Research Status of Relationship between Seismic Instrument Intensity and Ground Motion Parameters

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Abstract. Seismic intensity can simply reflect the extent and distribution of earthquake’s impact and damage. A comprehensive and detailed assessment of intensity requires a long time and a lot of manpower and material resources. The ambiguity of the intensity assessment index and the subjectivity of the professionals often result in differences in assessment results. Seismic instrument intensity based on strong earthquake observation records can effectively avoid the above problems, and can quickly and objectively assess the impact and possible damage degree of the surface near the strong earthquake station. This paper summarizes the research progress of seismic instrument intensity and points out the development direction of seismic instrument intensity.

1. Introduction

Destructive earthquakes often lead to foundation failure, ground rupture, building structure damage, property damage and casualties. If the earthquake’s impact range and the severity of the earthquake damage can be quickly assessed, the efficiency of earthquake relief can be greatly improved.

Seismic intensity is comprehensively assessed by human feeling, implement reaction, damage degree of buildings and surface rupture, which refers to the average influence degree of earthquake in a certain area. The traditional seismic intensity survey method requires professionals to go to the disaster areas for field investigation after the earthquake, and compare the damage degree of building structures and surface rupture with Seismic intensity scale of China\textsuperscript{[1]} to comprehensively assess the intensity. Post-earthquake damage survey need to spend enormous human and material resources, and it’s difficult to complete the survey in a short period. Timeliness is of great significance for government to formulate emergency rescue plan and make decisions for earthquake relief. For example, after the Wenchuan earthquake in 2008, the China Earthquake Administration organized a large number of professionals to carry out the intensity survey of the earthquake. The intensity distribution map of the earthquake wasn’t officially released until 109 days after the earthquake. The concept of intensity is endowed with the dual connotation of earthquake damage degree and intensity of shaking, which makes the intensity have properties of ambiguity, subjectivity, average and comprehensiveness\textsuperscript{[2]}. Researchers have been working to find objective physical quantities to quantify seismic intensity.

Seismic instrument intensity refers to the estimated intensity of the earthquake based on the strong motion observation of earthquakes\textsuperscript{[3]}. Seismic instrument intensity has the advantages of convenience...
and fast computation. It can quickly get the spatial distribution of seismic intensity within a few minutes after the earthquake and identify the mei-zoseismal area, which can make up for the disadvantages of timeliness of the Post-earthquake damage survey and provide scientific basis for government emergency rescue, damage assessment and reconstruction of disaster area. At present, the instrument intensity is mainly estimated based on the following ground motion parameters: (1) the peak parameters of the ground motion time history (peak acceleration, peak velocity); (2) spectrum parameters(response spectrum, Fourier spectrum and spectral intensity); (3) reference acceleration (the Japan Meteorological Agency intensity estimation method); (4) other parameters (cumulative absolute speed, Arias intensity); (5) Multiple parameter combinations (Multiple PGA and SI etc.).

2. Research progress of relationship between seismic instrument intensity and ground motion parameters

2.1. relationship between seismic instrument intensity and peak parameters

In recent years, the development of strong motion seismograph and the in-depth study of the quick reporting system of intensity have greatly promoted the development of disaster prevention and mitigation. The instrument intensity are commonly obtained by peak parameters(PGA, PGV). Trifunac et al.(1975) applied 187 ground motion records from 57 earthquakes in the western United States. This study analyzed the correlation between peak parameters PGA, PGV and intensity, and obtained a quantitative relationship between PGA, PGV and intensity with minimal square regression[4]. Murphy et al.(1977) analyzed the relationship between intensity and PGA, which was obtained nearly 900 seismic observations from Europe, the United States and Japan. And the study showed that the peak acceleration in the corresponding intensity range varies widely from different region[5]. Wald et al. (1999) used the records of eight earthquakes in California region to obtain the quantitative relationship between seismic intensity and ground motion parameters PGA and PGV, which improved the quantitative correlation parameter values by increasing the amount of seismic data compared with previous studies[6-7]. In this study, it was found that the PGA was saturated in the high intensity area. In the higher intensity level, there is a better statistical relationship with PGV. ShakeMap intensity rapid reporting system in the United States applied results of Wald’s study. After the Northridge earthquake in 1994, the United States Geological Survey began to promote ShakeMap system. The ShakeMap system computes the instrumental intensity by combining peak acceleration and peak velocity, and maps the contours of parameters such as instrument intensity, PGA and so on for public release. The ShakeMap system plays an important role in earthquake relief, reduction of casualties and decrease of property losses in the United States.

Yih-Min Wu et al. (2003) applied the strong motion data of the ChiChi earthquake and the database of seismic damage in the corresponding areas. The quantitative relationship between intensity and PGA, PGV was obtained by regression. The near-field acceleration records of shallow shocks are similar to a high frequency pulse, so that the computed intensity will be higher than the actual intensity, so the correlation between PGV and intensity is better than PGA, and PGV was recommended to compute instrument intensity[8]. Linkimer et al. (2008) applied data from 108 earthquakes in Costa Rica to regress the empirical relationship between the maximum value of the horizontal components of PGA ,the average of the horizontal component of PGA and seismic intensity[9]. Paiolplee (2012) used 10 strong motion data in the Myanmar region to regress the quantitative relationship between MMI and PGA, which was important for earthquake damage prediction and determination of engineering parameters in Myanmar. By comparing with other studies, it was found that the computed intensity of this study is higher when the PGA values were similar. The main reason is that the seismic requirements of buildings in Myanmar are not high, which leads to serious damage of buildings[10]. Caprio (2015) applied the orthogonal regression method to get the reversible relationship between PGA, PGV and intensity. In the study, the regional dependence of relationship was analyzed to obtain a new global relationship, and improved the intensity estimation in the application of seismic risk analysis[11]. Ogweno et al (2017) used the seismic data of 37 earthquakes in the United States to
obtain the empirical relationship between PGA, PGV and intensity by using orthogonal regression, which can be used to evaluate the seismic parameter distribution of historical earthquakes without instrument records[12]. Duke et al (2019) used the seismic data of 34 earthquakes in Western China, obtained the weight by analytic hierarchy process, and then regressed the quantitative relationship between the intensity and PGA, PGV by weighted least square method[13].

The damage caused by earthquake is a complex process of three factors: the rupture process of seismic source, the propagation of seismic wave in the earth medium and the site conditions of the corresponding area. In order to improve the error of instrument intensity calculated by the peak parameters of ground motion, some scholars added the parameters such as epicentral distance, magnitude and site conditions to the relationship, so as to improve the accuracy of instrumental intensity. Kaka et al. (2004) obtained the quantitative relationship between MMI and PGV, PSA by using the data of 18 significant earthquakes in the northeast of the United States. This study found that the residual has an increasing trend with the increase of the epicentral distance, so the epicentral distance was added to the quantitative relationship to improve the intensity error[14]. Atkinson et al. (2007) proposed the quantitative relationship between intensity and PGA, PGV, PSA of different periods based on the seismic data of Central America and California. Through analysis, it was found that the correlation between PGV and intensity was better. The quantitative relationship including magnitude and epicentral distance was applicable to the whole North America[15]. Nemati (2015) used the macro intensity and strong motion observation records of 16 earthquakes in Iran to obtain the empirical relationship between PGA and earthquake intensity, and then added magnitude and epicentral distance to the relationship, it was found that the regression equation including magnitude and epicentral distance had better results[16]. Panjamani (2016) used the data of 21 earthquakes in the Himalaya region to obtain the empirical relationship between the intensity and PGA, PGV by orthogonal regression, in which the magnitude and epicentral distance were added to eliminate the regional dependence, and the equivalent shear wave velocity was added to eliminate the influence of site factors[17]. Alvarez et al. (2012) found that the linear least square method would bias the specific value in the data to affect the regression results, so the statistical relationship between Modified Mercalli intensity and PGA, PGV was obtained by using three nonlinear regression methods: support vector regression, multilayer perceptron and genetic programming, then added the magnitude, epicentral distance to the relationship[18]. Li Liang et al. (2018) studied the instrument intensity algorithm of the USGS and Japan Meteorological Agency, filtered the seismic data records, and then substituted the peak value of the resultant acceleration and velocity of the three components into the empirical relationship to compute the instrument intensity[19].

The relationship of the intensity regressed from the single peak ground motion parameter has the advantages of fast calculation. And the peak ground motion parameter has the characteristic of simplicity. However, due to the great discreteness of the ground motion observation data within the same intensity range, the correlation between the peak ground motion parameter and intensity was low, and the calculated instrument intensity value error is large. The data from different regions also makes the coefficient of the instrument intensity relationship different.

2.2. Relationship between seismic instrument intensity and spectrum parameters

2.2.1. Response spectrum parameters

The response spectrum shows the relationship between the maximum response of single degree of freedom system with ground motion input and the natural vibration characteristics of single degree of freedom system. Atkinson et al.(2000) applied the data of 29 California earthquakes to get the quantitative relationship between PGA, PGV, pseudo acceleration response spectrum of different periods and intensity. It was found that the relationship between PSA and intensity is affected by magnitude at low frequency and epicentral distance at high frequency. The quantitative relationship is of great significance to establish the relationship between earthquake damage assessment and ground motion parameters[20]. Boatwright et al. (2001) applied the 66 strong motion records of Northridge
earthquake, regressed the quantitative relationship between PGA, PGV, pseudovelocity response spectrum and intensity. And the relationship between PGA, PGV, pseudovelocity response spectrum and intensity is better than the relationship of PGA[21]. Faenza et al. (2010) used data of Italy to obtain the relationship between MSC intensity and PGA, PGV, PSA of different periods by orthogonal regression, and the relationship is applicable to compute instrument intensity of ShakeMap system in Italy[22]. Saman et al. (2011) used the seismic records of 10 earthquakes in Iran, regressed the relationship between the intensity and PGA, PGV, PSA of different periods with the least square method. It was found that the intensity value which was computed by PGV is better than other parameters through the analysis of the intensity’s residual[23]. Dangkua et al. (2011) used the seismic data of the United States and Canada to obtain the relationship between PGA, PGV, acceleration response spectrum of different periods and intensity[24]. Worden et al. (2012) applied the intensity observation database collected by Do You Feel It? system and the ground motion data collected in California, established the probability distribution of ground motion parameters and intensity, and then get the quantitative relationship between intensity and PGA, PGV, PSA of different periods[25]. In most earthquake events, the number of strong motion records in the high-intensity area and the low-intensity area was less, and the distribution of data was uneven, which resulted in the regression results controlled by the intermediate intensity values. Considering the data heterogeneity, some scholars used the weighted regression to improve the empirical relationship of seismic intensity. Ma Qiang et al. (2014) used 115 strong earthquake records from 8 destructive earthquakes in China, established the statistical relationship between 24 different ground motion parameters and seismic intensity by using the weighted least square method. This study found that the intensity value computed by horizontal velocity response spectrum and PGV were better than other parameters[26].

The response spectrum can reflect the characteristics of both single degree of freedom structure system and ground motion input at the same time. From the engineering point of view, the response spectrum considers the frequency component of ground motion, which makes it possible to calculate the intensity by using the response spectrum parameters in the global scope, but the premise is that there is little difference in the architectural practice experience of different region.

2.2.2. Fourier spectrum parameters

The Fourier spectrum contains the characteristics of the amplitude and frequency of the ground motion and it was widely used to analyze the characteristics of the source and propagation path in seismic events. Trifunac (1979, 1989) applied the seismic data of the western region of the United States to estimate the Fourier amplitude spectrum by intensity and site conditions[27-28]. Sokolov et al. (1998, 2002) studied more than one thousand records of ground motion and proposed the method of using the Fourier spectrum of ground motion to evaluate the seismic intensity. In this study, the amplitude corresponding to the narrower frequency band in the Fourier spectrum was used to evaluate the seismic intensity, and the amplitude corresponding to the Fourier spectrum moved to the low frequency direction with the increase of the intensity[29-30]. The relationship between the Fourier spectrum and the seismic intensity considered the influence of the seismic frequency. It has a guiding role for the earthquake resistance of buildings but the evaluation of the seismic intensity by the Fourier spectrum is of great significance only in the range of the natural frequency of the structure.

2.2.3. Spectral intensity

In 1952, Housner proposed that the area of the velocity response spectrum between 0.1-2.5s as spectral intensity which was taken as the measurement index of ground motion intensity. Spectral intensity is intended to reflect the energy input to the buildings and the damage degree of the buildings. Wang Yushi et al. (2008,2010) applied the acceleration records and corresponding intensity data obtained from destructive earthquakes in the west of China to regress the relationships between different ground motion parameters and intensity by the hypothesis test method, it was analyzed that the relationship between spectral intensity and intensity was better than other parameters[31-32]. Karim et al. (2002) used strong motion records from 13 earthquake events in Japan, the United States and Taiwan to
obtain the quantitative relationship between ground motion parameters and intensity by two-stage linear regression method. The analysis results of this study show that the correlation between intensity and spectral intensity is better than PGA, PGV[33]. Japan has developed a spectral intensity sensor, which takes spectral intensity as a reliable index of ground motion intensity and has been widely used in the monitoring of railway and gas pipeline. When the spectral intensity exceeds 60cm/s, the gas pipeline will be forced to close and the rail train will stop running, which is of great significance to reduce the earthquake disaster.

2.3. Relationship between seismic instrument intensity and reference acceleration

The factors of structural damage caused by earthquake are complex. The seismic parameters used in the calculation of instrument intensity of Japan Meteorological Agency take into account the three elements of peak value, duration and frequency of ground motion, and the factors of earthquake influence are relatively comprehensive. The algorithm of seismic instrument intensity in Japan was put forward by Japan Meteorological Agency in 1996. the first step is to compute the Fourier spectrum of three component acceleration, then to multiply the Fourier spectrum by filter functions and to compute the filtered acceleration by inverse Fourier transform. The next step is to calculate the composite value of three component acceleration, in this step the amplitude with duration more than or equal to 0.3s was taken as the reference peak acceleration. Finally, the intensity value was calculated by the quantitative formula[34]. Shabestari et al. (2001) applied the method of calculating reference peak acceleration of Japan Meteorological Agency to the seismic records of three destructive earthquakes in California, regressed the quantitative relationship between Modified Mercalli intensity and reference peak acceleration, and suggested that this relationship should be regarded as a compatible empirical relationship for California[35]. Jinxing et al. (2013) designed band-pass filter with pure amplitude by referring to the algorithm of instrument intensity of Japan Meteorological Agency, taking into account the differences between Chinese building types and building materials and Japan, as well as the natural vibration period of main buildings in China. It was found that the amplitude with duration more than or equal to 0.5s was relatively stable and was taken as the reference peak acceleration to calculate instrument intensity[36].

2.4. Relationship between seismic instrument intensity and other parameters

With the development of seismology, scholars have also studied the correlation between other ground motion parameters which represent different characteristics of earthquake and intensity. A. Arias proposed Arias Intensity(Ia) as a physical parameter to measure the strength of ground motion and corresponded to the earthquake damage degree. The American Electric Power Research Institute proposed the cumulative absolute velocity (CAV) which was used for operational control of nuclear power plants during earthquakes. Tselentis et al. (2008) firstly analyzed the correlation between PGA, PGV, CAV, Ia and seismic intensity. The quantitative relationship between parameters and seismic intensity was regressed by using the seismic data of Greece. And the site conditions, magnitude and epicentral distance were added to the formula during the regression analysis[37]. Tselentis et al. (2010) proposed a new method based on artificial neural network and genetic algorithm to regress the quantitative relationships which included magnitude and epicentral distance between seismic intensity and PGA, Ia, CAV[38]. Lin Lin et al. (2011) took the seismic data obtained from 6 earthquakes in China and 3 earthquakes in California as data sets, and used multiple linear regression method to improve the error of intensity. In this study, the joint assessment of intensity by CAV and SI was superior to other parameters[39].

Seismic parameters which reflect different seismic characteristics greatly enrich the contents of seismology and provide a variety of quantitative relationships for the evaluation of instrument intensity. However, the correlations between seismic parameters and intensity are different, so taking great consideration to select appropriate seismic parameters to evaluate the seismic intensity is significant. Because the earthquake events, the focal mechanism of each earthquake, and the building seismic fortification standards are diverse in different areas, there is no unified standard quantitative
relationship between ground motion parameters and seismic intensity at present. And the computed instrument intensity is not completely consistent with the macroscopic earthquake damage. But the physical significance and scientific nature of the instrument intensity make it of significance.

3. Prospect and conclusion
The development of instrument intensity depends on the accumulation of reliable seismic records and the construction of strong motion observation networks. In the area with large numbers of strong earthquake observation instruments, it’s possible to know the region with heavy damage in a short time, which provides reliable basis for guiding emergency rescue after the earthquake.

with the continuous development of strong earthquake observation instruments and the accumulation of ground motion records, the quantitative relationship between intensity and ground motion parameters will be improved, which provides reliable guidance for the seismic fortification of buildings, earthquake disaster assessment and earthquake rapid rescue. However, there are still some deficiencies of the relationship between ground motion parameters and instrument intensity:

(1) There is a good statistical relationship between the intensity and the average value of the peak ground motion parameters, but the dispersion of the intensity and seismic peak parameters is large. The peak parameters may be several times or even higher different under the same intensity level.

(2) Rounding the instrument intensity value may cause the deviation of the instrument intensity result to increase, so the method of instrument intensity rounding needs to be carefully considered.

(3) There are many factors of structural damage caused by earthquake, so it’s necessary to study further to select appropriate ground motion parameters in the process of establishing reliable quantitative relationship.

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