WISE DYNAMIC TESTING FOR KNOWING STRUCTURES MORE

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ABSTRACT

In this decade, big shaking tables were installed to the UC San Diego in USA and the E-Defense in Japan. The bed of the E-defense can support 1200 metric tons and 20m tall structures. This is so big comparing to the past facility and is very strong machine, but actual buildings are bigger and taller than the one that could be on the table. Total weight of a tall building will be heavier over 100,000 metric tons and height of a tall building is higher than 300m in Japan and 800m in the world.
Researchers can test only 5 story buildings at the E-defense and test 10-story buildings but very small floor area at the UCSD. We cannot test actual buildings. Then, we need new wise ideas for understanding and knowing the behaviors of actual big structures due to large earthquakes. We will discuss the history of Japanese researches and introduce 4 wise dynamic tests.

EARTHQUAKE ENGINEERING GROWING BY PAST SEVERE DISASTERS

Before Galileo Galilee had written "Two New Sciences", the first textbook of structural mechanics about 370 years ago, we have not any equation for knowing strength of a beam or a column, but humankind is very craver and has some intuition. Old carpenters or old contractors could built very beautiful buildings and architectures such as Pyramids in Egypt, Parthenon in Greece, Pantheon in Rome or 5 story pagodas in Japan and so on more than 1000 or 2000 years ago. These buildings have very good performance in long time, but there should be more and more buildings and many of them were collapsed by many reasons. In some case, old engineers should mistake to make some buildings some time and they have learned new construction technology from seeing those failures. In the 20th century, we have had many severe earthquake disasters and we have learned many things for knowing the structures more under earthquakes.

a. Building structures have to have certain horizontal strength.
b. Structural members and total structures have to have some deformability.
c. A structure has to have enough integrity.
d. Supporting own gravity weight after an earthquake is basically important matter.
e. Location of construction, soil condition, and foundation are also basically important.
f. Soil-structure interaction has big influence to a response of a structure. In some case, good effect would be, but other case, bad effect would be to the response of the structure.
g. A pattern of maximum response of story shear forces could be defined against an earthquake, but it changes due to characteristics of earthquakes. The enemy cannot be defined in our science.
h. Strong columns and weak beams structure is preferable.
i. Strong shear-walls or steel braces are very effective to increase seismic capacity.
j. Negative slope of a relationship of story shear and deformation make a structure instable.
k. Not only horizontal movements but also rotation along Z-axis have strong effect to collapse a structure.

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l. Joints of beam to column or joints of brace to beam-column are very important. Detail design is very important.
m. Supplemental damping devices increase a seismic capacity. Passive controlled structure is one of good seismic structures.
n. Seismic isolation is also one of good seismic structures.
o. Three important roles of seismic design are 1) Preventing collapse of building to save human life, 2) Reparable structure after an earthquake to keep a building property, 3) Keeping a function of building to avoid business interruption due to an earthquake. If possible, we, structural engineers, want to make a building that can cover these three roles.
p. Requests and desires of people are growing up year by year.
q. Resilience of life, city and country is next important words for structural engineers.

ENGINEERS HAVE TO KNOW WHAT WILL HAPPEN BEFORE IT HAPPEN

Structural engineers want to know how a building behaves when an earthquake hits it in future. They have to know what will happen around the building that they are designing and constructing. We can test beams, columns and joints of these members taking a part from actual building structures. When we have enough research money, we can test two story to several story of whole building structure. Regretfully, we cannot test more than ten story-building structures, since we have not big enough testing laboratory in the world.
We have an analytical approach using high-speed computers to be able to know the structural behavior under earthquake loadings. When we can grasp the mechanical properties of structural members and structural frames through the results of individual tests, we can make a mathematical nonlinear model in the computer. Calculation itself has not any problem now, because that we can use high-speed and large-capacity computers. Then we can get a lot of information from the calculated results.
The structural test is the induction process, but the numerical analysis is the deduction process. The structural design is also deduction process and synthetic approach. This is very important. We are using many engineering products such as mobile phones, automobile cars, airplanes and so on, these products are made by mass-production and these functions will be check right after when consumers start to use. On the contrary to these products, building structures are made one by one and constructed on one place and other place. Since a severe earthquake will happen only once a hundred years or a thousand years, actual performance can be checked in very rare chance. Humankind has made many buildings and many big cities, all we have done are not inside of our experiences but out of them. Then we have to know what will happen around the actual building structures in future through any possible way before any trouble happen. The static tests and the dynamic tests should give us a lot of important information and important knowledge.

AIMS OF STRUCTURAL TESTS AND NEEDS OF REALISTIC TESTS

As I have discussed above, the structural tests give us important knowledge and many ideas, we do not need to explain more why we do structural tests. Structural materials are changing to increase their strength, such as concrete, steel and other kinds of materials. Structural engineering is a field of design works, the innovative engineers will make new structures or new structural systems beyond those we had past. Then we have to test the structures or new structural systems.

a. Understanding and knowing the structures more.
b. Making safer structures, more economical structures and higher performance structures.

c. Finding weak point of our structures before an actual earthquake hits them.
d. Avoiding failures and increasing the reliability of the structures.
e. Getting the government permission of new ideas.
f. Making a design guideline, a design standard and a design code.
g. Increasing sympathetic friends of engineers and researchers about new ideas and new deign.
h. Persuading the building owners about our design and persuading general people about new ideas.
i. Deep understanding of the structural behavior for young students and young engineers. The experimental test is good experience for young people indeed.

For these aims, realistic dynamic tests are most effective method and they have strong visual persuasive power. In this paper, we would like to introduce some examples of our researches in these 30 years.

TINY SEISMIC ISOLATED STRUCTURES WITH HORIZONTAL HEAVY INERTIA MASSES

Professors Hideyuki Tada and Mineo Takayama have tested tiny seismic isolated structures using also small shaking table in October 1982. 4 rubber bearings were supporting one floor and the diameter of the rubber is only 30mm. First natural period is too short because that the floor is too light and stiffness of rubber is little high. Always, small specimens have short natural period. At that time, they cannot see the typical behavior of seismic isolated structures. They need heavy horizontal inertia weight. Then, 5 metric-tons iron weight hanged from crane was connected to the side of the specimen. First natural period of the total system become longer as enough to show the dynamic behavior of seismic isolated structure as shown in Photo-1 and Photo-2. Next step, the same research group has done 5 story seismic isolated structure using same idea as shown in Fig-1. This system has 5-separated horizontal inertia masses hanged from the high tower in the laboratory.

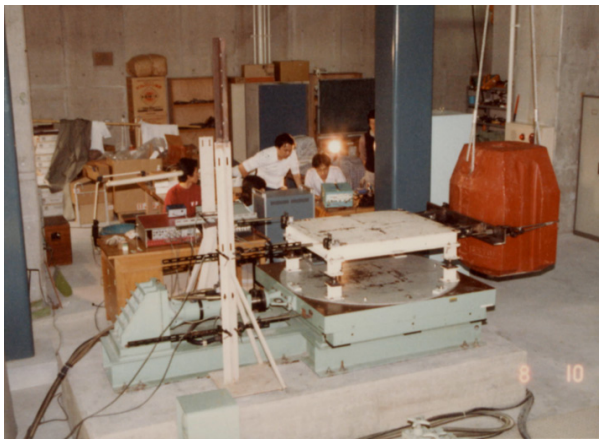

Photo 1. and Photo 2. Tiny seismic isolated structure with heavy iron weight

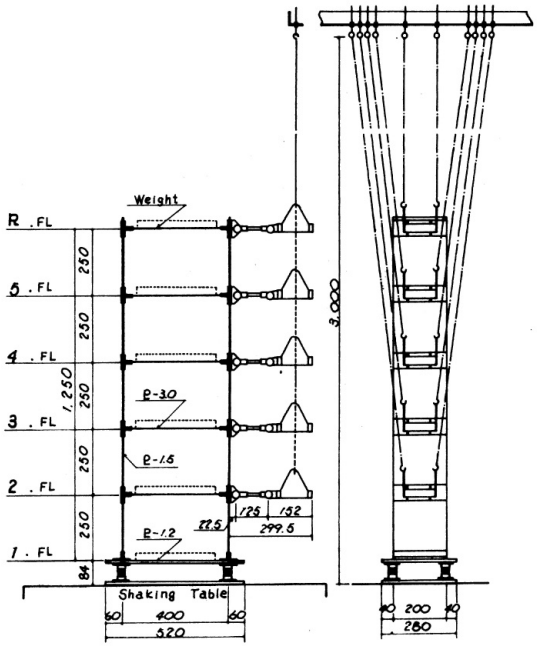

Fig. 1. 5-story seismic isolated structure and 5-horizontal inertia masses

SEISMIC RETROFITTED REINFORCED CONCRETE FRAMES ADDED SUPPLEMENTAL DAMPERS

The research team of Dr. Masanori Iiba and Professors Satsuya Soda, Eiichi Inai, Hiroshi Kuramoto and Akira Wada has done reinforced concrete frames having supplemental dampers with horizontal inertia mass set on 4 flexible rubber bearings at the large-scale earthquake simulator of the National Research Institute for Earth Science and Disaster Prevention in 1998. The reinforced concrete frames we tested were designed by old Japanese design standard and their seismic capacities were not enough. We can get many useful data and BBC took a film of our tests and broadcasted to the world through the program "Tomorrow's World".

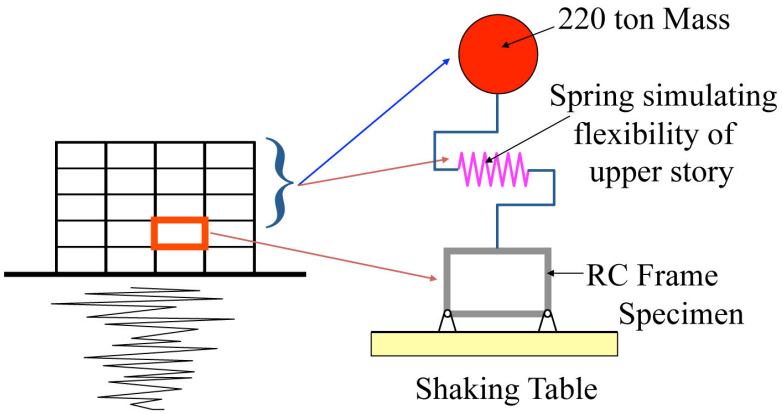

Fig.2. Additional mass and flexibility

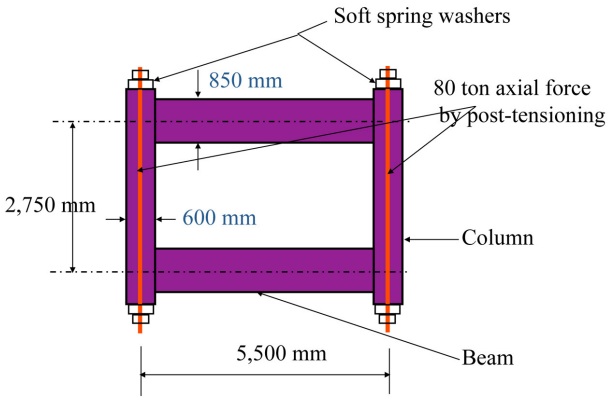

Fig.3. Introduction of column axial forces

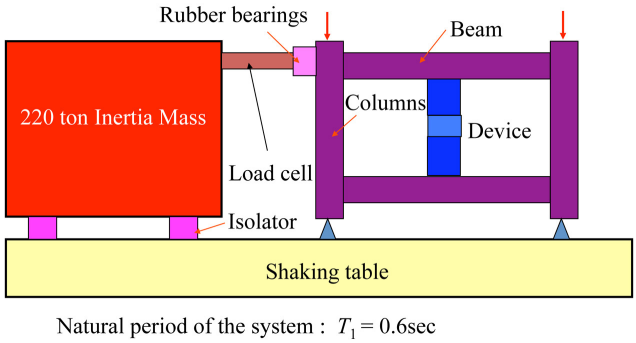

Fig.4. Elevation view during test

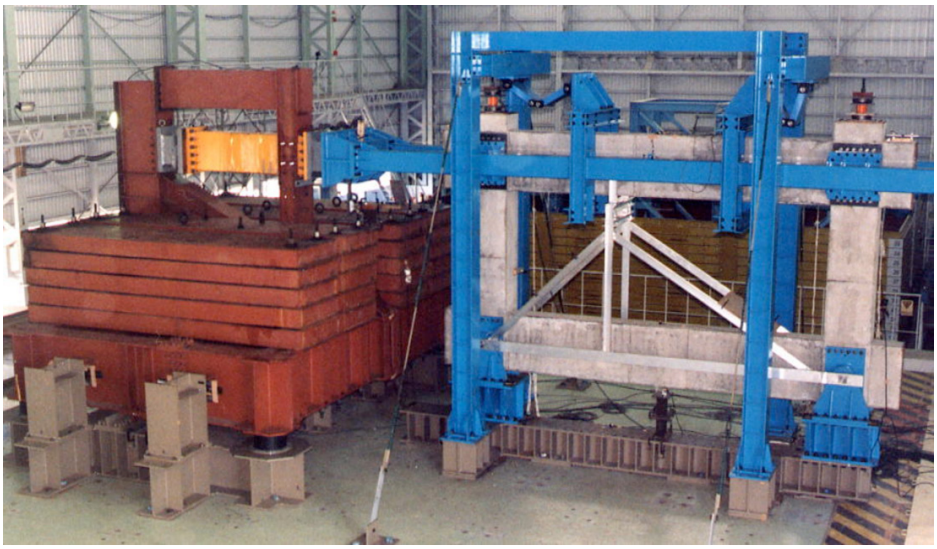

Photo 3. Very heavy steel inertia weight and reinforced concrete frame

PASSIVE CONTROLLED STEEL FRAMES WITH HORIZONTAL INERTIA MASS

The research team of Professors Satoshi Yamada, Masayoshi Nakashima, Toru Takeuchi and Akira Wada has done steel frames having supplemental dampers with horizontal inertia mass hanged from the crane beam at the shaking table of the Disaster Prevention Research Institute, Kyoto University in 1999. We tested only one story frame taken from a several story steel frame. Horizontal weight simulates other part of story of the original building. Soft spring made of rubber bearings simulates flexibility of other part of the original frame. Total system composed of the specimen frame, soft spring and horizontal mass has 0.6 natural period. We could test many frames using this system with not much research money.

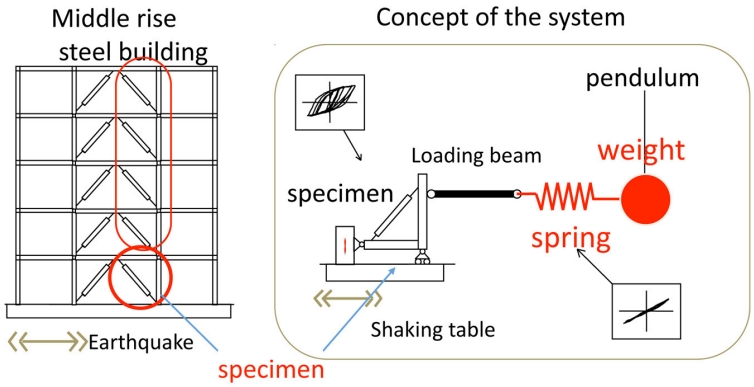

Fig.5. Model steel frame and a specimen with inertia weight and spring

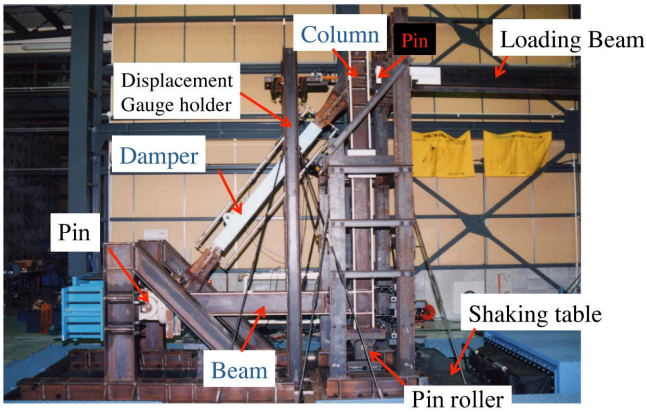

Photo 4. Beam, column and buckling restrained brace on the shaking table

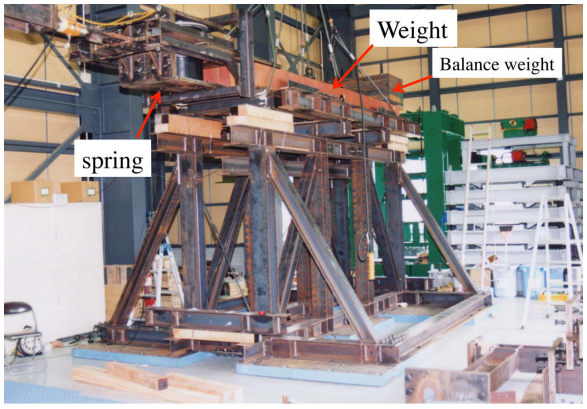

Photo 5. Inertia iron weight and spring of 2 rubber bearings

COLLAPSE TESTS OF VERY SMALL STEEL FRAMES IN HIGH GRAVITY CIRCUMSTANCE OF CENTRIFUGE MACHINE

The centrifuge machines have been used for the static or dynamic stability tests in the research field of soil mechanics and foundation engineering. When the specimen size is 1/10 of the actual scale of a structure, total weight of the structure become 1/1000, but sectional area of the member is only 1/100. Then, stress level become 1/10 of actual stress in the structure. Nonlinear effect of the structural member cannot be treated correctly in the 1/10 specimen. P-delta effect become also very small when the specimen's weight is too light. The research group of Dr. Hideo Katsumata, Professors Satoshi Yamada and Akira Wada have done the collapse tests of very small steel frames in the very high gravity circumstance of centrifuge machine at the Technical Research Institute of Obayashi Corporation. 3, 12 and 30 story steel frames have tested here. The centrifuge can produce 100G gravity and the testing container can have a 2m high specimen. We can test 200m tall buildings using this strong machine theoretically. Since the scale of a specimen is 1/100, it will be very difficult to make the specimen precisely.

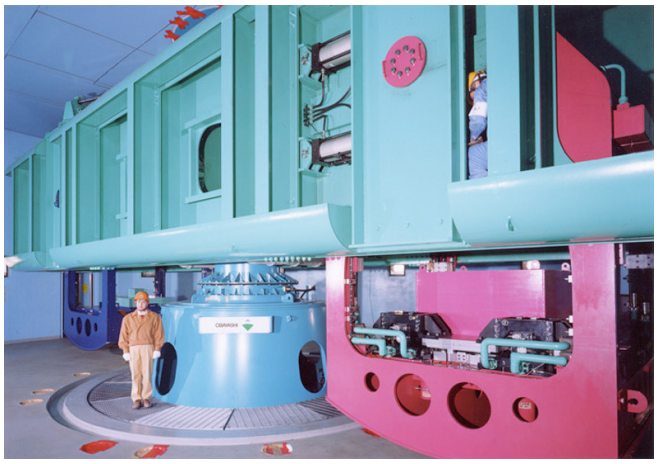

Photo 6. Big centrifuge and container at the Obayashi Technical Research Institute

3-Story week columns and strong beams steel frame

The first try was a test of a 3-story steel frame shown in Fig.6 and Photo 7. The frame has 4 columns in every floor, sectional shape of all columns is 1mm thickness and 20mm diameter tube. Beams are very strong. Then, the shear capacity of each floor is same. We took the test under 30G and shake the container horizontally. Finally, the columns at ground floor were broken, just after that, second and third floor collapsed. Most dangerous collapse mode was happened. We could take several valuable video movies.

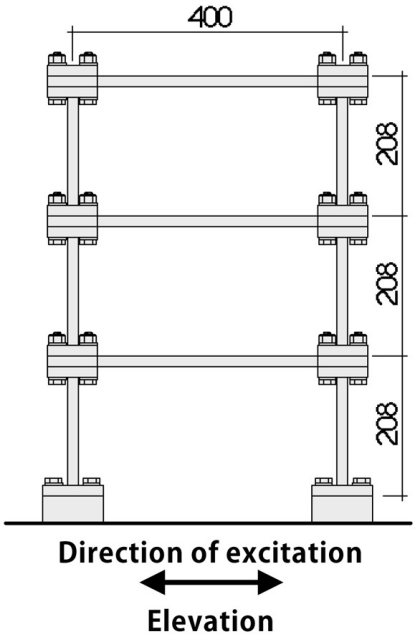

Fig.6. 3-story steel frame composed of 4 tube columns and 4 rigid beams

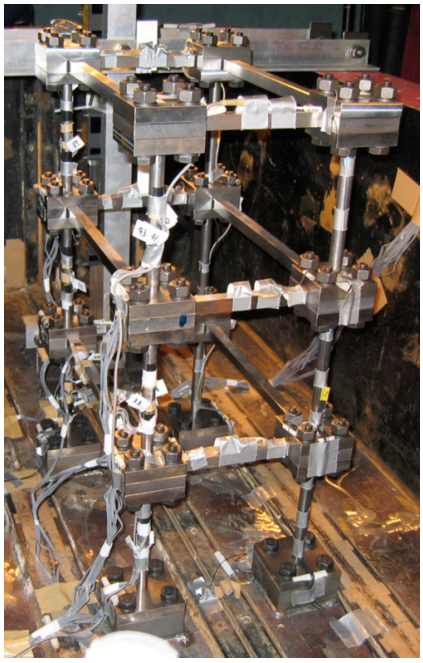

Photo 7. 3-story steel frame in the container of the centrifuge machine

12-Story strong columns and week beams steel frame

The second try was 12-story frame. The frame was made as weak beams and strong columns structure. We took the test under 60G and shake the container horizontally. It was very beautiful vibration under medium horizontal acceleration. Next, we applied large horizontal acceleration to the container, then the frame become unstable as shown in Photo 9. Finally, the whole frame was perfectly collapsed as shown in Photo 10.

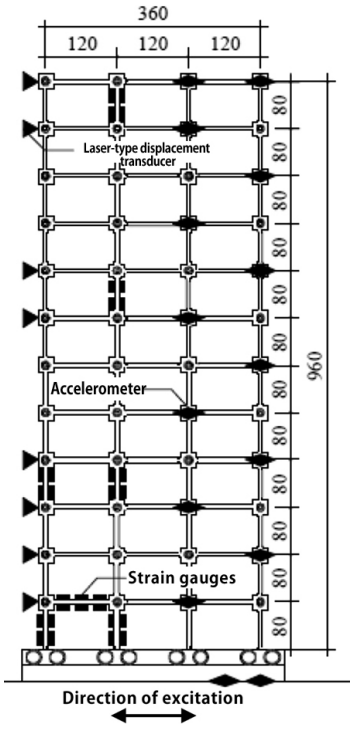

Fig.7. 12-story steel frame

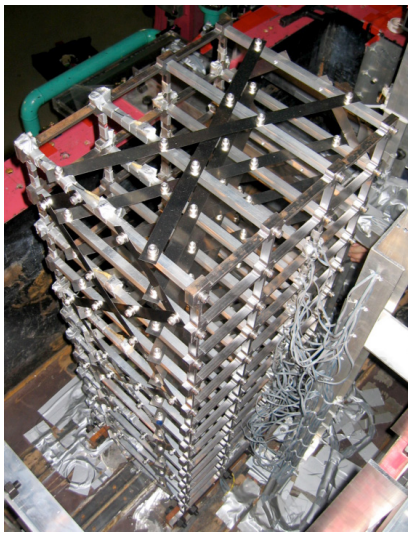

Photo 8. 12-story frame in the container

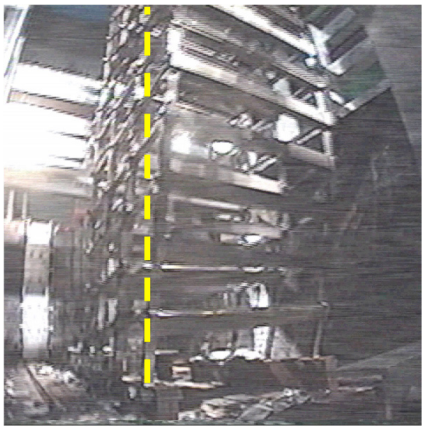

Photo 9. Loss the stability of frame just before collapse

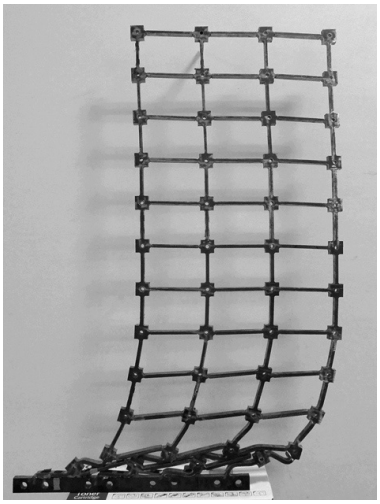

Photo 10. Final collapse of 12 story frame

30-Story steel frame having center wall and strong outrigger beam

The third try was 30 story frame having a center wall and a strong outrigger at middle hight. We took the test under 60G and shake the container. The relationships of sotory shear and story deformation getting from the test were very beautifull, almost all stories become to yield and ductility factors were around 2 to 3. The center wall and the outrigger were very effective to control the vibration mode, these member should increase the seismic capacity of the building structures.

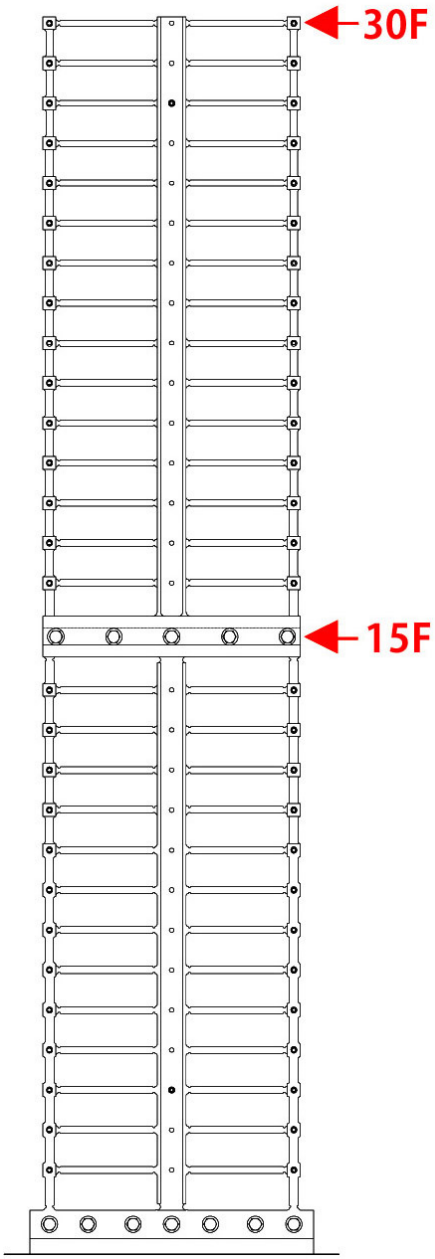

Fig.8. 30-story steel frame

Photo11. 30-story frame

CONCLUSIONS

Actual buildings become bigger and bigger every year, many cities in the world are growing up year by year. Structural engineers have to make safer buildings and safer cities for people. We have to know what the structure is, how to behave the structures under strong earthquakes. We need to do the structural test not only static but also dynamic. Always, test facilities have some limitation. Researchers and engineers have to use these facilities under the combination with deep thinking and new ideas.

After the Roma Prieta Earthquake happened in 1989, many professors and engineers discussed about the performance based earthquake engineering. Japan has 20% strong earthquakes in the world, but only 1% or 2% buildings are constructed by seismic isolated structures or passive controlled structures. We need to promote these new technologies and increase the number of practical applications to not only Japan but also other countries.

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