Table 1 A summary of the seismically isolated buildings in Kumamoto Prefecture

<table>
<tr><td>Uses</td><td colspan="3">Apartment
12</td><td colspan="2">Hospital
7</td><td colspan="2">Office or Warehouse
5</td></tr>
<tr><td>Story</td><td>1-4 stories
3</td><td>5-10 stories
6</td><td colspan="5">11-15 stories
15</td></tr>
<tr><td>Location
(City)</td><td colspan="4">Kumamoto
18</td><td>Yamaga
2</td><td>Yatsushiro
2</td><td>Others
2</td></tr>
</table>

Fig. 4 Photo of Medical Facility **M**

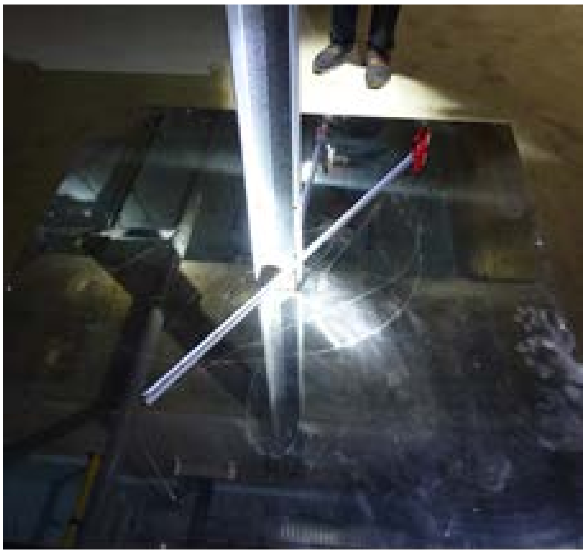

Fig. 5 Photo of scratch plate

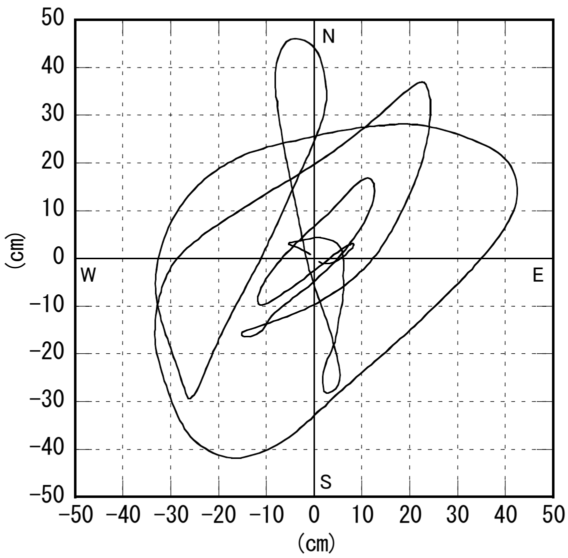

Fig. 6 Orbit recorded at Medical Facility **M**

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Table 2 A summary of the surveyed buildings

City		Uses	Built year	Structure	Story	Seismically isolation devices	Gap size (cm)	Scratch plate
Kuma-moto	**A**	Inpatient Ward	2002	SRC	13+B1	NRB,LRB,SD,CLB	50	○
			2010	SRC	13+B1	NRB,LRB,SD	50	○
		Outpatient Clinic	2006	SRC	7+B1	LRB	55	○
	B	Office	2015	S+SRC	7+B1	NRB,USD,SnRB	65	○
	C	Hotel	2002	RC	12	HDR,OD	45	
	D	Apartment	1998	RC	14	HDR	43	
				RC	11	HDR	43	
	E	Apartment	2002	RC	14	NRB,HDR	60	
				RC	14	NRB,HDR	60	
	F	Apartment	2008	RC	15	NRB,USD,LD	60	
	G	Apartment	2008	RC	13	NRB,USD,LD		
Yamaga	**H**	Medical facility	2011	RC	5	HDR	60	○
	I	Office	2014	S+CFT	5+B1	NRB,LRB,ESD,USD	60	○
Yatsu-shiro	**J**	Apartment	2008	RC	15	HDR,ESD,USD	60	(○)*1
	K	Apartment	2008	RC	14	NRB,USD,LD	55	
Kikuchi -gun	**L**	Warehouse	2013	S+SRC	2	NRB,LRB,ESD	58	○
Aso	**M**	Medical facility	2014	RC	4	NRB,LRB	50	○

*1: Valid data were not taken at this time

Structures RC: Reinforced concrete structure, S: Steel structure, SRC: Steel reinforced concrete structure, CFT: Concrete-filled steel tube structure

Seismic isolation devices NRB: Natural rubber bearing, LRB: Lead-plug rubber bearing, HDR: High damping rubber bearing, SnRB: Tin-plug rubber bearing, ESD: Sliding with elastomer, CLB: Roller bearing, OD: Oil damper, SD: Steel damper, USD: U-shaped steel damper, LD: Lead damper

Table 3 Maximum amplitudes recorded on the scratch plates

	Uses	A maximum **double** amplitude (cm)	A maximum **single** amplitude (cm)
A	Inpatient ward	60	38
	Outpatient clinic	72	41
B	Office	74	40
H	Medical facility	19	10
I	Office	16	8
L	Warehouse	50	33
M	Medical facility	90	46

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4. Effectiveness of seismically isolated buildings

The seismically isolated buildings in Kumamoto Prefecture include apartment buildings, medical facilities, accommodation facilities, offices, and warehouses. All of these buildings displayed a seismic isolation effect, and the functionality of the buildings was maintained even immediately after the earthquake. Here, from among the seismically isolated buildings that we surveyed, we describe the seismic behavior of the medical facilities and apartment buildings.

4.1 Medical facilities

The seismograph station JMA Kumamoto, located close to Medical Facility **A** in Kumamoto City, measured a seismic intensity of 6-upper during the main shock. At this medical facility, there is a mixture of seismically isolated buildings and 2 types of seismic-resistant buildings. The Japanese Building Standards Law is revised in 1981. The buildings after 1981 is called new seismic-resistant buildings, and before 1981 is called old seismic-resistant buildings. Some of the old seismic-resistant buildings sustained major damage, while the new seismic-resistant buildings sustained damage to non-structural elements and contents. Due to repair work on these buildings they were closed until the following Monday, but patients arriving at the facility were treated. There are two seismically isolated buildings, an inpatient ward building and an outpatient clinic building, within the facility. In an interview with the building manager, it was confirmed that the seismically isolated buildings were undamaged, and normal business continued without even any furniture or medical equipment falling over. Patients were not evacuated from the seismically isolated ward building. The seismically isolated clinic building was affected temporarily by water and power outages, but with external assistance and private power generation, the functionality of the hospital was maintained, and a system for accepting emergency cases was adopted immediately.

The seismograph station K-NET Yamaga, located close to Medical Facility **H** in Yamaga City, measured a seismic intensity of 5-lower during the main shock. In this facility, only the new ward building and clinic building are seismically isolated, while the waiting lounge and entrance hall are seismic-resistant buildings. The seismically isolated and seismic-resistant buildings are connected via internal expansion joints and gap covers. In an interview with the building manager, it was confirmed that none of the furniture or medical equipment in the seismically isolated buildings fell over, and normal business continued. Also, the facility accepted patients from hospitals that had sustained serious damage.

The seismograph station K-NET Ichinomiya, located close to Medical Facility **M** in Aso City, measured a seismic intensity of 6-lower during the main shock. The record on the scratch plate in the isolation level of Medical Facility **M** immediately after the foreshock showed a locus smaller than 5 mm in diameter. A single amplitude of 46 cm was recorded during the main shock, which indicates its severity. Also, the dominant period of the seismic motion measured at K-NET Ichinomiya was 3 seconds as shown in Figure 7. The seismic isolation period of the Medical Facility **M** is about 3 seconds, which is almost the same as the dominant period of the observation wave. From Figure 7, it is estimated that the maximum response deformation for a period of 3 seconds exceeds 1 m. The large difference between this and the observed deformation by the scratc plate requires investigation.

In an interview with the building manager, it was confirmed that the seismically isolated buildings were undamaged, and normal business continued without even any furniture or medical equipment falling over. Patients were not evacuated from the Medical Facility **M**. And this hospital accepted a total number of around 70,000 patients from 13 damaged hospitals with seismic-resistant structure.

A hotel with a seismic-resistant structure located about 1.4 km from Medical Facility **M** was closed after the earthquake disaster until its safety could be confirmed. A member of staff who was on the third floor of the hotel at the time of the main shock said that the building shook so violently that paper sliding doors, the shoji, in the Japanese-style room came out of place and he was very scared.

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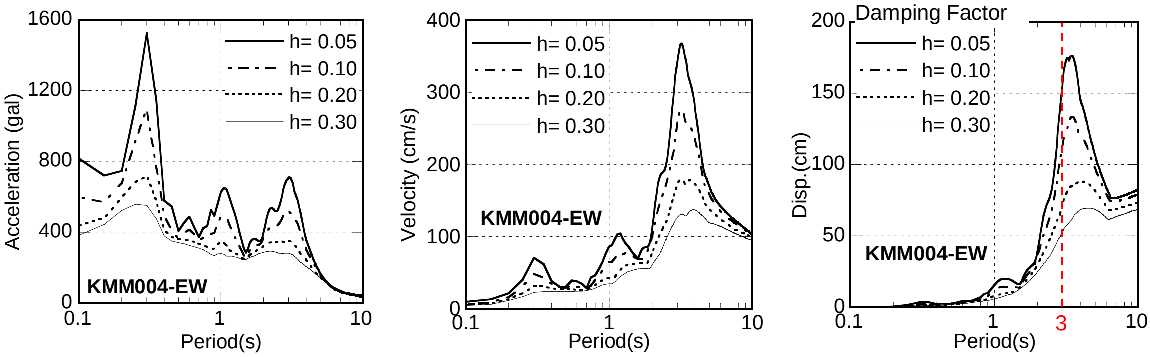

(a) Acceleration (b) Velocity (c) Displacement

Fig. 7 Response spectrum for observation record at K-NET Ichinomiya (EW component) [2]

4.2 Apartment buildings

Roughly half of all the seismically isolated buildings in Kumamoto Prefecture are apartment buildings. The first of these, Apartment Building **D**, was built in 1998. In our survey of Apartment Building **D**, we estimated that the building had moved with a maximum single amplitude of about 30 cm, but apparently none of the furniture in the rooms had fallen over. A resident told us that when they purchased their apartment, they didn't think that seismically isolated apartments were necessary in Kumamoto, but having experienced this earthquake, they were glad they had bought it. Also, the answers to a questionnaire targeting residents of seismically isolated Apartment Building **F**, a 15-story reinforced concrete structure also located in Kumamoto City, showed that the residents were satisfied with the performance of the structure—for example, furniture did not fall over, even slender cosmetic products that were standing up, everyday life could carry on as normal because essential utilities were not cut off, and relatives living nearby came to take refuge.

Yatsushiro City, away from the hypocenter, also has some seismically isolated apartment buildings. The seismograph station K-NET Yatsushiro measured a seismic intensity of 6-upper. A resident living on the top floor of Apartment Building **J** said that it felt as though the building swayed slowly for a long time during the main shock, but no furniture fell over and no damage was done to the superstructure, and they were able to continue living in the building without any problems. At a nearby 10-story accommodation facility with a seismic-resistant steel reinforced concrete structure, guests had to wait outside after the main shock until dawn when safety checks were finished.

Also, the answers to a questionnaire targeting residents of seismically isolated Apartment Building **K** in Yatsushiro City showed that 88% of residents knew that the building was seismically isolated, and 94% thought that the seismic resistance of the seismically isolated buildings was superior to that of conventional buildings during the Kumamoto earthquakes. The majority of the answers indicated that although the residents felt a bit scared by the slow swaying of the building during the main shock, they were able to continue living in the building without any problems, and they had come to realize the superiority of the seismically isolated structure.

5. Future works

The Kumamoto earthquakes revealed several problems. In almost all of the buildings, we found that the expansion joints and gap covers connecting the seismically isolated building with seismic-resistant buildings were deformed. Figure 8 shows a deformed gap cover. During an earthquake, the expansion joints move without interfering with the movement of the seismically isolated building. However, when they are subject to large forces or move more than expected, the expansion joints and the gap covers may become deformed, although this does not impair the performance of the seismically isolated building. During the Kumamoto

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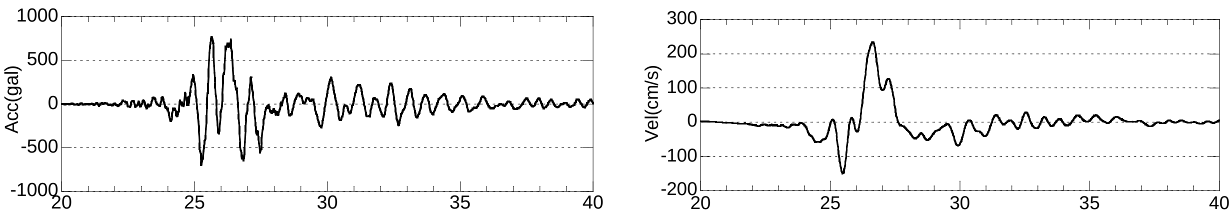
earthquakes, some of the joints showed greater deformation than expected, but there were no problems in terms of use.

Compared to when seismically isolated structures first started to be employed in buildings, the gap covers installed near building entrances have become more sophisticated. They allow completely barrier-free access, and recently many are designed to make it look as though the building is not seismically isolated at all. However, some of the expansion joints and gap covers appeared to have suffered excessive deformation due to a lack of consideration by the designers, who appeared to have forgotten that "during an earthquake, there will be relative movement between the seismically isolated building and the ground surface or the seismic-resistant building."

In the Kumamoto earthquake, long-period ground motion was observed in Nishihara Village. Figure 9 shows the recorded waveform. Looking at the velocity waveform, a pulse-like waveform with a period of 3 seconds can be seen. The maximum velocity is over 200cm/s. Recently, the response evaluation of long-period ground motions in high-rise buildings and seismically isolated buildings has become an issue in Japan. In general, large subduction zone earthquake and moderate to large crustal earthquake can generate far-source long-period ground motions in distant sedimentary basins. However, in the Kumamoto earthquake near-fault long-period ground motions [4] are generated. When such ground motion is input to a seismically isolated building, the response deformation of the isolation layer becomes very large. Measures for that are also required. Research on the generation mechanism of long-period ground motions and suppression of response of seismically isolated buildings is also needed.

Fig. 8 A deformed gap cover



(a) Acceleration wave (b) Velocity wave

Fig.9 Observed earthquake records (EW-dir.) at Nishihara Village

6. Conclusions

Seismically isolated buildings fully exhibited their function during the Southern Hyogo Prefecture Earthquake in 1995, the Fukuoka Prefecture Western Offshore Earthquakes in 2005, and the Tohoku Region

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Pacific Coast Earthquake in 2011. The Kumamoto earthquakes revealed some future work to be done, but the seismically isolated buildings could continue to be used immediately after the earthquakes, with no loss of building functionality. We confirmed that the users and managers of the seismically isolated buildings were fully satisfied with the performance of the buildings.

Unfortunately, seismometers were not installed in the seismically isolated buildings surveyed in this study. Also, scratch plates were not installed in most of the apartment buildings. Measurements from seismometers are useful for confirming the soundness of seismic isolation devices after an earthquake. If installing a seismometer is difficult, a scratch plate should be installed at the very least. The scratch plate records confirm the movement of the isolation level during an earthquake, and then provide a benchmark for reconfirming the soundness of the seismic isolation device. After the Kumamoto earthquakes, the amount of deformation of the seismic isolation devices in the seismically isolated buildings with scratch plates installed was confirmed based on the scratch plate records, and the buildings were quickly evaluated to be safe to continue using. The judgment could be made with reference to experimental data accumulated in the past, rather than just a superficial visual check. Also, the accumulation of these kinds of records stored every time an earthquake occurs is expected to help in improving the performance of seismically isolated buildings.

Promoting the use of seismically isolated structures that exhibit high safety and maintain their functionality during earthquakes is considered to be an effective way of reducing earthquake damage. However, the earthquakes observed recently have gradually come to be larger than before, and it is important that sufficient allowances are also made in the design of seismically isolated structures.

7. Acknowledgements

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