New method of earthquake damage prediction of Single Building

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ABSTRACT :

In order to predict seismic damage of single building rapidly and effectively, through analyzing a large number of single building samples and the participation coefficients of seismic damage impact factors (Generally, structure features, seismic damage characteristics and requirements of norm are considered in the selection of seismic damage impact factors, and the seismic damage impact factors are as following: Site type, Structure type, Built year, Story number etc), according to fuzzy comprehensive evaluation model, the method of seismic damage of single building of multi-factor comprehensive analysis is established, and the main advantage is dealing with the complexity of seismic damage of single building simply and feasibly. Then, a case is analyzed with the method of multi-factor comprehensive analysis.

KEYWORDS:

single building, seismic damage prediction,seismic damage impact factor, average damage index, regional database

Introduction

At present, the existing methods of earthquake damage prediction of our country are roughly divided into: Statistic law of the historical earthquake damage, Semi-experience and semi-theory method, Fuzzy analogy method, Specialist evaluation method, Structure computing method, dynamic analytic approach etc[1].(1) Statistic law of the historical earthquake damage carries on a kind of method of earthquake damage prediction to the building by statistical analysis and experience judgment according to the existing earthquake materials. This method has very high dependent on materials, and the limitation is big, but if the samples are sufficient, its reliability is high. (2) Semi-experience and semi-theory method, through observations, the foundations of statistics, comprehensive results of the similar things in the past, is a kind of method dealing with the relation between each variable with the strict mathematics method. Adopted more at present, its scope of application is bigger, but the adaptability to the theory model is expected much. (3) Fuzzy analogy method carries on the seismic damage prediction by utilizing the mathematics relation of fuzzy analogies. The application scope of the method is the same as statistic law of the seismic damage basically, but the reliability of the prediction of fuzzy analogy method is a little higher. (4) The Specialist evaluation method carries on a kind of method that assesses of seismic damage according to the experience judgments of several earthquake experts. Its key work is collecting and working out the sample data, and according to the experts' suggestions at all levels, and then sum up with statistical method. It is suitable for earthquake resume working, post-earthquake restoration work, and this method is a little higher in reliability to the old house without drawings.(5) Structure computing method, a method that analyzes the structure with seismic vibration theory, can understand structure response course from elasticity to destroyed under the function of shaking, and its calculation is relatively high in precision, however, the method needs a large number of theory preparing and a large amount of experimental studies, which is unsuitable to the general building. It is very limited, too, to application of structure with present popular method of pushover. (6) Dynamic analytic approach is a kind of prediction method [2] that considers resistance changing over time of structure. Because of considering the time effect, there is very good development prospect, which is suitable for combining with other methods suitably.

The author of this text, summarizing a large number of seismic damage prediction results of single building since our country "The Seventh Five-Year Plan Period ", sets up the model database of earthquake prediction results of single building, puts forward a method that applies fuzzy comprehensive evaluation theory. And it gives analysis method of seismic damage prediction of single building for further research, which there are some realistic meanings

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to the prediction of earthquake damage.

1. Method of earthquake damage prediction of Single Building

1.1 Seismic damage influence factor of the Single Building

Because seismic wave's characteristic through the medium will change very greatly, while the simple mechanics model cannot calculate the seismic damage of the structure accurately, thus this text provide the method of estimating combining all factors related to single building seismic damage. Impact factor, a physical quantity, signifies a certain impact factor to the seismic impact degree of the structure under the specific earthquake intensity, namely the degree of membership of seismic damage impact factor to the whole earthquake jurisdiction collection.

①**. Site type .**The domestic and international seismic damage materials show, the destruction degree of the same building, on the place of different geologic conditions, when there is an earthquake is obviously different. After summarizing seismic damage phenomena of the building, it is found: On the weak ground, the flexible structure is easiest to destroy, and the rigid structure is corresponding does well; On the hard ground, the flexible structure does well, and the rigid structure behaves differing, some poor, some well, and often presents the contradiction phenomenon; On the hard ground, the destruction of building is usually due to the destruction of some structures; On the weak ground, the destruction of building is sometimes due to the destruction of some structures, sometimes due to the destruction of foundation. As to total destruction phenomena of building on the ground, the destruction on the weak ground is more serious than the destruction on the hard ground [3]. In addition, the grade of place liquefaction will influence the earthquake directly; even cause the building sloping and collapsing when being serious.

②**.Structure type .**There are enormous differences in its seismic behavior of structure. Generally, the seismic behavior of high building is superior to multi-layer Reinforced Concrete structure, while the seismic behavior of multi-layer RC structure is superior to multi-layer masonry structure.

③**.Construction standard.** Construction standard here means whether building is built with standard or without standard, namely whether the building is built according to seismic code. It is found from all previous seismic damage materials that the seismic behavior of the structure that is built without seismic code is obvious poor.

④**.Integrity of the building .**The content of integrity of the building includes roof form, ring beam, constructional column etc. The structure is an assembly, and if the structure loses integrity under earthquake function, the seismic behavior of each component can't be given full play to, and it is apt to make the structure become flexible body and destroy. The horizontal bearing component is floor and roof. The project experiences of Tang Shan earthquake show, it is remarkable that the resist ability of structure strengthened with RC constructional column and ring beam. Constructional column can prevent wall from slipping, dislocation and slow down wall brittle. However, it is the same as the wall with constructional column but not ring beam to the wall without constructional column, collapsing too. Equally, if the ring beam is fixed up rarely and does not take shape to seal constructing, the seismic capacity of the structure that it improves is extremely limited too [4].

⑤**.Regularity of the building .**All previous heavy earthquakes, both at home and abroad, indicate that the size of the building has remarkable influence on seismic behavior of the structure. Plane size and elevation size are included in the size of the building. Regularity, symmetry and homogeneity of the plane layout are considered in the plane size; while height-width ratio, tower, vertical receiving and layer rigidity are considered in the elevation size, avoiding too outside and addiction. In the earthquake of Managua of Nicaragua in 1972, the damages of the Central Bank of 15 layers and Bank of America of 18-storey in city center that lies not far away with each other differ greatly. Trace it to its cause, it mainly caused the difference in the layout of the structure of the two.

⑥**. Built year of the structure .**The built year of the structure is a comprehensive factor. Because of the difference of built times, there is very great difference in its seismic behavior. Generally the seismic behavior of the structure built in near year is on better terms than that of far times, trace it to its cause, it is mainly with the development of seismic theory that relevant seismic design specifications are being revised constantly, and have been added more rational factors. It can be found out from 74, 78, and 89 to 2001 norms.

⑦**.Layer of the structure.** As to multi-layer structure, layers of the structure exert a tremendous influence on earthquake damage of the structure. All previous seismic damage materials show, in the same earthquake intensity district, low-layer structures have lighter seismic damage than that with many layers.

⑧**.Intensity of material .**Intensity includes intensity of mortar, intensity of concrete and intensity of masonry, etc... The main purpose of the requisition for material is to reduce the fragility of the material and avoid the new weak position and strengthen the integrity of the structure. For example, the intensity of mortar has decisive function in masonry structure.

⑨.**The current situation appraising.** The current situation of the structure has indispensable importance to seismic behavior. Obviously, the seismic behavior of the structure with good current situation is better than that with poor current situation. And current situation is divided into A, B, C, D grade, corresponding structure current situation intact, good, general, very poor.

Certainly, the seismic damage impact factors of structure are not only above several kinds, and its seismic damage impact factors of different structure are different, thus the main ones are listed here. See Fig. 1 concretely.

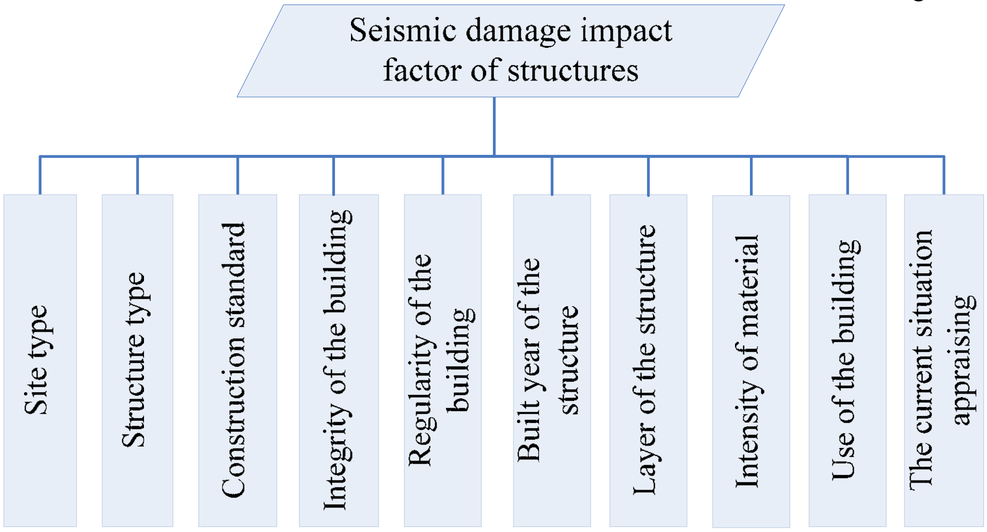


Fig.1 Seismic damage impact factor of structure

1.2 Calculation of the influence factor

Generally, the destruction of the structure is divided into 5 grades, namely intact, slight damage medium damage, serious damage and destroy. The seismic damage index is a kind of quantity definition to above-mentioned destroys the grade. It is a quantitative description of the seismic damage degree of the building, using 0 defining basic intact, 1 to destroy, the middle grade with the number between 0 and 1. The 5 destruction grade with corresponding seismic damage index and upper and lower limits have lain in following 1 form.

Table 1 The definition of seismic damage index [5]

Destruction grade	Basic intact	Slight damage	Medium damage	Serious damage	Destroy
Mean Value D of the seismic index	0	0.2	0.4	0.7	1.0
upper and lower limits of the index	[0,0.1]	(0.1,0.3]	(0.3,0.55]	(0.55,0.85]	(0.85,1.0]

Average damage index means the average of the seismic damage index of all buildings of architectural complex or in a certain regional range, namely it is the sum that the destruction rates that building account for multiply the corresponding seismic damage index. The average damage index shows the average seismic damage degree of this kind of building. Through the calculations of different damage indexes of all kinds of structures, it can be compared with the quality of the seismic behavior between all kinds of buildings.

(1).**The average damage index**

$$D_{avj} = \sum D \cdot n_p / N \quad \text{OR} \quad D_{avj} = \sum D \cdot P(D_p \mid J) \qquad (1)$$

here， $D \in [0, +1.0]$ ，Mean Value of the earthquake index，value shown in table 1;

n_p， the number of the structure with p class destruction in certain region,(class Ⅰ: Basic intact, class Ⅱ: Slight damage, classⅢ: Medium damage, classⅣ: Serious damage, class Ⅴ: Destroy）;

N, the total number of a kind of structure in an appointed area;

$P(D_p \mid J)$, the destruction rate of a certain kind of structure with p class destruction under J earthquake intensity;

Here J∈[6, 10] or ground peak acceleration［0. 05g, 0. 80g］ in the norm.

(2). **Impact factor**

The index reflecting the trends average change degree of many kinds of things or the phenomena synthetically is called the total index, and it shows many kinds of different things or phenomena the total change on different time. In fact, it reflects the direction and degree of average change of many kinds of different things, a kind of multifactor index. If a certain total amount index can be divided into two or a lot of factor indexes, and one or several indexes be fixed, the change degree of a certain index among them can then be observed out; Also the effect and direction to a certain phenomenon or result can be found out when observing a lot of indexes changing at the same time synthetically, then appraising it good and bad. The concrete steps are as follows:

1) In certain regional range, under a certain earthquake intensity, (for example multi-layer brick masonry structure) make statistics of a certain structure and set up a database of structures, including its impact factor information, and calculate out the average damage index Di at this moment(the factors at this moment are all considered).
2) Under the above-mentioned conditions, considering a certain single factor impacting on structure to what extent, the method taken is fixing the contribution that the factor to structure, that is, 'removing' the structure with the factor in the regional database, so as to reach the investigation of the goal factor. The average damage index $D_{[i]}$ of the structures without this factor after removing can be calculated out. (In fact, the numbers of samples in second step while calculating are fewer.)
3) In a situation that above-mentioned Di and $D_{[i]}$ are all calculated out, then the relative change on these two total indexes is the contribution this seismic damage influence factor to the structure. The formula is as follow:

$$C_{ij} = \frac{D_{i,j}}{D_{[i],j}} \tag{2}$$

Here, $C_{ij} \in (0, +\infty)$, the seismic damage impact factor of the structure, under J earthquake intensity. The ones that need paying attention to are, in different areas, influence factors of different structure type are different, and even the same structure type, its influence factors may be different in different areas, needing concrete problems to treat concretely. The definitions of $D_{i,j}$ and $D_{[i],j}$ are mentioned as above.

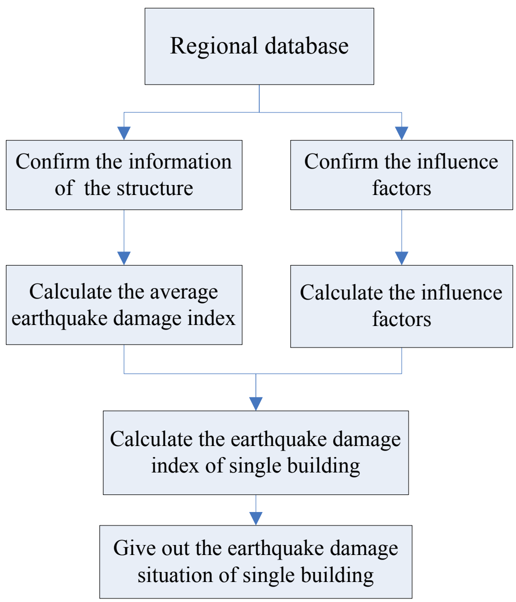
1.3 Calculation of the seismic damage index of single building

Because of coordination and unsubstitutability between the seismic damage factors, and uniformity, every factor, in different occasions, the multiplication [6] of fuzzy mathematics is adopted to calculate total effect of the impact factors.

Seismic damage index of the single building:

$$d_j = \left(\prod_{\substack{i=1 \\ J}}^{n} C_{ij}\right) D_{avj} \tag{3}$$

Herr, $d_j \in [0, +1.0]$, the seismic damage index of single building, under J earthquake intensity, the definitions of the other symbol are as above.



1.4 The prediction steps of seismic damage of

single building

a) Set up regional database

The samples in the database are mainly made up of the results of earthquake damage prediction and earthquake cases, and some theory analysis results of single building, earthquake samples of experts' prediction and regional earthquake damage matrix [7] are joined to the database that lacking of earthquake cases. The database includes ten sub-databases, namely the sub-database of multi-layer masonry structure, sub-database of multi-layer reinforced concrete structure, sub-database of industrial factory building, sub-database of spacious building, sub-database of stone building, sub-database of high building, sub-database of single-layer house own by citizen, sub-database of timber structure, sub-database of special structure, and sub-database of other type of structure. The number of the sub-database is confirmed according to the concrete conditions (earthquake damage prediction has been carried on in many cities), and the setting up of the database is not very difficult, if without, the matrix method [8] of simulation is all right.

Fig. 2 Steps of prediction of seismic damage of single building

b) Confirm the type of single structure
c) Calculate the average damage index
d) Confirm the impact factors
e) Calculate the impact factors
f) Calculate the seismic damage index of single building
g) Give out the seismic damage situation of single building

See Fig. 2 concretely

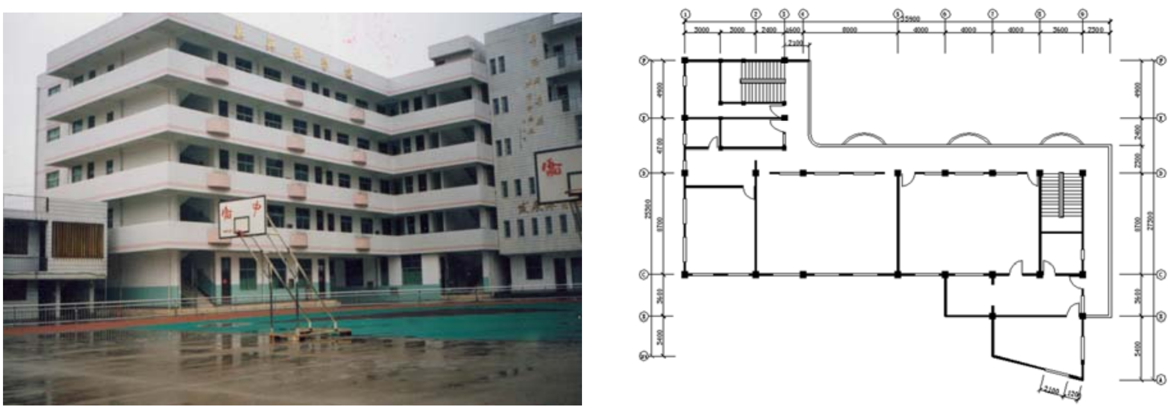
2 Example

This text has taken MEI-Ying scientific building of Chinese's middle school as an example. Its earthquake damage situations are calculated in different earthquake intensities with the method introduced above and original predicted results [19] have been compared with. Introduced concretely as follows:

MEI-Ying scientific building is the structure of a reinforced concrete frame of five storeys, designed by the building design office of capital construction commission of Jinjiang City, built up in 2000. The sectional size of the frame column is 450mm*500mm, and the sectional size of main frame beam is 250mm* 500-700mm .The infill wall in frame is 180 thick, adopting the red brick of MU10 and the mortar of M5.0. The construction area is 2628.18 square meters, and the height of the building is 18.6 meters. The first layer is 4.2 meters high, and 2-5 layers is 3.6 meters layers for each. It is designed against the earthquake intensity of 7 degree, and the site type is II. See Fig. 3 in elevation and plane figure.

Analysis: This single building is structure of 5 layers of reinforced concrete frames, found out from plane figure and elevation, and the plane of MEI-Ying scientific building of Chinese's middle school is irregular and the elevation is regular.

The impact factors include: Built year of the structure, intensity of material, Layer of the structure, .Regularity of the building, Site type.



(a) Elevation figure (b) plane figure

Fig.3 MEI-Ying scientific building of Chinese's middle school

Choose the database of multi-layer reinforced concrete frame in Jinjiang, an average damage index of multi-layer reinforced concrete frame is calculated with the formula 1 (see Fig. 4) .It can be found out that at the 0.05g, the structure is intact basically, and at the 0.15g and 0.20g, the structure is mainly slight damage, and at the 0.40g, the structure is mainly medium damage, and at the 0.80g, mainly damage seriously. On the basis of the database, utilizing step 1) -3) and formula2 impact of built year of the building can be calculated (See Fig. 5).

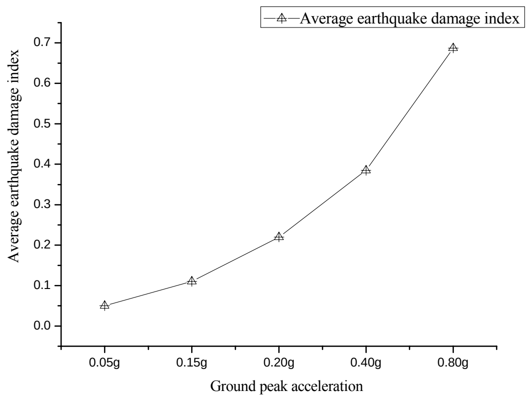


Fig. 4 average damage index of Multi-layer RC frame of Jinjiang City

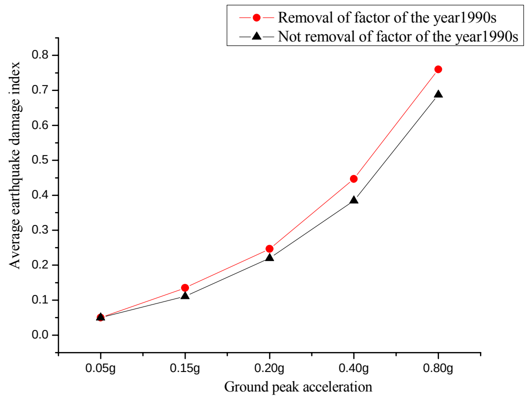


Fig. 5 effect of the impact factor of the year1990s

After calculating the first impact factor, while calculating other factors, the initial database should be used, namely database of multi-layer reinforced concrete frame of Jinjiang. Layer counts and material is calculated and shown in Fig. 6-7, and it can be found out, the effect of layer counts and mortar intensity is not obvious on structure of reinforced concrete.

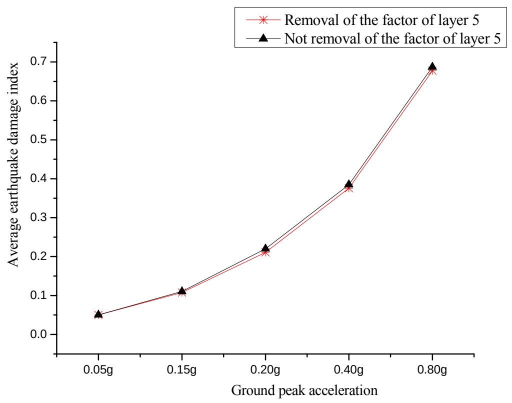


Fig.6 effect of the influence factor of layer 5

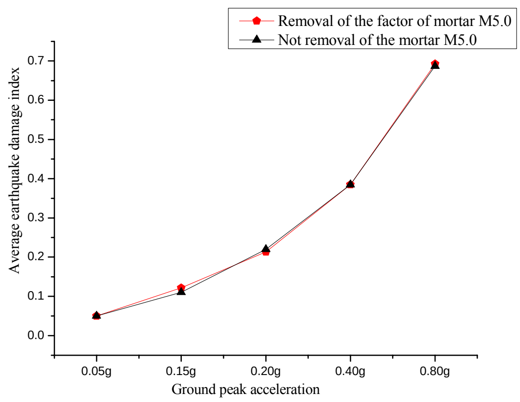


Fig. 7 effect of the influence factor of material mortar M5.0

Fig. 8 and Fig. 9 are and respectively. The impact on structure of multi-layer armored concrete frame of site type is very obvious after 0.15g, while the impact of regularity of the building is relatively small to lower reinforced concrete frame. The results of calculation are tabulated in Table 2.

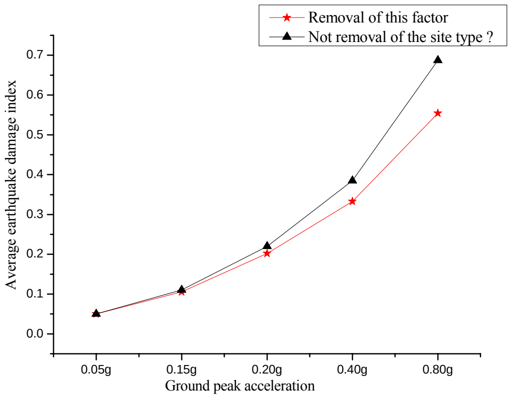


Fig. 8 effect of the influence factor of Site type II

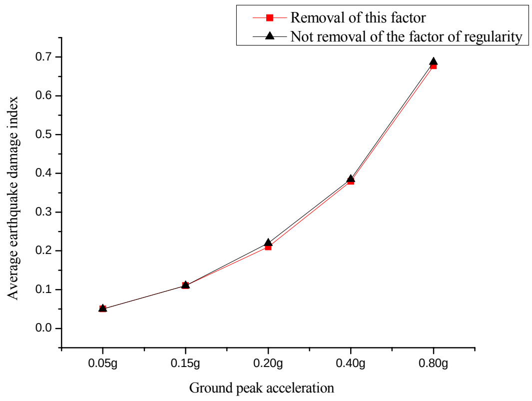


Fig. 9 effect of the influence factor of regularity of the building

Table 2 Calculation of the impact factor

ground peak acceleration (g)	average damage index of Multi-layer RC frame	Built year	Layer counts	Material	Site type	regularity of the building
0.05	0.050	1.000	1.000	1.000	1.000	1.000
0.15	0.110484	0.818399	1.024802	0.909045	1.047888	1.00076
0.20	0.219758	0.890911	1.042051	1.031356	1.086975	1.046218
0.40	0.384677	0.861218	1.023813	1.010672	1.156546	1.014445
0.80	0.687097	0.904075	1.01427	0.992473	1.239626	1.014779

It can be found out from Table 2: The impact of factors such as layer counts, Site type, etc. to the structure of multi-layer reinforced concrete frame has nothing in common with each other; Site type is the most influential, built year takes the second place; As to the structure of multi-layer reinforced concrete frame, mortar, layer counts, regularity of the building all have certain influence on seismic damage of the structure, but not obvious.

The seismic damage index of the structure, under different ground peak acceleration, can be calculated with the value of table 2 and formulae 3, tabulating the results in table 3 below. Utilizing the method in document [2], according to 'Seismic design code' (GB50011-2001) and 'Seismic identification standard' (GB50023-95), the maximum elastic seismic shear of the floor can be calculated with finite element method, and the yield shear of the floor can be calculated according to the real situation of the building. The yield shear coefficient of floor is the ratio of the yield shear and maximum elastic seismic shear of the floor, according to the relationship of the yield shear coefficient of floor and the average value of maximum elongation of the floor, and the seismic damage of the building is evaluated by the maximum elongation of the floor, synthetically considering construction measure and characteristics of the structure, etc...

Table 3 The seismic damage situation comparison with that with theory method

ground peak acceleration (g)	The result with the method of the text		The result [9] with method of document [2]
	seismic damage index	Destruction grade	Destruction grade
0.05	0.0500	Basic intact	Basic intact
0.15	0.088335	Basic intact	Basic intact
0.20	0.239287	Slight damage	Slight damage
0.40	0.402191	Medium damage	Medium damage
0.80	0.786605	Serious damage	Serious damage

It can be found that the result with the method of this text and theory method is roughly identical by the result of Table 3. In the theory method the calculation of the maximum elastic seismic shear and the yield shear of the floor needs detailed information of the structure, and if the structure is complicated, the calculation will be more tedious.

3 Conclusions

Based on the theory of fuzzy judgment, synthetically considering the influence of impact factors, a method of seismic damage prediction of single building is set up. The model of this method is simple and there is certain practicability. In addition, the main impact factors, the method to set up regional database, the content of regional database and steps of seismic damage prediction of single building are also provided, which can be regarded as the reference of seismic damage prediction of single building. What need to point out are: this method is dependent on the database with certain degree, and the more sufficient the samples in the database are, the more high the precision of the result will be; considering many samples in the database are results of seismic damage prediction, the results of seismic damage prediction of authoritative mechanism are the best choice; In different cases, the effects of impact factors are different, needing concrete problem to a concrete analysis.

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