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Prediction of seismic damage patterns of buildings

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ABSTRACT: An object-oriented knowledge base has been developed for inferring potential causes of seismic damage to a building from the data in the Project Database. Fuzzy pattern matching is then performed with the causes for historical seismic damage to buildings stored in the Seismic Damage Database, SDD, to identify those cases which are strongly correlated with the data on the building. These cases then serve as a basis for predicting the type and level of seismic damage that the given building is most likely to experience.

The performance of the system has been evaluated by applying it to quite a few existing or to-be-constructed buildings in Japan. We believe that results such as the visual images of damages shown on the console of strongly correlated historical cases are useful in devising countermeasures to reduce future seismic damages and planning post-seismic efforts.

1 INTRODUCTION

For a seismic risk management system to be useful it needs to evaluate damage in quantitative terms such as damage factor (dollar loss/replacement value) and also make qualitative assessments of patterns and characteristics of probable damage. The system described in this paper has been developed with the above in mind. As mentioned in Tatsumi et al. (1992), the system has a main control module, Damage Factor Evaluation Module and Pattern Matching Module for diagnosing a building in a qualitative manner.

In the Pattern Matching Module a qualitative assessment of damage is done by identifying cases of historical seismic damage by means of pattern matching of the cause set for the given building and for each past damage case in the Seismic Damage Data-base. The first cause set is inferred by the main control module using a knowledge base while the second has been built from published reports.

The operation of this module is guided by menus and the results are shown on the display in the form of visual images of damage together with some comments.

In this paper, we explain and discuss the contents of the Pattern Matching Module and the knowledge base which infers the causes of damage.

2 SEISMIC DAMAGE DATABASE

Records of historical seismic damage of buildings were investigated for encoding the building characteristics and observed damage in a database. We surveyed the building damages due to the 1968 Tokachi-oki and the 1978 Miyagiken-oki earthquakes which represent typical damaging earthquakes in Japanese urban areas. In our study we have focused on damage cases of reinforced concrete (RC) buildings which were published in the official reports of the Architectural Institute of Japan, AIJ (1968, 1978). The formats of these reports are not uniform so it is difficult to directly encode their contents in the database from the descriptions. Therefore, a survey sheet as shown in Figure 1 was devised to fill out the reported items in an unified manner.

The items on the data sheet are categorized into four groups.

1. Profile (name, location, year of completion, use, structural type, type of foundation, scales, conditions of site, facing and so on)

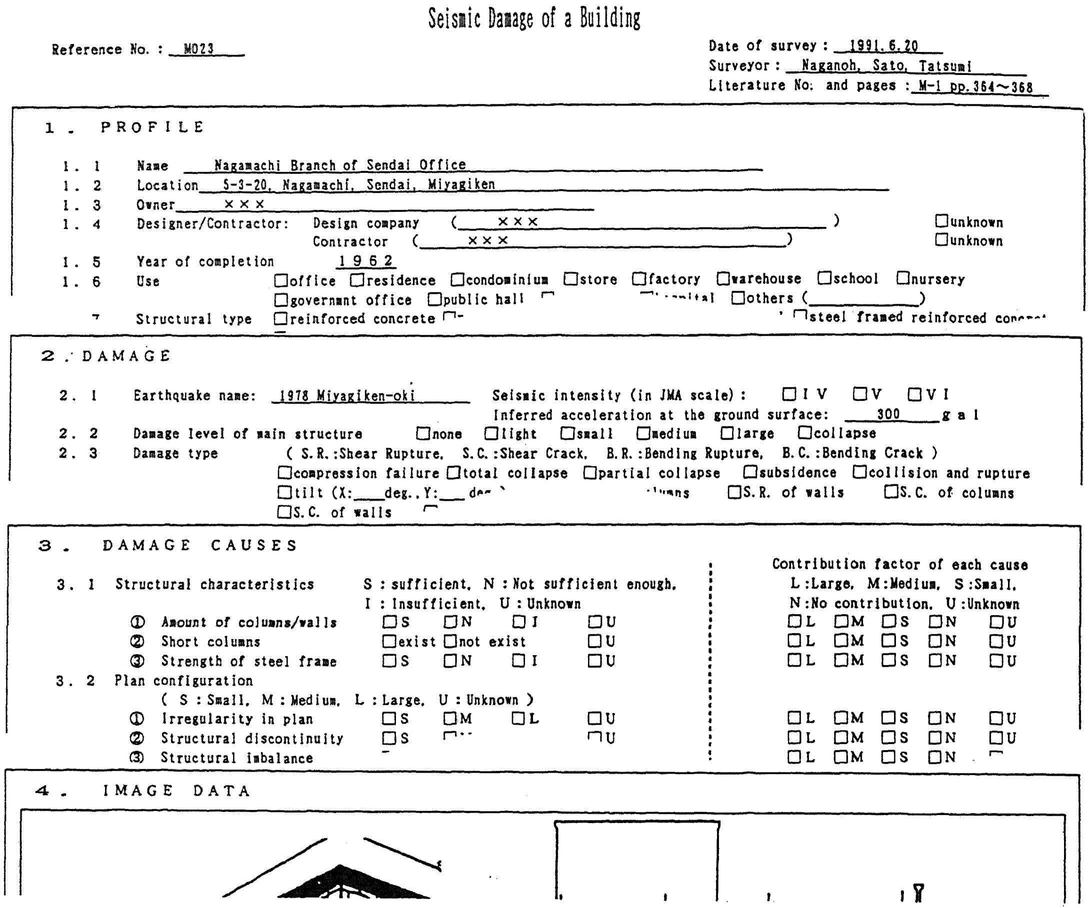
2. Damage (seismic intensity, inferred acceleration, level of damage, type of damage, damage of the foundation and type of repair)

3. Damage causes (structural characteristics, plan and section configurations, material quality, ground and foundation, adjacent buildings)

4. Image data (photographs of actual damage)

Each item in the third group (damage causes) is classified in terms of its potential and the extent of its contribution to the damage (as large, medium, small or none). When the descriptions in the official reports were too vague, the case was evaluated by experts in structural/earthquake engineering based on the available information. When judgement was impossible the causes were listed as "unknown".

A total of 60 survey sheets were filled out and the information contained in these were encoded into the SDD.



Seismic Damage of a Building

Reference No. : M023

Date of survey : 1991.6.20
Surveyor : Naganoh, Sato, Tatsumi
Literature No. and pages : M-1 pp.364~368

1. PROFILE

1.1 Name Nagamachi Branch of Sendai Office
1.2 Location 5-3-20, Nagamachi, Sendai, Miyagiken
1.3 Owner ×××
1.4 Designer/Contractor: Design company (×××) □unknown
Contractor (×××) □unknown
1.5 Year of completion 1962
1.6 Use □office □residence □condominium □store □factory □warehouse □school □nursery
□governmnt office □public hall □others ( )
Structural type □reinforced concrete □steel framed reinforced con

2. DAMAGE

2.1 Earthquake name: 1978 Miyagiken-oki Seismic intensity (in JMA scale): □IV □V □VI
Inferred acceleration at the ground surface: 300 gal
2.2 Damage level of main structure □none □light □small □medium □large □collapse
2.3 Damage type (S.R.:Shear Rupture, S.C.:Shear Crack, B.R.:Bending Rupture, B.C.:Bending Crack)
□compression failure □total collapse □partial collapse □subsidence □collision and rupture
□tilt (X:___deg., Y:___ □S.R. of walls □S.C. of columns
□S.C. of walls

3. DAMAGE CAUSES

3.1 Structural characteristics S : sufficient, N : Not sufficient enough, I : Insufficient, U : Unknown
Contribution factor of each cause L : Large, M : Medium, S : Small, N : No contribution, U : Unknown

① Amount of columns/walls	□S □N □I	□U	□L □M □S □N □U
② Short columns	□exist □not exist	□U	□L □M □S □N □U
③ Strength of steel frame	□S □N □I	□U	□L □M □S □N □U

3.2 Plan configuration
(S : Small, M : Medium, L : Large, U : Unknown)

① Irregularity in plan	□S □M □L	□U	□L □M □S □N □U
② Structural discontinuity	□S	□U	□L □M □S □N □U
③ Structural imbalance			□L □M □S □N

4. IMAGE DATA

Figure 1. Survey sheet for a historical damage case.

3 OUTLINE OF THE PATTERN MATCHING

3.1 Knowledge base for inference of damage causes

The potential causes of damage to a building are inferred from the information stored in its Project Database which has the basic information on the building in the planning, construction and operation stages. The information in the Project Database is related mainly to the use, scale, plan and structure of the building. The items are as follows:

1. Profile (project code, location, use and years of design/completion)
2. Scale (number of floors, total height, height of a story, building/basement areas and total floor area)
3. Structure (type of structure, number of columns, total length of aseismic walls, facing and type/size of foundation)
4. Others (existence of short columns, irregularity of plan, ratio of two sides of plan, existence of pilotis/wells and liquefaction potential)

Based on the expertise of structural/earthquake engineers and the knowledge from historical seismic damage, a knowledge base was created for inferring the likely causes of seismic damage of a building from information contained in its Project Database. The list of likely causes of seismic damage built into the knowledge base are:

1. Structure (insufficiency of columns and walls, existence of short columns)
2. Plan (plan irregularity, structural discontinuity, structural imbalance and existence of well)
3. Section (irregularity, existence of pilotis, top heavy)
4. Ground/Foundation (liquefaction potential, insufficiency of strength of ground/foundation)

As an example of inference of a cause, the potential of the cause "Insufficiency of strength of the foundation and ground" is judged by the following logic;

(1) basement area / building area < 0.5,
(2) the pile length ≥ 20 m and
(3) the year of the design is before 1974

$\Longrightarrow$ "True"

Condition (1) implies that the increase of aseismic resistance capacity by the basement cannot be expected, (2) implies that a high possibility of the existence of thick alluvium layer under the building is identified and (3) implies that the building was not designed according to the New Aseismic Design Code for Building Foundations used after 1974 in Japan.

Similar kinds of logic have been represented in the object-oriented knowledge base using the expert system shell, NEXPERT OBJECT.

3.2 Pattern matching using the fuzzy set theory

By carrying out a pattern matching between the inferred cause set of the building and the cause set of each damaged case in the SDD, the correlated damage cases are identified. The outline of the pattern matching is shown in Figure 2. The contribution of each cause in the SDD to the observed damage has been classified into four grades (large, medium, small or none) by experts. In order to deal with the vagueness of the amount of contribution of the causes, fuzzy set theory is applied in the pattern matching. When all causes of a historical damage case in the SSD belong to the cause set of the building, the coherence value between the two cause sets is 100%, i.e. there is a total match. For such a case the fuzzy vector (C_V), which is a discretized membership function, represented by C_{V_0} is written as (see Figure 3).

$$C_{V_0} = (0,0,0,0,0,0,0,0,0,0,1) \quad (1)$$

For the case when the building checked lacks some causes, the coherence value is decreased. We utilize the transmission matrices $M(l), M(m)$ and $M(s)$ which correspond respectively to the large, medium and small levels of contribution of the causes (Tatsumi et al. 1990). When i large, j medium, and k small causes are missing in the building, the fuzzy vector C_V is calculated as shown below (see Figure 3).

$$C_V = M(l_i) \circ ... \circ M(l_1) \circ M(m_j) \circ ... \circ M(m_1) \circ M(s_k) \circ ... \circ M(s_1) \circ C_{V_0} \quad (2)$$

where

$\circ$: Fuzzy matrix operator (Tatsumi et al. 1990)

$M(l_i) = ... = M(l_1) = M(l)$

$M(m_j) = ... = M(m_1) = M(m)$

$M(s_k) = ... = M(s_1) = M(s)$

In this study ,the coherence value at the center of gravity of a membership function is used as a measure of the correlation between the two cause sets. When this value is larger than a threshold value and also the degree of the damage of the case inferred in the Damage Factor Evaluation Module (Tatsumi et al. 1992) is close to the degree of the building the case in the SDD is selected as a correlated case.

4 DISPLAY OF THE CORRELATED DAMAGE CASES

The user inputs the building code to be checked and a specific earthquake name (or assumed lifetime of building). The system proceeds to carry out the pattern matching after retrieving the required data from the Project Database and to display the correlated damage cases in the SDD.

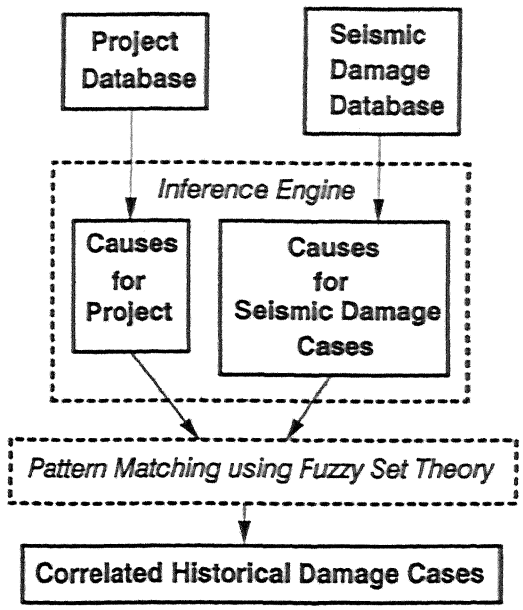


Figure 2. Flow for the pattern matching.

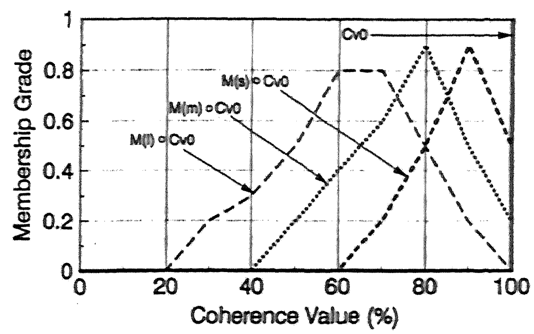


Figure 3. Transition of the membership function by missing causes.

As an example, we discuss the results for an existing reinforced concrete (RC) building located in Tokyo in the case of a recurrence of the 1923 Kanto Earthquake. This building has three floors above ground level and one floor in the basement. The total floor area is about 1580 m^2. The expected damage factor (dollar loss/replacement value) calculated in the Damage Factor Evaluation Module is about 10% as mentioned in Tatsumi et al. (1992). Three correlated damage cases are displayed as the result of pattern matching (see Figure 4). The comments associated with the damage causes confirm that the expected damage of the building may arise from an insufficiency of the columns and/or walls and structural imbalance in plan. It is recommended to stress on the above two causes when making the countermeasures.

The visual images shown on the display suggest that the damage is likely to go no further than some shear cracks on the columns and walls and that the structure itself may need only a minor repair. The building is expected to retain enough strength for operation even without the repair. However, the possibility of a malfunction of the water / electricity / information facilities is high. The visual image of the historical damages enable the users to grasp the seismic risk of the building in further depth as a complete view of the damage and the conditions of the damaged portions give valuable information not easily conveyed by numerical values alone. As shown above, the Pattern Matching Module can be utilized even by non-experts who may not have much knowledge on aseismic design of buildings.

5 RESULTS AND DISCUSSION

A qualitative evaluation of seismic risk of a building is possible by means of pattern matching in this expert system which integrates historical seismic damage data, a knowledge base and fuzzy set theory. Based on the correlated damage cases scientifically picked up by the system and also the users' own knowledge, the users can make story simulations including the secondary damages. The countermeasures prepared based on the results of such story simulations can contribute to higher efficiency of the risk management. The system is not only appropriate for seismic risk management but also because of the good use of the visual data and potential causes the system is considered to be appropriate for instructive uses such as

- to give preliminary knowledge of seismic damage to structural designers,
- to enable planning of post-seismic activities.

Through our research, we believe that a system for seismic risk management has become more practical by adding the qualitative evaluation to quantitative one.

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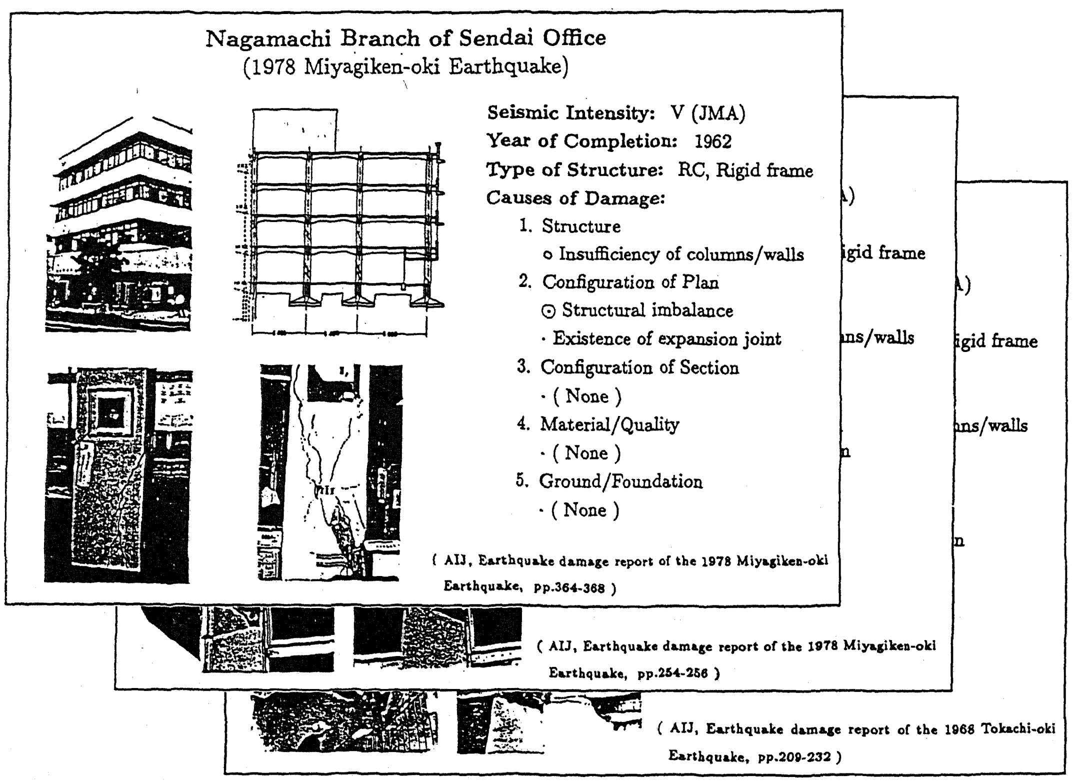

Figure 4. Display of the strongly correlated damage cases for the example.