Preliminary study on the minimum reinforcement ratio of RC members in China, America, and Korea

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Abstract. In this paper, the minimum reinforcement ratio of reinforced concrete members, the minimum reinforcement area of the T-section, and the selection of reinforcement ratio when the minimum reinforcement ratio is not satisfied are compared and analyzed. The selection of minimum reinforcement ratio was explored through an example. The results show that the values of minimum reinforcement ratio in Chinese code are low, while those in other countries are close.

1. Introduction
In recent years, the problem of the minimum reinforcement ratio of reinforced concrete has attracted more and more attention of Chinese and foreign scholars[1-4]. There are many complicated reasons and uncertain control factors that have been perplexing the determination of reinforcement ratio standard. In practical engineering, there are lots of load-bearing bars of RC (reinforced concrete) members according to constructional reinforcement (minimum reinforcement ratio). Thus, it is of great significance to study the minimum reinforcement ratio for reducing the project cost and improving the economic and technical value of the project.

At present, there is no unified standard for the minimum reinforcement ratio of RC members in the world[5]. Different countries determine the minimum reinforcement ratio of reinforced concrete members according to different standards. The minimum reinforcement ratio in the codes of the United States and New Zealand is related to the yield strength of the steel bar. The minimum reinforcement ratio in China is based on the Soviet code. For instance, the minimum reinforcement ratio of RC flexural member is only related to its yield strength and decreases with the increase of the yield strength of reinforcement in ACI CODE 318-77, ACI CODE 318-83 and New Zealand's code in 1982. By contrast to the Soviet CHNNII2-1-75 specification and CHNII2.03.01-84 specification, the minimum reinforcement ratio is constant[6].

Too little reinforcement will lead to the formation of RC members with less reinforcement, and it is prone to brittle failure under external load[7]. This is a very dangerous situation in engineering. It is well known that only the engineering components with appropriate reinforcement can give full play to the ductility of the materials and improve the engineering reliability. Because the minimum reinforcement ratio is between the critical value of the less reinforced member and the properly reinforced member, its value plays an important role in the discrimination of the properties of concrete members.

The calculation and value of the minimum reinforcement ratio in foreign countries are different from those in China. This paper explores the different calculation and value characteristics of the minimum reinforcement ratio in China, Korea, and the United States to provide a reference for engineers.
2. Comparison of minimum reinforcement ratio among China, Korea, and the United States

China: The old version code (GBJ10-89): \( \rho_{min} = 35f_t/f_y \). Meanwhile, the concrete strength grade below \( C35 \) \( \rho_{min} = 0.15\% \), on the contrary \( \rho_{min} = 0.2\% \). Code (GB50010-2010): Take the bigger one between \( \rho_{min} = 45f_t/f_y \) and 0.2% in flexural members. (\( f_t \)-the tensile strength of concrete, \( f_y \)-tensile strength of steel)

Korea: CODE KS D 3504 \( \rho_{min} = 0.25\sqrt{f_c}/f_y \geq 1.4/f_y \) (\( f_c \)-the compressive strength of concrete)

United States: ACI (American Concrete Institute) CODE 318-05: \( \rho_{min} = 3\sqrt{f_c}/f_y \geq 200/f_y \). Additional restriction 200/\( f_y \) is consistent with the minimum reinforcement ratio of 0.005 that the bearing capacity of ordinary materials should meet in early US code. For instance, concrete strength grade \( C30 \), load-bearing bar HPB235, china code (GBJ10-89), \( \rho_{min} = 0.238\% \), code (GB50010-2010) \( \rho_{min} = 0.31\% \), Korea \( \rho_{min} = 0.53\% \), United States \( \rho_{min} = 0.5838\% \). From the above, we know that the value of the minimum reinforcement ratio in Korea and the United States is greater than that in China's current code.

3. Comparison and analysis of minimum reinforcement area of tensile reinforcement in T-section flexural members between China, Korea, and the United States

For the case of T-section flexural members, China's "Code for Design of Concrete Structures" (GB50010-2010) stipulates the minimum reinforcement ratio of the load-bearing bar. The code points out that the reinforcement ratio of tensile reinforcement on one side of flexural member and large eccentric tensile member shall be calculated by the cross-sectional area \( (b'_f - b)h'_f \) that total cross-section area deduction of compression flange area. This indicates that the calculated area of T-section flexural members in the code is consistent with that of other types of flexural members when calculating the minimum reinforcement ratio. This is the same as Korea's minimum reinforcement ratio for T-section flexural members. However, the American CODE is different. The formula for the minimum reinforcement area of the T-type tensile member in ACI Code 318-95 is

\[
A_{s\text{,min}} = \frac{6\sqrt{f_c}}{f_y} b_w d
\]  

(1.a)

The minimum reinforcement area of a general tensile member greater than that specified in ACI Code 318-95 is

\[
A_{s\text{,min}} = \frac{3\sqrt{f_c}}{f_y} b_w d
\]  

(1.b)

The above indicates that the minimum reinforcement ratio of T-section flexural members in the ACI Code is higher than that of other flexural types. ACI Code 318-05 stipulates that the minimum tensile reinforcement area of a T-type member is greater than or equal to the minimum tensile reinforcement area of a general tensile member, where \( b_w \) is replaced by 2\( b_w \) or the lesser value of flange length. This is where the new American Code differs from the old one.

4. Comparison and analysis of Chinese and Korean codes when large components don’t meet the minimum reinforcement ratio

In China's engineering construction, large components are allowed to fail to meet the minimum reinforcement ratio, but it is required to be controlled within a certain range. When large components do not meet the minimum reinforcement ratio, Korea requires that the reinforcement ratio be increased by 1/3 based on the calculated reinforcement ratio. Then compared them to the original value and take the smaller one.

4.1. Examples

A simple beam is loaded with a bending moment of 100KN-m and a rectangular beam with section \( b\times h=500\text{mm}\times700\text{mm} \). The environment category is first class.
Take $f_c = 14.3N/mm^2$, $f_y = 1.43N/mm^2$, $f_y = 300N/mm^2$, $\alpha_1 = 1.0$, $\beta_1 = 0.8$, $\xi_b = 0.55$, cover $a = 35mm$, $h_0 = (700 - 35)mm = 665mm$.

Section resistance moment coefficient $\alpha_s$ is

$$\alpha_s = \frac{M}{\alpha_s f_y h_0^2} = \frac{100 \times 10^4}{1.0 \times 14.3 \times 500 \times 665^2} = 0.032 \quad (2)$$

The relative depth of compressive area $\xi$ is

$$\xi = 1 - \sqrt{1 - 2\alpha_s} = 0.033 < \xi_b = 0.55 \quad (3)$$

$$\gamma_s = 0.5 \left(1 + \sqrt{1 - 2\alpha_s}\right) = 0.984 \quad (4)$$

Reinforcement area $A_s$ is

$$A_s = \frac{M}{f_y, h_0} = \frac{100 \times 10^4}{300 \times 0.984 \times 665} = 509.4mm^2 \quad (5)$$

$$\rho = \frac{A_s}{b \times h} = 0.146% < \rho_{\text{min}} = 45 \frac{f_c}{f_y} = 0.215% \quad (6)$$

Then the reinforcement ratio of the beam is less than the minimum reinforcement ratio. In the face of this situation, domestic and foreign treatment methods are different.

The Chinese way: when $\rho < \rho_{\text{min}}$, the minimum reinforcement ratio $\rho_{\text{min}}$ is usually used.

The Korean way: when $\rho < \rho_{\text{min}}$, judge $1.33\rho = 0.194% < \rho_{\text{min}}$, take $1.33\rho$.

5. Conclusion

① From the above discussion, it seems that the minimum reinforcement ratio of the new version of China's code is improved to a certain extent compared with the old version. However, compared with the standard of developed countries, the minimum reinforcement ratio is still low. In contrast, the value of the minimum reinforcement ratio in the Chinese code is relatively conservative and should be further discussed.

② The minimum reinforcement area of T-shaped members in the Chinese code is the same as that in the Korean code. But the value is different from that of the American ACI standard. The old version of the ACI specification was slightly more conservative than the new one. The minimum reinforcement area of T-type members in ACI is larger than that in Chinese one.

③ When small components do not meet the minimum reinforcement ratio, take the minimum reinforcement ratio. China and Korea agree on this. But the situation is different for large components. The Chinese code allows large components to fail to meet the minimum reinforcement ratio within a
certain range. However, the Korean standard stipulates that when the minimum reinforcement ratio is not met, it should be increased by 1/3 based on the original reinforcement ratio. The results were compared with the minimum reinforcement ratio and the smaller value was chosen.

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