EARTHQUAKE RISK MANAGEMENT OF UNDERGROUND LIFELINES USING URBAN EARTH SCIENCE INFORMATION

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***ABSTRACT*:** The 1995 Hyogoken-Nanbu (Kobe) Earthquake (M_{JMA}7.3) caused severe damages of underground lifelines for water, sewage and gas. After the earthquake, we investigated the displaced joints of house inlets distributed in the urban area (Suma to Higashinada ward) of Kobe city. It became clear that the damaged house inlets have the characteristics of co-seismic deformations. The main ground surface movement is the direction of northwest. This direction is a little different from that of an average slope of the ground surface in the urban area of Kobe, but is almost similar to that of strong S waves of the earthquake. It can be consequently interpreted that the displacement of the house inlets was caused by a large ground movement owing to the strong S waves, not because of the mass movement.

On the basis of these considerations, a model explaining a displaced house inlet was built. And we calculated the “co-seismic impulsive force” (as total strength of S waves) using this model. In result, an area acted the large impulsive force is well concerned with that of the remarkably broken lifelines. Judging from our analysis of the distribution of the impulsive forces, in particular, the area acted large impulsive force is appeared (a) on loose sediments, and (b) above concealed active faults detected by using seismic reflection surveys and ground-penetrating radar (GPR) surveys. Therefore, the large impulsive force is thought to have been caused by the amplified seismic waves in the subsurface loose sediments and stronger motions which were transferred along the concealed active faults in Kobe.

Seismic reflection survey data indicate the existence of concealed active faults under the urban area of Kobe. The deformation of faults might be reached to the subsurface layers from the GPR survey and analysis of boring database “KOBE JIBANKUN”. The influences are not only deformation of layers but also soil classification and relative density.

Mega-cities have a common problem about renewal of the infrastructures and mitigation of an earthquake disaster. We think that the apt application of Urban Earth Science information is very useful for seismic risk management of infrastructures.

KEYWORDS: 1995 Hyogoken-Nanbu (Kobe) Earthquake, co-seismic displacements of house inlets, concealed active faults

1. INTRODUCTION

The 1995 Hyogoken-Nanbu (Kobe) Earthquake (M_{JMA} 7.3) was an inland earthquake. The east-west compressive stress caused by bumping of the Pacific plate and the Eurasian plate broke a right-lateral strike-slip fault from the northern part of Awaji Island (southwest side), through Kobe city, to the Rokko Mountains (northeast side). The surface fault appeared only in Awaji Island, which is named

Nojima Earthquake fault. The other side, some continuous cracks were reported in the urban area of Kobe city (Miyata and Maeda, 1998), but they are not recognized as earthquake faults. But large disaster especially occurred in Kobe city. Then the earthquake is also named Great Hnashin-Awaji earthquake disasters.

The strong ground motion caused a remarkable deformation of ground and structures. We can estimate the shear force by measuring subsurface deformed structures such as subway tunnels, pile foundations, pipes of lifelines and rings of manholes. Especially, house inlets are good indexes for understanding subsurface ground deformation caused by strong ground motion. The reasons are: (1) they are densely distributed along the sewage system. (2) The deformations are not interacted with constructions above the ground. (3) In this case, the topography of the urban area is composed mainly of slightly-sloped alluvial fans. The influence of mass movement, such as land slide, liquefaction and lateral flow of ground, however is weak except for the areas of the mountain and sea sides.

２. CO-SEISMIC DISPLACEMENT OF HOUSE INLETS

We investigated the directions, amounts and depths of dislocated joints of house inlets to understand strong ground movements (Ngauri and Miyata, 1998). To interpret the force during earthquake, impulsive force was introduced. The impulsive force can be calculated as the total momentum of necessary to deform house inlet. The strength of impulsive force is indexed *d* (depth of displaced joint (cm)) multiply square root *s* (displacement size (cm)).

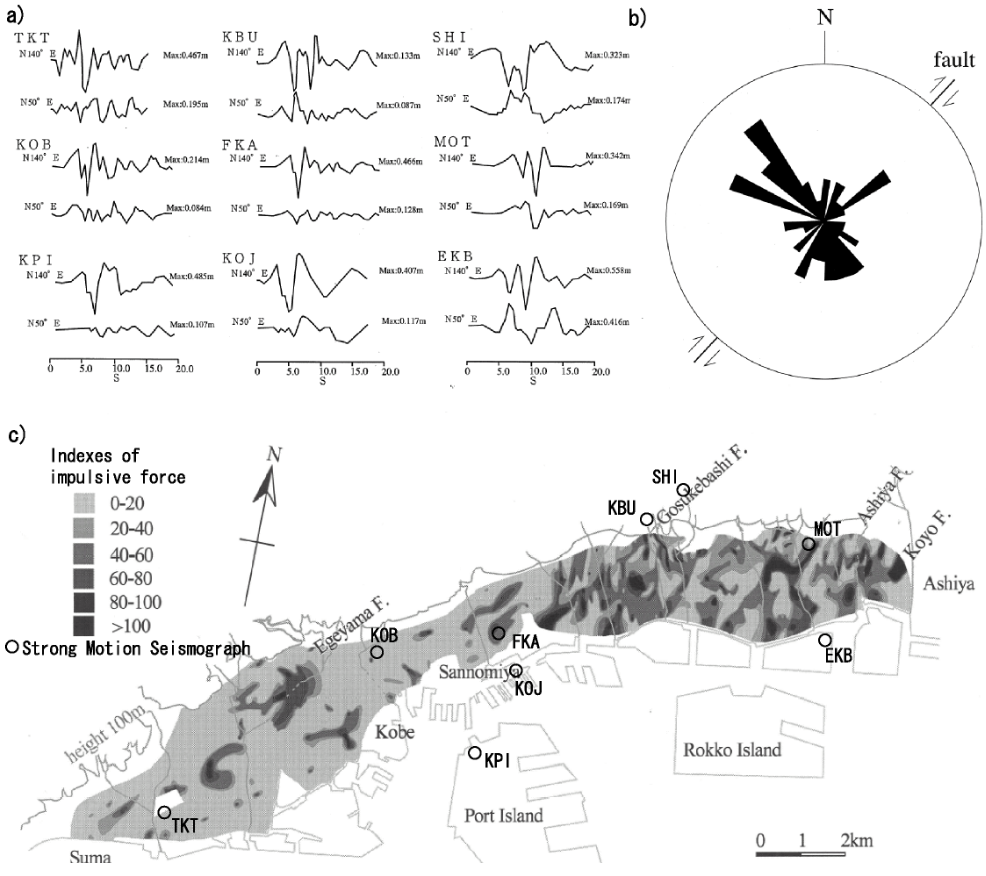


Fig. 1 a) Displacement records during the 1995 Hyogoken-Nanbu (Kobe) Earthquake. The direction of N140°E is perpendicular to the fault. The direction of N50°E is parallel to the fault. (after Irikura, 1995)

b) Direction of displaced house inlets. (after Nigauri and Miyata, 1998)

c) Displacement level of house inlets in the urban area of Kobe. (after Nigauri and Miyata, 1998)

The directions of displacements are strongly concerned measured strong ground motion (S wave) around Kobe city (Fig.1a). The predominant shaking is the direction of NW (Fig.1b). Theoretically, the strong S waves are generated perpendicular to a slip vector on the hypocentral fault (Kikuchi, 1995). They might be not caused by a landslide because the averaged fan slope inclined to the SSW.

The characters of large impulsive forced area (Fig. 1c) are concerned surface topography. The areas of the large impulsive force located on buried rivers and ponds compared with surface topographical maps (e.g. Land Bureau of Natural Land Agency, 1999). There supposed to be loose sediments around the topography. Other characteristic distributions are liner distribution connected large impulsive forced area from NE to SW. They are perpendicular to the already-known active faults in the Rokko Mountains such as the Gosukebashi Fault, Ashiya Fault and Koyo Fault. After the earthquake some researchers are insisting that there are concealed active faults under the urban area from analyzing the seismic reflection survey data (e.g. Yokota *et al.*, 1997).

3. APPLY TO LIFELINE RISK MANAGEMENT

3.1 Damage distribution of lifelines during the earthquake

Lifelines which are piped under ground, such as water, sewage and gas were severely damaged during the earthquake. Damaged places and situations are collected in the database “KOBE JIBANKUN” (Kobe city, 1999). The damages were widespread around urban area of Kobe. Figure 2 shows damaged places of water and sewage in Nada ward of Kobe city. Distribution of damaged area is similar to both water and sewage. Damaged places are concentrated south of the JR railway. On the other hand, between the mountains and the JR railway is almost safe area except for along the Ishiya River. There are some rivers in the southern side of the Rokko Mountains. Around Nada ward, the Nishigo River, Toga River, Ishiya River and Sumiyoshi River are lined from west to east. It is only along the Ishiya River that damaged places concentrate in the northern area of the JR railway.

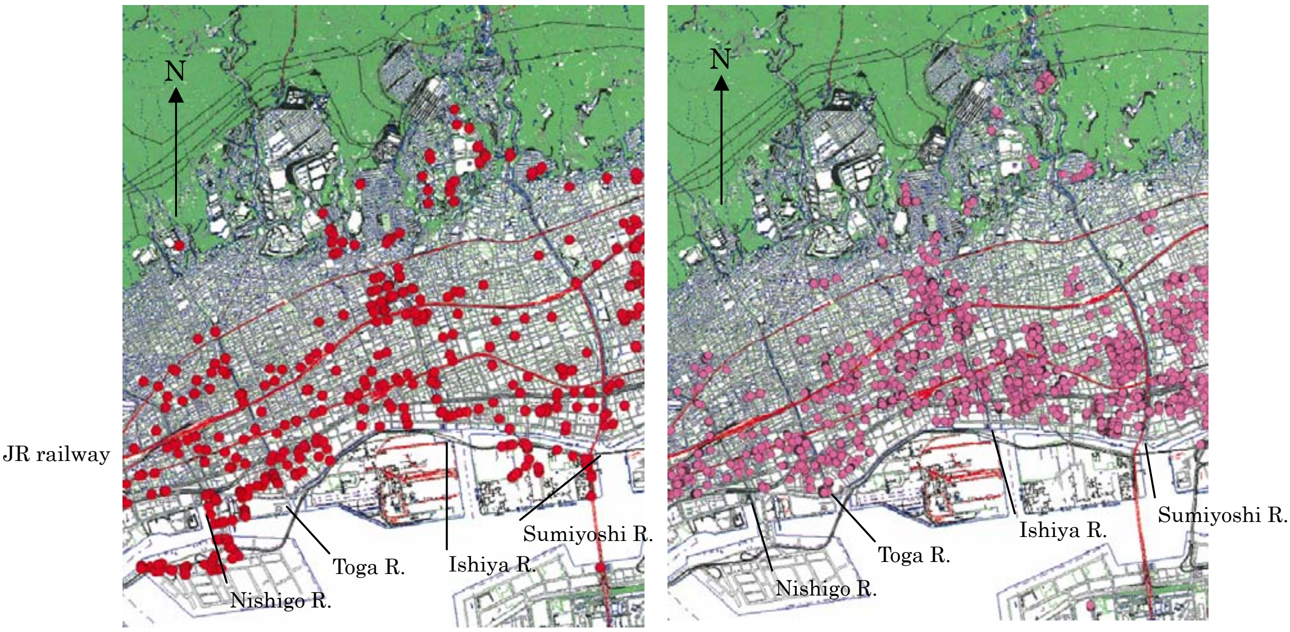


Fig. 2 Damaged points of a) water and b) sewage.
Data are collected in the database “KOBE JIBANKUN”.

3.2 Interaction topography and geology

Figure 3 shows the basement structures detected by seismic reflection survey along the Toga River (Yokota *et al*, 1997). Step like structures of the basement rocks and flexures of layers are imaged. In addition, subsurface structures are surveyed by using a ground-penetrating radar (GPR). The data indicate that the flexures are influenced to subsurface layers. Those types of underground deformation are also detected along the Ishiya River. There is a possibility that surface geology is influenced by geological active structures such as faults.

The topography of Kobe city is characterized as short range of the mountains and sea. The Rokko Mountains are a fault block. They are uplifting during the Quaternary especially latest 1 Ma (Huzita and Kasama, 1982). The altitudes of the mountains are 700 to 900 m, the other side that of urban area is lower than 100 to 150 m. The distance from ridge to urban area is only 3 km. Then mountain slopes are steep and rivers are rapids.

The geology of the Rokko Mountains is the granites formed in Cretaceous time. The rocks will be changed to boulders, gravels and sands under

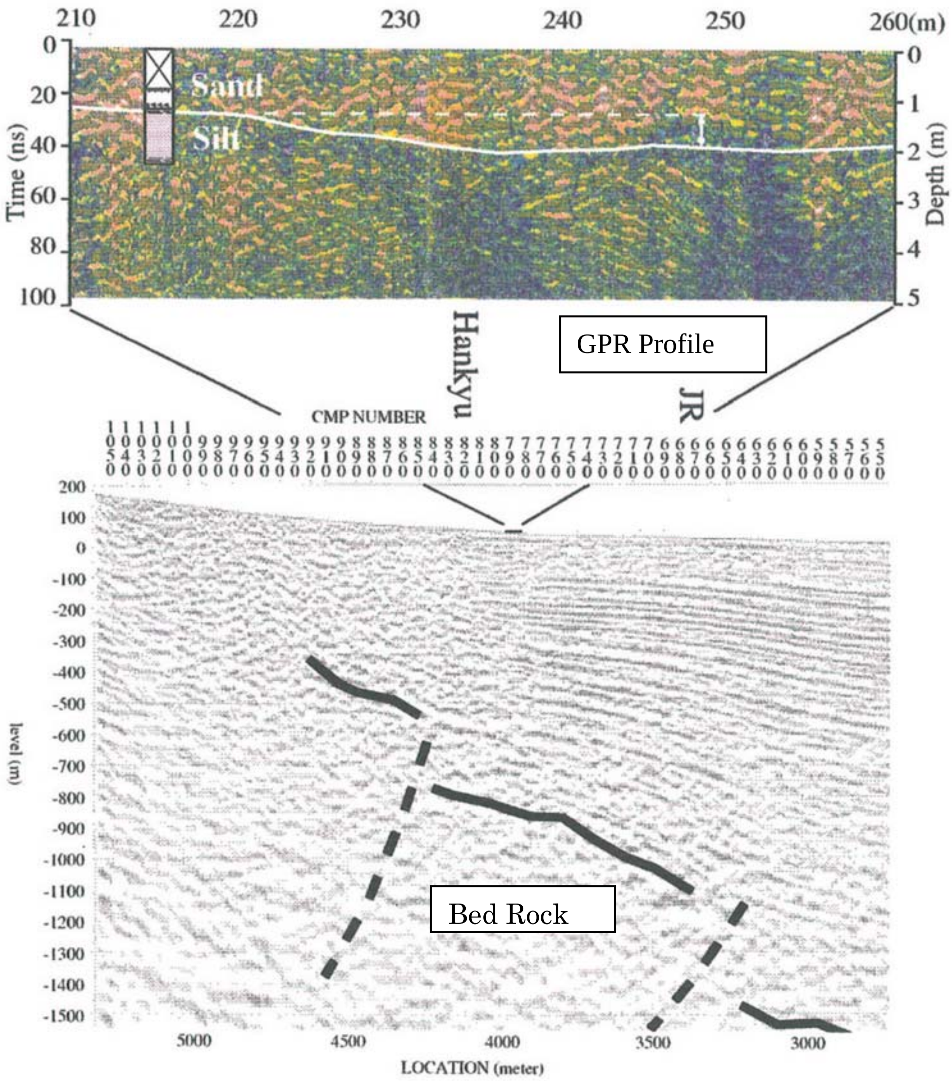


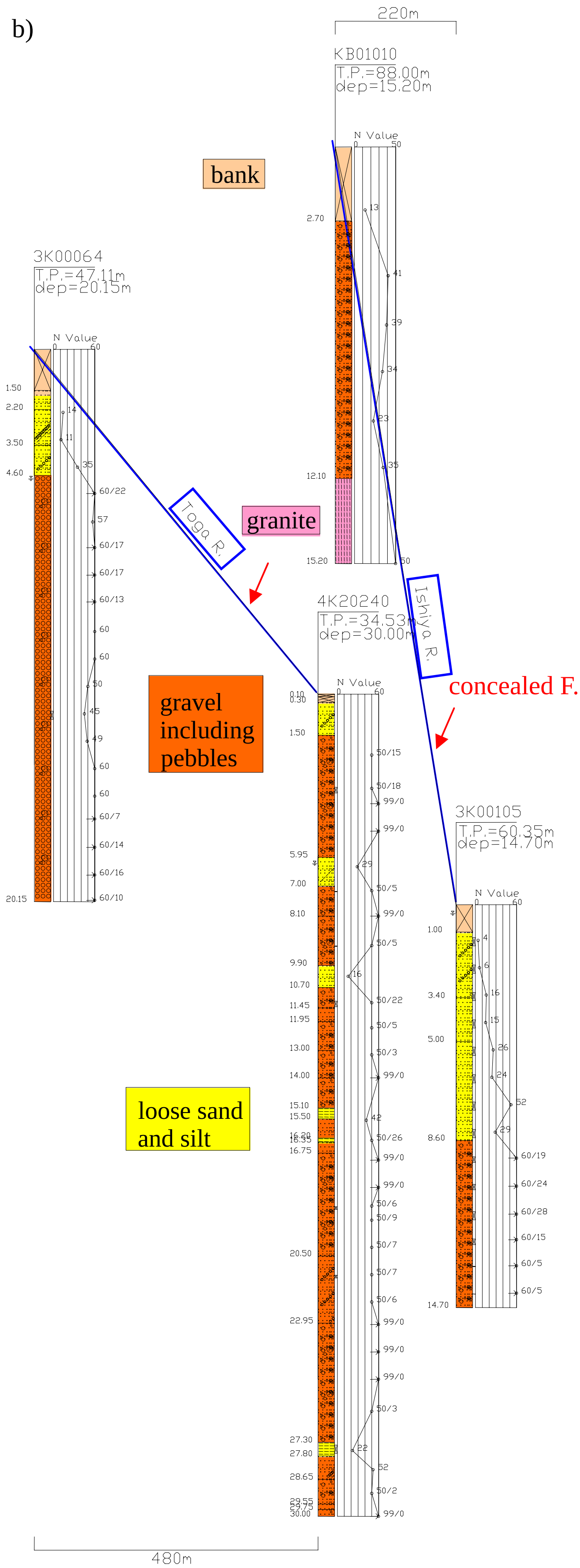
Fig. 3 Ground-penetrating radar profile (upper) and seismic reflection profile (lower, after Yokokura *et al*., 1997) along the Toga River. Solid and broken lines: Unconformity between the Cretaceous granites and the Quaternary sediments.

weathering condition. They are moved in debris flows. As a result of them, alluvial fans and raised bed rivers are generated. The Ishiya River and the Sumiyoshi River are raised bed rivers.

From those points of view, the alluvial fans in the southern Rokko Mountains have been generated in almost the same environment. Figure 4 shows the subsurface geology along the Ishiya River and the Toga River. Both areas have the grounds composed mainly of sand and gravel. Relative density is loose condition near surface and stiff condition in deeper under the ground.

At the northern area of the JR railway, the thickness of near-surface loose sand is larger at the Ishiya River than at the Toga River. Along the Ishiya River loose sediments (N-value < 50) are located in the depth of 0-8m. Especially boring (3K00105) indicates the very loose subsurface condition of N-Value <16. On the other hands, Along the Toga River subsurface loose zones are thinner (<4m, e.g., boring 3K00064) than the area along the Ishiya River.

b)



a)

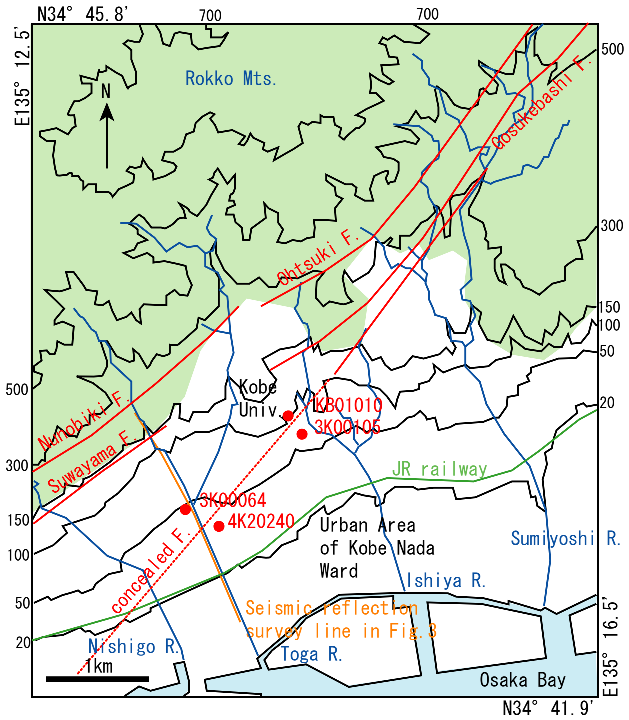


Fig. 4 a) Topography and active faults around Kobe Nada ward.

b)Boring logs on both side of concealed faults. Data are collected in the database “KOBE JIBANKUN”.

At the southern areas of the JR railway, loose sand and silt beds exist in deep (>10m) stiff layers because sedimentary environments are influenced by the sea. Stiff layers are the sand including pebbles from the Rokko Mountains. These loose beds might be generated in the marsh behind sand bar.

3.3 Damaged Lifelines and Ground Condition

The areas in which the damages of lifeline concentrated are distributed in the south of the JR railway and along the Ishiya River (Fig. 2). There are partly loose ground conditions in both areas. Loose grounds seem to have amplified strong ground motions and encourage ground deformations (Kamiya and Konagai, 2000). There is a possibility that lifeline damaged area will be able to predict by studying surface geology. Surface ground conditions are concerned with topographies which are created in the tectonic conditions. In this case, the subsurface geology of southeast side of concealed faults include much soft sand and silt beds, compared with northwest side of concealed faults (Fig. 4b). Geological information including deep depth is useful to a seismic risk management of lifelines.

4. CONCLUSIONS

The following results were obtained from analysis of the displaced house inlets and damaged lifelines (Fig.5):

1) Strong ground motion during the 1995 Hyogoken-Nanbu (Kobe) earthquake deformed subsurface loose sediments.

2) Underground lifelines such as water, sewage and gas damaged areas are concerned with the loose subsurface layers and loose beds in stiff layers underlying them.

3) Ground conditions have been generated in topographical and geological environments including structures of the basement rocks.

4) Understanding Urban Earth Science information helps us to preventing lifeline earthquake disasters.

Information of the basement rocks structure and active faults are one of an issue to manage earthquake disasters. But it is hardly to read such information from urban topography, because mega-cities are highly developed and changed natural ground formation. Seismic reflection survey is one of the effective tools. But the method needs

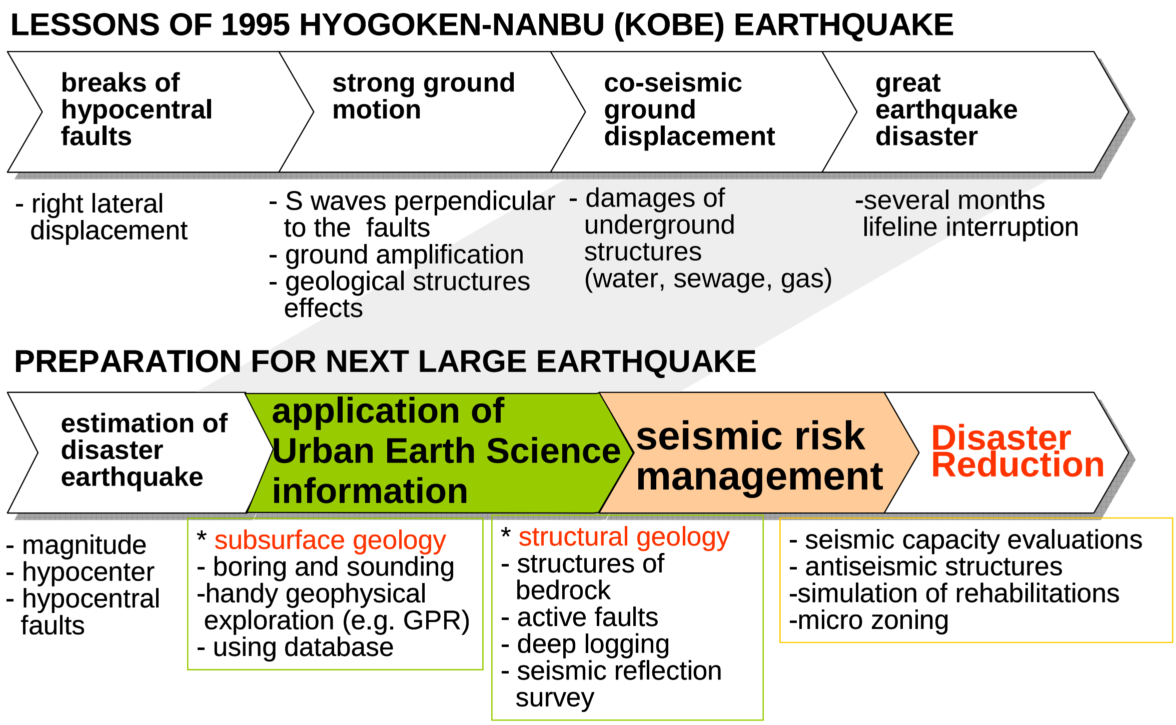


Fig. 5 Framework of lifeline seismic risk management using Urban Earth Science information.

high costs and has not attempted on all cities. Our study indicates a possibility to read deep underground information from subsurface information, such as boring logs and GPR survey data. To understand ground condition with Urban Earth Science information is important to the seismic risk management.

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