COMPARISON OF SAFETY FACTORS AMONG MAJOR DESIGN CODES ADOPTING THE PARTIAL FACTOR DESIGN METHOD

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1. Introduction

Recently, the partial factor design method was adopted in Japanese code: *Specification for Highway Bridges*[1]. It is also widely used in major codes such as Chinese code: *Code for Design of Steel Structure*[2], American code: *Specification for Structural Steel Buildings*[3], and Eurocode 3: *Design of Steel Structure*[4]. However, the provisions for the calculation of safety factors in those codes are different. In this study, their safety factors are calculated and compared. The results will provide a reference for the scholars and revision of codes.

2. The partial factor design method

The Partial Factor Design is a scheme of designing structures and structural components which is different from the allowable stress design. It is on the theoretical basis of limit state design and performed by the partial factor format on the both side of the action and resistance. Design according to the provisions by the Partial Factor Design Method satisfies the requirement when the design value of resistance equals or exceeds the action based on the load combinations.

2.1 Design in the codes studied

For the ultimate limit design, it shall be performed in accordance with equation (1):

$$S \leq R \tag{1}$$

Where, S is the action using load combinations, R is the structural resistance.

In Japanese code, design for limit state condition 3 shall be performed as follows:

$$\sum S_i(\gamma_{pi}\gamma_{qi}P_i) \leq \xi_1\xi_2\Phi_{RU}R_U \tag{2}$$

Where, S_i and R_U are the action and structural resistance, respectively; γ_{pi} is load combined factor, γ_{qi} is load partial factor, ξ_1 is the investigation and analysis factor, ξ_2 is the member and structure partial factor, Φ_{RU} is the resistance factor.

In Chinese code, design shall be performed as follows:

$$\gamma_0\left(\gamma_G S_G + \gamma_{Q_1}S_{Q_1} + \sum_{i=2}^{n}\gamma_{Q_i}\psi_{C_i}S_{Q_i}\right) \leq R(\gamma_R, f_k, a_k) \tag{3}$$

Where, S_G and S_{Qi} are the dead load and variable load, respectively; γ_0 is the structural importance factor, γ_G is the permanent load partial factor, γ_Q is variable load partial factor, ψ_{Ci} is the load combination factor, γ_R is the resistance partial factor, a_k is the characteristic value of parameter.

In American code, design shall be performed as follows:

$$\sum \gamma_i Q_i \leq \Phi R_n \tag{4}$$

Where, γ_i is load partial factor, Q_i is force effect, Φ is resistance factor, R_n is structural resistance.

In European code, design shall be performed as follows:

$$\gamma_G G_k + \gamma_Q Q_k + \sum_{i=2}^{n}\gamma_{Q_i}\psi_i Q_{k_i} \leq \frac{R_k}{\gamma_M} \tag{5}$$

Where, G_k is the permanent load, Q_{ki} is the variable load, γ_G is the permanent load partial factor, γ_Q is the variable load partial factor, ψ_i is the load combined factor, γ_M is the resistance partial factor.

2.2 Safety factor

Considering that the design theory and the formula format in the codes are similar, the safety factors can be formulated as a unified format consisting of load and resistance partial factor by using the formula listed above. In this study, only dead and one live loads are considered for simplicity. Therefore, the safety factor can be formulated as follows:

$$S = \gamma_0(\gamma_D D + \gamma_L L) = K_s(D + L) \leq \frac{R_k}{\gamma_R} \tag{6}$$

$$K_s = \gamma_0\frac{\gamma_D + \rho_D\gamma_L}{1 + \rho_D} \tag{7}$$

$$\rho_D = \frac{L}{D} \tag{8}$$

$$(D + L) \leq \frac{R_k}{K} \tag{9}$$

$$K = \gamma_R K_s = \gamma_R\gamma_0\frac{\gamma_D + \rho_D\gamma_L}{1 + \rho_D} \tag{10}$$

Where, D is dead load, L is live load, ρ_D is the ratio of live load to dead load, γ_R is resistance factor, K is the safety factor.

The partial factors according to the codes are listed in Table.1. In China, two kinds of structural importance factor are considered. The level 1 and level 2 are used in the structure with design working life of 100 years and 50 years, respectively. The resistance factor γ_R=1.11 correspond to steel Q345 whose nominal strength is 345N/mm^2. The safety factors according to the codes can be formulated as follows:

$$K_{Japan} = 1.307\frac{1.05 + 1.25\rho_D}{1 + \rho_D} \tag{11a}$$

$$K_{China\ Level\ 1} = 1.221\frac{1.2 + 1.4\rho_D}{1 + \rho_D} \tag{11b}$$

$$K_{China\ Level\ 2} = 1.11\frac{1.2 + 1.4\rho_D}{1 + \rho_D} \tag{11c}$$

$$K_{America} = 1.11\frac{1.2 + 1.6\rho_D}{1 + \rho_D} \tag{11d}$$

$$K_{Europe} = \frac{1.35 + 1.5\rho_D}{1 + \rho_D} \tag{11e}$$

To investigate the difference on safety factor between Japanese and other codes, Equation (12) shall be used.

$$K_d = \frac{K_i - K_{Japan}}{K_{Japan}} \tag{12}$$

Where, K_d is the difference of safety factor between Japanese and other codes.

3. Comparison of safety factors

The relationship between the ratio of live load to dead load and the safety factor is plotted in Fig.1. The figure shows that the safety factor increases as the ratio of live load to dead load increases from 0.1 to 5. When the ratio of live load to dead load is less than 2, the safety factor based on China level 1 is larger than those in other codes. When the ratio of live load to dead load varies from 2 to 5, the safety factor based on the American code is the larger than others. The safety factor based on European code is the lowest among the codes.

Fig.2 and Table.2 show the difference on the safety factor between Japanese code and others. It can be seen that the safety factor in Japanese code is lower than that of China level 1 and American code at most 6.5% and 7.0%, respectively. In the range of ratio of live load to dead load from 0.1 to 5, the safety factor in Japanese code is larger than that of China level 2 and European code at most 4.6% and 7.2%, respectively.

4. Conclusion

Main conclusions of this study can be summarized as follows.

(1)When the ratio of live load to dead load is less than 2, design based on China level 1 provides the highest safety factor corresponding to 6.5% more than that of Japanese code.

(2) When the ratio of live load to dead load varies from 2 to 5, design based on American code provides the highest safety factor corresponding to 7.0% more than that of Japanese code, while European code provides low safety factor corresponding to 7.2% less than that of Japanese code.

References

1) Japan Road Association, Specifications for Highway Bridges, Part II Steel Bridges and Members, Japan, 2017.
2) GB 50017-2003, Code for Design of Steel Structures, China, 2003.
3) AISC, ANSI/AISC 360-16, Specification for Structural Steel Buildings, AISC, Chicago, 2016
4) EN1993-1-1. Eurocode 3: Design of steel structure – Part 1-1: General rules and rules for buildings, 2005.

Table 1 Partial factors in multinational codes

Country	Partial factors γ_0	γ_D	γ_L	γ_R
Japan	1.0	1.05	1.25	1.307
China Level 1	1.1	1.2	1.4	1.11
China Level 2	1.0	1.2	1.4	1.11
America	1.0	1.2	1.6	1.11
Europe	1.0	1.35	1.5	1.0

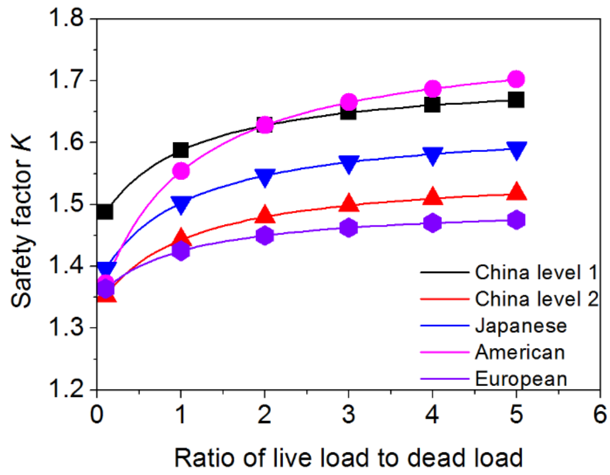

Fig.1 Comparison of safety factor

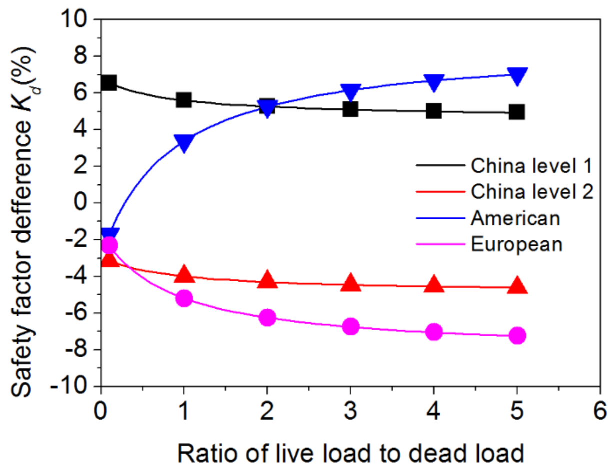

Fig.2 Difference of safety factor

Table 2 Difference of satefy factor(%)

Country	Ratio of live load to dead load 0.1	1	2	3	4	5
China Level 1	6.5	5.6	5.3	5.1	5.0	4.9
China Level 2	-3.1	-4.0	-4.3	-4.5	-4.5	-4.6
America	-1.7	3.4	5.3	6.2	6.7	7.0
Europe	-2.3	-5.2	-6.2	-6.8	-7.0	-7.2