Article

Research on Reliability of Structural Members Subjected to Snow or Wind Load for Design Working Life of 100 Years in China

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Abstract: Various national and international standards for building structures and other common structures specify a design working life of 50 years. Therefore, the statistical parameters of loads and the design expressions in current design codes are also based on a design reference period of 50 years. When the design working life is not 50 years, the variable load adjustment factor for the design working life needs to be considered. The corresponding load adjustment factors of office building live load, residential live load, snow load, and wind load are given in (GB50153-2008), (GB50009-2012), and (GB50068-2018) with different design working life (5, 10, 20, 30, 75 and 100 years), respectively. However, the recommended values presented in these documents are inconsistent and no provisions are found in those specifications for the selection of load design parameters in the design expression, which will result in designers having doubts in choosing design parameters, especially for building structures designed for a working life of 100 years. Using different design parameters in the design expression, the implied reliability level of the members with a design working life of 100 years was clarified in the paper. Furthermore, guidance for the specification in actual design is provided. For structural members designed for working life of 100 years, 14 representative structural members were selected to calculate their partial factors of resistance. Considering two simple combinations (dead load and wind load, dead load and snow load) and common load effect ratios, the reliability analysis of each member are carried out according to the load partial factors in China’s old and new codes. The study indicated that the structural importance coefficient of 1.1 needs to be taken in the design expression to increase all the load effects on the structural members designed for 100 years. The basic wind pressure and snow pressure should be taken with a return period of 100 years and the variable load adjustment factor for the design working life should not be considered.

Keywords: design working life; snow load; wind load; load parameters; load adjustment factors

1. Introduction

The design working life is understood as an assumed period of time for which a structure is to be used for its intended purpose without any major repair being necessary. Indicative values of design working life (10, 10–25, 15–30, 50 and 100 years for different types of new structures) are given in EN 1990:2002 [1] (Table 1). The reference period is understood as a chosen period of time used as a basis for statistically assessing the time variant basic random variables, and the corresponding probability of failure. The concept of reference period is therefore fundamentally different from the concept of design working life. Confusion is often caused when the difference between these two concepts is not recognized [2]. Various national and international standards for building structures and other common structures specify a design working life of 50 years. The reference
period of 50 years and the related target reliability values have been used in the derivation of the partial factors [3], and the statistical parameters of loads in various national and international standards for building structures are all based on a design reference period of 50 years [1,3,4]. When the design working life differs from the design reference period of 50 years, the relationship between the optimum target reliability levels of temporary structures, failure consequences, the design working life, and the discount rate has been clarified in [5]. The simple relations of the target reliability as a function of the reference period considered are provided in [6]. The reference design values and partial factors of basic variables are studied in [7]. The partial factors under the design reference period of 60 years are obtained in [8]. The durability model and the statistical properties of the model parameters of concrete structures for service life of 120 years are studied in [9]. The Chinese standards indicate that the variable load adjustment factor for the design working life needs to be considered in the structural design expressions if the design working life differs from the design reference period of 50 years [4,10,11].

Table 1. Indicative design working life.

| Design Working Life Category | Indicative Design Working Life (Years) | Examples                                      |
|------------------------------|---------------------------------------|------------------------------------------------|
| 1                            | 10                                    | Temporary structures                           |
| 2                            | 10–25                                 | Replaceable structural parts, e.g., gantry girders, bearings |
| 3                            | 10–30                                 | Agricultural and similar structures           |
| 4                            | 50                                    | Building structures and other common structures |
| 5                            | 100                                   | Memorial building structures, bridges, and other civil engineering structures |

The specific values of the variable load adjustment factors are given in Chinese structural reliability standards (GB50153-2008) [10] and (GB50068-2018) [11], and it is not stressed that these values are not suitable for wind load or snow load. The specific values of variable load adjustment factor in Chinese load code (GB50009-2012) [4] are quoted from (GB50153-2008) [10]. Meanwhile, the expressions and the calculated values of the variable load adjustment factors for live loads, wind load, and snow load under different design working lives, are shown in (GB50009-2012) [4]. Although the code (GB50009-2012) [4] gives the calculated values of the adjustment factors for wind and snow loads, it states that the variable load adjustment factors are only applicable to floor and roof live loads. The inconsistency of these provisions in the specifications will lead to doubts among designers. Furthermore, there are no clear specifications on the selection of the corresponding design parameters in design expressions in above-mentioned documents.

The Chinese load code (GB50009-2012) [4] lists wind pressure and snow pressure values of return periods of 10, 50, and 100 years for all cities across China. Take Xi’an as an example: if the return period is 50 years, the basic wind pressure and basic snow pressure are taken to be 0.35 kN/m$^2$ and 0.25 kN/m$^2$, respectively; and if the return period is 100 years, the basic wind pressure and basic snow pressure are taken to be 0.4 kN/m$^2$ and 0.3 kN/m$^2$, respectively. For structural members designed for a working life of 100 years, the structural importance coefficient of 1.1 is taken in the design expression to increase all the load effects on the structural members [12]. In this case, should the basic wind pressure and snow pressure values be taken with the return periods of 50 years or 100 years? If the return period of 50 years is used, what is the use of the wind and snow pressure values with a return period of 100 years in the code? If taken as the return period of 100 years, do we still need to consider the load adjustment factor? This issue was raised in the literature as early as 2014 [13], but these issues are not clearly explained in the specification and there is no relevant literature on the subject. Thus, it is not clear how load parameters and load adjustment factors should be selected for a given design working life different from 50 years (say 100 years), which will lead to the trouble in the actual design process. For example, when selecting load parameters for a building structure designed for a working life of 100 years, literature [14] adopts basic wind pressure and basic snow pressure with a
return period of 100 years and considers the variable load adjustment factor for the design working life, while literature does not consider the load adjustment factor for the design working life [15,16].

Designing structures involves ensuring an adequate level of safety. The load and resistance factor design (LRFD) method has been widely used in building design. This is done by applying the appropriate set of partial factors for resistance and loads and the corresponding design parameters in design expressions. Reliability-based structural analysis of buildings and constructions made from conventional materials such as masonry, steel or concrete is commonly available in literatures. The theoretical background and basic principles for the reliability analysis and calculations can be found in [17–23], which already has been applied in several studies [24–29]. Peng et al. [24] studied the reliability of long span structure under wind and snow loading, and their results indicated that the equivalent extreme-value of element stress of the structure subjected to the dead load and the 100-year return period of wind and snow loads is far less than the allowable value, and the long-span building structure is therefore safe enough. The probability of structural failure by use of design standards for assessing marine operations is studied using structural reliability analyses to shed light on the implicit reliability levels of such standards. Natskår Asle et al. [25] presented a structural reliability approach to accommodate the uncertainties affecting design checks. By applying the appropriate set of partial factor for strength and partial factors for actions in accordance with the recommendations of the Eurocodes. Joanna Ziȩba et al. [26] presents an analysis of the reliability of a compressive masonry structure on the example of a wall fragment made of silicate blocks, and the relationship between partial factors applied to actions in various configurations and factors for the compressive strength of masonry was investigated. Considering samples generated by Latin Hypercube Sampling (LHS), the appropriate target reliability levels based on simulations of different scaffold design situations for facade scaffolds were proposed, based on which partial factors are determined [27]. The appropriate probability distribution for annual maximum ground snow loads are studied in detail based on the samples of snow loads on the ground in [28]. Then, the reliability of members of steel roof structures subjected to snow load at four representative sites in China is investigated, and it is found that the probability distribution function and parameter estimation method for ground snow loads have a great influence on reliability assessment results. Zhang et al. [29] investigated the resistance uncertainty of the membrane material, proposed partial factors for the dimensioning of membrane structures and evaluated the obtained reliability index. For USL the membrane strength was considered. Zhang et al. used three different reliability analysis methods, the central point method [30], the Rackwitz-Fiessler method [31] and the response surface method [32] in combination with Monte Carlo simulations [33]. It was observed that the calculated reliability indexes for all cases meet the specified target reliability index from the unified standard of reliability design of engineering structures of China [10]. Because there does not yet exist a unified design approach for membrane structures as is available for conventional buildings. In [34], the partial factors for prestress, snow load and wind uplift load are calibrated, for the design of a 6 m by 6 m hyper-membrane structure. It can be stated that there is a need to adjust the common calibration methods to the application to tensile membrane structures.

The discussed article applied reliability analysis methods to structural members in order to determine the design parameters of the snow load and wind load in the design expressions of the members designed for working life of 100 years and to provide guidance for the specification in actual design. For structural members designed for working life of 100 years, 14 representative structural members were selected to calculate their partial factors of resistance. Considering two simple combinations (dead load and wind load, dead load and snow load) and common load effect ratios, the reliability analysis of each member are carried out according to the load partial factor in China’s old code (GB50153-2008) [10] and new code (GB50068-2018) [11]. The research can clarify the reliability levels implied by
using different design parameters and eliminate the doubts of designers, which can better meet the needs of actual design.

2. Partial Factors and Related Statistical Parameters

2.1. Partial Factors for Loads

The combination of loads controlled by the dead load has been cancelled in Chinese structural reliability standard (GB50068-2018) [11] and then the partial factor for dead loads changes from $\gamma_G = 1.2$ to $\gamma_G = 1.3$, the partial factor for variable loads changes from $\gamma_Q = 1.4$ to $\gamma_Q = 1.5$. Therefore, there is only one basic combination of load effect $(1.3S_G + 1.5S_Q)$ in current design. The partial factors for loads in national and international documents are listed in Table 2.

Table 2. Partial factors for loads in national and international documents.

| Country                  | Partial Factor for Dead Load | Partial Factor for Variable Loads |
|--------------------------|-----------------------------|----------------------------------|
| China codes (before adjustment) | 1.2(1.35)                   | 1.4                              |
| China codes (after adjustment)     | 1.3                         | 1.5                              |
| American codes            | 1.2(1.4)                    | 1.6                              |
| UK codes                  | 1.4                         | 1.6                              |
| Europe codes              | 1.35                        | 1.5                              |
| International codes       | 1.4                         | 1.6                              |

2.2. Statistical Parameters for Loads

Loads shall be classified by their variation in time as dead load and variable load [17,18,35,36]. The dead load is treated as a normal distribution with a variable coefficient 0.074 and a coefficient of mean value 1.06.

Probability distribution of the maximum snow and wind load in the design working life which is given by:

$$F_T(x) = [F(x)]^T$$

where T is the design working life of structural members, which is 100 years in this study. $F(x)$ is the cumulative distribution function for the annual maximum variable loads. $F_T(x)$ is the cumulative distribution function of the maximum variable loads in the design working life.

A Gumbel distribution is adopted for variable loads and its distribution function is [19,37]:

$$F(x) = \exp\{- \exp[-\alpha(x-u)]\}$$

where $\alpha (\alpha > 0)$ is the scale parameter of the distribution and $u(-\infty < u < +\infty)$ is the location parameter of the distribution. The mean value and standard deviation of the variable loads are:

$$\mu_X = u + \frac{C}{\alpha} \approx u + \frac{0.5772}{\alpha}$$

$$\sigma_X = \frac{\pi}{\sqrt{6} \alpha} \approx \frac{1.2826}{\alpha}$$

where $C$ is the Euler’s constant.

Only snow load and wind load are considered in this paper. The statistical parameters of snow load and wind load can be obtained from the method in [20,21,38,39], which suggests that taking the target service period of buildings as the recurrence period of the wind pressure and snow pressure firstly and then determined the statistical parameters based on the mathematical model of extreme value I type distribution and the principle of the consistency for the probability of exceeding the design value of load in the design reference period. The distribution types and statistical parameters for loads are listed in Table 3 [22,40].
Table 3. Distribution types and statistical parameters for loads.

| Load Type | Distribution Type      | Statistical Parameter | Design Working Life (Years) |
|-----------|------------------------|-----------------------|-----------------------------|
|           |                        | Coefficient of mean value $\chi_S$ | 50 | 100 |
|           |                        | Variable coefficient $\delta_S$ |               |
| Dead load | Normal distribution    | 1.06                   | 1.06                        |
|           |                        | 0.07                   | 0.07                        |
| Snow load | Extreme value I type distribution | 1.046                  | 0.941                       |
|           |                        | 0.235                  | 0.211                       |
| Wind load | Extreme value I type distribution | 0.908                  | 0.904                       |
|           |                        | 0.193                  | 0.174                       |

2.3. Statistical Parameters and Partial Factors for Resistance

The resistance of the structure is influenced by many factors. In the case of design, it should be considered that the factors should include the uncertainty in the material properties, the uncertainty in the geometrical data and the modeling uncertainty [1,23–25,41–43]. The suggestion distribution of the resistance of the structure can be defined by a lognormal distribution [27,44]. 14 representative structural members were selected and the statistical parameters for resistance of different structural members under different stress statuses are given in Table 4 [26,45].

Table 4. Statistical parameters and partial factors for resistance of different structural members.

| Structural Member Type | Stress Status          | Coefficient of Mean Value $\chi_R$ | Variable Coefficient $\delta_R$ | Partial Factors for Resistance $\gamma_R$ |
|------------------------|------------------------|-----------------------------------|---------------------------------|------------------------------------------|
| Steel                  | (1) Axial compression  | 1.11                              | 0.12                            | 1.23                                     |
|                        | (2) Eccentric compression | 1.21                           | 0.15                            | 1.22                                     |
| Thin-walled steel      | (3) Axial compression  | 1.21                              | 0.15                            | 1.22                                     |
|                        | (4) Eccentric compression | 1.20                           | 0.15                            | 1.23                                     |
| Reinforced concrete    | (5) Axial tension      | 1.10                              | 0.10                            | 1.18                                     |
|                        | (6) Axial compression  | 1.47                              | 0.17                            | 1.06                                     |
|                        | (7) Large eccentric compression | 1.16                          | 0.13                            | 1.21                                     |
|                        | (8) Bending            | 1.24                              | 0.10                            | 1.05                                     |
|                        | (9) Shear              | 1.36                              | 0.19                            | 1.21                                     |
| Masonry                | (10) Axial compression | 1.21                              | 0.25                            | 1.60                                     |
|                        | (11) Eccentric compression | 1.26                          | 0.30                            | 1.76                                     |
|                        | (12) Shear             | 1.176                             | 0.27                            | 1.74                                     |
| Timber                 | (13) Axial compression | 1.23                              | 0.23                            | 1.49                                     |
|                        | (14) Bending           | 1.38                              | 0.27                            | 1.48                                     |

According to the design value method, there is:

$$F_R(R_d) = \Phi(-\alpha \beta)$$  \hspace{1cm} (5)

where $R_d$ is the design value of the resistance, $\beta$ is the target reliability index, the recommended values are shown in Table 5, $\Phi(\cdot)$ is the cumulative density function of the standard normal distribution, $\alpha$ is the value of the FORM sensitivity factor and for resistance, it may be taken as 0.8. Based on the design value method and the current design expression, for resistance obeys to lognormal distribution [27,44], the partial factor for resistance can be expressed as:

$$\gamma_R = \frac{\mu_R}{\chi_R F_R^{-1}[\Phi(-\alpha \beta)]} = \frac{\sqrt{1 + \delta^2_R}}{\chi_R} \exp \left\{ -\alpha \beta \sqrt{\ln(1 + \delta^2_R)} \right\}$$  \hspace{1cm} (6)
where $\mu_R$, $\chi_R$ and $\delta_R$ are the mean value, the coefficient of mean value and the variable coefficient of the resistance, respectively. The calculated partial factors for resistance are shown in Table 4.

### Table 5. Target values for reliability indexes.

| Safety Categories | III | II | I |
|-------------------|-----|----|---|
| Ductile failure   | 2.7 | 3.2| 3.7|
| Brittle failure   | 3.2 | 3.7| 4.2|

#### 2.4. The Variable Load Adjustment Factor for the Design Working Life

The Chinese standards indicate that the variable load adjustment factor for the design working life needs to be considered in the structural design expressions when the design working life differs from the design reference period of 50 years. The specific values of the variable load adjustment factors are given in Chinese structural reliability standards (GB50153-2008) [10], (GB50068-2018) [11] and it is not stressed that these values are not suitable for wind load and snow load, see in Table 6. The specific values of variable load adjustment factor in Chinese load code (GB50009-2012) [4] are quoted from (GB50153-2008) [10]. Meanwhile, the expressions and the calculated values of the variable load adjustment factors for live loads, wind load and snow load for different design working lives are given in (GB50009-2012) [4], shown in Table 7. Although the code (GB50009-2012) [4] gives the calculated values of the adjustment factors for wind and snow loads, it states that the variable load adjustment factors are only applicable to floor and roof live loads.

### Table 6. The variable load adjustment factors for the design working life.

| Design Working Life of Structure | $\gamma_L$ |
|---------------------------------|------------|
| 5                               | 0.9        |
| 50                              | 1.0        |
| 100                             | 1.1        |

### Table 7. The calculated values of variable load adjustment factor for the design working life.

| Design Working Life of Structure | 5  | 10 | 20 | 30 | 50 | 75 | 100 |
|----------------------------------|----|----|----|----|----|----|-----|
| Office building live load        | 0.839 | 0.858 | 0.919 | 0.955 | 1.000 | 1.036 | 1.061 |
| Residential live load            | 0.798 | 0.859 | 0.920 | 0.955 | 1.000 | 1.036 | 1.061 |
| Snow load                        | 0.713 | 0.799 | 0.886 | 0.936 | 1.000 | 1.051 | 1.087 |
| Wind load                        | 0.651 | 0.756 | 0.861 | 0.923 | 1.000 | 1.061 | 1.105 |

#### 3. Reliability Analysis of Structural Members

Reliability of structural members subjected to snow load or wind load can be defined by the limit state function as follows [28]:

$$Z(R, G, Q) = R - (C_G G + C_Q Q)$$  \(7\)

where R and G are structural resistance and dead load on structural members, which are assumed to not change with time; Q is the maximum live load on structural members during the design working life; $C_G$ and $C_Q$ are the conversion coefficients of load to effect for dead load and live load, respectively.
For the ultimate limit states, considering the combination of dead and live load (snow load or wind load), the design value of load effect can be determined by Equation (8), the required characteristic value of structural resistance can be determined by Equation (9):

$$S_d = \gamma_G S_G + \gamma_Q \gamma_L S_Q$$  \hspace{1cm} (8)

$$R_k = \gamma_R \gamma_0 S_d$$  \hspace{1cm} (9)

where $R_k$, $S_G$ and $S_Q$ are the characteristic values of the resistance, the effect of dead load and the effect of live load, respectively; $\gamma_R$, $\gamma_G$ and $\gamma_Q$ are the partial factors of the resistance, the dead load and the live load, respectively; $\gamma_0$ is the structural importance coefficient, when the design working life is 100 years, it may be taken as 1.1; $\gamma_L$ is the variable load adjustment factor for the design working life. The combinations of loads are dead load + snow load and dead load + wind load. For the snow load and wind load of a building structure designed for working life of 100 years, 2 different conditions are initially assumed. The two conditions are: (1) the basic snow pressure or wind pressure with a return period of 50 years is adopted and the variable load adjustment factor for the design working life is considered in the design expression. And the ratios of the snow or wind load effect to dead load effect $\rho_1$ are 0.1, 0.25, 0.5, 1.0, 2.0; (2) the basic snow pressure or wind pressure with a return period of 100 years is adopted and the variable load adjustment factor for the design working life is not considered in the design expression. Because the ratios of the 100 years wind or snow pressure $R_{100}$ to the 50 years wind or snow pressure $R_{50}$ is about 1.1~1.3 for all cities in China. So the ratios of the snow or wind load effect to dead load effect can be taken as $\rho_2 = 1.2 \rho_1$, that is, 0.12, 0.3, 0.6, 1.2, 2.4. The reliability analysis of each member are carried out according to the load partial factor in China’s old code (GB50153-2008) [10] and new code (GB50068-2018) [11]. The flowchart for the calculation of the reliability index of the structural members is shown in Figure 1. The reliability indexes of members under partial factors in (GB50153-2008) [10] and (GB50068-2018) [11] based on 50 years snow pressure are shown in Tables 8 and 9. Figure 2 shows the corresponding variation trend of reliability indexes based on 50 years snow pressure. The reliability indexes of members of partial factors in (GB50153-2008) [10] and (GB50068-2018) [11] based on 100 years snow pressure are shown in Tables 10 and 11. Figure 3 shows the corresponding variation trend of reliability indexes based on 100 years snow pressure.

![Flowchart](image.png)

**Figure 1.** The flowchart for the calculation of the reliability index of the structural members.
Table 8. Reliability indexes of members under partial factors in (GB50153-2008) for 50 years snow pressure.

| \( \rho \) | Steel | Thin-Walled Steel | Reinforced Concrete | Masonry | Timber |
|---|---|---|---|---|---|
| 0.1 | 4.461 | 4.259 | 4.259 | 4.259 | 4.623 | 4.149 | 4.388 | 4.623 | 4.054 | 3.842 | 3.719 | 3.788 | 3.903 | 3.788 |
| 0.25 | 4.495 | 4.360 | 4.360 | 4.360 | 4.554 | 4.264 | 4.454 | 4.554 | 4.174 | 3.953 | 3.819 | 3.895 | 4.018 | 3.895 |
| 0.5 | 4.146 | 4.168 | 4.168 | 4.168 | 4.089 | 4.153 | 4.161 | 4.089 | 4.122 | 3.991 | 3.881 | 3.945 | 4.037 | 3.945 |
| 1 | 3.742 | 3.843 | 3.843 | 3.843 | 3.640 | 3.882 | 3.782 | 3.640 | 3.904 | 3.900 | 3.854 | 3.885 | 3.910 | 3.885 |
| 2 | 3.447 | 3.580 | 3.580 | 3.580 | 3.331 | 3.643 | 3.497 | 3.331 | 3.691 | 3.761 | 3.767 | 3.767 | 3.747 | 3.768 |

\( \beta \) 4.058 4.042 4.042 4.042 4.064 4.047 4.018 4.056 4.047 3.889 3.808 3.856 3.923 3.856

Table 9. Reliability indexes of members under partial factors in (GB50068-2018) for 50 years snow pressure.

| \( \rho \) | Steel | Thin-Walled Steel | Reinforced Concrete | Masonry | Timber |
|---|---|---|---|---|---|
| 0.1 | 5.083 | 4.773 | 4.773 | 4.773 | 5.342 | 4.609 | 4.970 | 5.342 | 4.471 | 4.166 | 3.993 | 4.090 | 4.253 | 4.090 |
| 0.25 | 5.092 | 4.877 | 4.877 | 4.877 | 5.204 | 4.732 | 5.023 | 5.204 | 4.600 | 4.286 | 4.101 | 4.205 | 4.378 | 4.205 |
| 0.5 | 4.679 | 4.650 | 4.650 | 4.650 | 4.656 | 4.603 | 4.676 | 4.656 | 4.541 | 4.350 | 4.199 | 4.263 | 4.401 | 4.263 |
| 1 | 4.234 | 4.299 | 4.299 | 4.299 | 4.155 | 4.313 | 4.262 | 4.155 | 4.311 | 4.242 | 4.151 | 4.207 | 4.273 | 4.207 |
| 2 | 3.917 | 4.021 | 4.021 | 4.021 | 3.817 | 4.065 | 3.957 | 3.817 | 4.092 | 4.106 | 4.071 | 4.095 | 4.111 | 4.095 |

\( \beta \) 4.601 4.524 4.524 4.524 4.635 4.464 4.578 4.635 4.403 4.226 4.097 4.172 4.283 4.172

Table 10. Reliability indexes of members under partial factors in (GB50153-2008) for 100 years snow pressure.

| \( \rho \) | Steel | Thin-Walled Steel | Reinforced Concrete | Masonry | Timber |
|---|---|---|---|---|---|
| 0.12 | 4.136 | 3.914 | 3.914 | 3.914 | 4.318 | 3.795 | 4.055 | 4.318 | 3.694 | 3.469 | 3.340 | 3.412 | 3.533 | 3.412 |
| 0.3 | 4.258 | 4.070 | 4.070 | 4.070 | 4.368 | 3.952 | 4.195 | 4.368 | 3.847 | 3.601 | 3.456 | 3.537 | 3.672 | 3.537 |
| 0.6 | 4.022 | 3.983 | 3.983 | 3.983 | 4.010 | 3.933 | 4.015 | 4.010 | 3.873 | 3.683 | 3.547 | 3.625 | 3.744 | 3.625 |
| 1.2 | 3.693 | 3.740 | 3.740 | 3.740 | 3.627 | 3.747 | 3.714 | 3.627 | 3.739 | 3.663 | 3.575 | 3.628 | 3.694 | 3.628 |
| 2.4 | 3.442 | 3.527 | 3.527 | 3.527 | 3.358 | 3.562 | 3.476 | 3.358 | 3.581 | 3.580 | 3.540 | 3.567 | 3.588 | 3.567 |

\( \beta \) 3.910 3.847 3.847 3.847 3.936 3.798 3.891 3.936 3.788 3.599 3.492 3.554 3.646 3.554

Table 11. Reliability indexes of members under partial factors in (GB50068-2018) for 100 years snow pressure.

| \( \rho \) | Steel | Thin-Walled Steel | Reinforced Concrete | Masonry | Timber |
|---|---|---|---|---|---|
| 0.12 | 5.050 | 4.748 | 4.748 | 4.748 | 5.302 | 4.587 | 4.940 | 5.302 | 4.452 | 4.152 | 3.981 | 4.077 | 4.237 | 4.077 |
| 0.3 | 4.999 | 4.810 | 4.810 | 4.810 | 5.091 | 4.677 | 4.940 | 5.091 | 4.553 | 4.254 | 4.075 | 4.176 | 4.342 | 4.176 |
| 0.6 | 4.538 | 4.532 | 4.532 | 4.532 | 4.501 | 4.498 | 4.543 | 4.501 | 4.450 | 4.269 | 4.123 | 4.208 | 4.331 | 4.208 |
| 1.2 | 4.062 | 4.143 | 4.143 | 4.143 | 3.973 | 4.170 | 4.095 | 3.973 | 4.180 | 4.143 | 4.073 | 4.117 | 4.163 | 4.117 |
| 2.4 | 3.724 | 3.841 | 3.841 | 3.841 | 3.616 | 3.895 | 3.768 | 3.616 | 3.934 | 3.978 | 3.964 | 3.976 | 3.972 | 3.976 |

\( \beta \) 4.475 4.415 4.415 4.415 4.497 4.365 4.457 4.497 4.414 4.159 4.043 4.111 4.209 4.111

4.32
The analysis indicates that when the basic snow pressure with a return period of 50 years is adopted and the variable load adjustment factor for the design working life of 1.1 is considered in the design expression, the average reliability index of 3.98 is much higher than the target reliability index of 3.7 with the partial factors in (GB50153-2008) [10] and the average reliability index of 4.42 is much higher than the target reliability index of 4.2 with the partial factors (GB50068-2018) [11]. Apparently, the corresponding design is unreasonable from an economic point of view. When the basic snow pressure with a return period of 100 years is adopted and the variable load adjustment factor for the design working life is not considered in the design expression, the average reliability index of 3.76 is much closer to the target reliability index of 3.7 with the partial factors in (GB50153-2008) [10] and the average reliability index of 4.32 is much closer to the target reliability index of 4.2 with the partial factors (GB50068-2018) [11]. This is more in line with the design principles of safety and economy in structural design. The similar results and conclusions can be obtained for wind load, the reliability indexes and the corresponding variation trend of reliability indexes are shown in Tables 12–15 and in Figures 4 and 5.
Table 12. Reliability indexes of members under partial factors in (GB50153-2008) for 50 years wind pressure.

| ρ  | Steel (1) | Thin-Walled Steel (2) | Reinforced Concrete (3) | Masonry (4) | Timber (5) |
|----|-----------|-----------------------|-------------------------|-------------|------------|
| 0.1 | 4.200     | 3.965                 | 3.965                   | 3.965       | 4.395      |
| 0.25 | 4.514     | 4.247                 | 4.247                   | 4.713       | 4.099      |
| 0.5 | 4.520     | 4.379                 | 4.379                   | 4.577       | 4.269      |
| 1   | 4.276     | 4.258                 | 4.258                   | 4.225       | 4.222      |
| 2   | 4.047     | 4.086                 | 4.086                   | 3.990       | 4.088      |
| β  | 4.311     | 4.187                 | 4.187                   | 4.385       | 4.104      |

Table 13. Reliability indexes of members under partial factors in (GB50068-2018) for 50 years wind pressure.

| ρ  | Steel (1) | Thin-Walled Steel (2) | Reinforced Concrete (3) | Masonry (4) | Timber (5) |
|----|-----------|-----------------------|-------------------------|-------------|------------|
| 0.1 | 4.791     | 4.455                 | 4.455                   | 5.078       | 4.279      |
| 0.25 | 5.073     | 4.721                 | 4.721                   | 5.331       | 4.526      |
| 0.5 | 4.963     | 4.787                 | 4.787                   | 5.044       | 4.652      |
| 1   | 4.631     | 4.590                 | 4.590                   | 4.623       | 4.539      |
| 2   | 4.350     | 4.372                 | 4.372                   | 4.305       | 4.362      |
| β  | 4.762     | 4.585                 | 4.585                   | 4.876       | 4.472      |

Table 14. Reliability indexes of members under partial factors in (GB50153-2008) for 100 years wind pressure.

| ρ  | Steel (1) | Thin-Walled Steel (2) | Reinforced Concrete (3) | Masonry (4) | Timber (5) |
|----|-----------|-----------------------|-------------------------|-------------|------------|
| 0.12 | 4.172    | 3.515                 | 3.515                   | 3.668       | 3.818      |
| 0.3  | 4.431    | 3.684                 | 3.684                   | 3.864       | 4.039      |
| 0.6  | 4.380    | 3.830                 | 3.830                   | 4.007       | 4.157      |
| 1.2  | 4.123    | 3.897                 | 3.897                   | 4.011       | 4.082      |
| 2.4  | 3.897    | 3.870                 | 3.870                   | 3.926       | 3.945      |
| β  | 4.201    | 3.759                 | 3.759                   | 3.895       | 4.008      |

Table 15. Reliability indexes of members under partial factors in (GB50068-2018) for 100 years wind pressure.

| ρ  | Steel (1) | Thin-Walled Steel (2) | Reinforced Concrete (3) | Masonry (4) | Timber (5) |
|----|-----------|-----------------------|-------------------------|-------------|------------|
| 0.12 | 4.763    | 4.431                 | 4.431                   | 5.048       | 4.257      |
| 0.3  | 4.986    | 4.652                 | 4.652                   | 5.224       | 4.465      |
| 0.6  | 4.822    | 4.663                 | 4.663                   | 4.891       | 4.539      |
| 1.2  | 4.481    | 4.449                 | 4.449                   | 4.468       | 4.402      |
| 2.4  | 4.206    | 4.231                 | 4.231                   | 4.157       | 4.224      |
| β  | 4.406    | 4.485                 | 4.485                   | 4.758       | 4.377      |
4. Conclusions

According to the load partial factor in China’s old and new codes, the reliability analysis of 14 representative structural members designed for working life of 100 years are developed with the basic snow pressure and wind pressure with a return period of 50 years and 100 years. The following conclusions are drawn from the present study:

1. When the basic snow pressure or wind pressure with a return period of 50 years is adopted and the variable load adjustment factor for the design working life of 1.1 is considered in the design expression, the average reliability index is much higher than the target reliability index, this lead to uneconomic design.

2. When the basic snow pressure or wind pressure with a return period of 100 years is adopted and the variable load adjustment factor for the design working life is not considered in the design expression, the average reliability index is much closer to the target reliability index, this is a more reasonable design.

3. For structural members designed for working life of 100 years, the structural importance coefficient of 1.1 needs to be taken in the design expression to increase all the load effects on the structural members. The basic wind pressure and snow pressure should be taken with a return period of 100 years and the variable load adjustment factor for the design working life should not be considered.
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