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QUANTITATIVE EVALUATION OF ENGINEERING FORTIFICATION MEASURES AGAINST EARTHQUAKE DISASTER

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Abstract

Seismic engineering fortification measures are widely adopted in earthquake countries and regions against disaster. The decision makers and engineers expect the measures to reduce loss and casualty during the next destructive shock. The most reliable way to validate the measures is the damage data from regions without and with fortification in same event. The 2008 great Wenchuang earthquake caused serious damage in a quite large area, where engineering measures had been carried out for up to 30 years before the quake, and fortification intensity was VII in most cities/towns, VI or VIII at some cities/towns, IX in few towns. The unique valuable fact is that the fortification intensities at some cities/towns had been changed from three versions of the zoning maps of China, such as VIII in 1980s to VII in 1990s in Maoxian, IX in 1980s to VIII in 1990s in Jiuzhaigou. As a quantitative evaluation of the engineering measures in that region, this paper deals with the relation between fortification level and damage of buildings on a firm foundation of the survey data. The fortification intensities of the damaged buildings are basically inferred from the construction years and the site locations on the corresponding zoning map with certainty, since most of those information are not available in all damage survey reports. The damage matrices related with fortification intensity for brick- concrete structure and frame structure building for the region are presented. The results show quantitatively the decreasing of damage with the increasing of fortification intensity as expected. They could be adopted further in benefit-cost analysis to improve the acceptable risk level in the region.

Keywords: damage survey; damage matrix; fortification intensity

1. Introduction

Seismic engineering fortification measures are widely adopted in earthquake-prone countries and regions worldwide against disaster. In general, some additional cost must be paid for the fortification. The decision makers and engineers expect the measures to reduce loss and casualty during the next destructive shock. We should recall the words of Housner, the founder of Earthquake Engineering in US, "it is necessary to balance the cost of seismic design against the reduction of future losses from earthquakes" and "it must also be kept in mind that if the cost of construction is increased by 5%, then 5% fewer structures will be built" [1]. The most difficult step in the balance is to evaluate the measures quantitatively. The most reliable way to validate the measures is to count the damage data from regions without and with fortification in the same event. In China, comprehensive seismic fortification has been carried out for more than 40 years, for the regions with intensity VII or more on the hazard map at the beginning, and then expanded to intensity VI region in this century [2]. Experience from many earthquakes show the fact that the loss and casualty mainly caused by damage of structures, especially by collapse [3, 4]. Therefore, the evaluation must be done from the damage data of buildings with various intensities. As the renewal of buildings in these years, most buildings in cities and towns of China are fortified now. The result of the evaluation must be very helpful for seismic planning, countermeasure and risk analysis.

The first example, showing benefit of seismic fortification, is in the Lijiang earthquake with magnitude 7.0 in 1996. The seismic intensity at Dayan town was VIII, while the fortification intensity before the event was VIII for about 10 years, and was IX for 5 years. Most brick - concrete structure or reinforced framing buildings were intact or slightly damaged, while 77 dead was 0.125% of the population [5]. A recent example is the case at three villages in the M8.0 Wenchuan earthquake in 2008. The villages had been newly built with fortification intensity VIII just before the quake, and suffered the same intensity during the shock, but all dwellings there were intact [6]. As well known, the damage of buildings depends on many factors, some of them could not be rated clearly, such as construction quality, so there must be strong randomness in damage data, single or a few examples are not enough to validate the fortification benefit.

The great Wenchuan earthquake in 2008, Sichuan, China, caused serious damage in a quite large area. Post-earthquake surveys provide a large amount of valuable data for the evaluation [7, 8]. This paper deals with the relation between fortification level and damage ratio matrix of buildings

In practice, it is much more difficult to build the matrix, since much more damage data must be available. One can see that statistic data must be four times of those without consideration of fortification, since a matrix must be built for each of the four fortification intensities, and the number of buildings with fortification intensity VIII or more is relatively few.

2. The fortification levels stipulated for the region before the 2008 Wenchuan earthquake

Before the great Wenchuan earthquake, seismic engineering fortification had been carried out for up to 30 years in the damaged region. There were three seismic zoning maps issued in China in 1977, 1990 and 2001, respectively [9, 10, 11]. The maps of Sichuan region from the national maps are shown in Fig. 1, Fig. 2 and Fig. 3.

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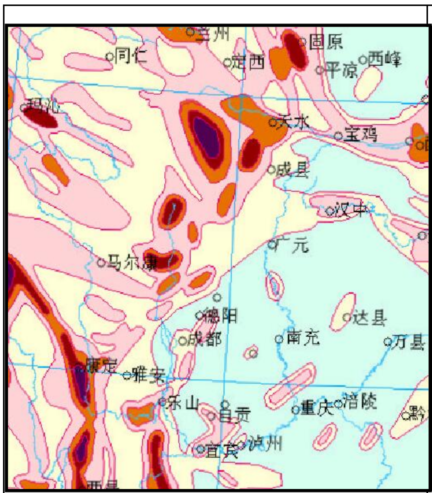

Fig.1 – Seismic zoning map (1977)

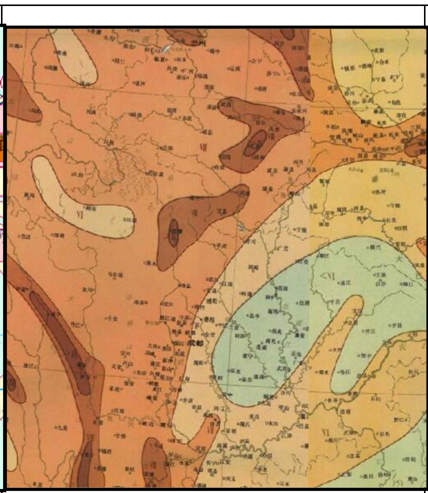
Fig.2 – Seismic zoning map (1990)

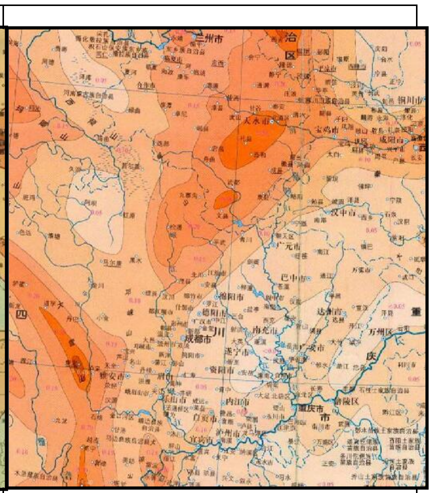
Fig.3 – Seismic zoning map (2001)

One can see from the maps that the fortification intensity of buildings constructed in most cities/towns was VII, VI or VIII in some cities/towns, IX in few towns during the three time periods. The unique valuable fact is that the fortification intensities at some cities/towns had been changed from the three zoning maps, such as VIII on 1977 map to VII on 1990 map at Maoxian, VIII on 1977 map to IX on 1990 map at Jiuzhaigou. It seems that the great earthquake provides an unprecedented opportunity to deal with the fortification benefit from the damage data of buildings with different fortification levels in the same town and during the same earthquake, at least in the same intensity area. Total 12 cities/towns with changed intensities in northern Sichuan are selected from hundreds of points on the maps, the fortification intensity as well as the intensity suffered in the Wenchuan earthquake for each of them are listed in Table 1. In the table, "Intensity in EQ" is for the suffered intensity in brief, the "In 80s" and "In 90s" are for the fortification intensities on the maps issued in 1977 and 1990 respectively, and the "In 01s" is for the equivalent intensity of acceleration on 2001 map.

Table 1- The fortification intensities and intensities suffered in the Wenchuan earthquake at the 12 cities/towns

No.	City (Town)	Intensity in EQ	In 80s	In 90s	In 01s
1	Beichuan	IX-X	VIII	VII	VII
2	Maoxian	IX	VIII	VII	VII
3	Songpan	VI	IX	≥IX	VIII
4	Jiuzhaigou	VI	VIII	IX	IX
5	Wenxian	VIII	VIII	VIII	VIII
6	Pingwu	VIII	VI	VII	VII
7	Jiangyou	VIII	＜VI	VI	VII
8	Mianyang	VII	＜VI	VI	VII
9	Anxian	VIII	VIII	VII	VII
10	Qingchuan	IX	VI	VII	VII

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11	Jiange	VII	＜VI	VI	VI
12	Guangyuan	VII	＜VI	VI	VI

One can find from the table that the fortification intensities cover VI, VII, VIII and IX, as well as the suffered intensity does.

The fortification intensities of the damaged buildings are basically inferred from their construction years and their site locations on the corresponding zoning map with certainty, since most of those information are not available in all damage survey reports.

3. The unique valuable damage data from a supplementary survey ten years later

Unfortunately, the fortification intensity information is not available in the survey data in most cases. For example, there are just 3007 damage data of buildings with fortification intensities, less than one tenth of the total damaged buildings [12], as listed in Table 2. In the table, BC is for brick-concrete building, RCF for reinforced concrete frame building, FFF for first floor frame, HR for high rise building, I&LS for industrial or large span structure.

Table 2 - Numbers of damaged buildings with fortification intensities in available data of the great Wenchuan earthquake [12]

Structure type		**BC**	**RCF**	**FFF**	**HR**	**I&LS**	**In total**
Number of damaged buildings	VI	609	236	176	43	43	1107
	VII	1066	138	316	11	78	1609
	VIII	261	16	8	6	0	291

One can see from the table that the total amount of damage data are thousands, but most are those with fortification intensity VII and less, and mainly of BC and RCF, those of FFF could be grouped into RCF. The data of HR and I&LS are obvious insufficient for statistics, and the data of BC or RCF are still insufficient if they are further grouped into four suffered intensities VI, VII, VIII and IX, and then into five damage ranks, almost intact, slightly damaged, moderately damaged, severely damaged and collapsed. Especially, the data with intensity VIII or more must be added for a stable result of the general damage statistics.

The reason of there is not enough fortification information of buildings in the post-earthquake survey reports is probably that it is very difficult to access that information in the environment of rescue and resettlement, much more than to take picture of damage buildings, to get information of gross area, floor number and purpose of the building, and to evaluate its damage rank. However, it is easy to know the construction year of a building, and the fortification intensity of a building in cities/towns listed in Table 1, may be inferred from the construction year with certainty.

A supplementary survey was organized in 2018. A team of 6 members went to the 12 cities/towns, to mine the information on construction years of the damaged buildings during the earthquake from various resources, such as building archives, building quality inspection station, and so on. After the survey, the data amount of damaged buildings with fortification intensities increased to 16471. The numbers of BC and RCF buildings with 4 fortification intensities are listed in Table 3.

One can see from the table that the data set is expanded significantly, in which the data number of each structure type with each fortification intensity is more than hundreds, except those with intensity XI.

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Table 3 - Numbers of damaged buildings with fortification intensities after the supplementary survey

Fortification Intensity	VI	VII	VIII	IX	In total
BC	10296	2415	973	49	13733
RCF	457	1964	296	21	2738
In total	10753	4379	1269	70	16471

4. Comparison of the statistical results

On basis of the data in Table 3, a damage ratio matrix is constructed by statistical analysis in groups of 4 intensities VI, VII, VIII and IX, and 3 fortification intensities VI, VII and VIII, since the data with IX is still not enough. The damage ratio is defined as the percentages of total gross area of buildings in each of five damage ranks, almost intact, slightly damaged, moderately damaged, severely damaged and collapsed, for each of four intensities and each of three fortification intensities. The results of BC and RCF buildings are listed in Table 4 and Table 5, respectively.

Table 4 - Damage ratio matrix of brick-concrete structure buildings （%）

Fortification intensity	Intensity	Almost intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
VI	VI	16.42	46.31	25.64	9.14	2.49
	VII	26.05	13.38	42.63	17.93	0.00
	VIII	8.55	22.28	39.12	16.63	13.42
	IX	0.13	18.84	36.2	41.28	3.55
VII	VI	79.63	13.17	4.95	2.25	0.00
	VII	52.73	30.73	12.89	3.5	0.16
	VIII	22.06	27.54	24.05	21.02	5.34
	IX	2.13	11.54	34.95	23.31	27.42
VIII	VI	84.64	11.37	3.99	0.00	0.00
	VII	65.40	29.05	3.24	2.31	0.00
	VIII	31.58	39.20	11.55	10.04	7.63
	IX	4.70	46.35	20.37	12.60	15.98

Table 5 - Damage ratio matrix of reinforced concrete frame buildings （%）

Fortification intensity	Intensity	Almost intact	Slightly damaged	Moderately damaged	Severely damaged	Collapsed
VI	VI	-	-	-	-	-
	VII	36.26	52.97	10.68	0.09	0.00
	VIII	15.41	23.24	38.03	10.88	12.44
	IX	0	6.3	44.61	49.08	0.00
VII	VI	89.57	4.56	3.25	2.62	0.00
	VII	76.01	21.78	2.02	0.19	0.00
	VIII	32.62	23.98	25.3	14.19	3.91
	IX	18.03	21.43	21.66	21.41	17.47
VIII	VI	94.40	1.82	3.78	0.00	0.00
	VII	64.17	32.65	3.18	0.00	0.00
	VIII	41.97	31.08	19.79	7.16	0.00

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	IX	0.00	79.37	20.63	0.00	0.00

One can see from the tables that the percentages in Almost intact, or in Almost intact and Slightly damaged rank(s) for the both types of buildings, increase obviously as the increasing of fortification intensity from VI to VII and to VIII, while those in Collapsed and Severely damaged ranks decrease, in general, especially for brick-concrete structure buildings. The percentages in a few grids do not decrease with fortification intensity increasing one degree, especially for RC frame structure buildings, as unexpected. The authors believe that it may come from the limited number of data for that situation.

5. Conclusion

The overall work of seismic engineering fortification has been carried for more than forty year in China, as well in Sichuan region. To evaluate the fortification measure quantitatively from damage data of the great Wenchuan earthquake, the authors of this paper study the relation between the damage ratio matrix with the fortification intensity.

We went to the 12 cities and towns for a supplementary survey in 2018, acquired rich data on the construction years of damaged buildings mainly of brick-concrete structure and frame structure during the great Wenchuan earthquake, and then inferred the corresponding fortification intensities of them with the seismic zoning maps of that region issued for three time periods.

Results of the damage ratio matrices of brick- concrete structure and RC frame structure buildings in Sichuan region, in total 13733 and 2738 respectively, are presented. The results show quantitatively decreasing of the damage with increasing of the fortification level as expected. They could be adopted further in benefit-cost analysis to improve the acceptable risk level in the region. Further study is going to be done with data from more other earthquakes.

6. Acknowledgements

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