SEVERAL SUBJECTS STILL REMAINED SINCE THE 1995 KOBE EARTHQUAKE

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Abstract: The 1995 Kobe earthquake brought serious problems from the earthquake disaster mitigation point of view. In this paper, several important subjects will be discussed after reviewing what happened during and after the earthquake. Most of all, the following subjects will be discussed in this paper.
1) Source model of the earthquake could be understood in detail using observed strong motions and damage direction of distributed structures. There is a possibility that one of asperities near Kobe city contributed to have brought heavy damage in Kobe city.
2) Significant later phase could be seen in the seismic record obtained in the coastal region of Kobe city. It can be explained as a surface wave that could be reflected at the southern boundary of Osaka basin. This later phase with long period component has the possibility to trigger the failure of Hanshin highway.
3) Two residential buildings, one was constructed with the older Japanese seismic code and the other one was constructed with the new seismic code that had been issued in 1981, showed different behavior during the earthquake. The former one suffered serious damage and the latter one did not suffer damage so much.
After all, such experiences should be taken into account in the future strategy about earthquake disaster mitigation.

1. INTRODUCTION

The Kobe (Hyogoken-Nanbu) earthquake of January 17, 1995, brought a serious disaster in Kobe and Hanshin districts including northern Awaji island. It was the worst that none of governors, reporters in mass communication, and even researchers, could estimate total amount of victims just after the earthquake. For this reason, we lost very important several hours in confusion not knowing what to do. Even after several days or several weeks from the earthquake, we were not sure that the most adequate countermeasures had been taken for the damaged area or not.

We have visited Kobe city many times, mainly in 1995 for field works to observe aftershocks, measuring microtremors and to perform refraction survey of deep underground structures using explosions. After that, we have also visited the area almost twice a year just to watch around the condition of restoration and reconstruction. In such occasion, we often found some of new subjects those were still remained without solving. Therefore we would like to report the following subjects because they could be very serious and important experiences when we consider earthquake disaster mitigation strategies in the future.

2. WHAT HAPPENED DURING AND AFTER THE EARTHQUAKE?

We have examined to draw a temporal flowchart as Table 1, to confirm what happened in and around Kobe city just after the earthquake. In this table, an item showing reported human victims was the most impressive one for us. The number of victims counted only a few at the beginning stage, and it showed rapid increase up to 5,000 within a week. Another very sad story was that additional 1,000 people had to die in sick and mental problem until seven years after the earthquake.

Most of residential people were in bed during the earthquake, and crashed in such condition as shown in Photos.1-3. Urgent rescue activity might be very hard because of the condition like Photos.2 and 4. Every transportation system was quit including JR Super Express (Shinkansen) as Photo.5 and Hanshin Highways as Photo.6. Therefore the only way was just to walk or to take bicycles or motorbikes as shown in Photo.7. Fortunately there were no big aftershocks, but local governors and polis men did not control the people passing through very dangerous areas like Photo.8. Residential people made temporal evacuation mainly into neighboring school buildings (Photo.9). But the term of temporal evacuation continued for a few months or several months. After they moved to temporal houses those were prepared by local governments, they had to live there for five years in maximum. Residential people living around the foot of Rokko Mountains had to repeat quick evacuation when the weather forecast predicted heavy rainfall. As Photo.10 shows such condition, it took almost two years to have completed Sabo-protection.

From earthquake engineering point of view, JR-Shinkansen exposed its vulnerable circumstances, in some case because of exceedingly heavy structure (Photo.11) and in another most of cases because of lack of binding hoops at the top of columns (Photo.12). It took four months to start working by repairing those columns like Photo.13. The other ordinary JR and private railways also suffered heavy damage mainly in embankment parts. Take Photo.14 for instance, it shows a very clear contrast between the enforcement of collapsed Hankyu railway (left) and remaining old houses without damage (right). Hanshin Highways were very quick to have reconstruction. It took only 20 months to have the condition as Photo.15. We remember that there was a very serious discussion about Embarcadero Freeway in San Francisco after the 1989 Loma Prieta earthquake, whether it should be reconstructed or not. Unfortunately there was no time for discussion in Kobe, although there was another opinion to abolish it.

Reinforced concrete buildings also suffered various kinds of structural damage. As shown in Fig.1, the discussion was made using statistical analyses to point out the fact that most of damaged buildings were constructed following to the older building code, and that others based on the 1981 newer code did not have serious damage. Then there is no reason to improve the existing building code. The only problem is how to maintain such remaining buildings with the older code. Here we have just two typical examples to show shear failures in columns (Photo.16) and a failure of middle floor (Photo.17). The upper floors of the latter building, Bldg. No.2 of Kobe municipality office, has demolished after a couple of years as shown in Photo.18, although it could be an educational monument to keep this earthquake disaster without forgetting.

From seismological point of view, we have also learned many things. Strong motions were observed in and around the damaging area as shown in Fig.2, and moreover a tendency was very clear that very large amplitudes were observed in the normal direction against the fault. At the beginning stage, strong motion in Kobe was regarded exceptionally large, but good understanding appeared very soon that the attenuation characteristics looked quite reasonable compared with past experiences like Fig.3. Inversion analyses with neighboring strong motions have been examined by many researchers to show the source mechanism in detail as shown in Fig.4. Some geologist doubted the existence of submerged fault just beneath the heavily damaged belt zone, but the general understanding after a while was to imagine two-dimensional or three-dimensional underground topography like Fig.5. Measured microtremors across this heavily damaged belt zone also showed very systematic change of characteristics as shown in Fig.6.

Table 1 TEMPORAL FLOWCHART SHOWING WHAT HAPPENED IN AND AROUND KOBE CITY JUST AFTER THE 1995 KOBE EARTHQUAKE

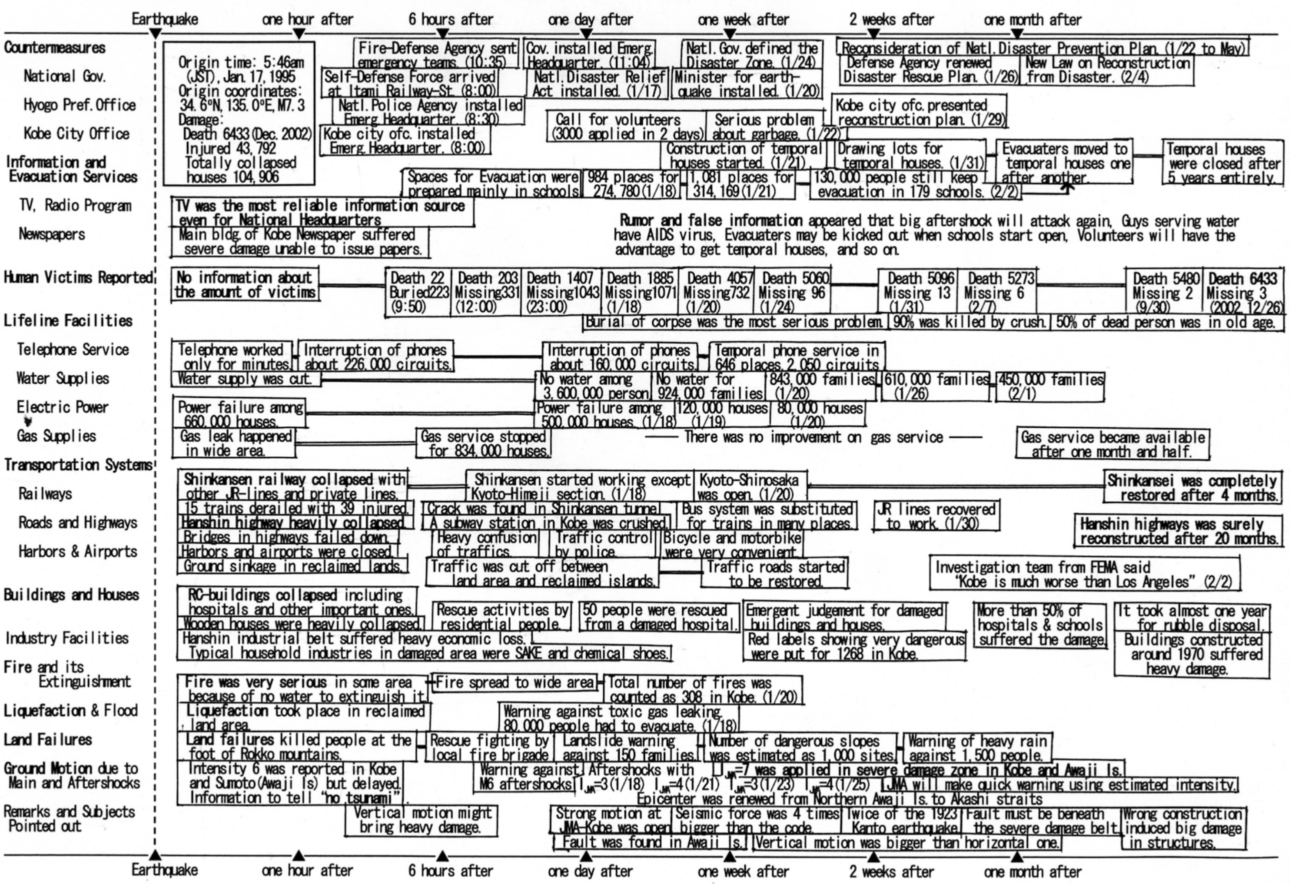


Photo.1 Typical example of collapsed wooden houses (Nishinomiya)

Photo.2 Collapsed houses disturbed rescue activities (Uozaki, Kobe)

Photo.3 Soft first story suffered heavy damage in many places (Motoyama, Kobe)

Photo.4 Such condition even after a couple of months (Uozaki, Kobe)

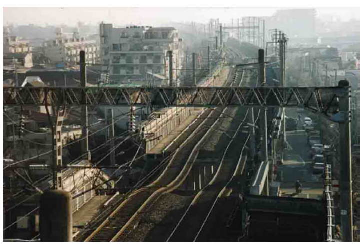


Photo.5 Failure of JR-Super Express called Shinkansen (Nishinomiya)

Photo.6 Overturning failure of Hanshin Highway (Fukae, Higashinada, Kobe)

Photo.7 Side-walks filled with bicycles and motorbikes (Root-43)

Photo.8 Walking people did not care about collapsed buildings (Motomachi, Kobe)

Photo.9 Evacuation to school buildings (Motomachi, Kobe)

Photo.10 Land failures protected after two years (Sumiyoshi-Yamate, Kobe)

Photo.11 JR-Shinkansen with heavy Beams and columns (Nishinomiya)

Photo.12 Failures of the top of columns in JR (Nishinomiya)

Photo.13 JR-Shinkansen after temporary repairs (Nishinomiya)

Photo.14 Restored railway (left) and old houses alive (right) (Okamoto,Kobe)

Photo.15 Restored Hanshin Highway after 20 months (Fukae, Kobe)

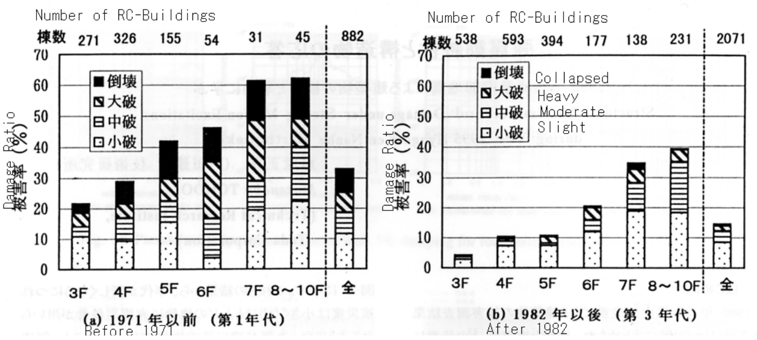


Fig.1 Statistics of damaged RC-buildings. (a) old structures before 1971, and (b) recent structures after 1982. (after Tohdo in AIJ, 1998)

Photo.16 One directional shear failure of a school building (Okamoto, Kobe)

Photo.17 Kobe municipal office just after the earthquake

Photo.18 The same building with Photo.17 after a couple of yea

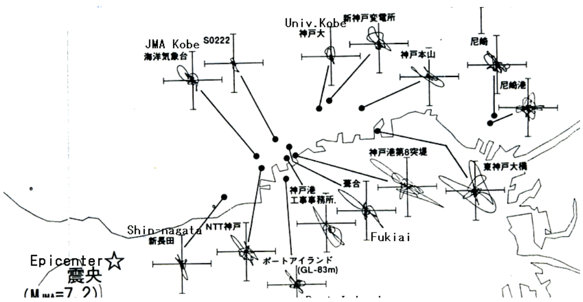


Fig.2 Observed strong motions (after Wakamatsu in AIJ, 1995)

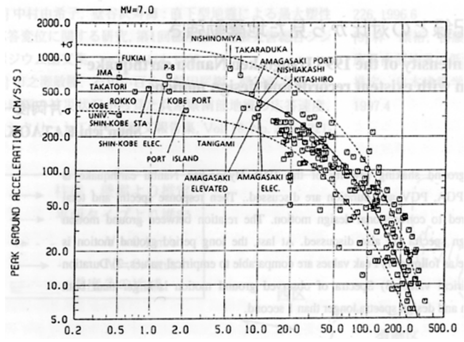


Fig.3 Attenuation of PGA during the 1995 Kobe earthquake (after Kataoka in AIJ, 1997)

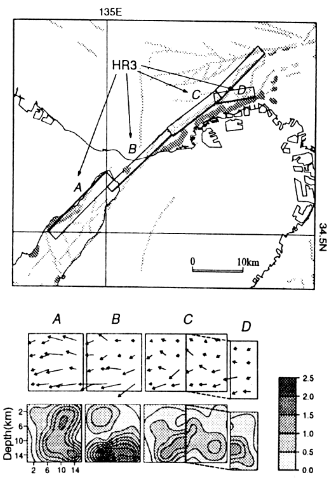


Fig.4 Source model and slip distribution for the 1995 Kobe earthquake (after Koketsu et al. in AIJ, 1997)

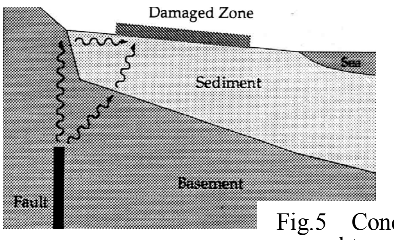


Fig.5 Concept to explain damaged zone with underground topography (after Koketsu et al. in AIJ, 1996)

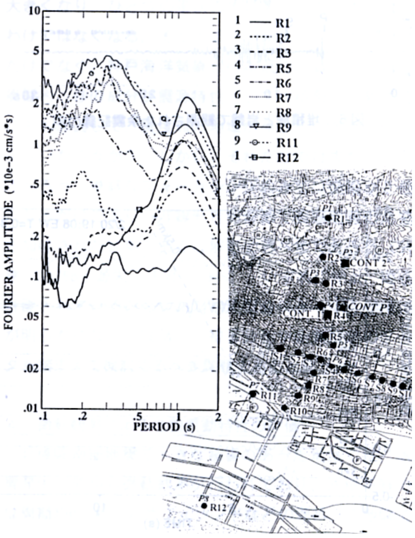


Fig.6 Measured microtremors across heavily damaged belt zone (after Seo et al. in AIJ, 1995)

3. SOURCE MODEL ESTIMATED BY OBSERVED STRONG MOTIONS AND DAMAGE DIRECTION OF DISTRIBUTED STRUCTURES

While we walked around Kobe and Hanshin districts many times, we noticed that the direction of failures for individual collapsed buildings, other structures including Hanshin Highways and overturned trains, looked very systematic as showing Fig.7. The direction was always towards the normal axis against the fault, to the northwest in the eastern side from Hyogo ward of Kobe city, on the contrary to the southeast in the western side. There was no exception in this tendency as if there were a node in Hyogo ward. Such direction of failures can be explained using neighboring strong motions like Fig.8 by assuming 1DOF response analyses. And to explain the polarity characteristics of strong motions, a source model for the 1995 seismic fault could be presented like Fig.9. The most important point is that the observed strong motion at JR-Takatori (TKT) will not accept the current rupture from the hypocenter. We need an effective asperity just beneath Hyogo ward in Kobe city to collapse structures distributed in Nagata and Takatori wards. Of course we need more careful consideration about this subject, but it is required in deed to prepare a synthetic interpretation throughout the source mechanism, underground structures, observed strong motions, and the behavior or damage of buildings and houses.

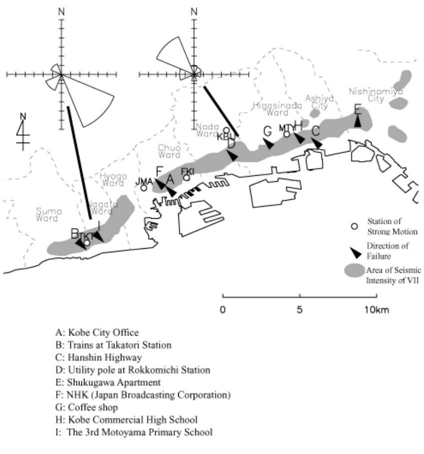


Fig.7 Direction of collapsed buildings and other structures including Photos.6, 16 and 17.

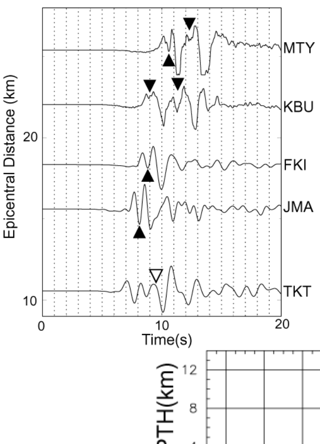
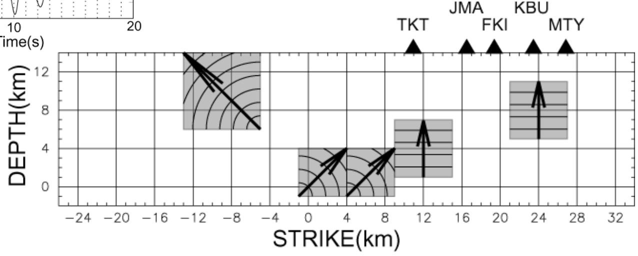


Fig.8 Velocity strong motions with effective phases contributed to the failure of structures

Fig.9 Reviced source model to explain the polarity characteristics of strong motions in Fig.8



4. EXISTENCE OF LONG-PERIOD LATER PHASE AS A BASIN EFFECT

When we were thinking about the failure direction of damaged structures mentioned above, Kobe No.3 of Hanshin Highways (Photo.6), overturned toward the north direction with more than 600m in length, was one of targets to be taken into account. At first we believed that it must have collapsed quite soon during the strong shaking, and we estimated that the failure had been triggered at the west end and transmitted toward the east following to the seismic wave propagation from the source. Then we wanted to find people just watching the failure because no other information was expected. But we hesitated to ask neighboring people about this matter, as they did not like remembering the catastrophic condition anymore.

After all we started the survey in 2001, after 6 years from the earthquake. We found two persons who were watching the failure by checking reliabilities very carefully. One person was working in front of gas station located just on the northern side from the highway (Photo.19). According to his explanation in our interview, he fell and landed during the strong shaking, and was watching the behavior of the highway. At that time the highway was shaking without falling down. After a couple of minutes from the strong shaking, the highway started falling down against his side (north) from the west toward the east grading up the speed. He also found an empty truck had landed from the highway to the ground level and run away.

According to Kawashima(2003 and 2004), he does not believe this person because he talked inconsistent experiences for different newspapers just after the earthquake. But we have a quite different understanding that the person was in an abnormal state of mind just after the earthquake, and he was able to make any kinds of replies against the different questions made by newspaper reporters. On the contrary our interview was made in his stable psychological condition after 7 years and we found nothing strange at all from his talking. Another person, a young guy, was watching the highway from the opposite side (south). He met the earthquake on the tenth floor of a residential building (Photo.19). He opened the entrance steel door during the strong shaking to keep the evacuation route, and got back inside of his home to recommend the evacuation for his family. When they went out to the passage, the highway was still standing. And then they found the failure of the highway after they arrived to the ground level.

Therefore we tried to find the possibility meeting with such experiences. We checked the nearest observed strong motion as shown in Fig.10 very carefully. There were no effective aftershocks in the record, but we found a later phase with about 6 seconds in period that was very clear in velocity seismogram. We could assume a possibility that the later phase might be Love wave as a result of two-way reflection across the Osaka bay like Fig.11. An examination has been tried with 2-dimensional finite differential method as shown in Fig.12.

On the other hand, the highway structure could be evaluated with Fig.13(top) at the original stage before the earthquake. The fundamental natural period in rectangular direction of the highway could be about 0.6 second. During the strong shaking, the dynamic characteristics would change the condition as shown in Fig.13(bottom) because of bending failure at the foot of the highway. In this case, the fundamental period could be around 6 seconds. Such drastic shifting of the natural period may be possible if the floor panels on the top of the highway are jointed each other without missing the connection. And it becomes possible to consider the resonance between a very soft highway and a later phase with very long period. Needless to say we are just proposing a hypothesis to explain the failure of Hanshin Highways. If the hypothesis is acceptable, it will be so good for related responsible people, because the highway might keep standing in the case such later phase did not appear.

Photo.19 Overturning failure of Hanshin Highway and the location of watchers

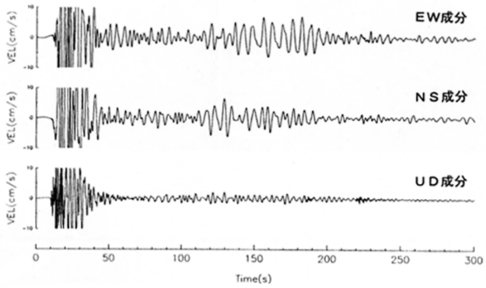


Fig.10 The nearest strong motion in velocity. A later phase appeared after two minutes with 6 seconds in period.

Fig.11 Concept to explain a possibility of long-period later phase in Fig.10 with surface waves across the Osaka bay.

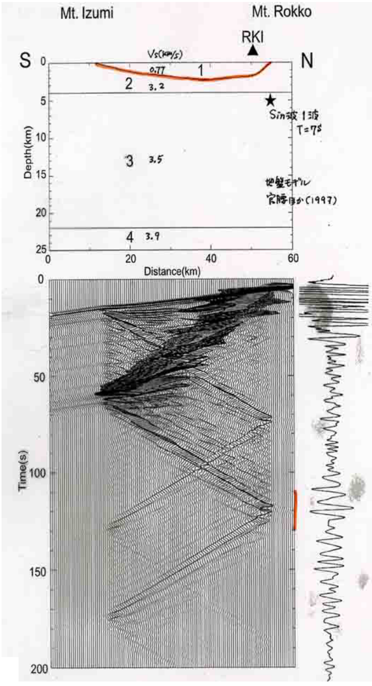


Fig.12 A trial of 2-DFDM analysis for Fig.11 by assuming basin structure.

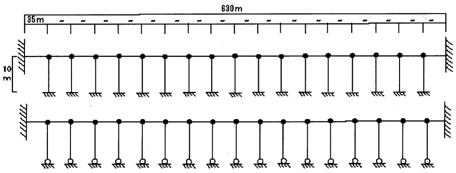


Fig.13 Structure model for Hanshin Highway

5. DAMAGE EVALUATION OF SIMILAR RC-STRUCTURES BUILT WITH DIFFERENT SEISMIC CODES

As we mentioned before, we have full of statistical data about damaged building structures such like Fig.1. But we do not have any practical case studies to compare building structures between the older and the newer building codes. When we were visiting the highway mentioned above, we met with a set of similar RC-structures in the same field, one was already repaired with steel frames (Photo.20) and the other without repairs (Photo.21). They were residential buildings constructed by Hyogo prefecture, the local government. It was quite interesting for us because the former one was built just before the revision of Japanese Building Code in 1981 and the latter one was built just after the revision. Therefore they were constructed following to the different building codes in spite of the similarity in plan, number of stories and even the appearance.

According to the results of our questionnaire to living people, the older building suffered much heavier damage than the newer one. For example, the people in the older building felt much harder shaking, suffered heavier damage on furniture, heavier cracks including seismic walls and around entrance steel doors. Therefore they could not open the doors for evacuation. Such people had to stay much longer duration in other evacuation places because it looked very dangerous to live there (Fig.14). The local government repaired these buildings without moving the living people using additional seismic walls on the ground level. The steel frames mentioned above were put only for the older building, because the government judged the damage of the older one looked much harder although they were not sure such countermeasures were good enough or not.

Then we made a comparison of these two buildings using measured ambient motions on the top of both buildings. Some of measured dataset was quite interesting to explain their dynamic behaviors. The natural period of longitudinal direction was about 0.60s for both buildings. It meant that the steel frames of the older building worked well to have similar characteristics with the newer one, and such natural period looked quite reasonable for general RC-building with 11 floors. In the rectangular direction, the older building showed much longer natural period as 0.54s, while the newer one showed

0.48s. It was also reasonable that the older building might be softer than the newer one, maybe due to the different building code. After the enforcement with steel frames for the older building, it became much easier to have torsions. As we have just examined such features with only ambient motions, we recommended the local governors to make more careful surveys for both buildings. They should have made such surveys just after the earthquake or at least before the repairs.

Photo.20 RC-building built with the older building code

Photo.21 Similar building built with the newer building code

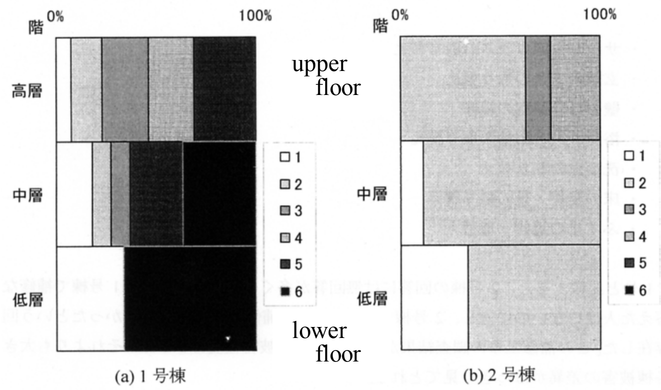


Fig.14 One of questionnaire results showing different degree of damage between the older (left) and the newer (right) buildings. Question was how long time you had to evacuate from your home. 1:not evacuated, 2:within one week, 3:within two weeks, 4:within one month, 5:within two months, 6:more than two months.

6. CONCLUSIONS

The 1995 Kobe earthquake brought really serious problems in the damaged districts. In this paper, after we reviewed what happened during and after the earthquake very quickly, we pointed out several important subjects. Most of all, the following subjects were discussed.

1) A source model for the 1995 earthquake was presented using damage direction of distributed structures and observed strong motions. There is a possibility, we are sure, that one of asperities just beneath the central Kobe city contributed to have brought heavy damage in some part of Kobe city.

2) Significant later phase could be seen in the seismic record obtained in the coastal region of Kobe city. It can be explained as a surface wave that might be reflected at the southern boundary of Osaka basin. This later phase with long period component as 6 seconds has the possibility to trigger the overturning failure of Hanshin highway.

3) Two residential buildings, one was constructed with the older Japanese building code and the other one was constructed with the newer code that had been issued in 1981, showed different behavior during the earthquake. The former suffered serious damage and the latter did not suffered so much.

After all, such experiences should be taken into account in the future earthquake disaster mitigation.

Acknowledgements:

This field investigation research was made with full of cooperations and supports by the local governors and the residential people including victims in Kobe. Hereby we will never forget the 1995 Kobe earthquake. We will try our further efforts to make clear the reason of heavy damage and to prepare the better condition for future earthquakes.

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