A Study of Earthquake Risk in Japan and its Peripheral Problems

By Hiroyuki Yoshida

Abstract

According to The Tectonic Plate Theory, Pacific Rim nations are located where ocean plates slide into and collide with continents, causing a number of earthquakes. It is said that most of Earth's seismic energy radiates from the Pacific Rim areas as shown in Figure 1.

In this paper, I would first like to explain the basics about earthquakes and introduce how earthquake risks are categorized in real estate securitization in Japan. Secondly, through my own experience of the recent Fukuoka Earthquake of March 20th 2005, I would like to share some thoughts about the earthquake resistance performance of buildings, and reflect on earthquake risks and land use, and point out some problems they seem to present.

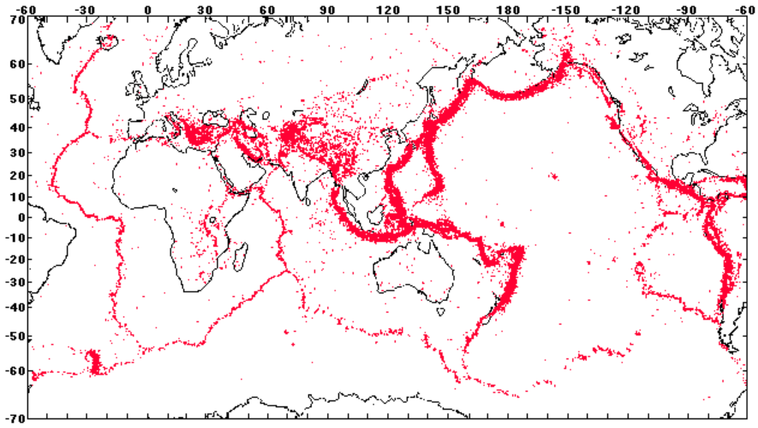

Figure 1. Worldwide earthquake distribution M>4.0 1975-1994

Introduction

Japan suffers the effects of earthquakes more frequently than any other nation on the Pacific Rim as four large plates converge under the Japanese Archipelago. In fact, 20% of large earthquakes (over 6.0 on the Richter scale) in the last ten years have been in Japan. Those tremors naturally caused a great deal of damage. However, until recently, few measures have been taken to minimize damage to traditional Japanese wooden architecture. People in Japan are becoming more concerned about earthquake risks these days. The reasons for the concern are:

- The securitization of real estate is well underway in Japan, and earthquake risk must be taken into consideration when purchasing buildings and property.
- Recently, many huge earthquakes have occurred around the world, as in Sumatra, Fukuoka, Pakistan, Java and so on. This seems especially more common after the Niigata Earthquake of October 23rd 2004.
- Many experts have predicted the possibility of a devastating earthquake in the Tokai area of Japan.

In addition to the reasons above, recent earthquake resistance scams by a now notorious Japanese architect made people living in condominiums and apartment buildings worry about their safety.

1. Types and features of earthquakes and the cycle of their occurrence

There are two categories of earthquakes that differ in their mechanics and distribution. One is the "Subduction Zone Type" and the other is the "Active Fault Type".

1.1. "Subduction Zone Type" Earthquakes

When one lithospheric plate slides under another and is subducted into the earth's mantle (Fig.2), the plates build up strain due to friction at the edges of the lithospheric plates but are eventually forced to slide against each other. This sudden shift causes huge Subduction Zone Type earthquakes to occur. This type of large earthquake releases energy over a very wide area. (The energy of the earthquake is shown in magnitude. When magnitude increases by one point, earthquake energy becomes thirty-two times more powerful.) This occasionally causes tsunamis. The wavelength of the tremor is usually more than one second long, causing strong shaking to tall buildings. Tremors can last one to three minutes. The focus of the quake can be tens or hundreds of kilometers beneath the surface. In Japan, large earthquakes of this type have occurred every 90 to 150 years around the Suruga Nankai Trough, a shallow and flat trench formed where the Philippine Plate meets the Eurasian Plate. Also, offshore of Miyagi Prefecture, large quakes have occurred every 30 to 40 years. Subduction Zone Type Earthquakes tend to occur at regular intervals.

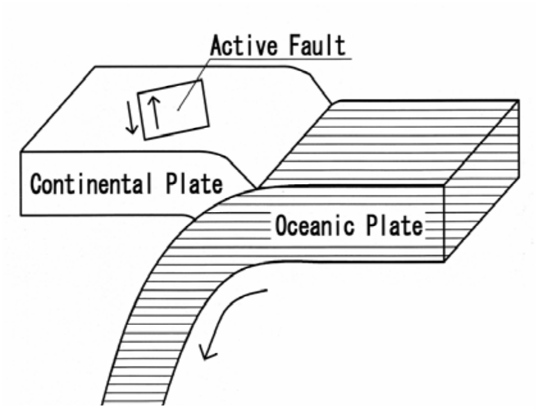

Figure 2. Movement of Plate and Fault

1.2. "Active Fault Type" Earthquakes

Different from Subduction Zone Type earthquakes, Active Fault Type earthquakes occur suddenly from inside the plate itself ranging from every several thousands of years to tens of thousands of years apart. These quakes tend to be smaller in magnitude but can cause considerable damage to a limited area. However, the tremors are shorter and have smaller fracture zones with a wavelength of less than one second. Both the Kobe and Niigata Earthquakes were of this type. There are about two thousand active faults in Japan and ninety-eight of them are believed to be capable of causing major economic and social damage.

Unlike Subduction Zone Type earthquakes that occur at regular intervals, it is quite difficult to predict Active Fault Type earthquakes, as the intervals between their occurrences are wide ranging. Although the Nojima Fault that produced the Kobe Earthquake had been known for some time, it was not regarded as dangerous. The recent Niigata and Fukuoka earthquakes were both on unknown faults. It can be said that there is no place free of earthquake risk in Japan as there are still many unknown active faults.

2. Earthquake Risk Analysis

Once a large earthquake occurs, it can cause a lot of damage to buildings and lifelines such as water supply, sewage, gas pipelines, etc. It can also cause collateral damage like fire and tsunamis.

2.1. What is Earthquake Risk?

When we think about earthquake risk, we need to consider whether the risk is to land, buildings, or to the region in which the real estate exists.

The risk to land, buildings, and earthquake-hit regions can be described as:

- Risk to land
  a. Damage caused by the collapse of reinforced embankments
  b. Damage caused by land liquefaction on reclaimed ground
- Risk to buildings
  a. Physical damage to buildings by earthquakes
  b. Fire caused by earthquakes

c. Incapability of building and infrastructure use (i.e., if offices were closed, rent cannot be paid.)

- Risk to earthquake-hit regions

a. Damage to infrastructures such as road collapses, water pipes bursting, and land liquefaction could give a negative image of the region to would-be purchasers.

b. Damage to the whole region caused by tsunamis and other related disasters

Among the risks above, earthquake risk in real estate securitization in Japan refers exclusively to damage to buildings. In this paper, I would like to consider only direct earthquake damage to buildings and exclude fire damage and income loss due to failure to pay rent.

2.2. What is Earthquake Risk Analysis?

The real estate securities industry of Japan has adapted for its use a concept established by the earthquake insurance industry of the United States called Probable Maximum Loss (PML). PML is the expected maximum loss due to damage resulting from large earthquakes. Earthquake risk analysis is the study of the probability of earthquakes that can cause damage and the extent of damage they may cause. This is practically done by calculating PML. What exactly is earthquake PML then? It is the expected maximum damage to buildings in the occurrence of an earthquake. In Japan, the real estate securities industry defines earthquake PML to be "the expected maximum loss with a 10% chance of occurring in the 50-year lifetime of a building." There is, however, no real global PML standard, and calculation methods differ among appraisers. There are two steps required to estimate earthquake PML:

1. An estimate of the probability of a large earthquake
2. An estimate of the loss caused by damage due to the same earthquake

The first estimate is related to the probability, and the second is to express the loss in a monetary amount. The result of this analysis is expressed as "Quantitative Risk Analysis based on probability".

2.3. Probabilities of earthquake occurrence (step1)

In the current Japanese real estate securities industry, the target of analysis is set for an earthquake that is expected to occur once every 475 years. "Expected to occur every 475 years" does not mean that a large earthquake will occur precisely once every 475 years, but there is a large earthquake expected to occur once in every 475 years (0.21%, 475 divided by one), that is to say, it can occur anytime.

Next, the intensity of an expected earthquake has to be assumed. The intensity of this earthquake for a given region can be estimated by looking at the damage reports in historical records and other data that may give clues to the intensity of past quakes. Through the study, the expected intensity of earthquakes can be estimated. In Japan, the trace can go back as far as the 8^{th} century when the oldest Japanese history book "Nihon-shoki" noted accounts of earthquakes by recording the number of building collapses and the falling of gravestones. In addition to that study, data from active faults are taken into consideration.

2.4. How to calculate "Earthquake PML" (step2)

After estimating the intensity of a quake likely to occur every 475 years, an estimate of the maximum loss (defined as repair costs) for that intensity is calculated for such a quake. This process, being complicated and requiring full knowledge of structural dynamics, has been omitted from this paper. However, data from the Kobe Earthquake's repair costs seems to have been used recently. The repair costs here do not mean the expected repair costs of an individual building but mainly the repair costs based on statistical data. Through that, the earthquake's PML for repair or restoration costs are expressed in percentage.

2.5. Using the PLM

Once the PML is estimated, it is used in the real estate securities industry. The most common uses are as follows:

1. Use PML as a guideline when purchasing real estate.
2. If the PML is over certain levels (10%, 15%, 20%, for example), insurance is often attached.
3. If the PML is above 20% for example, earthquake-resisting construction should be conducted.

Usually, PML is between 10 and 20 percent for common office buildings. Also, the J-REIT (Japan Real Estate Investment Trust) takes out insurance for PMLs between 15 and 20 percent.

2.6. Differences between "Earthquake Risk Analysis" and "Seismic Diagnosis"

Seismic diagnosis is often regarded similar to earthquake risk analysis but they are not. The structural codes in Construction Standard Law were dramatically revised in 1981, and regulations regarding earthquake safety were strengthened. There can be big differences in earthquake resisting performance regarding design processes between buildings constructed before and after 1981. Seismic diagnosis, therefore, is usually adopted to analyze the safety of buildings constructed before 1981.

Earthquake resisting performance in seismic diagnosis is exclusively applied to building frames, not to finishing or equipment, which makes it very different from earthquake risk analysis. The purpose of seismic diagnosis is to understand how much earthquake resisting performance each building has, and to consider what type of earthquake resisting construction should be undertaken in order to have old buildings satisfy required earthquake resisting performance codes. The result can be used to demonstrate the safety of the building to the purchasers and tenants, making it more appealing.

2.7. Problems of Earthquake Risk Analysis

The problems that earthquake risk analysis has are:

- Many institutes estimate PMLs by their own methods. Naturally, figures from different sources are rarely the same, which causes debate among experts.
- Only PMLs are shown to purchasers, while the means of their estimation is not clarified.
- No consideration is given to risk on collateral disasters such as fire or closure loss.

3. Earthquake Insurance

After estimating earthquake PML, earthquake insurance is sometimes procured, and I would like to explain a little about the Japanese earthquake insurance system.

The chances of an earthquake are rather small compared with the possibility of fire or automobile accidents. If a large earthquake occurs in a big city, however, insurance settlements may exceed the insurers' ability to pay for the incurred damage costs. That is the reason why a full earthquake insurance system was not introduced in Japan until 1966. The earthquake insurance system is based on governmental support that bears partial responsibility for insurance companies and their clients. This is provided in order to alleviate some of the companies' risk burdens.

Earthquake insurance has the following features.

- The insurance is limited to residential buildings and belongings.
- The one-time insurance settlement is limited to a set amount, (currently up to 5 trillion yen, about $50 billion). If an extraordinary disaster occurs and the insurance liability exceeds this amount, the settlements to all claimants will be proportionately reduced, but not exceed, the maximum settlement of 5trillion yen.
- Earthquake insurance can only be obtained as a fire insurance option.
- The amount of liability is limited to 30% to 50% of fire insurance coverage, and the limit of 50 million yen for residential buildings and 10 million yen for belongings.

In the case of an earthquake occurring and the resultant damage to a building is observed, insurance surveyors conduct an investigation and estimate the earthquake loss and then a fixed sum is paid. Annual insurance payments will be determined based on the prefectures' relative degree of earthquake probability, and is usually set at 0.05% to 0.175% of the cost of fire insurance (reconstruction costs). The age of the building, its earthquake resistance performance, and long-term customer discounts are taken into consideration as well.

Through examining these features in the earthquake insurance system, several problems can be pointed out:

- The maximum payout is 50% of reconstruction costs even in the case of complete collapse, or 50 million yen, which may not be enough to cover the loss.
- If an earthquake occurs in a metropolitan area, damage can exceed 5 trillion yen. If the damage is greater than the insurers coverage, the insurance payout will be proportionately less. (There is an estimate that if a large earthquake occurred to the north of Tokyo Bay, the total insurance payout could be over 7.5 trillion yen.)

As for nonresidential buildings, such as office buildings, no earthquake insurance coverage is available; therefore, insurance policies must be contracted individually, but the insurance premium is about the same as that of residential buildings.

4. Earthquake Resistant Performance of Buildings

4.1. Earthquake Resistant Performance of Traditional Japanese Buildings

Although Japan has experienced a number of earthquakes since the beginning of its history, almost no earthquake-proofing measures have been taken to improve traditional Japanese wooden buildings. It was not until 120 years ago, the time western construction technique was introduced, that Japan initiated earthquake-proofing measures. One of the reasons why practically no measures had been taken was because Japanese houses needed a high degree of ventilation due to Japan's hot and humid climate, which provided few earthquake resistant walls. Also, heavy ceramic fire and typhoon resistant tiles made buildings more susceptible to earthquakes. The yearly threats of typhoons and humidity, and the threat of fire far outweighed the threats posed by sporadic earthquakes. This is the probable reason why earthquake-proofing measures had not been taken and had prevented the improvement of earthquake proofing techniques in Japan.

4.2. Earthquake resistant Designs under Japanese Construction Standard Law

As is described in section 2-6, Japan's building code, the Construction Standard Law, was dramatically revised in 1981 and regulations regarding earthquake safety were strengthened. However, the code set only "the minimum requirements for health and cultural life" as is set in the Constitution, and does not require that buildings be free of risk in all imaginable earthquakes.

The aims of the new regulations are as follows:

- Structural damage should be very slight in a moderate quake with ground acceleration of 100gal or of seismic intensity of 5 on the Japanese scale, which can happen every several decades.
- Buildings should not collapse and there should be no casualties due to structural damage even in quakes with ground accelerations as high as 400gal's or of seismic intensity of 6 on the Japanese scale, which can happen every several hundred years.

The aims seem appropriate, out of 5500 victims who died directly caused by the Kobe Earthquake itself, 88% died due to structural collapse. However, even among compliant buildings, there were many structures that suffered sufficient damage, such as cracked walls, to be rendered uninhabitable in the Kobe quake. In other words, once large earthquakes occur, buildings built under the new earthquake resistant standards seem safe enough to save human life, but it does not indemnify against the destruction of assets. The codes in the Standard Law are not inappropriate, but the idea of designing quake-damage-free stiff buildings is not appropriate in terms of cost or residential safety.

Therefore, with the knowledge of the potential problems that real estate has, purchasers should carefully choose to buy, build, and use appropriately their real estate.

4.3. Earthquake Endurable Buildings and Unendurable Buildings

Buildings designed to endure earthquakes are, in a word, balanced. It is important to be both symmetrical and have stability in both plane and elevated shapes. Well-balanced building in a plane shape necessitates a balanced plane surface and its earthquake resisting walls appropriately arranged. For example, a box structure is resistant to twisting compared to L-shaped one. As for a horizontal plane structure, it is important not to have small floors with few walls like pilotis. Since earthquakes damage the weakest points of buildings most severely, many buildings with pilotis features were destroyed in the Kobe Earthquake. However, even buildings with complicated shapes suffered little damage in the Kobe Earthquake as they had been designed to reinforce the buildings' resilience to earthquakes.

4.4. Base-isolated Buildings and Vibration-controlled Buildings

Because of the enormous damage resulting from the Kobe Earthquake, the desire to have buildings that can withstand even a huge earthquake without damage has increased the use of base-isolated and vibration-controlled construction methods. In order to achieve the goal, they are being used along with traditional earthquake resistant structures. All three structures can be categorized as earthquake resistant structures as they are based on "earthquake endurable structure," but each method is different.

Figure 3. Base Isolation Device

Figure 4. Damper

4.4.1. Base-isolated Buildings

Base-isolation devices (Fig.3) are assemblies of thin rubber and iron plates in the base of the building that are put between the load bearing structures of the building and the load bearing structures of the foundation. They dampen high frequency seismic waves and can reduce the energy transmitted to the upper floors to as little as one-third to one-fifth of what would be absorbed by an ordinary building.

4.4.2. Vibration-controlled Buildings

Vibration-controlled buildings have dampening devices called dampers (Fig.4) between their columns and beams that absorb seismic energy and prevent protected structures from being damaged, and if the dampers are damaged, they can simply be replaced. Just like earthquake resistant buildings, the higher the floor is, the stronger the lateral displacement is. The vibration, however, can be reduced by 60% to 80% of its original scale on all floors.

4.4.3. Comparison of each structural system

Traditional earthquake resistant structures require an extra 3% of all construction costs to get 1.5 times greater earthquake resistance performance. Base-isolation, on the other hand, is expensive and adds about 10% to the cost of a five or six-story building. However, it can be more cost effective for a building of over fifteen stories. As for vibration-controlled buildings, no extra cost is needed.

Comparison of structural system

	Effectiveness in reducing damage	Effectiveness in dampening the tremor
Base-isolation	A	A
Vibration control	B	C
Basic Earthquake Resistant design	C	D

Very effective：A Effective：B Not very effective：C Not effective：D

Base-isolation is the most effective of the three. However, it has some problems, too.

- It is not effective against low frequency seismic waves.
- Base-isolated buildings sway even in wind. This is a big problem for skyscraper of over 200-meters, because the wind pressure becomes larger than that of an earthquake.
- A new problem has been pointed out that base-isolated buildings continue to sway for a long period even after the earthquake is over.

Also, vibration-control has the problem that it has little effect on the first and second floors of the building. Therefore, it is necessary to compare the merits and demerits of each structural system and the most suitable measure should be pursued.

4.5. Structural Problems of Japanese Residential Buildings

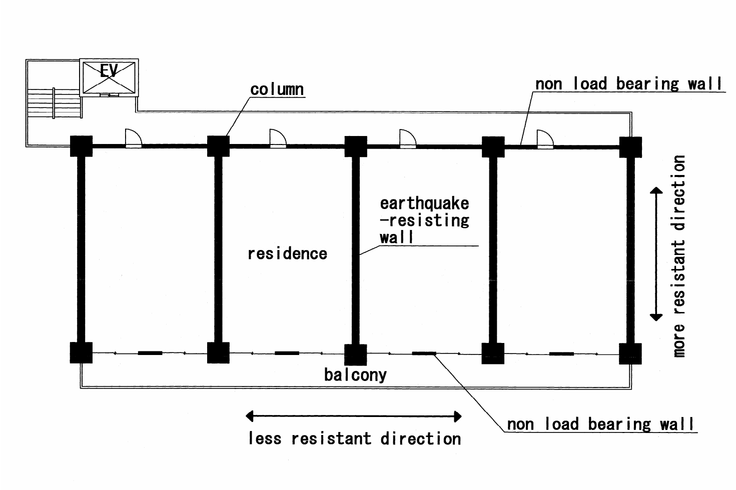

Figure 5. Common Plan of Condominium in Japan

Many Japanese residential buildings use earthquake-resisting walls. The frontages generally have many large openings, but partition walls are exclusively constructed using earthquake structural design. Once an earthquake occurs, there is a high risk of wall damage. In addition to that, when earthquake-resisting walls are only on one side of the building, cracks and other damage can be done to the non-load bearing walls on the opening side.（See Fig.5）

I happened to have the opportunity to visit the same building twice, before and after the Fukuoka Earthquake to write engineering reports. After the earthquake, I observed that the building had almost no damage. However, an adjacent building of the same construction type was damaged significantly. It had a number of large cracks and breakages along the frontage. The difference between the buildings is that their long axes were 90 degrees apart. This suggests that the degree of damage is relative to the orientation of the building and the direction of earthquake shock waves. The damage to the building was not significant and could be repaired. However, its market value as a residential building will remarkably decrease.

4.6. Problems in purchasing secondhand buildings.

Considering the described facts, I would like to point out several important points that should not be overlooked when purchasing buildings. (Things regarding construction and maintenance excluded).

The buildings should be:

- Not Built before 1981 (built under new earthquake-resistant codes)
- Built on solid ground within close reach of firm strata
- Symmetrical and well-balanced shape

Then, will the less-earthquake-resistant buildings (built before 1981) not be sold? This raises the question, if all the buildings built under the new earthquake-resistant design code are really safe, or not? The goal of the new earthquake-resistant performance standards is to have buildings constructed that would not collapse even with about 400gal earthquakes. However, the maximum acceleration of recent earthquakes was about 800gal in the Kobe Earthquake, over 1200gal in the Niigata Earthquake, and about 480gal in the Fukuoka Earthquake. Considering the results of those earthquakes, it cannot be said that the buildings built under the new standards are safe enough to cause zero casualty.

Furthermore, the earthquake resistance scams, by a now notorious architect discovered in November 2005, revealed that public offices responsible for checking the structural strength of buildings had not been functioning properly in Japan. It also led to anxieties about earthquakes and increased mistrust toward the building production system nationwide. In the process, many problems were uncovered in the investigation system of earthquake resistance building. As it became clear that the building confirmation application itself had practically collapsed, drastic measures must be taken immediately to solve these problems. In order to tackle these problems, Japan should consider increasing the number and improving the quality of building structure designers. There are only 3,500 of them in Japan now.

5. Earthquake Risks Reflected in Land Use

5.1. Various measures taken by each country

Between the two types of earthquakes, Subduction Zone Type earthquakes affect a wider range of areas, so it is more difficult to deal with them by just restricting land use. Active Fault Type earthquakes, on the other hand, have been addressed in various ways in some earthquake-hit countries.

In cases in which buildings stand on an active fault, an occurring earthquake will move the active fault and rip buildings on the stratum apart. In the United States, the state of California, where many earthquakes occur, established the Alquisito-Priolo Special Studies Zone Act in 1972, which can be called “active fault law”. According to the law, the state defined active fault strata and made an official map that shows a 1,000 foot-wide earthquake fault zone around an active fault. When building confirmation applications are submitted, cities and counties make sure that there is no active fault and give permission to develop the land and construct buildings. If active fault strata were found through geological research, buildings have to be built 50 feet away from the fault.

In New Zealand, some cities and towns have acts that limit the development of land on active fault strata. The Wellington government has a provision stating that buildings have to be built more than 20m away from the Wellington Fault, which lies in the south of the northern island.

5.2. Situation in Japan

In Japan, in cases where nuclear power plants or dams are constructed, research of active faults has to be done beforehand. However, little attention has been paid to the risks of land use for other purposes.

Some local governments have started making regulations in recognition of the danger of active faults though. For example, Nishinomiya City near Kobe City, established a law that developers must conduct geologic surveys to look for active faults within 100m of a proposed development. Unfortunately, developers complained that the government did not have the power to require them to do this research and the government reduced the requirement to only known active faults. In Yokosuka City, developers are requested not to construct buildings on active faults.

Although earthquakes occur frequently in Japan, few measures have been taken regarding risks on active faults. Its population density is four times as high as California, and twenty-five times that of New Zealand. Also, only a small percentage of flat land can be utilized, thusly land price is rather high. These are the main reasons for the setbacks. Even so, research of active faults must be of primary concern. Public buildings such as schools and hospitals, as well as lifelines such as expressways and railways should be built afterwards.

5.3. Dangers of soft land

Earthquake waves run fast through solid rock and slowly through soft sedimentary rock. When they transfer from solid rock to soft sedimentary rock, the velocities of seismic waves are reduced and the amplitude is increased. This is called amplification and it tends to occur on plains. The Mexico Earthquake (M8.1) occurred in 1985. Since part of the town had been developed on soft land, which used to be a swamp, many buildings collapsed, even though the quake center was 400km away.

Tokyo city lays on very soft sedimentary rock that is 3000m thick at its deepest point. In those conditions, even if the magnitude of an earthquake is small, it can become a large earthquake and cause enormous damage over wide areas. Through my own experience of the Fukuoka Earthquake, I can say that earthquake risks should not be solely dealt with at the time of earthquake. The Fukuoka Earthquake occurred due to the active faults in the sea northwest of Fukuoka city. They had nothing to do with Fukuoka's well-known Kego Fault, which passes through the center of the city. Nevertheless, the damage to buildings spread mostly to the east of the Kego Fault. On the west side of the fault there is hard dense rock, and on the east side there are sedimentary strata, where seismic waves are bent, amplified, and concentrated. (See fig.6)

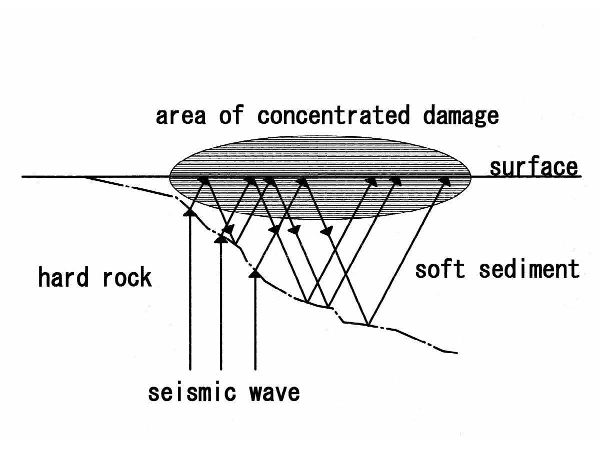

Figure 6. Cross Section of Kego Fault

It can be said that tremors get stronger on soft ground and it can make the damage even greater. Also, getting the strata data from boring can be used in predicting areas where great damage is expected.

6. Conclusion

Among all natural disasters, earthquakes are one of the most difficult disasters to predict. However, thanks to the development of seismology and architectural technology, it is now predictable to some extent where and how much damage can be expected. It also became clear that building structures merely complying with the Construction Standard Law is not good enough to protect buildings against damage. Having insurance is not sufficient, either. Simulations of damage in cases of huge earthquake occurrences have been carried out by various research organizations, too. The reality, however, even though seismic risks to buildings are somewhat taken into consideration, risks due to the lay of the land (whether the ground conditions are good or not, and whether there is active fault or not, etc.) have hardly been dealt with because of the difficulty setting regulations on land use.

Keeping things described in previous sections in mind, individual investors, therefore, should not just depend on the government for protective measures. It is essential that they get as much information as they can to assess the risks themselves. For example, seismic diagnosis can be done through checking old maps, the origin of place names, and estimating strata condition. Then measures against seismic risks can be taken. Along with that, federal government and local governments must correlate the study of past earthquakes and simulations of potential future earthquakes in respect to their city planning.

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