HEARING AND ANALYSIS OF HOSPITAL EVACUATION AFTER THE 2016 KUMAMOTO EARTHQUAKE

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ABSTRACT

In 2016 Kumamoto earthquake with MJMA of 7.3, 16 hospitals in the severely-affected areas decided to take the action of hospital evacuation. This action involves all inpatient transported to hospitals outside the affected areas or own houses. Kyoto iMED (Kyoto informatics-Medicine-Engineering research against Disaster) formed a multi-disciplinary team and conducted hearing surveys at ten hospitals in Kumamoto. The team included structural engineers, emergency physicians (also members of DMAT), a clinical engineer, a medical information engineer, and a hospital facility staff. The survey items were 1) damage to structure and non-structural component, 2) resource supply including damage level to building and regional infrastructure; 3) damage to medical equipment, 4) operation of electric cart system; 5) emergency response and decision-making process; 6) pre- and post-earthquake building diagnosis; 7) reoccupation. The preliminary analysis of the survey results revealed that the primary reasons for deciding hospital evacuation could be categorized into three: a) concern on structural safety (5 facilities), b) damage to facility water system (5 facilities); and c) stop of regional water supply (4 facilities). Note that four hospitals answered multiple reasons. Notably, the nine out of ten hospitals made decision of evacuation within 24 hours and there was no time to wait for the post-earthquake rapid inspection by registered structural engineers. As previous studies on hospital damage in earthquake events reported, water shortage was critical to medical services. The survey showed various possible failure mode of the water infrastructure in the hospital buildings.

Keywords: Medical function, Hospital evacuation, 2016 Kumamoto earthquake, Non-structural damage, Decision-making

1. INTRODUCTION

Natural disasters including seismic events interrupt demand-supply balances in medical facilities with rapidly increasing out-patient medical services and functionality decreases due to the damage to hospital buildings, infrastructure and equipment, and disturbance to the basis of employees’ livelihood. In this context, the extensive surveys on structural and nonstructural damage including medical equipment have been reported following each major seismic event, and their classification and prioritization in hospitals based upon their impacts on medical services have been attempted [e.g., Myrtle et al, 2005; Chapin et al, 2010; Achor et al, 2011; Mitrani-Reiserm, et al 2012; Tovaranonte and Cawood, 2013].

In Japan, 2011 Tohoku earthquake resulted in among 380 hospitals and clinics in Iwate, Miyagi and Fukushima prefectures, 11 severely damaged or collapsed, 289 damaged, 45 closed outpatient clinic, and 84 stopped

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activities and economy in the structure; one of those affected; conducted hearing surveys 3) damage to medical equipment, 4) operation of electric card system; 5) emergency response and decision making process; 6) pre- and post-earthquake building diagnosis; 7) reoccupation. The multi-disciplinary team conducted hearing surveys on 18 to 19 October 2016 at ten hospitals in Kumamoto.

2. SURVEY PLANNING

Kyoto iMED formed a multi-disciplinary team and conducted hearing surveys at ten hospitals in Kumamoto. The team included structural engineers, emergency physicians (also members of DMAT), a clinical engineer, a medical information engineer, and a hospital facility staff. The survey items were 1) damage to structure and non-structural component; 2) resource supply including damage level to building and regional infrastructure; 3) damage to medical equipment; 4) operation of electric card system; 5) emergency response and decision-making process; 6) pre- and post-earthquake building diagnosis; 7) reoccupation. The paper mainly covers the items related to structural engineering.
2.1 Surveyed Hospitals

A half year after the mainshock on October 18-19, 2016, Kyoto iMED conducted a hearing survey at ten hospitals that experienced hospital evacuation. Some of the hospitals have restarted in-patient and/or out-patient medical service and the rest were remained closed to due to severe damage to the facility buildings. At this period, the medical system in the earthquake-hit region have already regained most of functionality and order.

Figure 1 shows the locations of the hospitals and their geometrical relations with the estimated epicenters and fault lines. The hospitals include psychiatric hospitals, dialysis hospitals, and general hospitals (Table 1). The nearby seismic stations and the recorded PGA are also listed in Table 2. The size of the hospitals ranged from a private one with 47 beds to a public one with 556 beds. The PGA and PGV at the hospital sites are estimated using the estimated PGA and PGV distribution map for the mainshock on April, 16, 2016 based on the records in seismological stations of K-NET and KiK-net, nationwide strong seismograph networks in Japan [Suzuki et al, 2017]. For reference, the ground motion levels for the allowable stress design limit and ultimate strength limit stipulated by the Building Law of Japan, close to the serviceability and safety limits in ASCE 7, are 25 cm/s and 50 cm/s; the low-to-mid-rise buildings are normally are designed normally without time history analysis using the minimum seismic base shear coefficient of 0.2 for the elastic design limit and 1.0 for ultimate strength limit with the appropriate structural characteristics factors (similar to the reciprocal of strength reduction factors). Note that hospital buildings may be designed with the importance factor of 1.5 depending on the size and type of the hospitals.

![Figure 1 Surveyed hospitals with estimated epicenters.](image)

<table>
<thead>
<tr>
<th>Hospital</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type*</td>
<td>P</td>
<td>C</td>
<td>G</td>
<td>P</td>
<td>G</td>
<td>D</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beds</td>
<td>198</td>
<td>47</td>
<td>203</td>
<td>308</td>
<td>556</td>
<td>210</td>
<td>177</td>
<td>52</td>
<td>38</td>
<td>178</td>
</tr>
<tr>
<td>PGA (cm/s²)</td>
<td>920 &lt; 460-</td>
<td>920</td>
<td>920</td>
<td>920</td>
<td>920</td>
<td>920 &lt; 920 &lt; 920 &lt; 460-</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>PGV (cm/s)</td>
<td>100 &lt; 50-100</td>
<td>50-100</td>
<td>50-100</td>
<td>50-100</td>
<td>100 &lt; 100 &lt; 100 &lt; 50-100</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*Note: P, C, G and D denote psychiatric, care, general, dialysis, respectively.

<table>
<thead>
<tr>
<th>Station</th>
<th>K</th>
<th>L</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site code</td>
<td>KMMH16 (Mashiki)</td>
<td>KMM006 (Kumamoto)</td>
<td>KMM003 (Otsu)</td>
</tr>
<tr>
<td>PGA (cm/s²)</td>
<td>1362.1</td>
<td>843.4</td>
<td>669.3</td>
</tr>
</tbody>
</table>
Figure 2 shows the ages and structural types of the hospital buildings upon on survey data. The black bar indicates building built with the old Japanese building code, and the gray bar indicates building built with the new building code. In Japan, the amendment of the building standard law in 1981 had significant impact on building design and performance, and buildings constructed before 1981 requires seismic diagnosis. In the figure, structure classification is reinforced-concrete unless indicated. As indicated in the figure, more than a half of the surveyed hospitals had at least one building constructed prior to 1981.

2.2 Survey Items

The survey team included structural engineers, emergency physicians (also members of DMAT), a clinical engineer, a medical information engineer, and a hospital facility staff, aiming to collect data for holistic assessment on the anti-disaster capacity of medical facilities. The survey items were 1) overall condition after the foreshock and main shock, respectively, 2) process of hospital evacuation, 3) building and equipment damage, 4) preparation and enforcement of disaster countermeasures, 5) operation of electric cart systems, and 6) lessons learned from the earthquake.

Table 3 shows the details of the survey items 1) to 3), which are closely related to structural engineering. The item 1) included damage to regional infrastructures and its influence on hospital practice, post-earthquake continuity of medical service, restoration of hospital function. The item 2) included circumstances leading to hospital evacuation and patient transfer. The item 3) included damage to building, damage to building and medical equipment, and structural resistance.
Table 3 Survey items

1) **Situation of hospital after foreshock and mainshock**
   - Damage to regional infrastructures and its influence on hospital practice
     - Lifeline supply: electricity, gas, water, and network system.
   - Post-earthquake medical service
     - Treatment to inpatients and outpatients.
     - Medical demand in comparison with peacetime.
   - Restoration of hospital function
     - Required time or period to restore each hospital function level: outpatient service, inpatient service, and all function.
     - Situation and reason why you could decide to restart these hospital function.

2) **Hospital evacuation**
   - Circumstances leading to hospital evacuation
     - Decision making: primary reasons, damage situation, decision makers, required time for decision making.
   - Patient Transfer
     - Explanation to patients, and their families.
     - Required time to transfer patients, conveyance way and troubles.
     - Present situation and returns of patients who evacuated.

3) **Condition of hospital buildings**
   - Damage to building
     - Structure classification, number of floors, floor space, and age of the buildings.
     - Did/will you restore to the original state or make any changes?
   - Damage to equipment
     - Pipeline of electricity, gas, water, and network system.
     - Medical equipment and its setting condition.
   - Structural resistance of buildings
     - Pre- and post-earthquake seismic diagnosis result.

3. **SURVEY RESULTS**

3.1 **Primary Reasons of Hospital Evacuations**

The primary reasons for deciding hospital evacuation could be categorized into three: a) concern on structural safety, b) damage to facility water system, and c) suspension of regional water supply (Table 4). The primary reason for Hospital A to E was the concerns on structural safety, for Hospital F to I water shortage and for Hospital J a strong request by a local authority. A half of the hospitals answered multiple reasons that likely means there were no critical source of information leading to distinct decision.

<table>
<thead>
<tr>
<th>Primary reasons</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concern on structural safety</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Water shortage</td>
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<tr>
<td>Damage to facility water system</td>
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<tr>
<td>Stop of regional water supply</td>
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<td></td>
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<tr>
<td>Pre-EQ diagnosis result*</td>
<td></td>
<td></td>
<td>P</td>
<td>U</td>
<td>P</td>
<td>O</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note that O indicates that the buildings have no problem, where P indicates that the buildings have problem, and U indicates that the diagnosis had not been completed before the earthquake.
3.2 Concerns on Structural Safety

The buildings of hospitals A to E, which decided hospital evacuation because of concerns on structural safety, were relatively old (see Figure 2). Besides, these hospitals did not undergo seismic performance diagnose or the buildings were evaluated as seismically-deficient (Table 4). The concerns on structural safety may have increased with the successive strong ground motions by the foreshock and the main shock. Large size hospitals such as disaster-base hospitals had stationed facility staffs but most of the hospitals did not. Thus, in the most cases, the decision was made by the medical doctors and hospital owners based of the rapid screening by hospital workers including medical doctors, hospital staffs and nurse. A few hospital owners answered that they asked local constructors for advises but without following official rapid inspection procedure.

3.3 Water shortage

Hospitals F to I decided to take hospital evacuation because of water shortage after the foreshock. As characteristics of hospital, a large amount of water is required to continue medical services. Concerns on sanitation and infectious diseases were also reported. Thus, water shortage is critical to medical service continuity. Notably, Hospital I that specializes in dialysis, immediately decided hospital evacuation soon after the foreshock.

The survey showed various possible failure mode of the water infrastructure in the hospital buildings, including the rocking and overturning of a roof-top water tank, dislocation of connections to a water tank and a piping, dislocation of connections nearby sprinkler system, contamination of well water due to ground shaking, and so on. Figure 3 shows the photos of a damaged water receiving tank.

![Figure 3](image)

Figure 3 Damage to water supply equipment: a) fracture of water receiving tank in Hospital E (after Hospital E’s report) and b) overturning of a roof-top water tank on Hosp. B (returned to original position after the mainshock).

3.4 Guidelines for Hospital Evacuation

All hospitals answered that there were no guideline and training for hospital evacuation against seismic disaster but those limited to fire evacuation drill. Although, the WHLW urged preparation of disaster response plans to disaster-base hospitals in 2013 [WHLW, 2013], two disaster-base hospitals visited during the survey, one evacuated and the other not, did not have such response plan; it is now mandatory to disaster-base hospitals to prepare such a plan by March, 2019. Considering the high seismic activities and the predicted extreme earthquakes in Japan, the preparedness was not high compared to the case of California state, USA where hospital evacuation decision guide has been prepared and enforced by the governmental agency (Zane, 2010).

3.5 Medical Equipment Damage
There were some damages of medical equipment reported including console-type dialyzer and CT machine. Compare to the previous earthquakes such as 1995 Kobe, the damage to medical equipment was relatively small. The part of the reasons was likely that there were no hospitals equipped with precision mechanical equipment in the severely damaged area nearby the faults. For reference, the Kyoto iMED team has conducted a shake table testing of medical equipment in dialysis department and NICU using a strong ground motion recorded in the Mashiki area. Even with a half-scale motion, significant dislocation and rocking behavior was observed for the equipment with caster-free and caster-lock conditions, respectively. The test data is currently under investigation.

3.6 Post-earthquake diagnosis results

Although five hospitals decided evacuation with concerns on structural safety, the post-earthquake diagnosis actually concluded that the four out of the five hospitals sustained limited damage and were safety to reoccupy (Table 5). The decisions were mostly based on the visual inspection of buildings by the hospital owners and staffs without structural engineers. Consequently, they tended to decide the evacuations according to the underlying concerns on structural safety of the buildings and visually severe damages, which did not affect structural safety indeed (Figure 4).

<table>
<thead>
<tr>
<th>Damage Evaluation</th>
<th>Hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post-EQ rapid inspection</td>
<td>A</td>
</tr>
<tr>
<td>Post-EQ detailed damage evaluation</td>
<td>Half collapse</td>
</tr>
</tbody>
</table>

Table 5 Post-earthquake diagnosis results.

(a) cracks on a wall of Hosp. A and (b) fracture of an expansion joint of Hosp. H.

3.7 Time Required for Decision Making

The nine out of ten hospitals made decision of evacuation within 24 hours (Figure 5). The quickest case was only 15 minutes. Hospital C required 30 hours to decide complete evacuation, but they evacuated their patients to outside a hospital building in 5 minutes when the main shock occurred. There were no times to wait for the post-earthquake rapid inspection by registered structural engineers. Similar findings have been reported in the survey on hospital evacuation during Northridge earthquake where eight of 91 acute care hospitals (9 percent) were evacuated [Schultz, 2003]; six hospitals evacuated patients within 24 hours (the immediate-evacuation group), four completely and two partially; all six cited nonstructural damage such as water damage and loss of electrical power as a major reason for evacuation.
Figure 5 Time required for decision makings. Note that the required time in Hospitals A to E and J are elapsed times from the main shock, and in Hospital F to I are from the foreshock.

4. CONCLUSIONS

The Kyoto iMED team conducted a field survey at ten hospitals that experienced hospital evacuation in 2016 Kumamoto Earthquake. The main findings are:

1) The primary reasons for deciding hospital evacuations were: a) concerns on structural safety, b) damage to facility water system, and c) stop of regional water supply.
2) The four out of the five hospitals, which selected hospital evacuation because of the concerns on structural safety, actually sustained limited damage and were safe to reoccupy according to post-earthquake diagnosis results.
3) Most hospitals decided hospital evacuation within 24 hours, and so there were no time to wait for the post-earthquake diagnosis by registered structural engineers.
4) Considering the limited time for decision-making on hospital evacuation, it is highly recommended to develop and install a system that enable rapid screening of structural and non-structural damage including precision medical equipment. Such system shall provide engineering information that support the decision by the hospital managers, facility manger and incoming rescuing units in a prompt manner.

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6. REFERENCES


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