Analysis of unqualified factors and evaluation methods of Thickness of reinforcement cover

Yan Yang
Transportation And Automobile Engineering College, PanZhiHua University, Panzhihua, SiChuan, 61700, China

Abstract. Thickness of reinforcement cover is an important index to measure the durability of structure. It is difficult to measure the thickness of steel bar protective layer and to control the quality of steel bar protective layer. From design, construction and testing evaluation, this paper puts forward the deviation of the definition of the thickness of steel bar protective layer, and analyzes the factors affecting the fabrication, installation and testing standards. The design optimization, construction control and quality evaluation criteria based on mathematical statistics method are put forward. Through a series of measurements to improve the thickness index of bridge reinforcement protection layer, a scientific and complete evaluation system is established, and the quality acceptance criteria and detection methods are unified. It has a certain guiding role in construction self-inspection and project acceptance.

1. Introduction
Thick ness of reinforcement cover in highway and bridge engineering is an important index to measure the durability of structural concrete, and it is also a technical difficulty and key component that bridge engineering is difficult to control in the construction of "quality engineering". The definition of concrete cover in National Standard for Design of Concrete Structures (GB50010-2010) refers to the calculation of concrete cover thickness at the outer edge of the outermost steel bars (including stirrups, structural bars, distributed bars, etc.) in structural members. At the same time, in order to satisfy the durability requirements of concrete structural members and the requirements of effective anchorage of stressed steel bars, the minimum thickness of protective layer of steel bars is specified in the standard. Therefore, reasonable thickness of steel bar protective layer can not only protect steel bar from corrosion, but also ensure that the bonding and anchoring function of steel bar. That is, it can play a role that the structure will not crack prematurely, leading to insufficient stress of steel bar, under the effect of water and carbon dioxide invasion, steel bar corrosion occurs.

At present, scholars mostly study the thickness of steel bar protective layer from the aspects of detection technology and construction technology. For example, aiming at the reasons of abnormal construction of steel bar protective layer thickness of circular pier and square pier of bridge, Hu Yuqing researched control measures to guide construction and improve the qualified rate of steel bar protective layer thickness[1]. Liu Zhao [2] used high frequency electromagnetic data analysis to provide a new high-precision technical means for evaluating the protective layer thickness of reinforced concrete lining structure. Zhu Muqing [3] discussed the key points in the process of solenoid valve testing and the evaluation of the qualified rate of test results. Sun Xinhai [4] elaborated how to ensure the operation accuracy and control the thickness of steel bar protection layer from two aspects of steel bar processing and installation of square pier columns. Deng Yuzhong [5] took large diameter punched cast-in-place pile as an example, analyzed the main influencing factors of
reinforced concrete protective layer of punched cast-in-place pile in construction technology, and put forward improvement measures. Deng Yuzhong [5] takes the large diameter punched cast-in-place pile as an example, and analyses that the reinforcement coagulation of punched cast-in-place pile in construction technology has not systematically analyzed the unqualified factors of reinforcement protective layer thickness from design, construction and detection, and has not comprehensively analyzed the index and durability of concrete structure, nor has it put forward the evaluation system of reinforcement protective layer thickness in the process of quality inspection and acceptance.

Although the national standard "Code for Design of Concrete Structures" (GB50010-2010) and highway industry standard "Standard for Quality Inspection and Evaluation of Highway Engineering" [7] (JTG F80/1 2017) have strict requirements on the thickness index of steel bar protective layer. But, there are few studies on the control of the thickness of steel bar protective layer caused by unqualified factors caused by design, construction and detection methods, and the current acceptance criteria for highway engineering have some limitations in evaluating the thickness of reinforced protective coat only on the basis of the qualified rate. They do not combine the thickness of reinforced protective coat with the durability of the structure, and lack scientific evaluation. Therefore, the acceptance standard has not proposed to the corresponding treatment measures for the components with low qualified rate. Based on the comprehensive analysis of the unqualified factors of the thickness of reinforced protective layer and the durability evaluation method of bridge structure, this paper puts forward the acceptance evaluation method of the thickness and quality of reinforced protective layer, which further improves the evaluation system.

2. Current Situation Analysis

The author's research team has carried out spot checking and testing on the newly-built and under-construction bridges since 2016 by using the steel bar protective layer thickness detector. The qualified rates of the steel bar protective layer thickness index of Panzhihua Bridge Project from 2016 to 2018 are 74.1%, 62.5% and 61.5%, respectively. The qualified rates are generally low. At the same time, the long-term monitoring of concrete carbonization depth of a deck arch bridge built in an industrial park in the 1980s was carried out. The results show that the concrete carbonization of different strength grades and positions is more seriously affected by the external environment, as shown in Table 1.

| Bridge location | Strength grade of concrete | Built for 1 year | Built for 3 years | Built for 10 years | Built for 20 years |
|----------------|---------------------------|------------------|------------------|-------------------|-------------------|
| Pier and abutment | C30                        | 5.2              | 8.9              | 13.4              | 17.7              |
| Arch ring       | C40                        | 4.1              | 7.1              | 10.2              | 15.2              |
| Arch upper column | C30                       | 4.6              | 8.1              | 12.7              | 17.2              |
| Coping         | C40                        | 4.3              | 7.9              | 11.5              | 18.1              |
| Hollow slab     | C40                        | 5.0              | 8.4              | 12.9              | 18.5              |
| Guardrail       | C25                        | 6.3              | 8.2              | 16.7              | 20.1              |

The data are interpolated by Matlab, and the results are shown in Figure 1. It can be clearly seen that the carbonation rate of concrete basically develops linearly with time, and the change rate of carbonation depth is closely related to the strength grade of concrete and the external environment of components. According to the development trend of carbonization depth, it is estimated that the thickness of reinforced protective layer of the bridge concrete can meet the service life of 70 years at most, and its durability index will not reach the design reference period of 100 years. If considering the use of the bridge under abnormal conditions, the influence of various cracks in reinforced concrete, the safety situation of the bridge structure is worrying. At present, the thickness of steel bar protective...
layer is facing the difficulty of quality control, low pass rate of spot inspection, which has a great impact on the durability of bridges.

![Figure 1. Carbonation Trend Chart of Bridge Concrete in 20 Years](image)

### 3. Unqualified factors of protective layer thickness

Based on the statistical analysis of a large number of test data on the thickness index of steel bar protective layer in highway and Bridge Engineering in this region, it is found that the main factors that affecting the thickness of steel bar protective layer are design, construction and detection methods. Engineers generally believe that the thickness of the protective layer of steel bar is the distance from the main reinforcement to the edge of the member. But the author thinks that the protective layer of steel bar is used to protect steel bar. Considering the durability of concrete carbonation, debonding and steel corrosion, the thickness of concrete protective layer should not be calculated from the outer edge of steel bar under longitudinal loading. Thus, the thickness of concrete protective layer should be calculated by the outer edge of the outer reinforcement which including stirrups, structural reinforcement and distributed reinforcement.

#### 3.1. Design factors

The insufficient design of the thickness of the protective layer of steel bars often results in the smaller design thickness. As a bridge prestressing box girder is in type II environment, the reinforcement structure of box girder is shown in Figure 2. The diameter of longitudinal main reinforcement is 16 mm, the diameter of lateral stirrups is 20 mm, and the diameter of structural connecting reinforcement between double-deck reinforcement is 12 mm. The net thickness of protective layer of reinforcement in web of box girder is calculated as follows:

![Figure 2. Structural drawing of reinforcing bar in web of box girder of a bridge](image)

Design Value - Main Reinforcement Diameter/2 - Stirrup Diameter - Stirrup Diameter = 65 mm - 16 mm/2 - 20 mm - 12 mm = 25 mm

According to the "Standard for Quality Inspection and Evaluation of Highway Engineering" (JTG F80/1-2017), the allowable deviation of the thickness of the protective layer of steel bars for box girders is (+5 mm), and the minimum extreme thickness of the protective layer should be 20 mm.
However, the minimum extreme thickness of protective layer in Class II environment in the design standard of Highway Bridge Regulation is 25 mm. Therefore, the insufficient design of steel cover thickness will affect the bond and anchorage performance, durability and fire resistance of the stressed steel bars.

3.2. Construction factors

(1) Reducing the size of steel bar skeleton
In order to facilitate the vertical formwork and concrete pouring, the construction unit often reduces the size of the steel bar skeleton. It is considered that the greater the thickness of the concrete protective layer, the better. It often happens in the construction of bridge pile foundation, pier column and box girder. This treatment scheme has little influence on the compressive members, but it is more harmful to the flexural members. The thickness of protective layer is too large, which changes the mechanical characteristic of the beams of bending members. On the contrary, it will increase the probability of concrete cracking. A large number of transverse cracks appear in serious beams that affects the durability and operation safety of bridges. As shown in Figure 3.

![Figure 3: The calculation sketch of normal section bearing capacity of flexural members with rectangular section](image)

Calculation of flexural capacity of normal section:

$$r_0 M_d \leq f_{cd} b x \left( h_0 - \frac{x}{2} \right) + f'_{sd} A_s' (h_0 - a_s') + (f'_{pd} - \sigma_p') A_p' (h_0 - a_p') \quad (1)$$

From formula 1, it can be seen that when the net distance as of the protective layer of steel bar is too large, the distance from the joint point of steel bar and prestressing steel bar in the tension zone to the edge a of the tension zone will increase. At this time, the effective height of section $h_0 = h - a$ will decrease, the bearing capacity of bending members will decrease, and cracking will occur at the edge of tension zone. Therefore, it is not advisable to reduce the section size of reinforced skeleton, especially in bending members.

(2) Not fixed firmly of reinforcement skeleton
Some prefabricated members are not standardized in the binding of steel bars. When the steel bars are installed, they lack certain stiffness that results in the deformation of the steel skeleton in concrete casting. As shown in Figure 4, the average thickness of the protective layer of 30 20-meter hollow slab beams is measured.

![Figure 4: Curve of thickness variation of steel bar protective layer before and after pouring of 20 m prefabricated hollow slab beam](image)
As can be seen from Figure 4, the reinforced skeleton has undergone obvious deformation before and after pouring, the thickness of reinforcement protection layer in the middle of the beam deforms greatly. The reason is that the reinforcement of hollow slab beam is generally small and easy to deform, the amount of reinforcement at both ends of the beam is relatively large, and the skeleton formed has good stiffness, basically no deformation.

(3) Improper setting of the number and size of reinforcement pads

Based on the definition of steel protective layer, it is clear that the net distance of the steel bar in the outer layer of the component is the same. But the actual construction unit still understands the net distance of the main reinforcement of the component, only pays attention to the net protective layer distance of the main reinforcement, ignoring the control of the net distance of the protective layer of some structural reinforcement in the outermost layer. Therefore, the number and size of reinforcement pads are too small to be set, which results in the defect of the thickness of the protective layer of the component. The more prominent performance is in the production and installation of pile foundation reinforcement, the correct installation method is shown in Figure 5.

Figure 5. Installation mode diagram of reinforcing cage cushion block for pile foundation

4. Validation of evaluation methods

At present, there are two methods to measure the thickness of the protective layer of steel bar. One is to measure the thickness of the protective layer of steel bar directly before pouring concrete, the other is to detect the thickness of the protective layer of steel bar using non-destructive testing after pouring concrete. The choice of detection methods mainly depends on the application stage and purpose of the two methods themselves. Both the construction code and the quality inspection and evaluation standard adopt the method of steel ruler measurement. It still belongs to the quality inspection in the construction stage before pouring concrete. A large number of test data show that, even though the thickness control of the protective layer of steel bar before construction can meet the requirements of specifications and design, due to the influence of construction factors, the results of non-destructive testing after pouring concrete through the protective layer of steel bar detector are generally low. The author believes that the test results after construction can not simply replace the test results before construction, and only the qualified rate can be used to judge whether the index meets the requirements. The results of pouring concrete should be analyzed by mathematical statistics, and the durability of bridge components should be evaluated scientifically by comprehensive construction factors.

Taking the thickness detection of steel bar protective layer of No.1 pier of ramp B of Sanduizi Bridge in Panzhihua City as an example, as shown in Table 2 below, the results of self-inspection by construction units, independent supervision sampling inspection and quality supervision organization sampling inspection are quite different, and the difference of the three qualified rates is 17%.

Table 2. Summary of data for measuring the thickness of steel bar protective layer of pier No.1 on ramp B of Sanduizi Bridge

| Detection party | Test data | Qualification rate (%) | Location of survey area | Test method       |
|-----------------|-----------|------------------------|-------------------------|-------------------|
| construction unit | 40, 41, 46, 45, 41, 48, 50, 31, 35, 51, 34, 32, 47, 48, 39, 47, 40, 30, 96 | 2m from the ground | Steel gauge before pouring |
As can be seen from Table 2, the deviation between different detection methods and different testing personnel results is large. If we use the testing results of poured instruments, it will lead to the inconsistency of the testing standards and the failure of the qualified rate to meet the required results. In order to evaluate the index better, the data of thickness measurement of steel bar protective layer after pouring should be analyzed and processed.

The author suggests that in addition to calculating the qualified rate of the thickness of the steel bar protective layer of the component as the basis for the acceptance of the work, the durability of the structure should be assessed in accordance with the "Specification for Testing and Assessing the Bearing Capacity of Highway Bridges", and the corresponding treatment measures should be put forward more scientifically.

According to the Specification for Testing and Assessing the Bearing Capacity of Highway Bridges [6], the data collected by the quality supervision organization in Table 2 are calculated based on the evaluation methods of Formula 2, 3 and 4, and validated against Table 3 and 4:

\[
D_{n e} = \frac{\sum_{i=1}^{n} b_{ni}}{n} \quad (2)
\]

In the formula 2: \(D_{n e}\) - the measured thickness of the protective layer of steel bar is accurate to 0.1 mm.

\(n\) - Measuring points of components or parts.

The eigenvalue \(D_{n e}\) of the thickness of the protective layer of steel bars for testing components or parts is calculated according to the following formula 3.

\[
D_{ne} = D_{n} - K_{p} S_{D} \quad (3)
\]

In the formula 3: \(SD\) - standard deviation of measured thickness of steel bar protective layer, accurate to 0.1mm

\[
S_{D} = \sqrt{\frac{\sum_{i=1}^{n}(D_{ni})^2 - n(D_{n})^2}{n-1}} \quad (4)
\]

\(K_{p}\) - judgment coefficient, according to table 3.

Table 3. Decision Coefficient \(K_{p}\) Value Table

| \(N\)  | \(10\sim15\) | \(16\sim24\) | \(\geq25\) |
|-------|-------------|-------------|------------|
| \(K_{p}\) | 1.695       | 1.645       | 1.595      |

According to the ratio of the characteristic value \(D_{n e}\) to the design value \(D_{nd}\) of the protective layer thickness of the steel bar in the testing component or part. The evaluation scale of the protective layer thickness of the steel bar should be determined according to the rules of the table 4.

Table 4. Evaluation Scale of Reinforcement Protective Layer

| \(D_{n e}/D_{nd}\) | Effect on Durability of Structural Reinforcement Bars | Rating scale | Treatment countermeasures |
|-------------------|---------------------------------------------------|--------------|---------------------------|
| \(\geq0.95\)      | The effect is not significant.                    | 1            | It can't be handled       |
| \((0.85, 0.95)\)  | Mild impact                                       | 2            | It can't be handled       |
According to the mathematical statistics method in the formula, the average thickness $D_{n} = 44.375 \text{mm}$, standard deviation $SD = 7.2879$, and the judgment coefficient is $1.645$. Based on the above countermeasures, the eigenvalue $D_{ne} = 32.39$ of the protective layer thickness of steel bars is obtained. Then, the $D_{ne}/D_{nd} = 32.39/40 = 0.81$ is deduced. Based on Table 4, the influence evaluation scale of structural steel durability is 3 degrees, which can not be handled, but should be followed up.

Therefore, it can be shown that the qualified rate of component sampling inspection is only 79%, which does not reach the qualified rate of more than 95% of the quality inspection evaluation. It should be reworked for the unqualified products. However, according to the "Rules for Testing and Evaluating the Bearing Capacity of Highway Bridges" evaluation, the durability of the structural components can meet the requirements of use, and can not be handled.

5. Conclusion

Through the analysis of the unqualified factors of the steel protective layer thickness, we should strengthen the understanding of the index of the steel protective layer thickness. The index can be improved by the following aspects.

1. For some large bridge structures, the design value of the thickness of the protective layer can be increased appropriately. At the same time, the durability of the members can be improved by adding the crack-proof steel mesh at the outermost layer of the structural members. In some high and large section steel bar structures, some stiff skeletons are added to improve the stiffness of the steel bar skeleton.

2. Strict quality control in installation process of reinforcing bar skeleton in construction, setting up pads and steel bar binding according to requirements, and replacing wood mould with steel mould to improve the stiffness of internal mould to ensure that the steel bar in pouring is not deformed.

3. Unifying quality acceptance criteria and detection methods. In addition to calculating single-point qualification rate to judge the control effect of protective layer thickness, it is more important to determine the durability impact of the structure. In practical work, the qualified rate of steel ruler measurement should be taken as the evaluation standard for the manufacture, installation and quality inspection of reinforcing bars, and the quality evaluation should be carried out according to the "Quality Inspection and Assessment Standard for Highway Engineering". When concrete is poured, the quality acceptance of the components should be based on the qualified rate of the steel bar inspector, and the durability of the components should be evaluated in combination with the "Specification for Testing and Assessing the Bearing Capacity of Highway Bridges".

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