

Study on the relevant parameters of direct economic loss assessment of reinforced concrete structure buildings considering seismic fortification and use function

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Abstract. The main cost and decoration cost of the building are the key parameters in the evaluation of the direct economic loss of the building. In the *Earthquake Site Work Part 4 : Direct Loss Assessment of Disasters* (GB / T 18208.4-2011), considering factors such as economic development level, structural type, and building use, based on expert experience and engineering cost data, a grading index was developed and a corresponding correction coefficient was given to more accurately and reasonably assess the loss of the main building and the loss of decoration. In view of the rapid development of China 's economy and the acceleration of urbanization in the past ten years, the original grading indicators and coefficients need to be adjusted to adapt to the reality. This paper focuses on the reinforced concrete structure with various functions and wide distribution. By collecting a large number of corresponding building main body and decoration cost data, and combining with expert experience data, this paper analyzes the influence of seismic fortification level on the main body cost, as well as the influence of economic development level, decoration grade, use function and other factors on the decoration cost. The research results of this paper aim to provide reference for the update and refinement of several key parameters in the specification.

Keywords: Reset unit price ; seismic fortification ; use function ; reinforced concrete structure ; direct economic loss assessment of buildings

1. Introduction

Scientific, accurate and rapid assessment of earthquake disaster losses is of great significance for emergency rescue, earthquake relief and post-earthquake recovery and reconstruction. After decades of research and practice, China has made remarkable progress in the field of earthquake economic loss assessment, and has formed a systematic assessment method. The 1989 Datong-Yanggao Ms6.1 earthquake was the first application of a more scientific seismic loss assessment method in China ^[1]. Since then, with the accumulation of practical experience in the earthquake site, the evaluation methods and related parameters have been gradually improved and updated.

The *Earthquake Field Work Outline and Technical Guide* issued in 1988 ^[2] provides clear guidance for earthquake disaster loss assessment, which points out that earthquake loss is the result of the combined effect of earthquake risk, seismic capacity and social wealth. Since then, Yifan Yuan and other experts from the Institute of Engineering Mechanics of China Seismological Bureau further presided over the preparation of the national standard *Earthquake site work-Part 4 : Direct disaster loss assessment*(GB / T 18208.4-2005) ^[3], making China 's earthquake loss assessment work to a new level. On the basis of actual cases such as Wenchuan earthquake, Baitao Sun and other experts combined with the investigation data of earthquake disasters at home and abroad, revised the national norms in depth, and introduced the current national standard *Earthquake Site Work Part 4 : Assessment of Direct Loss of Disasters* (GB / T 18208.4-2011) ^[4]. This version of the specification is aimed at the urban evaluation area, which increases the work requirements and

technical content of the direct economic loss assessment of medium and high-grade decoration earthquakes, making the evaluation system more perfect.

When evaluating the direct economic loss of urban building decoration, the current standard comprehensively considers the influence of factors such as regional economic development level, city scale, decoration grade and building use function, and introduces the correlation coefficient^[5]; using the official data such as China's per capita GDP and urban population, the city is divided into different levels, and the empirical value of the correlation coefficient is given. However, these official data have been more than ten years ago. During this period, China's economic level has improved significantly, and the per capita annual income is about 6.3 times that of 20 years ago. The scale of urban population is growing, and the number of urban population is about 1.7 times that of 20 years ago. Therefore, the main cost and decoration price of the building are one of the main parameters in the evaluation process, and the influence parameters and experience values need to be updated to adapt to the development and changes of the society.

In view of this, this paper focuses on reinforced concrete structures with diverse functions and wide distribution. By collecting a large number of building body and decoration cost data, combined with expert experience data, the influence of seismic fortification intensity on the main body cost is explored. At the same time, based on the latest official population and economic data, this paper also updated the classification criteria of city size and development level, and recalculated the correction coefficients related to the direct economic loss assessment of decoration, in order to provide a more accurate and scientific basis for earthquake disaster loss assessment.

2. Composition of direct economic loss of building structure

The direct economic loss assessment method of urban earthquake proposed by Sun Baitao and Chen Hongfu^{[6][7]} pointed out that the direct economic loss of building earthquake damage includes three parts : main structure loss, house decoration loss and indoor and outdoor property loss, as shown in Equation (1).

$$L_a = \alpha \cdot (L_b + L_d + L_p) \quad (1)$$

In the formula : L_a —the sum of direct economic losses of housing construction and indoor and outdoor property, L_b —the direct economic loss of the main structure of the house, L_d —the direct economic loss of housing decoration, L_p —the direct economic loss of indoor and outdoor property of the house, α —the correction coefficient of the total loss value.

The calculation method and practical guidance of the above three types of losses are given in the national standard 'Earthquake field work-Part 4 : Assessment of direct disaster losses '. Based on the standard evaluation method, this section introduces the relevant parameters of the main structure and decoration loss, and focuses on the correction consideration of the main structure and decoration replacement unit price.

2.1 Direct economic loss of main structure

The direct economic loss assessment parameters of building damage include : total building area, damage ratio, loss ratio, and replacement unit price. The calculation formula for evaluating the main body loss of various buildings in the sub-region under a certain damage level is shown in Formula (2). By adding the main loss values of different types and damage levels of houses in each evaluation sub-area, the overall main loss of buildings in the disaster area can be obtained.

$$L_b = S_h \times R_h \times D_h \times P_h \quad (2)$$

In the formula : S_h —the total construction area of similar houses in the evaluation sub-area, R_h —the damage ratio of a certain damage level of similar houses in the evaluation sub-area, D_h —the loss ratio of a certain damage level of similar houses in the evaluation sub-area, P_h —the replacement unit price of similar houses in the evaluation sub-area.

As a basic parameter for the evaluation of direct economic loss of buildings, the accuracy and rationality of the reset unit price directly affect the accuracy of the evaluation results. The meaning of " replacement unit price " is the replacement cost per unit area of the same type and standard house based on the current local price, which does not include the developer 's profit, land price (land acquisition fee, site leveling fee) and the increase in the cost of improving the fortification level. At present, the depreciation of houses is not considered^[5].

The determination of the replacement unit price mainly relies on on-site sampling or data provided by local construction and civil affairs departments. After the Wenchuan earthquake, China has generally improved the seismic requirements of buildings, and updated and revised the relevant design codes and technical specifications accordingly. With the elimination of non-fortified areas in China 's ground motion parameter zoning map, the seismic fortification requirements in many areas have been improved. This has led to a significant increase in the proportion of seismic fortification in urban houses. While the seismic capacity is improved, the main cost of the building has increased. By considering the influence of seismic fortification level on the cost of the main body of the house, the reset unit price can be more in line with the actual situation, thus improving the accuracy of the evaluation results.

2.2 Direct economic loss of housing decoration

The formula for calculating the decoration loss of various types of house decoration in a certain damage level in the evaluation sub-area is shown in Equation (3). By adding the loss values of different types and damage levels of housing decoration in each evaluation sub-region, the overall loss of housing decoration in the disaster area can be obtained.

$$L_d = \gamma_1 \times \gamma_2 \times S_d \times R_d \times D_d \times P_d \quad (3)$$

In the formula : S_d —the total construction area of the same kind of middle and high-end decoration houses in the evaluation sub-region, R_d —the damage ratio of the same kind of houses in the evaluation sub-region to a certain damage level, D_d —the damage loss ratio of the same kind of houses in the evaluation sub-region to a certain damage level, P_d —the replacement unit price of the high-end decoration of the same kind of houses in the evaluation sub-region, γ_1 —the correction coefficient considering the difference of economic conditions in each region, γ_2 —the correction coefficient considering different uses.

This method comprehensively considers the influence of various factors on the decoration price. However, the division standard of population and economic level referred to in the specification has been more than ten years ago. Therefore, the correction coefficients related to the decoration loss assessment formula also need to be updated to adapt to the development of the times, which is helpful to improve the accuracy and reliability of the seismic decoration loss assessment results.

3. The influence of seismic fortification level on the cost of building main body

For the influence of the main body cost of the building with seismic fortification grade, this paper refers to the requirements of the national standard *Seismic Design Code* ^[16] and *Seismic Fortification Classification Standard* ^[15]. Combined with the existing research results and examples, the concept of unit cost increase coefficient is used to quantify its influence.

3.1 Seismic fortification grade requirements

The seismic fortification standard of buildings is a scale to measure the level of seismic fortification requirements ^[8], which is determined by the seismic fortification intensity (or ground motion parameters) and the seismic fortification category of buildings. Among them : (1) seismic fortification intensity : the seismic intensity approved as a basis for seismic fortification in a region according to the authority prescribed by the state. In general, the seismic intensity with a probability of exceeding 10 % within 50 years is taken. The seismic fortification intensity is divided into 6

degrees, 7 degrees, 8 degrees and 9 degrees. (2) Category of seismic fortification of buildings : Considering the severity of the consequences of earthquake damage to buildings, such as casualties, direct and indirect economic losses, the degree of social impact and its role in earthquake relief, etc., the category of buildings is divided. The seismic fortification categories of buildings in China are divided into special fortification(category A), key fortification(category B), standard fortification(category C) and moderate fortification(category D). The seismic design requirements of buildings with different seismic fortification categories and the types of buildings included are summarized in Table 1.

Table 1. Seismic design requirements of buildings with different seismic fortification categories

Protection Level	Design Requirement	Building Types
Special Fortification	Strengthen its seismic measures according to the requirements of seismic fortification intensity once higher than that of the region.	Important scientific research and medical buildings ; Key Infrastructure Buildings
Key Fortification	Strengthen its seismic measures according to the requirements of seismic fortification intensity once higher than that of the region.	Disaster prevention and relief buildings ; Primary and secondary education building ;Large infrastructure construction ;Large public buildings ; Mining, Raw material production Industrial buildings
Standard Fortification	According to the seismic fortification intensity of the region, the seismic measures and seismic action are determined.	General residential ; Ordinary public buildings ; Light industry, Manufacturing industrial buildings
Moderate Fortification	Compared with the requirements of seismic fortification intensity in this area, the seismic measures can be appropriately reduced, but the seismic fortification intensity should not be reduced when it is 6 degrees.	Warehouses, Open buildings

With the frequent occurrence of earthquake disasters in China, the public 's requirements for the seismic performance of housing buildings are getting higher and higher, which also increases the seismic fortification level of buildings, and the improvement of seismic fortification level will inevitably increase the main cost of buildings. Understanding the influence degree of seismic fortification level is conducive to a more reasonable assessment of the cost loss of the main building.

3.2 Study on the main cost of different fortification intensity

In order to consider the influence of seismic fortification level on the cost of building main body, this paper introduces a correction coefficient to quantify the influence of seismic fortification level. The calculation formula is as follows :

$$P_{hi} = \beta_i \times P_{h6} \quad (4)$$

In the formula : P_{hi} —the main cost of the building under the seismic fortification level, P_{h6} —the main cost of the building under the 6 degree fortification, β —the unit cost increase coefficient of the seismic fortification level compared to the 6 degree fortification.

There has been a deep research foundation for the value of the increase coefficient, and the reinforced concrete structure is a structural type that is widely distributed and has a large stock. Many experts and scholars^{[9]-[14]} used questionnaires, model calculations and other methods to give the seismic fortification cost increase coefficient of reinforced concrete structures under different fortification intensities. Because the current fifth-generation ground motion parameter zoning map

cancels the non-fortified area, the lowest seismic fortification level in China is 6 degree fortification at present. Therefore, taking the unit cost of 6 degree fortification as the reference value, the unit cost increase coefficient of higher seismic fortification intensity (7 degree fortification, 8 degree fortification, 9 degree fortification) compared with 6 degree fortification is given.

Table 2. The seismic fortification cost increase coefficient of reinforced concrete structure

Data Sources	Compared to the 6 degree fortification		
	7 degree fortification	8 degree fortification	9 degree fortification
Xiaowang Gao,(1997)	1.03	1.08	1.18
Shuzheng Li,(1998)	1.03	1.08	1.15
Han Miao,(2010)	1.01	1.08	1.25
Yiping Tan,(2010)	1.04	1.09	-
Kaimin Du,(2016)	1.04	1.08	1.17

In this paper, a typical five-story reinforced concrete building is designed by using PKPM structural design software. The layout and structural facade are shown in Fig.1 and Fig.2. According to the requirements of the latest version of the = *Seismic Design Code* ^[16], the main cost increase coefficients of the model with 7 degree fortification, 8 degree fortification and 9 degree fortification relative to the 6 degree fortification standard are obtained in table 3.

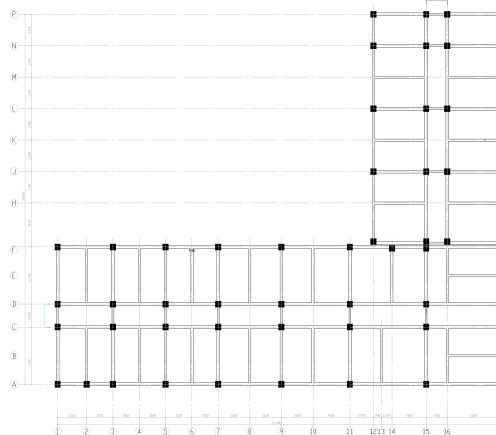


Fig. 1 Plane diagram of reinforced concrete frame structure example

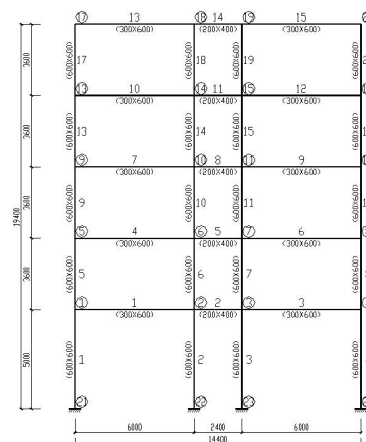


Fig. 2 Elevation diagram of reinforced concrete frame structure example

Table 3. Model calculation results

	Compared to the 6 degree fortification		
	7 degree	8 degree	9 degree

	fortification	fortification	fortification
Results	1.03	1.09	1.20

Compared with the conclusions drawn by experts and scholars, the results calculated in this paper are within the corresponding reasonable range, but the value is slightly improved. Based on the expert experience and the calculation results of engineering examples, the reference value of the main cost increase coefficient of reinforced concrete structures under different fortification intensities is given, as shown in table 4.

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Table 4. Construction cost increase coefficient of reinforced concrete structure under different seismic fortification intensity

	Compared to the 6 degree fortification		
	7 degree fortification	8 degree fortification	9 degree fortification
Range	1.00~1.05	1.05~1.10	1.15~1.30
Median	1.03	1.08	1.23

4. The influence of economic level and use function on decoration cost

The decoration cost of urban buildings will be affected by the level of regional economic development and the use function. Considering the influence of the above factors, the proportion of high-end decoration houses in different city scales and the ratio of house decoration cost to main body cost are given, and the economic level correction coefficient γ_1 and the use function correction coefficient γ_2 are given. In this paper, the four types of values are recalculated according to the new official data and classification criteria.

4.1 The proportion of the number of high-end decoration houses

In *Earthquake site work-Part 4 : Assessment of direct disaster losses* [4], according to the classification criteria of urban scale stipulated by the National Bureau of Statistics, the urban scale is divided into three levels : large cities ($>100,000,0$), medium-sized cities ($200,000\sim100,000,0$), and small cities ($\leq 200,000$) with the index of urban non-agricultural population. On the basis of urban scale classification, based on the sample survey data, the recommended value of the proportion of medium and high-end decoration of steel-concrete structure and masonry structure houses is given.

In the past ten years, with the development of China 's social economy, the scale of cities has been expanding, and the proportion of high-end decoration has also increased accordingly. Based on the latest urban scale division standard, this section re-gives the grading index ; based on the stratified sampling data of building decoration price and the results of industry questionnaire survey, the proportion of middle and high grade decoration of reinforced concrete structure is given.

The scale of the city is based on the updated classification criteria of the *Notice of the State Council on Adjusting the Criteria for the Classification of City Size* issued in 2014. The city is divided into five levels:super-large cities ($>100,000,00$), megacities ($500,000,0\sim100,000,00$), large cities ($100,000,0\sim 500,000,0$), medium-sized cities ($500,000 \sim 100,000,0$), small cities ($\leq 500,000$).

In order to understand the proportion of high-end decoration houses in various cities in China, this paper obtains the survey data of the construction and decoration industry. The research data show that : on the whole, the consumption level of decoration cost in China presents a ' water droplet ' structure. In the survey sample, the proportion of decoration costs within 100,000 yuan is 40.36 %, the proportion between 11~20 million yuan is 42.95 %, the proportion between 21~30

million yuan is 10.43 %, and the proportion above 30 million yuan is 6.26 %. In terms of the size of subdivided cities, large cities are “olive-shaped”, medium-sized cities are “water droplets”, and small cities are “pyramid-shaped”.

Based on the stratified sampling data of building decoration price and the results of industry questionnaire survey, this paper adopts the latest official city standard division basis, and gives the value range and median value of the proportion of high-end decoration houses in the five types of city scale, see table 5.

Table 5. The proportion of high-grade decoration houses in reinforced concrete structure

City Size	The proportion of the number of high-end decoration houses (%)	
Super-large cities	Range	40~60
	Median	50
Megacities	Range	35~45
	Median	40
Large cities	Range	30~40
	Median	35
Medium-sized cities	Range	15~35
	Median	20
Small cities	Range	10~20
	Median	15

Note : The classification standard of city size is stipulated by the State Council, and it is divided into five grades with 'urban resident population' as the index: super-large cities (>100,000,00), megacities (500,000,0~100,000,00), large cities (100,000,0~500,000,0), medium-sized cities (500,000~100,000,0), small cities ($\leq 500,000$).

4.2 The ratio of house decoration cost to main body cost

In *Earthquake site work-Part 4 : Assessment of direct disaster losses* [4], the value range and median value of the ratio of building decoration cost to main body cost are given to calculate the building decoration cost P_d . The calculation formula is shown in Formula (4).

$$P_d = P_h \times \eta \quad (4)$$

In the formula : P_d —housing decoration cost, P_h —housing replacement unit price, η —the ratio of housing decoration cost to main body cost.

In order to analyze the ratio of decoration cost to main body cost in various cities in China, this paper collects the unit price data of multi-storey reinforced concrete structures in various provinces and cities in China published on the official website of housing construction and urban and rural construction. Based on the sample data of house decoration and main body cost of stratified sampling in five typical cities, the ratio of decoration cost to main body cost of reinforced concrete structure is given, as shown in Table 6.

Table 6. The ratio of decoration cost to main body cost of reinforced concrete structure

City Size	The ratio of decoration cost to main body cost (%)	
Super-large cities	Range	45~65
	Median	55
Megacities	Range	40~55
	Median	43
Large cities	Range	35~45
	Median	40
Medium-sized cities	Range	20~40

Small cities	Median	30
	Range	15~35
	Median	25

4.3 Decoration loss correction coefficient considering the difference of economic development level

For regions with different economic development levels, factors such as material prices, labor costs, design and process levels, market supply and demand, etc., may affect the decoration price. Therefore, differences in economic development levels need to be considered and adjusted accordingly in the assessment.

In *Earthquake site work-Part 4 : Assessment of direct disaster losses* ^[4], based on the data of the National Bureau of Statistics, using *Per Capita GDP* as an indicator, the level of economic development is divided into three levels : general ($\leq 15,000$), more developed (15,000 ~30,000), and developed ($\geq 30,000$), and corresponding correction coefficients are given to consider the impact of differences in economic conditions in various regions.

This paper obtains the per capita GDP index data of each city in China by 2023, sorts and groups them, and gives a new classification of economic development level. The level of economic development is divided into three levels : cities with per capita GDP of more than 90,000 (28.8 % of all cities) are classified as developed, cities with per capita GDP between 50,000 and 90,000 (42.1 % of all cities) are classified as more developed, and cities with per capita GDP of less than 50,000 (29.1 % of all cities) are classified as general.

Based on the stratified sampling data of decoration prices in regions with different economic development levels, the correction coefficients of the impact of three types of economic development levels on housing decoration are analyzed and given. The correction coefficients are listed in table 7 together with the standard coefficients of *Earthquake site work part 4 : direct disaster loss assessment* ^[4] for comparison and reference.

Table 7. Correction coefficient of economic development level γ_1

Economic development level	General	More developed	Developed
Correction Factor (National regulation)	1.0	1.15	1.3
Correction Factor (This paper)	1.0	1.2	1.35

Note : The classification standard of economic development level is based on the provisions of the National Bureau of Statistics, and per capita GDP is the index.
In national regulation:developed(>300,00),more developed(150,00~300,,00),general($\leq 150,00$)
In this paper:developed(>900,00),more developed(500,00~900,00),general($\leq 500,00$).

4.4 Considering the decoration loss correction coefficient of different uses

For buildings with different use functions, the correction γ_2 is used in *Earthquake site work-Part 4 : Direct disaster loss assessment* ^[4] to take into account the difference in their renovation costs.

In this paper, the use function of the building is divided into six categories : residential, medical, educational, office, industrial and commercial, and the decoration price is investigated and counted respectively. The research and analysis show that commercial buildings have higher requirements for scale, image, design, environment and quality due to the existence of commodity sales and the need to attract buyers with the help of indoor environment, so their decoration prices are relatively high ; medical, education and office buildings because of its decoration design and material selection relatively pay attention to practicality and economy, simplify the decoration design and construction process, thus reducing the overall decoration cost ; the factory building is

generally used for production work, and its interior needs to be equipped with a large number of mechanical equipment, with more emphasis on functionality and durability, so its decoration price is correspondingly low ; the decoration cost of residential buildings is determined according to the needs of homeowners, and the price of high-end decoration is higher.

Based on the decoration price data of different use functions, the correction coefficient of the influence of use function on house decoration is analyzed and given, which is listed in Table 8 together with the standard coefficient of *Earthquake site work-Part 4 : Direct disaster loss assessment* ^[4] for comparison and reference.

Table 8. Use function correction factor γ_2

National regulation	Function	Dwelling house	Education、 Medical building	Public building
	Correction factor	1.0~1.1	0.8~1.0	1.1~1.2
This paper	Function	Dwelling house	Education、 Medicalp、 Office、 Industry building	Commercial building
	Correction factor	1.0~1.2	0.8~1.1	1.1~1.3

5. Summary

This paper refers to the evaluation method of building main body and urban decoration loss in the fourth part of *Earthquake site work-Part 4 : Direct disaster loss assessment* ^[4], expert experience and engineering example calculation results, and gives the reference value of main body cost increase coefficient of reinforced concrete structure under different fortification intensity. Based on the newly released official data, the urban division standard is updated, and the correction coefficient in the calculation process of decoration loss assessment is recalculated.

The values obtained in this paper are improved compared with the values given in the specification. The phenomenon that the seismic fortification level causes the main body cost to increase reflects that China 's requirements for building seismic capacity are more stringent, especially for areas where the seismic fortification level has changed. In the process of loss assessment, the impact of seismic fortification level should be taken into account. The increase in the cost of urban decoration highlights the continuous development of China 's economic level, the improvement of people 's living standards, and the consumption of housing decoration. The proportion of high-end decoration in developed cities is higher than that in small cities, and the cost of decoration is also higher. The decoration cost of commercial buildings is also much higher than that of other functional buildings, so various factors should be fully considered when evaluating the loss of decoration.

The obvious differences in standard division and coefficient values in different periods also reflect the importance of updating. The process of loss assessment not only relies on mature calculation methods, but also needs to be combined with real-time data to obtain scientific and realistic results.

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