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RELATIONSHIP BETWEEN STRONG MOTION AND DAMAGE TO HOSPITALS IN THE 2004 NIIGATA-KEN CHUETSU EARTHQUAKE IN JAPAN

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ABSTRACT

The present paper is focused on the damage to hospitals in the 2004 Niigata-ken Chuetsu Earthquake in Japan. Health care facilities such as hospitals carry great importance and principally following a disaster. The function of hospitals after an earthquake depends on many factors such as structural damage, lifeline damage, lack of staff, lack of medicine and others. Investigation of the relation between strong motion and damage to each component of a hospital during a large earthquake is necessary for evaluating the seismic performance of life saving facilities. A questionnaire survey was conducted for the hospitals suffering damage due to the 2004 Niigata-ken Chuetsu Earthquake. The damages to each component such as structures, lifelines, instruments and so on in the hospital were investigated. The relation between strong motion and damage to each component was also studied.

Introduction

An earthquake with a magnitude of 6.8 occurred in the Chuetsu region of Niigata Prefecture in Japan on October 23, 2004 at 17:56 (local time). The earthquake caused the loss of 46 lives and injured approximately 4,800 people. The earthquake had unusual after shock activity and at least four large after shocks with a magnitude greater than 6.0 occurred. Many rock and soil slope failures took place, particularly in the mountainous area and along Shinano River. The permanent ground deformation as well as ground shaking caused some structural damage to residential houses, buildings, bridges, road, highways, railways and lifelines.

Health care facilities such as hospitals carry great importance and principally following a disaster. The function of hospitals after an earthquake depends on many factors such as structural damage, lifeline damage, lack of staff, lack of medicine and others. We carried investigations to 40 hospitals to find out the damage that was found after the earthquake. The relation between malfunction of the hospital and damage to each component such as structures, lifelines, instruments and so on was investigated. The relation between strong motion and damage to each component was also studied.

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Outline of Investigation

The investigation was done through a questionnaire survey, sent by postal mail, and visits to some of the facilities. It concerned damage to structure, equipment and furniture, medical equipment and lifeline. Table 1 points in detail to the parts that were considered in the investigation. The investigation was also concerned with the age of buildings and the number of floors. The last points up more than 42% of them have four to six floors. Among the 40 facilities, at least 26 hospitals, which represents 65% of the total number, have emergency services. More than half of the facilities are classified as 2nd class emergency hospitals.

Damage to Health Care Facilities

Relation between seismic intensity and damage

The earthquake caused damage to at least 27 hospitals, which varied between very severe and slight damage. The minimum intensity registered at the site of the facilities was 5^- (Japanese Meteorological Agency seismic intensity scale) while the maximum registered intensity was 6^+. Fig. 1 illustrates that the majority of the facilities suffered intensity 5^- and 6^-. At least 5% of the facilities suffered problems to their entrances, balconies and some of their equipment was displaced and even turned over in some cases. In more than 10% of the facilities there were some cracks in their external and internal walls. Further more, several facilities suffered damage to their lifelines, internal installations and medical equipment, see Tables 2 and 3, respectively for more detail. It should be mentioned that in these tables the sign "●" indicates that the ratio of facilities suffering that type of damage exceeds 10%. While the sign "○" indicates that at least 5% of the facilities have experienced that type of damage. As these tables illustrate, the intensity 6^+ caused damage to all investigated elements in more than 10% of the facilities.

Estimation of peak ground acceleration

We estimated the peak acceleration at each facility and compared it to the damage in each case. The calculation of the peak ground acceleration was completed according to Eq. 1. In the estimation of the peak ground acceleration (in cm/sec^2), the magnitude, *M*, and the hypocenter distance, *X*, (in km) should be provided.

$$\log A = aM - \log X + bX + c \qquad (1)$$

Where *a*, *b* and *c* are regression coefficients. To be able to estimate the acceleration at each facility the regression coefficients should be found. A multiple regression analysis was employed by using data of the main shock and seven aftershocks (Nebil et al. 2005).

Damage to the structural element

The external walls of various facilities began experiencing cracks at an acceleration of less than 200cm/sec^2. Concrete started to peel off at about 300cm/sec^2 as shown in Photo 1. Facilities built before 1970 had the reinforcement of their walls exposed as shown in Photo 2, while those built between 1971 and 1980 did not suffer more than the peeling off of their concrete. Newly built structures did not experience severe damage; only some cracks were found in three facilities. The situation of internal walls was not very different from the external ones; see Photo. 3. Pillars withstood more than walls as the majority of them did not suffer a lot of damage. However, for facilities built before 1970, the reinforcements were exposed. The state of ceilings and flooring was not very different from the main structure, as both elements suffered slight damage to falling and cracks to peeling off of the concrete respectively; see Photo 4.

Relation between damage to lifeline and peak ground acceleration

The investigation showed that lifelines started to experience problems from 150-250cm/sec^2. A

150cm/sec^2 acceleration was able to render some hospitals without electric power for about two days, while an acceleration of 750cm/sec^2 caused the loss of the electric power for six days, see Fig. 2. Due to the fragility of the piping system, water and gas supplies was damaged more than the electric power system.

Table 1. Aspects to be checked during the investigation.

Elements			Contents
Building	Interior	Wall	Cracking of concrete and facing/peeling Reinforcement exposure
		Window - glass	Glass cracks/break up, sash deformation Window difficulties/failure of opening/closing
		Entrance/Exit	Deformation/failure of door, glass cracks, Door difficulties/failure of opening and closing
	Exterior	Pillar/Wall	Cracking/peeling off/reinforcement exposure of concrete/facing
		Door	Deformation/failure of the door, glass cracks, Difficulty/failure of opening and closing of door
		Ceiling	Slipping of ceiling board/falling
		Floor	Tiles cracking/peeling off
		Furniture	Furniture displacement/turning over Television/glassware displacement/turning over
Lifeline and Equipment		Lifeline supply	Electric, water supply, gas, communication, laundry, kitchen
		Electric installation	Damage/falling of illumination
		Plumbing equipment	Sink damage, rest room unserviceable, toilet damage Wall tile peeling off, piping damage
		Air-condition equipment	Breakdown and exit cone damage of air conditioning machine, Damage to piping system
		Equipment attached to roof	Air conditioning/elevated tank unit turning over/displacement End of piping
		Anti-disaster equipment	Damage of sprinkler/erroneous operation Opening/closing difficulty of fire door, damage of fume tight flap wall
		Transport equipment	Stop of elevator/breakdown
Medical elements		Inspection equipment	X-Ray/Film development units, CT Scanner, MRI
		Remedy/Disposal equipment	Washing of scar, CSR unit life support system Artificial dialysis, operation execution
		Medication	Medical supply, diagnosis and treatment units, nurse call Chemical shelves/containers turned over/damaged
		Medical space	Ward, clinic and examination room Operation room, preparation room and material room

Table 2. Lifeline damage experienced in facilities.

Damaged element	Seismic intensity (JMA)			
	5-	5+	6-	6+
Lifeline				
Failure of power	●	●	●	●
Suspension of water supply		●	●	●
Cut off of gas supply	●	●	●	●
Difficulties to use landline phone	●	●	●	●
Difficulties to use mobile phone	●	●	●	●
Laundry facilities could not be used	●	●	●	●
Kitchen could not be used	●	●	●	●

Table 3. Medical equipment damage experienced in facilities.

Damaged element	Seismic intensity (JMA)			
	5-	5+	6-	6+
Inspection equipment				
Inoperability of X-Ray unit		●	○	●
Inoperability of film development unit		●	●	●
Inoperability of blood test unit	○	●	○	●
Inoperability of CT Scanner	○	●		●
Inoperability of MRI unit	●		●	●
Inoperability of blood vessel contrast and Cardiac Catherisation units				●
Remedy and disposal equipment				
Inoperability of scar-cleaning unit				●
Inoperability of CSR unit		●	●	●
Inoperability of life support system		●		●
Inoperability of artificial dialysis			●	●
Inoperability of general remedy and medical examination			○	●
Inoperability of operation room			●	●
Medication in addition				
Inoperability of automatic amount package machine	○	●		●
Inoperability of medical supply and the diagnosis and treatment material		●	○	●
Inoperability of nurse calling system	●	●	●	●
Inoperability of chart compilation				●
The chemicals shelf turned over	○	●	●	●
container for the chemicals broke down		●	●	●
Use of medical space				
Ward (patients rooms) could not be used			●	●
Clinic could not be used				●
Examination room could not be used				●
Operation room could not be used			●	●
Preparation room could not be used				●
Material room could not be used				●

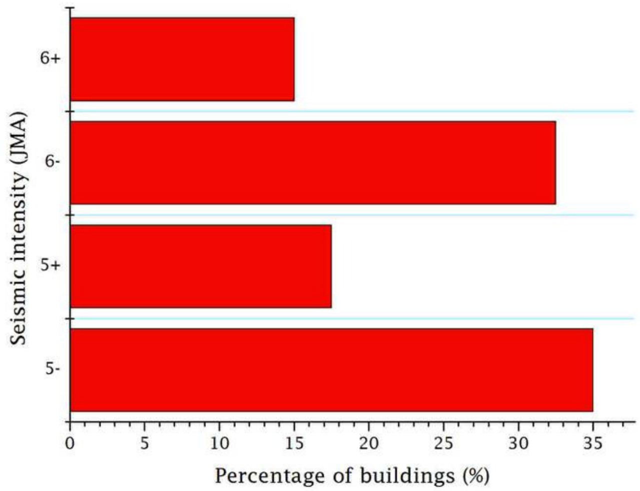

Figure 1. Proportion of buildings and the seismic intensity.

Photo 1. Exterior wall peeled off, Ojiya Hospital.

Photo 2. Exposure of reinforcement, Ojiya Hospital.

Photo 3. Interior wall peeled off, Ojiya Hospital.

Photo 4. Damage to ceiling, Ojiya Hospital.

The shortage of water and gas was up to 18 days. An acceleration of 200cm/sec^2 caused a 2-day period of shortage; while higher acceleration can cause the shortage period longer, see Figs. 3 and 4.

Relation between medical situation and peak ground acceleration

Obviously, the earthquake affected the situation of medical services. That effect was a reduction in space that is available and/or damage to the equipment. Fig. 5 illustrates that an acceleration of 300 cm/sec^2 is able to reduce 20% of the space in a facility; and an acceleration of 800cm/sec^2 can cause the loss of 80% of the space. It has to be mentioned that the condition can be improved if the response of equipment is studied and some measures are considered. The equipment can be affected by an acceleration of 200-300cm/sec^2; Figs. 6 and 7 show that it can reach the 100% in some cases, 40% in others and 0% in different occurrences. The difference of results is due to the preservation of those equipments which differs from a facility to another.

Conclusions

The present study is focused on the damage to health care facilities in the 2004 Niigata-ken Chuetsu Earthquake in Japan. A questionnaire survey was conducted for the hospitals suffering damage by the earthquake. The damages to each component such as structures, lifelines, instruments and so on in the hospital were investigated. The relation between strong motion and damage to each component was also studies. The following conclusions are made from the study.

(1) The external walls of various facilities began undergoing cracks at an acceleration of less than 200cm/sec^2. Concrete was peeled off from about 300cm/sec^2. Facilities built before 1970 had the reinforcement of their walls exposed. While those built between 1971 and 1980 did not suffer more than the peeling off of their concrete. Newly built structures did not experience severe damage; only some cracks were found in three facilities.

(2) The situation of internal walls was not very different from the external ones. Pillars withstood more than walls as the majority of them did not suffer a lot of damage. However, for facilities built before 1970 the reinforcements were exposed. The state of ceilings and flooring was not very different from the main structure.

(3) The investigation showed that lifelines start experiencing problems from 150-250cm/sec^2. A 150cm/sec^2 acceleration was able to render some hospitals without electric power for about two days, while an acceleration of 750cm/sec^2 caused the loss of the electric power for six days. An acceleration of 200cm/sec^2 caused a 2-day period of shortage of water and gas; while higher acceleration can cause the shortage period to be longer.

(4) An acceleration of 300 cm/sec^2 is able to reduce 20% of the space in a facility; and an acceleration of 800cm/sec^2 can cause the loss of 80% of the space. It has to be mentioned that the condition can be improved if the response of equipment is studied and some measures are considered.

(5) The equipment can be affected by an acceleration of 200-300cm/sec^2. However the results had large variety in each facility. The difference of results is due to the preservation of those equipments which differs from a facility to another.

Acknowledgements

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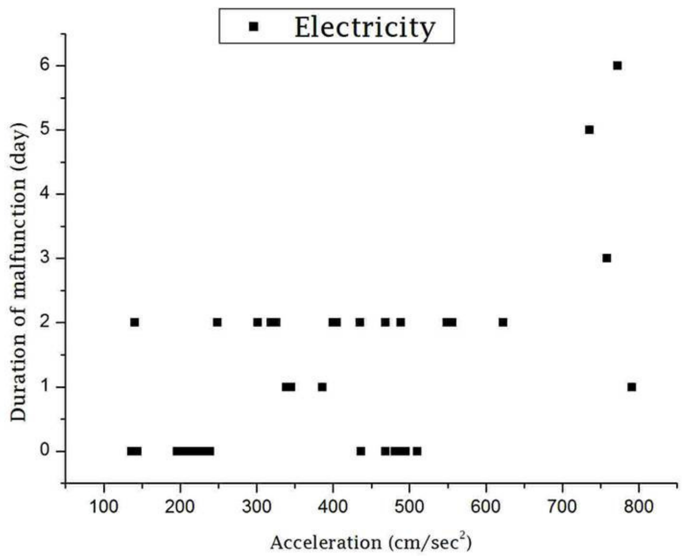

Figure 2. Duration of malfunction of electric power.

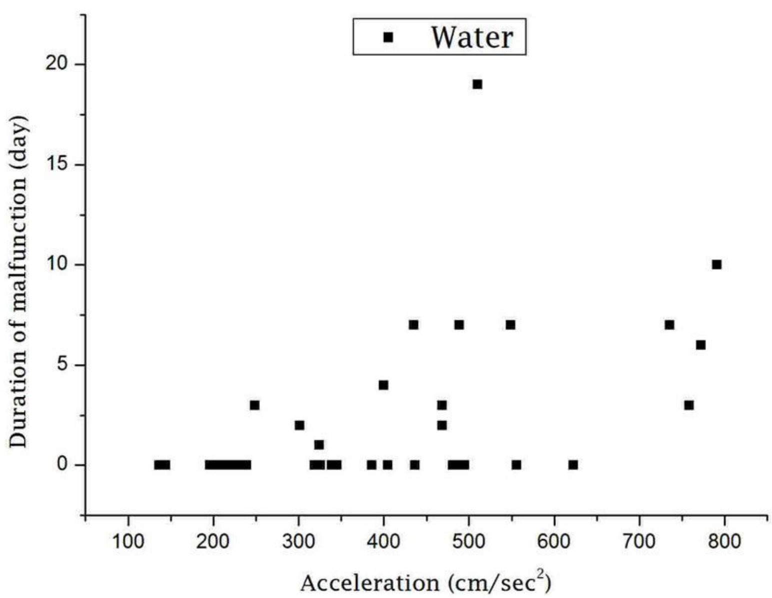

Figure 3. Duration of water supply shortage.

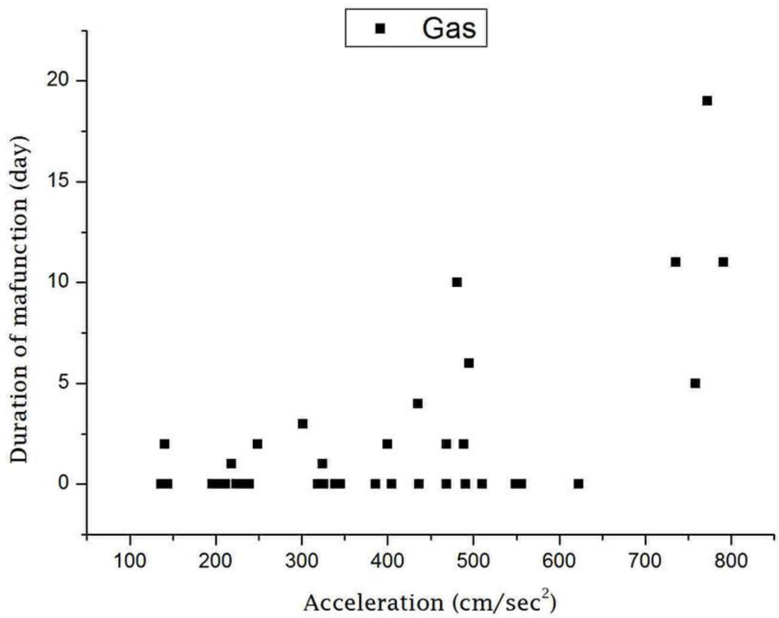

Figure 4. Duration of malfunction of gas supply.

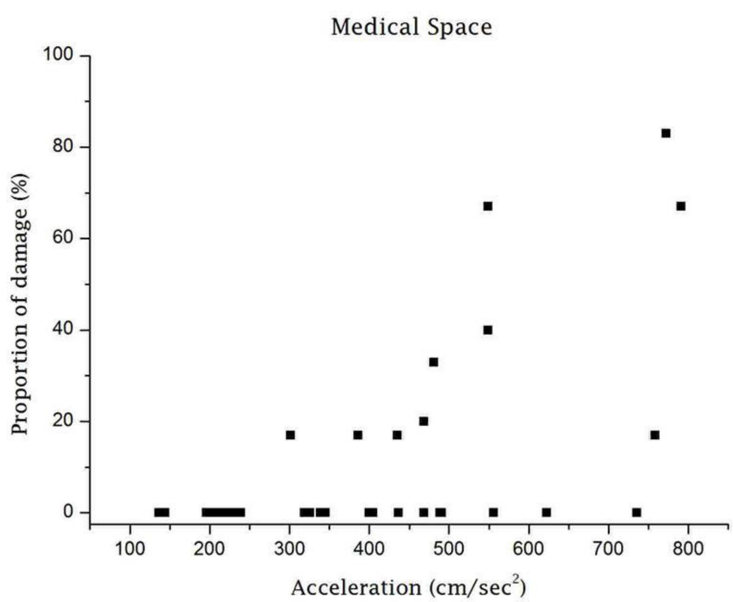

Figure 5. Relation between availability of space and peak ground acceleration.

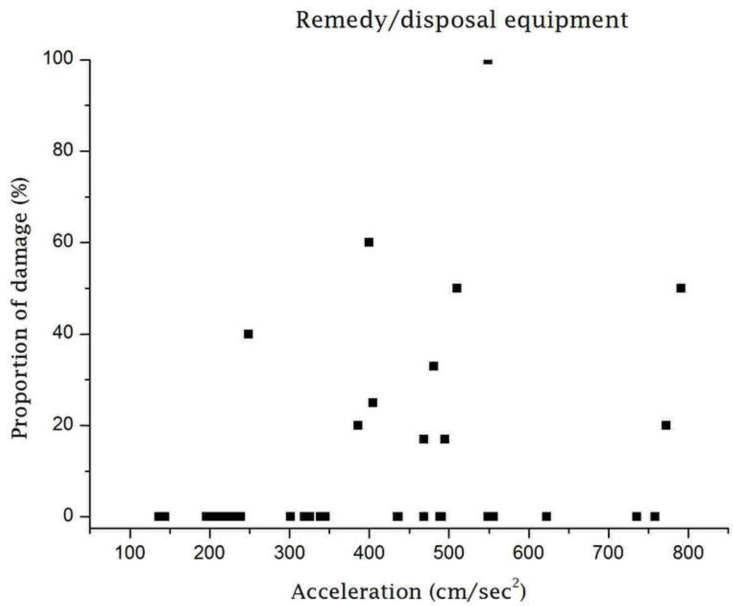

Figure 6. Relation between damage to remedy and disposal equipments and peak ground acceleration.

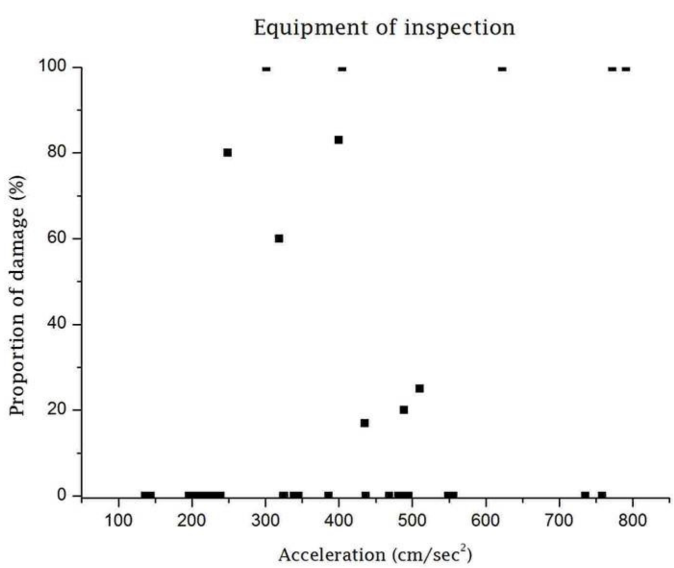

Figure 7. Relation between damage to equipment of inspection and peak ground acceleration.