Ishinomaki Red Cross Hospital:
The hospital that sparked the spread of seismically-isolated structures.
•Ishinomaki Red Cross Hospital's seismically-isolated structure allows it to function as a disaster base.

The damage to Ishinomaki City as a whole in the Great East Japan Earthquake was enormous, with 3,173 deaths and 717 missing, the highest number of any city or town in the affected prefectures. We pray for the repose of the souls of those who lost their lives.
Among them, Ishinomaki Red Cross Hospital, which adopted a seismically isolated structure with the aim of becoming a regional disaster base hospital, fully demonstrated the performance of its seismically isolated structure, and was the only facility in the Ishinomaki area that was able to maintain its hospital functions even immediately after the earthquake, saving many lives.
This was reported through television and newspapers, widely raising awareness of the benefits of seismically isolated structures in society, and became a material that will greatly contribute to their future spread.

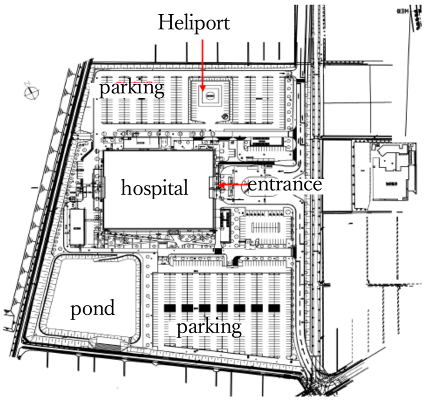
Among the matters that were incorporated in the design of the disaster base hospital, the following (1) and (2) were particularly effective in terms of structure, and the following (3) and (4) were effective in architecture and facilities.
(1) The seismically isolated structure reduced floor response acceleration, preventing important medical equipment being no damaged, making a major contribution to maintaining the hospital's functions.

(2) Embankments were built as flood prevention measures for the old Kitakami River near the site, which ultimately prevented the hospital from being inundated by tsunamis.
In addition, because the ground was at risk of liquefaction in a major earthquake, ground improvement work using sand piles was used for areas that would need to maintain their functionality in the event of a disaster, such as the main building, medical gas building, infrastructure intake sections, and the heliport. As a result, the ground was able to be maintained without liquefaction, and the heliport in particular was useful for the rescue and transport of many lives.

(3) In preparation for blizzards, a large eaves was installed at the entrance, which could provide temporary rain protection for victims and medical equipment. Furthermore, many spare medical gas outlets were installed in the entrance hall on the first floor, making it possible to provide simple emergency medical care in the hall on the first floor.

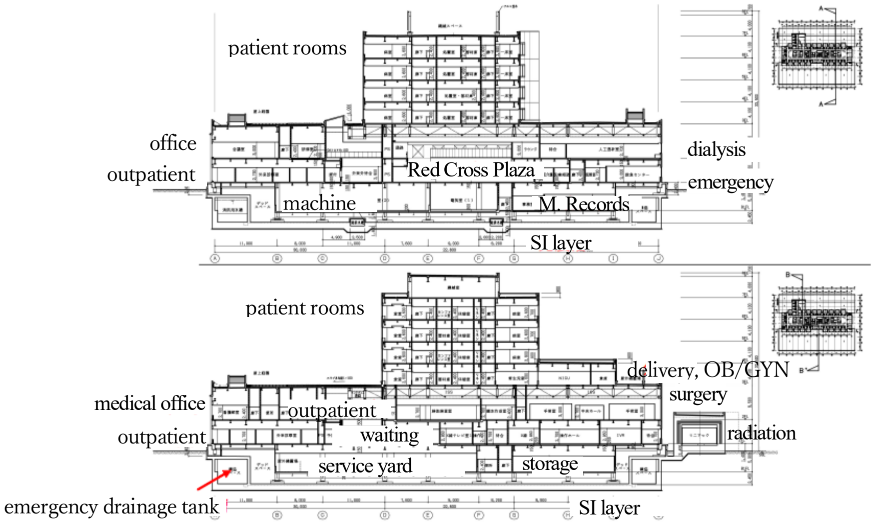
(4) Along with having two electrical intake systems, a private generator installed on the top floor made it possible to supply power even if the infrastructure was cut off.
Furthermore, the equipment plan, which took into consideration ensuring functionality in the event of earthquakes, such as storing a large amount of miscellaneous water, was successful, making it possible to continue medical treatment in the long term.
The building's seismically isolated structure prevented these facilities and equipment from falling over and malfunctioning.
These measures (1) to (4) have enabled the building to function as a disaster base, and at the end of the report, we had also removed one steel damper and conducted a fatigue test to confirm its performance for future reuse, providing valuable information for the future.
As the results ensured the required performance, it was decided that no replacement would be required.

Overall view of the building



Site layout

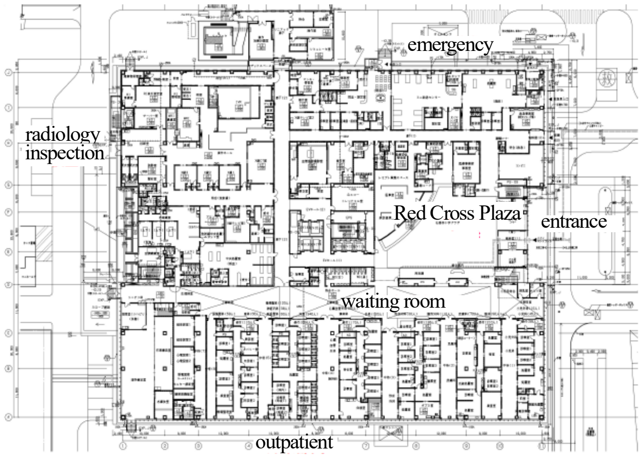
Building Overview
Architecture/Total floor area: 10173 m^2/32486 m^2
Number of floors: 1 basement floor, 7 above ground floors, 1 penthouse floor
Eaves height/Maximum height: 21.4 m/26.2 m
Structure type: Steel frame, seismic isolation
Foundation: RC mat foundation with nodular piles
Number of hospital beds: 402
Client: Japanese Red Cross Society
Design: Nikken Sekkei
Construction: Kajima Corporation
Construction period: August 2004 to February 2006



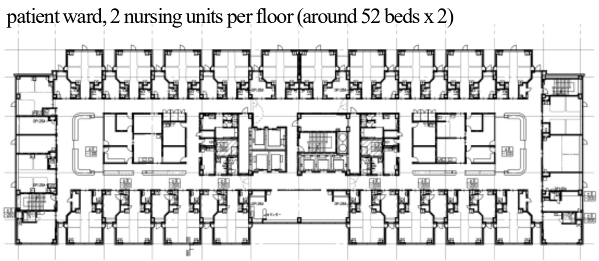
Cross-section

The building is designed as follows: the basement houses facilities such as aquariums and machine rooms, a two-story atrium entrance hall (Red Cross Plaza) at the first floor entrance, the first and second floors are mainly rooms for the outpatient and medical departments, the third to sixth floors are mainly patient rooms, and the top floor (seventh floor) is home to the machine room for the emergency generator and other equipment.

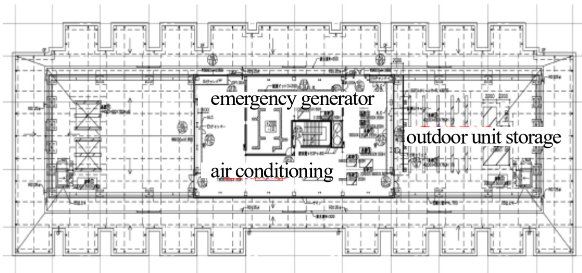
The superstructure is characterized by the truss beam layer on the upper part of the second floor, which is intended to convert the span layout of the patient rooms, which are intended as private multi-bed rooms, and the span layout required for the medical department on the lower floor, and to deploy various equipment piping on the patient floor and medical department.



1st floor plan



Plan of patient rooms (4th to 6th floors)



Plan of 7th floor (top floor)

Structure overview

・Site ground and foundation

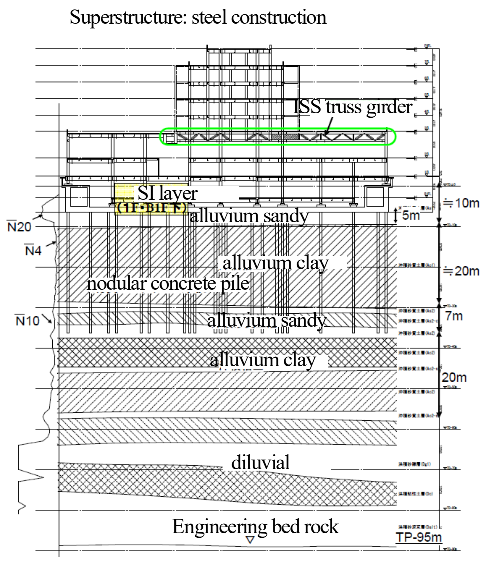
There are three important elements to the site ground.

Diluvial deposits appear at a depth of about 70 m or more, but because methane gas is generated from this layer, it is risky to excavate it for support piles. The diluvial clay layer in the middle is normally consolidated, and will sink significantly if excessive load is applied.

The top sand layer has a maximum N value of 20, but the lower part is at risk of liquefaction in a major earthquake.

For this reason, a pile raft foundation was created that utilizes the high-strength sand layer at the top and supports the building at the middle layer with friction piles.

In addition, sand piles are used to prevent liquefaction in areas where there is a risk of liquefaction.



Structural Outline

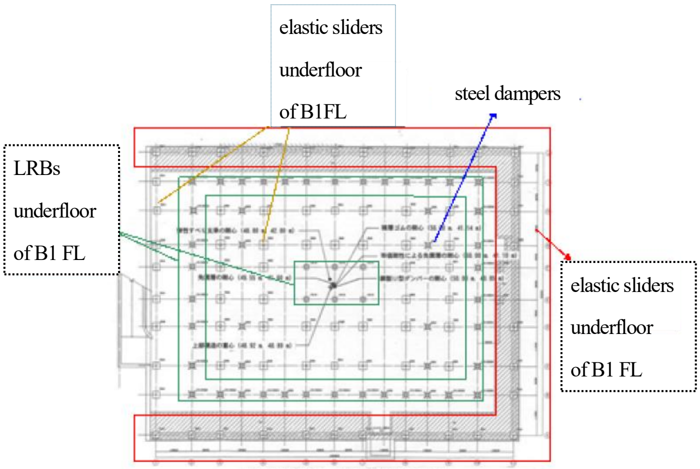
・Superstructure

Given the above ground conditions, the structure was designed as light as possible, and because trusses would be needed to connect the upper and lower floors, steel frame structures were planned.

In addition, the low-rise area around the perimeter of the building was made of reinforced concrete for the first basement floor, and heavy objects such as water tanks were placed there to ensure the overall weight balance.

・Seismic isolation structure

The dominant period of the ground was long at 1.40 seconds, since the dominant period of the ground is long at 1.40 seconds, the seismic isolation layer was designed to have a relatively long natural period so as not to match the natural period of the seismic isolation and to prevent excitation.



Layout of SI devices

As a result, NRBs, elastic sliding bearings, and steel dampers were used, and set the seismic isolation layer with a natural period of 1.45 seconds at initial stiffness, 3.73 seconds at extremely low strain (49 cm), and 5.39 seconds with only the isolator.

The damper was set at approximately 5 % of the building weight.

(1) Seismic isolation structure

Floor response and seismic isolation layer status

・Deformation during earthquake

Measurements of the scratch board showed a maximum deformation of 26 cm (east-west direction).

This was about half of the maximum response value of about 49 cm during an extremely rare earthquake assumed at the time of design.

The floor response acceleration of the top floor (6th floor) of hospital rooms in the east-west direction during an extremely rare earthquake assumed at the time of design was about 300 gal, so it was thought that an acceleration of about 150 gal, roughly half of that, occurred during the earthquake.

・The situation on the 6th floor immediately after the earthquake
No important facilities or medical equipment toppled over on the 6th floor or on the upper facility floors.
However, since it was estimated that an acceleration of about 150 gal occurred, documents on desks and documents placed on shelves without doors slid and fell to the floor, as shown in the photo. However, no one was injured, and medical activities were quickly resumed by simply arranging the documents.

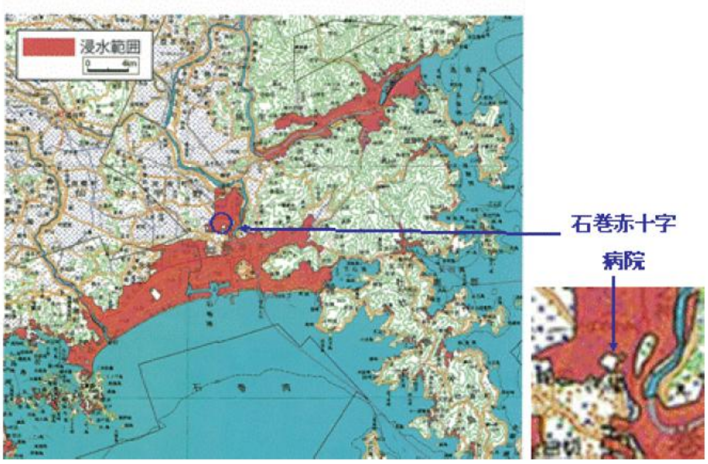
6th floor Situation after the quake

・Status of the seismic isolation layer after the earthquake
Paint peeling was observed on almost all steel dampers, and the damper mounting bolts were loose in many areas. However, given the change in shape of the dampers and the resulting peeling of paint, it was believed that they were still performing as intended. In addition, the isolators and elastic sliders only had a few peeled paint spots, and no loose bolts were found. Emergency measures such as retightening in necessary areas had been implemented, and the structure had adequately withstood the aftershocks since 3/11.

Steel damper after the quake

(2) Ground measures, situation after the Earthquake
・Tsunami inundation situation
The area near the site was inundated by the tsunami, but the site had been filled with soil up to 3m in the highest part as a flood prevention measure for the old Kitakami River, and as a result, it was spared from tsunami inundation.

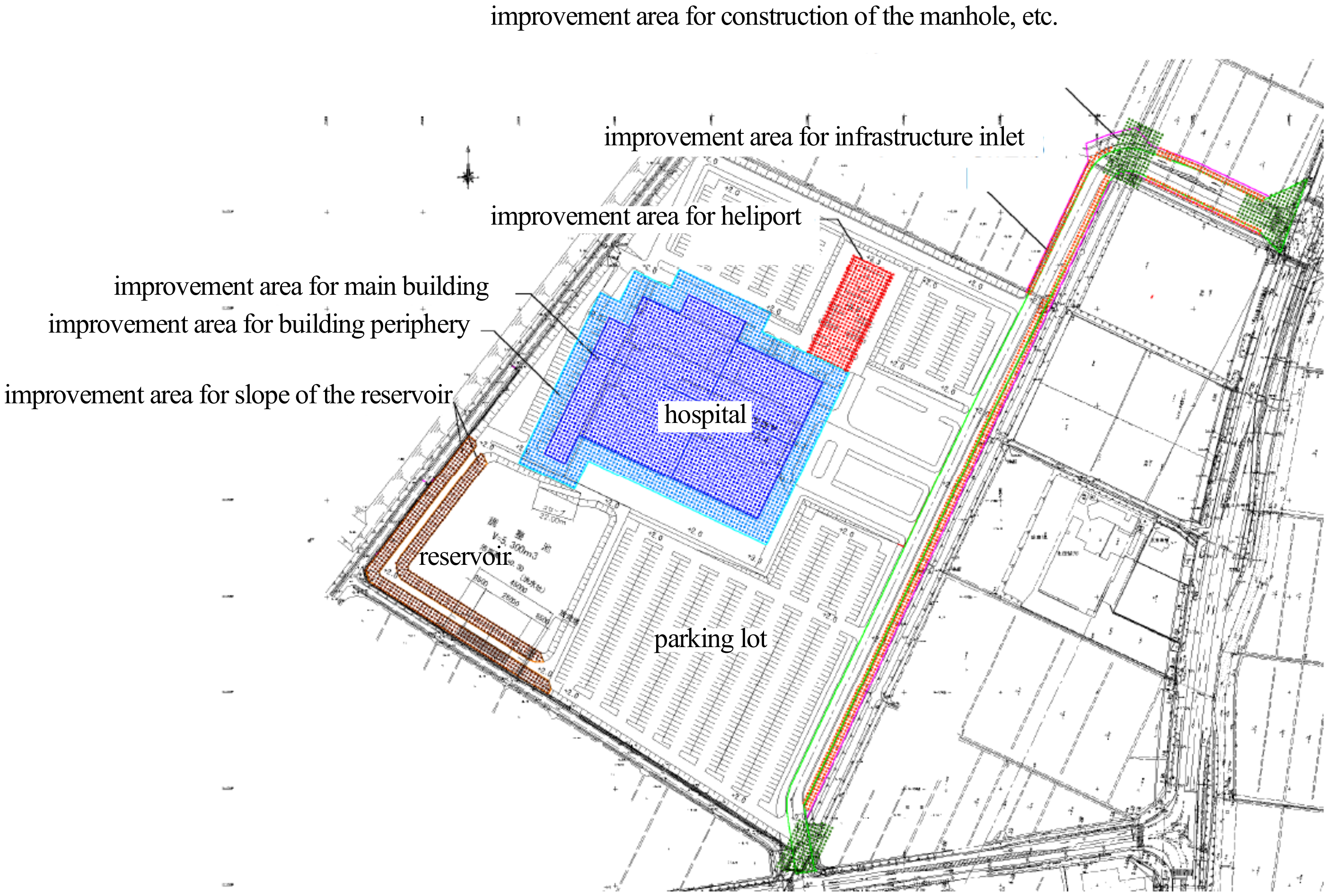
Ishinomaki
Red Cross
Hospital



Red Cross Hospital　　　　　Flooded areas(red colour) in the Ishinomaki region

・Soil liquefaction countermeasures

As shown in the figure below, the dynamic compaction sand pile method was used for ground improvement in areas that need to maintain functionality in the event of a disaster, such as the main building, medical gas building, infrastructure intake section, and heliport, and as a result, the soil was able to be maintained without liquefaction.



Layout of the ground improvement area

(3) Disaster base countermeasures

Situation after the Earthquake

・ The heliport

The heliport also had ground improvement work done, so it did not liquefy. Many lives were saved.

Heliport and large eaves in front of the entrance

View of the heliport

・Appearance of the large eaves

A large eaves was placed at the entrance in preparation for storms and snow, and it effectively served as a temporary rain shelter for disaster victims and medical equipment.
Many tents were set up using this large eaves as an outside base, enabling emergency medical services to function.

Eaves in front of the entrance and Tents

・Situation of the first floor (1)
The first floor entrance hall was made up of movable furniture so that it could function as an activity base in the event of a large-scale disaster. In the event of an earthquake, as envisaged in the design, chairs and other furniture were removed to create an open space in the waiting room, allowing the hospital to accept patients with minor injuries and provided simple emergency medical care.

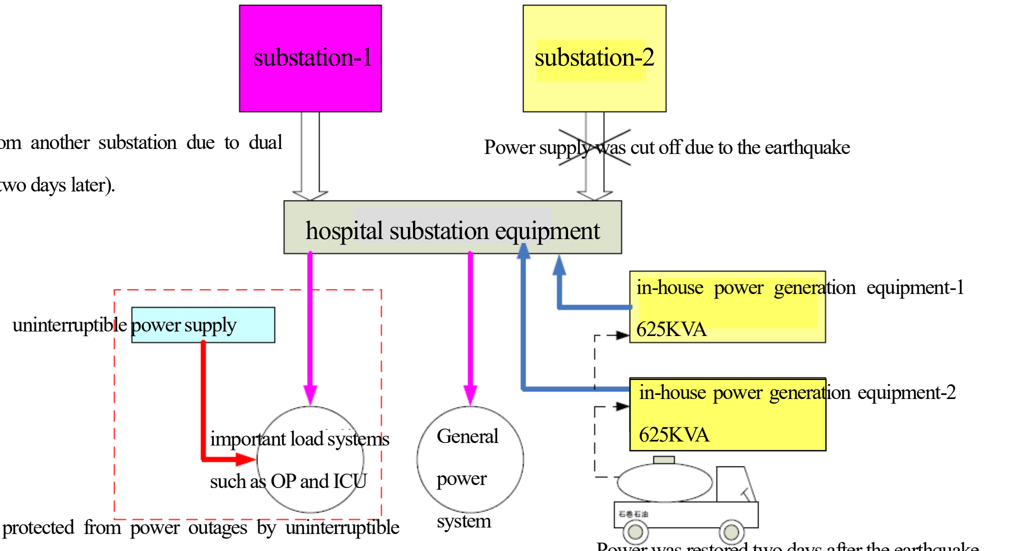
The first floor entrance hall (Red Cross Plaza) under normal conditions (left) and after the earthquake (right)

・Situation of the first floor (2)
The outpatient waiting room adjacent to the first floor entrance hall also functioned as a base of operations in the event of a large-scale disaster. In particular, many spare medical gas outlets were installed on the walls of the outpatient waiting room, so that it could handle even slightly seriously injured patients. During the earthquake, emergency medical treatment could be given to patients with moderate injuries.


The first floor outpatient waiting room under normal circumstances (left) and after the earthquake (right)

(4) Countermeasures for disaster base
Equipment status
・Overview for electrical equipment
There were two power receiving and transforming systems from separate substations (see right), which was very helpful in restoring power two days later.
・Overview for drinking water
Under government guidance, only 0.5 days' worth of drinking water could be stored. Therefore, the hospital was managing the emergency by sending water from a water truck to the drinking water storage on the first basement floor.
・Overview for gas
The medium pressure gas base along the coast was unable to deliver due to the tsunami. Therefore, gas pressure transmission equipment was installed on the site, and gas was sent from tank trucks to the hospital through this equipment.
This was also possible because the liquefaction countermeasures of the infrastructure on the site and the seismic isolation structure meant that the piping inside the building was not damaged.

Power was secured from another substation due to dual power supply (restored two days later).



Important loads were protected from power outages by uninterruptible power supplies, and power was subsequently secured by emergency generators, etc.

General power outlet circuits were 100% powered by in-house generators.

In the event of a disaster, partial air conditioning and lighting were restricted.

Power was restored two days later and supplied to the entire hospital.

Power was restored two days after the earthquake.

Until then, power was provided by in-house generators (fuel stockpiles lasted 72 hours)

Water tanker (left) and water tank on the first basement floor (right)

Temporary gas pressure transmission equipment (left) and tanker truck (right)

(5) Steel damper

Situation after the Earthquake

・Plan for fatigue test

By 3/11, this hospital had already experienced two earthquakes of intensity 5 or more, and in order to check whether the heavily deformed steel damper still had sufficient energy absorption capacity, one of the eight-piece external type was removed (and replaced with a new one) and fatigue tests were conducted. Four test pieces were made, each consisting of two pieces, and the following two types of tests were conducted.

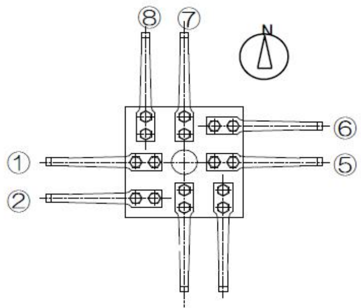
Test (1) Three pieces were given the maximum deformation amplitude of the marking plate ($\delta 1 = \pm 213$ mm in the figure below) and the number of loops until breakage was measured.

The method of evaluating low cycle fatigue of steel materials using Miner's law is well known, but this earthquake lasted a long time, and the marking plate was completely black within a radius of 80 mm because the marking lines overlapped, so three tests were conducted to accurately consider the degree of fatigue in this area.

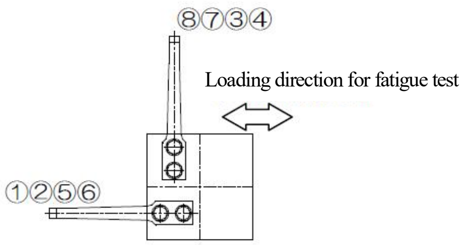
Test (2) The remaining one was given the amplitude of the design allowable deformation (49 cm) and the number of loops until breakage was measured.

The design specifications (initial performance) call for a total energy absorption capacity of "design allowable deformation (490 mm) x 10 loops," and this test was carried out to confirm whether this value was met when reused.

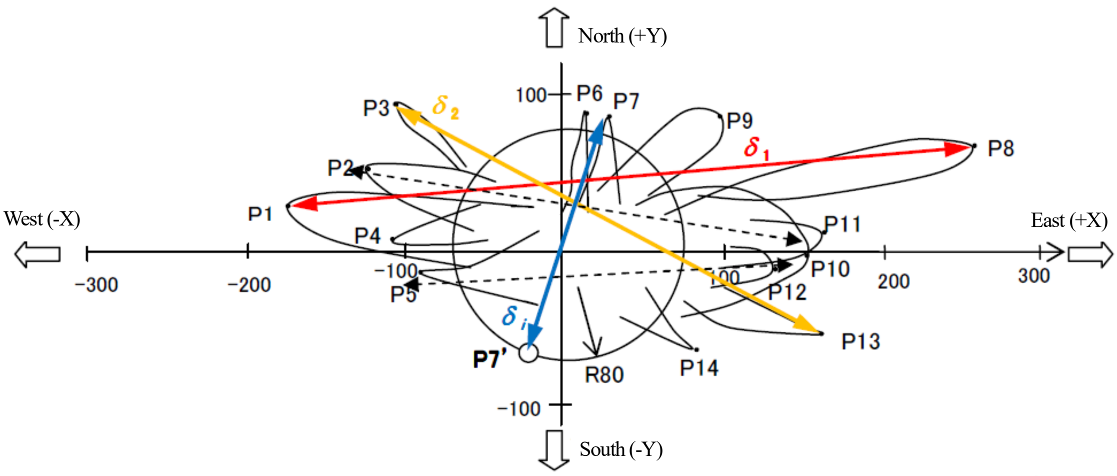
Test specimen of steel damper (removed)



Damper number Test number



Specimens such as ① + ⑧



Appearance of scratch board No. 1

・Prediction and result for fatigue test

The predicted number of fracture loops based on previous test results for test (1) ±213 mm (γt=127%) and test (2) ±490 mm (γt=292%) are shown in a separate figure.

The test results are shown in the table below.

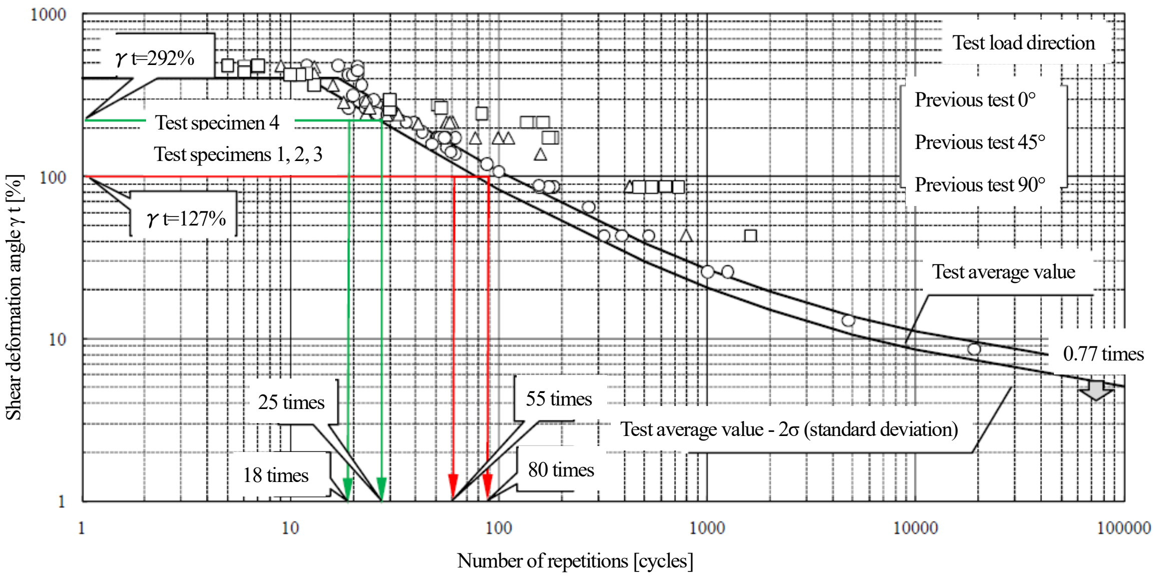
The following two points were made clear from the test results.

	Average value	Average value - 2σ	Test result	Required value (Test (2) only)
Test (1)	76 times	51 times	①76 times ②70 times ③77 times	
Test (2)	24 times	15 times	④25 times	10 times

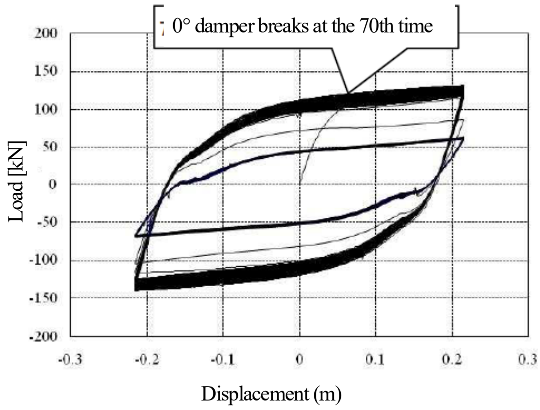
1) The degree of fatigue damage excluding the 80 mm radius part was in good agreement with the test results, so it could be said that the influence of the 80 mm radius part was small and that it was possible to adequately estimate the degree of fatigue damage by considering only large displacements.

In addition, in this test, the fatigue damage estimate was sufficiently safe even when taking into account the variation in the test results of the average value -2σ.

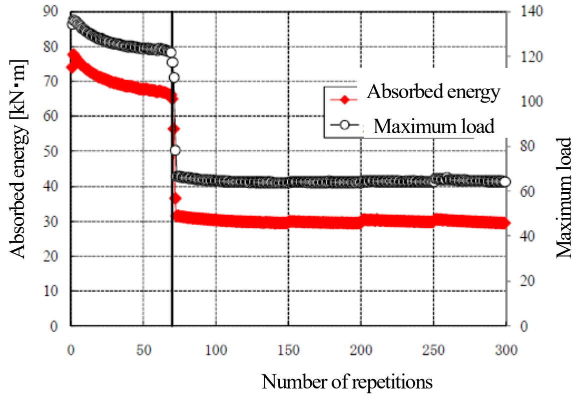
2) Although the U-shaped damper suffered fatigue damage, it met the design performance requirements and could continue to be used.



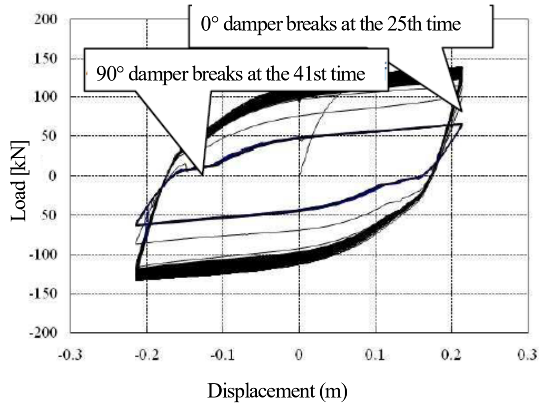
Fatigue performance curve of U-shaped damper



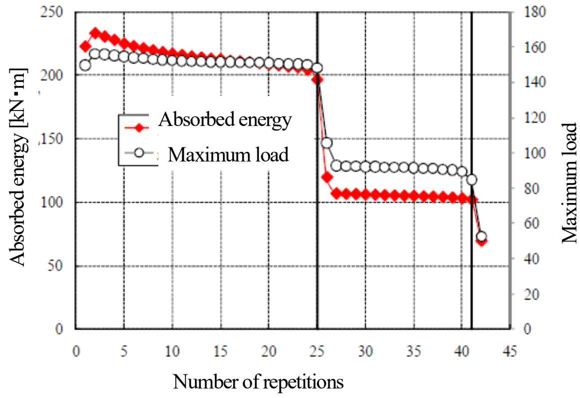
Load-displacement relationship for specimen 2



Changes in maximum load for specimen 2



Load-displacement relationship for specimen 4



Changes in maximum load for specimen 4

Top: specimen 2 with amplitude ±213mm (γt=127%), bottom: specimen 4 with amplitude ±490mm (γt=292%)

・Conclusion

The fact that damage could be significantly reduced by reducing floor response through the seismic isolation structure during a major earthquake shows that adopting a seismic isolation structure is the most realistic answer when aiming to maintain functionality after an earthquake disaster.

As a prime example of a hospital that continued to function even during a large-scale earthquake, we believe this will provide a great impetus for the adoption of seismic isolation structures in many facilities in the future.

This facility also faced many difficult situations in continuing medical activities immediately after the earthquake, but we have heard that they overcame them thanks to the enthusiasm and efforts of the people involved.

We deeply admire the efforts of all those involved in the hospital.