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Predicting Debris Distribution of Collapsed Buildings

Pronostics sur la répartition des décombres de constructions

Vorhersage der Schuttverteilung einstürzender Bauten

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SUMMARY

In order to predict the earthquake damage and the influence on road transportation of the debris of existing buildings in future earthquakes, the software system named "Prediction Earthquake Damage and Debris Distribution in a City" is developed. The functions of the system, the description of the data, the debris accumulation model of collapsed buildings and the reasoning procedure are explained in this paper.

RÉSUMÉ

Cet article décrit un système de logiciels développé dans le but de prévoir la répartition des dommages dûs aux tremblements de terre futurs ainsi que l'influence des masses de décombres des immeubles écroulés sur les voies de circulation urbaine. Les auteurs exposent les différentes fonctions des logiciels, la description des données, le modèle d'accumulation des décombres des immeubles écroulés et le processus de raisonnement à suivre .

ZUSAMMENFASSUNG

Es wurde ein Softwaresystem entwickelt, um die Verteilung von Erdbebenschäden und die Auswirkung der Trümmermassen auf die Befahrbarkeit städtischer Strassen für künftige Beben vorherzusagen. Der Beitrag behandelt die Datenbeschreibung, das Modell der Schuttanhäufung einstürzender Gebäude und die Vorgehensweise beim Schliessen.

1. INTRODUCTION TO THE SOFTWARE SYSTEM —— PEDDD

In order to predict debris distribution of collapsed buildings during the earthquake, and to find out the influence of collapsed buildings both on road transportation and the rescue areas, the software PEDDD developed by Research Institute of Structural Engineering, Tsinghua University.Based upon it, Earthquake Resistant Office can organize a scientific aseismic and disaster relief plan and rescue scheme more effectively[1]. PEDDD can run on a micro–computer IBM PC / AT 286, 386 with graphics system or compatible. A digitizer and a plotter are needed. PEDDD consists of four functional modules as shown in Fig.1.[2]

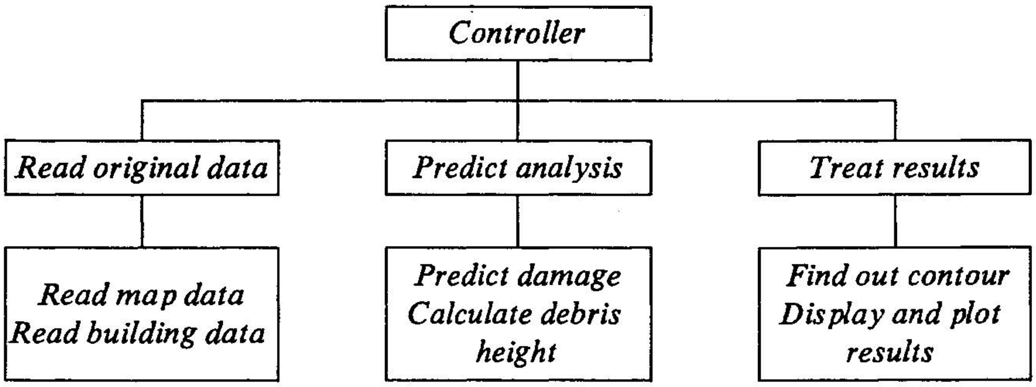


Fig.1 Functional modules diagram of PEDDD

PEDDD includes two characteristics: 1. In the earthquake damage, the accumulative effect of aftershock is considered, i.e. the effects of both the main shock and aftershock are all considered in PEDDD. 2. PEDDD has versatile graphics functions and make it easy to operate and to understand.

In order to realize the functions and characteristics of PEDDD, data and photographs from the surveys of post earthquake damage in many earthquakes in China and the ripe methods to predict earthquake damage in China are studied. These data, photographs and methods are turned into knowledge base described by computer. Finally,based on the earthquake damage prediction methods, the debris accumulation models and computer graphics technology, the objective of PEDDD is realized.

The approach of describing the building data and getting the debris accumulation type of a collapsed building will be explained in this paper.

2. REQUIRED PARAMETERS AND THEIR REPRESENTATION IN PEDDD

In the current version of PEDDD, two kinds of building i.e. multi–story masonry buildings and old brick timber buildings are considered. The selection and description of the parameters of a building are the keypoints during the process of prediction by computer.

Which parameters are required in PEDDD is determined by the applied methods which are come from the study of the surveys of the post earthquake damage in many earthquakes. The approach of getting the data of predicted buildings of PEDDD is to carry out the investigation of the existing buildings. Since the buildings are various and were built in different years, the data from the user may not contain all of them, i.e. it is impossible to get the accuracy initial parameters to predict.

In order to solve the above problem, the design maps of more than ten typical buildings are chosen to analyze and calculate. The basic data such as the weight per area and the wall percentage per area are obtained by statistics. It makes the work of getting initial data more rationally and rapidly. During the work of determining the parameters used in PEDDD, another contribution is to solve the determination of the existing station coefficient (the service condition coefficient) of the buildings. Because the coefficient of the situation of existing station of the building is a experience value evaluated by the experts, the method to get the coefficient in PEDDD is to consider the structural conditions of the building in different weight and to choose 12 factors to sum up in their weight. The coefficient is determined by using the sum to compare to the standard value.

After determining the required parameters of the building, the next problem is how to describe them in computer language. Based on the programming language Quick BASIC 4.5 used in PEDDD, the TYPE statement is used to solve it. There is a example to show how to describe the parameters in masonry buildings. The initial required parameters in predicting a masonry building which don't include the story information are 26. They are described as 'TYPE bricktype' in PEDDD. In the list of the explaining, 'non' means the parameter is not a required initial one, it is needed in linking another information of the buildings.

```
TYPE    bricktype
    ibs       AS  INTEGER   ' the pointer looking for the building number
    itype     AS  INTEGER   ' the type of the building
    istory1   AS  INTEGER   ' non, link to the story information
    istory2   AS  INTEGER   ' non, link to the story information
    score     AS  SINGLE    ' the coefficient of the existing station of the building
    shape     AS  INTEGER   ' the shape of the building
    support   AS  INTEGER   ' the load-bearing system of the building
    time      AS  INTEGER   ' the time build the building
    slab      AS  INTEGER   ' the panel system
    roof      AS  INTEGER   ' the roof system
    max1      AS  SINGLE    ' the maximum distance between the adjacent transverse
    max2      AS  SINGLE      'wall in the top (max1) and bottom story (max2)
    l         AS  SINGLE    ' the length of the building
    w         AS  SINGLE    ' the width of the building
    column    AS  INTEGER   ' the situation of the constructed column
    beam      AS  INTEGER   ' the situation of the circle beam
    connect   AS  INTEGER   ' the situation of the connection between the
                              ' longitudinal wall and the transverse wall
    brick     AS  INTEGER   ' the type of masonry block
    place     AS  INTEGER   ' the ground condition
    hp        AS  SINGLE    ' the height of the parapets
    area      AS  SINGLE    ' the area of the building
    sb        AS  INTEGER   ' there is a little house on the top or not
    ns        AS  INTEGER   ' the number of the story of the little house
    floor     AS  INTEGER   ' there is a shop in the bottom or not
    brick1    AS  INTEGER   ' the type of masonry block of the little house
    h         AS  SINGLE    ' the total height of the building
    g         AS  SINGLE    ' non, the total weight of the building from calculating
    owe       AS  SINGLE    ' non, the product of the l and w
    tw        AS  SINGLE    ' the thickness of the non load bearing wall
END   TYPE
```

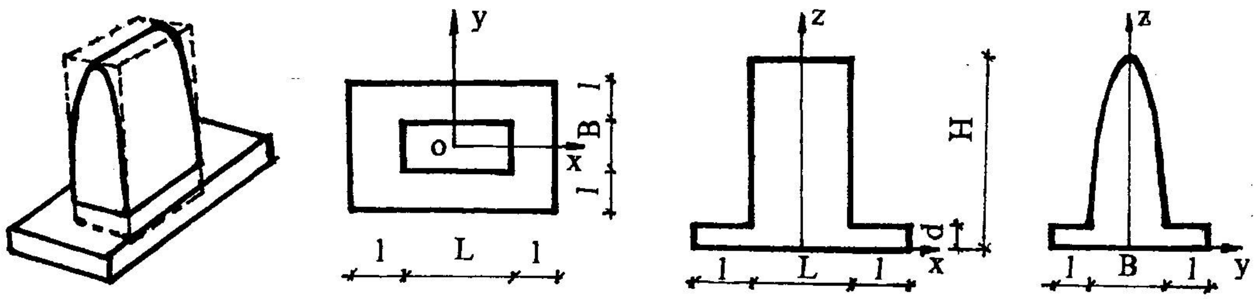
3. MODELS FOR DEBRIS ACCUMULATION OF COLLAPSED BUILDINGS

Based on the surveys of post earthquake damage of many earthquakes, especially on the photographs of TangShan earthquake[3], 1976, China and other eight strong earthquakes in China, the authors analyzed and summarized these photographs and data, then proposed three debris accumulation models to describe the shape and the distribution of the debris of the collapsed buildings. So far, only masonry buildings and old brick timber buildings are considered.

3.1 Accumulation model of partial collapsed buildings

In this case, the external longitudinal walls and gable walls are collapsed, but the transverse walls and internal longitudinal walls still exist. Sometimes, the falling of the external walls maybe cause the falling of the adjacent internal walls or the corner of the house partly collapse. Therefore, partial collapsed model mainly describes the characteristics of the collapsed external wall. The debris distribution sketch is shown in Fig.2. The shape of the collapsed building is described in the following Eq.(1).

$$Z = He^{-\left(\frac{y}{2B}\right)^2} \tag{1}$$



a) The shape b) The plan c) The section

Fig.2 Accumulation model of a partial collapsed building

To describe the debris that come from the collapsed wall, the average thickness d in the involved range l is used. Assume that the wall are broken one story by one story, distance l to the horizontal position of the debris of the top story can be determined by Eq.(2).

$$l = \sum_{i=1}^{n} h_i Sin\left(\frac{i\pi}{2n}\right) \tag{2}$$

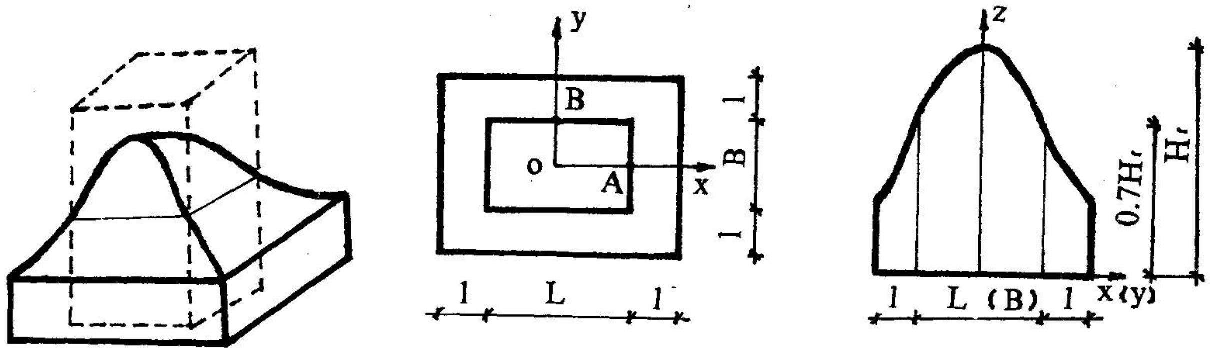
where n —— the total number of stories; h_i—— the height of the i–th story;
If $l > l_c$ then the final value is l_c , l_c is the nearest distance from the other adjacent buildings.

$$d = \frac{HW_d}{l} K_V \tag{3}$$

where W_d—— the thickness of the external wall;
H —— the total height of the building;
K_v—— the numerical coefficient with consideration of non–dense debris accumulation, for brick masonry buildings K_v = 1.5; for old brick timber buildings K_v = 2.0.

3.2 Accumulation model of overall collapsed buildings

Overall collapse means that a building is totally collapsed, or the falling of the bottom story lead to the building all collapsed. The debris graph is shown in Fig.3.



a) The shape b) The plan c) The section

Fig.3 Accumulation model of a overall collapsed building

The formula to calculate the height Z of the debris accumulation is described as Eq.4.

$$Z = H_f\, e^{-\left(\frac{x}{\alpha}\right)^2} e^{-\left(\frac{y}{\beta}\right)^2} \tag{4}$$

where α, β—— are the falling gradient along the x,y axis respectively. Assume that at the point A and B in Fig.3 , the height of the debris accumulation height is equal, and $Z = 0.7H_f$ then $\alpha = 0.837L$, $\beta = 0.837B$.

$$H_f = \frac{GK_V}{\gamma_{eq}\int_{\frac{L}{2}-l}^{\frac{L}{2}+l}\int_{\frac{B}{2}-l}^{\frac{B}{2}+l} e^{-\left(\frac{x}{\alpha}\right)^2} e^{-\left(\frac{y}{\beta}\right)^2}\, dxdy} \tag{5}$$

where G —— the total dead load of the building;

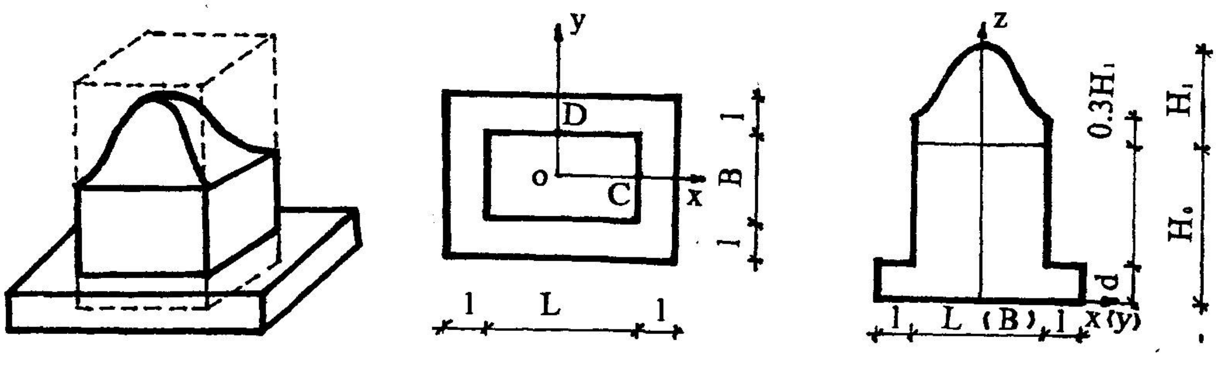
γ_{eq}—— the equivalent material volume weight;

l —— minimum of 0.5 H and l_c ;

K_v, H —— the same meaning as Eq.(3)

3.3 Accumulation model of top collapsed buildings

In this case, several stories of a building are collapsed. Nevertheless, other lower stories of this building still exist. The debris accumulation graph is shown in Fig.4. The height of debris accumulation can be expressed as Eq.(6). The thinckness of debris accumulation in the involved range *d* is determined by Eq.(7).



a) The shape b) The plan c) The section

Fig.4 Accumulation model of a top collapsed building

$$Z=\begin{cases} H_0+H_1 e^{-\left(\frac{x}{\alpha}\right)^2} e^{-\left(\frac{y}{\beta}\right)^2} & (\ |x|\leqslant 0.5L,\ |y|\leqslant 0.5B\ ) \\ d & (\ |x|>0.5L,\ |y|>0.5B\ ) \end{cases} \tag{6}$$

$$d=\frac{\frac{G'}{\gamma_{eq}}K_V-4\int_0^{\frac{L}{2}}\int_0^{\frac{B}{2}} e^{-\left(\frac{x}{\alpha}\right)^2} e^{-\left(\frac{y}{\beta}\right)^2}dxdy}{(L+2l)(B+2l)} \tag{7}$$

where H_0—— the height of the part building non–collapse;
H_1—— the maximum collapsed height;

$$H_1=\frac{G'K_V}{\gamma_{eq}BL} \tag{8}$$

and G'—— the weight of the part collapsed building;
α,β—— the same meaning as the Eq.4 . Assume that at the point C and D in Fig.4 , the height is equal and $Z = H_0 + 0.3H$, then in Eq.(6) $\alpha = 0.456$ L, $\beta = 0.456$ B.

4. REASONING PROCEDURE OF THE DEBRIS ACCUMULATION MODEL

4.1 The method to predict earthquake damage level

The kind of the debris accumulation of a collapsed building is deduced by the damage level. The debris accumulation model of partially collapsed building is gained from the partial collapsed building. Whether the accumulation models is the top one or the overall one is determined by the different collapsed degree of the overall building. Here two methods to predict earthquake damage level are introduced in brief.

4.1.1 Mutil–story masonry buildings

Refer to the reference [4], the ripe method to predict earthquake damage for multi–story masonry structure in China is applied in PEDDD. The suitable amendments are purposed when aftershock is considered. The keypoints of this method is to check the shear strength of the wall. The kernel thought is in the following:

The damage level of the buildings can be divided into six class: Basic no–damage, Slightly damaged, Moderately damaged, Seriously damaged, Partially collapsed and Overall collapsed. The classification is determined by the aseismic capability of the building. The main formula to represent the aseismic capability is Eq.(9).

$$K=K_{\mathrm{I}}\ K_{\mathrm{II}} \tag{9}$$

where K —— the aseismic capability index, represents the earthquake resistance capability of the masonry building in the given earthquake intensity.
K_{I}—— the aseismic strength coefficient of masonry building, obtained by calculating and comparing with the shear force of the building under the earthquake action.
K_{II}—— the secondly criterion coefficient. It is a revised coefficient considered other influenced factors on earthquake damage such as the connection, the existing station, the measure to strengthen the aseismic capability and the ground condition of the building.

Based on the above method and initial data of the masonry buildings, the aseismic capacity index of the each story of the building can be obtained. Using the following criterion in

Table.1, the earthquake damage level can be determined.

DAMAGE LEVEL	THE CRITERION	NOTES
Basic No–Damage	$K_0 > 1.0$	$K_0 = \underset{1 \leqslant i \leqslant n}{Min}\{K_{Ii}, K_{II}\}$ n —— the total stories of the building; N_0 —— the story number of unsatisfied aseismic capacity, if all are not satisfied then $N_0 = 2n$.
Slightly Damaged	$0.9 < K_0 < 1.0$	
Moderately Damaged	$0.6 < K_0 < 0.9$	
Seriously Damaged	$\frac{1}{3} \leqslant K_0 < \begin{cases} 0.6 & (N_0 > 1) \\ 0.7 & (N_0 > n/2) \\ 0.8 & (N_0 > 2n/3) \\ 0.9 & (N_0 > 3n/2) \end{cases}$	
Partially Collapsed	$K_0 < 1/3$ *and* $K_{Ii} \geqslant 1/3$	
Overall Collapsed	$K_0 < 1/3$ *and* $K_{Ii} < 1/3$	

Table.1 The Criterion to predict earthquake damage level

4.1.2 Old brick timber buildings

There is a little different in damage level classification between the old brick timber buildings and masonry buildings. There is no partial collapse damage level in old brick timber building. If the building collapsed then it should be overall collapsed.

The method used to predict old brick timber buildings is very different from the method in masonry buildings. According to the features of the earthquake damage in data, refer to the reference [5], probability theory and fuzzy mathematics technique are combined to predict earthquake damage for old brick timber structure. In this method, take the length, the existing station and the number of the stories of the building as the fuzzy number and build up fuzzy subset A . At the same time,from the extensive survey of the post earthquake damage form the fuzzy subset of earthquake damage index R . Therefore, according to the fuzzy relation $B = A\ R$, the value B which express the damage level will be obtained.

4.2 Reasoning procedure of debris accumulation model

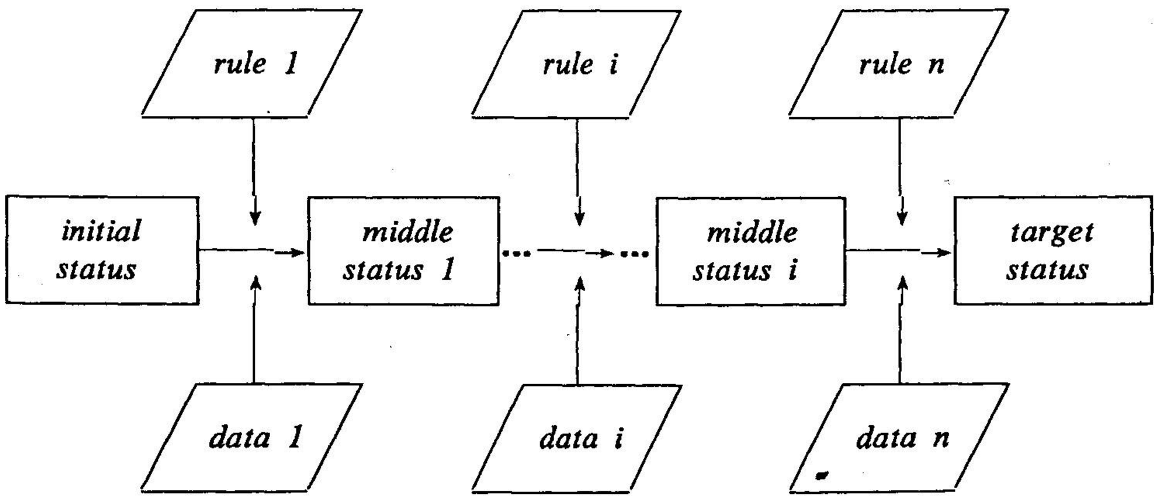


Fig.5 The reasoning procedure in PEDDD

In PEDDD, the following reasoning procedure is used. A reasoning path is formed by the driving status, the deductive method and the IF–THEN rule chains. Generally speaking, different initial data make the system use a suitable rule to obtain a approciate conclusion and to make the system be in different status. The current status will drive the system to choose another rule, be in another status, ... , and go on, until the earthquake damage level or the debris accumulation model is determined. The path can be shown in Fig.5.

5. APPLICATION AND CONCLUSION

In order to verify the reliability and practicability of PEDDD, the earthquake damage of the buildings which introduced in the collected data about TangShan Earthquake damage, is analyzed and 'predicted'. The results obtained are coincide with the true situation. Because the interface of PEDDD is friendly, operation is convenient, promptness and help are enough and error processing and maintenance are strong, user can use it very well. The application of PEDDD in two small streets of Yangpu District, Shanghai City where there are 1100 masonry or old brick timber buildings show the good reliability and practicability. It is quite promising to apply PEDDD in the seismic zone in China where multi–story masonry buildings and old brick timber buildings are crowded.

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