Serious Lessons Learnt from Big Project

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ABSTRACT: Big project is an attractive idea for ambitious engineers. The present level of construction technology allows such big projects to be carried out and our world may be drastically changed. The problem is that we still do not know how nature would respond to such a significant human action. We need to know bad consequence was sometimes the case in the past. Although it is difficult, we need to have some provision by which the worst and catastrophic consequence is avoided by stopping or cancelling the project.
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1. INTRODUCTION

The 20th Century enjoyed a significant development of construction technology. The source of power changed from human and animal muscle in the former centuries to mechanical engines that utilize coal and oil. This change gave human an overwhelming power above nature. It thus became possible to construct huge canals, man-made islands, bridges etc.

The situation until 1970s was full of optimism. Behind such a situation, however, many negative aspects of the overwhelming human power were emerging gradually. Their consequence became evident after 1970s. Consequently, many people such as naturalists started to insist on the need to stop big construction projects and protect nature. It is true that human has to be aware of the importance of conservation of nature and control human power not to seriously damage the global natural system. On the other hand, the world population is increasing rapidly towards 10 billion. Increased population needs food and drinking water. People desire healthful life, comfortable living conditions, and safety of life from natural disasters. To cope with this new situation, human has to keep seeking for better and wiser use of the natural system. Thus, big construction projects will be necessary as well from now on. However, it is important for human to keep in mind what mistakes happened during the past big projects and try not to repeat them. The present paper attempts to provide some information in this regard.

2. ARAL SEA

The Aral Sea region of the Central Asia is wide in space and enjoys ample sunshine. It was supposed to be a wealthy agricultural zone if ample water is provided. It was decided in early 1960s to construct big canals and long irrigation channels that transported water of Amu Darya and Syr Darya Rivers, which were two major tributaries of Aral Sea. It was intended by this water supply to convert the region from an arid area into a newly developed cotton agricultural area (Figure. 1). Many farmers immigrated from present Russia and started successful cotton agriculture.

Figure 1 Newly Developed Cotton Agriculture (Uzbekistan)

The problem was the high rate of water evaporation from the lake surface. Together with the significant reduction of water supply from its two major rivers, Aral Sea started to shrink in 60s. Nowadays, Aral Sea, which used to be the 4th biggest lake in the world, is disappearing. Because the lake water was salty, the deposit of salt on the dried lake bed is blown by wind and is causing health problem among local residents (Whish-Wilson, 2002). It is not possible anymore to turn reverse the clock because cotton agriculture has been well established in the region and the immigrant farmers cannot go back to Russia because it is a foreign country after disappearance of USSR.

There have been several efforts to save the lake from disappearance. One of them was the idea to transport water from huge rivers in Siberia to the Aral Sea (Borovskiy, 1980; Aladin and Potts, 1992; Elhance, 1997). Although the idea looked attractive to some extent, the obvious problems were the difficulty to pump up water across high mountains on the way. Later, the environmental issues became more important such as the effects of less water flow into the Arctic Sea, and introducing different animal species from those rivers into the Aral Sea. Finally, Siberia and Aral Sea area became different countries after disappearance of USSR and such a project became impossible.

The Aral Sea project had both positive and negative aspects. The positive one is the development of agriculture and the negative one is the environmental damages which are disappearance of the Sea and salt-induced health problems. Kazakhstan constructed a huge dam in the northern part of the Sea and produced fresh-water Little Aral Sea (Figure. 2). This may be a solution of the problem to some extent but not complete or final. Note that a similar problem is going on in other places of the world. The Urmia Lake in Iran is shrinking quickly as well because of the water of tributary rivers is sent to irrigation.

Figure 2 Big Earth Dam to Create Little Aral Sea

3. DIVERSION OF RIVER WATER

Quick industrialization and modernization often sacrifice environmental issues everywhere in the world. Water in lakes is polluted by careless release of waste water or prevention of clear water supply into lakes. Later, human realizes the problem and has to repair the damage. This procedure may not be very easy but has to be executed as a responsibility of the present generation to the future.

Taihu Lake in China was one of the examples of polluted lake. Recently, canals have been and are being constructed between the lake and the lowermost section of the Yangtze River. It is intended thereby to accelerate the water circulation and improve the quality of the lake water (Figure. 3).

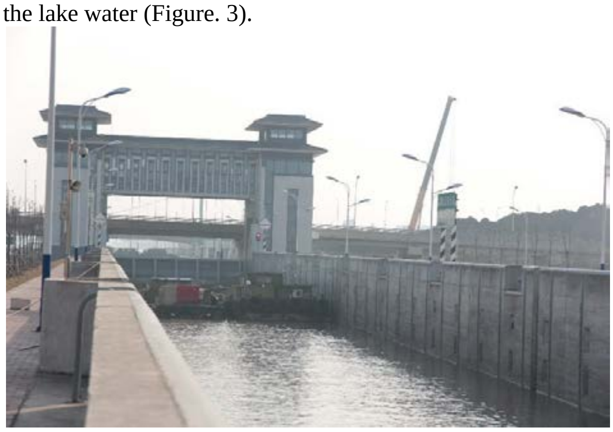

Figure 3 Canal to Promote Water Quality Improvement for Taihu Lake

The author cannot draw final conclusion Waon this project. What he can say is that the take-in and take-out of river water in the downstream part of a river (near the sea) does not affect the water level and that the amount of diverted water is not much as compared with the total flow rate; thus the environmental effect would be small. Certainly careful field monitoring will be important.

More interesting project in the same area is the South-North Water Transfer Project. In the history of this region, a grand canal was constructed during the Sui Dynasty (AD 581-618) and, in the later era, helped combine the north and south parts of China economically. To date, the water is diverted from the downstream part of the river (Figure. 4) and sent to the north where water resource is not sufficient to maintain mega cities. Due to the same reason as mentioned above (short distance to the sea and ample river flow), the environmental effect would be minor. Care must be taken of the effects of two more plans of water diversion from the upstream and the middle parts of the river because water level therein may be affected. Human does not know everything about nature and there is always a possibility that unpredicted situation may happen. Detailed monitoring is essentially important.

Figure 4 Water Intake For South-North Water Transfer Project (Yangzhou, China)

4. MANMADE ISLAND ON THICK SOFT SUBMARINE DEPOSIT

Kansai Airport near Osaka, Japan, was constructed in the southern part of Osaka Bay where the geological subsidence is most significant and the seabed is composed of thick marine clay and Cenozoic deposits at hundreds of meters below the seabed. From the geotechnical viewpoints, this least site was chosen because other candidate sites refused the airport project because of the possible noise problem.

The consolidation settlement of the airport island was serious as has been reported by many authors (e.g., Nakase, 1992; Furudoi and Kobayashi, 2009). The rate and extent of consolidation settlement were underestimated in the original design stage. Reasons for this are :

- The consolidation in the deep layers (>300m deep) was thought to be minor because of building experience in Osaka City. However, the sizes of the airport island and ordinary buildings were completely different, and the bigger island increased the stress in such deep layers.
- During the design stage, there was not a reliable technology for soil investigation at 500 or 700 m below the surface.
- All the minor sandy layers sandwiched between clayey layers functioned as drainage channels and promoted consolidation volume change in clay.
- Construction of the second-stage island would finally increase the subsidence of the first-stage island because the second island increases the stress level in the seabed under the first-stage island.

As a provision for significant subsidence of the airport island, building foundation is equipped with jack-up systems. This provision has already been fully activated and there is not much margin anymore. The recent problem is the insufficient height of seawall around the island. In September 2018, a typhoon induced high tide and high waves. As a consequence, the major part of the island and terminal buildings were inundated (Figure. 5) and the function of the airport was stopped. It is difficult to make the walls higher than present because aircrafts need sufficient safety space from ground structures during take-off and landing. The original ideas in the design thus did not work well because of the uncertainty in ground conditions and an unexpectedly strong storm which may be possibly related with the recent global climate change.

Figure 5 Kansai Airport One After Sea-Water Inundation (see brown color of dead lawn)

5. VAJONT DAM

Construction of Vajont Dam in Northern Italy (Fig. 6) was planned and designed in 1950s as an extremely important project as the energy resource that would contribute to the development of Italian industries and economy. The dam site was situated in a narrow and deep gorge and looked like an ideally efficient dam site: rigid rock mass, narrow and high dam with good amount of impoundment, and significant height difference for hydropower generation.

There were several problems at the site (Nonveiller, 1987; Semenza and Ghirotti, 2000). In the valley, there was a trace of an ancient slope failure that suggested possibility of slope failure. During dam construction, the left bank of the reservoir (Toc Mountain) started to move and cracks developed in the mountain slope. This further suggested the risk of natural disaster but was considered minor. In those days, there was not a reliable technology to collect rock specimens from the depth of hundreds of meters and measure their mechanical strength. Thus, safety factor of the slope was not precisely assessed. However, the experienced senior engineers felt that something wrong may happen in the dam.

Figure 6 Vajont Dam in Italy

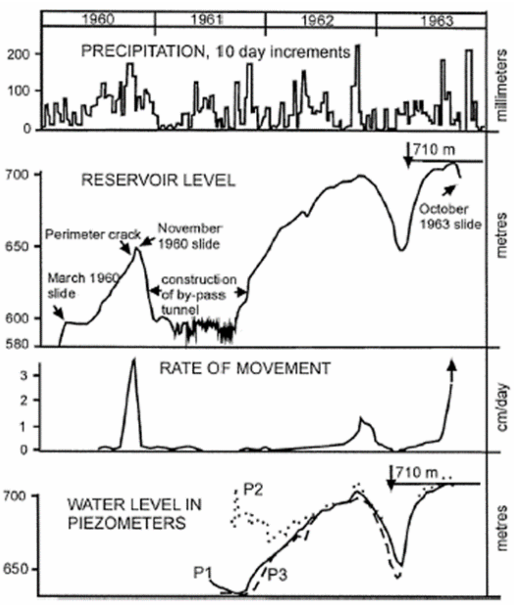

Figure 7 Time history of water level in the Vajont Reservoir and rate of slope movement (Semenza and Ghirotti, 2000)

Concrete arch dam was completed in 1960 and impounding started. Then, the feared left bank started to move gradually. Fortunately, however, this slope movement stopped when the reservoir water level was lowered. This experience gave an impression that it is possible to safely control the slope movement by raising and lowering the reservoir water level. During the first and second raising, this idea worked well (Fig. 7). However, the third raising triggered very rapid slope movement. The gauge became narrower quickly, the reservoir water level came up very fast, and it was impossible anymore to lower the water level. Finally, the entire mountain slope jumped into the reservoir and induced high tsunami. This wave overtopped the dam and destroyed villages in the downstream area. The number of victims was more than 2000.

The causative mechanism was the existence of weak rock layer at depth beyond the capability of subsurface investigation. Reservoir water pressure propagated into this layer, reduced the effective stress and shear strength, and made the entire slope unstable. Then the question is whether or not the senior engineers who feared the possibility of disaster were able to stop the project. Issues to be considered are;

- This dam project was a national project that was expected to help develop the economy of Italy.
- Huge money had been spent for the success of this project.
- In spite of fear, it was not possible to verify the risk of slope failure because deep subsurface investigation was not possible.
- Accordingly, the project was continued as scheduled until the last moment of tragedy.

Good engineers should not behave against their official missions because of personal fear. Professional engineers have to respect confidentiality and should not leak important information to outsiders. Then how could experts then avoid the tragedy? The Vajont tragedy still remains an important material for study on responsibility of engineers.

6. RESERVOIR-INDUCED SEISMICITY

The reservoir of Koyna Dam in India (Figure 10) is one of the earliest examples of reservoir-induced seismicity where significant earthquake was triggered by impoundment. The 1967 Koyna earthquake that registered M=6.3 claimed more than 100 victims. The focal depth of the quake was 30 km. Fig. 8 shows a correlation between the elevation of reservoir water and the number of associating earthquake swarms. There is a reasonable correlation between them, while exhibiting some time delay. The causative mechanism of reservoir-induced seismicity has been considered two-fold: stress in earth crust induced by weight of reservoir water, and/or the increased pore water pressure in unstable faults, leading to reduced effective stress and shear strength. The author supposes that the former is not likely the cause of fault rupture because reservoir is always located at low places (bottom of a valley) and the increased gravity at the valley bottom tends to equalize the surface stress distribution. Hence, the subsurface shear stress decreases. In contrast, the pore water pressure increases the chance of fault rupture. This situation is same as the cause of slope failure at the Vajont dam site.

The second well-known example of reservoir-induced seismicity is that of the Nurek Dam of Tadjikistan for which the induced earthquake was of M=4.6 at maximum, while the focal depth was 10 km or less (Simpson and Negmatullaev, 1981). The correlation and the reservoir water level (depth) is significant as illustrated in Figure. 9.

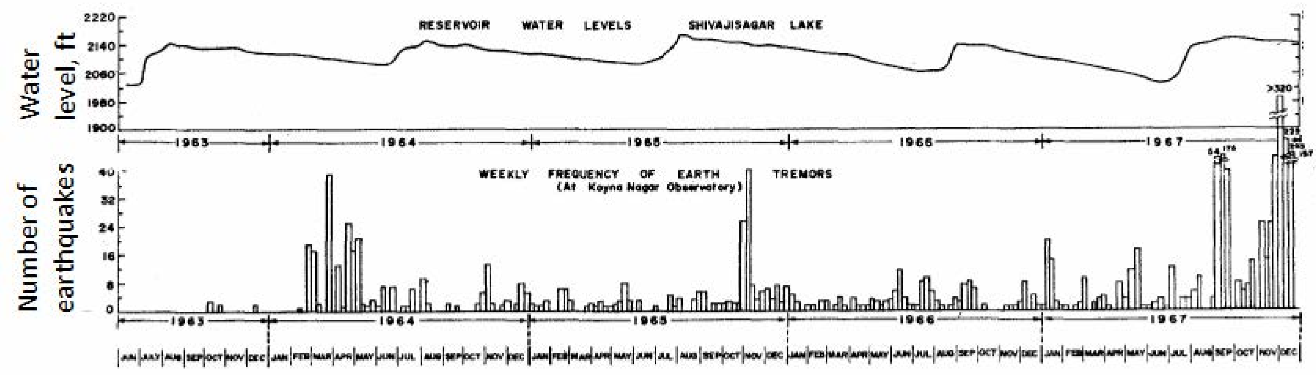

Figure 8 Correlation between number of earthquakes and level of Koyna reservoir water (Gupta, et al., 1969)

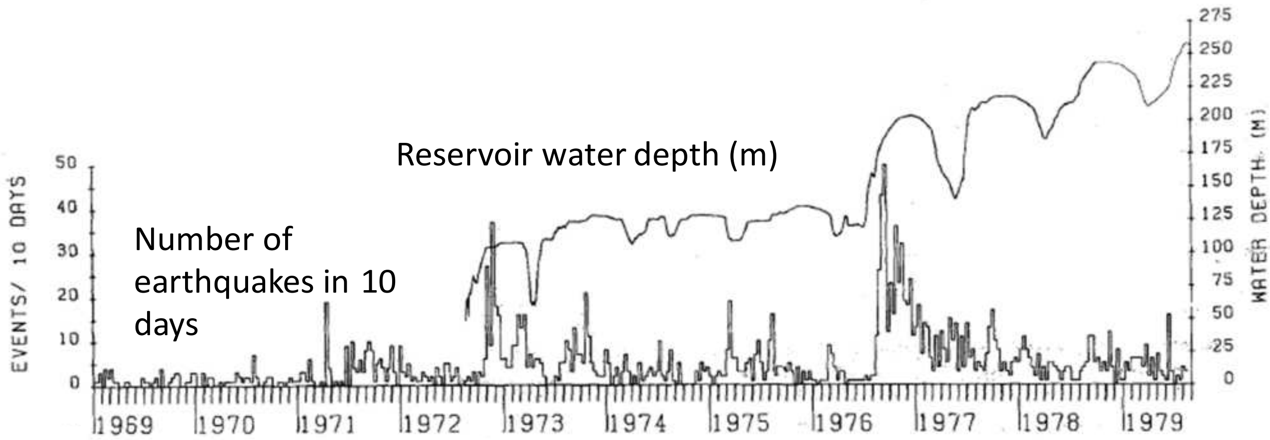

Figure 9 Correlation between reservoir water level and frequency of earthquakes in Nurek Dam (Simpson and Negmatullaev, 1981)

Figure 10 Koyna Dam in India

Figure 11 Aswan High Dam in Egypt

Aswan High Dam (Figure. 11) is a good example of a "big" project for which both positive and negative effects have been discussed. The maximum magnitude of induced earthquake was 5.6 and the focal depth has been in the range of 0-10km or 15-25 km (Foulger et al., 2018). Gupta (1992) quoted Simpson's data on the correlation between water level and number of earthquakes. It is discussed therein that the occurrence of earthquakes is correlated wither with the height of reservoir water level or its rate of change (Figure. 8).

Apart from induced seismicity, the benefit of Aswan High Dam (Benedick, 1979) is the production of renewable energy (hydropower) as well as control on the water level in the Nile Delta. The latter enabled stable farming and reduced the epidemic that used to be very bad after floods. Although the natural supply of fertile soil had been supposed to stop by the Dam, it was thought to be compensated for by production of chemical fertilizers. The unexpected negative issues are more reliance of chemical fertilizers and soil decay in addition to a limited extent of coastal erosion and salt contamination of firm land. Occurrence of those unexpected negative issues is seen here similarly to the afore mentioned big projects.

There are controversies on possible correlation between the gigantic Wenchuan earthquake of Mw=7.9 in 2008, China, and the construction of Zipingpu Dam of which the reservoir impoundment was completed in 2006. Because the epicenter is located close to the reservoir and the first filling of the reservoir and the onset of the earthquake were close to each other, there have been many discussions for and against the hypothesis that the gigantic earthquake was induced by the reservoir impoundment. Lei et al. (2008) mentioned the increased microtremors near the reservoir. The same point was made by Liao (2009) and Klose (2012); see Figure. 13.

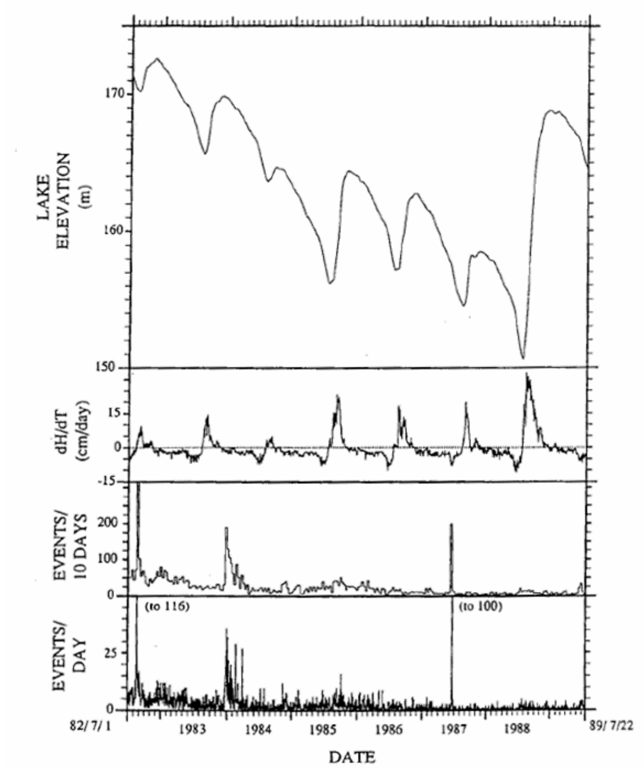

Figure 12 Correlation between reservoir water level and number of earthquakes for Aswan High Dam (after Simpson, 1989, quoted by Gupta,1992)

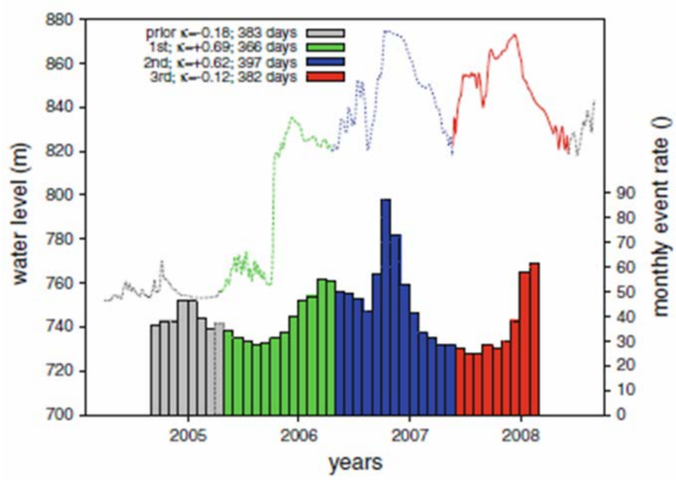

Figure 13 Correlation between occurrence of minor earthquake and reservoir water level of Zipingpu Dam (after Klose, 2012)

In contrast, Chen (2009) discussed the occurrence of fore-, main and aftershocks and argued that the observed pattern of those shocks is different from those of known induced seismicity. Gahalaut and Gahalaut (2010) calculated the stress that was induced by the reservoir water to discuss that the induced stress is oriented in opposite direction to trigger the earthquakes.

To date, it is difficult to draw a definite conclusion on the cause of the Wenchuan earthquake. However, this controversy in conjunction with other induced earthquakes recommends the community to be more careful of the possible risk of damaging induced earthquakes.

Figure 14 Zipingpu Dam

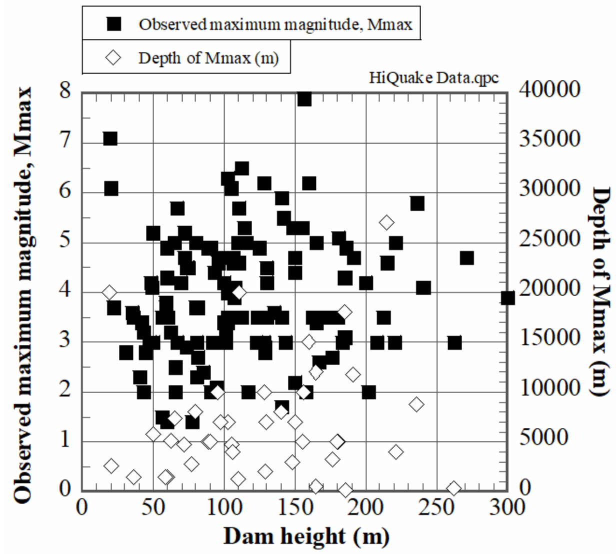

Figure 15 Relationship between dam height and maximum magnitude as well as depth of the focus in induced earthquakes (after HiQuake database by Wilson et al., 2017)

More reservoir-induced earthquakes have been known to date such as those in Lake Mead in USA (Carder, 1945) and Hsinfengkian Dam in China (M=6.1; Wang et al., 1976) among many others. See Gupta (1992) for more details. Figure. 15 was drawn by using HiQuake database of induced seismicity (Wilson et al., 2017). It is found here that the focal depth of the induced earthquakes may be as shallow as less than 5 km. Hence, the devastating effects at the ground surface can be significant in spite of the relatively small magnitude and energy. To assess the risk of induced seismicity, bore hole injection tests may be useful (Ohtake, 1974; Ma et al., 2015).

7. EARTHQUAKES INDUCED BY EXTRACTION OF OIL AND GAS

The most recent technology for extraction of oil and gas from the earth crust injects pressurized water and other liquids in order to facilitate the outward flow of the desired resources. The collection of shale oil relies on hydraulic fracturing and hence injects pressurized fluid into earth crust as well. It is obvious that such a procedure may induce earthquakes as was discussed in the previous chapter (Hubert, M.K. and Rubey, 1959).

One of the earliest earthquakes induced by liquid injection occurred near Denver, USA, in late 1960s when waste water was being injected into the earth crust (Healy et al., 1969). Afterwards, similar phenomena have been reported from such oil/gas projects as in Colorado (Raleigh at al., 1970). Fig. 15 illustrates a correlation between gas production and number of earthquakes in Groningen oil field in the Netherlands. There is an evident correlation between the amount of gas production and the rate of earthquakes. Because of this trend and the seismic risk in the country, the gas production in this region will be terminated in 2030 or so. In spite of the recent decreasing trend, however, a relatively big earthquake of M=3.4 occurred in January, 2018.

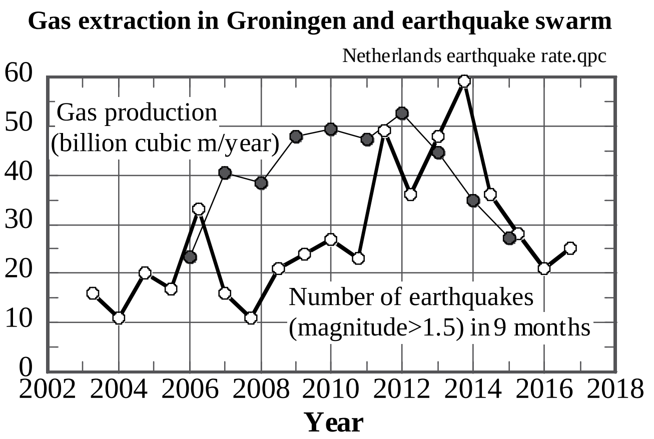

Figure 15 Correlation between gas production and number of earthquake in Groningen Gas field (after NWO, 2017)

8. CONCLUSION

The present paper addressed several recent big projects by which some negative aspects became evident. It is thought herein that, although civil engineering has been doing many good projects for the welfare of people, sometimes mistakes are made to cause unfavorable consequences. The reason for this is that nature is still more complicated than what human knows. To cope with this difficult situation, it is important to continuously monitor what is going on in nature and detect small phenomena that suggest more serious situations that are going to occur in near future. If the future situation seems serious, it is important to stop or cancel, in the extreme case, the project. The current society does not have a system that allows such a very serious decision to be made.

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