一般講演（General Session）
岩盤工学（ Rock Engineering）
Rock Engineering
2017年9月28日(木) 13:00 ～ 15:15 第3会場 B31 (B3棟1階/Fl.1.,Build. B3)

[3305-12-02] Prevention of Large Earthquakes beneath Big Cities
Prevention of Large Earthquakes beneath Big Cities

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キーワード：Large earthquakes beneath big cities, Prevention, Induced seismicity, Silica carbide composite, Water injection

Twenty two M 6 earthquakes occurred beneath big cities between 2000 and 2016, for example, in Japan excluding aftershocks. They induced severe human and property damages. By Kumamoto 2016 (M6.5), for example, 110 people died, 184,643 buildings including the Kumamoto Castle collapsed and the economic loss was 2.4-4.6 trillion JPY. Gradual release of seismic energy by injecting water through a drill hole to the seismic fault is proposed. An M6 is occurring at the average interval of 100 years in Kumamoto for example. One thousand M4 earthquakes (an M4 causes almost no damage in Kumamoto) in 100 years will release the seismic energy for an M6. Namely, 10 M4 for one year or ca. an M4 for a month will prevent an M6 earthquake. The necessary water amount is 9.4×10^5 m^3 for an injection based on a study on mostly cases of enhanced geothermal system (EGS). The scheduled injections would be carried out very carefully under a dense microseismic and seismic monitoring to ensure safety. Focal depths of typical large earthquakes under big cities are deeper than the deepest records of drilling. The problems of deep drilling are high temperature and corrosion and would be solved by the silica carbide composite and electro pulse drilling. The total cost of ca. 56 billion JPY is much cheaper than the economic damage. The risk of unexpected induction of an M6 can be minimized by gradual injection under careful monitoring. The injection can be cancelled when the released energy exceeds an M4.

1. Introduction

Imminent prediction methods for catastrophic volcanic eruptions, large earthquakes beneath big cities or giant earthquakes at subduction zones have never been established so far except that volcanic eruptions can only be predicted by exceptional efforts by dedicated researchers. For example, the eruption of Mt. Usu, Japan in 2000 (Jones, 2016, Yamagishi et al., 2004) was predicted by Prof. Hiromu OKADA at Hokkaido University, Japan. Even if a prediction method was established, the method could not significantly reduce infrastructure damages although it could slightly reduce the number of fatalities. On the other hand, prevention of eruptions or earthquakes, if developed, could significantly reduce not only the number of fatalities but also infrastructure damages.

The authors already proposed prevention methods for catastrophic volcanic eruptions (Fujii et al., 2017a) and giant earthquakes at subduction zones (Fujii et al., 2017b). Gradual energy release by supercritical power generation was proposed to prevent catastrophic eruptions. The necessary technical innovation is drilling into the depth. However, after the innovation, the power generation may be profitable. The risk is unpredicted induction of unwanted catastrophic eruptions. Prevention of giant earthquakes at subduction zones by exploding the existing nuclear warheads underground was proposed. Cost is less than 1/60 of average giant earthquake damages. Risk is the possible unexpected induction of giant earthquakes. The biggest problem would be obtaining the social consensus. However, it is worth to further consider this method because it would significantly contribute the world peace by not only preventing giant earthquakes but also by disarming the nuclear weapons.

This paper considers how to prevent large earthquakes beneath big cities and try to clarify necessary technical developments, cost, risk and problems.

2. Prevention of Large Earthquakes beneath Big Cities

Twenty two $M \geq 6$ earthquakes occurred beneath big cities between 2000 and 2016, for example, in Japan excluding aftershocks (http://www.data.jma.go.jp/svd/eqdb/data/shindo/index.php). They induced severe human and property damages. By Kumamoto 2016 (M6.5), for example, 110 people died, 184,643 buildings including the Kumamoto Castle collapsed and the economic loss was 2.4-4.6 trillion JPY (http://www.bousai.go.jp/updates/h280414jishin/pdf/h280414jishin_35.pdf). By Tottori 2016 (M6.6) in Japan, for another example, 30 people died, 14,748 buildings collapsed and the agricultural damage was 1.6 billion JPY (http://www.bousai.go.jp/updates/h281021jishin/pdf/h281021jishin_09.pdf).

2.1 Method

Gradual release of seismic energy by injecting water through a drill hole to the seismic fault is proposed. An M6 is occurring at the average interval of 100 years in Kumamoto for example. One thousand M4 earthquakes (an M4 causes almost no damage in Kumamoto) in 100 years will release the seismic energy for an M6 based on the following relationship between the seismic energy E_S (J) and magnitude M.

$$E_S = 4.8 + 1.5M \tag{1}$$

Namely, 10 M4 for one year or ca. an M4 for a month will prevent M6 earthquakes.

Fujii et al. (2014) evaluated the amount of water injection V (m^3) and the maximum magnitude M_{max} of the induced seismicity based on mostly cases of enhanced geothermal system (EGS) as follows (Fig. 1).

$$M_{max} = 0.75 \log V - 0.48$$

Namely, 9.4×10^5 m^3 water should be injected to induce an M4. This amount of water can be injected, for example, for a week at 1.5 m^3/s. The scheduled injections would be carried out very carefully under a dense microseismic and seismic monitoring to ensure safety.

2.2 Problems to be solved

Focal depth of typical large earthquakes under big cities is 23 km for Tokyo (1923), 24 km for Nankai (1946), 16 km for Hyogo (1995), 12 km for Kumamoto (2016), 11 km for Tottori (2016) (http://www.data.jma.go.jp/svd/eqdb/data/shindo/index.php), etc. On the other hand, even such world deepest drillings as 12.3 km by Kola Superdeep Borehole (2011) or 9.1 km by KTB (1994) is not enough. The problems are high temperature and corrosion, and would be solved by the silica carbide composite (Nakazato et al.,

2013) and electro pulse drilling (Schiegg et al., 2015).

2.3 Cost

The cost for 9.4×10^5 m^3 water is 136 million JPY/y based on the price for the public baths in Sapporo, Japan. The cost for 100 years is 13.6 billion JPY. The cost for 12 km drilling would be 56 billion JPY based on the total cost of 42 billion JPY for KTB (https://www.japt.org/html/iinkai/drilling/seikabutu/fukaboriiin/fukabori.html). The total cost of ca. 70 billion JPY is much cheaper than the economic damage of 2.4-4.6 trillion JPY. Moreover, the cost would become as low as 15.2 billion JPY by adapting the electro pulse drilling (100 EURO/m, Shiegg et al., 2015).

2.4 Risk

There is a possibility that an M6 is unexpectedly induced while water is being injected to induce an M4. This risk can be minimized by gradual injection under careful monitoring. The injection can be cancelled when the released energy exceeds an M4.

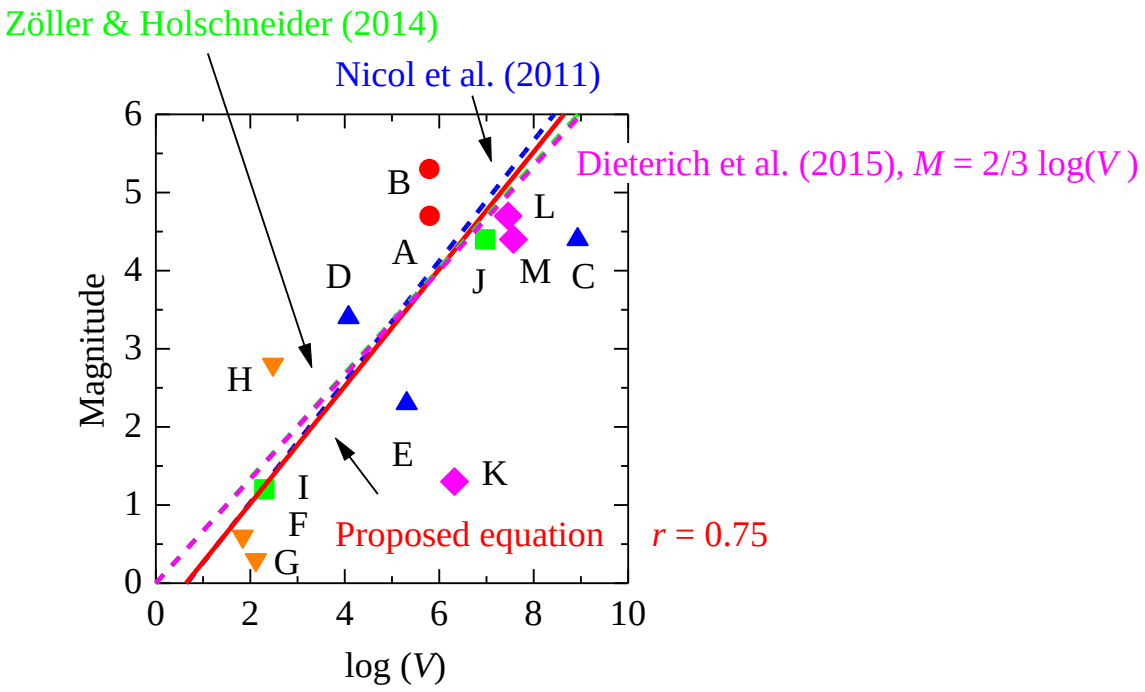

Fig. 1 Relationship between injected water volume and the maximum magnitude of induced seismicity (Fujii et al., 2014)

3. Concluding remarks

Gradual seismic energy release by injecting water into the seismic sources was proposed to prevent large earthquakes beneath big cities. The necessary technical innovation is the drilling depth. After the innovation, the cost would be less than 1/300-1/30 the average damage by the earthquakes. The risk is unpredicted induction of unwanted large earthquakes.

Large earthquakes beneath the cities can kill up to several hundred thousand people (ex. 1976 Tangshan earthquake). Giant earthquakes also can cause similar fatalities, typically by the giant tsunami after the mainshock (ex. 2004 Indian Ocean earthquake and tsunami). Human will not be made extinct by them but it would be much better to prevent them. On the other hand, catastrophic eruptions in a hemisphere can make human in the hemisphere extinct and impaction of near earth objects (NEO) can make human completely extinct.

Development of prevention methods for impaction of NEO are actually being carried out by various organizations. People should realize that we may be also able to prevent other disasters not just to wait for them reinforcing infrastructures and that the development of prevention methods for such catastrophic disasters is desperately needed not only for academic purposes but also for human survival.

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