# ON THE DAMAGE OF FUKUI EARTHQUAKE AND THE DESTRUCTIVE POWER OF EARTHQUAKE OF SUCH A KIND

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About ten years have elapsed since a great earthquake occurred in and around Fukui, Japan. A number of scientific investigations, researches and experiments have been carried out to accumulate abundant and comprehensive data on the subject. The painstaking effort on the part of many investigations should be greatly appreciated. The data, although complete from a technical point of view, seem to lack first hand observation of the destructive action of the earthquake.

I feel it therefore, my duty to furnish such information. Now let me enumerate some instances which I consider important. On July 28, 1948, coming home from school I was reading newspapers when I felt strong vibrations, which developed in a short time into tremendous motion. Seeing the things on the shelf bigin to fall down, I cried out to my family to run out of the house at once. I saw some large cracks opening in the plastered wall, and a bookcase tumble. As I was running out of my house through the kitchen entrance, I happend to notice a heavy alminium "Kama" in the kitchen. When I ran about 7 steps I suddenly fell down with all others who were gathering there. Standing up to look back I saw my house falling down toward us. I noticed that houses collapse very slowly at the same instant and in the same direction. But amidst the tremendous vibration I could still inspect several kitchens of neighbours for fire prevention. And there in my kitchen I found the aluminium pot which I had been in the kitchen just a few minutes before was crushed horizontally by the doorsill which had dislocated two feet away. I thought the tremendous vibrations which I had experienced before our tumbling corresponded to the "initial tremour" of common earthquake. The collapse of the houses took place a little after the tumbling of the people. One of my family who was at work stooping in the vegetable garden, fell down foreward and then was thrown backward heels over head. Standing on her feet she saw people escaping from a factory which was falling down. At that instant we could see the far end of the city right through over the roofs of destroyed houses, which appeared like the waves of the ocean. At the instant the eaves of the falling houses reached the ground, the roof tiles slid down with tremendous noise. In a short time the sky was filled with dust. Perhaps it was caused by the crushing of the cusion earth of roof tiles or earthen walls. No other noise was heard except this. It was quite beyond my expectation. The collapse of all houses as far as I could see was very slow, just like large birds alighting upon the ground. Tumbling of ourselves gave us no pain. Several students who were then at work on the gallery of our college assembly hall told me later that they felt as if they were in a cabin of a ship sailing in a storm, and that they could see the grand piano being overturnd, while they grasped the handrail of the gallery. I estimated the period of the terrible vibrations to be about 1/3 to 1/2 second. But it seemed to me that the duration of tumbling motion of houses to reach over 2 seconds. It is regrettable that I could not confirm the time required by watching some standard object — flowing of clouds, for example — with which to compare the sliding motion.

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I can give two examples about the tumbling of people who had gathered in a place in the city. One is the tumbling togather of people at a dance-hall and another that of people standing in line to receive rations at Darumaya Departments Stores. As far as I could investigate, there were only two persons who kept standing all throuth the period of severest vibrations. One was Dr. T. Yamada, who managed to support himself with the aid of his bicycle by which he happend to be standing and talking with his friends. The other was Mr. Nanbu, a teacher of Maruoka high school which was located very near the epicenter. Being a skilful skier he felt as if he were sliding on the ground just as he was on a ski, and prevented himself from tumbling by balancing himself. He told me that all the other persons in the playground of his school including a teacher of athletics fell down. As he saw the principal standing by the window of the school, he cried out loud to come out quickly, but it was too late for him, because the school house already began to fall down. He fell just like a portrait in the frame. Of course at the instant when we tumbled there were violent vibrations of short period. Few houses which did not wholly break down were found to be violently shaking, which however, was an exceptional ease. For example, according to Mr. R. Teranishi our staff official engineer, the main building of our school (two-story wooden structure) resisted the seismic forces, but the ridge of the roof was twisting like a snake. He made the observation while grasping the old anchor bolt left on the concrete foundation from which he was thrown off. Mr. K. Nishimura, director of the branch office of Toda Co., was fishing in a sitting position on the bank along the southern side of the office. He noticed at first some faint reverberation on the water surface. Realizing that the surface of water was getting rough he stood up and then felt vivid vibration. Walking towards Tsukumo bridge, he suddenly fell down. Standing up again he found the reinforced concrete bridge ahead was safe, felt the handrail was twisting like a snake. The telephone poles in Fukui city tilted 15 to 20 degrees from upright position. It is reported however towards Maruoka (nearer the epicenter) the inclination was gradually increased up to 60 degrees. They all tilted in one direction. I found that ordinary one-story houses in the city slid in north south direction from 1/2 to 2 feet.

Mr. Nonome, a friend of mine showed me at his house his bathtub that crashed into the wooden wall more than one foot. One remarkable example of lateral displacement is that of a light wooden office building constructed upon a mass concrete foundation survived the air-raid. Sliding horizontally about 3 ft, it left straight traces upon the concrete surface and no damage was found even on window panes. It has long been known that building sliding more were safer than those sliding less. Formerly some of our engineers advocated "Menshin" construction which means a construction that is perfectly free from earthquake damage. Houses may practically be biult upon a row of parallel sleepers. Based on the same principle Prof. S. Ban once suggested that the bridge piers should be enlarged at the top. During earthquake it was proved that bridge girders or trusses fell off the supports as they were simply anchored to the pier. The water in the swimming pool at the Fukui university surged over the rim together with swimming students. A dictionary on my desk was found as far as 6 feet away from its original position. Examples of such a kind are too numerous to be mentioned here.

As to earthquake foresigns I can cite a few of them: Prof. T. Tsujimura (topographer) had suggested to me that the great faults crossing the central part of Japanese main land extending from Ise Bay on the Pacific coast toward north up to the Japan Sea had not cut all their way through, and that there were the possibilities of the faults taking place at the northern end. Prof. N. Nasu told me that he also was aiming to find the fault in this part, and he with his coworkers, remained in the earthquake stricken area one month longer than other research workers and at last found out the hidden faults by precise levelling as he had predicted. The damage to steel trussed poles of high voltage power lines were not generally severe, but the one which stood on that fault was badly damaged. One month before the earthquake the well water of Sakai Seiren refining and beaching factory changed into hard water, Mr. H. Takeuchi, director of the factory, went to Osaka to buy some softening apparatus. After the earthquake the water recovered to the normal condition by itself, the apparatus was no longer needed. It is reported that in the northern part of Fukui plain some explosive or thunder like sounds were heard. A student told me that such sounds were heard even on the forenoon of the day of the earthquake at Asozu, a village located near the southern end of the plain. After the earthquake precise investigation of change of magnetic field, underground current, etc, was carried out with the indication that there occurred some change under the ground. Summing up all these, I feel sure that it would have been possible to give an advance warning if some apparatus such as strain meter or proper toromometer etc. had been installed. So much now for my experience of the earthquake and I will try some interpretation of these phenomena in my own way. Some researchers enumerate the following being characteristic to Fukui earthquake:

1. The epicenter was very densely populated.
2. The ground was remarkably soft.
3. The seismic focus was located comparatively close to the ground surface.
4. The faults ran parallel to the main axis of the plain.
5. The faults did not expose themselves on the surface of ground.
6. Quadrant motions were very clear,etc.

A geologist had told me that Fukui plain was formerly under the bottom of the sea. Near the rivers we find many thin layers of flood sedimentation. The depth of the seismic focus under the ground surface was said to be about 17 miles (30 km).

Faults running along the main axis of the plain may characterize the earthquake. This may have some relation to the hidden faults, which were fortunately discovered. A researcher seems to consider the quadrant motion as a feature peculiar to this earthquake. But I believe it is comparatively clearly seen because the earthquake hit the plain only. The reason for this is that the earth's crust or the bedrock is always strained, namely being under strain and stress condition. The forces express themselves as shear stresses on the faults, and a pair of normal stresses in the quadrant direction, which I will mention later. It is very important that this action appeared in the initial main motion.

It is also significant to find that the destruction was brought about not only in the main motion but only once in one direction at that instant in the direction catched. The direction of a point in earthquake motion in space is ascertained to be always changing. I believe therefore that the destructive power must have been the shock action. Of course it accompanied elastic vibration, but the shock itself was plastic rather than elastic. Our researchers have already measured over 6 feet of horizontal displacement at the triangular bench mark. Still we are apt to think that the acceleration comes from the elastic vibration of some period and amplitude. For example, someone assumed 2-ft 8-in. amplitude with 12-second period. The time required is longer than that of the motion of a long swing. It seems to me that people are accustomed to the period of the seismograph used for the measurement of the distant earthquake. These periods are perhaps very much multiplied. Not only people but the seismographs are however entirely insensitive to such plastic motion. I feel it absolutely undeniable that the shock motion plays the main part on the destruction near the epicenter. The elastic motion goes so far with out losing much energy, while the shock plastic motion fades rapidly as the distance increases. In other words it does not propagate as the wave motion, but it is hindered by the resistance of the earth material. It causes, however, acceleration as the velocity is changed. Thus such researchers might well have taken the vibration as the source of destructive force. Against the structures the up and down forces act less severely than horizontal forces. Regrettable to say that the horizontal displacements were measured at only several places, but not at so many places as vertical ones which were done by levelling.

Here I must quote two remarkable phenomena. One was reported by the researchers group, and the report says that in Awara in the north end of the plain, the suction pipe of hot spring water was cut off at the depth of from 108 feet to 120 feet under the ground level. On the other hand at Daiwa Weaving factory which lies in Yamaokucho at the southern corner of the city, four deep well pipe with 300 ft spacing were cut off at 54 to 56 feet below the ground surface. The total depth of the pipes was 250 feet. This was detected by Prof Z. Tsukano (geology). I am not sure if such very shallow shear surfaces may be called faults, as they are too shallow. These phenomena, nevertheless, must have exerted certain influence upon the structures which stand upon such ground. A memorial stone pole several meters tall was thrown over a meter high stone fence, and yet there was no trace of contact found on both the pole and the fence. In Japan we feel earthquake very often, and are accustomed to the tremor of the ground, but we rarely find ourselves quite near an epicenter as in the case of Fukui earthquake. It appears that we nearly have forgotten that we have such words as earth-shock or German "Erdstoss" instead of earthquake or "Erdbeben". In such a case as Fukui earthquake, is it not more suitable to use the word, earth-shock instead of quaking of the earth? In the Kwanto earthquake of 1923, the slipping action in Tokyo was not remarkable. But the damage was considerably large. I consider it the limiting case of severest earthquake mainly accampanied by pure vibrations. The same earthquake caused some phenomena in Odawara quite similar to those in Fukui earthquake. Prof. T. Tsujimura told me as follows:

he felt some reverberation upstairs in a Japanese two storied wooden house. After a moment he felt suddenly that the room was rolling and shaking just like a ship sailing in the storm. The next instant he found himself sitting on the ground floor facing to the garden. All the houses in sight were seen at that same moment to collapse and the roof tiles to slide down, the sky being covered with dust. Moreover, one of his family who was washing clothes in the garden, got herself washed by the water in the tub all over the body. I happened to cite these stories in my lecture in May 1948 just one month before the earthquake occurred in Fukui. The students were astonished to find how these two earthquakes had things in common through their own experience. Some one guesses that the collapse of the building is caused by the resonance action of the vibration, namely when the period of earthquake being nearly the same with the natural period of vibration of one building, the effect is multiplied. We cannot perceive the sliding motion of the ground, because we are on the same ground, but on the contrary we feel vibration very sensitively. So in the neighbourhood of the epicenter we are apt to attribute the destructive power to the vibration of the ground. The seismographic records are considered as a scientifically reliable measurement, if the index pointer is not broken. We do not generally imagine that there are some motions which do not affect the seismographs. These apparata record instantaneous motion with respect to some steady point in space. Elastic vibrations which are instantaneous and occilating are most suitable, but the plastic motions such as the sliding of the ground are too slow and too wide to be recorded by a steady point of inertia in space. It is reasonable to attribute the failure of the index pointer to an excessive amplitude of vibration. In order that we may record the horizontal motion with the magnification of 100 times, it is quite impossible for 3 feet, if not so much for 6 feet.

Why did the low wooden houses collapse so slowly as birds alighting on the ground? My reasoning is as follows: a wooden house whose structural members are weak by themselves may withstand considerable shock before it collapses if the members are tighly framed. Rectangular frames will at first change their form, receiving up and down acceleration of the vibration, and then will come to the ground surface. But about the tall building the shock acts differently. The acceleration of the bodies on the tall building is generally believed to increase with the height, that is quite natural if the structures are fixed in space at the base, and if the structure themselves are vibrated by external forces. But if the shock plays the main part of destruction, the result will become reverse, it decrease with the height, as the body on a spring. For instance, as in our building code we should assume 20 percent of gravitational acceleration (horizontal acceleration) at least and increase the percentage in proportion to the height of the structure. Of course tall buildings are more dangerous than the lower ones. But it does not follow that the horizontal acceleration of the higher parts is larger than that of the lower parts. If the horizontal accelerations remain the same at any height, taller buildings receive larger overturning moment than lower buildings, which makes us to think that the higher part receives more horizontal acceleration. In order to agree with the above code we must grant that part of the structure moves voluntarily with its own force at each point, the foundation fixed and the upper parts free. Moreover the whole part moves with the same period with uniformly increasing displacement. Someone guesses that the collapse of building is caused by the resonance effect of the vibration, namely the period of the earthquake being nearly equal to the natural period of each building, thus the repetition makes the multiple effect of destruction. Still people agree with the dominant part of the main movement which is not grasped at the actual place of destruction as other than shocks. If the vibration alone is the main source of the destruction, we must explain why the different houses tumble at the same time in a definite direction. It is very fortunate that the earthquake in Fukui occurred before erection of the regular atomic reactor for which the horizontal acceleration may be taken as 50 to 60 percent of that of gravity, I believe, although they are built just upon the ground. I recollect now that Prof. S. Ban had designed in Kyoto a vibration table, which he says as a shock tester, having large horizontal spring dischanger.

The acceleration takes place suddenly but according to simple harmonic motion with subsequent vibrations which fade very rapidly. Thus it may be considered as a shock tester, but at the same time the shock is taken as the dominant part of the vibration. It interested me very much because the stroke was very large as compared to the scale of structural models. It seems that I must explain why the shock motion occurs in the form of quadrant motion. But its rigorous treatment is too troublesome as they involve the stress-strain theory in space. On the other hand, its two-dimensional treatment is too common. So I admit that the result remains as a pair of orthogonal principal stresses. At the same time there it accompanies relative maximum shear stress which is inclined to them, and produces the faults. They are commonly detected upon the ground surface. We believe that the faults are the slipping of the earth crust which exist at great depths. The focus is regarded the centre of the resultant forces. I assume the plastic shock motion comes more slowly than elastic vibrations. Thus very near the epicentre we can feel the elastic vibrations at first. In Maruoka people could do so as the focus lay deep in the ground. But they hesitated as they experienced the destructive earthquake for the first time. They say there was no time to get out from the house. But this expression is not reasonably right at all, if they are exactly spoken. If the doors were light enough to open and people were told beforehand that they should not hesitate to get out from the house at that moment. Many people did after the first time, ever, at very near the epicentre. In the case of Fukui, considerably near to the epicentre, still we could do so, while others could not, as, we were on the first floor. I know a teen age boy, at first shock, after running 50 feet and get out from the house just before it collapsed. In Fukui as usual, almost all one-story houses collapsed in the form of parallelogram. Two-story or taller houses were rare. They collapsed at the first floor as in other earthquakes. But there was one exception of main building of Fukui university. This was shown as a remarkable example of failure of two-story building, but the fact was that the lower story was braced and the upper not. It was built along the new instruction by Prof. C. Taniguchi only at the lower story, but could not do so in the upper story with the old budget which comes too short to build the both stories completely.

CONCLUSION

Nowadays all scientists try to study things as rigorously and objectively as possible. For this purpose they adopt scientific methods, as logic, physics, and mathematics together with observations and experiments. Thus the trend is towards more analytical and less synthetical aproach. Earthquakes are usually treated as vibration of the grounds. The assumption is generatly valid, but cannot explain many phenomena when it comes to the destructive action of earthquakes.