Analysis of Frame House Damage Based on Instrumental Seismic Intensity

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Abstract. The instrumental seismic intensity, obtained from seismic instruments recording ground motion, is an important indicator for assessing earthquake intensity and the degree of damage to buildings. Frame structures, as common building forms, attract significant attention for their performance during earthquakes. This study aims to explore the correlation between instrumental intensity and the seismic damage of frame structure buildings, deepening our understanding of earthquake disaster mechanisms and providing scientific basis for seismic design and disaster management. Using OpenSees software, 125 nonlinear model groups of 1-5 story frame structures were established, and their damage indices under seismic conditions were calculated. The relationship between instrumental intensity and seismic damage indices of frame structure buildings was analyzed. The results indicate a certain correlation between building damage and instrumental seismic intensity, with class D buildings designed for seismic resistance meeting engineering requirements.

Keywords: Instrumental Seismic Intensity; Frame Structure; Building Damage

1 Introduction

Earthquakes are highly destructive and extremely sudden natural disasters [1]. China is situated between two active seismic zones, the circum-Pacific seismic belt and the Eurasian seismic belt, experiencing frequent, intense, and shallow earthquakes, making it one of the countries most affected by seismic disasters. Therefore, the scientific and effective prevention and mitigation of earthquakes is a pressing issue for researchers. Instrumental seismic intensity refers to the seismic intensity calculated based on seismic observation records. Instrumental intensity, compared to macroseismic intensity, can be quickly obtained post-earthquake using observational data from seismic stations and following certain calculation methods. Instrumental seismic intensity is characterized by its intuitiveness, simplicity, and speed, providing crucial information for rapid post-earthquake damage assessment and emergency response decision-making[2]. How-

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ever, there still exists a significant difference between macroseismic intensity and instrumental seismic intensity[2],in actual seismic events, different buildings may experience varying degrees of damage within the same intensity zone, even if they are of the same type. Research by Cai [3] indicates a clear correlation between seismic damage to masonry structures and instrumental seismic intensity, while research by Wen [4] suggests that the peak ground acceleration (PGA) and peak ground velocity (PGV) required for calculating instrumental seismic intensity are well-correlated with structural seismic responses. In order to better analyze the relationship between instrumental intensity and frame house damage, this study establishes a group of 1-5 storey nonlinear structural models based on D-class buildings in the Chinese Seismic Intensity Scale, aiming to explore the correlation between instrumental seismic intensity and frame house damage.

2 Instrumental Seismic Intensity

Instrumental seismic intensity is calculated from seismic motion records obtained by seismic observation instruments. It reflects the degree of damage in the vicinity of the station based on the empirical relationship between macro seismic intensity and seismic motion parameters, providing a calculated intensity.

2.1 Selection of Ground Motion Data

Considering regional differences and data completeness, a broad range of data was selected. The seismic motion data chosen for this study include acceleration records from three components (two horizontal components and one vertical component) obtained from seismic stations within a 100km radius of 10 earthquakes in seven provinces of mainland China (see Table 1). In total, there are 1068 records.

Table 1. List of 10 Seismic Events Used in This Study

No	Earthquake Name	Location of Epicenter	Epicenter Time	Magnitude
1	WenChuan Earthquake	SiChuan Province	2008.05.12	M8.0
2	LuShan Earthquake	SiChuan Province	2016.04.20	M7.0
3	JiuZhaiGou Earthquake	SiChuan Province	2017.08.08	M7.0
4	YangBi Earquake	YunNan Province	2021.05.21	M6.4
5	MenYuan Earthquake	QingHai Province	2022.01.08	M6.9
6	LuDing Earthquake	SiChuan Province	2022.09.08	M6.8
7	PingYuan Earthquake	ShanDong Province	2023.08.06	M5.5
8	PuLanDian Earthquake	LiaoNing Province	2023.08.23	M4.6
9	Atushi Earthquake	XinJiang Uygar Autonomous Region	2023.11.08	M5.4
10	JiShiShan Earthquake	GanSu Province	2023.12.18	M6.2

2.2 Instrumental Seismic Intensity Calculation

Calculate instrumental seismic intensity according to the the Chinese Seismic Intensity Scale：① Subtract the pre-event arithmetic mean from the seismic motion records' recording time process.② Convert acceleration records to velocity records.③Digital Filtering: Apply a digital filter with a bandpass range of 0.1 to 10 Hz to each component of the seismic motion acceleration and velocity records. ④Calculate the composite acceleration records $a(t_i)$ in three directions (EW, NS, UD) using Equation (1), and compute the composite velocity records $a(t_i)$ according to Equation (2).⑤Compute PGA and PGV of the three-component synthesized seismic motion using Equations (3) and (4).⑥ Determine the instrumental seismic intensity parameters, I_A for peak acceleration and I_V for peak velocity, using Equations (5) and (6). Then calculate the I_I using Equation (7).

$$a(t_i) = \sqrt{a^2(t_i)_{E-W} + a^2(t_i)_{N-S} + a^2(t_i)_{U-D}} \tag{1}$$

$$a(t_i) = \sqrt{v^2(t_i)_{E-W} + v^2(t_i)_{N-S} + v^2(t_i)_{U-D}} \tag{2}$$

$$PGA = \max\left[a(t_i)\right] \tag{3}$$

$$PGA = \max\left[v(t_i)\right] \tag{4}$$

$$I_A = 3.17\,\lg(PGA) + 6.59 \tag{5}$$

$$I_V = 3.00\,\lg(PGV) + 9.77 \tag{6}$$

$$I_I = \begin{cases} I_V & , \ I_V \geq 6.0 \ and \ I_V \geq 6.0 \\ (I_V + I_A)/2, & I_V < 6.0 \ and \ I_V < 6.0 \end{cases} \tag{7}$$

3 Seismic Damage Assessment of Buildings

3.1 Simplified Structure

For frame structures, as shown in Figure 1 below, simplification is achieved using the storey model. The shear storey model offers a moderate level of simplification and relatively lower computational requirements. Compared to using a single-degree-of-freedom system, employing the concentrated mass shear model enables the assessment of the damage state of each storey within the structure.

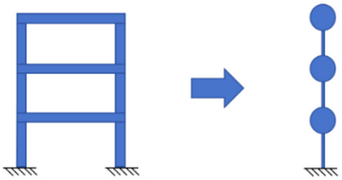

Fig. 1. Multi-story concentrated-mass shear model for a building

3.2 Model Parameter and Damage Parameter Determination

Model parameter and damage parameter determination for shear layer models based on Chinese standards primarily control the structure's response through bearing capacity and displacement. Since most RC frames undergo seismic design, the horizontal seismic action values can be calculated using the base shear method, and then the shear design values can be calculated from this. The design bearing capacity of each layer is then multiplied by the structure's yield amplification factor [5] and peak amplification factor [5] to obtain the yield bearing capacity and peak bearing capacity of each layer of the structure. A model for 1-5 story frame structures was established based on the reference [6]. Taking a three-story frame structure as an example in Table 2, a model is established according to the 7-degree design level.

Modeling is done using OpenSees software, OpenSees is a finite element modeling software developed by the PEER. It is widely used in the field of earthquake engineering, with the selection of the Hysteretic Material constitutive model, which aligns with the recommendations in the literature [7]. A three-line hysteretic curve is chosen to simulate the hysteresis energy dissipation between layers of RC frame structures, providing a relatively simple single-parameter hysteresis curve model. This model uses only one hysteresis energy dissipation parameter to describe the structural hysteresis energy dissipation characteristics and can better reflect the actual situation, with a value of 0.25.

$$\tau = \frac{A_p}{A_b} \tag{8}$$

In the equation:A_p represents the area enclosed by the pinching hysteresis loop, A_b represents the area enclosed by the ideal elastic-plastic hysteresis loop.

The structural damping is referenced from literature [8]. By controlling key parameters such as storey height and mass variation, and through permutation and combination, 25 three-story structures are obtained, forming a group of nonlinear structural models.

Table 2. Three-story frame structure model parameters

		1	2	3
Stiffness KN/mm	K_0	10305.6	10305.6	8120.1
	K_1	2516.7	2516.7	2030.0
Strength (KN)	Q_y	34358.1	27915.2	15031.6
	Q_u	106509.8	86537.1	46597.9
Mass(t)	T	915.6	915.6	721.6
Height (m)	H	106509.8	86537.1	46597.9

The Chinese Seismic Intensity Scale divides structural damage into five levels: (1) basically intact; (2) slight damage; (3) moderate damage; (4) severe damage; and (5) destroyed. Referring to Xiong Chen's suggestion [7], the determination of structural damage level is based on a comprehensive consideration of force and displacement. For the frame structures studied in this paper, it is recommended to use force-based damage limits when the structural damage is minor, and displacement-based damage limits when the structural damage is significant, as shown in Table 3 below.

Table 3. Damage Limits for Three-Story Frame Structures

	Threshold for Slight Damage	Threshold for Moderate Damage	Threshold for Severe Damage	Threshold for Destruction
Three-Story Frame Structures	Q_y	$(Q_y + Q_u) / 2$	0.0133	0.0333

Quantitative ranges of seismic damage indices corresponding to different levels of damage [3] are as follows, as shown in Table 4.

Table 4. Quantitative Range of Seismic Damage Indices

Damage Level	Range of Seismic Damage Index	Quantitative Seismic Damage Index
Basically Intact	$0.00 \le d \le 0.10$	0.05
Slight Damage	$0.10 \le d \le 0.30$	0.20
Moderate Damage	$0.30 \le d \le 0.55$	0.43
Severe Damage	$0.55 \le d \le 0.85$	0.70
Complete Damage	$0.85 \le d \le 1.00$	0.93

3.3 Seismic Damage Calculation

For the established nonlinear structural group, input seismic motion, and determine the damage value based on the results. Take the maximum value of the east-west direction and the north-south direction as the damage value of the structure under this seismic motion.

For example: Select the record from the southwest direction of the SD. P0025 station in the M5.5 earthquake on the plain, as shown in Figure 2.

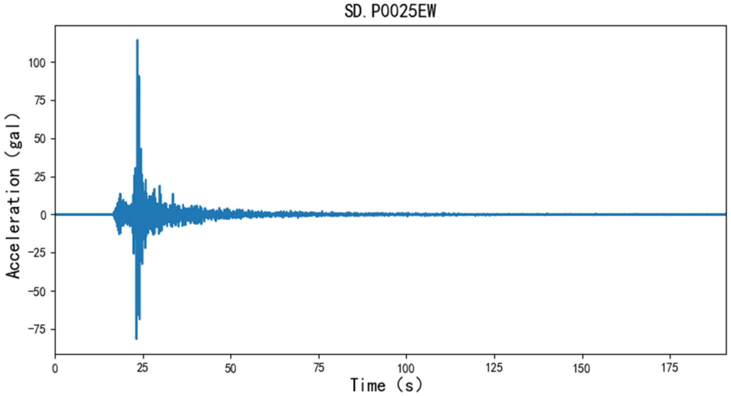

Fig. 2. Acceleration Time History Plot for SD. P0025 in the East-West Direction

The seismic intensity calculated by the station instrument is 7.0. The input seismic motion for the established three-story nonlinear structural group yields the following results:

Table 5. Proportion of Each Damage Level for Three-Story Frame Structures

	Basically Intact	Slight Damage	Moderate Damage	Severe Damage	Destruction
Proportion	0.76	0.24	0.00	0.00	0.00
Quantitative Seismic Damage Index	0.05	0.20	0.43	0.70	0.93

The seismic damage index for this three-story frame structure group as shown in Table 5, is calculated by averaging the damage indices according to their respective proportions:

$$D = \sum_{i=1}^{5} d_i \lambda_i = 0.76 * 0.05 + 0.24 * 0.20 + 0.00 * 0.43 + 0.00 * 0.70 + 0.00 * 0.93 = 0.086$$

The distribution of the model group for different numbers of stories refers to the post-earthquake statistics from Yangbi [9].

Table 6. Proportion of Each Damage Level for Three-Story Frame Structures

	Basically Intact	Slight Damage	Moderate Damage	Severe Damage	Destruction
Proportion	0.32	0.28	0.27	0.09	0.04
Seismic Damage Index	0.05	0.05	0.086	0.086	0.086

For this seismic record, as shown in Table 6, the average seismic damage index for the frame structure is calculated as follows:

$$D = 0.32 * 0.05 + 0.28 * 0.05 + 0.24 * 0.086 + 0.09 * 0.086 + 0.04 * 0.086 = 0.0644$$

4 Analysis and Conclusion

According to the calculation results, there is a clear correlation between the instrument seismic intensity values and the damage level of the frame structures, as shown in Figure 3 below. As the instrument seismic intensity increases, the frame structures gradually transition from being basically intact to being destroyed. The calculated Spearman correlation coefficient is 0.648.

Before the 7th degree, the frame structures experience only slight damage or less under seismic motion, indicating that Class D buildings, which require seismic fortification, meet the seismic fortification requirements in terms of damage level under seismic action. Around the 8th degree, moderate damage begins to appear, and at the 9th degree, structures gradually start to experience destruction. In comparison with Cai[3], the significantly smaller damage observed in class D buildings under the same instrumental intensity indicates that frame structures inherently possess good ductility, demonstrating their advantages over other types of structures under earthquake loading.

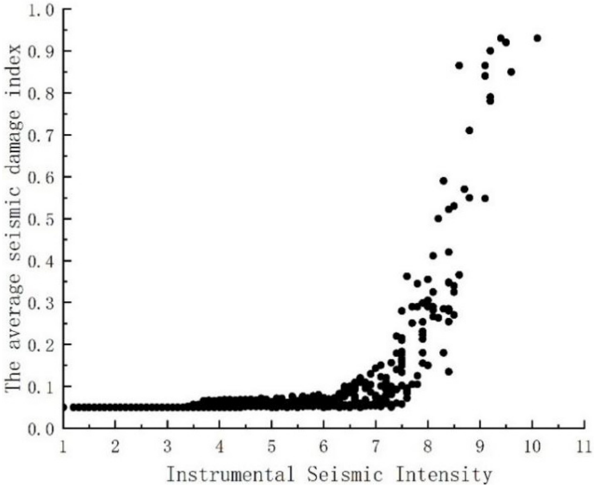

Fig. 3. Fragility Curve of the Structural System Diagram of the relationship between the seismic intensity of the instrument and the seismic damage index of the frame house

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