IMPORTANCE OF THE ACTIVE FAULT RESEARCHES FOR EFFECTIVE EARTHQUAKE RISK MANAGEMENT

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ABSTRACT**:** An intra-plate earthquake is one of the major threats to mega cities. For the effective earthquake risk management, we need to answer the following questions, when, where, and how large earthquake will occur in the near future. The earthquake occurs along the fault zone. The fault zone is divided into many fault segments. Some of the segments move during the earthquake. It is important to become clear the activities of individual fault segments.

Kobe is in the center of the Rokko-Awaji fault zone. The total fault length is 71 km. The fault movements are predominantly right-lateral slip with dip-slip (reverse fault) (HERP, 2005b). And the Osakawan fault zone, having the whole length of 39 km exists in the Osaka bay, south of Kobe.

From the length of the fault segment, the magnitude of earthquake can be estimated (e.g. Matsuda, 1975). There are nine active fault segments in a circle of 10 km from the center of Kobe. The average length of the nine segments is 6.6 km. The magnitude of 6.2 is obtained from the Matsuda’s empirical formula. If the earthquake energy was enough to break the single fault segment, the fault movement could propagate to the next segment. This propagation was caused during the 1995 Hyogoken-Nanbu (Kobe) earthquake. There are sixteen active fault segments in the circle of 20 km. When we have chosen two fault segments in the circle of 20 km from Kobe based on a topographical connection, we can imagine the six combinations. Their average length is 19.3 km. From this length, the magnitude of 7.0 is estimated. This magnitude is larger one order than that of single segment.

The estimation of the earthquake magnitude from the Headquarter for Earthquake Research indicates simultaneous activity of the fault zone. The large earthquake (M 7 ~ M 8 classes) shakes in a wide area. In the case of the smaller (M 6 class) earthquakes, severe disasters are occurred in the limited area near the epicenters. Generally comparison of the large earthquakes, smaller earthquakes often occur. For the effective earthquake risk management, we need the cost analysis using the proper estimation of the earthquake. It is effective to prepare the large earthquake against the large network and the long-time using institutions, such as roads, bridges, tunnels and plants. On the other hand, for the short-time using and small structures such as buildings and housings, it is more effective to prepare the smaller earthquake.

KEYWORDS: seismic risk management, fault zone, fault segment, cost analysis

1. INTRODUCTION

An intra-plate earthquake is one of the major threats to mega cities. For the effective earthquake risk management, we have to know when, where, and how large earthquake will occur in the near future. (1) Earthquake prediction is impossible in present science technology. But the active fault investigation which measure ages of cutting or bending layers will answer probability. (2) The intra-plate earthquake had occurred many times along the active faults in the Quaternary. So the area of near active faults has large hazard than other area. (3) The size of the earthquake can be estimated by the fault length. There are some empirical formulae. For example, Matsuda (1975) indicated the following empirical formula:

$\log L = 0.6\,M - 2.9$, where L and M are the fault length (km) and the magnitude of earthquake, respectively.

The definition of the fault length can interpret in many different ways, because the fault is not always single line. Generally the fault (zone) consists of many fault segments.

The Headquarters for Earthquake Research Promotion of Japan (HERP) evaluates long-term probabilities of the earthquake occurrence about the ninety eight main fault zones in Japan. The estimated earthquakes are simultaneous activity of the entire fault zones.

2. APPLICATION TO KOBE CITY

Kobe experienced severe damages after the 1995 Hyogoken-Nanbu (Kobe) earthquake. The earthquake was caused by the activity of the three fault segments in the Rokko-Awaji fault zone. The braked segments to the surface are considered the Nojima (No.15), Takaiso (No.12) and southern part of Yokooyama (No.11) faults (Fig. 1).

In spite of the great earthquake disasters, there are many unmoved segments. Concerning about the position and the length of the fault segments, the potentials of earthquakes around Kobe are discussed in this section.

2.1 Fault zones through Kobe

The Rokko-Awaji fault zone is on the northwest side of the Osaka bay block. The Rokko-Awaji fault zone is along the Rokko Mountains and the Awajishima Island from northeast to southwest. The total length is 71 km (from No. 1 to No. 18 in Fig. 1). The fault movements are predominantly right-lateral slip with dip-slip (reverse fault) (HERP, 2005b). Kobe is in the center of the Rokko-Awaji fault zone. The Osakawan fault zone is discovered by the sonic prospecting under the Osaka Bay. It is almost parallel to the Rokko-Awaji fault zone. The total length is 39 km (from No. 20 to No. 22 in Fig. 1). The fault movement is apparently dip-slip (reverse fault) (HERP, 2005a). And concerning east-west direction of compressed crustal stress, it may also have right lateral movement.

2.2 Fault segments and earthquake estimation around Kobe

The Rokko-Awaji fault zone consists of the several fault segments. Some of them are parallel to the southern edge of Rokko Mountains and the urban area of Kobe. At the Awajishima Island, both sides of the island are divided by fault segments (Fig. 1).

There are nine fault segments in the circle of 10 km from the center of Kobe. The Suma (No. 10), Suwayama (No. 8) and Okamoto faults (No. 7) are along between the Rokko Mountains and the urban area of Kobe. The Motomachi flexure (No. 9) is concealed faults under the urban area. They are clearly seen on the topographic map. The Gosukebashi fault is the biggest fault in the Rokko Mountains. The Sumiyoshi River runs along the Gosukebashi fault. The Wadamisaki, Maya and Rokko Island faults are splay faults of the Osakawan fault. The strike direction rotated a little anti-clockwise near the northern tips. They may be connected to the faults in the Rokko Mountains.

Their average length is 6.6 km. The magnitude of 6.2 is obtained from Matsuda’s empirical formula. It is almost the same size of the 1961, M 6.1

earthquake at the Akashi Strait.

If the earthquake energy is enough to brake the single fault segment, the fault movement can propagate to the next segment. The epicenter of the 1995 Hyogoken-Nanbu earthquake is under the Akashi strait. The fault movements along the Nojima fault (No.15) and the southern part of Yokooyama fault (No.11) are appeared on the ground surface and in the tunnel. And piers of the Akashi Kaikyo Bridge seem to have moved by the activity of Takaiso fault (No.12).

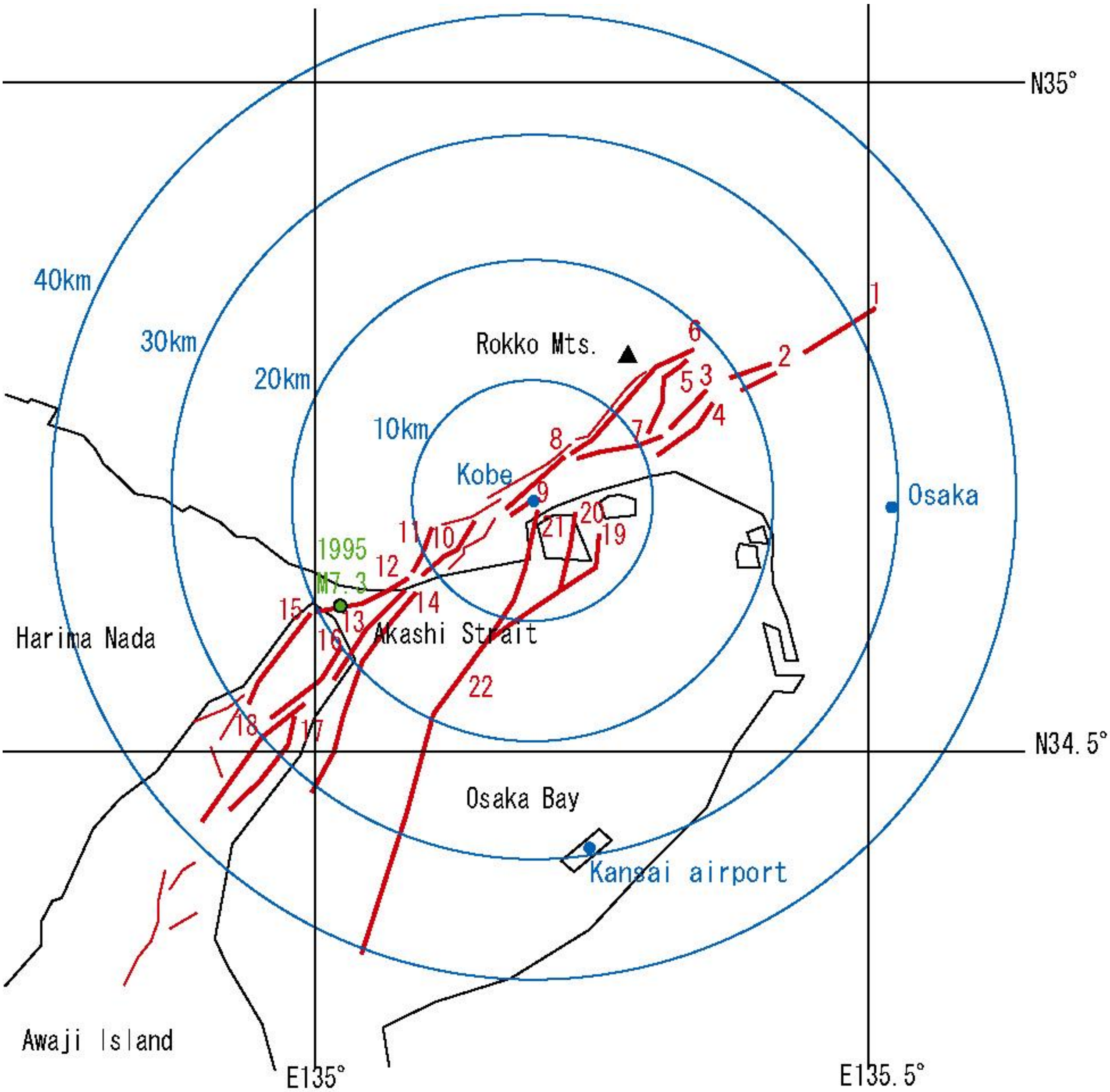

Fig.1 Active faults around Kobe city. Fault segments (No.1~No.18) are in the Rokko-Awaji fault zone. The fault segments (No.19~No.22) are in the Osakawan fault zone.

Fault name: 1. Nobatake fault (f.), 2. Itami f., 3. Koyo f., 4. Nishinomiya flexure (fl.), 5. Ashiya f., 6. Gosukebashi f., 7. Okamoto f., 8. Suwayama f., 9. Motomachi fl., 10. Suma f., 11. Yokooyama f., 12. Takaiso f., 13. Kariya f., 14. Kariyaoki f., 15. Nojima f., 16. Kusumoto f., 17. Higashiura f., 18. Nodao f., 19. Rokko Island f., 20. Maya f., 21. Wadamisaki f., 22. Osakawan f.

Table 1 The list of fault length and estimated earthquake by Matsuda's empirical formula.

a) Single Segment in the curcle of 10 km from Kobe

Fault Name	Fault segment Number	Length	Magnitude
Yokooyama	11	4	5.84
Suma	10	8	6.34
Suwayama	8	8	6.34
Gosukebashi	6	14	6.74
Motomachi	9	2	5.33
Okamoto	7	5	6.00
Wadamisaki	21	10	6.50
Maya	20	6	6.13
Rokko Island	19	2	5.33
Average Length		6.6	6.20

b) Example of Double Segments in the curcle of 20 km from Kobe

Fault Name	Fault segment Number	Length	Magnitude
Yokooyama + Kariya	11, 13	15	6.79
Suma + Kariyaoki	10, 14	27	7.22
Gosukebashi + Suwayama	6, 8	22	7.07
Koyo + Okamoto	3, 7	12	6.63
Nishinomiya + Motomachi	4, 9	20	7.00
Ashiya + Rokko Island	5, 19	20	7.00
Average Length		19.3	6.98

c) The 1995 Hyogoken-Nanbu earthquake

Nojima + Takaiso + southern part of Yokooyama	11, 12, 15	19.5	6.98

d) Estimated earthquake by HERP

Rokko-Awaji fault zone	1 ～ 18	71	7.92
Osakawan fault zone	20 ～ 22	39	7.49

There are sixteen fault segments in the circle of 20 km from the center of Kobe. When we have chosen two fault segments based on a topographical connection, we can imagine the six combinations, consisting of the two faults in the Rokko-Awaji fault zone. Their average length is 19.3 km. From this length, the magnitude of 7.0 is estimated. This magnitude is larger one order than that of single segment.

2.3. Activity of fault zone

To know activity of a fault (when and how many times), based on the trench excavation investigation, dating is very important. For example, the Nojima fault (No. 15 in Fig. 1) becomes clear to have at least three events. (Awata and Suzuki, 1996). The latest event is the Hyogoken-Nanbu earthquake in 1995. The former two events were of about 2000 and 4000~5000 years ago (Fig. 2). Judging from these results, the activity interval of the Nojima fault is presumed to be about 2000 years.

Also the similar surveys for another fault segments in the Rokko-Awaji fault zone, were carried out (Fig. 2). As a result, at least two events were detected on the Higashiura fault, while one event was found on the Nodao fault, the Gosukebashi fault and the Osakawan fault. Concerning the plural earthquake events, it is really difficult to detect them along the Gosukebashi fault in the Rokko Mountains, because the distribution of the overlying young sediments is generally limited along the fault in the Rokko Mountains. On the other hand, concealed faults, like the Motomachi flexure zone (No.9), in the uraban area of Kobe are covered with the thick sediments. These sediments are bended on the fault, based on the seismic reflection profiles (e.g. Yokokura *et al.*, 1999) and the ground-penetrating radar images (Nigauri and Miyata, 2007ab). But it is difficult commonly to carry out the trench excavation investigation in order to make clear the activity of the concealed active fault in the urban area, because of too many buildings and housings.

If some fault segments in the Rokko-Awaji fault zone had move simultaneously, the interval of the earthquake would be presumed about 900~2800 years (Fig. 2). As there is a possibility that unknown earthquake events are still remained in the other segments, this amount is regarded as the uncertain interval.

2.4 Damage and Size of earthquake

The large earthquake causes damage in a region. The seismic energy is increase about thirty times by one magnitude. During Jan., 1995 to Nov., 2007, the earthquake that recorded large Seismic Intensity (SI),

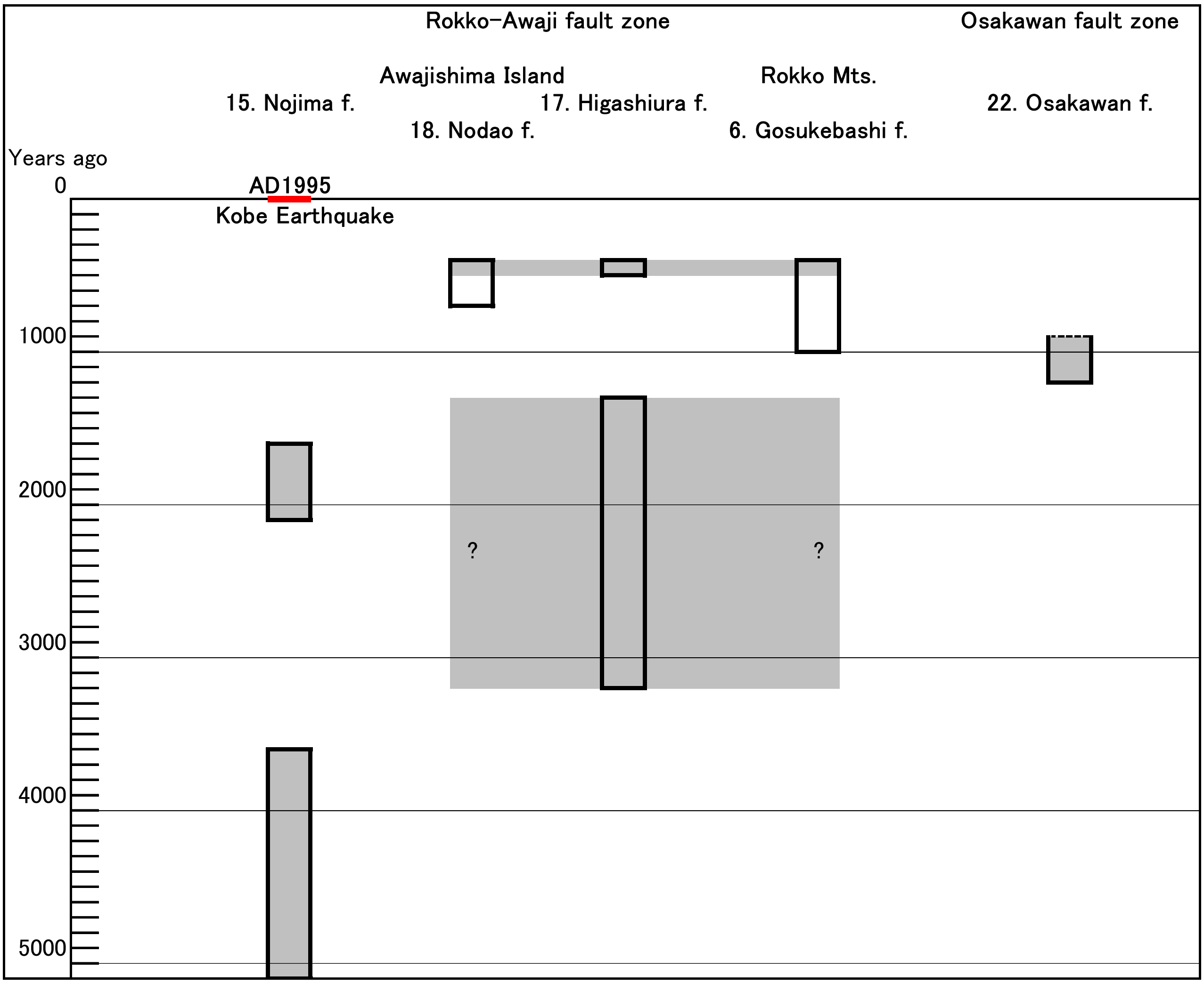

Fig.2 Ages of surface fault ruptures in the Rokko-Awaji and Osakawan fault zone.

(6 upper or 7) occurred eight times. Figure 3 shows the relations of the seismic stations and the distance from the epicenters. It can be seen that smaller size earthquakes also cause damage near the epicenter. If the earthquake of M 6 will occur within 20 km, it will be shook the SI 6 upper.

And it is known that the smaller earthquakes often happen than the larger earthquakes. The magnitude decrease one, the numbers of earthquakes are about ten times around Japan. For the structures of the short working life, they have less possibility to experience the large earthquake.

3. EARTHQUAKE RISK MANAGEMENT

In the case study, it is considered that the earthquake risk is simply circulated the costs of disasters times the frequencies of the earthquakes. To prepare for the large earthquake, the cost needs much, but the earthquake seldom will happen.

It is effective to prepare the large earthquake against the large network and the long-time using institutions, such as roads, bridges, tunnels and plants (case 1 in Fig. 4). Those types of structures perform the function as network. The costs increase rapidly at the larger earthquake with the spread of strongly shaken area. In the case 2, the costs increases normally but the frequency of the large earthquake is higher. That is the case of the lengths of each fault segments is relatively long.

On the other hand, for the short-time using and small structures such as buildings and housings, it is more effective to prepare the smaller earthquake that will experience several times during their lifetime, which also need to avoid destructive situation against the large earthquake. In Nagaoka city, Nigata Prefecture, the SI 6 upper was recorded three times during recent 3 years: The first and second are the 2004 Nigataken-Chuetsu earthquake (M 6.8 and M 6.5) and the third is the 2007 Nigataken-Chuetsuoki earthquake (M 6.8). as shown in Fig.4 case 3, concerning about each structure, the risk of smaller earthquake is larger.

In the case 4, the frequency of the small earthquake is large. That is the case of the lengths of each fault segments is relatively short. If there is a little possibility of large earthquake, we would need to evaluate small earthquakes caused by individual fault segments for effective earthquake disaster prevention.

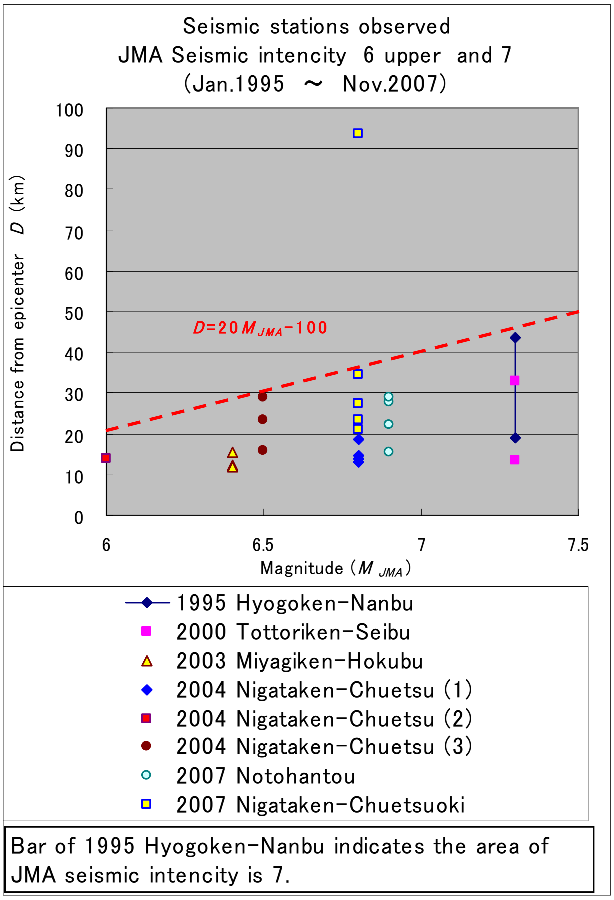

Fig.3 Seismic stations observed SI 6 upper and 7. (during Jan., 1995 to Nov., 2007)

The Benchmark

BM	M 6	M 7	M 8
C	1	10	100
F	100	10	1
R	100	100	100

Legend
C: Costs of disaster
F: Frequency of earthquake
R: Earthquake Risk

For large netwark institution

Case1	M 6	M 7	M 8
C	1	20	400
F	100	10	1
R	100	200	400

Along long fault segments

Case2	M 6	M 7	M 8
C	1	10	100
F	100	15	2
R	100	150	200

For each small structure

Case3	M 6	M 7	M 8
C	4	20	100
F	100	10	1
R	400	200	100

Along short fault segments

Case4	M 6	M 7	M 8
C	1	10	100
F	200	15	1
R	200	150	100

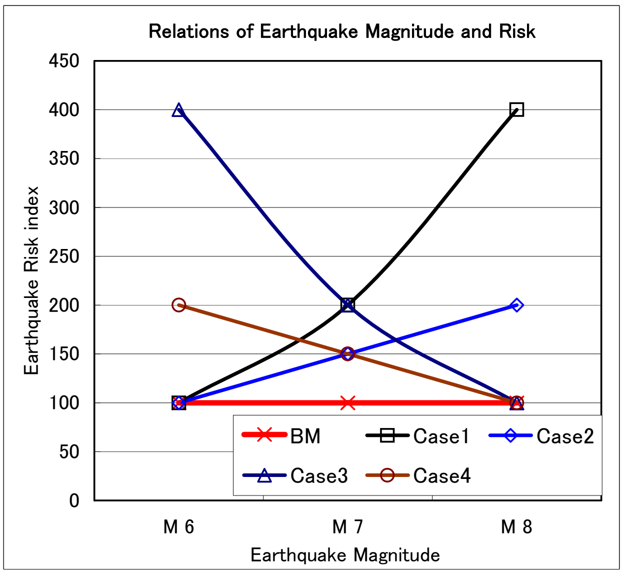

Fig.4 The case study of Earthquake risk cost analysis.

4. CONCLUSIONS

The earthquake magnitude and the strong motioned area could be estimated from the activity of the fault segments. Types of earthquake disasters depend on the earthquake magnitudes and intervals. It is important to choose the earthquakes for the effective earthquake risk management.

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