. For the professional requirement of the equipment is that the point load is not less than 8kN, the designing load of the embedded part is checked with 8kN load to meet the installation requirement.

The lining structure is calculated with the finite element software MIDAS / Gen, and solid model (C3D8R) is selected for the concrete structure. To construct the model of NEC, a beam element model is adopted. The boundary conditions of whole structure are that the vertical axis of the circle is taken as the axis of symmetry, the upper section intersecting with the axis of symmetry is constrained horizontally, and the nonlinear springs is used in both horizontal and vertical directions at the lower section. (Horizontal coefficient of subgrade reaction is 85MPa/m; vertical coefficient of subgrade reaction is 90MPa/m). The parameters of depth, location and load of ENC are all input according to the actual situation, as shown in Figure 2.
The results are shown in Figure 3. When the nylon casings are embedded in the lining structure, the maximum tensile stress is 1.71N / mm² and the maximum compressive stress is 1.97N / mm². The comparison of the lining structure with or without the ENC is as follows:

The deformation of the lining structure without the ENC is 0.04% under the load, which is small. After the ENC being embedded, the deformation increases and does not exceed 0.06%.

The principle tensile stress of concrete at the location of the ENC is under the value of the allowable stress of concrete cracking. The maximum change of the principal tensile stress is less than 6% with NES or not.

After NES is set, the thicknesses of the section and protective layer of the structure in the original scheme are unchanged. Also, calculation of the bearing capacity and cracks still meet the design standards.

3. FORCE ANALYSIS OF THE NYLON CASING

3.1. Design details of the nylon casing
According to the load calculation of the cable rack, two types of casings of M12 (82.5mm in length) and M20 (100mm in length) are adopted, as shown in Figure 4. The outer convex rings are provided on the outside of the casing to increase the bond stress of the contact surface between concrete and casing, thereby improving the pull-out resistance. Among the structure, four M12 casings and five M20 casings are set with both height and widths being 3mm. The thread hole is reserved on the flank of the casing for the installation of the screw, and the wall thickness of the casing is 4mm.
3.2. Theoretical calculation of nylon sleeve

According to the load calculation of the cable rack, two types of casings of M12 (82.5mm in length) and M20 (100mm in length) are adopted, as shown in Figure 4. The outer convex rings are provided on the outside of the nylon sleeve.

Guo Xiangxi has analyzed the pulling force on the nylon casing of steel thread and sulphur cement anchorage bolts on the broad concrete. Based on that, two types of materials are selected when calculating: common nylon casing (PA6) and reinforced nylon casing (PA6 + G30), and the results of theoretical comparison are shown in Table 2~Table 4.

**TABLE 2. VALUE OF ULTIMATE TENSILE STRENGTH OF NYLON CASING**

| Type | Area of tensile section /mm² | PA6 tensile strength /MPa | PA6 ultimate tensile stress /kN | PA6+G30 tensile strength /MPa | PA6+G30 ultimate tensile stress /kN |
|------|-----------------------------|---------------------------|-------------------------------|-----------------------------|-----------------------------------|
| M12  | 201                         | 63                        | 12.6                          | 170                         | 34.17                             |
| M20  | 301                         | 63                        | 18.9                          | 170                         | 51.1                              |

**TABLE 3. VALUE OF ULTIMATE TENSILE STRENGTH OF OUTER CONVEX RING**

| Type | Shear area of single convex ring /mm² | Number of outer convex ring | Reduction coefficient of shear stress | PA6 tensile strength /MPa | PA6+G30 ultimate tensile stress /kN |
|------|--------------------------------------|-----------------------------|--------------------------------------|---------------------------|-----------------------------------|
| M12  | 282                                  | 4                           | 0.75                                 | 53                        | 144                               |
| M20  | 439                                  | 5                           | 0.75                                 | 104                       | 279                               |

**TABLE 4. VALUE OF ULTIMATE TENSILE STRENGTH OF INTERNAL THREAD**

| Type | Thread length /mm | Transformed area /mm² | Reduction coefficient of shear stress | PA6 tensile strength /MPa | PA6+G30 ultimate tensile stress /kN |
|------|-------------------|-----------------------|--------------------------------------|---------------------------|-----------------------------------|
| M12  | 30                | 734                   | 0.75                                 | 35                        | 94                                |
| M20  | 40                | 1630                  | 0.75                                 | 77                        | 208                               |

The results from the above calculations show that the ultimate tensile strength of M20 reinforced nylon casing is 51.1kN, which is much larger than the design value of 8kN and has definite safety stock. At the same time, it also meets the construction requirements and is preferred in the project. In addition, the shear strength of the internal thread and outer convex ring is more than 200kN, which could not affect the bearing capacity of the nylon casing.
3.3. Test
The microcomputer-controlled electronic universal mechanical tester (CMT5105) was selected for the test. The ultimate tensile strength test was performed on the test block embedded in the nylon casing, and the block was a 15 cm × 15 cm × 15 cm C40 concrete block, which had been cured for 9 days. There are two types of failure modes occurred on the block: cleavage cracking and Thread fracture, as shown in Figure 5.

![Figure 5. Failure of the reinforced nylon casing sample](image)

The cracking is mainly caused by concrete splitting for the cause that the material is plain concrete (4 test blocks). And, as the concrete is cured for 9 days, it is the initial setting strength, which is expected to be 70% of the final strength. Therefore, the ultimate tensile stress could be improved in practical application. In the test, the failure of one block is the crack of internal thread and the other could be crack of external thread. The nylon casing can be lengthened appropriately if the ultimate tensile stress need to be increased further.

| TABLE 5. STATISTICS OF ULTIMATE TENSILE STRENGTH OF THE BLOCKS |
|-------------------------------------------------------------|
| ![Graph](image)                                             |

Taking the blocks of M20 nylon casing as an example, it can be concluded that the values of ultimate tensile stress of the six blocks except the block No.5 are all above 50KN, which meets the requirements of bearing capacity from Table 5.

4. IMPLEMENTATION SCHEME OF THE NYLON CASING

4.1. Implementation scheme of the embedded construction
The work of the embedded construction is mainly to fix the nylon casing on the formwork, and then vibrate and pour along with the reinforced concrete. The nylon casing is provided with thread inside, and the casing can be fastened to the formwork by fixing the bolt, nut and washer, as shown in Figure 6. For the template trolley (or steel formwork), the most concise and efficient method is ① positioning and opening in the formwork -- ② centering welding and fixing of nut and hole -- ③ fastening of screw and the fixed nut -- ④ fastening of the nylon casing and screw. Gaskets could be added to the end of
the nylon casing to adjust the flatness of the casing and the surface according to the actual pouring conditions of the first set.

![Figure 6. Diagram of the nylon casing embedded on the formwork](image)

The embedment of the first section on site is shown in Figure 7. After being buried by the contractors, the companies of equipment system design and installation have conducted site investigation and pull-out tests. The pull-out resistance of the ENC is greater than 55kN, and the positioning is accurate. There is almost no residual concrete mortar in the casing, but there are few casings exceeding the structural surface for 2mm-5mm, which could be grinded and flattened to meet the requirements of installation equipment.

![Figure 7. Picture of the ENC on site](image)

For the fact that wood formwork is not as rigid as steel formwork, it is necessary to weld several iron plates around the nut. Each iron plate with three nail holes is fastened to the formwork to ensure the position of the nut. Then the screw is tightened with the nut. Apart from that, a serrated protrusion is set on the nylon casing to cooperate with the metric thread to prevent the casing from falling off when the concrete is vibrated.

### 4.2. Adjustment scheme of the evacuation platform support

The design working load of the evacuation platform is 4kpa, and the longitudinal spacing between supports is 1m. Besides, there is a certain adjustment space required for the design of the supports along with the plane and longitudinal slope of the tunnel. The setting deviation of the casings is 125 ~ 200mm, and the platform surface has an error of ±15mm from the theoretical value when being adjusted, as shown in Figure 8.
4.3. Adjustment scheme of the cable rack

According to the radiation distance of the tunnel cable, each rack is installed separated and the spacing between the embedded casings is 20cm (as shown in Figure 9). That leaving a long-round hole (L = 5cm) in the cable rack could handle the deviation of 5cm. At the same time, it can solve the large adjustment deviation with conversion parts.

(a) Theoretical reserved hole position; (b) Hole position up by 100; (c) Hole position down by 100;
1--Embedded nylon sleeve; 2--Adjustable cable support; 3--Adjustable bolt hole

Figure 9. Diagram of the cable rack (mm)

5. CONCLUSION

1) This paper analyzes the deformation before and after the ESC of the lining structure with mine tunneling method and concludes that the deformation of the structure is basically unchanged under external load. With the premise of constant section thickness and material properties, the bearing capacity and cracking check of the structure are meet the design standards well.

2) The theoretical ultimate value of pull-out resistance (M20 model) of the reinforced nylon casing, embedded in the lining structure with mine tunneling method, is 51kN, the value by laboratory test is greater than 50kN and that by on-site test is greater than 55kN, which are all greater than 8kN required for equipment installation. Therefore, the casing can be used for installation and electromechanical equipment systems, and has a certain safety stock.

3) By drilling, welding nuts and temporary plugs in the steel formwork, the problem of installing embedded casings on the trolley is solved. The design scheme adopting the equal spacing along the longitudinal direction of the tunnel also provides convenient foundation for construction.

4) This paper takes tunnel with mine tunneling method as an example to study the technology of ENC. It could also be applied in the discuss the pre-burying and pre-reserving technology of underground stations with cut and cover method. Meanwhile, the technology is also adopted in the subway for the first time, and problems in operation and maintenance need to be solved in the future.
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