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Development and Application of Reliability Assessment Software for Historic Masonry Structures

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Abstract Most of the existing historic buildings are masonry buildings in China. Among them, some of buildings have served for a long time, their mechanical performance deteriorated significantly. They need to be inspected thoroughly and assessed accurately for the purpose of protection. However, there is still no available engineering software designed for the reliability assessment of existing historic masonry structures. Therefore, a Masonry Assessment software Package with three modules of pre-processing, core analyzing, and post-processing was developed based on the characteristics of historic masonry building structures. In this paper, the development technology for the software is introduced, and the suitability of the software is verified through the application of the software in a real historic masonry building.

Keywords: Masonry structure, reliability, software, historic masonry building

Introduction

Masonry structures are widely used in civil engineering all over the world. Some of them have served for a long time, for example, the pyramids in Egypt, the Great Wall, different type of pagodas, and different type of ancient buildings distributed in different parts of China, and protected by the government due to their architectural and cultural values. However, the human activities and the environment actions have caused some damages for these significant constructions especially for the historic buildings. For the purpose of protection, it is very important to know the status and the mechanical behavior of a historic masonry building through the inspection and the assessment. Assessment of historic masonry buildings often needs a lot of calculations and analyses. Therefore, it is significant to develop applicable software for the reliability assessment of existing historic masonry structures to increase the accuracy and the efficiency of the assessment (Li et al. 2002). This is just the objective of the paper, and in following sections the short name MAP for the Masonry Assessment software Package developed by the authors will be used.

System and Functions of MAP

There are three modules in MAP, which are pre-processing, core analyzing, and post-processing. In the pre-processing, data including axis network information, geometrical and material information of members, storey information, load information and so on, are supplied to the core analyzing by the way of direct input and the way of graphic input methods. The module supports the operations of undo and redo, and both two-dimensional and three-dimensional views can be displayed (Fig. 1), which is convenient for the users to build models. The main tasks for core analyzing module are model checking, structural calculating, member analyzing, reliability assessment, and so on. The

post-processing module includes two parts, text output and graphic display, which are convenient for users to use the results.

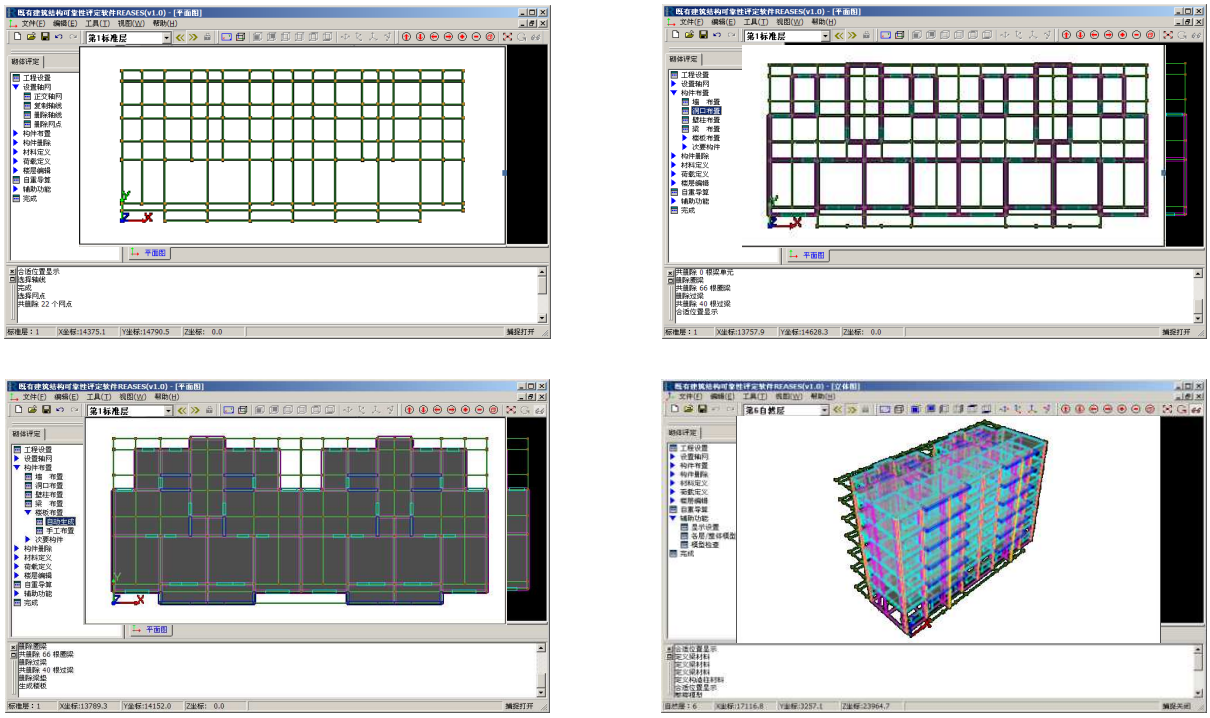

Figure 1: Interface of MAP

The main functions of MAP are as follows:

1. Build models for existing masonry structures by three-dimensional graphic interface, including geometric information, material information, load information, structural information and so on.
2. Determine the structural system and perform the static and the dynamic analysis.
3. Calculate the bearing capacity of structural members.
4. Determine the reliability grade for each structural member based on the calculation results, the structural status, and the structural measures.
5. Determine the reliability grade for the whole structural system.

Key Technology in MAP

Structural Analysis Linear structural analysis method for existing masonry building structures was used in MAP. When doing static analysis, walls between windows are taken as the calculating units in the software (Ding 1997). Under the vertical loads, walls are simplified as vertical elements which are hinged at two ends. Under the horizontal loads, walls are simplified as vertical continuous beams. When doing dynamic analysis, the internal forces caused by earthquake action are calculated by the response spectrum method (Lv et al. 2002).

Assessment of Structural Measures Structural measures are the measures which should be taken to ensure the safety of structural or non-structural components without calculation, such as the minimum width of the wall, the ratio of height to thickness of the wall, the reinforcement ratios in structural columns, and so on. Structural measures are essential to guarantee the stiffness and the integrity of a building, and to ensure the ability of seismic resistance. It is an important content for reliability assessment of structures. The involved codes are: “Code for seismic design of buildings (GB50011-2001)”, and “Codes for design of masonry structures (GB50003-2001)”. The software

can check the items which do not follow the codes by logical comparison between the structural status and the corresponding specifications listed in the data lib, and output the result in the text form finally.

Assessment of Structural Elements The safety, suitability, and durability of existing historic masonry structural members can be assessed separately (Fig. 2). At the present stage, the software can only calculate the grade of safety and suitability well.

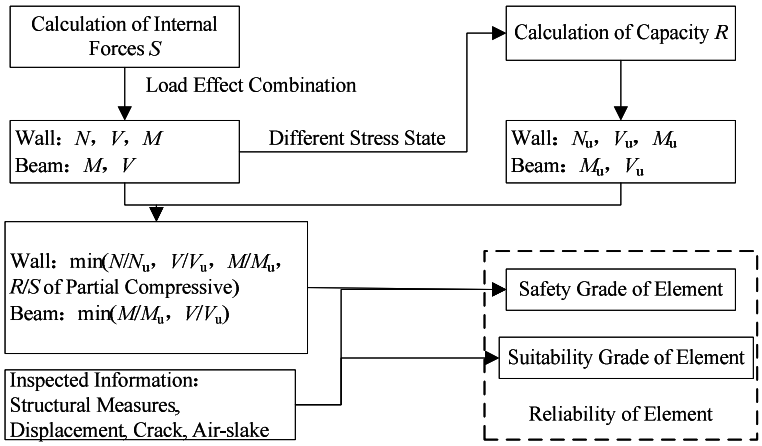

Figure 2: Reliability assessment of Structural elements

The safety of a masonry structural element is assessed based on the four items of bearing capacity, structural measures, displacement which is not suitable for adding loads and the cracking status (Gu et al. 2004). The minimum grade is regarded as the safety grade of the structural member by comparing the structural member behavior or status with the requirements. The suitability of a masonry structural element is assessed based on the three items of displacement, non-stress cracking, and air-slake. Also the minimum grade is regarded as the suitability grade for the structural member. Finally, the smaller value between the safety and suitability grade is taken as the reliability grade for the structural member.

Assessment of Structural System After finishing the assessment for all of the structural members, MAP can give a reliability grade for the whole structure. When the user chooses the "Standard for appraiser of reliability of civil buildings (GB 50292-1999)", the software will calculate the grade for the structural system according to the reliability grades of all elements and the ratios of the elements with the same grade. When the user chooses the "Standard of structural inspection and assessment for existing buildings (DG/TJ08-804-2005)", the software will uses the practical method shown in Fig. 3 to assess reliability grade for structural system (Gu et al. 2007). In Fig. 3, the safety, or suitability, or durability grade for every storey of the structure is assessed first, then the grade for structural system will be calculated according to the assessment results of each storey and the relations among storeys.

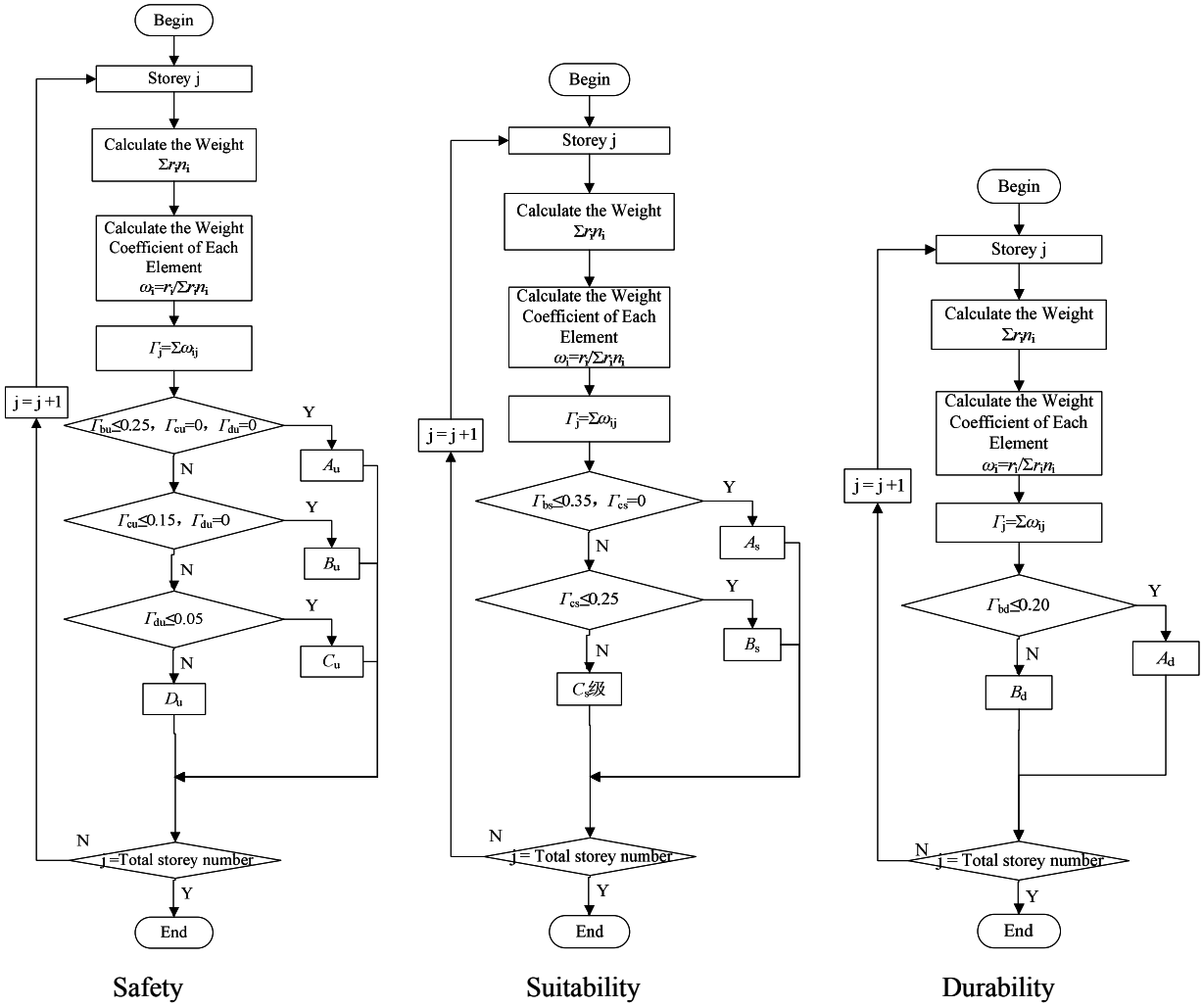

Figure 3: Reliability assessment for structural system

Application of MAP

Fig. 4 is a historic masonry building located in the Bund of Shanghai (Gu et al. 2008). It was built in 1873, the whole building area is 3000m^2, the height of each storey is 4500mm, the whole height of the building is 12870mm. Strengths of block in the first and second storey are 6.0Mpa and 4.8Mpa, and strengths of mortar are 0.5Mpa and 0.4Mpa. The structural planes of the 1st and 2nd storey are shown in Fig.5 and Fig.6. Fig. 7 is image of model built with MAP.

Fig. 8 gives the assessment results for structural members according to the compressive capacities of the walls. There is only one wall whose grade is c_u. In Fig. 8, numerators of the values are the ratios of capacity to the partial coefficient, that is R/γ_R, and the denominators are the internal forces multiplied with the coefficient of importance, that is $\gamma_0 S$. Because of other deficiency in the items of cracking width, structural measures of connection and the displacement, the final safety grades for structural members (Fig. 9, Table 1) are not the same with that based on the bearing capacity assessment only (Fig. 8).

Figure 4: Photo of the building

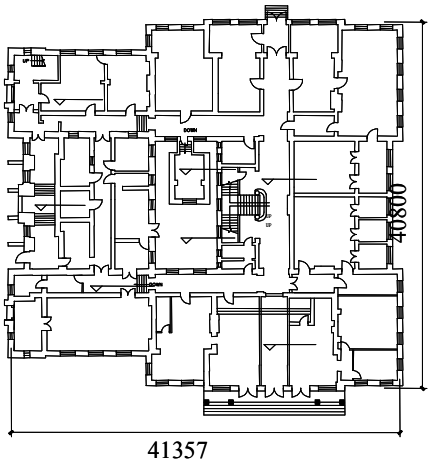

Figure 5: Structural plane of the 1st storey

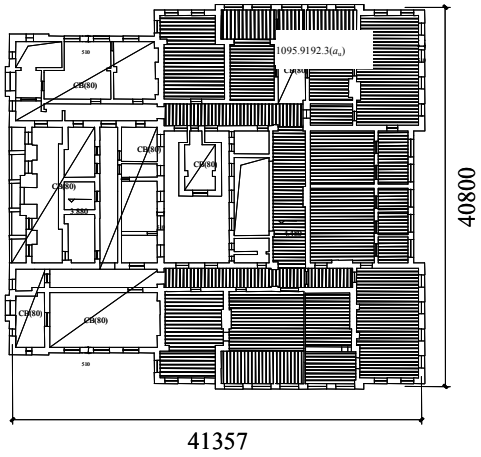

Figure 6: Structural plane of the2nd storey

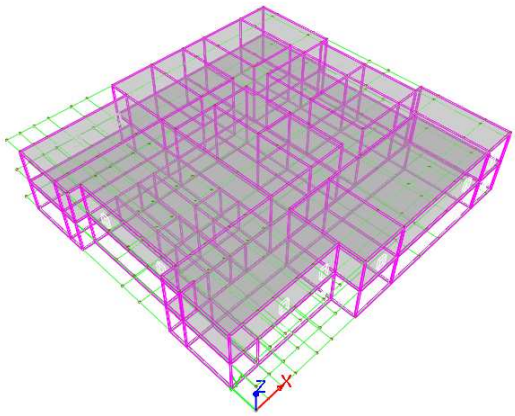

Figure 7: Image of model built with MAP

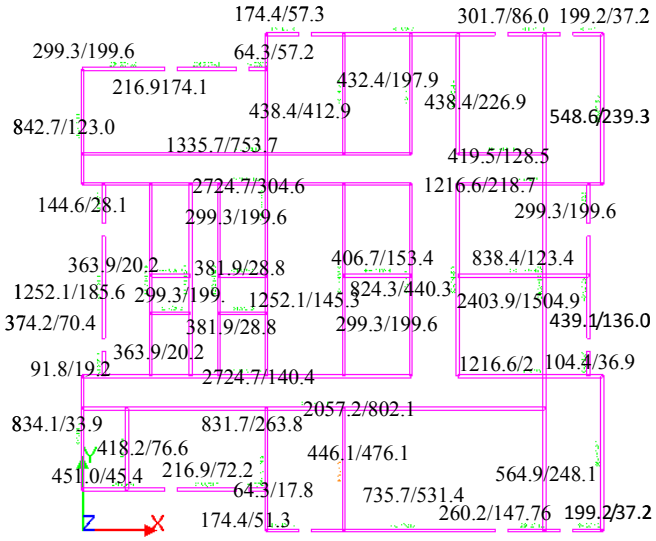

Figure 8: Compressive capacity assessment of the 1st storey

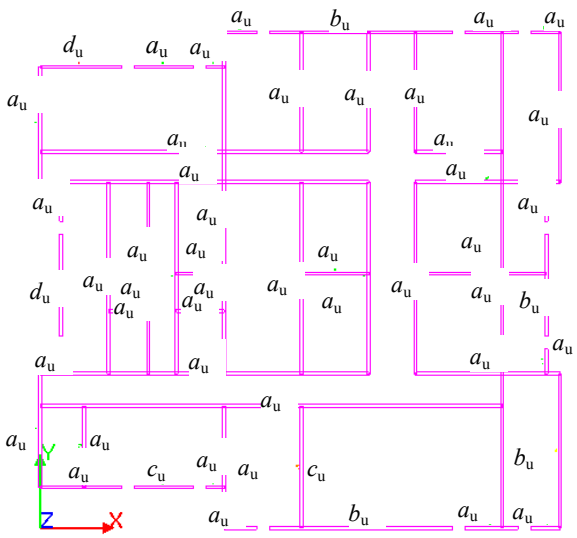

Figure 9: Safety grade of the 1st storey

Table 1: Safety grade situation of elements in each storey

Storey index	*Number of elements whose safety grade is B_u*	*Number of elements whose safety grade is C_u*	*Number of elements whose safety grade is D_u*
1	4	2	2
2	3	1	0

The safety grade of each storey is C_u. Accordingly, the safety grade for structural system is C_u too, which reflects the real situation of the building very well.

Concluding Remarks

MAP developed in the paper can be used to assess the reliability of existing historic masonry structures to increase the accuracy and the efficiency of the assessment. In the future, the software will be modified to suitable for the reliability assessment for other kinds of historic building structures.

Acknowledgements

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