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Autor: Yang, Yucheng / Yang, Yaling / Wang, Zhishan

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Knowledge-Based System for Evaluating Earthquake Damage to Buildings

Système expert pour évaluer les dommages des bâtiments sous l'effet des séismes

Expertensystem für die Auswertung von Erdbebenschäden an Gebäuden

Yucheng YANG
Professor
State Seismological Bureau
Harbin , China

Yucheng YANG
Yaling YANG
Zhishan WANG
Dahua LI
Liu YANG

State Seismological Bureau
Harbin, China

Yucheng Yang, born 1937, graduated from the Civil Eng. Dep. of Tsinghua Univ., Beijing. Prof. Yang makes research on structural and earthquake engineering and knowledge-based engineering.

SUMMARY

Two knowledge-based systems which have been put into operation are presented in this paper. The first can be used to predict earthquake damage to multistorey masonry buildings and the second can be used to predict earthquake damage to existing building stocks in ancity, to evaluate casualties and property losses, to identify high risk subareas and high risk building types, to decide the goal of disaster mitigation and its countermeasures. A wealth of domain knowledge is the prerequisite to develop the two systems and the manner of modelling after nature is the basic point of the knowledge engineering of the system.

RÉSUMÉ

L'article présente deux systèmes experts actuellement utilisés dans le cas de séismes, le premier servant à pronostiquer les dommages subis par les constructions en maçonnerie à étages multiples, l'autre permettant de prédire les dégâts subis par l'ensemble des bâtiments d'une ville, le nombre de victimes et les pertes subies en propriétés. Cela donne ainsi la possibilité d'identifier les zones à haut risque et les types d'immeubles particulièrement mis en péril, ainsi que de fixer les mesures et les objectifs destinés à réduire les dommages. Une base de données de connaissances exhaustives et une modélisation naturelle en matière d'ingénierie constituent les fondements du développement de ces deux systèmes.

ZUSAMMENFASSUNG

Der Beitrag erläutert zwei in Betrieb befindliche Expertensysteme, von denen das eine die Bebenschäden an mehrgeschossigen Mauerwerksbauten behandelt, während das andere dazu dient, den Schaden am Gebäudebestand einer Stadt, die Anzahl Opfer und die Verluste am Eigentum vorherzusagen. Damit können Zonen hohen Risikos und besonders gefährdete Gebäudetypen ausgeschieden und die Ziele und Massnahmen für die Schadensminderung beschlossen werden. Eine umfangreiche Wissensdatenbank und die naturalistische ingenieurmässige Modellierung sind die Grundlage für die Entwicklung der beiden Systeme.

1. INTRODUCTION

According to the experience of earthquake damage in China, casualties and property losses during an earthquake are mainly due to the damage to and collapse of buildings and the losses are much larger in city than in countryside, thus the prediction of damage to urban existing buildings is the basic work of earthquake prevention and disaster mitigation in China. Predicting earthquake damage to multistory masonry buildings, reducing and preventing the earthquake damage to this kind of building efficiently are urgent, protracted and strenuous works because multistory masonry buildings are widely used in China and they are easy to damage. Therefore, the expert system PDSMSMB−1 which can be used to predict earthquake damage to multistory masonry buildings and the intelligence aided decision making system PDKSCB−1 which can be used to predict earthcuake damage to existing building stocks in a city have been established during the research work on the prediction of earthquake damage to existing urban buildings and its countermeasures which belong to the important subject "the research on the application of intelligence aided decision making system to engineering" of the National Natural Science Foundation of China. The research work started from 1987 and the systems have been gone into application. It has been proved that the operation is efficient, the results are reliable, it has been reached expert level and have great sociological and economic benefit. The research work was sponsored by National Natural Science Foundation, State Seismological Bureau and Ministry of Construction of China.

The research object of PDSMSMB−1 system is to establish an expert system for predicting earthquake damage to multistory masonry buildings, to help common technicians to predict earthquake damage to this kind of buildings as the same level as the domain experts and make decision making analysis of earthquake resistance and disaster prevention reasonabl.

The research object of PDKSCB−1 system is to establish an intelligence aided decision making system for predicting earthquake damage to existing building stocks in a city and making its countermeasuers. The information of the predicting object and its environment are saved into computer to help people remember it accurately, manage it efficiently and process it fastly. The engineering knowledge and the experience of domain experts are saved into computer to help common civil technicians and managers of disaster prevention to predict earthquake damage, evaluate property losses and conduct decision making analysis of earthquake resistance and disaster prevention, to help the decision maker of goverment and relevant departments to make the goal of disaster mitigation and its countermeasures.

The relevant content of the two systems have been stated in reference [1]−[3] and [4]−[10]. The object of this paper is to expound something about the establishment of knowledge engineering and its application.

2. KNOWLEDGE SOURCE

According to the current Chinese aseismic criterion of buildings, the existing buildings are only evaluated whether they collapse or not under their fortifying earthquake intensity. According to the new aseismic design code of buildings(GBJ11−89), the damage degree of new designed buildings are limited to that the building can continue been used after repairing, the building are not damged under minor earthquake and not collapse under major earthquakr(the so called minor earthquake is about 1.5 grade lower than the fortifying intensity and the major earthquake is about 1 grade higher than the fortifying intensity). Both the aseismic criterion and the design code are in the light of giving the elements of building a basic requirement, mean while, in the vulnerability evaluation and the earthquake damage prediction, the buildings are handled as a system, and in the system, not only the affection of the elements themselves but also the affection of their mutual relation, interrestriction and interaction are considered. Therefore, to reach the object of this research, the domain knowledge of the two systems should go beyond the limit of the content of both the aseismic criterion and the design code, and the knowledge base of the two systems should be established not only according to the items of both the two standards.

The data and experience of earthquake damage espicially of multistory masonry buildings are very plentiful in China. Many experts of earthquake engineering experienced the site investigations from 1966 Xingtai earthquake to 1976 Tangshan earthquake, and many experimental research and theoritical analysis have been conducted. The research on prediction of earthquake damage to various kind of buildings was started from 1980's and the earthquake damage prediction are being conducted in hundreds of cities of China. Therefore, the two systems have a extensive knowledge source which includes the experience of earthquake damages and its statistical results, the research results of aseismic experiments and material property, general aseismic computation method and site affection, the corresponding items and content of aseismic design code and aseismic criterion, olso, the methods, experience and results in the earthquake damage prediction practice, the countermeasures to earthquake prevention and disaster mitigation in cities. The research group have been engaged in many practice of earthquake damage investigation, earthquake damage prediction and research works on disaster prevention, structural experiment and aseismic analysis for a long time, and participated to draw up the aseismic criterion, the design code and the guide to earthquake damage prediction, have plentiful expert knowledge and experience for establishing the two systems. Meanwhile, in the process of establishing the two systems, the research group also paied attention to absorbing the knowledge and experience of other experts, espicially those experts in the compilation groups of the aseismic criterion of buildings, the regulation of strengthening of aseismic buildings and the urban earthquake countermeasures. All of the knowledge above gave the two systems a extensive knowledge source.

3. DESIGN IDEOLOGY OF KNOWLEDGE ENGINEERING

A wealth of domain knowledge is the prerequisite for constructing applicable intelligence aided system. To design the knowledge engineering elaborately is the key to develop applicable intelligence aided system.

The knowledge engineering of the two systems is designed by domain experts themselves. Not rigidly adhere to common regulation and structural form, the design of knowledge engineering was taked great pains to "model oneself after natural" in order to reach the efficiency of "better than nature". Although the design is more difficult in this way, the constructed intelligence aided system can both reflect the knowledge, experience and logical thinking of domain experts and bring the techniqne of computer intelligence into full play. In this way, the intelligent system can reach the level of experts and have the function of intelligence better than experts.

For the design of knowledge engineering, the ideology of researchers in China and foreign country should be different owing to the difference of affection of their traditional thought. Take the landscape gardening as a example, the traditional gardening is regular landscape architecture in Europe and America, but the ancient landscape architecture of China had the greatest esteem for nature. When the expert system for predicting earthquake damage to multistory masonry buildings was researched by PRC–US cooperation, the writer of this paper gave the idea that the knowlege engineering (primary form) designed if according to the common formation of expert system at that time could not reflect the knowledge and experience of the domain experts, therefore designed a complicated network relationship according to the inference logic of domain expert. It looks as if exceed the technique of intelligence at that time and so not realized until the PDSMSMB–1 was constructed in 1988. We think that it is being pursuit with diligent care if the knowledge engineering is designed according to practical need and the expert system is constructed to be applicable instead of flourishing form, also, it is valuable, though it may be difficult and spend a long time.

The primary forms of knowledge engineering of the two systems in 1986–1987 were different. The knowledge base system of the PDSMSMB–1 which has a complete primary form, was partially substantiated and improved gradually, and extended from evaluation of earthquake damage to analysis of decision making; The block diagram of the PDKSCB–1 system was almost not changed from beginning, but the primary form was only a data base system, and it was developed into a knowledge base system in the practice and made the system extended from the prediction of status quo of buildings to developing prediction of future state and decision making goal of disaster mitigation. Therefore, it is quite necessary to substantiate, extend and improve the knowledge engineering in the developing process of intelligence aided systems.

4. KNOWLEDGE ENGINEERING FOR PDSMSMB–1

The system is divided into 6 parts, they are: information collection, experience inferece, computation analysis, earthquake damage prediction, seismic risk evaluation and result output.

4.1 Block Diagram

The block diagram of the system is shown in Figure 1 from which we can see that the earthquake damage to multistory masonry buildings is dependent on the future earthquake and defence state. The affection of the effective factors and site condition is considered in the defence state. For the evaluation of seismic risk degree, the vulnerability of the building, the damage degree and its acceptable degree and satisfaction degree to the three level of aseismic fortification according to intensity of 63%, 10% and 2–3% exceed probability of seismic hazard assessment in the next 50 years are synthetically evaluated, then, the decision making analysis whether the building is satisfid with the requirement of earthquake fortifying is conducted combining with present use of the building.

4.2 Information Collection

The information is collected by man–machine dialogue, the information includes 10 items, they are: ① present use, ② number of stories and neighbour relationship to other building, ③ kind of building structure, ④ status quo and construction age, ⑤ earthquake fortifying standard, ⑥ the property of structure, ⑦ whether the entirety is good or not, ⑧ the aseismic capacity of its wall, ⑨ the foundation, ⑩ site condition. There are three or more then three grades of sub–items for the continue of the information. A information card with its specification have been provided in order to save time in man–machine dialogue.

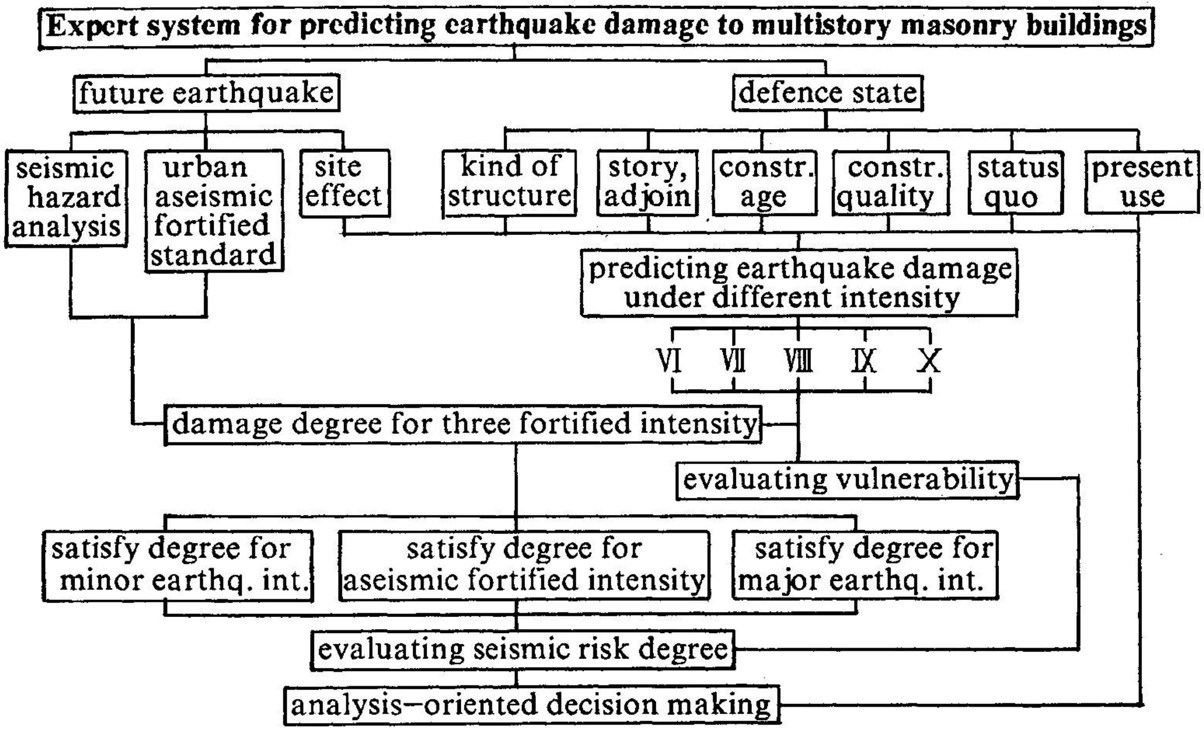

Figure 1. The block diagram of the expert prediction system PDKSCB–1

4.3 Experience Inference and Computing Analysis

The knowledge engineering of the system has been designed combine the calling of the knowledge base and digital computation with the logic inference. The data base and knowledge base are constructed by using as fas as possible the current analysis method and ready–made data espicially of the data of earthquake damage and its statistical results as the knowledge of fact and judgement, meanwhile the knowledge base and inference network are constructed by using the experience of experts as the knowledge of judgement and inference. The knowledge is expressed and the interrelation amoung information is processed by production rule, two dimensional table, modulus and nature network in the system. The uncertainty in the specific building and in the predicting process are expressed as method of expanding certainty coefficient, i.e., the uncertainty problem is implied in the deterministic inference process by using deterministic single value, multi–value and value range. The multi–value predicted results or evaluating range are realized by modifying the corresponding information or realized among the system.

4.4 The Evaluation of Earthquake Damage

The evaluation of earthquake damage in the system includes: the aseismic capacity analysis, predicting earthquake damage degree, evaluating vulnerabilty, casualties, economic losses, earthquake hazard and decision making analysis.

The aseismic capacity of multistory masonry building is marked by a synthetical coefficient K_i . The damage degree is divided into 6 ranks, i.e., basically intact, slightly damaged, moderately damaged, seriously damaged, partially collapsed and total collapsed, and they are marked as a earthquake damage index the range of which is 0–1.0. According to the aseismic capacity coefficient of each story and the earthquake damage index, the earthquake damage to longitudinal and transversal walls in each story can be expressed respectively, as 12 ranks in this system, from intact to collapsed.

Vulnerability is an inherent property of a building in a specific site. The vulnerability index is the weighted mean value of damage index of the building under the earthquake intensity of Ⅵ—Ⅹ with consideration of additional value of the affection of neighbour building..When the hazard is evaluated, the rate of casualties and economic losses is related to the damage index and type of building. The general earthquake hazard of the building is synthetically judged. The satisfying degree is divided into four ranks, i.e., ① very good ② ordinary ③ reluctantly and ④ not. The seismic risc degree is divided into 6 ranks, i.e., ① very small, ② quite small, ③ moderately(it can be accepted for common building), ④ slightly large(it can be reluctantly accepted for common building but it can not fit all requirements of the fortifying earthquake), ⑤ quite large(it can not be accepted), ⑥ very large. The decision making analysis is made according to vnlnerability and earthquake hazard degree for important building and common building respectively.

4.5 Output Results and its Inquirements

The system can provide a result report in a fixed form which includes 4 parts:

① The survey of the building. This is the predicting object formed in the information collecting process by the system itself. The users can modify the report about survey of the building in the screen of computer conveniently.

② The predicted results of earthquake damage. The earthquake damage index, the earthquake damage degree, the loss rate of the property in the building and the building itself and casualties under the intensity for Ⅵ—Ⅹ will be provided in a digital table.

③ The evaluation of vulnerability which includes vulnerability index, aseismic capacity and vulnerability evaluation.

④ The evaluation of earthquake hazard and decision making analysis. The satisfication degree with the requirements of 3 levels of fortifying intensity and the general comment will be provided.

If the earthquake damage index and phenomenon of the each story are inquired by users, the corresponding results will also be provided in table form.

4.6 The Realization of the System and Earthquake Example Inspection

The system is installed in IBM / AST microcomputer, the Chinese character is realized by Chinese character DOS system. It is compatible to operate in Eenglish and Chinese and the display and output is in Chinese. To solve the complicated network inference and large computation problem, the main program is wrote in FORTRAN language. The structure of the program is in card of patterns lump which is combined and managed by command file. The data base is constructed utilizing DBASE soft ware and the file manage ment and report compilation are conducted by calling the chinese character Wordstar. The batch processing function under the DOS is utilized to control and manage the system which has friendly interface which let the users can use the system rightly.

The system have been inspected by earthquake damages to masonry building in Tangshan, Haicheng, Tonghai, Yangjiang, Dongchuan, Wulumuqi earthquake, there is a good agreement between the predicted results and the data information from practical earthquake damage investigation and the agreement degree is 90 percent, the mean error is 0.1 degree of earthquake damage.

5. KNOWLEDGE ENGINEERING FOR PDKSCB–1

5.1 Block Diagram

The block diagram of the PDKSCB–1 system is shown in Figure 2. The system includes 3 subsystems, i.e., building, man–economic and diagram subsystem. The following results can be obtained.

① The predicted earthquake damage, casualties and economic losses in the whole city under given intensity Ⅵ, Ⅶ, Ⅷ, Ⅸ and Ⅹ, respectively, or / and under complete probability of seismic hazard assessment in the next 50 or some years.

② The predicted earthquake damage, casualties and economic losses of various subareas, and the identified high risk subareas.

③ The predicted earthquake damage, casualties and property losses of various types of building, and the identified high risk types.

④ The potential earthquake damage and risk distribution diagram in the city.

⑤ The possibility and condition of realization for the goal of disaster mitigation.

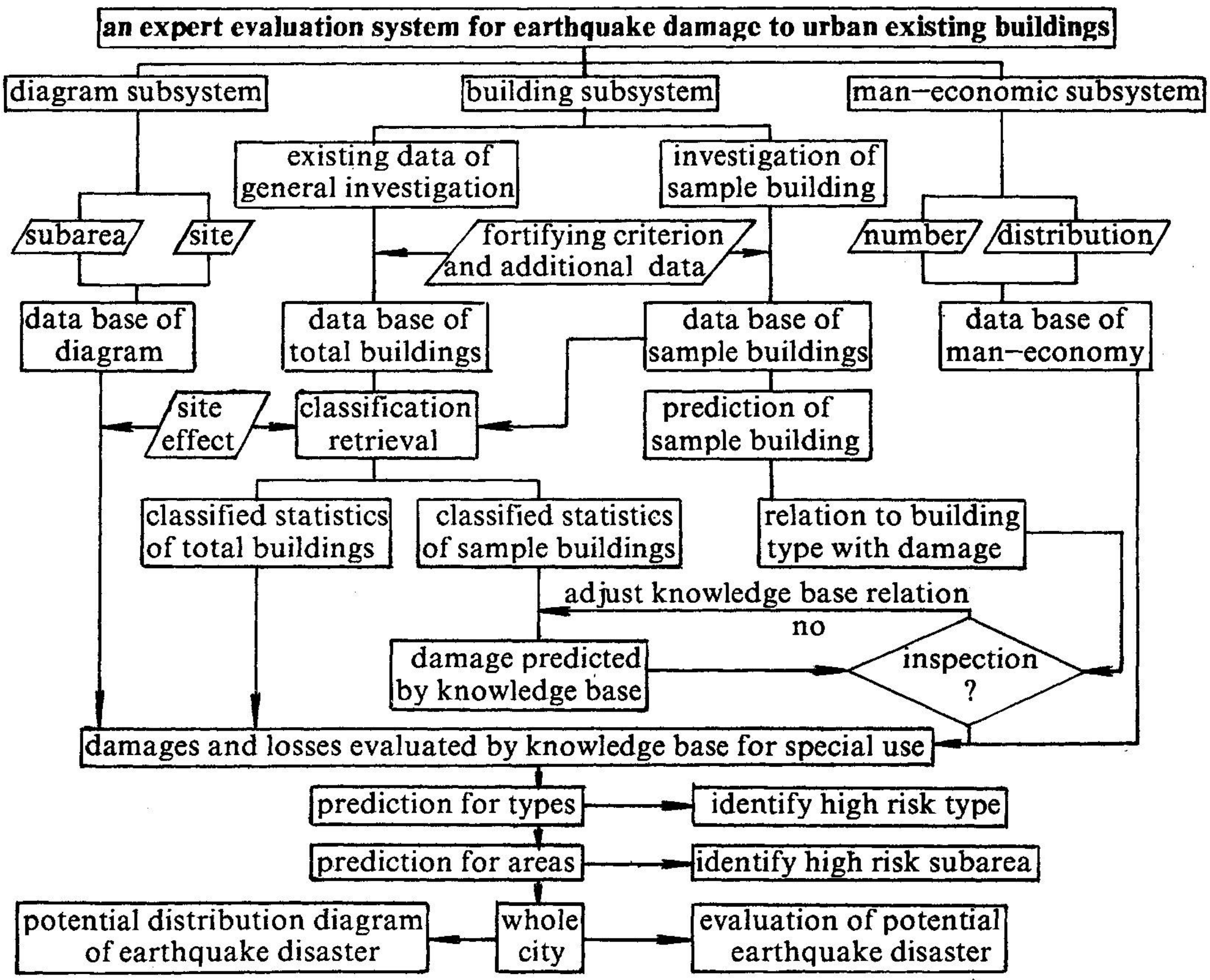

Figure 2. The block diagram of the expert evaluation system PDKSCB–1

5.2 Data Base

Collecting a large amount of data for predicting damage to existing buildings in a city and storing them up in a computer, the data base can be constructed directly or supported by knowledge base. Each datum is represented by a character string with a definite length, a digit code or a numerical value. There are six basic data bases in the system, ie., data base of buildings in the whole city, data base of sample buildings, data base of population, data base of property in building and value of building itself, data base of diagram and data base of site condition.

The type of a building in the data base is represented by 5 items, ie., kind of building structure, amount of the story, construction age, building status quo and present use. There are 6 kinds of structure, 9 kinds of story, 5 kinds of age, 5 kinds of status quo and 8 kinds of present use. The type of building can be retrieved either by one–element or multi–elememts. There are 33 types according to one–element retrieval and 10800 types according to 5–elements retrieval, but most of them in the 5–elements retrieval are empty sets, generally, there are only about one thousand types of building in a middle or big city.

5.3 Knowledge Bases

The evaluating earthquake hazard is considered to 5 effective factors , ie., earthquake effect, earthquake damage, economic losses, casualties and building importance. There are four major knowledge bases in this system.

①. Knowledge base for predicting damage to existing building. It is the basic and the largest knowledge base, in which the probability matrix of different damage degree under Ⅵ, Ⅶ, Ⅷ, Ⅸ, Ⅹ intensity for 10800 types of building according to 5–elements retrieval is constructed. Damage degree is divided into 6 ranks.

②. Knowledge base for evaluating direct economic loss. The losses are related to the damage degree and the earthquake effect and they are also related to factors for evaluating both the property in building and that of building itself, such as floor area, structure, stories, age, status quo and present use.

③. Knowledge base for evaluating casualty. The casualties are related to the damage degree and earthquake intensity and also related to the scale (floor area and type) of the building and occurred time (day or night).

The casualties or economic losses under given intensiy i are evaluated according to $P(D)_{ij}$ that is the predicting damage probability for the degree $j$under intensity i, and, under complete probability of seismic hazard assessment in the next 50 years is evaluated also.

④. Knowledge base for site condition. Some new knowledge bases in specific site condition can be constructed making use of the following formula, thus

$$P(D)_{ijs} = a_i P(D)_{(i-1)j} + b_i P(D)_{ij} + c_i P(D)_{(i+1)j} \qquad (1)$$

where s is the specific site, a_i, b_i and c_i are the coefficient of site condition and the sum should be equal to 1, if the effect of site exceed 1 grade for intensity, $(i \pm 1)$could be instead of $(i \pm 2)$or $(i \pm 3)$in the formula(1).

The knowledge base for predicting damage is constructed according to earthquake damage data, aseismic behavior analysis and experts′ experience. Because of considerable difference in aseismic capacity of same type of building in different cities, the key step to construct the knowledge base for special use is consistent inspection. Its means to let the earthquake damage to building samples predicted by the knowledge base for special use be identical to that predicted as building unit. It is controled by Hamming distance in two fuzzy sets, the distance of total deviation is limited in 0.02, the distance of point deviation is required to be less than 0.05, ie., 1 / 10 and 1 / 4 rank of damage degree, respectively.

5.4 Search of High Risk

To evaluate the potential earthquake risk, a synthetic decision analysis is conducted in the system based on 3 elements, ie., building damage, casualties and property losses. Each of the 3 elements is represented by 3 risk factors, ie., damage index, vulnerability index and easy damage probability for building damage, the number, rate and density for both the life and property losses. The high risk subarea is searched according to 9 undimensional risk factors which are obtained by dividing the 9 factors that have different dimension by their corresponding mean value of the whole city .

Identification of high risk type of building would be conducted in two steps, since the amount of building types is too many. The first step is searching vulnerability index reached threshold value. The search is conducted according to damage index, number of both the casualty and property losses under different intensity for minor, fortifying and major seismic state, respectively, as the second step. Denote the risk factor which reaches the threshold value as 1, otherwise as 0, summing up the risk factors which takes value of 1 or 0, the building type which summing number reaches 9 is the high risk building type and that reaches 5 to 8 is the next high risk building type.

5.5 Developing Prediction

The developing prediction is predicting earthquake damage to buildings, casualties and economic losses for some schemes of engineering measures and sociology countermeasures of disaster mitigation up to 2000 or a certain age accoroding to urban developing plan and experts′ experience. From results of developing prediction, we can see for the goal of disaster mitigation and the decision making.

5.6 Input, Output and Display

The system is constructed in the IBM / AST microcomputer and the VAX / 780 computer, there are input, output and display in Chinese character. The system provides four types of user interface, including menu–driven interface, query interface, natural language explanation and graphics interface. Output of the system is a series of table in fixed form and can also represented by colour figure.

6. APPLICATION

The two systems have been widely used in China. PDSMSMB–1 system has been used to the earthquake damage prediction and / or aseismic appraisal and strengthening measure selection in nearly 20 cities. PDKSCB–1 system has been used in various cities from Sanmenxia city of 80 thousand population to Zhanjiang and Xiamen city of 300 thousand population and also to Taiyuan city of 1500 thousand population. The geographical positions of these cities are from Central Plains to south east sea bank, also to North of China, some of the sub–system have been also used in Wuxi city in south bank of Yangtse river and Tieling city in Northeast of China. The fortifying intensity of these cities are Ⅵ, Ⅶ,Ⅷ. It has been proved from the practical application that the reliability of the system is high, the decision making is efficient and applicability is strong, it will play its important role in improving the aseismic fortifying status and the public psychology status to earthquake.

7. CONCLUSION

The characteristics of the two systems are as follows:

①The wealth of domain knowledge is the outstanding characterization of this research. Therefore, the reliability of the two systems is high.

②The knowledge engineering is designed by domain experts themselves, model oneself after nature and make it better than nature are basis of the system. The system could fully reflect the knowledge, experience and logical thinking of experts, the inference is very natural, it can not only agree with the engineering concept, but also make use of the advantages of technique of computer intelligence.

③The two systems had been progressively developed, further improved and extended in the practice. PDSMSMB−1 system experienced primary form, demonstration stage, application stage and commercial stage; PDKSCB−1 system experienced man−machine system, moderate test and knowledge base system.

④The serving objects are clear, the content is complete and the usage is public. Both of the two system can be installed in microcomputer and operated in Chinese character.

This research also shows that it is efficient to develop intelligence aided decision making system in earthquake damage prediction domain. The two systems will be widely used and produce greater sociological and economic benefit in the International Decade for Natural Disaster Reduction.

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