DOCTORAL THESIS

ESTIMATION OF MALFUNCTION OF A HEALTHCARE FACILITY IN CASE OF EARTHQUAKE

地震時における医療機関の機能被害評価に関する研究

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March, 2007

Dedication

"قُلْ إِنَّ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ رَبِّ الْعَالَمِينَ"

"Truly, my prayer and my service of sacrifice, my life and my death, are (all) for Allah, the Cherisher of the Worlds" Quran 6:162

This body of research is dedicated to the memory of my late father who would be very happy if he was able to see this modest work. It is also dedicated to my mother for being very patient in waiting to see her only son at this level. It is also dedicated to my wife and son for being very patient especially the last few months in which I was very busy. I also want to dedicate it to my family members and friends especially Grandada Deegan for keeping us always smiling even in hard times. Finally this very modest work is dedicated to all those who have been victims of natural disasters especially earthquakes. I want to tell them all that indeed we can work together and make life better for all.

With love Nebil

Acknowledgment

The author wishes to acknowledge all those who have contributed to achieving this work. Beginning with Professor Masakatsu Miyajima for the guidance, encouragement and help that he provided as my main theme supervisor and for being a member of my referee panel and continuing with Professor Masaru Kitaura for the great instruction and exceeding patience he provided me with while explaining difficult concepts and for his support as a referee member. I also wish to sincerely thank the other panel members, Professor Mitsuhiko Kawakami, Professor Hiroshi Masuya and Professor Hiroshi Kagami for their constructive observations, time and endorsement.

In addition to the above mentioned panel members, I wish to extend my gratefulness to Mr. Akira Murata for the help he provided me with in collecting data and providing me with the tools required to produce the present work. Dr. Toshikazu Ikemoto and Dr. Sun Hong need acknowledgement for the information they provided me with and for their help in making computer programmes. A special thanks to Dr. Masaho Yoshida and Ms. Hiromi Nakamura from Fukui University for the significant help they gave me in analysing data. I also want to express my appreciation to Professor Masanori Hamada and Professor Kenji Kosa for giving me the opportunity to be part of their investigation teams following the 2003 Bourmedes Earthquake, Algeria and the 2003 Bam Earthquake, Iran, respectively. Sincere thanks also to Dr. Michiko Banba and Dr. Nelson Pulido, formerly of EDM, for the fruitful discussions that we had and for the estimation of variables that Dr. Pulido attained for me.

Particular thanks to Dr. Ahlem Ben Hassine for being a guide and aid throughout my academic like. A very particular and sincere thanks to Mrs. Mairi Deegan for editing and proof reading this work so thoroughly and to Mrs. Caroline Deegan Achour for being a spring board for my ideas and frustrations as well as a constant support. Thanks are due to all those who helped me with this research, especially all the students of the Disaster Prevention Laboratory and staff of Kanazawa University. My apologies if I have forgotten to mention anyone by name. Finally I would like to thank my family and friends whose support has been steadfast and true.

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CHAPTER 1

INTRODUCTION

1- CONTEXT AND MOTIVATION

Human beings have been trying to make their lives easier in all areas and by all means. Despite all their efforts natural disasters still threaten to all their goods and even their lives. Between 1900 and 2005, floods, landslides, earthquakes and other natural disasters caused death to more than 36 million people and injury to more than 5.8 million people in more than 85 countries around the world. With the purpose of reducing these numbers we should first classify the disasters into two categories; a) disaster with material impact and b) disaster without material impact. The first type includes flooding, landslides, earthquakes etc; besides affecting human life this type of disaster causes damage to material goods mainly infrastructure, structures and lifelines. The second type, which does not affect material goods, includes famine, disease etc. To reduce the impact of the first category we need medical teams, engineers in all fields, architects, and other categories of professionals whose expertise can be of constructive help. While for the second category we need in the first instance medical teams, humanitarian assistance. As engineers, we, authors, are more concerned about the first category.

Several researchers are seeking ways to reduce the impact of natural disasters on human life. Their proposed solutions can be classified into several categories, here we mention 3: 1) Structural solutions, 2) Lifeline solutions, 3) Medical solutions and others. Solutions may vary from one disaster to another, e.g. solutions proposed for landslides are not those proposed for extreme temperature. As a consequence of a) their existence in various regions of the world, b) large members of people can be affected in a very short time, and c) the economic damage that they may cause to the entire country. Earthquakes were the disasters considered in this study.

When an earthquake hits in any location it kills, injures, makes people homeless, collapses structures, damages infrastructures etc. Obviously the severity of damage depends on many factors; strength of structures and infrastructure, material of constructions (reinforced concrete, wood, steel etc), strategies used in the face earthquakes (emergency plans, shelters etc). Some countries have prepared for earthquakes after a difficult history and some others are still facing problems. For example, Japan has learned from its previous experience and has prepared to face them. For example, in 1923 Kanto Earthquake, M=7.9, the death toll reached 142,000 people, while the number was reduced to 6,000 in 1995 Hyogo-ken Nambu Earthquake (known as Kobe Earthquake), M=7.2, and in recent years the death toll has become very low, about 40 people in the 2004 Niigata-ken Chuetsu Earthquake, M=6.8. The 2003 Tokachi-Oki Earthquake, M=8.0, which excessively was described as being the strongest of the century. Other countries are still suffering from these disasters such as Pakistan which lost more than 82,000 people when the Kashmir area was hit by an earthquake in October 2005, M=7.6, see Figure 1.1. Iran also lost more than 26,000 people when an earthquake occurred in the historical city of Bam in 2003, M=6.6, see Figure 1.2.

The reduction of an earthquake's impact on human life can be done in two stages pre-event and post-event. The pre-event preparedness can be done through strengthening structures and infrastructures and lifeline response as well as planning for the emergency before it happens. The pre-event preparedness can also be as methodologies to follow such as proposed by Porter et al. (1993) and Johnson et al. (1999) who proposed a methodology to assess critical facilities for seismic activities. Kim et al. (2006), Ghobarah et al. (2006), Kuwamura (1998), Kiyono et al. (2004), Hoshiya et al. (2004), Hjelmstad et al. (1998) and others worked on strengthening structures and their stability in case of earthquakes. Some of them were based on real cases such as Ghobarah et al. (2006) and Kuwamura (1998). Some others worked on strengthening the response of lifelines such as in Hoshiya et al. (2004), Torres-Vera et al. (2003), Menoni et al. (2002). The post-event issue considers mainly rescuing the victims in an effort to reduce mortality. This has to be done by medical individuals and also engineers. Shih et al. (2002), Iskit et al. (2001) and Naghi et al. (2005) considered the problems faced during the earthquake-related emergency from medical point of view, while Kuwata (2004) took it from an engineering point of view by studying the search, rescue and life-saving of earthquake related causalities. Some other researchers were limited to the case of preparing healthcare facilities for earthquakes such as Nagasawa (1996) and Myrtle (2005).

Figure 1.1- Pakistan Earthquake, 2005
(Source: www.pakquake2005.com)

Figure 1.2- Bam Earthquake, 2003
(Source: www.farsinet.com/bam)

Much research has been done on strengthening the response of structures, response of lifelines, rescue and search. Kuwata (2004) discussed search and rescue activities but did not mention the damage to healthcare facility systems which may affect the rescue activities as well. A victim with severe injury should be treated in the shortest time to save his life and if a hospital is unable to treat him because of being full or damaged the risk to his life will be higher. This happened in Iran after the 2003 Bam earthquake, where many people died in hospitals waiting for treatment. Therefore dispatching injured people depends not only on the flow of traffic but also on the level of damage to healthcare facilities. Following the 1995 Hyogo-ken Nambu Earthquake hospitals in the affected areas were all unable to receive patients, while those around the city were empty. Hospitals in affected areas might survive if their fragilities were analysed. Nagasawa (1996) showed some cases of damage which affected the functionality of healthcare facilities. He discussed the damage to medical equipment after the 1995 Hyogo-ken Nambu Earthquake without specifying the system that affects the hospital the most. Myrtle et al. (2005) have classified the importance of hospitals' systems although they did not show how much a damaged system can affect the functioning at the facility. The methodology presented by Porter et al. (1993) and Johnson et al. (1999) is a good tool. The methodology consists of evaluating a coefficient to each system to judge whether the system is safe or not. The main problem of the methodology is that it does not have any reference so that the coefficient may be compared. This makes the judgment very difficult, and therefore the final result is not precise.

As we mentioned, preparation for earthquakes can be done by many methods, but in this study we focus more on lifelines rather than the structural or medical categories. The lifeline category is very wide and many factors can be considered in it. It includes not just water, electricity, and gas but as their name indicates they are "*Life Lines*" in other words all services that have direct relation to life saving including medical equipment.

2- OBJECTIVE

The purpose of this study is to save the maximum number of earthquake-related-causalities and reduce the toll of death. This can be done by different disciplines; engineers, medicine, politicians, economist etc. However, we being of the engineering discipline will focus on engineering concerns. The focus will be to find a new methodology that estimates the damage to healthcare facilities in case of an earthquake. The proposed methodology should fulfil the following requirements

- Detailed estimation of malfunction of each system,
- Estimation of malfunction of the entire facility, and
- Universal applicability

In order to reach the final purpose, we need to set some targets and fix the work frame; Figure 1.3 summarizes all targets. To understand the condition of hospitals after an earthquake it is necessary to study real cases. Moreover, to establish universal methodology we should consider not only one particular case but many cases taken from different locations in the world. This step will be to study the vulnerabilities of healthcare facilities. This is very difficult to establish given that the condition of healthcare facilities are very difficult between countries. For example, it is impossible to compare a Japanese healthcare facility to an Iranian one simply because the Japanese ones have very strong structures which make them resist to strong earthquakes, while the Iranian hospitals were built using adobe. This step will concentrate mainly on finding the common weakness shared between all facilities around the world. The second step is studying the response of internal systems; mainly the lifelines and equipment. As it is impossible to study each installation of systems we will be limited to the most important lifelines and the most important equipment or commonly used equipment. This includes some experimental studies and computer simulations. The third step is finding the degree of damage to each of the systems, lifelines and equipment, and evaluating its appropriate fragility. The last step is the final goal: finding the fragility of the entire system. It should be noted that studying the fragility of a system helps the prediction of damage of that system and strengthens if that is possible or finds better solution if strengthening is not possible. We believe that this will be the best to consider in responding to all the above requirements.

To summarize, the methodology consists on finding the fragility curves of the systems existing within a healthcare facility and combining all of them into one curve which will be the fragility of the entire facility.

The question now is "*what benefits would this methodology bring?*" The answer can be encapsulated into the following points and in Figure 1.5, in which H_i represents a hospital of the healthcare system, composed of n hospitals named H_1 through H_n. If the methodology is applied to H_i hospital the results will be the fragility of each service existing in it, this helps greatly to strengthen each of them if they are vulnerable. Also the results will be useful for dispatching the injured in case of earthquake by estimating systems that are not in function. Moreover, the fragility of the entire facility will be obtained too and it will mainly help the decision makers to classify the facilities according their most urgent needs to be strengthened. The next three points summarize what has been mentioned so far:

- Very useful information about the situation of facilities can be of use to the rescuers. A rescuer on-site will be able to send the injured to receive the necessary treatment where it is available without the possibility of transferring him to other facilities unnecessary.

- To strengthen a facility, the decision makers need a clear plan of what is vulnerable within the facility so that it may be fortified.

- Comparison of damage level between facilities helps in fortifying the healthcare system within the area, city and country.

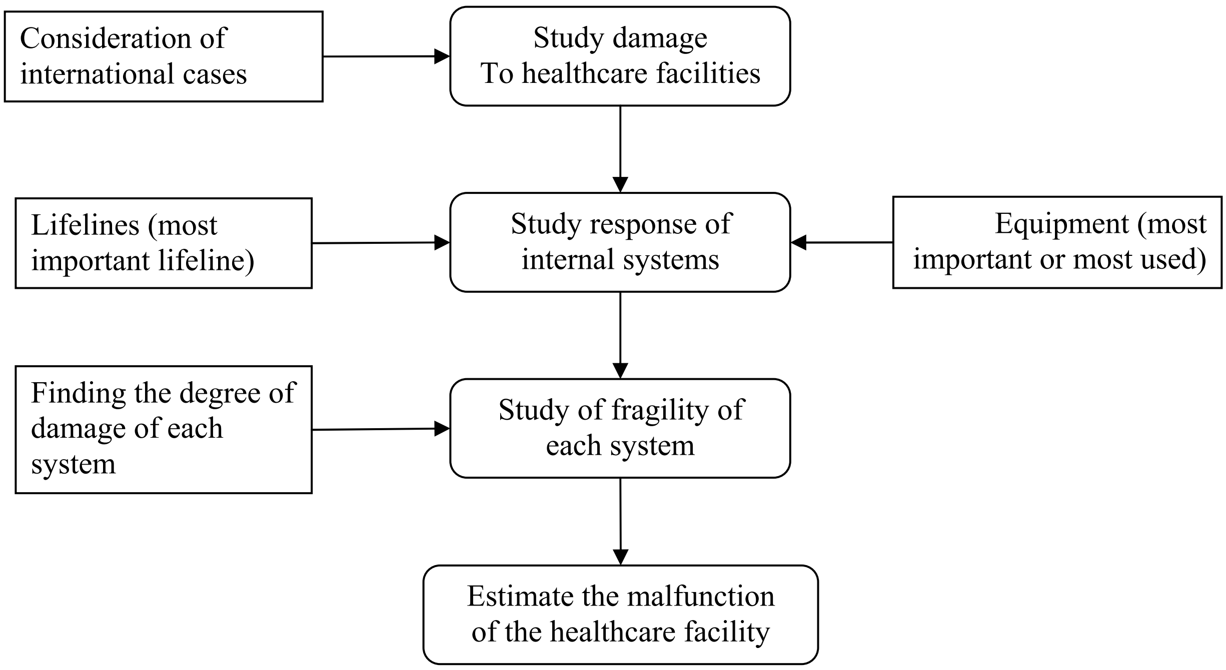

Figure 1.4- Steps of the study

3- OUTLINE OF THESIS

The present thesis is composed of 5 chapters organized into the following order:

Chapter 2: This chapter is an introduction to healthcare facilities. It details their importance and the different systems they contain. The chapter also presents the factors that affect the transfer of the injured from the affected area to hospital.

Chapter 3: This chapter presents two main sections; the first is a study of old events which can be taken from literature or original results found after investigations and the second section is analysis and discussion of the investigations that we carried out. The purpose of the chapter is to find out the common problems that affect any hospital around the world and to investigate in detail the source of problems that were faced through studying particular cases.

Chapter 4: This chapter is divided into three main sections. The first section discusses the most important lifeline for the functioning of a healthcare facility. Investigations of its vulnerabilities were carried out and a solution was provided. The second section discusses the determination of finding the most important services that are able to treat the maximum number of injuries resulting from an earthquake. The third section is a study of the response of some equipment; free standing, mounted on locked and unlocked wheels and attached to their support. The purpose of this section is ensuring the functionality of a facility through assuring the availability of lifelines and then the operation of its most important services by studying the equipments that are used for treatment; several factors were considered such as the acceleration and the frequency. The focus is on finding the response of the equipment which will be shown in the next chapter.

Chapter 5: This chapter is the final stage of the entire study. The purpose is finding the fragility of hospitals. To reach the final goal the fragility of hospital systems were found and that includes: lifelines and equipment. Among the lifelines two systems were considered given that they are vital for the functioning of a healthcare facility. Several types of equipment were considered based on several possibilities: wheeled tables, freely standing tables and shelves. The total fragility is a combination of all system fragilities.

Chapter 6: Conclusion and future work.

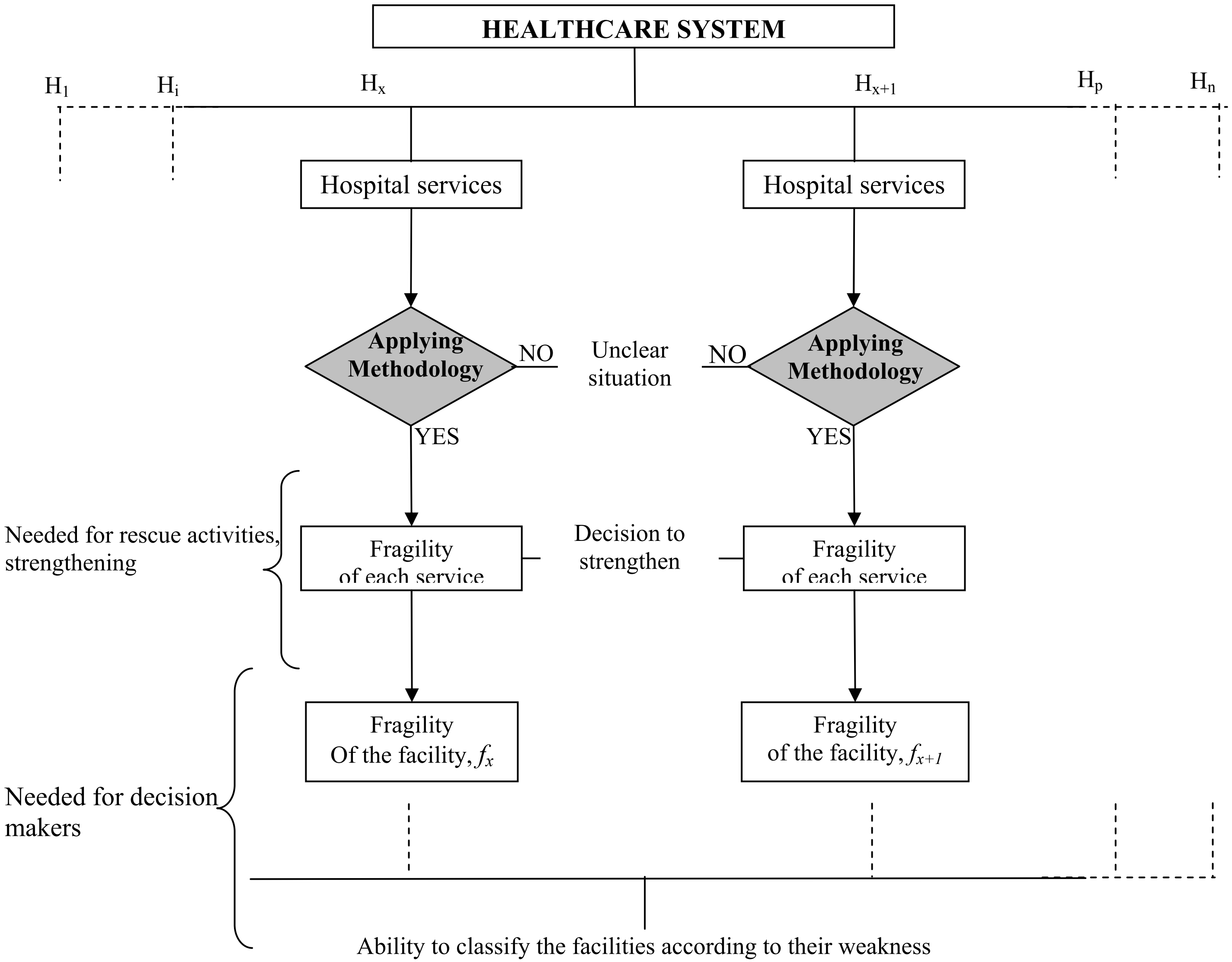

Figure 1.5- Contribution of the study

CHAPTER 2

OVERVIEW ON HEALTHCARE FACILITY SYSTEM

1. HOSPITAL SYSTEM

1.1 Overview

Hospitals are very complicated systems given that they hold large numbers of people, large amount of equipment, systems and installations. The Pan American Heath Organization (PAHO, 2000) has described hospitals as multi-facilities in one facility. They can be compared to hotels or residential areas with regards to the number of people and as industries with regards to the equipment, systems and installations that they include. Figure 2.1 shows a simplified model of a healthcare facility. The contents can be categorized into two areas: the Human category and the Physical category. The latter category is a group of systems that are inter-related in a very intricate way. Figure 2.2 illustrates a diagram in which all the systems that constitute a healthcare facility are shown.

1.2 Human category

The human category is composed of different parts; medical staff, i.e. doctors, nurses and technicians, administrative and technical support staff. This category is extremely important for the functioning of the facility. Experience shows that when this category is affected the treatment of patients becomes difficult if not impossible. Moreover, these personnel need a lot of information as knowledge about the emergency may be very limited which causes stress and problems in treating patients.

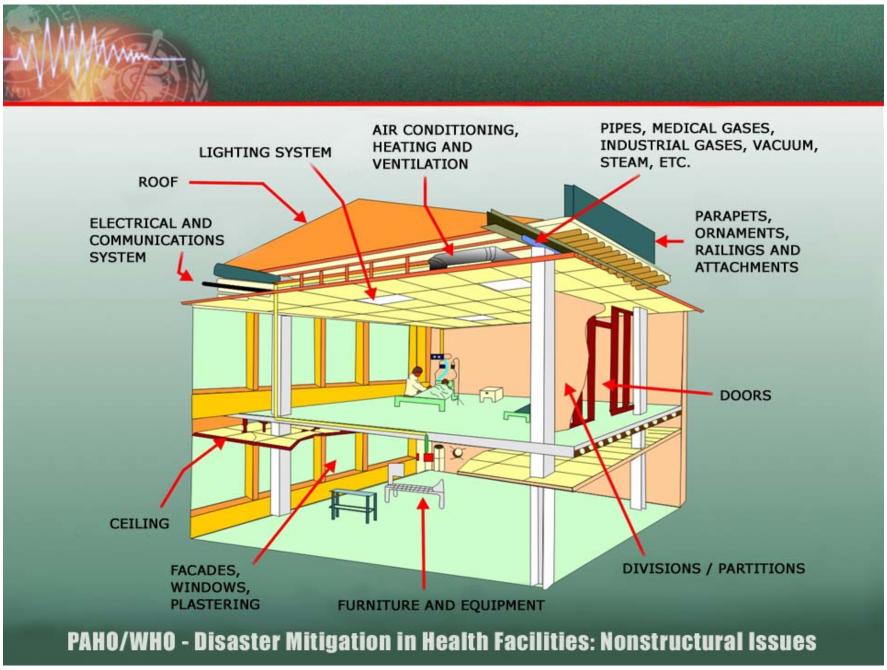

Figure 2.1- Simplified model for a healthcare facility
(Source: PAHO)

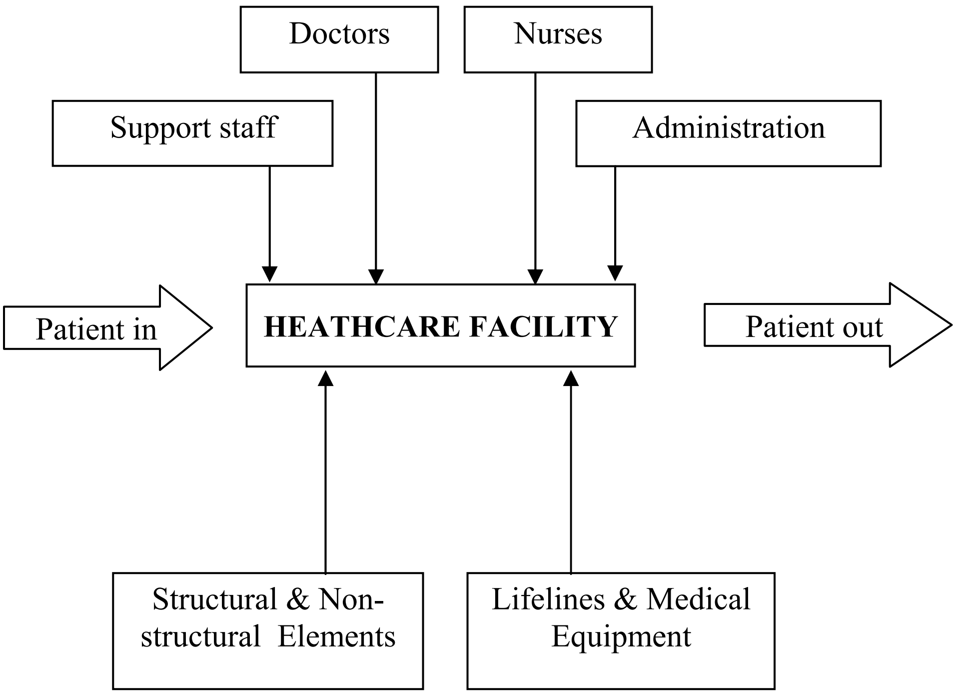

Figure 2.2- System of the Hospital

1.3 Physical category

The physical category is a set of many groups, which can be classified into three main groups: 1) structural group, 2) lifeline group and 3) human group.

1.3.1 Structural and non-structural group

The structural group includes all structural elements beams, columns etc. and non-structural elements (partition walls, doors, windows and such like). If this group suffers damage it may result in damage to all the remaining of groups; in other words it is of great importance to all the groups. For that reason, researchers have been focusing on finding new ways to make the structural group strong enough to sustain the shaking that it experiences during an earthquake. In classical buildings, new factors were proposed such as, construction materials, ways of construction, new theories to make the structure stronger among others. New structures were introduced, mainly the base isolation system which reduced greatly the damage to the structure. The isolation system allows the structure to experience non-linear deformation without being damaged; also it makes the natural frequency of the building very low which makes it survive earthquakes especially those with high frequencies.

1.3.2 Lifelines and equipment group

The lifeline group includes what is known as “lifeline” (electric power system, water supply installations, gas supply installations etc.) and equipment. Equipment can be divided into many categories: industrial equipment (electric power, such as generators shown in Photo 2.1, or Uninterruptible Power (UPS) system shown in Photo 2.2, air-conditioning controls, water tanks, see Photo 2.3, gas supply tank, see Photo 2.4 etc.). Alternative sources are used in hospitals given that the main sources can suffer damage or malfunctioning. Usually the problems can be damage to the actual source (electric power plant, water supply reservoir, telecommunication centres etc.) or it can be to their means of transport (cables, pipelines, antennas etc.).

Medical equipment: large as X-ray units, see Photo 2.5, Magnetic Resonance Imaging (MRI), see Photo 2.6, Computerised Tomography Scanner (CT), see Photo 2.7, Cardiac Catheterisation, see Photo 2.8; or small such as bottles/boxes of medicine, X-ray films, laboratory quipment, computers, and printers such as shown in Photo 2.9 and Photo 2.10 etc.

Photo 2.1- Electric power generator

Photo 2.2- UPS system

Photo 2.3- Water supply tank

Photo 2.4- Gas supply cylinder

Photo 2.5- X-Ray unit

(Source: www.schroeder-medical.com)

Photo 2.6- MRI Unit

Photo 2.7 CT scanners
(Source: www.lawrencewray.co.uk)

Photo 2.8- Cardiac Catheterisation
(Source: www.fremantleheart.asn.au)

Photo 2.9 Blood vessel contrast unit
(Source: www.niigata-cc.jp)

Photo 2.9- Portable computer

Photo 2.10- Printer

2. ROUTE OF PATIENT TO RECEIVE TREATMENT

During the transportation of a patient to receive treatment in a healthcare facility many factors interfere with and may threaten his life given an obstacle. The obstacle that an injured party will most probably encounter on the way to a hospital is transportation difficulties. Depending on the level of damage, it is not unlikely that wide spread chaos will ensue on all remaining undamaged roads. Having passed through traffic problems and reached a hospital it should be noted that the patient may not yet be able to receive treatment, if the hospital itself is damaged or if it is full to capacity, transfer to another hospital may be necessary. As the following chart shows, many parameters can influence the route of an injured person seeking treatment.

After being injured the injured party must be transported hospital. However on the way to the hospital he has to pass through traffic and use the roads. This means that the transportation systems becomes a very important parameter that affects the time it takes the injured party to get treatment. Some studies have been carried out with the purpose of determining the most vulnerable roads that will be used in the case of an earthquake for transporting patients to hospitals. The second parameter that can affect the treatment of casualties is the damage within the hospital itself. There are two kinds of damage: lifeline and structural damage.

The structural damage represents the damage to the structural elements such as beams, columns, walls, slabs and such like. There are many levels to this kind of damage: slight damage, severe damage and total collapse. The affect of the damage on human life can vary between the different types of damage as well as the location of the damage within the facility. For example if a part of the building that is not used becomes damaged, the treatment will not be affected. However if a treatment room is damaged the treatment will be highly affected.

The other parameter that can affect the hospital functioning is lifelines such as electric power, water supply, telecommunication and such like. Their damage can be the result of shaking of the ground itself as well as structural damage or it could even be damaged at the source of the supply itself, such as the central electrical supply, the conduits, the water reservoirs, the pipes, the antennas etc. Once the patient arrives at the hospital his treatment depends on the level of damage to the hospital. In the event of non-damage the patient will be treated and will return home or will be admitted to the hospital for more treatment. However, if the facility is damaged the patient has to be moved to another facility. In this case the traffic parameter will be involved again.

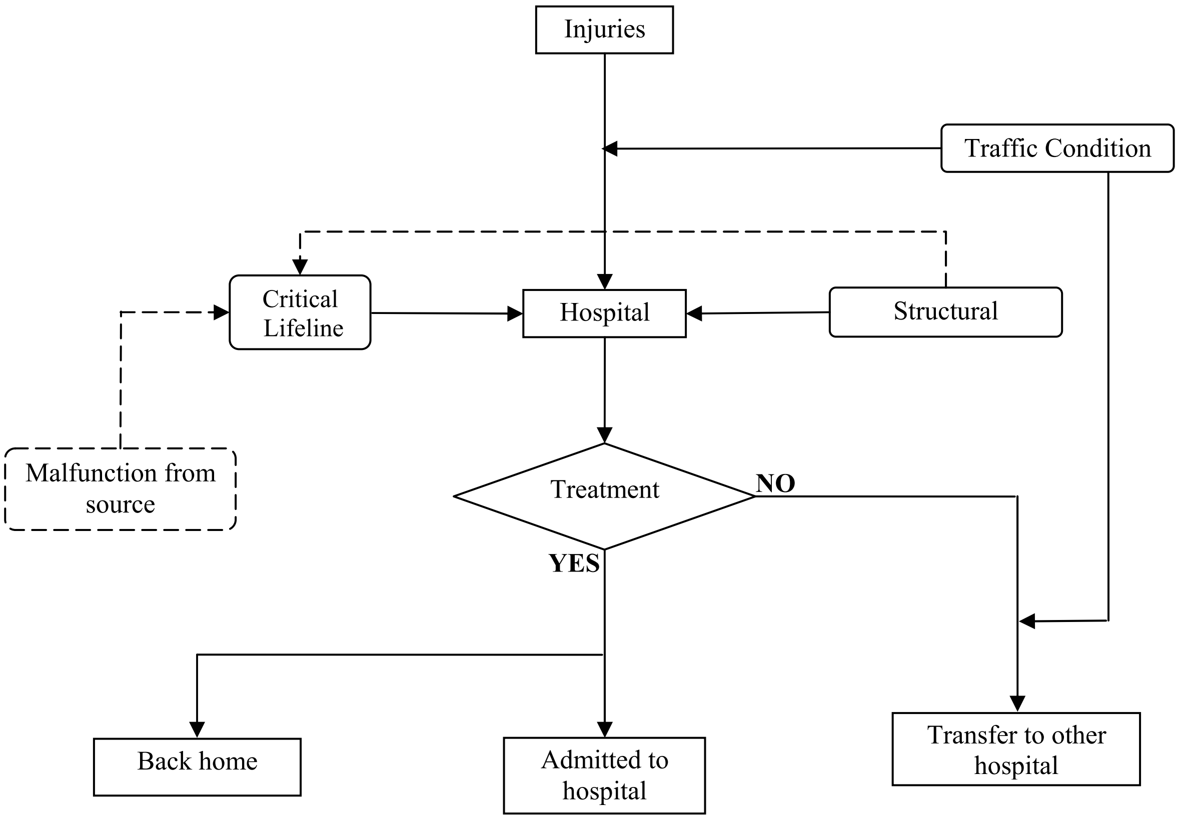

Figure 2.3- The Route on which an injured person should be taken to receive treatment

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CHAPTER 3

DAMAGE TO HELTHCARE FACILITIES (PREVIOUS EXPERIENCE)

1. INTRODUCTION

In order to accurately assess hospitals in the event of an earthquake it is necessary to fully understand their condition after an event and isolate the common problems that are repeatedly found within them, aside from some of the factors that have a direct bearing on the malfunction of hospitals. It is for this reason that this chapter focuses on some cases of damage to hospitals from previous earthquakes. The chapter is composed of three main parts; A, B and C. Part A covers past experiences from a general point of view. Information acquired from literature about past earthquakes is presented from such events as the Northridge Earthquake of 1994, the Hyogo-ken Nambu Earthquake of 1995, the Marmara Earthquake of 1999, the Chi-Chi Earthquake of 1999 and the Bhuj Earthquake of 2001. We considered only these events because they are recent events which reflect the situation of hospitals at present and therefore bring into focus the accuracy of the final results. Part B is an original contribution to the literature. The information of which was gathered from onsite visits and/or surveys that were carried out following the occurrence of each of the events. Seven events occurring in 2003 and 2004 are considered in the section; the Algerian, Boumerdes Earthquake, the Japanese, Sanriku-Minami Earthquake, Miyagi-ken Hokubu Earthquake, Tokachi-Oki Earthquake, the Iranian, Bam Earthquake and the Niigata Chuetsu Earthquake. The final Part C is a discussion and conclusion of parts A and B.

The events presented in Part B occurred in different locations in the world that have varying hospital preparedness levels, some of them occurred in areas where no preparedness was found such as in Algeria and Iran following the Boumerdes Earthquake and the Bam Earthquake respectively, while the others occurred in Japan where preparedness levels are high and safety measures are being applied. In the first cases, we suggested some ideas which we hope will be considered to improve the situation with the purpose of helping these countries. Concerning the cases from Japan we analysed the events differently; the analysis of the Niigata-ken Chuetsu Earthquake and the Sanriku-Minami, Miyagi-ken Hokubu and the Tokachi-Oki Earthquakes were done together since they occurred in the same area and time period (with just two months between them). The result of their analysis was used to determine the factors to be considered and the most important lifeline as shown in the following chapter, Chapter 4.

PART A

DAMAGE TO HEALTHCARE FACILITIES, EARLIER EVENTS

2- NORTHRIDGE EARTHQUAKE, USA, 1994

2.1 Overview

This earthquake occurred on January 17th, 1994 in the San Fernando Valley of Northern Los Angeles at 4:31AM pacific standard time; its magnitude was 6.7 (SCEDC, 2007). Figure 3.1 illustrates the area where the damage was found. The earthquake was not the first that occurred in the region, two others occurred; the latest was 5 years before the Northridge earthquake and the other in 1971. The magnitudes were almost equal; however this earthquake was the most damaging. Table 3.1 summarises the damage that resulted from the earthquake.

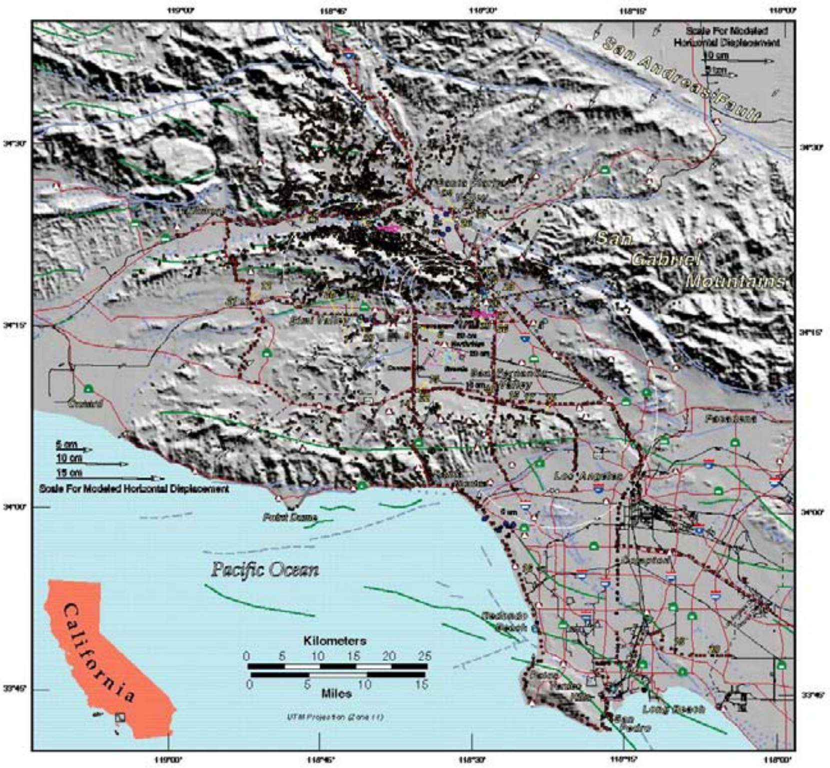


Figure 3.1- 1994 Northridge earthquake, damaged area
(Source: Hodgkinson et al., 2006)

Luckily the damage was not as severe as it might have been due to the fact that that day was a holiday and also due to the time the earthquake occurred at. According to some reports, the main cause of fatalities was damage occurring to buildings constructed in the 1920s and 1930s, www.eqe.com.

The earthquake caused damage to 750 health care facilities, 400 of them were checked in the first week after the earthquake. About 20 facilities suffered structural damage; eight hospitals were considered unsafe to be entered into because of severe damage to their structures. Of four hospitals in Santa Monica six structures were considered the most damaged having being built between the 1920s and the 1970s. The facilities experienced severe damage to their lifelines and their non-structural elements; the toppling of storage shelves was widespread. To summarize, the damage can be classified into the following categories:

- Structural damage
- Non-structural damage: roof-mounted equipment, vibration-isolation devices, equipment crossing a seismic joint
- Lifeline damage: piping, duct systems, falling of shelves
- Equipment damage: problems of anchorage,
- And others.

Table 3.1- General Data, Northridge earthquake

Damage	**Number**	**Remarks**
Deaths	57	
Injuries	more than 1,500	Seriously injured
Blackout	9,000 homes	
Gas outage	20,000 homes	
Water outage	More than 48,500 homes	
Damaged buildings	3,993 11,313 51,240	Severely damaged Moderately damaged Slightly damaged
Road damage	Up until 32 km from the epicentre	On major motorways
Road closure	11 major rods	In all directions to downtown Los Angeles

2.2 The Northridge Hospital

This hospital is very old, composed of many wings inter-connected to each other. Its structure, steel frame with brick veneer, suffered severe damage. The failure of the main girder connecting the wings of the facility caused damage to some corridors. Some structural damage was caused by equipment; some fans fell on the fourth-floor roof causing severe damage to some walls. Non-structural elements and lifelines were found to be the most damaged. Ceilings and interior lights fell down, several pipelines and their elbows were damaged. Emergency power generators could not be used when they were needed the most. It was reported that the facility suffered severe lifeline damage even more than has been mentioned above.

2.3 The Olive View Hospital

After its total collapse following the 1971 Sylmar earthquake, the facility was totally rebuilt with a very strong structure that resisted the 1994 earthquake, even-though it went through the highest ground motion acceleration ever recorded in buildings (S&VT, 2004 and USGS, 2005). In spite of that, its lifelines suffered damage; the vibration isolators of two chillers situated on the roof of the facility were damaged. Their damage caused the chillers to move and damage the pipes that were related to them. The damage to pipelines caused the air-conditioning and water systems to fail. Given that the emergency power engines were well attached to their supports, none of them were damaged.

3- HYOGO-KEN NAMBU EARTHQUAKE, JAPAN, 1995

3.1 Overview

The earthquake occurred on the 17th January 1995 in Kobe, Japan, at 5:46 AM local time, its magnitude was 7.2 (JMA), see Figure 3.2. The earthquake caused severe damage to the whole area. Total economic losses were estimated to be 96 billion US dollars. The largest part of this loss occurred to 75-80% of residential and commercial structures (Shinozuka et al., 1995). The remaining 20-25% of damage occurred to port, river and agricultural facilities. The damage was very widespread; it spread over a 100 km radius from the epicentre. Other cities, Kobe, Osaka and Kyoto, were touched by the earthquake with different levels of damage; Kobe was the most affected area. There was no problem with telecommunications after the earthquake. The NTT had cut off 25,000 lines in the affected areas. However, 2,000 lines were installed for public use at public offices and shelters. Table 3.2 illustrates more data about the impact of the earthquake.

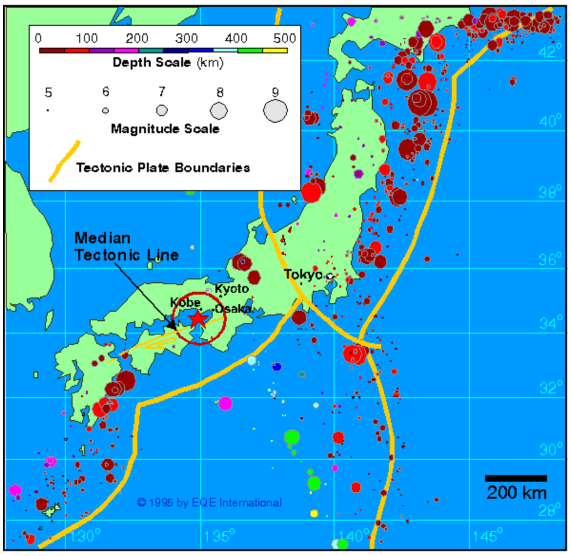


Figure 3.2- Hyogo-ken Nabmu earthquake, Japan
(Source: www.eqe.com)

Rescue operations were made very difficult due to damage to many motorways and expressways and in other cases they were closed due to the rubble of destroyed buildings. The ambulances could neither take the injured to other hospitals in non-destroyed towns nor meet the demand. Some ambulance staff were injured by the earthquake too. Many hospitals could not offer a high quality of treatment because of the lack of water and electric power. Some hospitals were severely affected by the earthquake and there was no communication between them. In the following part examples of damage to some health care facilities are summarised.

Table 3.2- General Data, Hyogo-ken Nambu earthquake

Damage	**Number**	**Remarks**
Deaths	Approximately 5,500	
Injuries	35,000	
Blackout	More than 1,000,000	Excluding the collapsed houses.
Gas outage	1,400 breaks	
Water outage	367,000 houses	2,000 breaks in the system
Damaged buildings	>100,000 80,000	Complete collapse Severe damage
Road damage	Hanshin 20km, Nishinomiya bridge, Wangan bridge…etc	20km was totally reversed
Road closure	--	No data
Fire	150 fires occurred	
Telecommunication	Generally it was fine	
Homeless	300,000 people	In the first night of the earthquake

3.2 Medical College of Kobe University

The facility, which is located 10km from the epicentre, was built in different stages. The oldest was built in 1967 and the newest in 1985. The earthquake caused structural and lifeline damage. However, the lifeline, including equipment damage was more serious. On the 10th floor some equipment shifted and some fell down. The oxygen system was damaged and caused a drop in the pressure that caused the transfer of one patient to another hospital. The oxygen was centralized and then distributed to a different area of the hospital. Both air and water tanks were well anchored. The hospital has two emergency power generators, one in each building. They were installed on rubber elements to reduce the shocks in case of an earthquake. The generator's connection utilities were all provided by flexible couplings to avoid any damage. The water was transported to the hospital buildings by four main pipes, the failure of one of them made the electric power engines switch off, since the water was used for their cooling. Therefore the facility lost electric power on top of the water supply. The hospital did not have any facilities to store water; however it had the possibility to pump water from a well at the university. There was a shortage of food since the gas supply was cut off. There was no problem with the telecommunication system, as the system was very well strengthened (Shinozuka et al., 1995).

3.3 Hyogo Medical Centre

The hospital had a water tank placed on its roof. The tank fell over causing flooding of the hospital. As a consequence, the emergency power engines had to be turned off as their cooling system depended on water, causing a shortage of both, water and electric power. The hospital was evacuated and then closed for about two weeks until the water damage was repaired (Shinozuka et al., 1995).

4 MARMARA EARTHQUAKE, TURKEY, 1999

4.1 Overview

The earthquake occurred at 3:01 AM local time on the 17th August, 1999 with a magnitude of 7.4 on the Richter scale in the North West of Turkey, see Figure 3.3. Its impact was very wide all over the city, which suffered damage to all its facilities. The affected area was one of the most important cities for the Turkish economy; it represents about 10% of the entire Turkish economy. The earthquake collapsed large number of multi-story buildings. Many roads were completely destroyed which hampered transportation of the patients to hospitals. More information about the impact of the event is shown in Table 3.3.

The major cause of death was the total collapse of buildings. Many injured suffered broken legs or arms as they were jumping from heights out through windows. The injured were taken to hospitals by ambulances, cars, trucks, helicopters, etc. In the first 48 hours the rescue activities were very slow. Hospitals could not provide the injured with the necessary treatment; patients were treated in corridors, parking lots, outside in the ruins or in mobile hospitals that were installed in stadiums. Many were simply turned away because there was absolutely no room, no supplies and even no physicians available to treat them, as many hospital staff were among the casualties. Some medical facilities were severely damaged or completely collapsed. According to some reports, the Kocaeli University Hospital treated 700 patients in the first 24hours, 130 of them died (Scawthorn et al. 2000).

Figure 3.3- Marmara earthquake, 17 August 1999
(Source: USGS homepage)

Twelve days after the earthquake twenty mobile hospitals and 16 permanent hospitals were in use for treating the injured. Three days later the health ministry announced that 115 facilities were in use. Unfortunately due to much stress and calamity some private facilities increased the cost of treatment by 100% of that which was charged before the earthquake occurred (MCEER, 2000). Table 3.4 illustrates more information about the damage to healthcare facilities, and detailed information is provided in the following paragraphs.

Table 3.3- General Data, Marmara earthquake

Damage	Number	Remarks
Deaths	More than 17,000	According to non-official source 30,000-40,000 were killed.
Injuries	44,000	
Blackout	The whole country	Shortly after the earthquake and up to 12hours
Damaged buildings	214,000 residential buildings 30,500 business buildings	Lightly to heavily damaged
Roads damage	At least 5	One of them a motorway
Homeless	More than 500,000 people	

4.2 Izmit SSK Hospital, Izmit

The hospital is composed of two buildings, located at about 10km from the epicentre. The buildings are old, the first was built in 1938 and the second in 1978. The structural damage was not severe, but it suffered some minor damage to its non-structural elements. Plates in the expansion joint were buckled and caused non-accessibility to the hospital. The older buildings suffered a blackout for about 24hours and the newer building for two days. However, the emergency power generators were sufficient. There was no problem with the internal water system, waste water, heating system and hazardous waste disposal system. Some cylinders were moved and toppled, but no explosion or leaking was reported (Pickett, 2000). In the first 24 hours 500 injured people were treated in tents set up in the parking lots and about 94 patients were sent to other hospitals.

Table 3.4- Hospital Damage, Marmara earthquake

Name of the facility	Damage	Remarks
Duzce's Faculty of Medicine	Total collapse	
Duzce's private Omur Hastanesi	Total collapse	9 doctors were killed among other injured staff
Kocaeli University Arslanbey	Very severe damage	
Kocaeli University Hospital	Very severe damage	Accepted patients to be treated outside. 250 doctors were treating injuries.
Golcuk Hopital	Damaged	Remained open without electricity 100 beds were moved outside

4.3 Izmit State Hospital, Izmit

The hospital is located 5km from the epicentre. It is composed of two buildings; the older was 60 years old, at the time of the event, and the newer was 10 years old, at that time.

No severe structural damage was observed except cracks at the masonry and expansion joints; as a result of this, the transfer of patients was difficult. The hospital lost electrical power for about two days. However, the emergency generators compensated. External telecommunication was inoperable for more than two days (Pickett, 2000). Internal telecommunication, including cellular phones, was inoperable for more than twenty-five days. Some oxygen cylinders toppled but no leaking or exploding was reported. The hospital accepted 1000 outpatients to be treated in tents within the first 24 hours, about 150 of them were evacuated to others hospitals in Istanbul, Ankara or Bursa.

4.4 Adapazari SSK Hospital, Adapazari

The facility is located about 40km from the epicentre. It is composed of three buildings built in different period, 1975, 1985 and 1996. The hospital suffered damage to one column and a wall. The emergency power engines worked well after the loss of commercial power (for about 11 hours). There was no damage to the water supply system; however, the sewage system suffered some ruptures. The hospital had no external telecommunications for more than two days including cellular phones. Interior communications were cut for more than twenty-five days. Walkie-talkies were however being used (Pickett, 2003). Some oxygen cylinders toppled over without leaking or exploding. Many shelves and nurses' stations fell to the floor. During the first 24 hours 400 patients received treatment, 160 of them were transferred to others facilities.

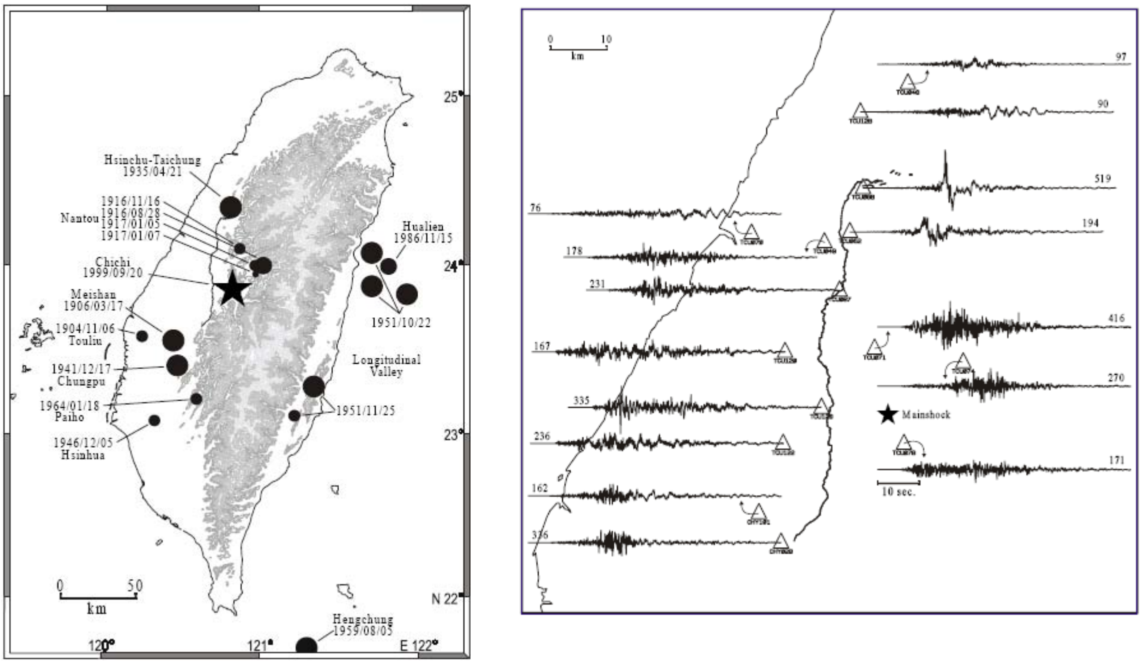
4.5 Adapazari State Hospital, Adapazari

The multi-wings facility is located at 45km from the epicentre. The oldest wing was built in 1970 and the latest in 1998. The hospital suffered very severe damage; two wings could not be accessed for more than twenty-five days. The building was erected on very bad quality soil, described as alluvial. Personnel stated that plans were being made to build an entire new facility in about 1 year "on better soil conditions" (Pickett, 2000). Generally the hospital did not suffer severe damage to its lifelines. The electric power was cut off for eleven hours, however the electrical power emergency generators were sufficient. The only means of communication was by cellular phone for internal and external calls. In the first two days there was no means of communication as even cellular phones were inoperable, then they became the only way of telecommunication for more than twenty-three days. The water and oxygen systems were fine and did not suffer any kind of damage. However, as a result of the shaking some oxygen cylinders were moved and overturned but without causing any leak or explosions, some medical equipment, mounted shelves and monitors fell down. All the elevators were inoperable. About 3,600 injured people were treated in tents set up outside the facility; the majority of them were transferred to other hospitals.

5. CHI-CHI EARTHQUAKE, TAIWAN, 1999

5.1 Overview

This earthquake occurred in the early morning, 1:47am local time, of the 21st September 1999. It measured 7.6 on the Richter scale; its epicentre depth was about 8km (Lee et al., 2000), see Figure 3.4 (a-b). About 10,252 aftershocks were registered during the weeks after the main shock; four of their magnitudes measured greater than 6.5 occurred in the next few days after the main shock. The earthquake was considered to be the strongest since Shin-Chu Taichung earthquake of April 1935 which measured a magnitude 7.1 and caused the death of more than 2,400 people (Lee et al., 2000). Further information is shown in Table 3.5.



(a) Epicentre (b) Fault

Figure 3.4- Chi-Chi earthquake, Taiwan

(Source: Shin et al., 2000)

The damage was widespread in six counties; about 100 school buildings were damaged. About 4,375 healthcare facilities exist in the affected area, 163 of them are hospitals. Damage to hospitals can be divided into 3 major categories:

- Minor structural and non-structural damage,
- Minor/partial structural damage and major non-structural damage, and
- Severe structural damage or total collapse.

The following is a summary of damage to three hospitals: Christian Hospital (Puli), Veteran Hospital (Puli) and Shiu-Tuan Hospital (Tsushan).

Table 3.5- General Data, Chi-Chi earthquake

Damage	Number	Remarks
Deaths	More than 2,400	
Injuries	More than 10,000	
Electric Power damage	593 stations	Total collapse or severe damage
Buildings damage	10,000 Over 7,000	Total/Partial collapse Damaged
Road damage	45km Over 10 bridges	Remained closed for 10 days Totally collapsed
Homelessness	100,000 people	

5.2 The Christian Hospital, Puli

The hospital is composed of two main reinforced concrete structure sections. The oldest was built in 1979 and the newest was built in 1995. The main shock did not cause any structural damage, slight non-structural and lifeline damage occurred and equipment moved, see Photo 3.1. However following one of the aftershocks the facility suffered significant damage to its non-structural elements and lifelines which resulted in its evacuation, one week after the main shock; some of patients were moved to prefabricated buildings and some others to different facilities. The severity of damage was the cause of reducing the capacity of the hospital by 50 beds (which represents 8% of its real capacity). The first floor remained open and it was used for emergency treatment, patient registration and so forth, see Photo 3.2. The following are the most important results of that damage:

1- The capacity was reduced in the time when the demand was the highest,
2- Due to the equipment damage the quality of the service was reduced
3- As a result of the relocation many patients suffered trauma.

Photo 3.1- Exterior damage, Christian Hospital (Source: Lee et al, 2000)

Photo 3.2- Interior damage (1st floor, remained open) Christian Hospital (Source: Lee et al, 2000)

5.3 Veteran Hospital, Puli

The Veteran Hospital is a multi-buildings facility as Photo 3.3 illustrates. The oldest buildings were built in 1974 and the others three years before the event. Some buildings suffered very severe damage, causing their complete closure, see Photo 3.4 and Photo 3.5. Some of the patients were moved to the other buildings while others to different facilities. The capacity of the hospital was dramatically reduced to 50% (220beds). The Medical Centre suffered considerable structural damage, lost its water supply and lost its electrical power. Emergency power did not work, since it was situated on the second floor of a separate building and as result of the amplified acceleration the majority of the components broke and caused their damage. Later on, the Medical Centre building had to be demolished and rebuilt, and the Administration Centre had to be repaired.

Photo 3.3- Veteran Hospital, Puli
(Source: Lee et al, 2000)

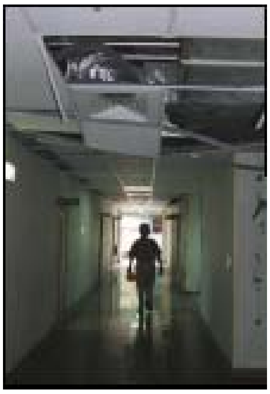


Photo 3.4-Interior damage, Veteran Hospital

Photo 3.5- Exterior damage, Veteran Hospital

(Source: Lee et al, 2000)

5.4 Shiu-Tuan Hospital, Tsushan

This facility represents a special case as it is a private hospital, the largest in Nantou County and was only built two years before the earthquake. It was composed of 9 stories with a reinforced concrete structure. Given that the facility was very close to the Chelungpu fault (about 120m); it suffered sizable damage to its non-structural elements, see photos 3.6 and 3.7. The second and the third stories suffered the most damage, see Photo 3.8, and since the most important facilities operation rooms, recovery rooms were located there, the 400-beds facility had to be totally evacuated to other hospitals. Finally the hospital was closed. Resembling the previous two hospitals, many patients suffered trauma during their transfer. “Seven patients died due to the stoppage of life-support systems” (Lee et al, 2000).

Photo 3.6-Interior damage, Shiu-Tuan Hospital

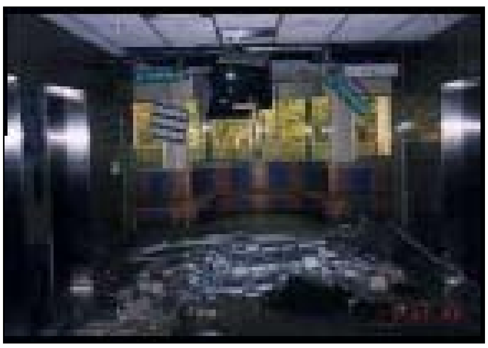


Photo 3.7- Interior damage, Shiu-Tuan Hospital

(Source: Lee et al, 2000)

Photo 3.8- Exterior damage, Shiu-Tuan Hospital
(Source: Lee et al, 2000)

6. BHUJ EARTHQUAKE, INDIA, 2001

6.1 Overview

The earthquake occurred at 8:46am local time on the 26th January 2001 in Bhuj city, see Figure 3.5. According to the Indian Meteorological Department the quake measured 6.9 on the Richter scale and according to the US Geological Survey it measured 7.7 on the Richter scale. The earthquake occurred in the Kachchh area. The earthquake occurred near the Pakistani border and it was felt in Bangladesh and Nepal. The seismographs in Bhuj failed and owing to this important data was lost. However, using broadband velocities the peak ground acceleration was estimated to be 375gal in Bhuj city. The earthquake affected 15.6 million people in 21 districts and 8,800 villages, more information is shown in Table 3.6.

Table 3.6- General data, Bhuj earthquake

Damage	Number	Remarks
Deaths	13,805	* 12,221 In Kachchh area * 1,584 In other parts
Injuries	167,000	* 20,000 of them serious injuries
Buildings damage	210,000	Totally collapsed
	930,000	Damaged

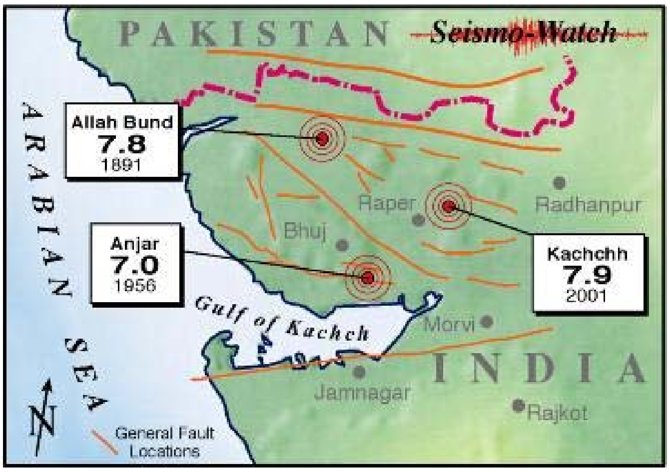


Figure 3.5- Bhuj earthquake, India 2001
(Source: Seismo-Watch homepage)

The majority of the hospitals in the area that were supposed to receive injuries failed to do so and in many cases this caused the death of many people. Aside from patients, doctors, nurses and other support staff were killed in this earthquake. In Bhuj General Hospital more than 172 were killed after it collapsed, see Photo 3.9. Since the latter facility collapsed, the Military Hospital provided medical treatment to 12,254 patients through its Out-Patient Department. However, the Military Hospital became over crowded in a very short time. The Jubilee Hospital completely collapsed too as shown in Photo 3.10. The fairgrounds and Jubilee Grounds, were opened to receive patients, many doctors volunteered to give the injureds initial treatment. Within the two first days hundreds of patients were transferred to other hospitals.

Photo 3.9- Collapsed Bhuj Central Hospital

Photo 3.10- Collapsed Jubilee Hospital

6.2 Hospitals in Ahmedabad

The city of Ahmedabad has a sufficient number of hospitals which helped the facilities to avoid the problem of overcrowding. The Ahmedabad Civil Hospital treated 675 patients in the first 3 weeks. Some hospitals in the Ahmedabad region were equipped to treat earthquake related injuries, and in others the lack of preparedness was the main cause of the crises. “There was adequate arrangements for backup electric power supply at these hospitals” (Durgesh, 2002). The Saradabenh had no emergency power generators. In Vadilal Hospital the trauma division was closed because of some structural damage. Tertiary Care Hospitals, operated by the municipality, suffered structural damage

6.3 Summary of damaged hospitals

Tables 3.7 and 3.8 list and number some health care facilities that were damaged and/or collapsed in the State of Gujarat and Bhuj.

Fortunately, the warehouses of the Central Medical Stores Organizations were not affected. Therefore medical supplies were available even if they were not in the needed quantities. Later there were enough supplies but there was a lack of surgical instruments and paramedic personnel since the majority of the local personnel were affected by the earthquake.

Table 3.7- Damage to health care facilities in Gujarat State

	Facilities	**Collapsed**	**Damaged**
GUJARAT	District Hospitals	5	26
	Community Health Centre	21	46
	Primary Health Centre	48	118
	Sub-centres	227	357
	Integrated Child Development Scheme	800	2180
	Chief District Project Officers office	11	4
	Go-downs (warehouses)	6	4
	Homeopathic Dispensaries	110	8
	Medical College and Special hospitals	-	15

Table 3.8- Damage to health care facilities in Bhuj

	Facility name	**Collapsed**	**Damaged**
BHUJ	General Hospital	✓	
	Jubilee Hospital	✓	
	Nursing School Hostel		✓ (serious)
	ANM Training School		✓
	Tuberculosis Centre		✓
	Mental Hospital		✓

PART B

DAMAGE TO HEALTHCARE FACILITIES, RECENT EVENTS

7. BOUMERDES EARTHQUAKE, ALGERIA, 2003

The present section will focus not only on what happened during the above mentioned event but also on previous quakes. Some suggestions will also be given which can be the start of ideas to make the situation better in the future.

7.1 Overview

Algeria has experienced many earthquakes of different intensities and varying resulting damage. Table 3.9 shows that between 1365 and 2003 twenty major earthquakes measuring *M*5.0 or higher had occurred; eight of them were believed to be destructive. The locations of the epicentres of those events are shown in Figure 3.6. The disasters have caused various forms of damage to human life as well as material goods as Table 3.9 shows. However, it is clear that the earthquake that occurred in 1716 had the largest impact on human life, since it caused the death of 20,000 people. In the 20^{th} Century, Al-Asnam earthquake of October 1980 caused the largest number of human casualties; more than 2,600 were killed, 8,300 injured and 348 were reported missing (CRAAG Homepage).

The event that is considered in this section occurred in the Boumerdes province of northern Algeria. To be more precise, the epicentre was located 70km east of the capital Algiers; off the shore of the Zemmouri region, see Figure 3.7. The damage was widespread particularly in three main cities: Boumerdes, Thenia and Zemmouri. The damage was centred in an area of 3,500km^2 within Boumerdes city. Some of the damaged buildings were not occupied yet, since they were brand new as shown in Photo 3.11 and Photo 3.12. There was damage to 187,839 buildings; about 3.3% of which were public buildings and at least 285 buildings were health care facilities (Belazougui, 2003). The earthquake affected a total of 3.5million people; one million of whom were severely affected, either by death, injury, homelessness or otherwise. Table 3.9 illustrates more information about the impact of the Boumerdes earthquake.

The National Earthquake Engineering Centre (CGS) has placed some accelerometers in some pertinent areas to record the seismic activity of the country. Figure 3.8 shows the measured peak ground accelerations at each station. As Figure 3.8 shows, the maximum ground motion was measured in the second station of Keddara and it was equal to 0.58g. Judging by the large amount of previous seismic activity in Algeria and the high levels of ground motion being currently measured, Algeria has had and will more than likely continue to suffer from earthquakes. We therefore feel that it imperative that the Algerian Nation begins to seriously prepare to save not only the lives of its people but also its valuable and costly infrastructures.

7.2 Damage to hospitals

The City Planning and Hosing Ministry had sent teams composed of engineers to visit the affected buildings, including health care facilities, to assess their damage. Their report includes details about educational buildings in addition to health care facilities. The assessment was conducted in accordance with the level of structural damage. For this purpose, they used five colours, Green1 to Red5, to assess the damage; each colour represents a particular level of structural damage. The description of each colour and the appropriate structural damage are shown in Table 3.11. In the province of Boumerdes, at least 242 hospitals of varying importance were affected; more than 30 of them suffered very severe damage or total collapse. The distribution shown in Figure 3.9 was achieved by the investigation of the Algerian engineers; the distribution represents the number of hospitals that were found in each damage category.


Photo 3.11- Damage to new buildings


Photo 3.12- Collapse of residential building

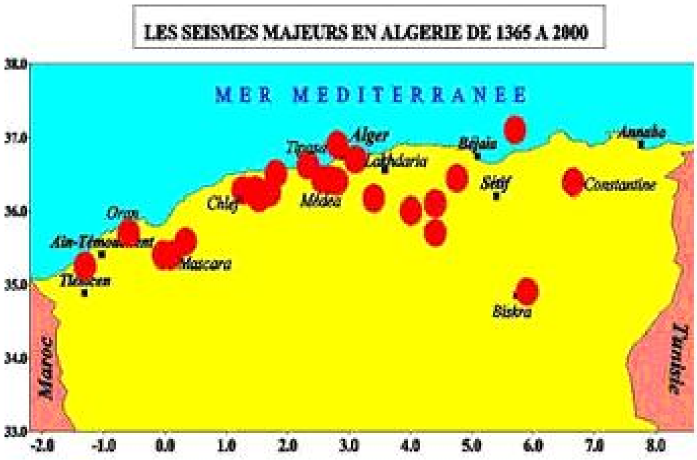


Figure3.6- Major earthquakes 1365-200

(Source: CRAGG homepage)

Figure 3.7- Epicentre of Boumerdes Earthquake

(Source: neic.usgs.gov)

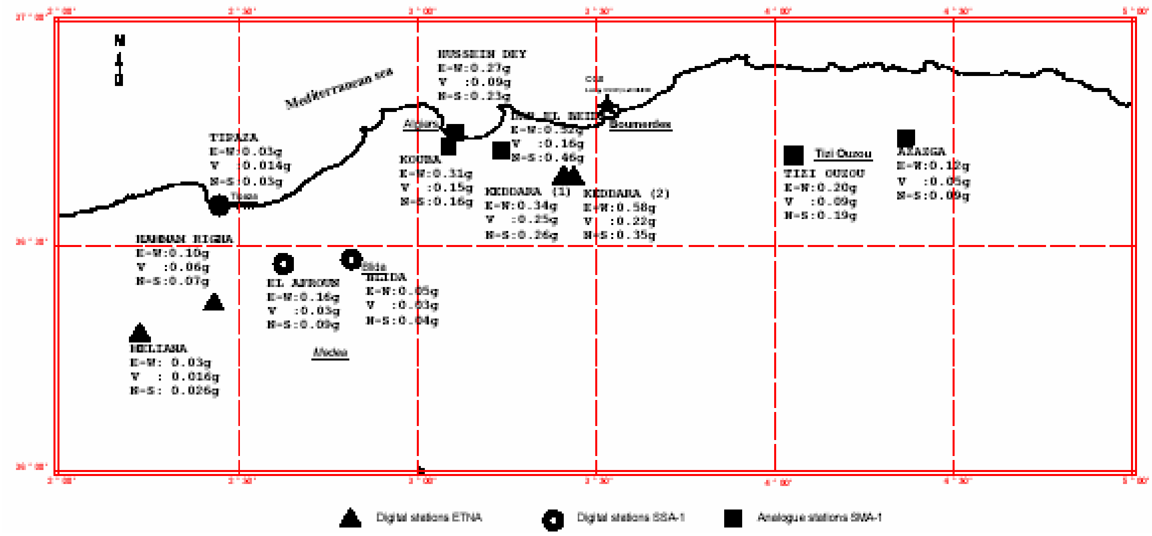


Figure 3.8- Accelerometers Stations

(Middle East Seismic Forum home page)

Table 3.9- General data, Zemmouri earthquake

Damage	Number	Remarks
Deaths	2,278	
Injuries	11,450	
Homeless	200,000	
	79,121	Slight damage
	64,316	Significant damage
Buildings damage	16,022	Very severe damage / should be demolished
	1,758	Total collapsed

Table 3.10- Major earthquakes that occurred between 1365 and 2003 in Algeria
(Source: The National Centre for Research in Astronomy, Astrophysics and Geophysics Homepage, modified)

Location	Date	Max. Intensity	Magnitude	Death	Injuries
Algiers	3 January 1365	Strong	Strong	Many	N/A
Algiers	3 February 1716	N/A	N/A	20,000	N/A
Gouraya	15 January 1891	X	7.5	38	N/A
El-Kalaa	29 November 1897	IX-X	6.5-7.5	20	N/A
Sour. El-Ghouzlene	24 June 1910	X	6.4-6.6	30	N/A
A. El-Hassan	25 August 1922	IX-X	5.1	2	N/A
El-At El-Ab	7 September 1934	IX	5.0	0	112
Bejaia	12 February 1950	VIII-IX	5.6	264	N/A
Chlef	9 September 1954	X-XI	6.7	1,243	N/A
M'sila	21 February 1960	VIII	5.6	47	88
M'sila	1 January 1965	VIII	5.5	5	N/A
Mansourah	24 November 1973	VII	5.1	4	50
Chlef	10 October 1980	IX	7.3	2,633	8,369 (+348 missing)
Constantine	27 October 1985	VIII	5.9	10	300
El-Affroun	31 October 1988	VII	5.4	0	5
Dj. Chenoua	29 October 1989	VIII	6.0	22	N/A
Mascara	18 August 1994	VII	5.6	N/A	N/A
Algiers	4 September 1996	VII	5.7	N/A	N/A
Ain-Telmouchent	22 December 1999	VII	5.8	Many	N/A
Beni-Quartilane	10 November 2000	VII	5.4	2	N/A
Zemmouri	21 May 2003	X	6.8	2,278	11,450

Note: The presented intensity is expressed in the Mercalli Scale.

Table 3.11- Scale used by the CTC-Centre for the assessment of structural damage (Source: CGS)

Colour	Description
Green 1	Displacement of furniture
Green 2	Slight damage to non-structural elements
Orange 3	Slight damage to structural elements and severe damage to non-structural elements
Orange 4	Considerable damage to structural elements Very severe damage to non-structural elements Cracks on "X" shape for RC walls, bursting of joint beam-column
Red 5	Total collapse Very severe deformation Repair cost higher than the building itself

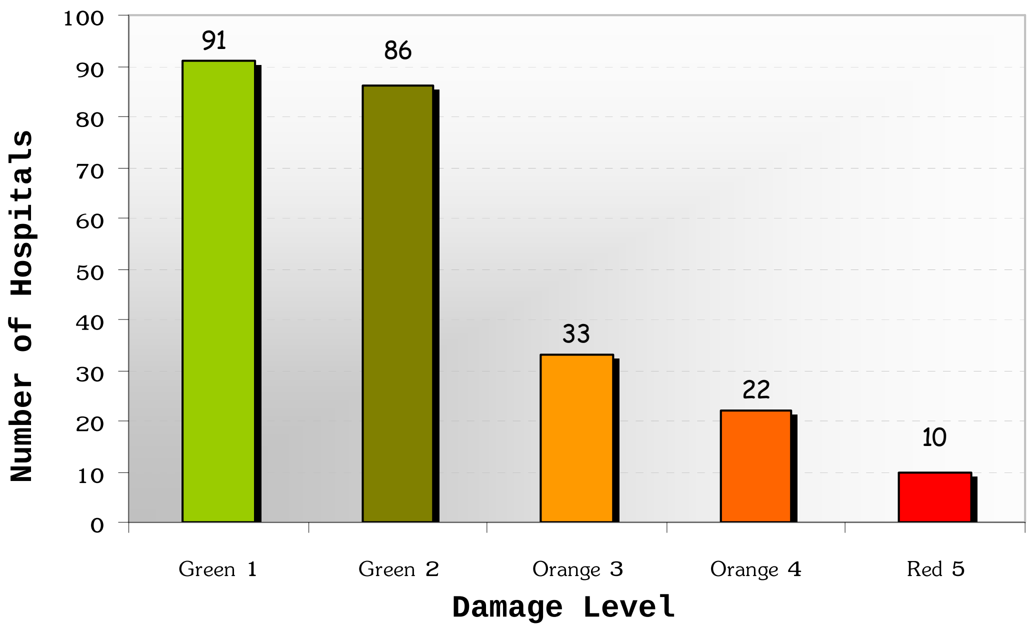


Figure 3.9- Distribution of structural damage

More than 73% of the health care facilities suffered damage to their furniture and non-structural elements; the remaining approximately 27%, suffered slight to severe damage to their structures. The main materials that were used for the construction of health care facility structures were RC, masonry and bricks. The age of the facilities were also variable, some facilities were built in the era of French colonization and were still in use. This issue made many facilities very vulnerable and weak to resist against any earthquake of such magnitude and perhaps of an even weaker magnitude.

7.3 CHU Central Hospital, Algiers

7.3.1 Overview

This hospital is located in the capital Algiers, about 70km from the epicentre. The facility is considered to be the largest hospital in the whole country, according to some sources. Its capacity is about 2,500 beds. It is an old hospital, built by the French during their colonization of Algeria so it was more than 60 years old at the time of the event. The facility is composed of many buildings; each building houses one or more of the hospitals life saving services. We observed that the building suffered only slight damage; therefore it did not stop functioning after the earthquake. The facility was able to accept casualties for treatment, but in some cases the staff had to transfer the injured because treatment was not possible in that facility. Some onsite medical staff helped in dispatching injured parties to different hospitals according to the possibility of treatment. One member of these teams stated that they had no plan of rescue; therefore the destination was decided by the doctor himself based on their own knowledge about the facilities available in the hospital. A total of five personnel were interviewed; two residents, two nurses and an assistant.

7.3.2 Management aspects

Among the five interviewed people, only one person, who commenced work there one year before the occurrence of the event, stated that he had attended training; however he claimed that it was not enough to prepare for such a disaster. The rest of the interviewed staff did not attend any form of training activity that would help them to act in the appropriate manner during an emergency. They declared that the situation would have been made better if they had had some form of training.

The number of personnel present in the facility during the event was a serious problem as we observed. Some of the personnel, who were not at the hospital during the earthquake, had themselves been injured or members of their families had been injured or killed. Due to such circumstances, they were unable to be at the hospital and the lack of their valuable services caused additional organisational crisis. Others couldn't physically get to the facility because of road closure and failure. Moreover, some of those interviewed stated that the number of personnel was insufficient even before the earthquake. The result of this inadequate organization resulted in inferior management of the patients, an increase in stress levels and/or difficult work conditions for the staff and poor quality of treatment.

7.3.3 Structural/non-structural damage

The facility suffered slight structural damage. Some cracks in the walls were observed, see Photo 3.13. Some structural damage made the area inaccessible and therefore had an impact on the tasks of the personnel. Non-structural equipment fell down, broke and made some areas inaccessible; this in turn made moving patients difficult.

7.3.4 Lifeline damage

The electricity and telecommunications were cut for more than 12 hours. The staff reported that the commercial electric power was replaced by alternative sources. However telecommunications were cut in many buildings until July 2003, two months after the occurrence of the event. The facility had no alternative source of telecommunications, personnel were forced to use their own mobile phones.

The water supply and gas were cut in some areas. Alternative sources were however available for use. Some equipment, including medical equipment, was displaced as a result of the earthquake. This caused them damage and/or un-operability. The radiology service was rendered inoperable due to the damage to its equipment. Other equipment was damaged as Photo 3.14 shows; the electric equipment fell because of weak attachment to its support; two months after the earthquake the equipment was still not fixed and therefore it remained unused for the whole period since the event. This damage caused delays in treating patients and difficulty in transferring injured people to other hospitals. Additionally, that damage in turn decreased the quality of services and stressed the staff who could not work under such conditions, as was stated by some of the personnel.

7.4 Thenia Hospital

7.4.1 Overview

This hospital is located just several kilometres from the epicentre. It is composed of 2 parts: The French built the original part in 1870 during their colonization of the country. The second part was added in recent years. The older part of the structure, suffered very severe damage due to its age and the poor quality of the masonry that was used in its construction, see photos 3.15 to 3.17. The facility has a capacity of 213 beds. In total four people were interviewed: two doctors, and two administrative staff.

7.4.2 Management aspects

Personnel never received any preparedness training such as lectures or seminars to help them deal with such a huge disaster. All of them were of the option that the situation would have been made better had they undergone some training or preparation. The number of personnel was not sufficient, even before the earthquake; staff members could not work due to injury or inability to get to the facility because of road closures. Problems with organization stressed the personnel and made them uncomfortable during their work. The same problems resulted in difficulties in treating patients and decreased the quality of treatment.

Photo 3.13- Cracks in the structure
CHU Hospital

Photo 3.14- Damage to electric equipment
CHU Hospital

Photo 3.15- Damage to the emergency wing

Photo 3.16- Collapsed roof of another wing

Photo 3.17- Cracks in the walls of the emergency wing

7.4.3 Structural/non-structural damage

The building had itself suffered severe damage. A lot of damage to its structural and non-structural elements was observed which affected the duties of personnel. The structural elements were totally collapsed throughout the majority of the facility. Non-structural elements had fallen, became broken and made the area inaccessible from all wings. The damage obliged the government to supply prefabricated buildings that were used instead of the actual facility, as is shown in Photo 3.18. The prefabricated buildings were used as the actual facility in which patients were being treated. Those prefabs were equipped with electricity and air conditioners to make life easier for the medical staff as well as the patients. The structural damage had a clear impact on the patients since they had difficulty being treated. The staff could not access or move the inpatients and many patients had to be transferred to other hospitals because their treatment became impossible in that hospital.

7.4.4 Lifeline damage

The situation in the hospital was dreadful; at least until July 2003. Many facilities were unavailable. Electrical power was cut for approximately 12 hours. During the first hours, candles were used until the back up emergency power began to operate. The gas and water supplies were cut off for more than 2 days; however alternative sources were used such as water tanks shown in Photo 3.19. Telecommunications were also cut, and there were no other options that could be used as alternative sources. Telecommunications were still not restored at least until July 2007, two months after the event. The lifeline damage made treatment difficult or even impossible; personnel stated that they could not work in the hospital under such difficult conditions. Damage to lifelines in particular affected life-saving by delaying treatment, delaying the movement of patients and hindering the transfer of casualties to other hospitals, as equipment was strewn everywhere.

Photo 3.18- Prefabricated buildings used instead of the actual building

Photo 3.19- Reservoir of water used as alternative source

7.5 Findings and discussion

7.5.1 Structural problems

The age and type of structure were the two main reasons for the severe damage of structures. A building 130 years old cannot be used anymore without being reinforced; particularly if it is built with masonry as it is known that masonry structures cannot resist horizontal efforts; this issue alone made the structures very weak and therefore unable to withstand the earthquake. As mentioned previously, the Thenia Hospital was closer to the epicentre than the CHU; this issue was well witnessed; seeing as the Thenia Hospital was completely destroyed the personnel were obliged to transfer the majority of injured people to other hospitals such as the CHU. On the other hand, two main reasons show the vulnerability of the CHU. The first factor is its location; the facility was located about 50km from the epicentre. The second factor was the peak ground acceleration (PGA) that was found to measure about 300 cm/sec^2 (CRAAG); noting that such a value of PGA can not cause the damage that was found in the facilities. In other words, the poor state of the structure was what made it unable to resist any earthquake even if it was weak.

7.5.2 Lifeline problems

In addition to structural damage, the CHU suffered non-structural damage that was visible in the failure and collapse of some electrical elements, as shown in Photo 3.14. The radiology service was inoperable and patients who depended on that service had to be transferred to other hospitals. It is important to note that a radiology service is one of the most important facilities in a health care facility; the majority of earthquake-related patients need such a service because of the type of injury that they can suffer from.

The situation of lifelines was not much better than that of the structure. The lifelines were cut for months from the occurrence of the event, which made the functioning of the hospital very difficult and sometimes even impossible. A hospital might be able to function for a few days without telecommunications but for months it cannot function properly. Generally, alternative sources are placed inside facilities, however in this case they were not. The use of candles to illuminate the hospital for the first few hours and the presence of a water tank is evidence that the facility did not have any supplementary sources onsite.

7.5.3 Management problems

The personnel did not have any plan for rescuing the patients and did not have any training or lectures that could help them to act more appropriately during a disaster. The lack of personnel had a very severe impact on the treatment of patients as the personnel became stressed and could not carry out their tasks as they have. The CHU is the largest health care facility in Algeria; therefore it was expected to have a large number of personnel, especially considering that it has 2,500 bed places, and that it would be prepared for any form of disaster. Nevertheless, that was not the case given that both hospitals stated the lack of personnel to be a problem even before the earthquake and the absence of any disaster training activity or guidelines that might have helped them to respond more efficiently during a rescue.

It is important to report that some of the personnel coped very well during the disaster because they were onsite treating and dispatching the injured without a plan. Many of the patients had to be transferred twice; the first was from the original facility to the CHU and since the latter was damaged too they then had to be transferred again to another facility to receive the necessary treatment. It is obvious that the situation would have been so much better if they had a rescue plan that at least aimed to reduce the number of transfers. Such transfers resulted in the immobilisation of a large number of staff, as they had to repeat their work and as such wasted time that could have been better used to save other patients.

In conclusion, it was expected that at least the CHU would have been well prepared for such a disaster, given that it is the most important in the country and it is capable of accepting a large number of patients. The matter of transferring the patients twice shows the vulnerability of organization that health care facilities within Algeria are experiencing. For that reason it is recommended to make plans to protect these facilities to enable them to face any disaster that may occur in a country that has over a hundred year history of earthquakes. Some suggestions to build a methodology to protect the health care system in the country are shown in Appendix I with the purpose of making the situation better in the future.

8. SANRIKU-MINAMI, MIYAGI-KEN HOKUBU AND TOKACHI-OKI EARTHQUAKES, JAPAN, 2003

8.1 Overview

Since May 26th Northern Japan has experienced three large earthquakes shown in Figure 3.10. The first two were in the Tohoku area, Miyagi Prefecture and the third was in Hokkaido.

Sanriku-Minami Earthquake: The earthquake occurred on May 26th 2003 at 6:24 PM local time. The magnitude was equal to 7.0 on the JMA scale with a hypocentre situated approximately 60km below the sea. The maximum peak ground acceleration was measured at 1111 cm/sec^2. The earthquake caused injury to 174 people. Buildings suffered varying levels of damage between total collapse (two houses), half collapse (21 houses) and slight damage (more than 2,300 houses). Health care facilities were also affected; some suffered damage to their structure while the lifelines in others were affected. This made functioning difficult as was the case in the Public Kesennuma Hospital, Kesennuma City. As a result of this earthquake many hospitals suffered a lack of telecommunications.

Miyagiken-Hokubu Earthquake: This earthquake occurred at 7:13am local time on the 26th July, 2003. The hypocentre was located at a depth of 12km in the Asahiyama fault line shown in Figure 3.11. The event measured 6.2 on the JMA scale and it caused large physical damage; the maximum acceleration reached $367cm/sec^2$. The earthquake was preceded and followed by two strong shocks; at 00:13am and 16:56pm. Fortunately, there were no deaths related to the event. However, about 600 people were injured, the majority of them only had slight injures. The earthquake caused damage to a large number of houses. There was an outage of lifeline facilities such as water and electricity. Two hospitals were severely damaged: the Fukaya Hospital and the Kashimadai hospital.

Tokachi-Oki Earthquake: On the 26th September, 2003, an earthquake occurred in the eastern part of Hokkaido, its epicentre was approximately 100km off the coast and 40km below the sea. The Tokachi-Oki earthquake occurred at 4:50am local time and it measured 8.0 on the JMA scale with a maximum acceleration that reached $988.4cm/sec^2$. The quake was followed by 53 aftershocks; the strongest measuring 7.1 on the JMA scale. The earthquake caused severe physical damage and more than 700 injuries, but fortunately there were no deaths. The lifeline outage was very clear in the affected areas. The earthquake caused a Tsunami which caused two people to be reported missing. About 41,000 people had to be evacuated from different areas. Table 3.12 provides more information about the event.

Figure 3.10- Epicentres of the earthquakes

The damage was found to vary from one hospital to another, which may be as a result of the age of the structures, or with the site effect which needs more investigation to find the main cause. Lifeline malfunction was found to be one of the main problems faced during the events. Hospitals were equipped with alternative sources for water supply, electric power; these spare sources were used during the shortage of the main sources until total restoration was achieved. On the other hand, the facilities were experiencing miss-telecommunication given that there was no alternative source for such a lifeline component. A study has shown that, within the first 10 hours more than 95% of the hospitals had their lifelines restored (Achour et al., 2004b). Again, the problem of displacement occurred in many hospitals; equipment toppled and/or turned over causing inaccessibility in the facilities, see photos 3.20 through 3.22. The analysis of the questionnaire will be done in the next chapter.

On a positive note, the earthquakes did not cause severe injury to many people and that is a very good outcome. However, some hospitals did suffer severe damage like was the case of Kashimadai Hospital and Fukaya Hospital in Miyagi Prefecture; which will be considered later in detail.

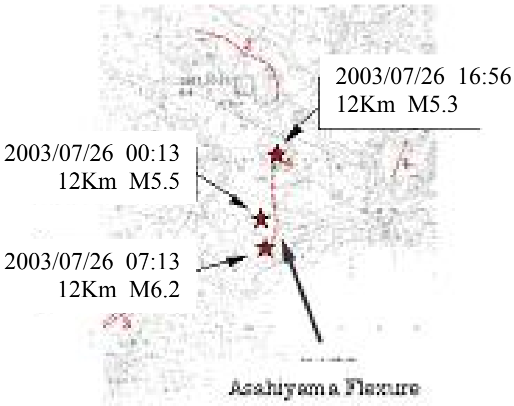


Figure 3.11- Asahiyama fault

Photo 3.20- Toppling and damage to small equipment, Kushiro Urinary Clinics

Photo 3.21- Inaccessible door, Kushiro Urinary Clinics

Photo 3.22- Turning over of medicine shelves, Kushiro Urinary Clinics

8.2 Fukaya Hospital

The facility was built in 1968 and it suffered very severe damage to its columns, see Photos 3.23 and Photo 3.24. One building collapsed, which obliged the staff to transfer patients. One member of the personnel was injured and some others couldn't reach the hospital. As well as structural damage the facility suffered damage to its lifeline. The electric power was cut for about two hours but the emergency electric generators were sufficient. The water pipelines were damaged and caused the outage of water for about four days. A mobile water supply was used instead of the local water system. All forms of telecommunication; landlines, mobiles and PHS were cut for about one hour.

Medical equipment was also damaged, the radiology service room was damaged and that obliged staff to make a temporary room for that service but the quality of treatment was low. Three injured people had to be transferred to other hospitals to receive treatment. The hospital suffered from a shortage of personnel (doctors and nurses) as well as medicine.

One of the reasons that made the management of the 196 beds facility difficult after the earthquake was the absence of the "Disaster Management Manual"; the hospital does not have such a manual. However, there was training for the personnel twice a year and there was one lecture a year to teach the personnel the methods of management during a disaster.

Table 3.12- Miyagiken Hokubu and Tokachi-Oki earthquakes: General Data

	Damage	Number	Remarks
MIYAGIKEN HOKUBU	Death	0	
	Injured people	628	Treated in 17 hospitals
	Building damage	8,079	Partial damage
		2,245	Very severe damage / should be demolished
		1,017	Total collapsed
	Water outage	13,925	
	Electric outage	More than 10,000	
	Road damage	288	Locations, including 3 bridges
	Resulted Tsunami	0	
TOKACHI-OKI	Death	0	
	Injured people	755	According to japantimes.com
	Water outage	More than 100,000	Families
	Electric outage	More than 370,000	Families
	Resulted Tsunami	1	To our knowledge
	Economical loss	9.3 billion yen	Damage to houses and other buildings
		1.7 billion yen	Others

8.3 Kashimadai Hospital

The Kashimadai hospital, shown in Photo 3.25, was built in 1969 and just like the previous institute it suffered very severe damage to its structure. Columns suffered severe cracks as seen in Photo 3.26. As a result of the structural damage some patients were transferred to other hospitals. The 113 bed facility lost its electric power and when the engines stopped, a company representative went and did all the necessary repairs. There was a shortage in the water supply since a water pipe was broken; this too was later repaired.

Medical equipment was damaged, such as the X-Ray fluoroscope table, auto crepe, inspection equipment and such like. Fourteen injured people were treated in the hospital, only one of them had serious injures. The hospital was equipped with a "Disaster

Emergency Manual" that takes into consideration earthquakes and fire. Staff members have at least one training session per year to always be prepared for disasters.

Photo 3.23- Fukaya Hospital Photo 3.24- Damage to Fukaya Hospital

(Source: JECC homepage)

Photo 3.25- Kashimadai Hospital Photo 3.26- Damage to Kashimadai hospital

(Source: JECC homepage)

9. BAM EARTHQUAKE, IRAN, 2003

9.1 Overview

The earthquake caused damage to the majority of Bam City. The epicentre location is shown in Figure 3.12; it also caused more than 26,500 deaths and injured more than 25,000 people. On account of its location, Iran has a long history of earthquakes; between 1948 and 1998 the country has experienced at least 14 earthquakes measuring M=5 and over. Among those 14, at least two of them measured over magnitude 7.3 and caused the death of between 13,500 and 21,500 people.

It is obvious to say that the large number of victims confirms the vital role of hospitals; the USAID reported that the IFRCS hospital received 550 patients per day. On the other hand, the local hospitals were not able to function because of the damage that they experienced at the time when they were needed the most. The World Health Organization (WHO) described the damage caused by the earthquake to health care facilities as "significant"; 120 health care facilities were severely damaged or completely collapsed; two of them were main hospitals: the Aflatoonian Hospital and the Imam Khomeini Hospital. The author, who was member of the Japanese investigation team, visited those two facilities to assess the smoothness of the rescue activities.

Figure 3.12 – Location of the epicentre
(Source: FARSINET homepage)

9.2 Rescue activities

As it has been mentioned the disaster was massive, which made the Iranian rescue teams incapable of rescuing all the victims; at least 44 countries sent 1,800 rescuers to help in the relief activities. During the first hours there was no treatment. A doctor stated that they had to “lie” to patients by informing them that help was coming to make them wait and resist the pain that they were feeling. The doctor stated that they did not even have IV lines which are vital in emergency situations. Moreover he declared that during the first five hours there was no treatment at all, later the help started coming from the neighbouring cities and the serious cases, which made up the majority of victims, were transferred to other hospitals. The hospitals of Kerman (about 200 km), Shiraz (about 120km) and Jeroft (120km) cities received the victims mainly by helicopter and by other means including their own cars. The personnel of the Aflatoonian hospital stated that during the first days, before the arrival of the international teams, all victims were transferred to the above mentioned cities. The personnel used the equipment, which they received from other cities, to treat the victims until the arrival of international teams who setup their mobile hospitals nearby the local facilities and helped them to operate, see Photo 3.28 and Photo 3.29.

It is not uncommon to find problems during rescue activities, so this should be seriously addressed during the planning and preparedness for future disasters. The IRCS reported that there were mis-communication and mis-co-ordination between the 13 sectors, which they created in Bam for the rescue, and the 28 provinces. The same trouble caused unequal distribution of aid between the different sections. The local government estimated the number of people who needed long-term psychological support at 25,000 patients.


Photo 3.28- Mobile hospitals, German team, Photo 3.29- Tent, Spanish team
February 2004

9.3 Damage to hospitals

9.3.1 Aflatoonian Hospital

9.3.1.1 Overview

The Aflatoonian hospital is a private hospital; the 2-story building was built about six years before the earthquake 5km from the centre of Bam. The facility has a capacity of 70 beds which can be extended to 120 beds in case of emergency. Between 25 and 30 patients are treated every day in the hospital in addition to 70 inpatients which makes the facility full without being in emergency mode. The medical service is composed of 57 people; 17 of them are doctors, 40 nurses. A problem with the facility's insurance forced it to close on January 5th 2004; after that the facility partially opened to provide treatment in its garden and parking lot, where the international teams setup their tents, the personnel stated. The actual building was totally closed until July 2004, then opened again and started treating patients. The government of Kerman helped in repairing the facility, which was exempted from paying water supply fees until October 2005. Photo 3.30 and Photo 3.31 show the front of the facility before and after being repaired, respectively.

Photo 3.30- Aflatoonian Hospital, February 2004

Photo 3.31- Aflatoonian Hospital, September 2005

9.3.1.2 Structural damage

The hospital suffered severe structural damage; some columns tilted, some others cracked and some parts collapsed, see Photo 3.30. According to one member of the hospital, the structural damage cost 5 billion IRR, *Iranian Rials* (65 Million JPY, *Japanese Yen*) of the cost of the entire building which is about 12 billion IRR (155.6 Million JPY). It should be noted that the cost of construction has become more expensive than a few years ago, in other words the damage to the facility is less than 41.6% of repair cost of entire building. The facility suffered malfunction to its lifelines; electric power was cut for about two days, there was no landline telecommunication until February 2004, there was no mobile telecommunication for at least 12 days following the quake. With regard to concerning the water supply the facility was provided with two reservoirs that were used as alternative sources. The tanks are able to store 13m^3 of water which can be used for about two days, see Photo 3.36 and Photo 3.37. The damage to lifelines caused malfunction of medical equipment which caused delay in treatment. International aid teams provided the facility with some equipment which helped it to re-open and provide necessary care. Nevertheless, some medical equipment has not been used since it fell or was displaced causing its damage, see Photo 3.38 and Photo 3.39. At the time of the earthquake the facility did not have any alternative source except the water tanks shown in photos 3.36 and 3.37. Later, a 32KW electric power generator was brought to be used in case of emergency, as Photo 3.40 illustrates. The generator is used only for the operation room. However, the engine is able to make the majority of the equipment function; it can produce 768KWh/day, thus it produces 23,808KWh in 31 days which is 80% of the consumption of August 2005.

Photo 3.36- Water Tank 1, Aflatoonian Hospital

Photo 3.37, Water Tank 2
Aflatoonian hospital

Photo 3.38- Topple of equipment
Aflatoonian Hospital

Photo 3.39- Displacement of a sterilizer
Aflatoonian Hospital

Fortunately, none of the hospital staff members were injured in the hospital, however some of the personnel could not reach the hospital during the emergency. The personnel who were not available in hospitals were directly or indirectly affected by the quake; one doctor was killed and the others had injured/dead members in their families which obliged them to stay with them and take care of them. The facility had to manage with the present personnel. With more than 600 patients, shortage of lifelines and damaged medical equipment the situation became very difficult and obliged hospital staff to transfer the majority of those injured to other facilities. The large amount of medicine that the facility had could not save all the patients since many patients died given that they did not receive the necessary care because of the insufficient number of personnel. One of the questions asked was about the most needed item during the salvage operations; the answer was "doctors" then "nurses".

Photo 3.40- Electric power generator, Aflatoonian Hospital

The facility was provided with an emergency manual that was made two years before the occurrence of the earthquake. Regrettably, that manual considers only fire and traffic accidents. On the other hand the hospital provides its personnel with disaster prevention lectures, 5 times per year, and 24 disaster training modules per year; such preparedness helped the personnel to find solutions and to share the stress of the work together during the emergency phase. Also, during the emergency the hospital grouped with four other hospitals in the vicinity to pool their resources.

9.3.1.3 Equipment stability

As a result of the shaking many pieces of equipment got damaged which may be the result of displacement, topple, rocking or displacement-rocking. The personnel of the Aflatoonian Hospital stated that almost all the equipment was damaged with various degrees of severity; the cost of repairing the damage was between 10-100% of the price of the equipment itself. For instance, Table 3.13 shows some of the equipment and the severity of its damage. Some of them were fixed and some others were disposed, such as the radiology unit shown in Photo 3.41. As a result of the displacement the pipelines to the water supply attached to the Central Sterilization Room (CSR), shown in Photo 3.42, were damaged rendering the equipment useless.

Some services are still operating in prefabricated buildings, such as the operation room and women's ward. The prefabs are located on small masonry walls without being attached to any support which may make them unstable in case of strong shaking, see Photo 3.43 and Photo 3.44. The masonry is not capable of resisting horizontal loads, which is the case of earthquakes; this may result in their damage during an earthquake. The damage to walls leads to the total malfunction of the service provided in the prefabricated building.

Photo 3.41- Radiology unit

Photo 3.42- CSR unit


Photo 3.43- Operation room, Women's ward


Photo 3.44- Operation room, base view

Table 3.13- Medical equipment damage

Unit	Severity of damage	Remarks
X-Ray	10%	
Sterilizer (CSR)	10%	Damage to the water pipes because of the displacement, Photo 3.42 and Photo 3.39
Radiology	100%	Photo 3.41

9.3.1.4 Lifeline

The facility was provided with electric power generators, and water tanks which can be used during an emergency. As a result of the shaking of one of the water tanks buckled as

Photo 3.45 and Photo 3.46 show. The buckling was found on all 4 feet with various degrees of severity. However, two of them had serious impact and they affected the tank itself as it is shown in Photo 3.46. The feet should be replaced and the damaged area of the tank should be repaired to avoid any failure in case of another earthquake.

Photos 3.45, 3.46- Buckling of feet of the water tank, Aflatoonian Hospital

9.3.2 Imam Khomeini Hospital

9.3.2.1 Overview

The facility is a public hospital located in the centre of Bam City. Its capacity is 100 beds, and it hosts 290 staff members; 24 doctors, 146 nurses and 120 administrative personnel. The facility had many problems that hampered its normal functioning; mainly the severe structural damage that it experienced, see Photo 3.47. The international aid teams installed prefabricated hospitals beside the actual building, as Photo 3.28 and Photo 3.29 show. They lent Iranian personnel some of their equipment, which was used for treatment. Later the rubble was cleared and the rest of the original building was demolished. Some prefabricated buildings were installed by international companies and societies and are being used as small clinics, Photo 3.48, Photo 3.49 and Photo 3.50.

9.3.2.2 Structural damage

The facility suffered severe damage to its structure; some parts totally collapsed, see Photo 3.47. The lifelines malfunction was widespread since electricity was cut for two days in some areas and seven days in others. There was no water supply until the day of our research teams' first visit, there was no telecommunication; landline phones were cut for about 14 days and mobile phones were cut for at least one day, the heating system was inoperable until February 2004. The damage caused the facility to close. However, after receiving some equipment from the international aid teams, such as a water tank and an electric power generator, the hospital re-opened partially and started receiving patients. Later it had to be closed again after transferring all the patients to other facilities. Personnel stated that the damage had an awful impact on the patients. The facility was not provided with any alternative sources of water and electricity. After the event a 20KW electric power generator was brought to be used in the event of an emergency. The generator is provided with a fan for its cooling system which makes it independent from the water supply. Nevertheless, the facility is still in need of an alternative source of water.

The number of victims was significant, the number of personnel was not satisfactory; large numbers of staff could not reach the hospital to aid in treatment efforts because they had to help their own injured families, or they were themselves the victims. The Imam Khomeini hospital suffered also from an inadequate supply of medicine. All the stated factors added to the malfunction of the hospital and the torment of the victims who did not receive the necessary treatment before the arrival of international aid teams. The staff reported that medicine, water, food and sheets were the most vital items that the facility required.

The facility did not provide any activities to train personnel on appropriate action to take in an emergency situation. Moreover, there was no emergency manual; lectures were very limited and restricted to a certain category of personnel.

Photo 3.47- Total collapse of Imam Khomeini Hospital February 2004

Photo 3.48- Prefabricated buildings installed instead of the Imam Khomeini Hospital September 2005

Photo 3.49- Dental Station donated by some companies


Photo 3.50- Building donated by Save the Children Society Japan

9.3.1.3 Lifeline

The facility was equipped with electric power generators. No water tank was available, at least until September 2005, which renders its emergency service ineffective in the event of an emergency.

9.4 Synopsis of the problems and strengths

What it can be learned from the previous sections is that there are some problems which need to be treated and some strengths that need to be made widespread in hospitals. The two hospitals under consideration have some common problems; both facilities suffered severe structural damage, lack of personnel, lifeline and medical equipment problems. It is clear that the Aflatoonian Hospital was more prepared than the Imam Khomeini Hospital. The latter facility was not providing its personnel with any type of training activities that could make the situation better, the limited quantity of medicine was used up shortly after the patients started arriving and there was no emergency manual that could help personnel in understanding the situation that they faced. The Aflatoonian hospital was a member of a group of hospitals that work together during emergencies, which gives more possibilities to save more people and protect human life.

Iran has a very long history of earthquakes and has the highest number of victims which shows the lack of preparedness or the insufficiency of the preparedness; in other words there was no planning and organizing for emergencies. To help in reducing some of the problems we provided some suggestions which are shown in Appendix II.

10. NIIGATA-KEN CHUETSU EARTHQUAKE, JAPAN, 2004

10.1 Overview

The earthquake occurred on 24 October 2003 at 5:56 PM local time, lasting for about 20 seconds. The disaster measured 6.8 on the JMA scale. The peak ground acceleration was very high and it measured 1715 cm/sec^2 at Tokamachi town. Fortunately the earthquake did not result in a large number of fatalities as about 48 people died and 4,160 were injured (Scawthorn et el., 2006). The earthquake caused a lot of material damage; the total damage was estimated to be US $40 billion (Scawthorn et al., 2006). Further information is shown in Table 3.14.

Table 3.14- General data, Niigata-ken Chuetsu earthquake

Damage	Number	Remarks
Road damage	6,000 locations	
Landslides (caused by the event)	442	
Building damage	100,000 more than 3,000	Damaged Totally collapsed

The event caused damage to a large number of facilities; here we present the damage to some facilities and in Chapter 4 we analyse the induced damage.

10.2 Damage to hospitals

10.2.1 Ojiya Hospital

The facility is composed of 5 buildings built in different periods; 1968, 1969, 1980, 1984 and 1990. The oldest buildings, built in 1968 and 1969, suffered severe damage as shown in Photo 3.51, and Photo 3.52. The joint relating the west and east wards was also damaged as shown in Photo 3.53. Buildings built in 1980 suffered damage to their ceilings, as shown in Photo 3.54, and cracks to their structures. The facility also suffered damage to its lifelines. Electric power was cut off for four days and water supply was cut for nine days. The facility was provided with a daily supply of water by a mobile tank mounted on a truck. The damage to pipelines caused the loss of gas supply for ten days from the occurrence of the earthquake. The shortage of lifelines and the shaking caused malfunction to medical equipment.

10.2.2 Uonuma Hospital

The facility is composed of one building, built in 1978. The shaking caused some cracks in its structure. The facility lost its electric power and water supply for five days; while the gas supply was lost for 18 days from the occurrence of earthquake. The telecommunication system was also inoperable. The loss of electric power caused malfunction to several pieces of medical equipment such as CT scanner, MRI etc.

Photo 3.51- Structural damage to 1968 building, Ojiya Hospital

Photo 3.52- Structural damage to 1968 building, Ojiya Hospital

Photo 3.53- Damage to separation joint

Photo 3.54- Damage to ceilings, Ojiya Hospital

10.2.3 Tamiya Hospital

The facility, which is composed of three buildings, built in 1967, suffered slight to moderate damage. The damage to an elevated tank caused a shortage of water supply; the damage lasted for 19 days after the occurrence of the event. Telecommunication was very difficult for two days. Electric power was restored the first day after the earthquake. The loss of electric power caused malfunction of computers. The use of plastic medicine containers protected them from being damaged when they fell down from shelves.

10.2.4 Nakajo Hospital

The facility is composed of several buildings built in different periods; 1967, 1970 and 1988. The earthquake caused moderate damage; some joints were damaged as Photo 3.55 illustrates, or problems related to soil as seen in Photo 3.56 and Photo 3.57. Shortly after the earthquake all lifelines ceased because of external damage. The electric power was restored one day after the event while the water supply was restored six days later. Equipment damage was noticed mainly in the toppling of some shelves.

Photo 3.55- Damage to building's joint

Photo 3.56- Damage caused by liquefied soil

Photo 3.57- Liquefied soil

Table 3.15 summarizes the damage to 11 hospitals in the main affected cities: Ojiya City, Kagaoka City and Tokamachi City. The "✓" illustrates the existence of damage while the "×" illustrates the absence of any damage and N/A illustrates the unknown situation.

Table 3.15- Summary of damage to hospitals

City	Hospital	Structural damage	Duration of malfunction of lifelines (in hours)				
			Elec.	Water	Gas	Land. Tel.	Emerg. Tel.
Ojiya	Ojiya Hospital	✓	96	216	240	96	216
	Uonuma Hospital	✓	120	120	432	≤ 24	≤ 24
Nagaoka	Tamiya Hospital	✓	≤ 24	456	×	48	48
	Nagaoka Central Hospital	✓	≤ 24	24	120	×	×
	Yoshida Hospital	✓	×	×	×	×	×
	Nagaoka West Hospital	✓	≤ 24	≤ 24	×	≤ 24	≤ 24
	Tachikawa Hospital	✓	×	×	216	×	×
	Niigata Psychological Centre	×	×	×	×	×	×
Tokamachi	Nakajo Hospital	✓	24	144	N/A	×	N/A
	Ojiya Hospital-Tokamachi Clinic	✓	24	×	96	96	96
	Niigata national Tokamachi Hospital	✓	24	144	72	×	×

PART C
DISCUSSION AND CONCLUSION

11. DISCUSSION AND CONCLUSION

At the end of this chapter, it is necessary to summarize the points that are found to be interesting and can be considered in the study. Table 3.16 summarizes the main problems that were faced during all previous experiences. The occurrence of a particular type of damage was marked with "✓". In the case of no damage and/or no information nothing was marked in the appropriate cell. Damage caused to facilities can be categorized into three categories: *structure* (including non-structural elements), *lifeline* and *equipment*. In this part a discussion of all categories is done to find the problems that are common and can be considered in the present study.

11.1 Structure and non-structure

In all the presented cases, the structures of healthcare facilities were damaged. The damage varied between cases; the difference was mainly because of the strength of structures, which depends on many factors such as age, construction material among others, but also on the strength of the earthquake. For example the magnitude of the Boumerdes, Algeria, and the Bam, Iran, earthquakes was not as strong as the Sanriku Minami, Miyagi-ken Hokubu and the Tokachi-Oki earthquakes of Japan; however the damage was huge in the first two cases and slight to moderate in the last one; at least none of the Japanese facilities collapsed while collapse was widespread in Algeria, Iran, India and others. The age and the construction material were the main causes for the destruction of the latter cases. Whilst, the location of the Shiu-Tuan hospital that was constructed just 2 years before the earthquake hit Taiwan in 1999.

What can be concluded here is that factors play a very different role in each case. The Japanese experience shows clearly that it is possible to build a structure able to withstand strong earthquakes. For that reason, we think that focusing on structural issues may not be very beneficial for this study, as we are seeking a universal solution to reduce earthquake impact.

11.2 Lifelines

The situation of lifelines is not very different between countries. For example, electricity is transported using cables, so the damage to any of those cables during shaking can cause the entire city to blackout. The other main cause of the vulnerability of lifelines is pipelines; to transport gas and water, pipelines are used. Pipelines constitute one of weakest elements in the lifeline systems as their geometry makes them very weak and irresistible to shaking.

The difference between prepared and unprepared countries lies with alternative sources. Prepared countries are making use of alternative sources while unprepared countries do not consider them seriously. The loss of lifelines is still able to affect the functioning of healthcare facilities and can even cause its closure. The majority of medical equipment depends on one or more of the lifelines such as water, electricity, gas or others, so a malfunction to any of the dependent lifelines will cause the malfunction of the medical equipment and therefore the reduction of the quality of treatment and put people's lives under threat.

The lifeline issue is still being investigated by researchers with the purpose of finding a solution to protect its systems. In this study we will focus on the same issues but with different focus than other researchers. Our purpose is finding a solution to some problems and making a contribution to the literature. The investigations showed that internal lifeline system malfunction depends not only on the ground motion but also the external functionality of the system source. Lifeline shortage affected greatly the functionality of the equipment in some cases. As the ground motion increases, the damage becomes easier to occur and therefore malfunction is also more likely to happen. The following chapter, Chapter 4, discusses further problems and suggests some solutions to strengthen the systems.

11.3 Equipment

Equipment was the most unstable part that was found in all studied cases, simply because they are not attached to any support, i.e. they are freely standing, or are fixed by bolts if the size is large. Table 3.16 illustrates that almost all facilities have experienced damage to some of their equipment. Hospitals contain a very large amount of equipment of different sizes and with differing maintenance requirements. Some of them are attached to their supports; others are free standing or mounted on wheels and such like. This maintenance difference makes their responses different too.

Attached equipment shake then fall down, while free standing equipment move and hit other elements which may cause damage to them too. The latter also causes untidiness in hospitals and reduces the availability of space when it is needed the most. In both cases, being attached or not, the damage to equipment is apparent. This would be a good subject to consider in detail in ensuing chapters.

11.4 Other issues

Some other problems were found during the investigations but may not be considered in the present study as they are not directly related to engineering; however, they impact upon the functioning which is the goal of this study, Appendix II presents some of them.

Table 3.16- Summary of damage caused by previous earthquakes

	Lifelines				Equipment				Structure
Event	**Water**	**Elec.**	**Gas**	**Telecom.**	**Mechanical**	**Anchorage failure**	**Displacement / Toppling**	**Elevator**	
Northridge 1994	✓	✓				✓	✓		✓
Hyogo-ken Nambu 1995	✓	✓	✓	✓			✓		✓
Marmara 1999	✓	✓		✓			✓	✓	✓
Chi-Chi 1999	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bhuj 2001									✓
Boumerdes 2003	✓	✓		✓		✓	✓		✓
Sanriku Minami, Miyagi-ken Hokubu, Hokkaido Tokachi 2003	✓	✓		✓	✓		✓		✓
Bam 2003	✓	✓		✓			✓		✓
Niigata-ken Chuetsu 2004	✓	✓	✓	✓				✓	✓

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CHAPTER 4

PERFORMANCE OF LIFELINES AND RESPONSE OF EQUIPMENT

1. INTRODUCTION

This chapter focuses on assuring the treatment of all injuries. This can be done by different methods. Here we suggest 1) ensuring the functioning of the required medical services so that the majority of casualties can receive treatment, 2) a strategy to dispatch the injured at the time of the emergency. In this study we will focus on treatment of the majority of casualties by ensuring the preparedness of vital lifeline systems. Given that the number of systems is rather large and given that making experiments is costly we will be limited to the preparation of certain systems rather than all systems. A system is chosen according to its importance for the functioning of a facility, or its extensive use in a facility. The idea is summarized into the next:

- Finding the most important lifeline that affects the functioning of the entire facility. Studying its vulnerabilities and strengthening its response to emergency. The strengthening should reach the rest of the systems and installations.

- Finding the service that ensures the treatment of the majority of earthquake-related injuries. Studying the response of each of its systems to shaking and estimating damaging factors.

To fulfil the above purposes the chapter is divided into three divisions; the first division discusses in detail the impact of the Chuetsu earthquake of 2004 in Japan on the lifelines and the equipment. The second division classifies the lifelines according to the most important lifeline for the functioning of a facility. The last division is an evaluation of the response of equipment to dynamic waves.

2. ANALYSIS OF DAMAGE DUE TO NIIGATA-KEN CHUETSU EARTHQUAKE

2.1 Outline of investigation

We carried out investigations on 40 hospitals to find the damage caused by the earthquake. The investigation was conducted via a survey (sent by postal mail) and by visits to some of the facilities. It is concerned with damage to *structural and non-structural elements*, e*quipment and furniture*, *medical equipment* and *lifelines*. Table 4.1 points out the detailed parts that were considered in the investigation. It is also concerned with the age of buildings, as seen in Figure 4.1, and the number of floors, as shown in Figure 4.2. More than 42% of buildings are composed of four to six floors. Among the 40 facilities at least 26 hospitals, which represents 65% of the total number, have emergency services, as is illustrated in Figure 4.3. More than half of the facilities are classified as 2nd class emergency hospitals, see Figure 4.4.

The purpose behind the investigations is to find in detail the problems caused to lifelines and equipment. The structural and non-structural elements are not considered as it was discussed in the last chapter, however some information found during the investigations are shown but will not be analyzed in this study.

2.2 Damage to healthcare facilities

2.2.1 Impact of the earthquake on the healthcare system

The earthquake caused damage to at least 27 hospitals varying between very severe and slight damage. The minimum intensity registered at the site of the facilities was 5^{-} (Japanese intensity) while the maximum registered intensity was 6^{+}; Figure 4.5 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 equipments were displaced and even turned over in cases. In more than 10% of the facilities there were some cracks in the external and internal walls, see Table 4.2. Furthermore, several facilities suffered damage to their lifelines, internal installations and medical equipment as shown in tables 4.3, 4.4 and 4.5, respectively. As the last four tables illustrate, the intensity 6^+ caused damage to all the investigated elements in 10% of the facilities.

It should be mentioned that in tables 4.1 through 4.5 the sign "●" illustrates that the ratio of facilities suffering that type of damage exceeds 10%. While sign "○" demonstrates that between 5% and 10% of the facilities have experienced that type of damage.

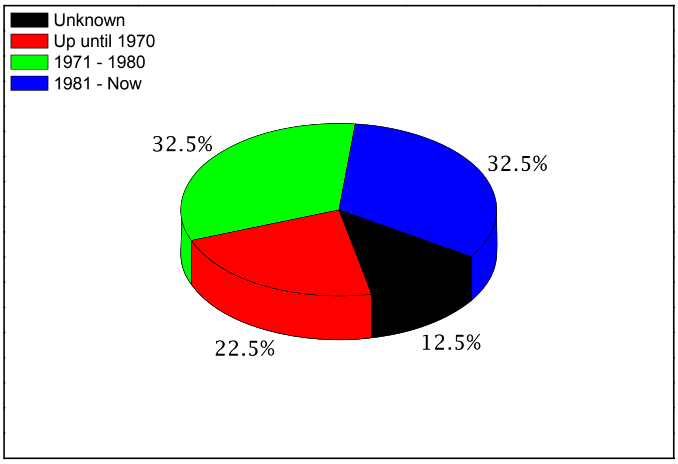


Figure 4.1- Periods of construction

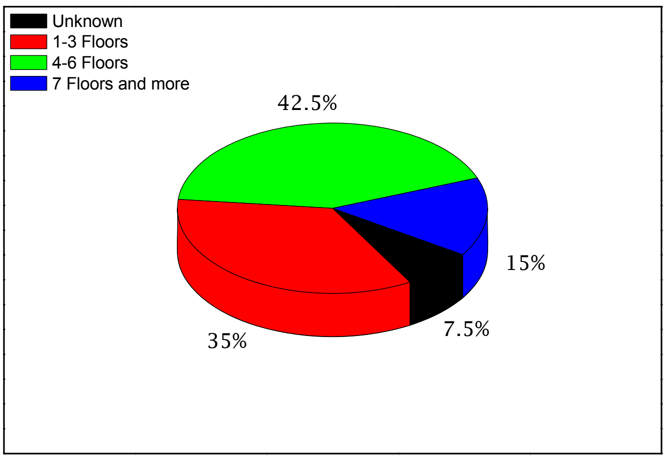


Figure 4.2- Number of floors

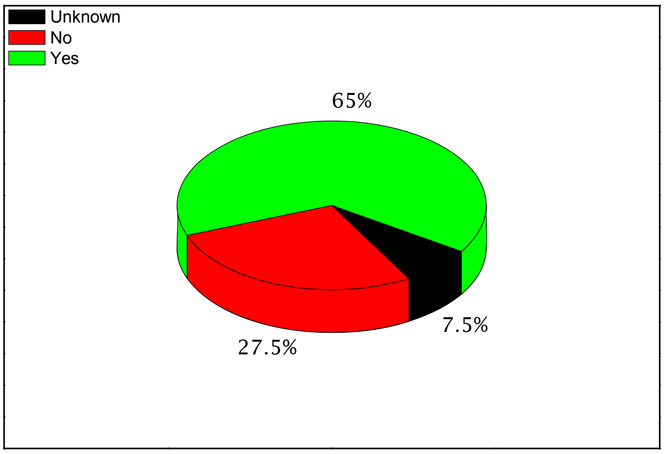


Figure 4.3- Existence of an emergency service

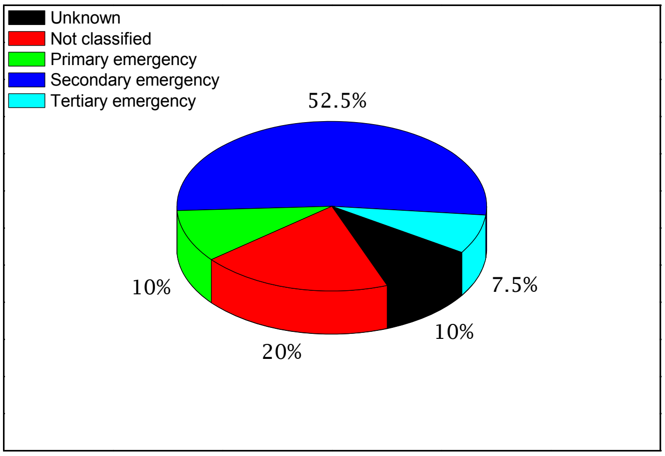


Figure 4.4- Classification of emergency service

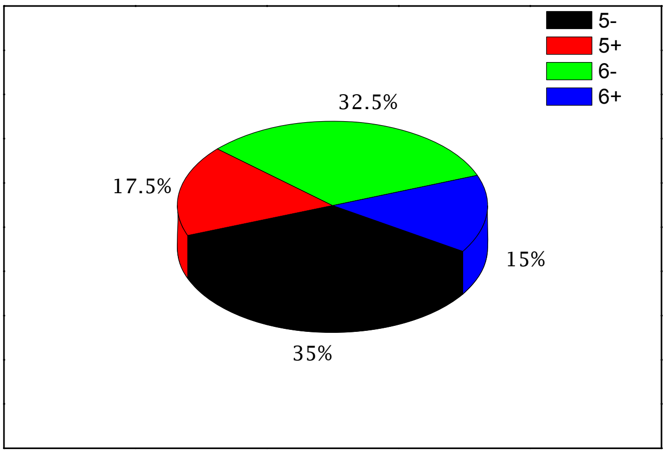


Figure 4.5- Proportion of buildings and seismic intensity

Table 4.1- Aspects checked during investigations

		Elements	Contents
Building	Interior	Wall	Cracking of concrete and peeling of facing Reinforcement exposure
		Window - glass	Glass cracks/breakage, sash deformation Window difficulties; failure to open/close
		Entrance/Exit	De-formation/failure of door, glass cracks, Door difficulties; failure to open and close
	Exterior	Pillar/Wall	Cracking/peeling of concrete facing and reinforcement exposure
		Door	De-formation/failure of the door, glass cracks, Difficulty/failure to open and close
		Ceiling	Slipping/falling of ceiling board
		Floor	Tiles cracking/peeling off
		Furniture	Furniture displacement/turning over Television/glassware displacement/turning over
Lifeline and Equipment		Lifeline supply	Electric, water, gas, communication, laundry, kitchen
		Electric installation	Damage/falling of illumination
		Plumbing equipment	Sink damage, rest room unserviceable, toilet damage Wall tiles peeling off, piping damage
		Air-conditioning equipment	Breakdown and exit cone damage of air conditioning unit, Damage to piping system
		Equipment attached to roof	Air conditioning/elevated tank unit turning over/displacement End of piping
		Anti-disaster equipment	Damage to sprinkler/ incorrect operation Opening/ closing difficulty of fire door, damage of fume tight flap wall
		Transport equipment	Stoppage of elevator/breakdown
Medical elements		Inspection equipment	X-Ray/Film development units, CT Scanner, MRI
		Remedy/Disposal equipment	Wound irrigation, 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 4.2- Structural and non-structural damage experienced in facilities

Damaged elements	Earthquake Intensity			
	5-	5+	6-	6+
External walls				
cracks	●	●	●	●
concrete was peeled			●	●
Exposure of steel bars			○	●
Windows: Glass and its Frame				
Glass of windows was cracked		●	●	●
Window glass was broken		●		●
deformation of the frame		●		●
Difficulty in opening/closing the window		●	○	●
Window couldn't be opened/closed				●
Entrances and Balconies				
Deformation of the entrance	○			
Door came off				
Glass of the door broke down	○	●		
Difficulty in opening/closing of the door	○		○	●
Door couldn't be opened/closed	○		○	●
Columns				
Cracks in column	○	●	●	●
Concrete was peeled	○	●	○	●
Exposure of steel bars	○			●
Internal walls				
Cracks in walls	●	●	●	●
Concrete was peeled		●		●
Exposure of steel bars				●
Doors				
Deformation of the door				●
Door came off				●
Glass of the door broke down				●
Difficulty in opening/closing of the door		●	○	●
Door couldn't be opened/closed				●
Ceilings				
Ceilings partially came off	●	●	●	●
Ceiling fell down			○	●
Floors				
Flooring cracked	●	●	●	●
Tiles came off		●	●	●
Internal Equipment				
Displacement of desks		●	●	●
Items on top of desk turned over	●	●	●	●
Book-shelves and tall equipment moved	○	●	●	●
Book-shelves and tall equipment turned-over	○	●	●	●
Displacement of TV		●	●	●
TV turned over		●	●	●
Glass items on top of the desk broke	●	●	●	●

Table 4.3- Lifeline damage experienced in facilities

Damaged elements	Earthquake intensity 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 4.4- Internal installation damage experienced in facilities

Damaged elements	Earthquake Intensity 5-	5+	6-	6+
Electric Installation				
Ceiling illumination slipped		●	●	●
Ceiling illumination breakdown		●	●	●
Ceiling illumination fell down		●	○	●
Plumbing equipment				
Sink breakdown	○	●	○	
Toilet could not be used		●	●	●
Toilet breakdown		●		●
The wall tile of the rest room and the sink peeled off	●	●	●	●
Damage to pipeline/occurrence of leakage	●	●	●	●
Air conditioning equipment				
The ceiling and wall mounted air conditioning unit was broken			●	●
The ceiling and wall exit cone was broken		●	○	●
The piping for air conditioning units was broken		●	●	●
The cooling unit outside the room turned over	○			●
Roof-mounted equipment				
The air conditioning machine moved			●	
The air conditioning machine turned over	○		○	
The elevated tank broke		●	●	●
The elevated tank turned over				●
Pipes were removed from attachments	○	●	●	●
Anti-disaster facility				
The sprinkler broke			○	●
The sprinkler malfunctioned			○	
The fire door became difficult to open and close	○		○	●
The fume tight flap wall broke				
Transport equipment				
The elevator stopped automatically	●	●	●	●
The elevator stopped due to power failure	●	●	●	●
The elevator was broken	○	●	●	●

Table 4.5- Medical equipment damage experienced in facilities

Damaged element	Earthquake Intensity			
	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 wound irrigation 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 medicine scaling 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				●

2.2.2 Analysis of the results

2.2.2.1 Estimation of peak ground acceleration

We lead the investigation into more detail and we calculated the peak acceleration at each facility and we compared it to the damage in each case. The calculation of the peak ground acceleration was completed according to Equation 4.1. The estimation of the peak ground acceleration (in cm/sec^2), the magnitude, M, and the hypocentre distance, X, (in km) should be provided.

$$\log A = a_r M - \log X + b_r X + c_r \qquad (4.1)$$

Where

a_r, b_r and c_r are regression coefficients.

To be able to estimate the acceleration at each facility the regression coefficients should be found. A multiple regression analysis was conducted using data from the main shock and seven aftershocks. The detail of each of the events is shown in Table 4.6. The data was obtained from the accelerometer networks of the Kyoshin Network (K-NET) and the Digital Strong-Motion Seismograph Network (KiK-net) in the cities shown in Table 4.7. Once the coefficients were determined the attenuation relation becomes as it is shown in Equation 4.2. The acceleration at each of the facilities is shown in Table 4.8.

$$\log A = 0.596M - \log X - 0.0031X + 0.0497 \quad (4.2)$$

Table 4.6- Detail of events considered during the estimation of acceleration

Niigata Chuetsu Earthquake	**Magnitude *M***	**Hypocenter *X* (km)**	**Date and time**
Main shock	6.8	13	2004.10.23 at 17:56
Aftershock 1	6.3	9	2004.10.23 at 18:03
Aftershock 2	6.3	10	2004.10.23 at 18:34
Aftershock 3	6.0	10	2004.10.27 at 10:40
Aftershock 4	6.0	12	2004.10.23 at 18:12
Aftershock 5	5.9	10	2004.10.23 at 19:46
Aftershock 6	5.7	15	2004.10.23 at 18:07
Aftershock 7	5.6	10	2004.10.25 at 06:05

Table 4.7- Name of cities used to calculate the accelerations

K-NET		**KiK-net**	
Iwataniguchi,	Samugawa,	Nagaoka,	Muika and
Murakami,	Shibata,	Kamo,	Yuzawa
Niigata,	Niitsu,	Shimoda,	
Maki,	Sanjou,	Yunotani,	
Matsumura,	Teradomari,	Shiozawa,	
Nagaoka,	Ojiya,	Myoukou,	
Koide,	Tookamachi,	Seiro,	
Shiozawa,	Tsunan,	Matsumura,	
Yasuzuka,	Naoetsu	Kawanishi,	
Arai,	NagaokaShisho	Maki,	

Table 4.8- Acceleration at the site of each facility

Era of construction	PGA (cm/sec^2)	Name of facilities
1970□	790.6	Ojiya General Hospital
	548.8	Nakajou daini hospital
	548.8	Nakajou Hospital
	510.0	Tamiya Hospital
	495.0	Nagaoka Chuo General Hospital
	490.8	Yoshida Hospital
	435.1	Niigata Prefectural Tokamachi Hospital
	400.0	Saito Memorial Hospital
	386.2	Tochiogo Hospital
	235.3	Sannocho Hospital
	218.5	Oshima Hospital
	196.2	Niigata Prefectural Kamo Hospital
1971～1980	771.8	Uonuma Hospital
	758.0	National Health Insurance Municipal Hrinouchi Hospital
	735.4	Ojiya Sakura Hospital
	556.0	Minamiuonuma Municipal Yukigunidaiwa Hospital
	404.8	Minamiuonuma Municipal Jounai Hospital
	324.4	Niigata Prefectural Matsushiro Hospital
	318.7	Kashiwazaki Central Hospital
	301.4	Kamimura Hospital
	248.6	Municipal Tsunami Hospital
	211.0	Niigata Prefectural Kakizaki Hospital
	209.2	Tsubame Rosai Hospital
	200.0	Niigata Prefectural Yoshida Hospital
	140.7	Joetsu General Hospital
	139.0	Takada Nishishiro Hospital
	136.2	Joetsu Medical Center Hospital
1981～	622.7	Honda Hospital
	488.7	Yuuyuu Kenkoumura Hospital
	480.6	Tachikawa General Hospital
	468.6	Nagaoka Red Cross Hospital
	468.6	Itsukamachi Hospital
	436.8	Niigata Prefectural Psychiatry Medical Center
	344.9	Kariwagun General Hospital
	338.7	Mitsuke Municipal Adult Diseases Center Hospital
	325.5	Seki Hospital
	238.9	Sanjo Hospital
	230.4	Tominaga Kusano Hospital
	229.0	Sanjo Higashi Hospital
	223.6	Sanjo General Hospital
	143.7	Niigata prefectural Central Hospital
	137.1	Kudo Hospital

2.2.2.2 Influence of acceleration on lifelines

The investigation showed that from 150-250cm/sec^2 lifelines start experiencing problems. 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 Figure 4.6. Due to the fragility of the piping system, water and gas supply was damaged more than the electric power system. The shortage of water and gas was for up to 18 days. A 200cm/sec^2 acceleration caused a 2-day period shortage; while higher accelerations can cause the shortage period to be longer, see Figure 4.7 and Figure 4.8.

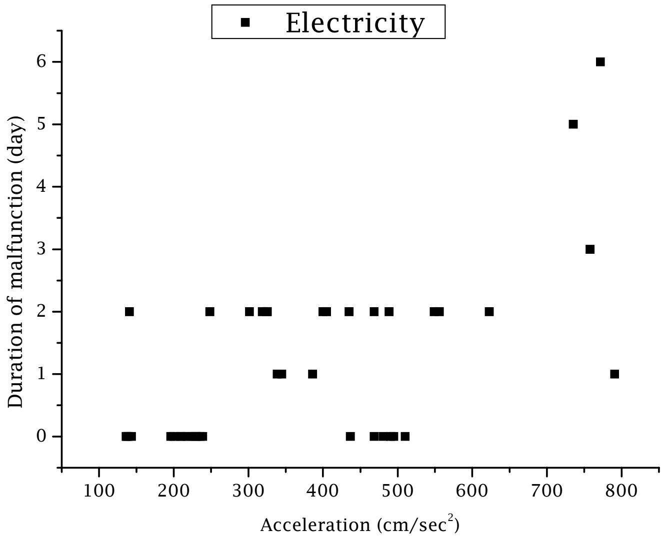


Figure 4.6- Duration of malfunction of electric power

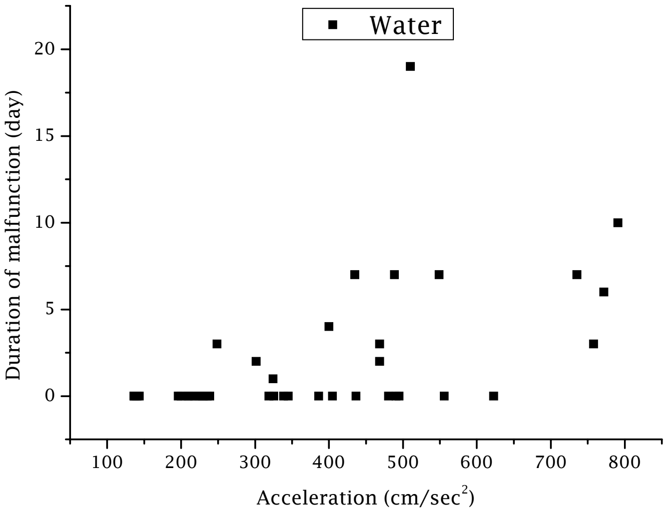


Figure 4.7- Duration of water supply shortage

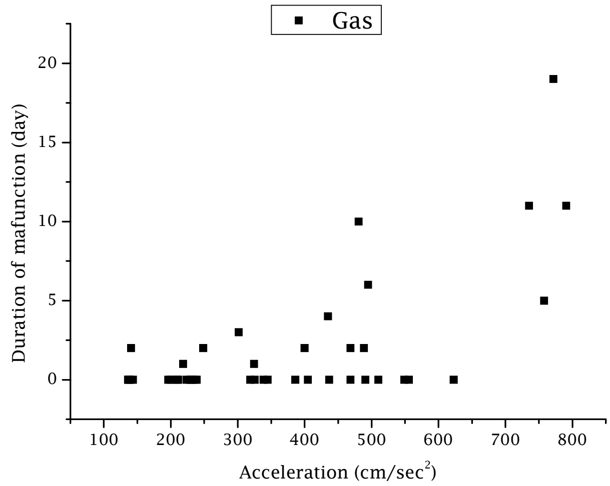


Figure 4.8- Duration of malfunction of gas supply

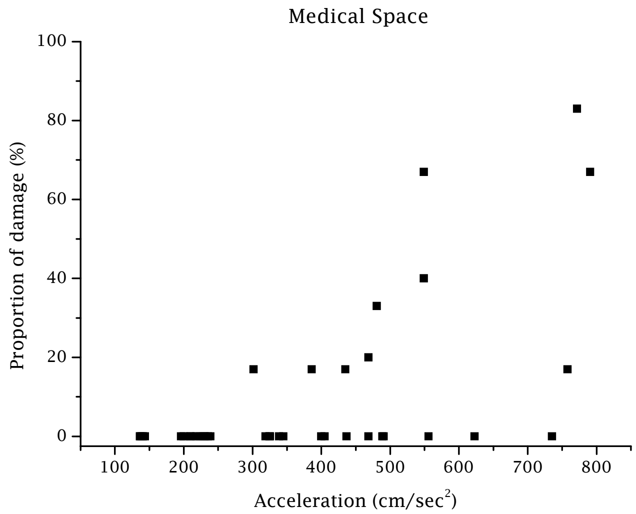


Figure 4.9- Impact of acceleration on the availability of space

2.2.2.3 Influence of acceleration on the medical situation

Obviously the earthquake affected the situation of the medical services. That effect was by reducing the space that is available or damaging equipment. Figure 4.9 illustrates that an acceleration of 300 cm/sec^2 was able to cause untidiness in 20% of the space in a facility; where as an acceleration of 800cm/sec^2 can cause untidiness in 80% of the space. It has to be mentioned that the condition can be made better 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, figures 4.10 and 4.11 show that it can reach 100% in some cases, 40% in others and 0% in different occurrences. The difference in results is due to the preservation of equipment that differs from one facility to another, in addition to the stochastic problem of equipment displacement when nothing is connecting them to their support and thereby controlling their motion.

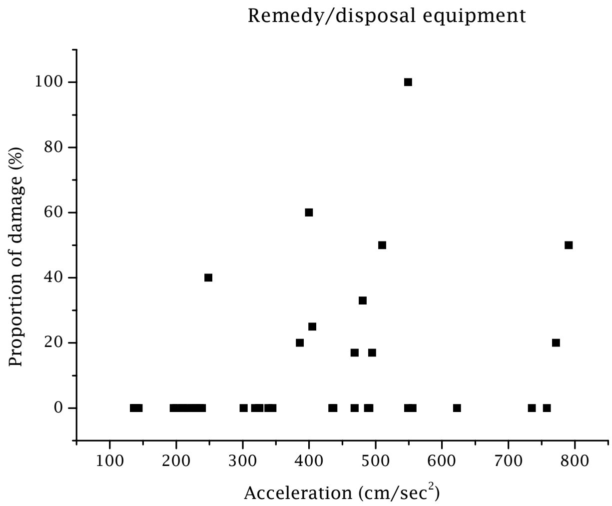


Figure 4.10- Impact of acceleration on remedy and disposal equipment

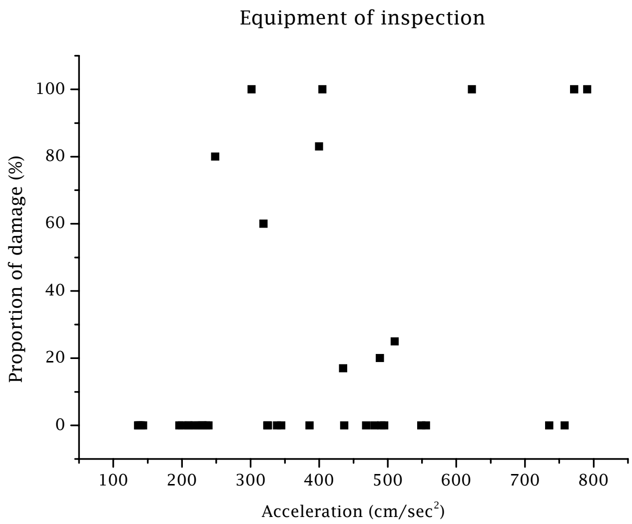


Figure 4.11- Impact of acceleration on equipment of inspection

3. PERFORMANCE OF LIFELINES

3.1 Introduction

Previous events have highlighted problems which faced healthcare facilities in Japan (Shinozuka, 1995), Taiwan (Lee et al., 2000), Algeria (Hamada et al., 2004) and Iran

(Achour et al., 2005) particularly structural, non-structural and lifeline vulnerabilities. Damage to healthcare facilities is a worldwide problem. The severity of the structural damage varies from country to country, but lifeline damage is still somewhat comparable. For example, after studying several cases we learned that Japan, Turkey, Taiwan, Algeria, and Iran have all experienced lifeline shortage after the occurrence of earthquakes in January 1995, August 1999, September 1999, May 2003 and December 2003 respectively. The bulk of the damage lead to the same problems: blackouts, water shortage, equipment dysfunction among others. These problems reduced the capacity of the hospitals (Lee et al., 2000) and caused death to patients and personnel in some cases. Consequently, healthcare facilities are urged to be more prepared for emergencies, not only structurally but also in terms of non-structural elements such as lifelines. This study focuses only on lifeline related issues; therefore it is vital to know the causes of lifeline damage. Specifically, it clarifies the importance of electricity to hospitals as a result of the experience of hospitals after the 2003 earthquakes; the Sanriku-Minami earthquake of May 26th, the Miyagi-Ken Hokubu earthquake of July 26th and the Tokachi-Oki earthquake of September 26th.

The present section discusses the reinforcement of the lifelines of healthcare facilities by using solar energy. Myrtle et al. (2005) classified the importance of essential systems in hospitals under extreme events and other researchers have worked on the use of renewable energy such as solar systems (Paksovy et al., 2000) and fuel cells (Damberger, 1998); some of the studies were done on international cases such as Italy (Bizzari et al., 2005), Spain (Gomez-Amo et al., 2004) and the UK (Al-Daini et al., 1994). Some studies were applied on hospitals in Paksovy et al. (2000), Damberger (1998) and Bizzari et al. (2005). But, unlike those previously mentioned, this study clarifies the problem faced in healthcare facilities and provides a solution by discussing the use of renewable sources of energy in the event of an emergency, particularly an earthquake related one.

This section aims to 1) show the importance of electric power in hospitals and 2) study the possibility of taking advantage of solar systems to strengthen the response of healthcare facilities during earthquake-related emergencies. Five main sub-sections constitute the section; a) introduction to the events under consideration and the questionnaire, b) illustration of the importance of electric power, c) the weaknesses of the actual systems used in healthcare facilities, i.e. fuel systems and proposition of the Solar System and comparison between both systems d) conclusion of the comparison and e) the seismic response of the proposed system.

3.2 Questionnaire outline

We carried out a survey in the north of Japan in areas affected by the earthquakes to find out the difficulties encountered by healthcare facilities during the emergency. A total of 120 copies of the questionnaire were sent, by postal mail, to different hospitals in Tohoku and Hokkaido areas, Japan in December 2003. Unfortunately not all facilities have replied to our request since only 66 facilities responded to our survey. Each hospital which did respond was assigned an identifying code H1 to H66. Responses numbered 66 which represent 55% of the total. The facilities are located in affected areas near the majority of incidents. Since about 45% of the respondents accepted victims, this indicates the importance of the sample considered in this study. The questionnaire is composed of 45 questions divided into seven different sections: *Structural Damage*, *Injury to Personnel*, *Lifeline Damage*, *Medical Equipment Damage*, *Relief Activities*, *Crisis Management* and *General Data*.

3.3 Questionnaire analysis

Of the total respondents, 45 hospitals were found suitable for further study on how lifeline outages impact their operations. These 45 facilities did not suffer any structural damage that might in turn cause damage to equipment and therefore can be judged to have suffered from lifeline damage caused by true failure. The analysis was achieved by using a program code that applies "*Discriminant Function Analysis*" to resolve equations (Aoki, 2005). The method consists of finding an equation that relates all the variables that affect the functioning of the facilities and classifies the lifelines according to their importance. A total of six lifelines identified in Table 4.9 are considered in the analysis, given that they exist in any facility. Some other lifelines were found only in a few other hospitals but were not included in the analysis; such as elevators, special gases for treatment, among others. Each of the lifelines was illustrated with a mathematical variable, x_i, which means the duration of the malfunction of each lifeline, as Table 4.9 shows. The 45 hospitals were screened according to the usefulness of cases; 21 cases were removed since some of them had incomplete information or did not suffer any malfunction to their lifelines and thus they functioned without any problem. The remaining 24 hospitals were found to be suitable for analyzing lifeline impact. Table 4.10 shows the duration of malfunction of each lifeline for those hospitals analyzed each is identified by their respective codes. The data was divided into two groups according to the impact of the lifeline on the functionality of the hospital. The first group was designated by "y=0" which represents *no impact*, i.e. the facility could function, and the second group was designated by "y=1" which implies an impact on the performance of the hospital, i.e. existence of malfunction. We decided whether the impact had an effect on the performance or not by asking in question Number 10 "*Did the lifeline malfunction have any impact on your task, Yes or No?*" Having calculated the coefficients of the variables, using the Discriminant Function Analysis mentioned above, the duration of malfunction shown in Table 4.10 and the answer to question Number 10, Equation 4.3 was found. To perform a check Equation 4.3 was used to determine the malfunction of the facility by calculating value "y" and then comparing if the hospital had actually experienced a malfunction or not. A positive value of y implies functionality of the facility, i.e. considered as y=0, whereas a negative value implies malfunction, i.e. considered as y=1. The calculated values of "y" and the estimation of malfunction are shown in Table 4.10. As the table illustrates the majority of cases, about 67%, the result was validated with the reality. The wrong estimations are displayed with "False" in the Remark/Results column. The standardized coefficient of each variable is calculated and the values are plotted in Table 4.11 (a). The classification of the importance of each variable is done according to the absolute value of the standardized coefficients (Aoki, 2005). The most important variable, i.e. lifeline, is that which has the highest standardized coefficient. Table 4.11 (b) shows the degree of importance of each variable. The coefficient of electricity is the highest among the others, thus lack of electricity having a standardized coefficient of 0.534 represents the most important cause of malfunction in hospitals. This result concurs with Myrtle et al. (2005) in which he classified the electrical system as the second most important lifeline after the piping system in hospitals.

$$y = -1.36x_1 + 0.163x_2 + 2.059x_3 - 0.067x_4 + 0.043x_5 + 1.27x_6 + 0.123 \quad (4.3)$$

Table 4.9- Parameter/System - Mathematical variable

Parameter – System	Mathematical variable
Electricity	x_1
Gas Supply	x_2
Water Supply	x_3
Telecommunication – Landline	x_4
Telecommunication – Mobile phone	x_5
Telecommunication – PHS phone	x_6
Judgement Value (occurrence of malfunction)	y

3.4 Performance of fuel power generators in emergencies

The use of electric power generators as alternative sources helped the functioning of facilities greatly; this can be seen in Table 4.10 where only one facility, H61, lacked electrical power and suffered malfunction. Consequently, it is obvious to say that if power generators were not present the facilities could not function given that a significant amount of equipment, including medical equipment, depends on electricity to function. The Ishimaki Night Emergency Centre, H51, was forced to halt X-Ray services as the power generator could not cover the requirements of this vital service, a further example is the Tohoku Koseinenkin Hospital, H29, which uses well water which must be filtered electrically before use, if filtration does not occur the water is unsafe for human consumption. The use of emergency power generators is not always reliable as a lack of water or oil can cause the generators to malfunction; such as occurred during the Hyogo-ken Nambu earthquake when the Hyogo Medical Centre had to be closed for two weeks because of damage to the water tank which caused a blackout (Shinozuka, 1995). The same was found in the Medical College of Kobe University when the generators had to be turned off to prevent overheating (Shinozuka, 1995). During the Niigata-ken Chuetsu earthquake, several facilities could not use their emergency generators for several reasons such as lack of water, oil and others. In Taiwan, as a result of the Chi-Chi earthquake of 1999 the emergency engines of the Christian and Shiu-Tuan hospitals were inoperable because they were damaged during the shaking (Lee et al., 2000).

3.5 Comparative study

3.5.1 The need of Photovoltaic Technology in hospitals

If we comprehend the previous sections correctly, we will understand that current alternatives, i.e. power generators, are at risk of failure, thus there is a need to find other sources which are more reliable and not dependent on other lifelines to function. Photovoltaic (PV) systems respond positively to this situation as they do not depend on any other lifeline. The PV system is also reliable, economical and environmentally friendly. However, is it possible and beneficial to substitute engine power? We carried out a comparative study to answer this question which will be the subject of next two sections. The seismic safety of the PV system will be considered later.

3.5.2 Electricity Production

Fuel System: In general, energy is defined as the product of power, *PE*, by time, *t*. The energy produced by an engine, *EE*, can be obtained according to Equation 4.4. Table 4.12 illustrates the energy that can be produced within 3 days.

$$EE = PE \times t \tag{4.4}$$

Solar System: The total energy delivered, *EPV*, shown in Equation 4.5, is the energy delivered by a single array, *EA*, shown in Equation 4.6, multiplied by the number of arrays, n_A , and the co-efficients for inverter losses, η_{invs} , and absorption rate, η_{abs}.

$$EPV = n_A \times EA \times \eta_{inv} \times \eta_{abs} \tag{4.5}$$

$$EA = S \times \eta_p \times \overline{H}_t \times (1 - \lambda_p) \times (1 - \lambda_c) \tag{4.6}$$

Unlike the fuel system, which depends only on the power of the engine, the solar system must consider more than one factor; a) the individual characteristics of each array, b) the location of the system, i.e. radiance, and c) the availability of space. To satisfy these factors we chose different types of PV arrays, see Table 4.13, and different locations where the system can be installed. The locations considered have different radiance levels and are all seismically active areas so as to realize the purpose of the entire study. The countries Algeria, Iran, Japan and Turkey were considered because of their earthquake vulnerability and because they represent an array of radiance levels from low to high. Table 4.14 shows the different radiance values considered in the analysis. Please note that Kanazawa, Japan's minimum sunshine of 1,300 hours/year is additionally factored so as to illustrate the worst case scenario and also to broaden the possible spectrum for other countries in the world to make use of PV systems. In the other cases we considered the average brightness as shown in Figure 4.12.

To make the comparison easy we sought the same amount of energy produced by the generators by using the solar system within the same period of time, 3 days.

Table 4.10- Malfunction in each hospital -No structural damage

Hospital	x_1	x_2	x_3	x_4	x_5	x_6	Malfunction- *y*			Remark	
			(hour)				*Real*	*Calculation*	*Estimation*	*Earthquake*	Results
H2	0.1	0	0	0	0.1	0.1	0	0.118	0	Hokkaido	
H3	1	0	0	0	0	0	0	-1.238	1	Hokkaido	FALSE
H7	0.2	0	0	0	0	0	0	-0.149	1	Hokkaido	FALSE
H9	0	0	0	1.5	1.5	1.5	0	1.993	0	Hokkaido	
H14	0	0	0	0	6	0	0	0.378	0	Hokkaido	
H21	0	0	0	0	2	0	1	0.208	0	Hokkaido	FALSE
H22	1	0	0	0	0	0	0	-1.238	1	Miyagi-H	FALSE
H26	0	0	0	0	1	0	0	0.166	0	Miyagi-S	
H28	0	0	0	0	3	0	0	0.251	0	Miyagi-S	
H30	0	0	0	0	3	0	0	0.251	0	Miyagi-S	
H36	0	0	0	0.5	0.5	0.5	0	0.746	0	Miyagi-H	
H37	0	0	0.7	3	3	0	0	1.491	0	Miyagi-S	
H38	0	0	0	3	3	0	0	0.050	0	Miyagi-S	
H39	0	0	0	0.1	0.1	0	1	0.121	0	Miyagi-N/A	FALSE
H41	0	2	0	0	0	0	0	0.448	0	Miyagi-H	
H42	0	0	0	8	8	0	0	-0.072	1	Miyagi-H	FALSE
H43	0	0	0	1	1	0	0	0.099	0	Miyagi-S	
H45	0	0	0	1	1	1	0	1.369	0	Miyagi-H	
H53	0	0	0	1	1	1	0	1.369	0	Miyagi-N/A	
H54	0	0	0	3	0	0	0	-0.078	1	Miyagi-N/A	FALSE
H57	0	0	0	3	3	0	1	0.050	0	Miyagi-S	FALSE
H61	1.5	0	0	1	1	0	1	-1.943	1	Miyagi-H	
H62	0	0	0	0	1	0	0	0.166	0	Miyagi-S	
H65	0	10	0	2	2	0	0	1.670	0	Miyagi-S	

Hokkaido: Tokachi-Oki Earthquake, Miyagi-H: Miyagi-ken Hokubu Earthquake,
Miyagi-S: Miyagi-ken Sanriku-Minami Earthquake, Miyagi-N/A: the response is not précised Miyagi-H or Miyagi-S.

Table 4.11- Standardized coefficients and classification of lifelines

(a) Standardized coefficients

System	Standard. Coef.
Electricity	*-0.534*
Gas	*0.328*
Water	*0.288*
Tel. Landline	*-0.120*
Tel. Mobile phone	*0.083*
Tel. PHS phone	*0.506*

(b) Classification

Degree of importance	Absolute value of Standard. Coef.	System
1	*0.534*	Electricity
2	*0.506*	Tel. PHS
3	*0.328*	Gas
4	*0.288*	Water
5	*0.120*	Tel. Landline
6	*0.083*	Tel. Mobile phone

PV installation: The PV installation depends on two main techniques for its use: Off-Grid and On-Grid techniques (Ministry of Natural Resources, 2005). The evaluation was achieved according to the On-Grid technique. Panels are supposed to be fixed and placed 30^{o} from the horizontal to collect the maximum energy. The stability of the system will be discussed in a different study.

Evaluation Results

Productivity of energy: To produce a certain amount of energy in a fixed period of time the solar system should have a minimum power. The results in Table 4.15 show that minimum power is constant and it does not depend on the individual power of the array. This is met by adjusting the number of panels in relation to the panel power

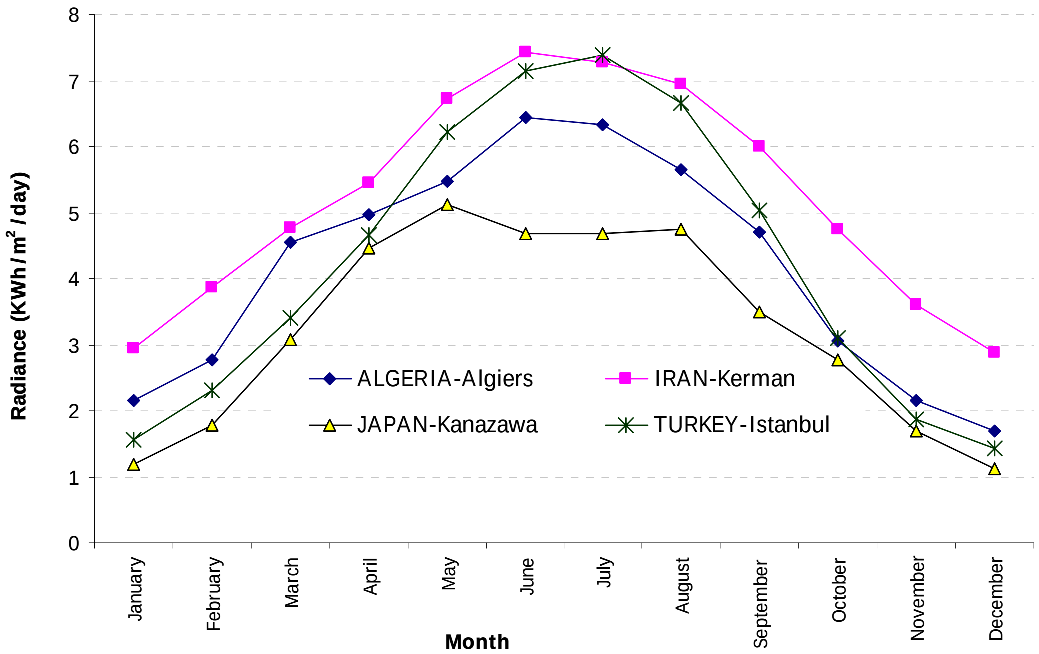


Figure 4.12- Average radiance in Algeria, Japan, Iran and Turkey

Table 4.12- Engines characteristics and energy produced in 3 day

Nominal Engine Power- *NPE* (KW)	η (%)	Prime-Power- *PE* (KW)	Produced energy in 3 days (KWh)
30	10	27	1,944
500	10	455	32,760
770	10	700	50,400
1,000	10	909	65,061
1,840	10	1,673	120,456
5,200	10	4,680	371,799

Table 4.13- PV arrays' characteristics, module type Mono-Si

Rating (W)	Nominal module efficiency (%)	Nominal Power (KW)	Area (m^2)	Weight (Kg)
285	11.7	0.285	2.43	47
195	17.3	0.195	1.28	14
190	16.1	0.190	1.18	14
185	14.2	0.185	1.30	17
180	15.3	0.180	1.18	14
175	13.5	0.175	1.30	17

Table 4.14- Considered locations and their radiance

Country/City	Radiance (KWh/m2/day)		Month	Remark
	Horizontal Plane	PV array Plane		
Japan/Kanazawa	0.83	1.25	December	1300h/year
	3.83	3.66	May	Average
Algeria/Algiers	6.34	5.93	July	Average
Iran/Kerman	7.28	6.53	July	Average
Turkey/Istanbul	7.39	7.07	July	Average

Table 4.15- Delivered Energy by PV arrays

Panel Power (KW)	No. of panels	Sys. Total power (KW)	Delivered Energy (KWh)
0.285	2,062	587.67	1,944
0.195	3,014	587.73	1,944
0.190	3,093	587.67	1,944
0.185	3,177	587.75	1,944
0.180	3,265	587.70	1,944
0.175	3,358	587.65	1,944

For each of the radiances we determined the PV power system *PPV* relevant to each engine power *PE*, Figure 4.13 shows the relation between *PPV* and *PE* for each radiance case. The PV power varies linearly with the engine power in accordance with Equation 4.7. Besides its dependence on the engine power, the PV power depends on the radiance, given that the curves are different for each of the radiances. The coefficient, α, was plotted against radiance to find its relation, see Figure 4.14. Equation 4.8 illustrates the variability of the coefficient α as a function of total daily radiance in the plane of the PV array, $\overline{H}_t$. The two equations 4.5 and 4.6 were found graphically from the curves shown in Figure 4.13 and Figure 4.14 respectively.

$$PPV = \alpha \times PE \tag{4.7}$$

$$\alpha(\overline{H}_t) = \delta \times \overline{H}_t^{-\gamma} \tag{4.8}$$

Where,

δ: constant = 26.673 and γ: constant = 0.9246

The lower the value of *α,* the easier the deliverance of energy will be; Figure 4.13 and Figure 4.14 show that for high radiance, i.e. a low value of *α*, the possibility of producing a high quantity of energy is greater. For low radiance, i.e. a large value of *α*, the production of a large amount of electricity is quite difficult, yet still possible. Table 4.14 shows different radiances, when the radiance is low, such as in Kanazawa City where the maximum solar energy does not reach the 0.83KWh per square meter per day, the PV system needs more power to deliver a small quantity of energy. While in high radiance areas, such as Istanbul where the maximum solar energy is 7.39KWh per square meter per day, the system needs low power to deliver a large amount of energy. This explains why the PV system power reduces when the radiance is high and vice-versa.

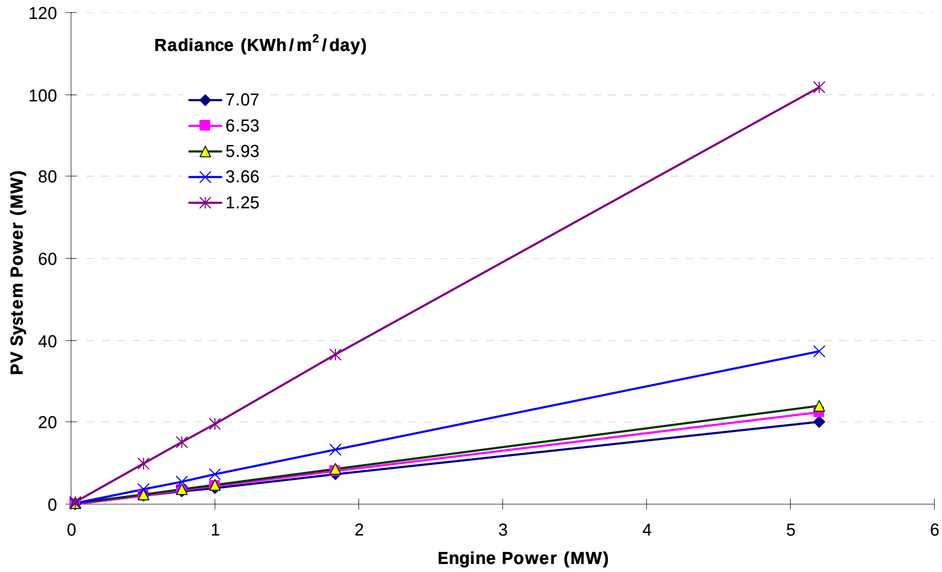


Figure 4.13- PV system power - Engine power

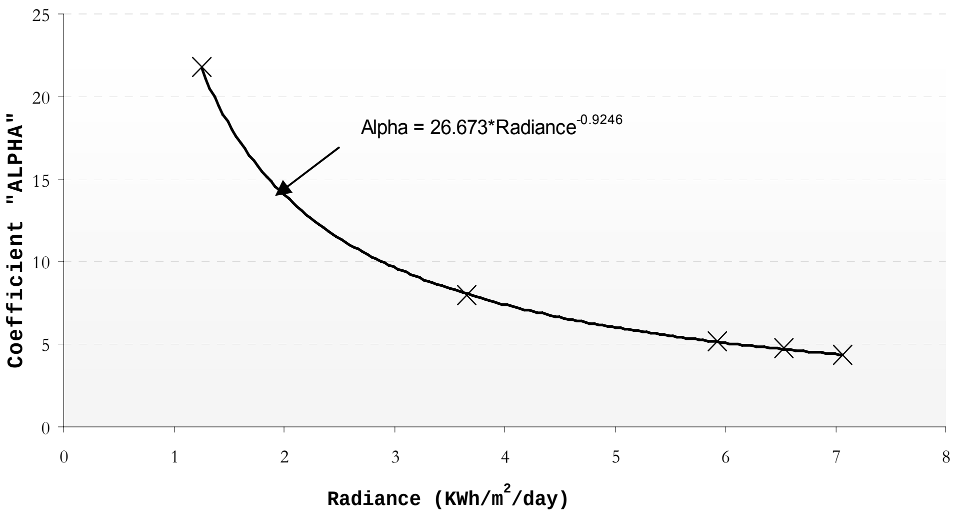


Figure 4.14- Variance "α" – Radiance

Space: According to Equation 4.7 and Equation 4.8, *EA* is zero only when $\overline{H}_t$ is equal to zero. In other words, as long as the radiance is different from zero (existence of brightness) the array delivers energy. However, the area needed to install the system should be verified to find the practicability of the system. During the analysis of power we also determined the total area needed to install the solar system that can deliver the energy sought. Unlike the power, the total area varies from one panel to another, given that the characteristics of panels are different. The required-areas of each panel were plotted versus the engine power. For instance, Figure 4.15 represents the case of six panels considered to be placed in Kanazawa City. Each of the radiances has its relevant diagram. Figure 4.15 shows that the required area, *S*, varies linearly with the power of the engine to-be-substituted, *PE*. The 195W panel requires the least space while the 285W panel requires the largest space. This is because the module of efficiency of panel 195W is the highest, while panel 285W is the lowest, see Table 4.13. The curves have the form shown in Equation 4.9.

$$S = \beta \times PE \tag{4.9}$$

The coefficient β was found depending on the radiance and the individual PV array power. In this study only the radiance will be considered because further studies of the coefficient may not benefit the present study. The coefficient will be noted with little PV to show that it depends on the type of the panels as well. To find the relation between β and the radiance we plotted its values versus the radiance, see Figure 4.16. The coefficient has the form shown in Equation 4.10.

$$\beta_{PV}(\overline{H}_t) = \xi \times \overline{H}_t^{\,-\psi} \qquad (4.10)$$

Where,

$\overline{H}_t$: Daily total radiance average in the plane of the PV array

ξ and ψ are constants, depending on the type of panels, see Table 4.16 for numerical values

The results show that in low radiance areas it is not practical to substitute engines with high power since the total required PV area becomes very large. On the other hand, in high radiance locations it may be beneficial to do so.

Table 4.16- Value of ξ and ψ

PV Array Power (KW)	ξ	ψ
0.285	227.97	0.9254
0.195	154.15	0.9248
0.190	165.63	0.9247
0.185	187.81	0.9248
0.180	174.30	0.9248
0.175	195.54	0.9247

Finally, it is theoretically possible to deliver any amount of energy by a solar system, yet it may not be a viable proposition for large quantities if the radiance is low. The result that is found is beneficial not just for hospitals/primary response centres but also for other facilities. It may be beneficial not just in a state of emergency but also for normal use.

To make an economical comparison we found that it is best to use an actual example of a facility. We decided to consider one of the worst cases that can be found, low radiance and high consumption.

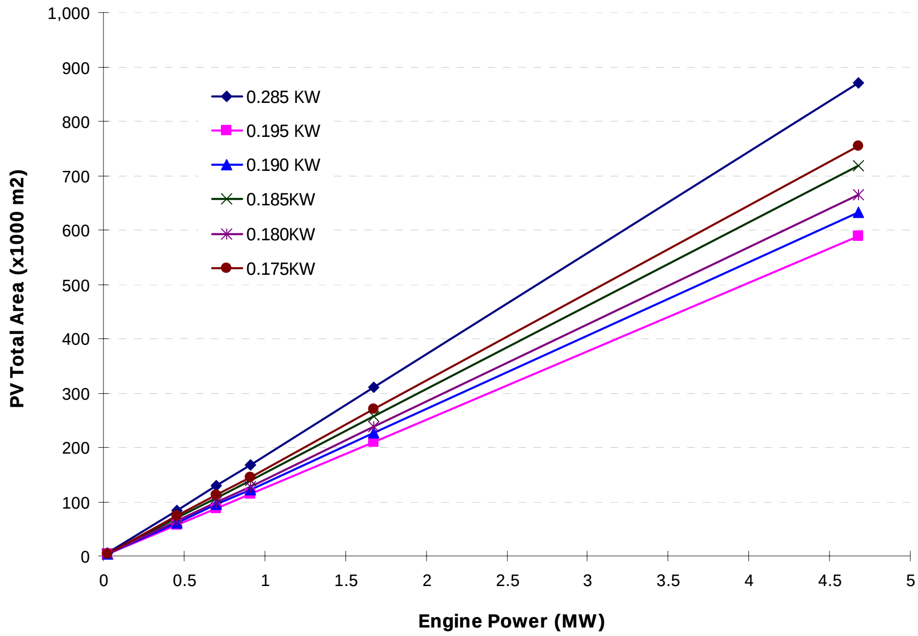


Figure 4.15- PV total area - Engine power (Radiance 1.25KWh/m^2/day)

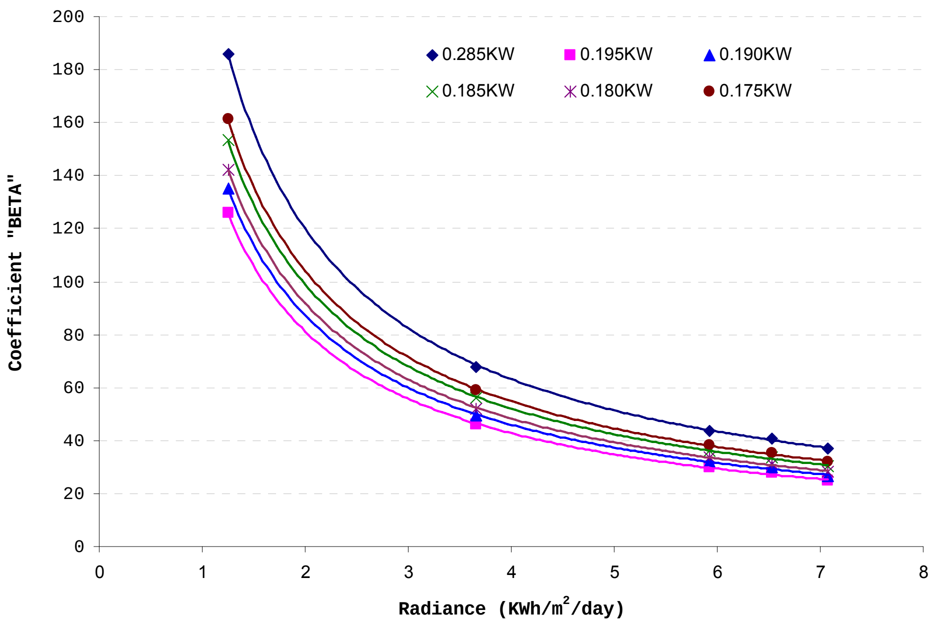


Figure 4.16- Variance β – Radiance

3.5.3 Case study; Kanazawa University Hospital

3.5.3.1 Overview

It is commonly believed that Japan has low radiance which makes the use of solar systems limited. Kanazawa City has a very limited annual sunshine rate and so we decided to use it as our case study to find out whether it is possible to use solar panels as an alternative power source or not. Between 1971 and 2000 Kanazawa City had a radiation average of

1,706 hours/year (Meteorological Data, 2005) which makes it one of the lowest in Japan; see Figure 4.17 and Table 4.17 illustrating the average monthly radiance for Kanazawa City. The minimum radiance on a horizontal area in December reaches 1.11 KWh/m^2/day. Kanazawa City is home to a very large hospital, Kanazawa University Hospital. The facility has a total area of 150,000m^2; 33,541m^2 of which comprises built areas, which have a total floor area of 153,678m^2 (Kanazawa Medical University Hospital, 2005). Kanazawa University Hospital is composed of many buildings, the oldest was built in 1974 and the newest in 2003. It provides health care to more than 723,000 patients every year, among them 2% are emergency patients served by 1,482 staff members. This makes its power consumption very high. It rose from 11GWh in 1982 to 26GWh in 2004, see Figure 4.18.

The present study takes into consideration only the new building, which is one of the most important buildings in the whole facility. It is reinforced concrete and steel in some areas. The building is composed of 12 floors with a total area of 51,849m^2. Its isolated base is able to protect the structure from earthquakes. The facility has a capacity of 673 beds, representing 72% of the capacity of the entire facility which is 938 beds. The roof of the building has a total area of 4,380m^2. The building has annual power consumption of 6GWh. During an emergency the emergency power generators can produce 2,050KWh, which is sufficient for 72hours according to the hospital staff, in other words the daily minimum consumption is 683.3KWh, and thus the annual minimum consumption is 250MWh.

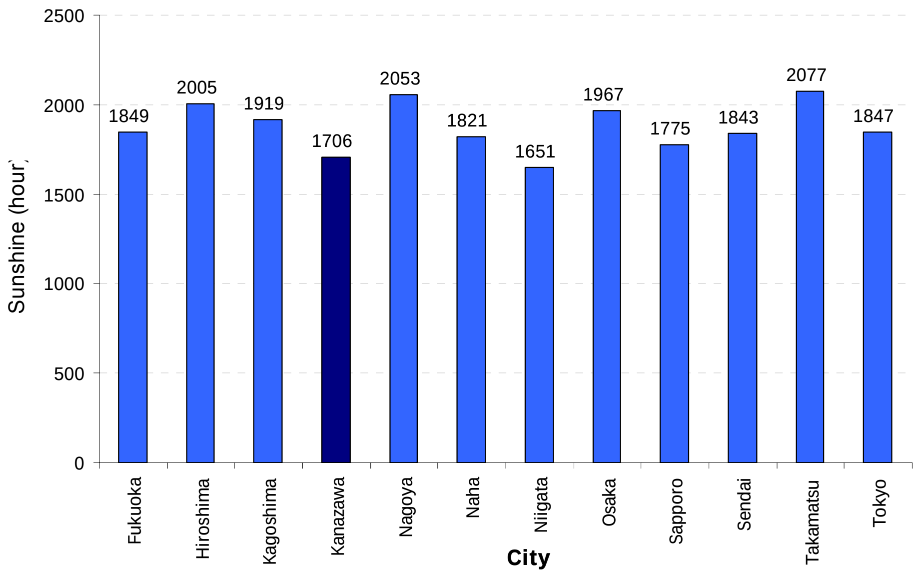


Figure 4.17- Annual average sunshine in Japan

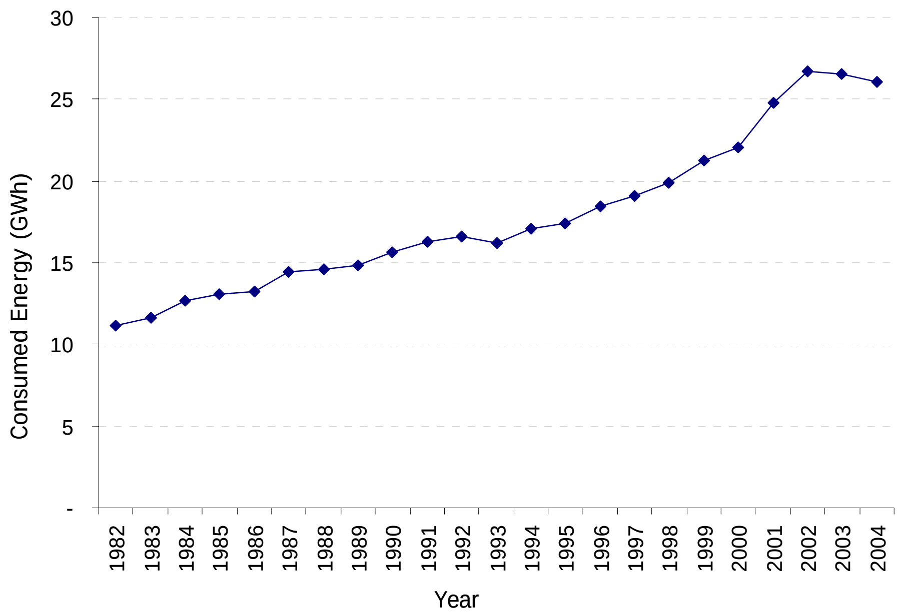


Figure 4.18- Hospital annual consumption (1982-2004)

3.5.3.2 Power Evaluation

At first, let's apply the results of the previous sections to find out the power required by a PV system that may replace the engine and its relevant area. To do that, we should find a) the equivalent engine power able to produce the same amount of energy within the same period and b) the minimum radiance to cover the whole year. An engine of 28.5 KW power shall produce 2,050KWh within 72 hours, the minimum amount for the facility to function. According to Table 4.17 and Figure 4.12, December has the lowest radiance, thus it is the appropriate case for the study. Once the evaluation is done according to equations 6 and 5, the PV power should be at least 519.32KW. The relevant area is shown in Table 4.18.

Ultimately, the second type of panel, 195W, gives the lowest area and therefore it shall be adopted further in the study. It is clear that the installation of the system is possible given that the system is able to deliver the required energy and it can be installed since the required area represents only 68.5% of the building roof area.

To find the number of panels and to check whether the result is correct or not we used a program code called RETScreen® (RETScreen International, 2005). The results showed that 2,664 panels have a power of 519.48KW and a total area of 3,002.8.4m^2. The estimation achieved by the equations found in the previous sections agrees with the analyses that have been achieved by RETScreen®. This confirms the study done previously and that the equations are able to give a good estimation for the system power and the required area to install the system.

Table 4.17- Average monthly radiance, Kanazawa City

Month	Radiance ($KWh/m^2/day$) Horizontal Plane	PV array plane
January	1.19	1.57
February	1.78	2.07
March	3.08	3.39
April	4.47	4.58
May	5.11	4.88
June	4.69	4.36
July	4.69	4.41
August	4.75	4.72
September	3.50	3.75
October	2.78	3.31
November	1.69	2.12
December	1.11	1.51

Table 4.18- Total area required to deliver 2,050 KWH/72hours

Array Power (KW)	Area (m^2)	Total weight (Kg)
0.285	4,437.08	85,820
0.195	3,001.03	32,824
0.190	3,224.66	38,259
0.185	3,656.33	47,814
0.180	3,393.32	40,260
0.175	3,845.90	50,293

The 2,664 panels are able to deliver 2,050KWh within 3days and 21,186KWh during the month of December and the annual average energy delivered may reach 528,924KWh as is illustrated in Figure 4.19. The deliverance of energy is verified. Some of it has to be stored in an uninterruptible power system (UPS) system i.e. batteries. The number of batteries depends on their capacity and the amount of energy that the facility desires to store; in the present case we chose the same as the actual situation of the facility i.e. 72hours. To avoid any risk of not being able to deliver energy within a certain period (case of very low radiance or less than 3 days period after installation of the system) the batteries have to be stored with commercial power so that it can be used for any emergency that may occur. Batteries are usually stored in cupboards as Photo 4.1 shows. They are very well tightened with bars from the four directions covered with rubber to reduce the shocks that they can experience in case of an earthquake. Photo 4.2 illustrates the control of the UPS system. Finally, it can be concluded that it is safe to consider a PV system as an alternative source of electrical power.

Photo 4.1- Batteries' cupboard

Photo 4.2- UPS control system

3.6 Environmental and economical issues

Evidently, the PV system does not release any toxic waste where as power engines do, but the question is how much pollution is produced in the considered case of Kanazawa University Hospital. The following paragraph reveals the mount of toxic elements released by using such a supply.

3.6.1 Environmental issue: toxic waste

There are many types of generators which use different types of fuel, in this study we considered; *oil*, *western coal*, *eastern coal*, *gas* and *biomass*. At least five types of toxic waste are released in using these fuels; *Sulphur Dioxide* (SO_2), *Oxides of Nitrogen* (NO_X), *Particular Matter smaller than 10 microns* (PM_{10}), *Carbon Dioxide* (CO_2), *Volatile Organic Compounds* (VOC_S). The evaluation of the quantity of waste was achieved by a calculator available online (EPPC, 2006). To produce a quantity of energy enough for 3 days, *2,050KWh*, the generator emits the quantity of toxic components shown in Table 4.19.

3.6.2 Economical issue

The best system should help reduce extra expenses on the facilities, principally when hospitals are suffering from economic difficulties. In fact, in California a study showed that 33% of the facilities in California are loosing money (Myrtle, 2004); therefore the alternative source should not burden the healthcare facilities with further expenses. The present section compares both the solar system and the fuel system. The comparison includes *the cost of installing the system*, and *the power production expenses*, some other expenses may be difficult to calculate such as the pollution effect on the environment as well as on lives.

Table 4.19- Pollution emitted by producing 2,050KWh

Pollutant (Kg)		SO_2	NO_x	PM_{10}	CO_2	VOC
FUEL	Oil	11.381	14.060	0.446	18.746	0.670
	Western Coal	38.832	64.728	2.232	22.316	1.339
	Eastern Coal	18.076	49.079	1.339	23.187	2.009
	Gas	0.067	12.719	0.446	14.282	1.116
	Biomass	1.339	27.896	2.455	0.000	13.612

Table 4.20- Cost of commercial energy

Plan No.	Period	Cost (tax included, 5%) dollar/KWh*
412	July-September	0.1039
	October-June	0.0945

* 1 Dollar=118Yen.

Table 4.21- Produced energy and cash flow, 1st year

	January-June	July-September	October-December
Energy (KWH)	273,333	159,442	93,148
Cost (dollar)	25,830	16,571	8,803
Total Cost (dollar)	51,204		

3.6.2.1 Case of PV arrays

Information we gathered from a company that manufactures and installs solar arrays in buildings confirms that the price of 1KW is 11,017 dollars. However, from April 2005 the price decreased by 70% to 3,305 dollars. This discount was confirmed by a study showing that prices have decreased by 73% in 2005 compared to prices in 1992 (Moony et al., 2003). The prices will continue to decrease at least until 2008; in fact 2008 prices will be 18% of those in 1992 (Moony et al., 2003).

The whole system has a capacity of 519.48KW therefore the total cost becomes 171,924 dollars. To calculate the amount of savings we used the prices provided by the Hokuriku Denryoku Company, from where the facility obtains its supply. The company has different prices for each KWh depending on a) the set plan that the facility joins and b) on the months; July, August and September which are the most expensive months. Table 4.20 illustrates the plan to which the hospital subscribes (HDC, 2005). The savings that the facility makes within 3 days is calculated according to Table 4.21. They are 213 dollars or 194 dollars, July-September or October-June respectively.

3.6.2.2 Case of power generators

Unlike the solar system, the evaluation of the cost of generator-produced energy includes the cost of the engines, the cost of the fuel, cost of cooling water and cost of toxic waste, which includes the impact on the environment and on lives. The impact on the environment, on lives, (mainly human), diseases which may ensue and the cost of treating them are not considered. Hence only the cost of engines, fuel and water are considered.

Unfortunately we could not get the exact cost of an engine of 5,200KW such as that which the facility has; however according to some internet sites we found that an engine of this type costs around 169,492 dollar. By converting the amount of electric energy, 2,050KWh, into oil using the conversion rate oil/electric energy, 1,000litter equal to 4,110KWh (ZEXEL, 2005), the necessary amount of oil is 498.8 litres. Before calculating the cost of oil we should consider that the price of oil has become very expensive, the record of oil prices of the last two years is plotted in Figure 4.20. According to the records of the first week of June 2004 the prices became 40% higher than that of 2003; the price in the same period in 2005 is double that of 2003 (OPEC, 2005). To calculate the cost of oil we used 0.593dollar/litre thus 296 dollars in 72hours. The generator in question needs 69.84m^3 of water which costs about 158 dollars. Finally the total amount needed to produce electricity for 3 days is 509 dollars. Table 4.22 summarizes the expenses and savings for both systems.

According to Table 4.22 it is clear that the solar system is more beneficial than the fuel system even though both cannot pay back the amount that they consume to produce the required energy. Moreover, the Japanese government encourages the use of renewable energy by offering a subsidy of up to 50%, to those who are willing to install solar power to reduce environmental pollution. Finally, it is clear that by using the solar system the facility would reduce its expenses, use a reliable power source, save lives and be more compliant with the Kyoto convention.

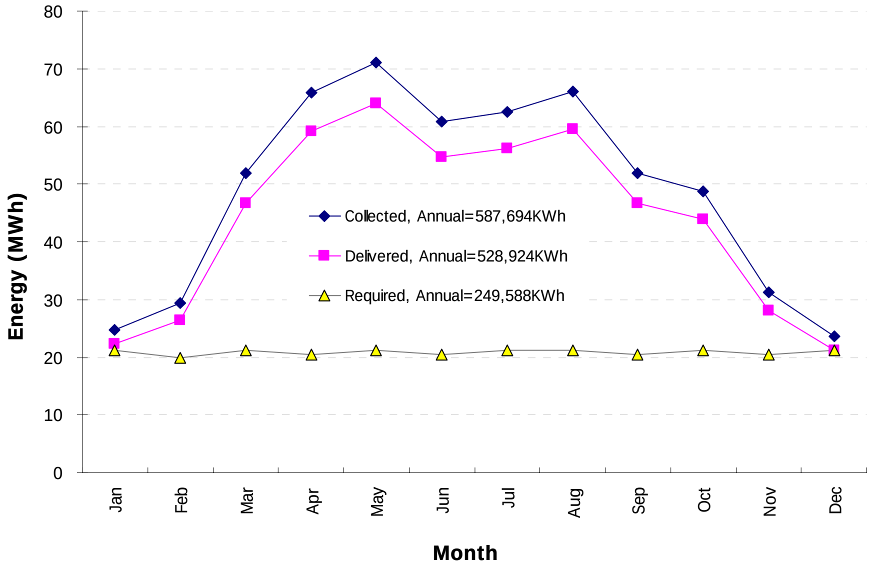


Figure 4.19- Monthly PV system delivered energy

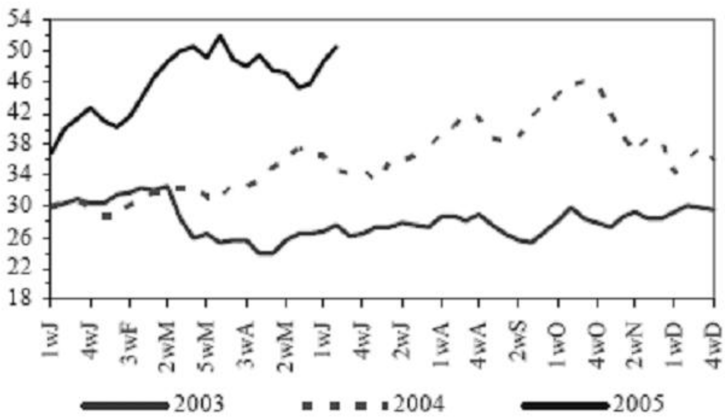


Figure 4.20- Oil price (OPEC, 2005)

Table 4.22- 3-day expense summary (dollar)

	Equipment	Operation cost	Savings	Total
PV	564	0	213 194	-351* -370**
Engine	56	453	0.000	-509

*July-September **October - June

Table 4.23- Comparison Summary

	Fuel System	Solar System
Deliverance of the required amount of energy	✓	✓
Limited space use	✓	×
Environment friendly (no impact after use)	×	✓
Economical savings	×	✓

Table 4.24- Annual energy production

Country (City)	Delivered Energy (MWh)
Iran (Kerman)	848.831
Turkey (Istanbul)	721.511
Algeria (Algiers)	692.057
Japan (Kanazawa)	528.924

3.7 Analysis result

3.7.1 Results of comparison

At this point it is necessary to look back at what has been achieved in the previous sections to ascertain the usefulness of replacing a fuel system with a solar system. Table 4.23 re-encapsulates the results of the previous sections; the symbol "✓" is used when the proposition is true and the symbol "×" is used when it is false. According to the table the solar system responds positively to three out of four propositions while the fuel system responds only to two of four. Therefore, Table 4.22 shows that the solar system is generally better than the fuel system.

3.7.2 International Cases

It may be useful to study cases of other countries that may benefit more than Japan by using a photovoltaic system, by looking at Algeria, Iran and Turkey. The radiance in these countries is higher than in Japan as Figure 4.12 illustrates. To compare all cases we kept the same data (number and type of arrays, some model of googlanalysis etc.) and we carried out the evaluations for all cases and plotted the results in Figure 4.21. Iran has the highest production of energy except in June-August when Turkey has the highest amount; that difference is because of the difference of temperature between both locations. Nevertheless, Iran still has the highest annual delivered energy, see Table 4.24. The Aflatoonian Hospital in Bam city, Iran, consumed 29,680KWh in August 2005. According to Figure 4.21 in August the system is able to deliver over 83,000KWh. It is clear that the system can be used not just as an alternative source but also as a main source.

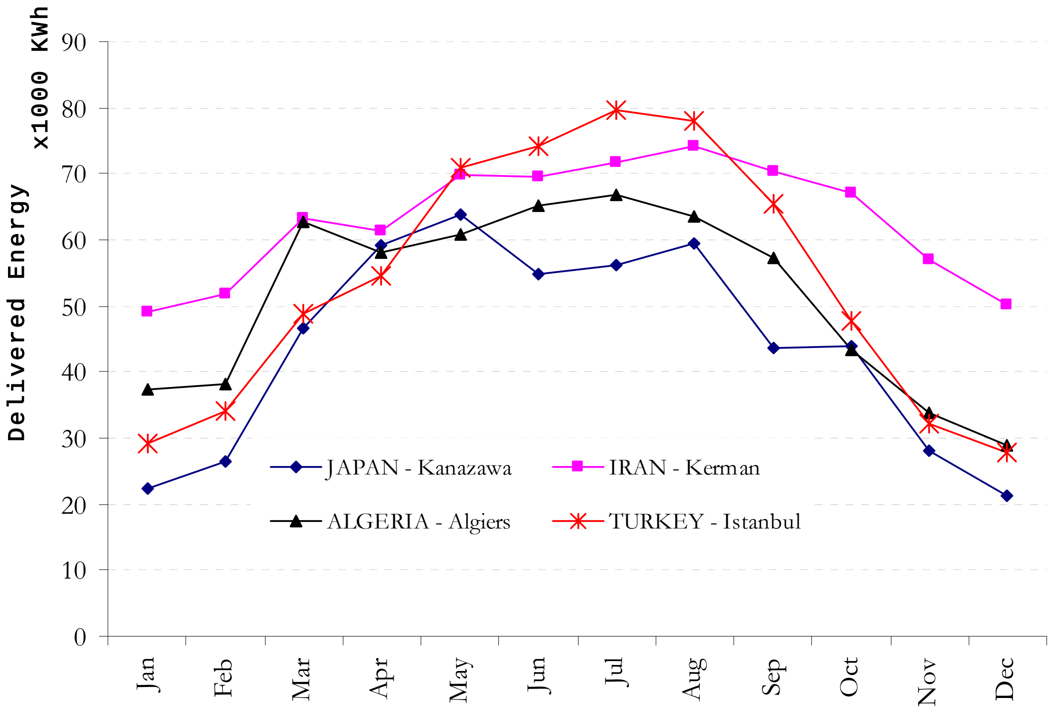


Figure 4.21- Possible energy production for Algeria, Iran, Japan and Turkey

3.8 Seismic response of the system

3.8.1 Models

To support the panels two models can be adopted; mobiles and fixed. As mentioned before only fixed models are considered as they are more stable than the mobile ones. Within the fixed model the design of a model depends on the requirement of the designs and on the engineer who designs it. We visited the solar system installed in our university, Kanazawa University, and we found that there are several types that were used. The models depend on the type and size of panel. We chose two models which will be considered in the study. The first model is that shown in photos 4.3, 4.4 and Figure 4.22 and the second is shown in Figure 4.23; Table 4.25 shows the detail of each of both models. The numbers shown in the figures are the number of bars, on top or below the appropriate bar, and the number of Nodes. The detail of each of the sections used in the models is shown in Figures 4.24, 4.25 and 4.26. Both structures are considered to be fixed to the building.

Photo 4.3- Solar panel support

Photo 4.4- Attachment support-building

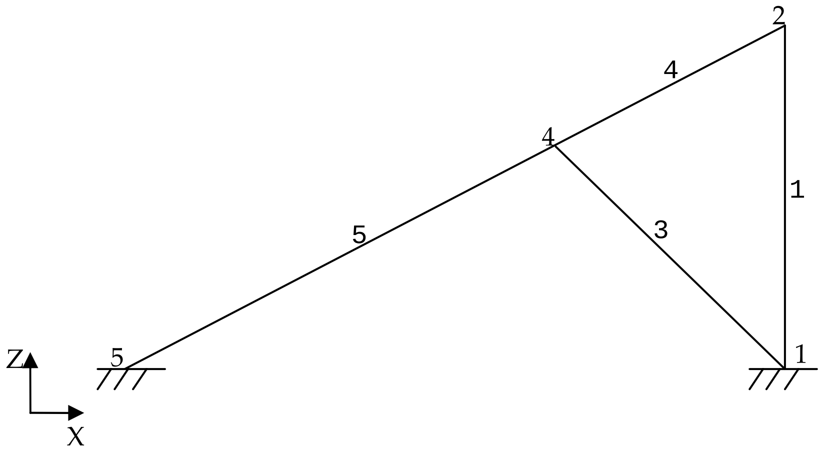


Figure 4.22- View of the first model considered in the study, *Model 1*

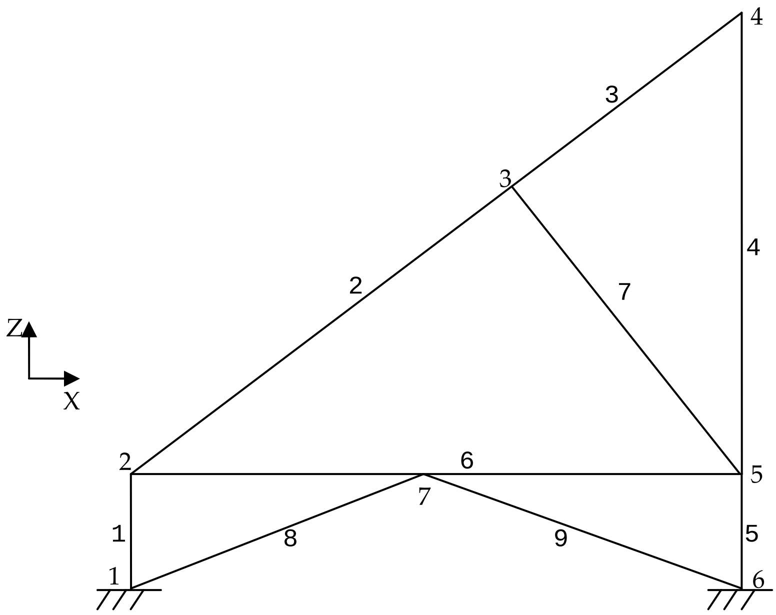


Figure 4.23- View of the second model considered in the study, *Model 2*

Table 4.25- Detail of models

Model	Bar #	Node I	Node J	Section	Length (cm)
Model 1	1	1	2	Double-Angle-50	150.0
	3	1	4	Double-Angle-50	121.5
	4	2	4	Double-Angle-50	86.4
	5	4	5	Double-Angle-50	167.7
Model 2	1	1	2	Angle-50	100.0
	2	2	3	Angle-50	228.8
	3	3	4	Angle-50	156.1
	4	4	5	Double-Angle-50	247.6
	5	5	6	Double-Angle-50	100.0
	6	2	5	IPE50	294.7
	7	3	5	Angle-50	192.2
	8	1	7	Angle-50	178.1
	9	7	6	Angle-50	178.1

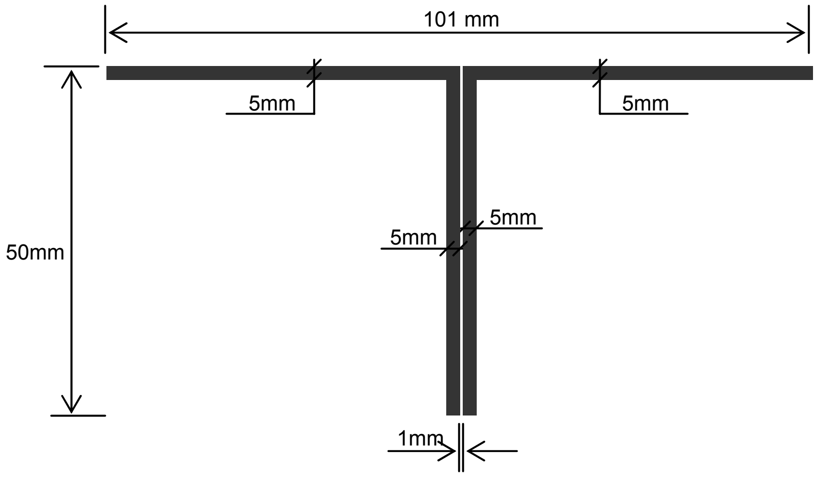


Figure 4.24- Detail of section "Double-Angle-50"

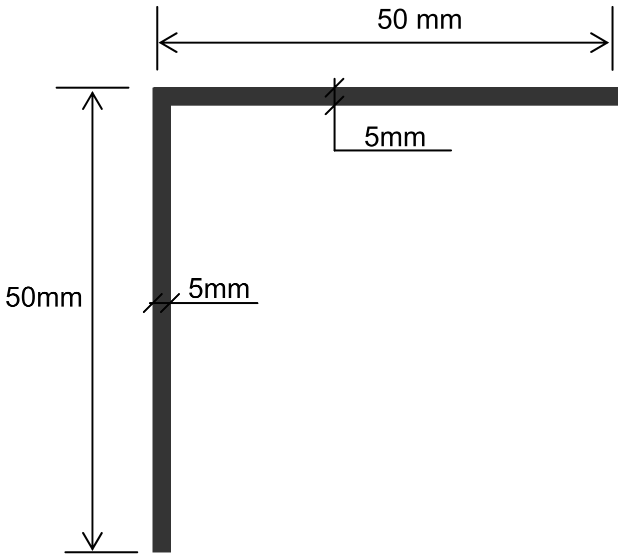


Figure 4.25- Detail of section "Angle-50"

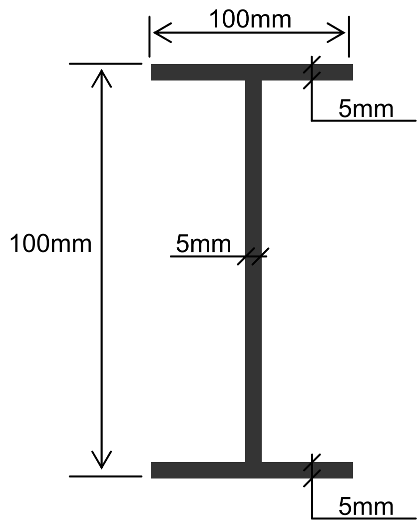


Figure 4.26- Detail section IPE

3.8.2 Loading

The purpose behind this study is to find out the response of the solar system on top of a building. The building may be provided with a base isolation system as it can be a regular building. To fulfil this criteria we considered different frequencies and different accelerations. We considered a sinusoidal pulse with variable frequencies (1Hz-10Hz). It is known that buildings with base isolation system have low natural frequencies. These systems were created to move with the natural frequency of the building far from the predominant frequencies of earthquakes and therefore avoid its collapse. The models were considered to be linear models given that the structure is very stiff (large cross-sections and relatively small size of the entire structure).

3.8.3 Response of structure

Calculation of the response of the structure was done with software called "SAP2000®" version 10.0.1 by Computers and Structures Incorporation. At first we made a modal analysis to find out the modes and the natural frequencies of the structure. Table 4.26 illustrates the different frequencies and their relevant periods as well as their Eigen values. The first mode in both models was found to be very far which means that the structures will never pass through resonance and therefore the response will be very low. We considered the maximum response at Node 2, i.e. maximum response, and we compared it to Node 1, i.e. input acceleration, for Model 1 and Node 4, i.e. maximum response, to Node 6, i.e. input acceleration, in Model 2. In all cases the response was the same as the input acceleration, Figure 4.27 and Figure 4.28 show the cases of 1Hz and 10Hz respectively.

Table 4.26- Natural modes of both structures

Model	**Mode #**	**Period** (sec)	**Frequency** (Hz)	**Eigen value** (Rad^2/sec^2)
Model 1	Mode 1	0.003477	287.56	3264600
	Mode 2	0.001877	532.62	11200000
	Mode 3	0.001791	558.35	12308000
	Mode 4	0.000911	1098.3	47621000
Model 2	Mode 1	0.008661	115.47	526340
	Mode 2	0.00519	192.67	1465400
	Mode 3	0.004488	222.82	1960000
	Mode 4	0.003696	270.55	2889700
	Mode 5	0.00273	366.3	5297100
	Mode 6	0.002141	466.99	8609300
	Mode 7	0.002058	485.84	9318400
	Mode 8	0.001645	608.03	14595000
	Mode 9	0.0015	666.5	17537000
	Mode 10	0.001207	828.39	27091000

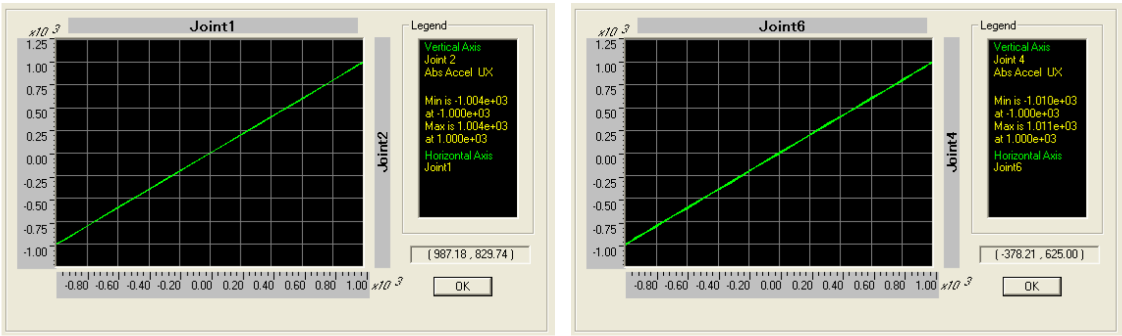


Figure 4.27- Response acceleration versus input acceleration for Model 1 (left) and Model 2(right) for the case of 1Hz

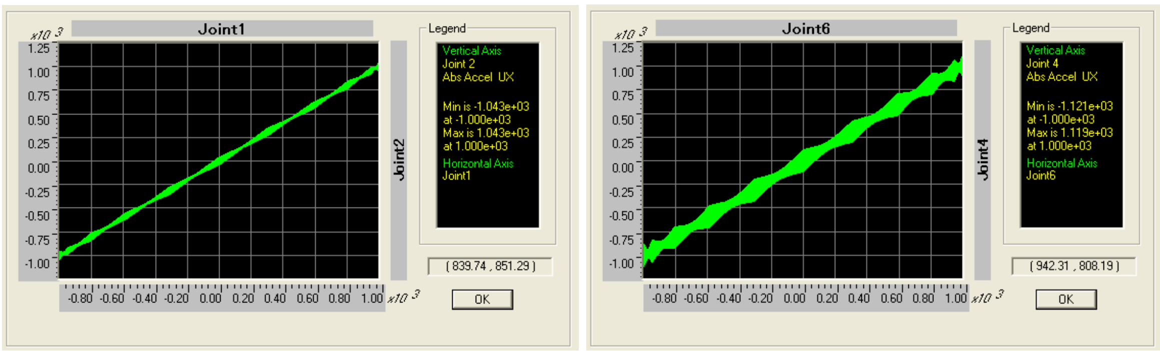


Figure 4.28- Response acceleration versus input acceleration for Model 1 (left) and Model 2(right) for the case of 10Hz

For further investigations we considered the amplification factor *AMP1*, defined in Equation 4.11, and plotted it versus the frequency, Figure 4.29, and the input acceleration, Figure 4.30. The response increases with the frequency but only very slightly as at 10Hz the amplification becomes equal to 1.042, i.e. 4.2% of the input for Model 1 while it becomes 17.9% for Model 2. The difference of response can be explained simply by the difference in height of both nodes in both models (1.5m for Model 1 and 3.47m for Model 2) as well as the difference of the stiffness in both structures. Moreover, the amplification varies with the frequency according to the Gauss model, in which the peak is at each of the frequencies relevant to the first mode, i.e. 287Hz for Model 1 and 115Hz for Model 2. The amplification does not vary with the acceleration and that is simply because the analysis was supposed to be linear. The amplification factor *AMP1* of the Model 1 is lower than Model 2 and this is for the same reasons précised previously for the amplification-frequency relation. In both cases the structure is very strong; the reaction at the base is very small as it is seen in Table 4.27. F_x, F_z and M_y represent the horizontal reaction according to X-direction, vertical direction according to Z-direction and the bending moment around Y-direction. The reactions, F_x, F_z and M_y, are very low which makes the structure safe and the possibility of its collapse low because shaking is very low.

$$AMP1 = \frac{a + \ddot{x}}{a} \tag{4.11}$$

Where

a: Input maximum acceleration;

$a + \ddot{x}$: Maximum absolute acceleration (response)

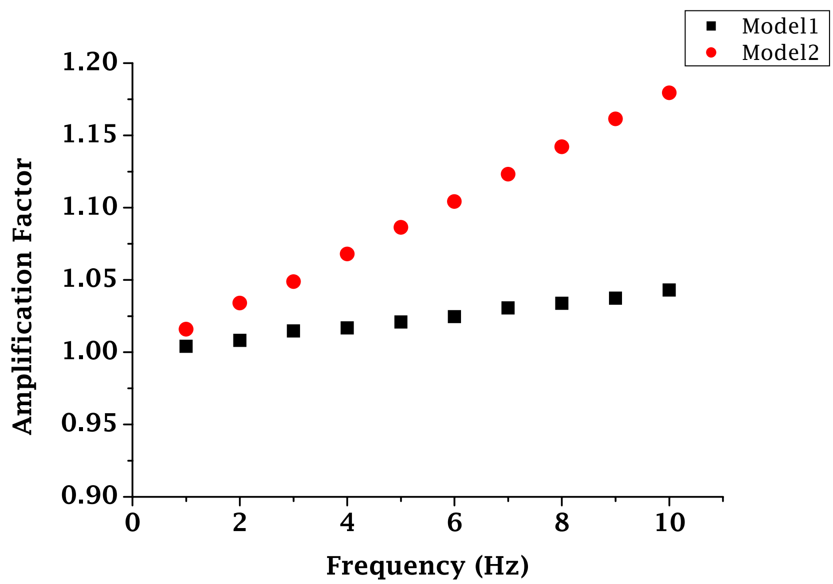


Figure 4.29- Effect of the frequency on the response

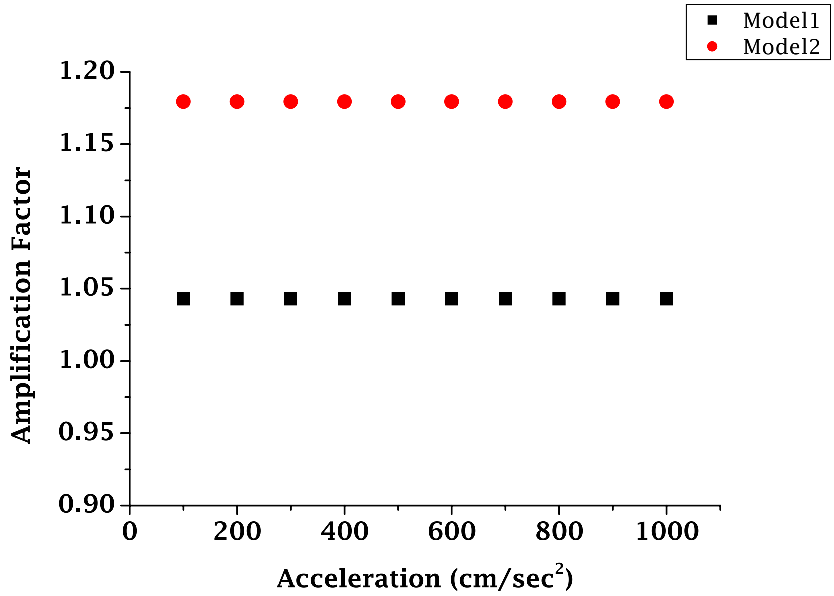


Figure 4.30- Effect of the acceleration on the response

4. RESPONSE OF EQUIPMENT; STABILITY

4.1 Introduction

As mentioned in chapter 2, a healthcare facility is a mixture of a variety of facilities. Equipment, that a facility has, has different sizes, shape, attachment methods, materials etc. Large equipments are difficult to be moved, but the damage that they may go through can be mechanical, electrical or malfunction caused by the shortage of something they depend on. Previously we studied their fortification by strengthening the electric power which is one of the most important lifelines that they depend on. This section represents a study of the response of services' equipments. The question is *how best to select the service that's equipments are needed the most in an emergency*? There are many ways to determine this but here we propose using the information about previous earthquakes, i.e. casualties.

4.2 Determination of most required equipments- Casualties

4.2.1 Dependence of casualties

Since 1900 and until 2005, over 1.7 million people were killed as Figure 4.31 illustrates, and 1.5 million were injured by main earthquakes that occurred in 85 countries. It is obvious to say that the preparedness of a county reduces the number of causalities, and that the number of causalities varies from one country to another proportionally to its preparedness. The question that can be asked is *"Is it possible to classify data taken from different locations in the world to find out the most important type of injury that should be considered?"* To answer this question we used the Contingency Table Approach (Johnson et al., 2006).

The null hypothesis, H_0, represents the independence of the classification, i.e. number of casualties is independent from one country to another. H_0 is true if the value of the test static shown in, Equation 4.12, is higher than the critical value also known as Chi-Square value. Table 4.28 shows the data that was used for this test. As Table 4.29 shows, the test static value is larger than the critical value, i.e. hypothesis H_0 is true. Thus, the number of casualties does not depend on the countries, but rather on the level of its preparedness for earthquakes. Therefore the classification of casualties should be done always within the same country.

Table 4.27- Reactions at the base of structures for an acceleration of 1000cm/sec^2

Model 1					Model 2			
Node	**Frequency** (Hz)	**Fx** (kgf)	**Fz** (kgf)	**My** (kgf.cm)	**Node**	**Fx** (kgf)	**Fz** (kgf)	**My** (kgf.cm)
1	1	4.94	13.43	4.86	1	38.02	41.74	17.81
	2	4.95	13.48	4.88		38.30	42.11	17.94
	3	6.29	15.19	5.03		38.42	42.39	18.00
	4	4.97	13.59	4.91		38.90	42.90	18.23
	5	4.98	13.65	4.92		39.20	43.30	18.37
	6	4.99	13.65	4.93		39.52	43.72	18.52
	7	5.00	13.68	4.95		39.84	44.11	18.67
	8	5.01	13.80	4.97		39.92	44.54	18.72
	9	5.02	13.81	4.98		40.43	44.98	18.95
	10	5.04	13.91	5.00		40.80	45.41	19.13
5	1	18.27	13.44	0.38	6	38.04	41.74	31.48
	2	18.33	13.49	0.38		38.32	42.11	31.70
	3	18.43	13.56	0.59		38.44	42.35	31.77
	4	18.45	13.58	0.39		38.92	42.93	32.19
	5	18.52	13.63	0.40		39.22	43.34	32.44
	6	18.55	13.65	0.40		39.54	43.77	32.69
	7	18.62	13.70	0.41		39.86	44.16	32.95
	8	18.70	13.76	0.41		39.94	44.58	32.97
	9	18.76	13.81	0.42		40.44	45.07	33.41
	10	18.84	13.86	0.42		40.81	45.53	33.73

$$\chi^2 = \sum_{i=1}^{85} \sum_{j=1}^{2} \frac{\left[n_{ij} - \hat{E}(n_{ij})\right]^2}{\hat{E}(n_{ij})} \qquad (4.12)$$

Where

$$\hat{E}(n_{ij}) = \frac{r_i c_j}{n} \qquad (4.13)$$

n_{ij}: expected cell frequency

n: total number of casualties

r_i and c_i: row i and column j

4.2.2 Classification of injuries

To prepare a healthcare facility for an earthquake it is useful to find out the most important systems required to treat the maximum number of injuries. This can be done by many means; here we suggest using statistics related to old earthquake experiences. The suggestion is based on the type and cause of injuries; a study, similar to the previous one, can show the classification of each type of injuries and its cause. If the variables, type and cause of injuries, are dependents, then the classification should be done according to the cause. If the type and the cause are independent then the classification should be done according to the type of injury. The classification in both would lead to a need for a particular service, which has to receive the highest attention.

There are several types of injury, but they can be classified into six categories: slight injuries, fracture, spine and pelvic problems, crush syndrome, burns and others. These types of injury have many caused, which we cite here: falling debris, falling, struck by objects, traffic accident, burns/electrocution, piercing/cutting, and others. It was difficult to collect the relevant information. Samples of five different earthquakes, each from a different country, are considered. The data that we did collect is from Armenian et al. (1997), McArthur et al. (2000), Peek-Asa et al. (1998), Tanaka et al. (1999), Erek et al. (2002), Server et al. (2002), Demirkiran et al. (2003), Ozdogan et al. (2001), Kurt et al. (2001) and Roy et al. (2005), following the 1988 Armenia, 1994 Northridge, 1995 Hyogo Nambu, 1999 Marmara and Bhuj earthquakes, see Table 4.30. A rough classification is done according to the type of injuries, and the results are shown in Figure 4.32 through Figure 4.36. The main causes of those injuries are shown in Figures 4.37 through 4.39.
To explain further the usefulness of this study we considered the case of Japan. To prepare a healthcare facility, a Japanese engineer should pay attention to the service that treats the fractures as it has the highest probability to occur; Figure 4.34 shows that 44.6% of the

injuries may have a fracture. Therefore with the purpose of saving the maximum number of injuries, all equipments required to treat a fracture should be functioning after an event.

It should be mentioned that this classification is true only for the cases shown, given that the number of data is limited which does not allow us to generalize the case. Another type of causality not previously mentioned are psychological traumas and difficulties related to earthquakes. These should not be overlooked as there effects can be serious and long lasting.

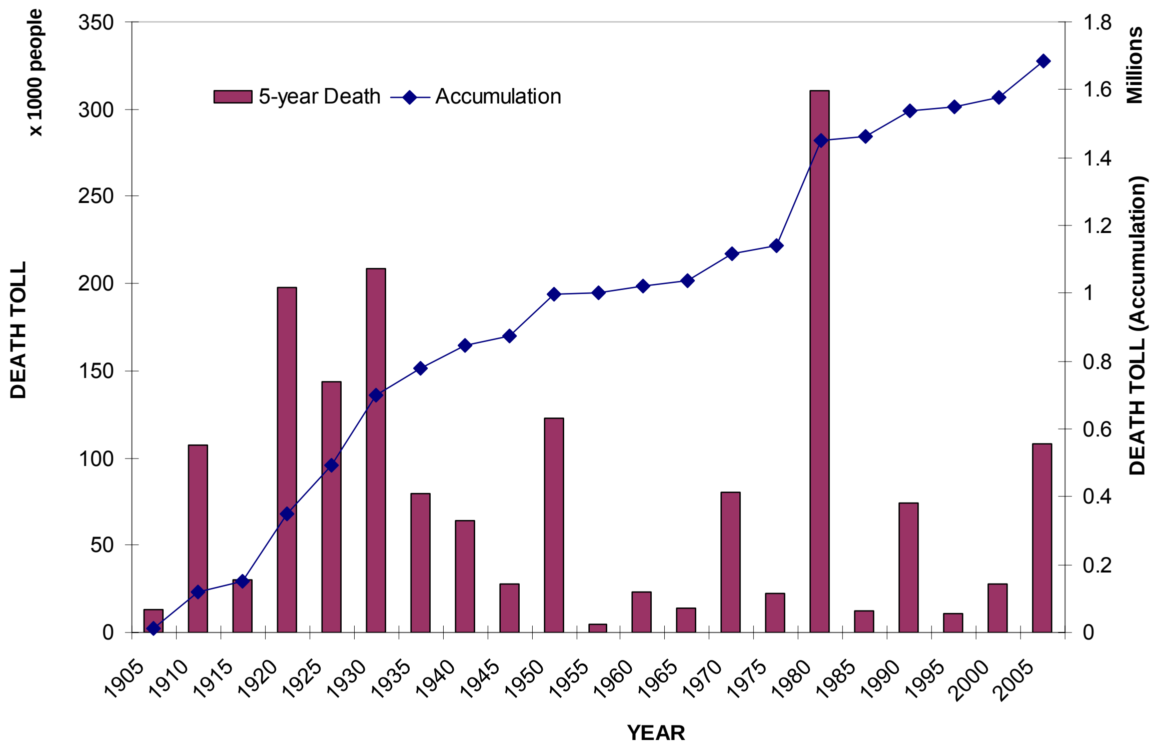


Figure 4.31- Accumulation of major earthquakes related death toll 1900-2005 in 85 countries

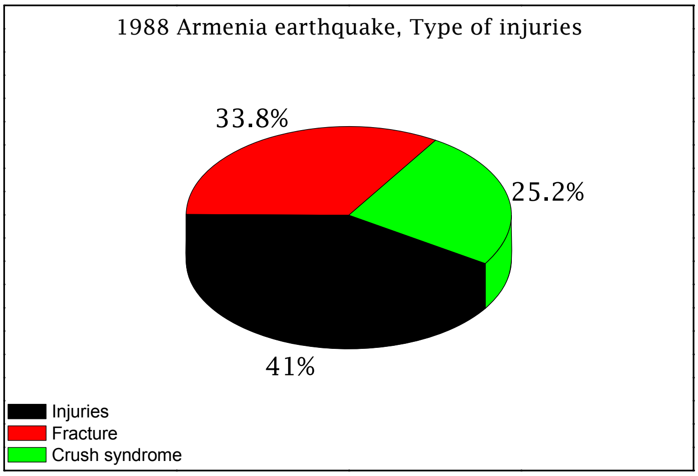


Figure 4.32- Classification of injuries caused by the Armenia earthquake

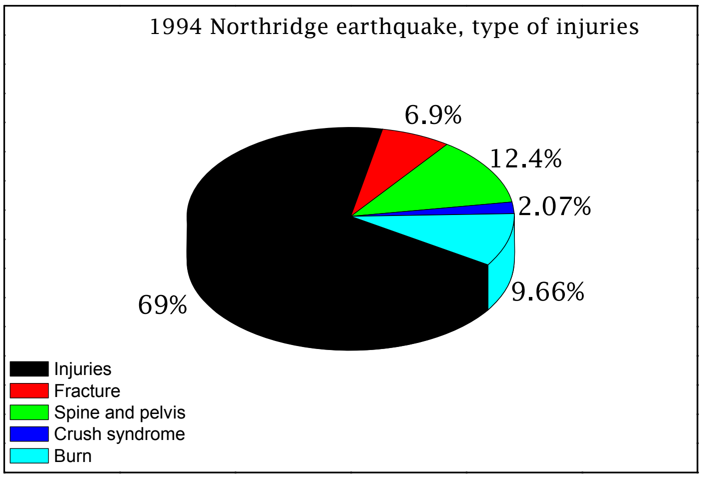


Figure 4.33- Classification of injuries caused by the Northridge earthquake

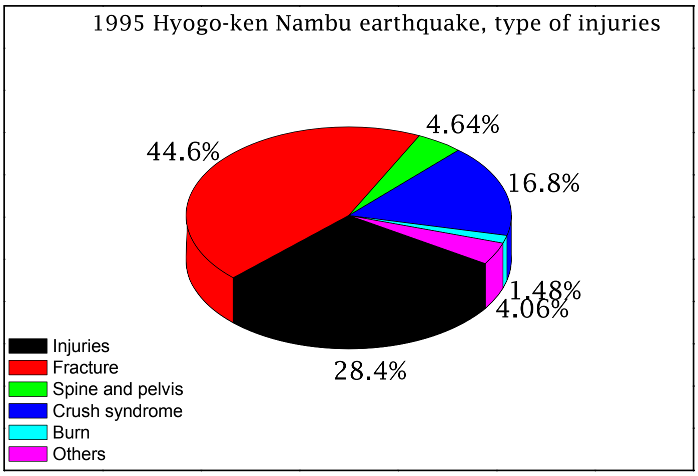


Figure 4.34- Classification of injuries caused by the Hyogo-ken Nambu earthquake

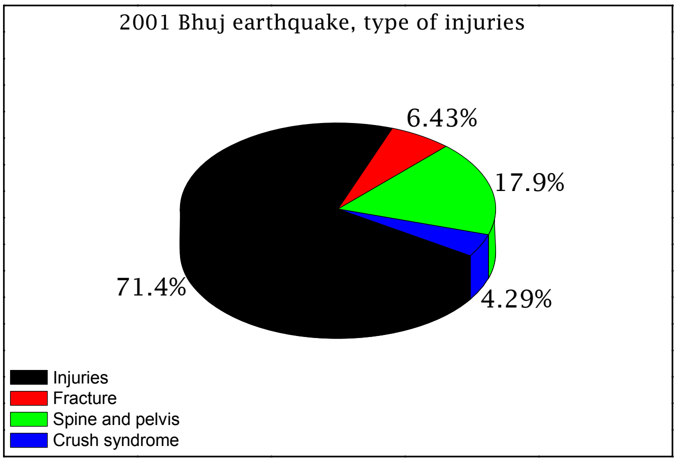


Figure 4.35- Classification of injuries caused by the Bhuj earthquake

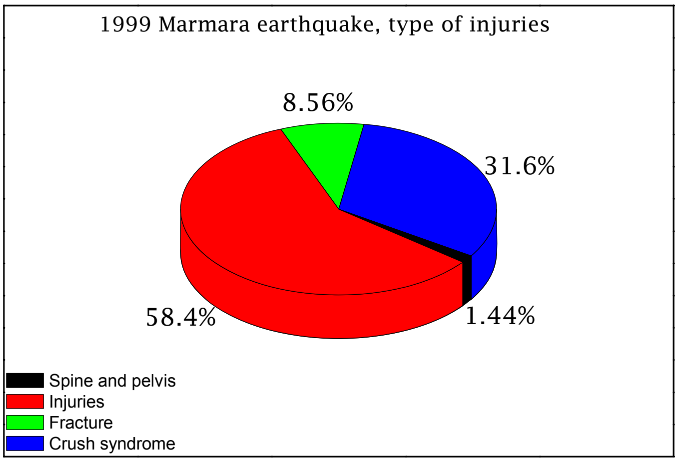


Figure 4.36- Classification of injuries caused by the Marmara earthquake

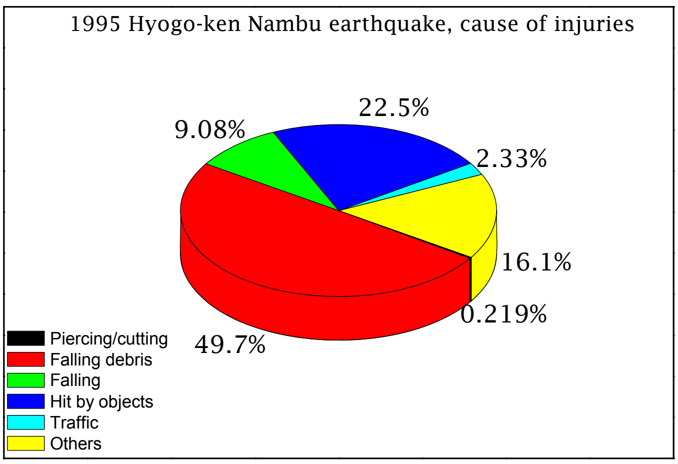


Figure 4.37- Classification of causes causing injuries in Hyogo-ken Nambu earthquake

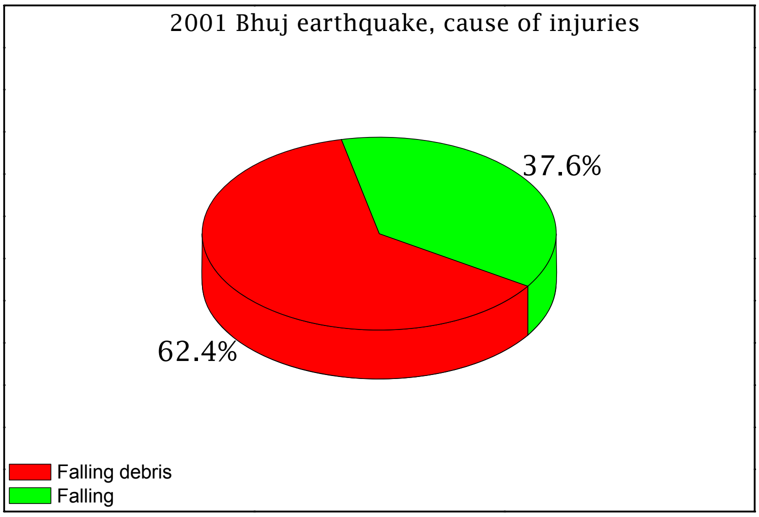


Figure 4.38- Classification of causes causing injuries in Bhuj earthquake

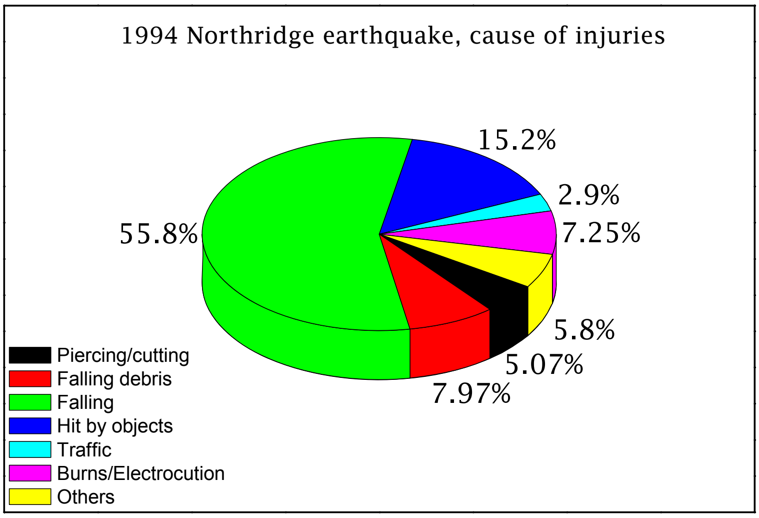


Figure 4.39- Classification of causes causing injuries in Northridge earthquake

4.2.3 Steps to follow

Finally it may be interesting to show the steps to find the most probable service required post earthquake. Figure 4.40 is a chart summarizing all steps. The first step involves relating the cause of injuries and the type of injuries. In the case of a relation the classification shall then be done according to the cause of injuries. Otherwise the classification shall be done according to the type of injuries. Therefore, the most probable type of injury and the most important medical service needed to save the maximum number of injuries can be found.

Table 4.28- Earthquake-related Casualties in 85 countries (part 1/2)

COUNTRY	CASUALTIES (death/event)	(injuries/event)	TOTAL (people)	PROBABILITY P_C
1	471	440	910	0.007011551
2	9	98	107	0.000825636
3	375	1128	1503	0.011574135
4	2015	7073	9088	0.069995750
5	11	210	221	0.001702104
6	26	233	260	0.001999908
7	6	104	110	0.000845917
8	1	15	16	0.000123229
9	38	17	55	0.000423601
10	33	56	89	0.000685463
11	3	0	3	2.31055E-05
12	1681	2752	4433	0.034143806
13	7926	2223	10149	0.078166004
14	157	605	763	0.005874661
15	2	0	2	1.54037E-05
16	154	65	219	0.001684775
17	1	24	25	0.000188695
18	21	53	74	0.000566084
19	38	8	46	0.000350433
20	709	30	739	0.005690688
21	119	2005	2124	0.016358682
22	426	3658	4083	0.031448488
23	3	24	27	0.000207949
24	46	0	46	0.000354284
25	71	445	516	0.003976069
26	0	20	20	0.000156604
27	17	0	17	0.000130931
28	34	132	166	0.001276379
29	1	13	14	0.000107826
30	0	71	71	0.000546830
31	2516	7016	9532	0.073411721
32	275	1436	1711	0.013177827
33	0	2	3	2.05382E-05
34	2468	8563	11031	0.084958553
35	294	273	567	0.004366744
36	1730	1976	3706	0.028544061
37	20	0	20	0.000154037
38	4119	409	4528	0.034873050
39	1200	0	1200	0.009242193
40	3868	3455	7323	0.056401200
41	242	0	242	0.001863842
42	3	626	629	0.004844450
43	19	33	53	0.000405630
44	136	200	336	0.002587814
45	320	0	320	0.002464585
46	9	100	109	0.000839499
47	395	1233	1628	0.012540857
48	1200	0	1200	0.009242193
49	4243	1414	5657	0.043569239

Table 4.28- Earthquake-related Casualties in 85 countries (part 2/2)

COUNTRY	CASUALTIES (death/event)	(injuries/event)	TOTAL (people)	PROBABILITY P_C
50	110	0	110	0.000848741
51	1986	1354	3340	0.025724104
52	0	20	20	0.000154037
53	55	8	63	0.000486756
54	1523	2567	4090	0.031500475
55	6490	4011	10501	0.080878993
56	8	168	176	0.001353596
57	7	23	30	0.000229129
58	1947	4289	6237	0.048032662
59	456	621	1078	0.008300003
60	116	0	116	0.000893412
61	202	923	1126	0.008670481
62	286	146	433	0.003332691
63	45	108	153	0.001178380
64	1	100	101	0.000777885
65	1	3	3	2.31055E-05
66	18	0	18	0.000134782
67	9	20	29	0.000224316
68	6644	655	7299	0.056219323
69	2	8	9	6.93164E-05
70	1755	1294	3050	0.023488863
71	1	13	13	0.000102049
72	1	1	1	1.11249E-05
73	1	5	6	4.62110E-05
74	0	2	2	1.54037E-05
75	13	0	13	0.000100124
76	1247	1308	2555	0.019678061
77	11	0	11	8.47201E-05
78	28	128	155	0.001195709
79	83	384	468	0.003600831
80	9	0	9	6.93164E-05
81	2	13	15	0.000112639
82	60	329	390	0.003001512
83	759	770	1528	0.011768393
84	115	542	657	0.005057300
85	17	331	347	0.002672534
TOTAL	61460	68380	129839	**1.000000001**

Table 4.29- Evaluation of the Approach and results, *level of significance=0.001*

Variable	$\sum_{i=1}^{85} p_{c_i}$	p_d	p_i	$(p_d + p_i)$	χ^2	$\chi^2_{0.001,84'}$
Value	1.0	0.47335	0.52665	1.0	36559.4	129.8

Table 4.30- Type and cause of injuries after the Northridge, Hyogo Nambu, Armenia, Marmara earthquakes

Type of injuries		**Northridge (1994)**		**Hyogo Nambu (1995)**		**Armenia (1988)**			**Marmara (1999)**			**Bhuj (2001)**	**TOTAL**
		Number of Cases											
Injuries		**100**	**24**	**0**	**955**	**646**	**0**	**571**	**0**	**796**	**0**	**100**	**3192**
	Lower extremities	74	10									70	154
	Upper extremities	26										15	41
	extremities							512		790			1302
	soft tissue damage				955							15	970
	non-fracture injuries					646		59		6			711
	bruise/sprain		14										14
Fracture		**10**	**0**	**0**	**1539**	**533**	**46**	**83**	**0**	**133**	**0**	**9**	**2353**
	Fracture				934	533				133			1600
	Extremities				555		46	83					684
	head injuries	10			50							9	69
Spine and pelvis		**18**			**160**		**44**					**25**	**247**
Crush syndrome		**3**	**0**	**63**	**518**	**397**	**63**	**110**	**18**	**749**	**26**	**6**	**1953**
	chest and abdominal	3		63	146					110	26	5	353
	crush syndrome				372	397	63	110	18			1	961
	renal problems									639			639
Burn		**14**			**51**								**65**
Others					**140**								**140**
TOTAL CASES		**145**	**24**	**63**	**3363**	**1576**	**153**	**764**	**18**	**1678**	**26**	**140**	**7950**

Cause of injuries		**Nothridge (1994)**		**Hyogo Nambu (1995)**		**Armenia (1988)**			**Marmara (1999)**			**Bhuj (2001)**	**TOTAL**
		Number of Patients											**3013**
	Falling debris	11	4		1360							83	1458
	Falling/stumbling	77	1		248							50	376
	Struck by objects	21	11		607								639
	Traffic	4			64								68
	Burns/Electrocution	10											10
	Piercing/Cutting	7	6										13
	Others	8	2		439								449
TOTAL PATIENTS		**138**	**24**	**487**	**2718**	**1454**	**273**	**639**	**18**	**5302**	**356**	**133**	**11542**

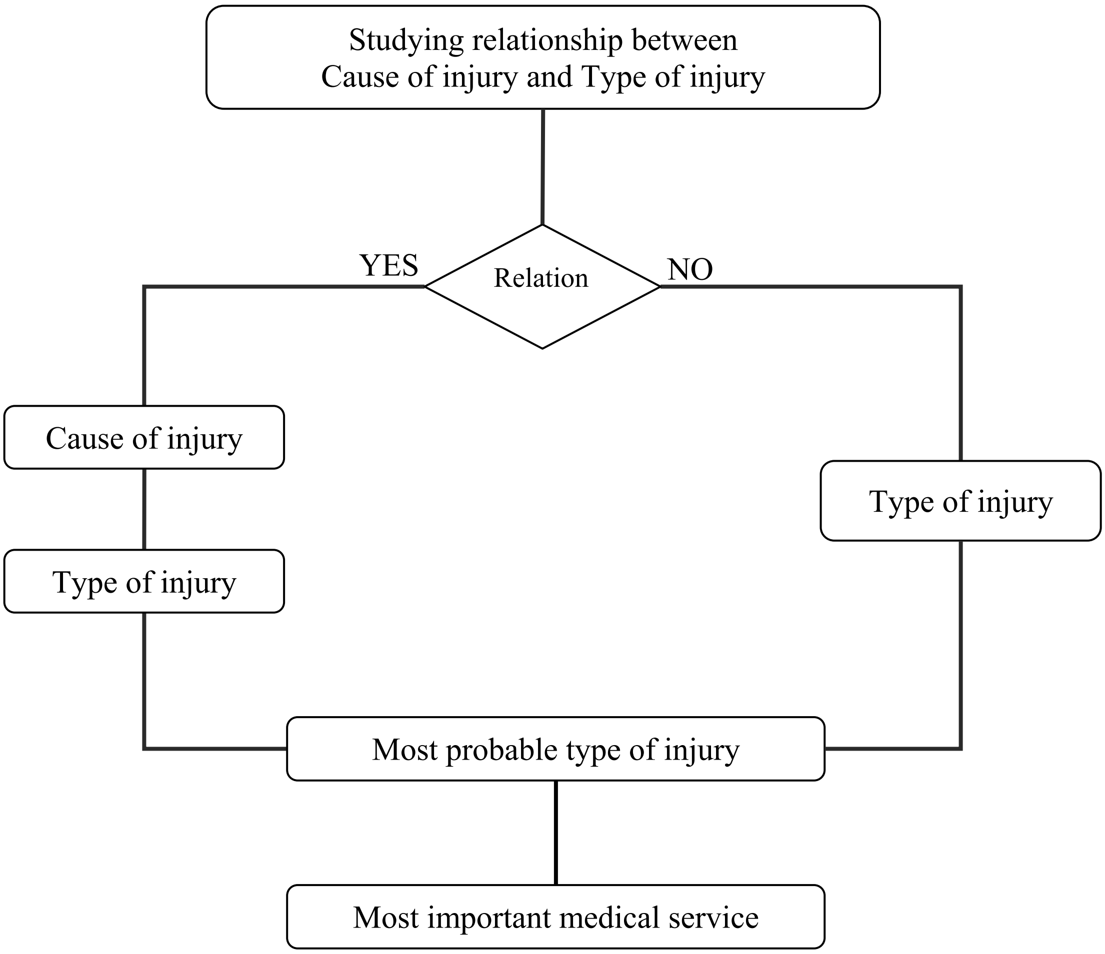


Figure 4.40- Steps to find the most important equipment

4.2.4 Considered equipment

We decided to consider only three different types of equipment; a wheeled table, shelves and small equipment which can be a medicine container (bottle or any other type). Each of them has different characteristics and will be studied under the majority of possible states which can be found or used.

The idea of choosing these particular elements came from their excessive use in healthcare facilities. Photo 4.5 and Photo 4.6 show the case of some equipments mounted on wheels. In some cases, wheels turned out to be the cause of malfunction in some facilities, see Photo 4.7. Photo 4.8 shows the large number of small equipment placed in shelves and illustrates the risk of being thrown given an earthquake.

Photo 4.5- Blood bank

Photo 4.6- Incubator, supports

The smallest equipment is supposed to be freely standing on top of the table, see Figure 4.41, or stored in shelves as shown in Figure 4.42. Experiments were done only to find out the response of the nurse table, the results are shown in the following section.

Photo 4.7- Displacement of furniture

Photo 4.8- Equipment toppled from selves

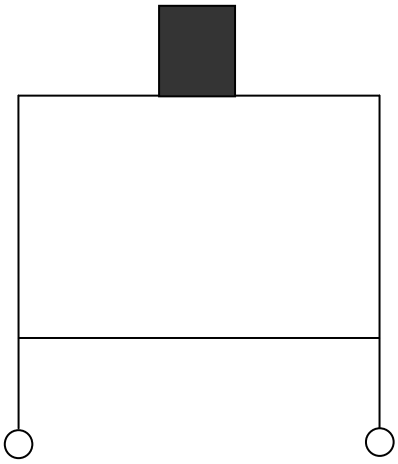


Figure 4.41- equipment placed on top of table

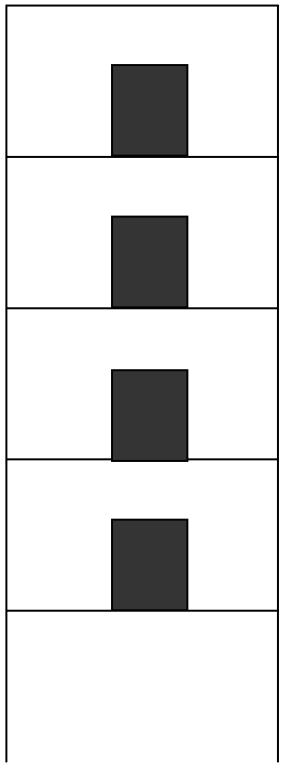


Figure 4.42- equipment stored in shelves

4.3 Response of a wheeled equipment: nurses table

4.3.1. Case I-1: Unlocked wheels

4.3.1.1 Theoretical Model

Figure 4.43 (a) shows the motion of the table. The table is considered as a rigid body, i.e. all legs move in the same way at any moment. Therefore, the entire table can be considered as one degree of freedom system (1DOF) as shown in Figure 4.43 (b). The system verifies the second law of Newton of a system in motion shown in Equation 4.12. The system's motion is a forced vibration without any restoring system; in other words only the loading, i.e. input acceleration, the response of the system and the frictional force which makes the latter the only resistance to the loading. The system will not start moving only when the external forces exceed the frictional force. The nearest system that responds similarly to our system is the Friction Pendulum System (FPS). A regular FPS has a radius, R, of curvature of the sliding surface, which affects the stiffness, k, and the natural period, T_0, of the system as Equations 4.13 and 4.14 show respectively. The present system has a radius equal to infinity which makes it without any stiffness and with very high natural period, i.e. very low natural frequency. Figure 4.43 shows one motion of the table under motion and the model relevant to it.

$$\sum_{i=1}^{n} F_i = -m \times a \qquad (4.12)$$

Where

F_i: Loads applied on the system

m: mass of the system

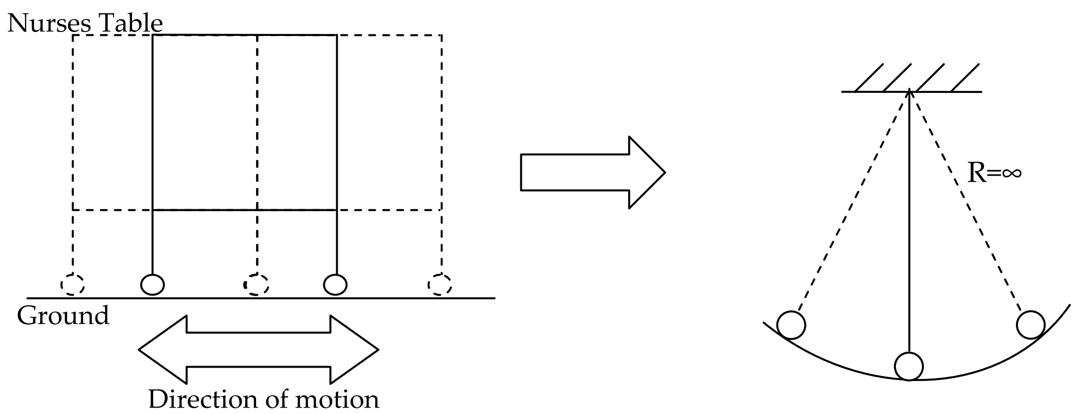
a: acceleration

$$k = \frac{W}{R} \qquad (4.13)$$

Where

W: weight of the system

$$T_0 = 2\pi\sqrt{\frac{R}{g}} \qquad (4.14)$$



(a) Real case (b) Theoretical model

Figure 4.43- Model of the unlocked wheels case

4.3.1.1.1 Friction

Friction is the main factor in the present case, as it is the only factor that affects the response of the system. Up until now, there is no exact definition that describes the precise phenomena of this factor. Many researchers have been working on this issue. However, all of them are based on the Coulomb definition of friction. Chowdhury et al. discussed the influence of duration of rubbing on friction; while Chaudhuri et al. (2005) presented the influence of acceleration on friction. Friction was considered by mechanical engineers such as in Vil'ke et al. (2004), Friberg (2005), Kinkaid et al. (2005) and Bucher et al. (2006); some of them used in industry such as in Uranker et al. (2006), and others of the impact of plane viscosity on friction such as in Poscel et al. (1999 and 2004). Civil engineers were also interested in using friction such as Wen et al. (1976), Mosaghel et al. (1987), Papageorgiou et al. (1990), Tsai et al. (2003), Ates et al. (2006) and others. Other researchers considered the affect of dryness or wetness on friction such as Sinopoli (1987)

In our case it is best to consider those models that are used in civil engineering, mainly in FPS systems, i.e. base isolation systems. Among the models that we have checked we found that the model proposed by Mokha et al. (1990) is the best, as it gives the best results. The case study considered by Ates et al. (2006) is very similar to our case which maybe useful for this study. The model is used for finding the response of bridge isolated with FPS. In this model the friction force is shown in Equation 4.15. The equation will be simplified more since the radius of the isolation system is considered to be infinity which makes the first part of the equation, stiffness of the system k, vanish and becomes as shown in Equation 4.16.

$$F_r = \frac{W}{R}x + \mu_s W \operatorname{sgn}(\dot{x}) \tag{4.15}$$

Where

W: Weight of the equipment,

R: Radius of the spherical concave surface (isolation system),

μ_s: Coefficient of friction of the sliding surface,

x: Sliding displacement

$\dot{x}$: Sliding velocity

$$F_r = \mu_s W \operatorname{sgn}(\dot{x}) \tag{4.16}$$

The coefficient of friction was measured by making a simple test in which we pulled the table and measured the minimum force that causes its movement. The force then was divided by the weight of the table to finally obtain the coefficient sought. Table 4.31 illustrates the COF for each of the cases that were considered in the study.

Table 4.31- Coefficient of frictions

Case	Coefficient of friction (C_{rr}/μ_s)
No Locks (Case I-1)	0.050
4 Locks (Case I-2)	0.570

4.3.1.1.2 Equation of motion

The general system's equation of motion is shown in Equation 4.12, considering each of the applied forces the equation becomes as shown in Equation 4.17.

$$m\ddot{x} + c_e\dot{x} + F_r = -m \times a \qquad (4.17)$$

Where

c_e: Equivalent damping factor

F_r: Friction force

The equivalent damping factor depends on the friction which makes it the most important factor that affects the response of the equipment. It is defined as in Equation 4.18 (Ates et al., 2006), in which the linear viscous damping, c_b, is shown in Equation 4.19 (Chopra, 2000).

$$c = c_b + \sqrt{\frac{2}{\pi}}\frac{\mu_s W}{\sigma_{\dot{x}}} \qquad (4.18)$$

$$c_b = 2\xi_b m\omega_b \qquad (4.19)$$

Where

$\sigma_{\dot{x}}$: Root mean square value of velocity defined in Equation 4.20

$$\sigma_{\dot{x}} = \frac{\mu_s g}{2\sqrt{2\pi}\xi_b\omega_b}\left(\sqrt{1+\frac{4\pi^2\xi_b S_a(\omega_b)}{\mu_s^2 g^2}}-1\right) \tag{4.20}$$

ξ_b: damping ratio

ω_b: Natural frequency

S_a: Power spectral density function of the input acceleration (Ohsaki, 1976)

To determine the damping ratio we made a small test and we found that it is about 10%. The natural frequency of the table was found by making a modal analysis by SAP2000® version 10.0.1 (Computers and Structures Inc.) the results are shown in Table 4.32. In our case we are between Mode 1 and Mode 2, so the natural frequency that will be used is that of the 1st mode. The mass of the table is about 7.5kg. Equation 4.17 was changed to have the form of Equation 4.21, in which the new parameters are defined in Equation 4.22 and Equation 4.23. To resolve Equation 4.17 we made a programme code in a flowchart as is shown in Figure 4.44. The detail of the programme is shown in Appendix III. The expected results of the programme are: Displacement, x, velocity, v, Acceleration, A, and absolute acceleration, ABA. Also the hysteresis loop of the movement.

$$\ddot{x} = 2\gamma\dot{x} \pm \mu_d^{'} mg - a \tag{4.21}$$

Where

$$\gamma = -\frac{c}{2m} \tag{4.22}$$

$$\mu_d^{'} = \frac{\mu_d}{m} \tag{4.23}$$

4.3.1.1.3. Results of simulation

The simulation showed that the equipment responds similarly to a base isolated building. The response was defined as an amplification factor that was defined in Equation 4.11; the amplification reduces with the acceleration, the results are plotted in Figure 4.45. In other words, the absolute response of the equipment reduces when the acceleration increases which makes the equipment more stable.

The fist shock makes the equipment relocate and then it vibrates constantly, as shown in Figure 4.46. As much as the shock gets stronger it affects the relocation of the equipment; “d” increases with the acceleration as shown in Figure 4.47. To find out the influence of the frequency on the stability of the equipment we plot the residual displacement, d, versus the frequency as shown in Figure 4.48. In low frequencies the equipment moves for long distances. The stability of the equipment depends on both acceleration and frequency. Low frequencies and high accelerations tend to make the equipment instable, while high frequencies tend to stabilize the equipment. This can be explained by the fact that the equipment’s first mode is at very low frequencies, see Table 4.32. The first mode of the equipment is translation which explains that the equipment tends to resonate when the frequency is low, i.e. relocates easily with low frequencies. The second mode is rocking, i.e. displacement tends to become nil even with high acceleration. The acceleration makes the equipment rock since it is not able to move. What can be learned here is that equipment mounted on wheels might not be safe in buildings with base isolation systems.

Isolation systems are usually provided with systems to restore their initial conditions, i.e. position. These systems can be the use of springs with stiffness k, or equivalent stiffness such as a curvature radius in FPS systems. In the present case none of these systems were used, i.e. $k=0$ and $R=\infty$, and this caused the displacement of the equipment from its original position to a new location. In other words, the non-existence of restoring force caused the equipment to relocate. In point of fact, the equipment has a restoring force; the friction force can be that force. However, it is very low. So increasing the friction may be a good option to reduce the relocation. Figure 4.49 illustrates the hysteresis curve relevant to the case of 1Hz and 900cm/sec^2. The curve shows that the elastic period is very short or maybe it can be considered as nil, after that the equipment becomes pure elastic, i.e. non-linear, behaviour.

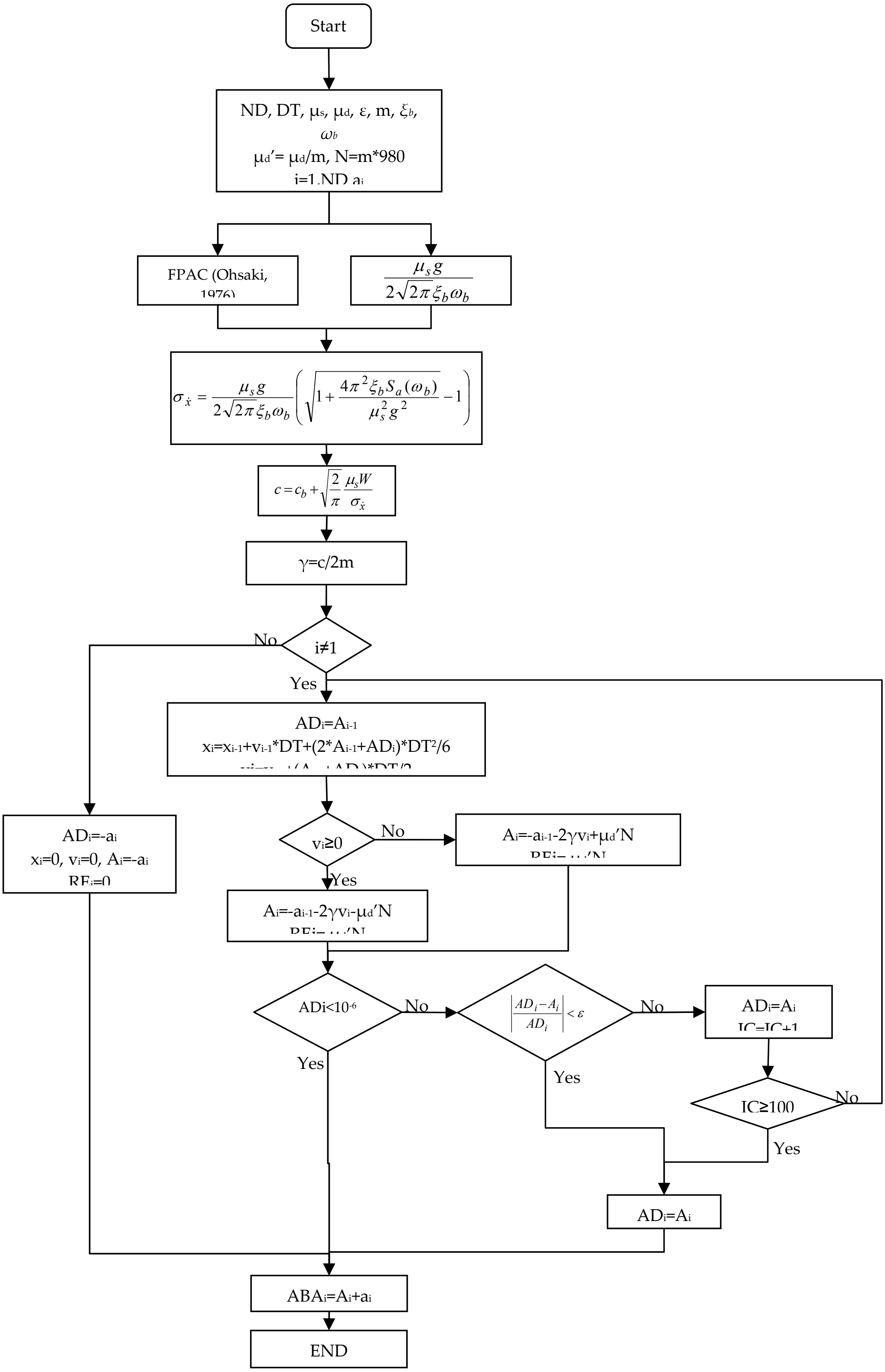


Figure 4.44- Flowchart followed to resolve the equation

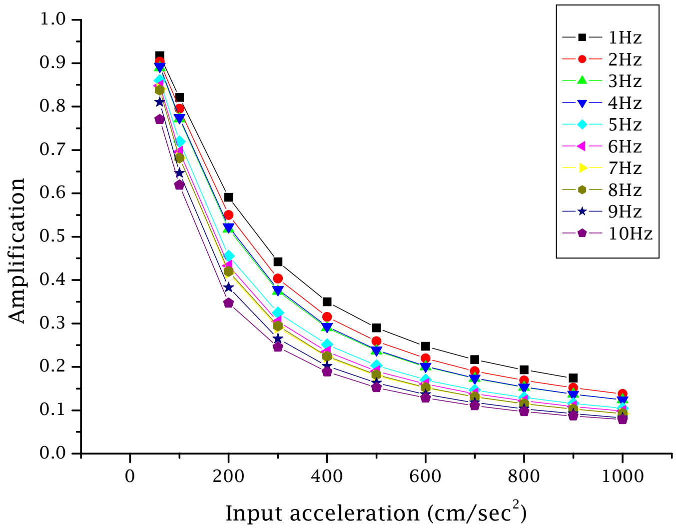


Figure 4.45- Variation of amplification versus the input acceleration

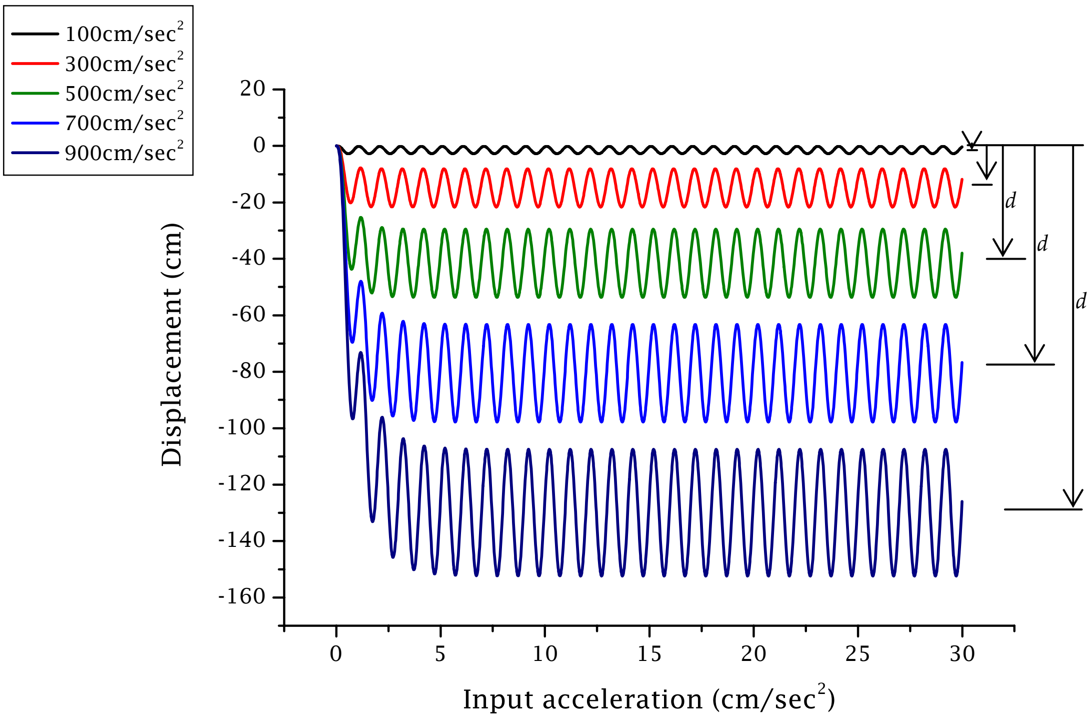


Figure 4.46- History of equipment displacement, 1Hz

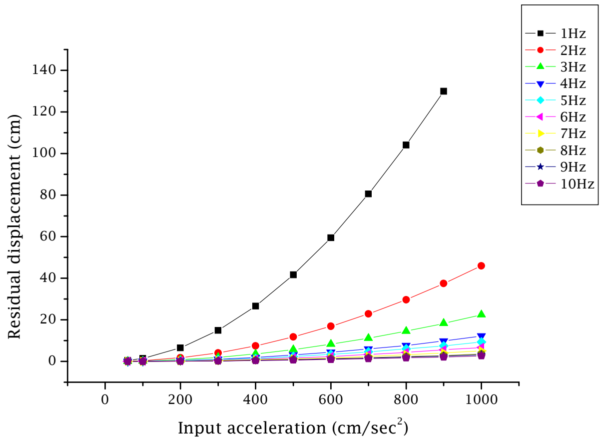


Figure 4.47- Relationship between residual displacement, d, and acceleration

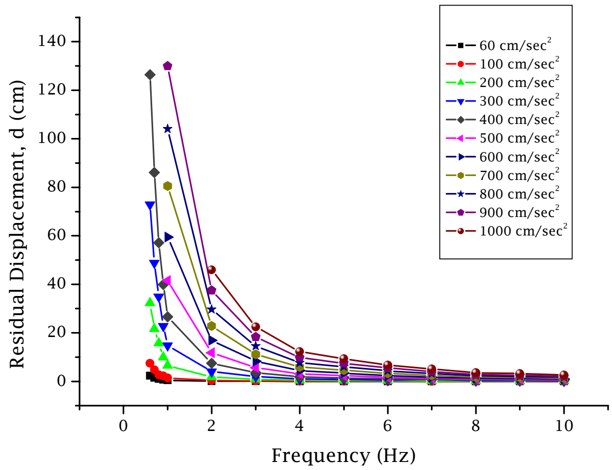


Figure 4.48- Relationship between residual displacement, d, and frequency

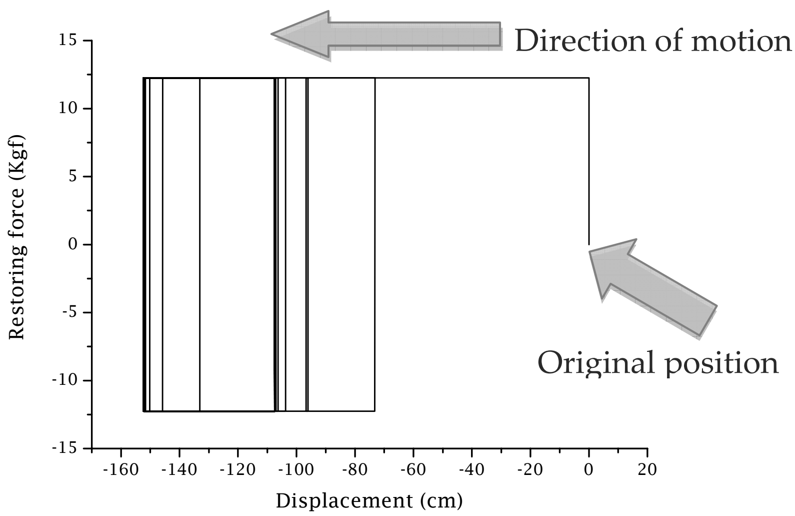


Figure 4.49- Hysteresis loop of the equipment, 1Hz-900cm/sec^2

Table 4.32- Natural frequencies of the table

Mode	Period Sec	Frequency Hz	Circular Frequency rad/sec	Eigen value rad2/sec2
Mode 1	7.073969	0.1414	0.8882	0.7889
Mode 2	0.058429	17.115	107.54	11564
Mode 3	0.031656	31.589	198.48	39395
Mode 4	0.025975	38.499	241.90	58513
Mode 5	0.018601	53.761	337.79	114100
Mode 6	0.017980	55.617	349.45	122120
Mode 7	0.017913	55.827	350.77	123040
Mode 8	0.017323	57.728	362.72	131560
Mode 9	0.012885	77.608	487.63	237780
Mode 10	0.011304	88.463	555.83	308950
Mode 11	0.009454	105.77	664.59	441690
Mode 12	0.008488	117.82	740.28	548010

4.3.1.2 Experiment

4.3.1.2.1 Overview

The experiments were done using typical equipment found at any hospital in the world. It is a nurse's table mounted on casters, see Photo 4.9, the sizes are shown in Figure 4.50. The use of wheels is common in healthcare facilities since they make movement and distribution of medicine, food, etc between the patients easier. The wheels are able to rotate around two axes; horizontal and vertical. The wheels can be fastened which makes them unable to rotate around a horizontal axis by using little brakes on the side of each wheel, see Photo 4.10. Four possible cases can be considered; 1) wheels unlocked, 2) one wheel locked, 3) two wheels locked and 4) four wheels locked.

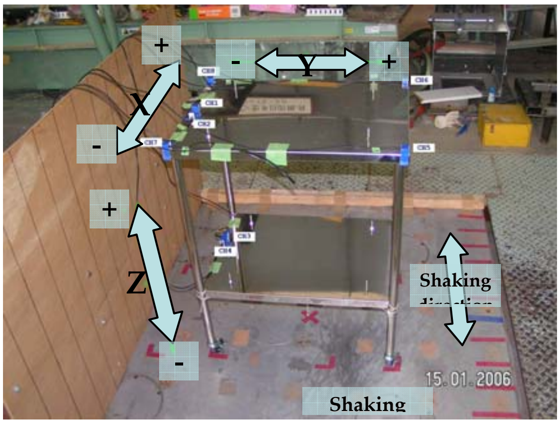


Photo 4.9- First table used for the experiment

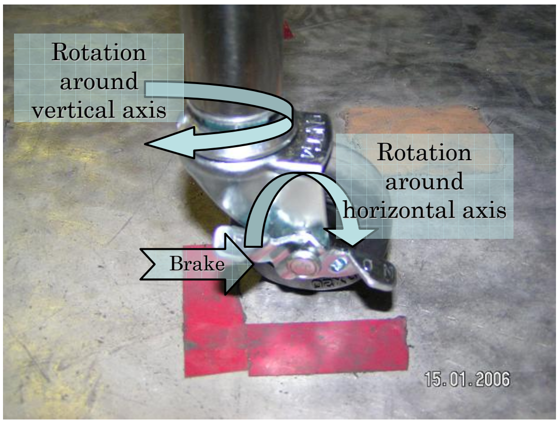


Photo 4.10- Wheel of the table

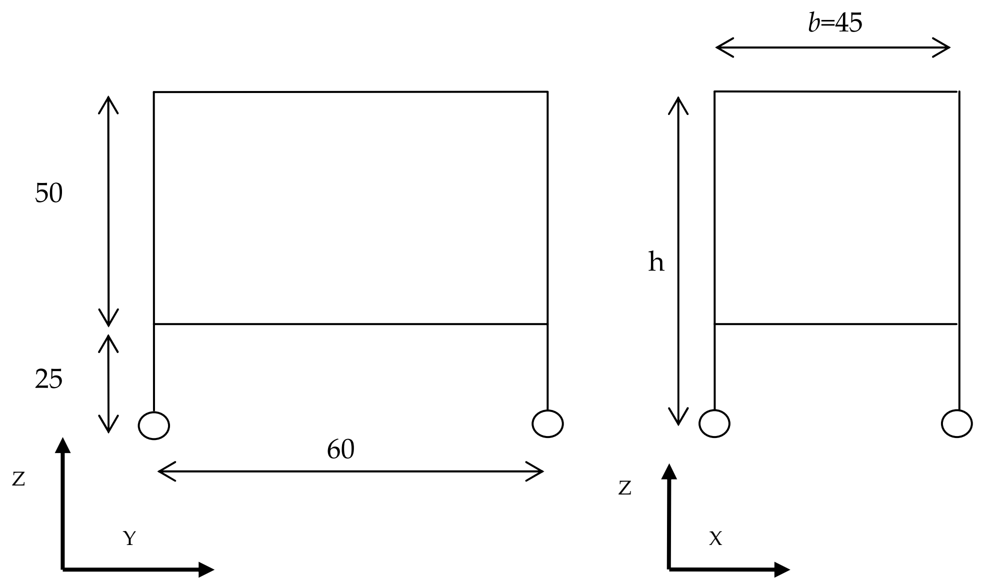


Figure 4.50- Detail of the table

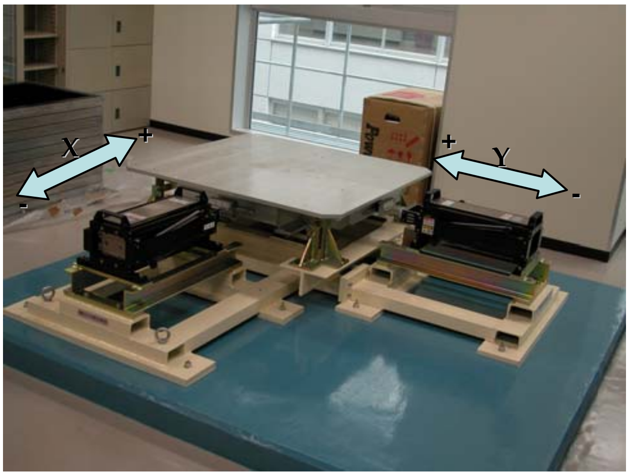


Photo 4.11- Second table used for the experiment

The experiment was done using two shaking-tables; the first is shown in Photo 4.9 and the second is shown in Photo 4.11. As Table 4.33 illustrates, table 1 is larger than the second but unfortunately its ability is limited. The second table has to possibility to reach very low frequencies; and it also has the possibility to shake equipment in two directions; X and Y. However its limited dimensions make its use very limited. For that reason we had to use both tables, each of them was used in particular cases:

- Table 1: One and two wheels locked cases,
- Table 2: No locks and four wheels locked cases.

During the experiment we limited the motion of the equipment by blocking the vertical rotation with the purpose of making the analysis easier and assuring a 2D model rather than 3D one. We measured the horizontal accelerations at the level of plates, top and bottom, the vertical acceleration and the input acceleration. The vertical accelerometers were placed on top of each leg of the equipment. With the purpose of reducing errors the experiments were done three times for each case. We could have more possibilities with the unlocked-wheels case; frequencies varied between 0.9Hz and 6Hz and the measure of the residual displacement was possible.

Table 4.33- Characteristics of the shaking tables

Characteristics		Table 1		Table 2
Size		1500×1500mm		1000x1000mm
Force of excitation		±100kN	±60kN	±0.5kN
Maximum amplitude		±50mm		±75mm
Maximum velocity		±40cm/s	±30cm/s	±50cm/s
Maximum acceleration	no loading	±3.3G	±5.0G	±0.62G
	Loading	±2.0G	±1.0G	N/A
Frequency range		0.5-25Hz		0.1-50Hz

4.3.1.2.2 Loading

To cover different cases of response we decided to use sinusoidal wave rather than earthquake waves. As it gives the possibility to cover all desired frequencies, which in turn depends on many variables: soil conditions, building type (usual or with base isolation system), height of building and other criteria. Frequencies were varied between 0.6Hz and 6Hz as it is very difficult to measure the motion with higher frequencies. Within the same building, floors have different responses, i.e. accelerations. This makes the acceleration another factor to be considered. For that reason, we varied it between 60 and 1000 cm/sec^2. Also, because of some technical limitations, it was very difficult to reach high accelerations with low frequencies, for that reason only medium and high frequencies were considered in the case of high accelerations.

4.3.1.2.3 Results

Shenton (1996) showed that the response of equipment freely standing on an accelerating ground can be 1) rest, 2) slide, 3) rock, 4) slide-rock or 5) free flight. Equipment passes from a rest state to another state depending on the strength of excitation, friction and geometry. The equipment does not start moving only when the load exceeds the friction force. Table 4.34 shows the value of the coefficient of friction of each case as well as the minimum equivalent acceleration that is able to make the equipment move. The acceleration was calculated according to Equation 4.24. The case of all locked wheels was calculated according to Equation 4.25 (Shenton 1996) because the coefficient of friction is large enough to make the equipment rock rather than slide.

$$\ddot{x} = \mu_s g \qquad \text{or} \qquad \ddot{x} = C_{rf}\, g \tag{4.24}$$

Where

μ_s: Static Friction (or C_{rf} for Coefficient of Rolling Friction for the case of no locks)

g: Acceleration due to gravity

$\ddot{x}$: Equivalent acceleration that is able to move the equipment from resting status

$$\frac{\ddot{X}}{g} \le \frac{\left(1+4\psi'^2\right)\mu_s - 3\psi'}{\left(4+\psi'^2\right) - 3\psi'\,\mu_s} \tag{4.25}$$

Where

ψ': size ratio defined as $\psi' = h/b$; b and h: width and height respectively

As in the theoretical analysis the response was defined as an amplification factor, shown in Equation 4.11, to facilitate the analysis of the results as well as to compare the response between the different cases.

Table 4.34- Coefficient of friction and minimum acceleration to make the equipment move

Case	**Coefficient of friction (C_{rr}/μ_s)**	**Minimum Equivalent Acceleration (cm/sec^2)**
No Locks (Case I-1)	0.050	49
4 Locks (Case I-2)	0.570	475

Given some limitations, the experiments could not be performed for all frequencies and accelerations, only frequencies varying between 0.6-6 Hz and accelerations varying between 60-400 cm/sec^2 were performed. In the following section we will show the results relevant to both experiment and simulation to make sure that the model conforms well with the reality, after that only simulation will be considered.

In this case the wheels were free to move, the motion started from very early stages as the rolling friction coefficient is very low, see Table 4.34. For low accelerations the equipment moves slightly, which makes the amplification equal to unity. However, for high accelerations the equipment seems to respond less than the input acceleration. The system responds similarly to a friction pendulum system (FPS), in other words a base isolation system. Figures 4.39 (a-g) illustrate that for an acceleration of 400cm/sec^2 the response reduces to 20%. The figures show that there is a slight difference between the experimental results and the simulation. However, considering the fact that errors may occur during experiments and that some other factors may be overlooked during the simulation. Not withstanding the "uncertain" definition and values of friction we believe that the results can be accepted and that the theoretical model is verified vis-à-vis the acceleration.

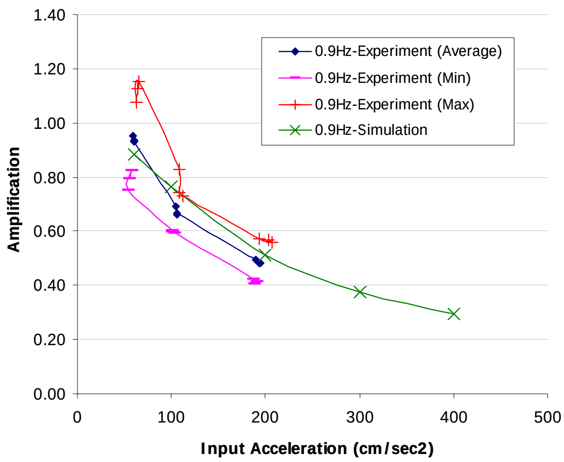


Figure 4.51 (a)

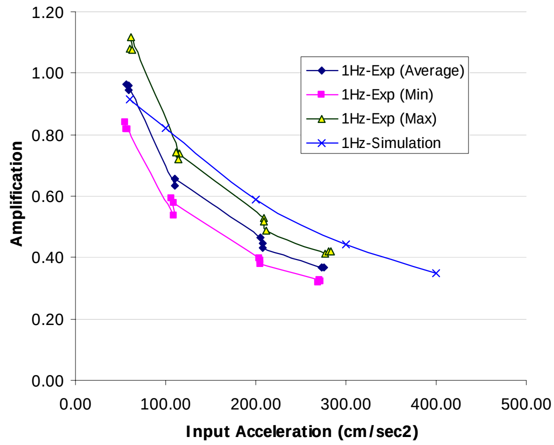


Figure 4.51 (b)

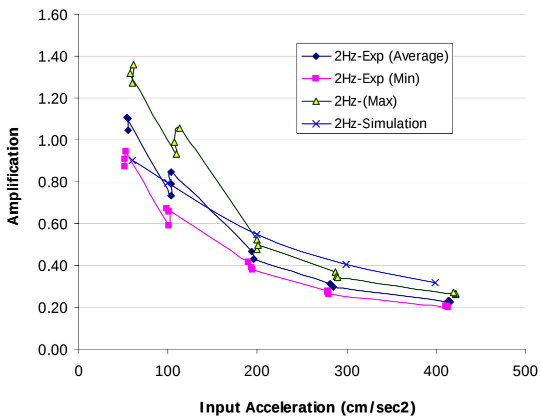


Figure 4.51 (c)

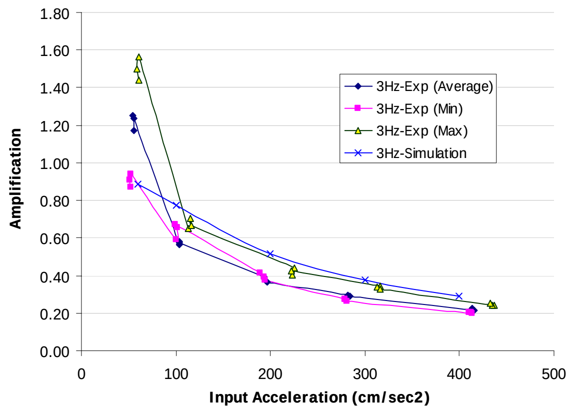


Figure 4.51 (d)

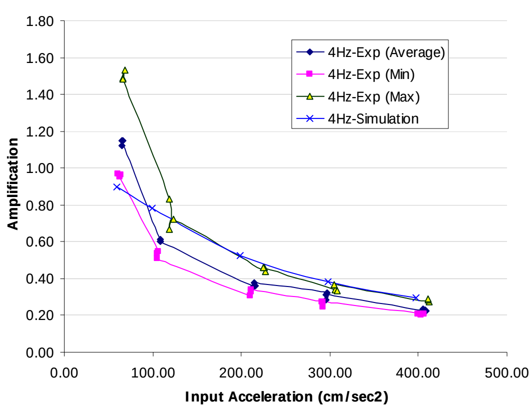


Figure 4.51 (e)

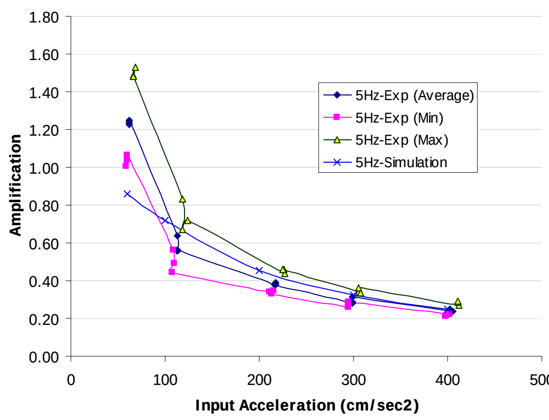


Figure 4.51 (f)

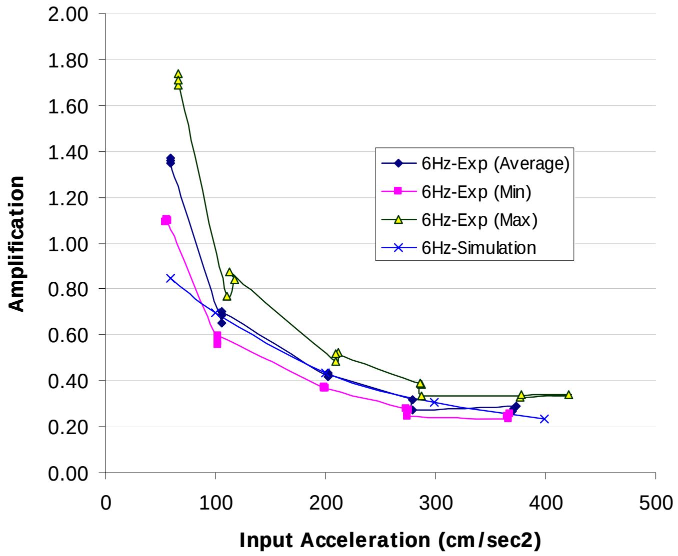


Figure 4.51 (g)

Figure 4.51- Relationship amplification-Input acceleration

We measured the residual displacement, d, using a laser sensor, an example of the data recorded by the sensor is shown in Figure 4.52. The experiments confirm what has been found during the simulation. The frequency is anti-proportional to displacement, *d*. Figures 4.51 (a-g) show that the equipment stabilizes more with high frequencies and becomes unstable with low frequencies. This may lead us to say that when wheeled equipment is placed in a base-isolated-building, where frequency is very low, the risk of displacement of the equipment is very high and then the risk of hitting people, damaging other equipment becomes high too. The experimental and simulation results are very similar, even though slight difference was found between both results. However, considering the same factors as in the acceleration the theoretical model can be adopted and used for the rest of the study.

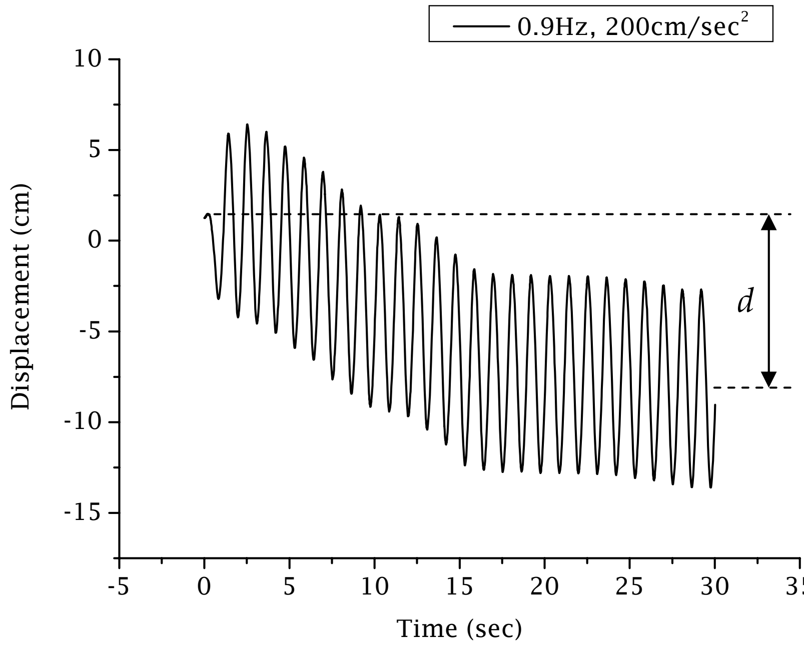


Figure 4.52- Time history of displacement, 0.9Hz-200cm/sec^2

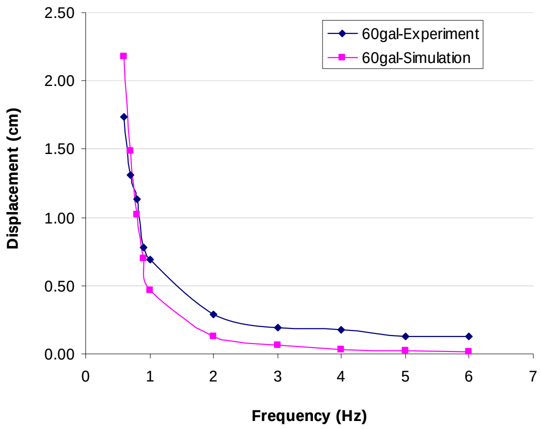


Figure 4.53 (a)

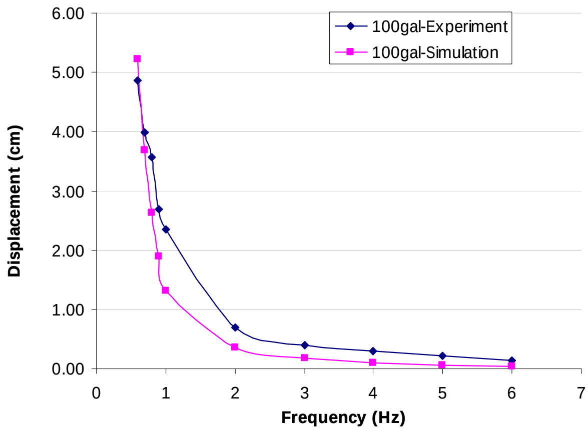


Figure 4.53 (b)

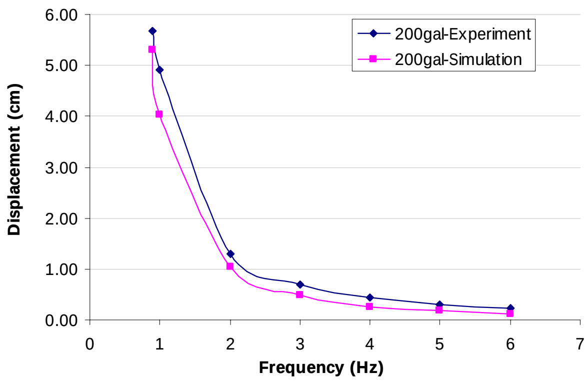


Figure 4.53 (c)

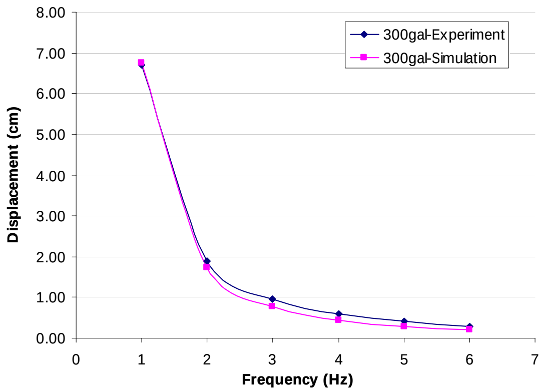


Figure 4.53 (d)

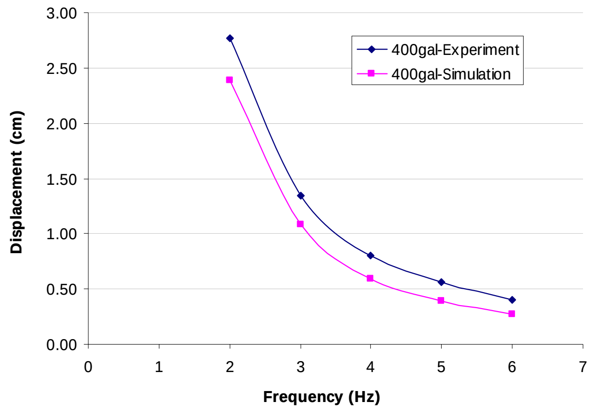


Figure 4.53 (e)

Figure 4.53- Relationship between residual displacement and frequency

4.3.2 Case I-2: All wheels locked

4.3.2.1 Theoretical model

4.3.2.1.1 Overview

Once the wheels are locked the equipment becomes difficult to move as the friction becomes about 10 times larger as shown in Table 4.34. Two possible behaviours can occur; sliding or rocking. The first step therefore should be finding which of both motions will start first. Table 4.34 illustrates that at 475cm/sec^2 rocking starts, while applying Equation 4.24 it starts sliding at 559 cm/sec^2. This shows clearly that the equipment will start rocking first therefore the study will be done for rocking.

Several researchers have been working on equipment overturning, i.e. rocking. Some of them have discussed symmetric rigid bodies such as in (Shenton et al., 1991a and 1991b), (Andreaus et al., 1999), (Makris et al., 2000), (Zhang et al., 2001), (Makris et al., 2001), (Makris et al., 2003), (Ozer et al., 2005), and others. Boroshek et al. (2004) studied the overturning of non-symmetric rigid bodies freely standing on a shaking ground. Other studies focused on blocks anchored to their support such as Makris et al. (1999). More studies were subjected to blocks placed on top of each others such as in Spanos et al. (2001) and Bende (2000). This has helped us to analyse our case and to find out its response.

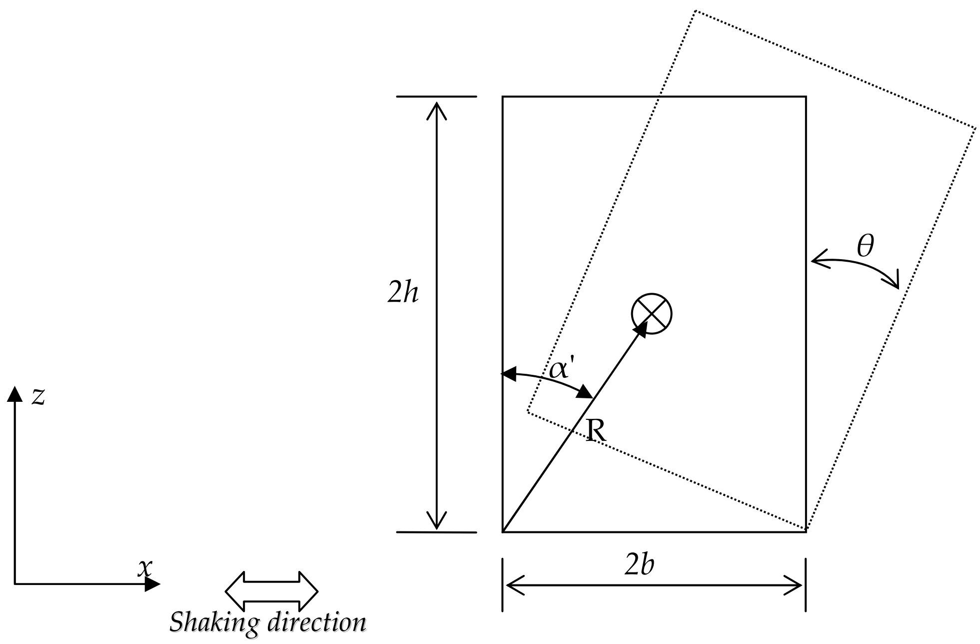


Figure 4.54- Model considered for the rocking study

4.3.2.1.2 Equation of motion

The equipment, i.e. table, was considered to be a rigid block as shown in Figure 4.54. The equipment is considered to have a height equal to 2h and width equal to 2b. R represents the half-diameter of the block, defined in Equation 4.26, and p is its frequency parameter, defined in Equation 4.27 and the slenderness α' shown in Figure 4.54. The block is under a rotational movement, i.e. the equation of motion has the form of Equation 4.28. The block is submitted to two movements; the first is due to the horizontal force caused by the acceleration and the second is due to the weight. Considering all the forces being applied at the centre of gravity, see Figure 4.55, the equation of motion becomes as seen in Equation 4.29, in which I_g is the moment of inertia about the block's centre of gravity defined as shown in Equation 4.30. After rearranging Equation 4.29, the equation of motion becomes as shown in Equation 4.31. The block is considered to be stable until the angle θ becomes equal to the slenderness of the equipment α. The equation is non-linear which requires special programmes, here we used the solvers provided in Matlab version 7.0 (R14) by The MathWorks, Inc. A programme was made to solve the equation the detail of which is shown in Appendix IV.

$$R = \sqrt{b^2 + h^2} \qquad (4.26)$$

$$p = \sqrt{\frac{3g}{4R}} \tag{4.27}$$

$$\sum M_{/g} = -I_g \ddot{\theta} \tag{4.28}$$

$$maR\cos(\alpha' \operatorname{sgn}\theta - \theta) + mgR\sin(\alpha \operatorname{sgn}\theta - \theta) = -I_g \ddot{\theta} \tag{4.29}$$

$$I_g = \frac{4}{3} mR^2 \tag{4.30}$$

$$\ddot{\theta} = -p^2 \left\{ \sin(\alpha' \operatorname{sgn}\theta - \theta) + \frac{a}{g}\cos(\alpha \operatorname{sgn}\theta - \theta) \right\} \tag{4.31}$$

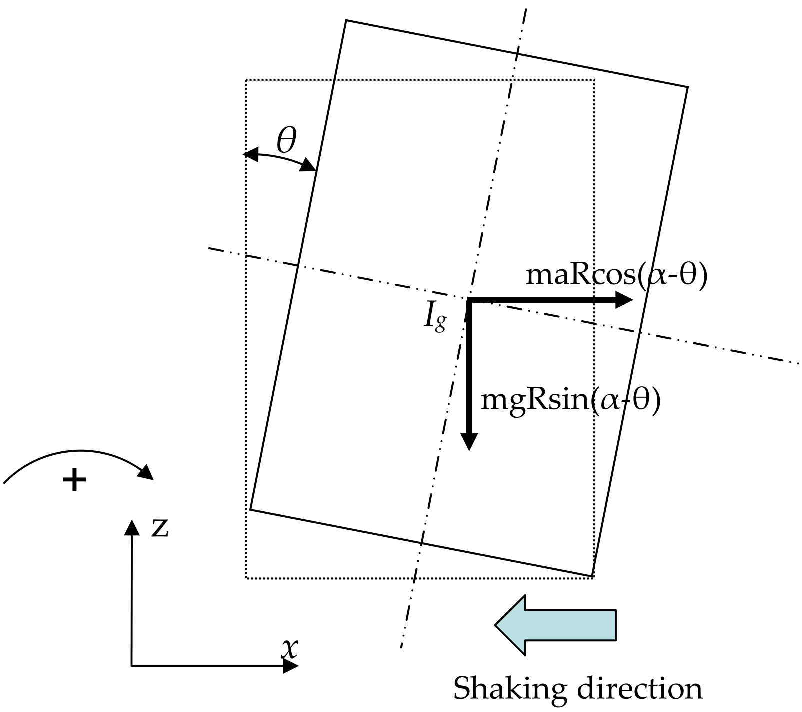
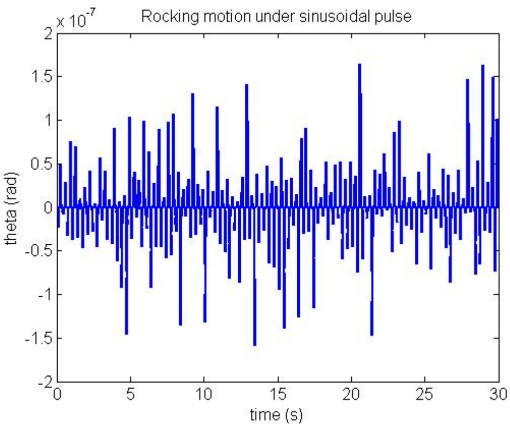


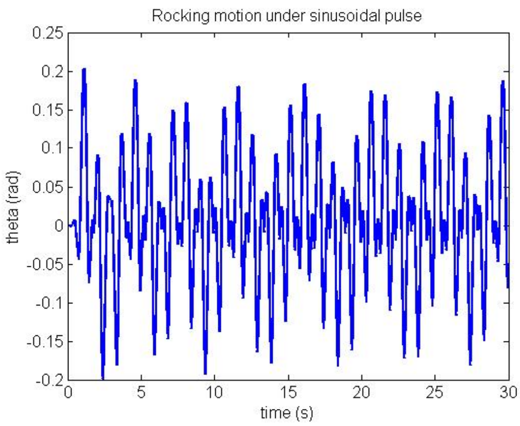
Figure 4.55- Loads of the block

4.3.2.1.3 Results

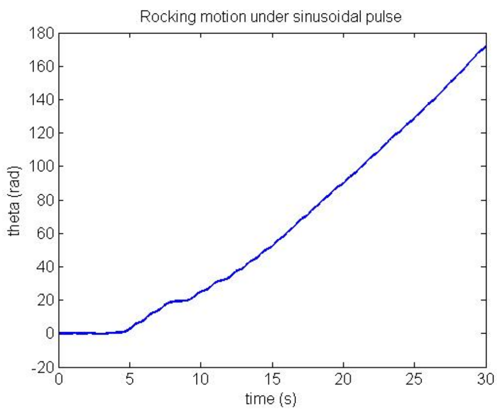
After solving the equation of motion, we obtained the velocity and the angle of rotation of the block. We chose to have velocity rather than acceleration since our experiments were done with accelerometers that measures only angular velocity. Some of the results are shown in Figure 4.56 (a, b and c) relevant to case of frequency 2Hz and accelerations 0.5g, 0.55g and 0.57g successively. The first figure represents the block before rocking, the second is during rocking and the third is its turning over. We kept varying the acceleration and frequency until the block turned over. We plotted the maximum attended velocities, for each case of the frequencies, against the input acceleration and we obtained the Figures 4.57 (a-i). The block remains rocking at very high acceleration when the frequency is very high too, and may fall from the first time it starts rocking in low frequencies. The block starts rocking at about 500cm/sec^2 regardless of the frequency.



(a) Before rocking starts



(b) During rocking



(c) Overturning of the block

Figure 4.56- Response to sinusoidal wave with a frequency 2Hz

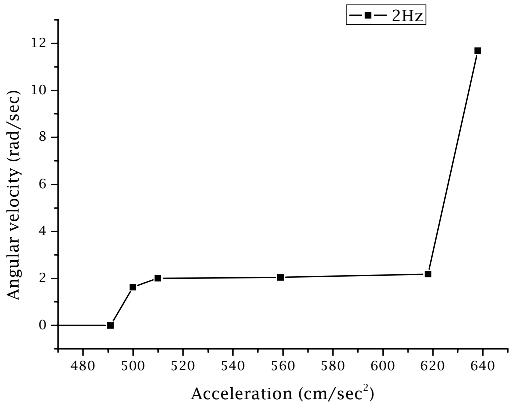


Figure 4.57 (a)

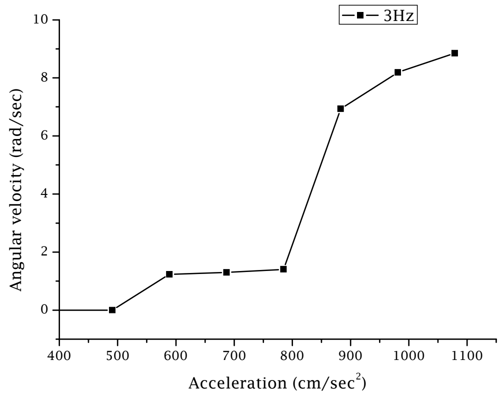


Figure 4.57 (b)

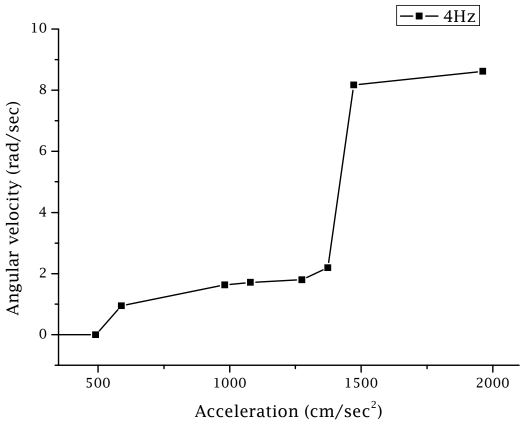


Figure 4.57 (c)

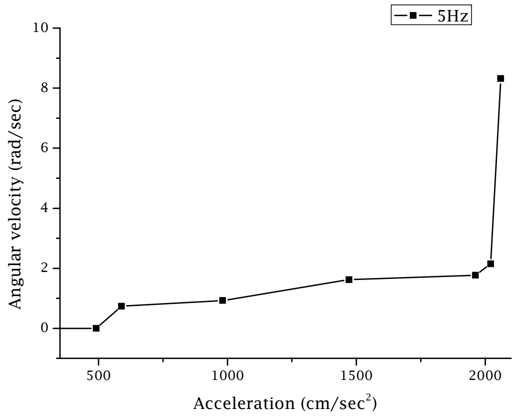


Figure 4.57 (d)

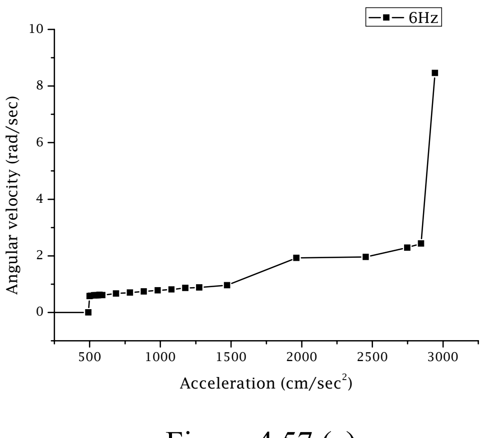


Figure 4.57 (e)

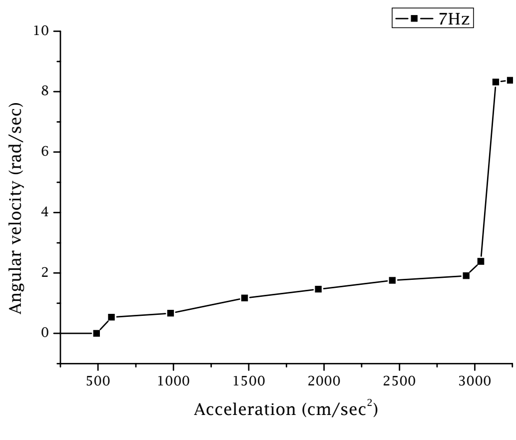


Figure 4.57 (f)

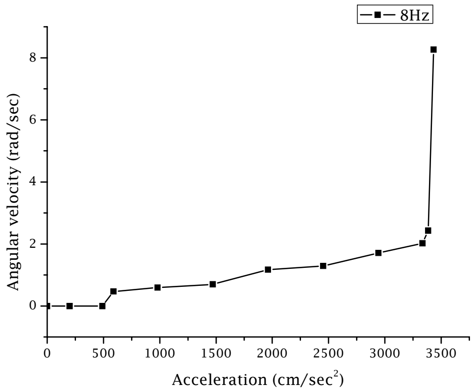


Figure 4.57 (g)

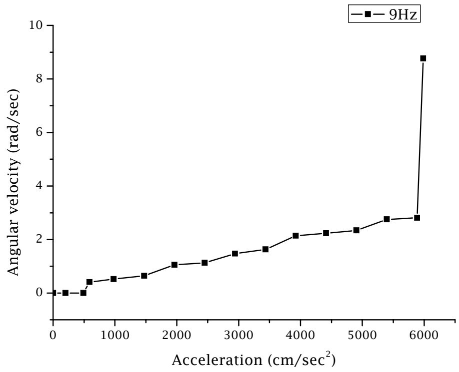


Figure 4.57 (h)

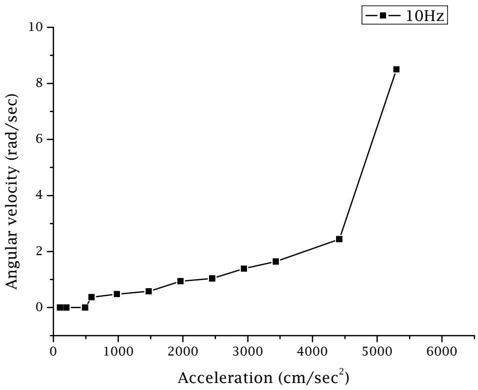


Figure 4.57 (i)

Figure 4.57 Relation of angular velocity and input acceleration

4.3.3.2 Experiment

4.3.3.2.1 Overview

The equipment was put on the shaking table with four wheels locked. Two seismographs were used to measure the accelerations and angular velocity. Each of them is able to measure three accelerations (Ax, Ay and Az) and three angular velocity (Vx, Vy and Vz) at the same time. We placed the first on top of the equipment and the second on top of the shaking table as shown in Photo 4.12. As in the previous case, i.e. unlocked wheels, a sine wave with variable acceleration and frequency was used during the experiment. Because of some limitations we could not go below 2Hz for high accelerations that are able to cause rocking. Also we were limited to accelerations around 600-700cm/sec^2. The shaking was done according to the X-axis as shown in Photo 4.12. The duration of shaking was 30 seconds which is the duration of many earthquakes such as the Japanese Hyogo Nambu earthquake of 1995. The friction of the system is already measured and shown in Table 4.31.

4.3.2.2.2 Results

The experiments were repeated three times for the purpose of reducing errors. For the same purpose and because of the influence of electric and other factors all experimental values (input and response) were filtered by using twice the input frequency filter, i.e. frequencies with over twice the input frequency were not allowed to pass. We used software called Origin version 7.0265 by OriginLab Corporation. In none of the cases did the equipment turn over. Figure 4.58 and Figure 4.59 show the response of the equipment before the rocking starts and when the rocking starts successively. The equipment starts rocking at about 450cm/sec^2 which is slightly lower than the model in which the block starts rocking at about 500cm/sec^2.

Unlike the previous case (unlocked wheels), the model considered is not exact as it gave some difference in results as can be seen in Figure 4.60 (a-e). There are two main differences; the first is the experimental angular velocity is less than that of the model. This may be because the wheels are not rigid, i.e. the equipment is not a totally rigid box, but it is a mixture between a rigid body and a soft attachment which can be considered as unilateral springs that works only when the equipment falls on the floor. Each time the equipment hits the floor wheels absorb some of the energy and therefore reduces its velocity. The second difference is with the starting point of the rocking; this issue requires more time for investigations which includes more experiments and analysis. Figure 4.61 shows the first accelerations that were recorded when the rocking started. The acceleration reduces with the frequency. Table 4.32 illustrates that the second mode after sliding is rocking if the first mode is sliding which is at very low frequencies. Furthermore, the frequency and the displacement are anti-proportional, i.e. high frequency leads to low displacements and vice versa. These two phenomena would affect the type of response and make the rocking easier to start which explains Figure 4.61. However, since not all equipments are mounted on wheels and that the difference between both results is not very large we will accept this model for the rest of the analysis.

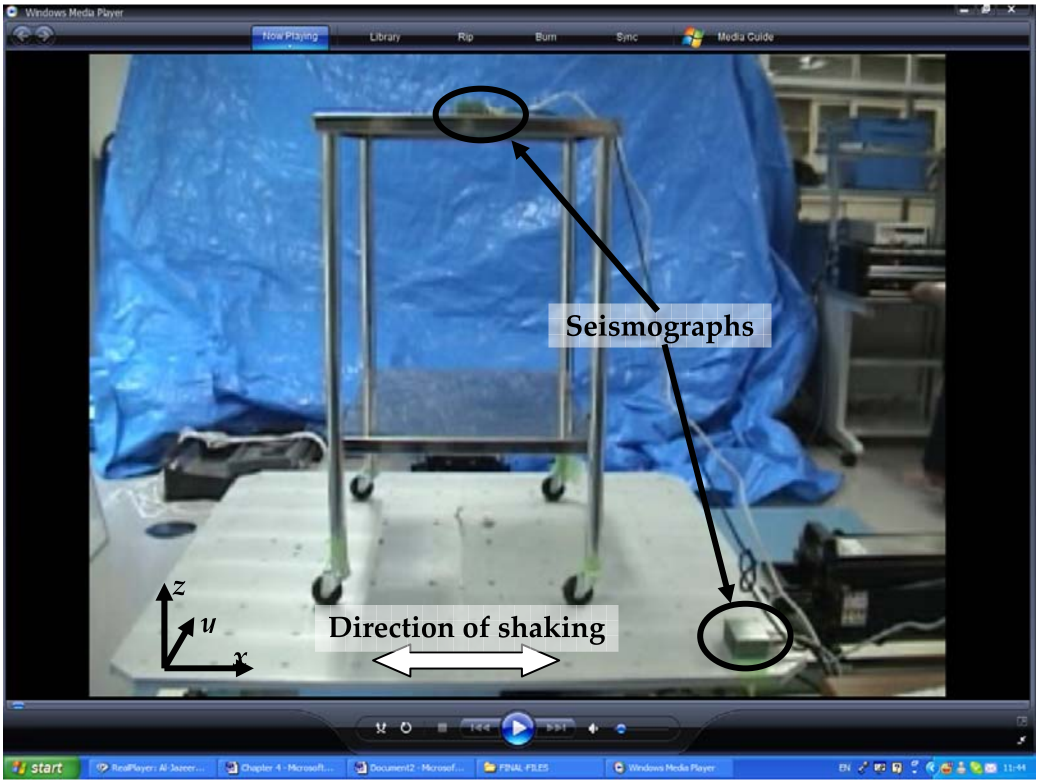


Photo 4.12- Equipment before the start of rocking

Photo 4.13- Equipment during the rocking

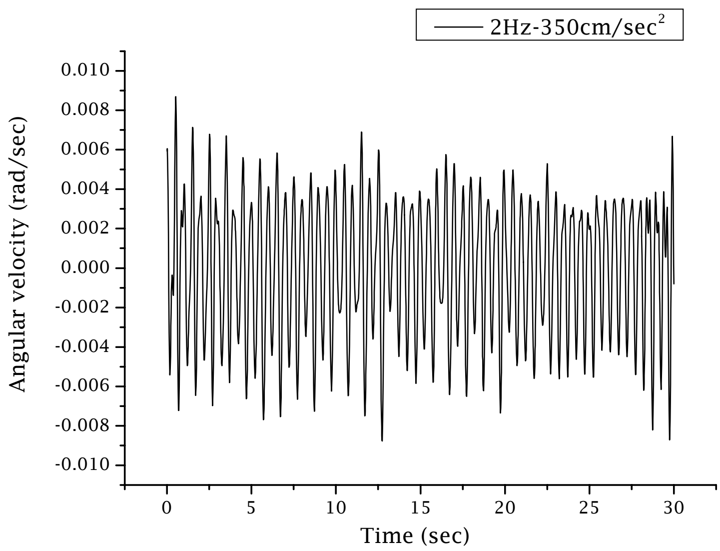


Figure 4.58- Response of the equipment before the rocking starts

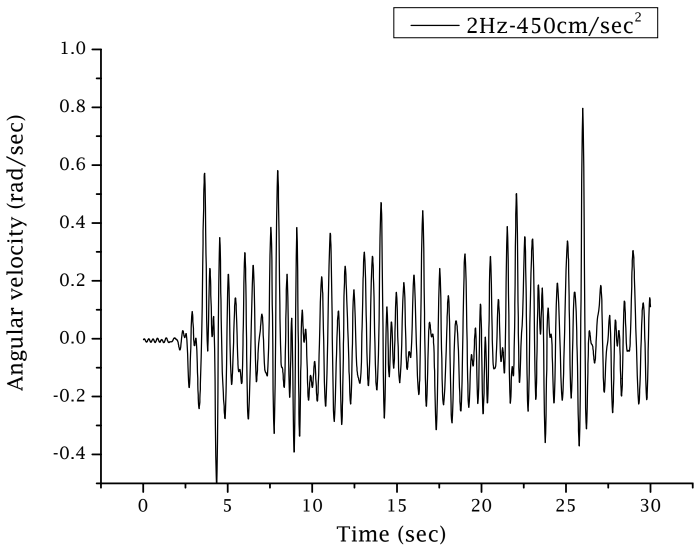


Figure 4.59- Rocking of the equipment

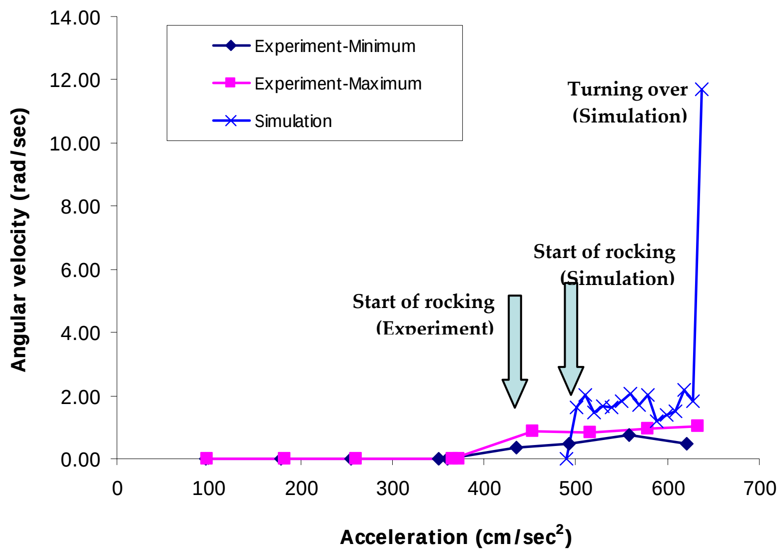


Figure 4.60 (a)- Results 2Hz

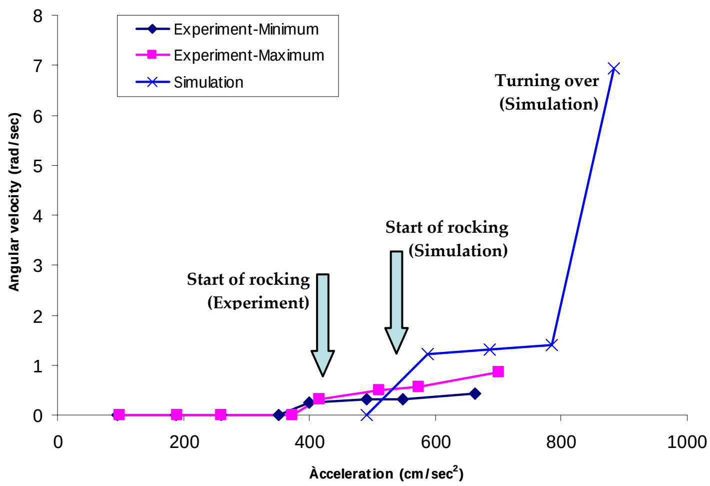


Figure 4.60 (b)- Results of 3Hz

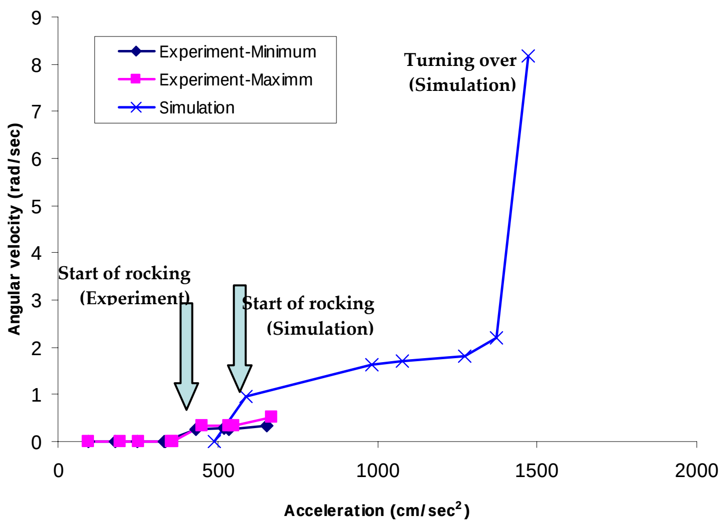


Figure 4.60 (c)- Results of 4Hz

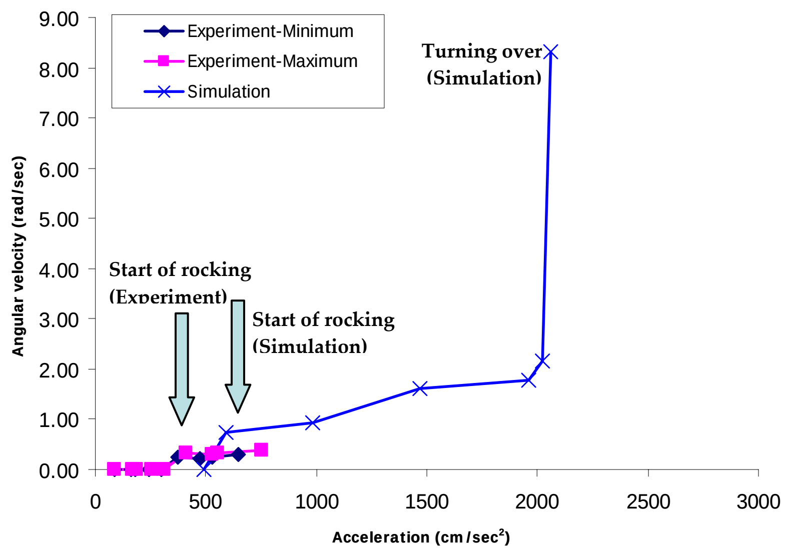


Figure 4.60 (d)- Results of 5Hz

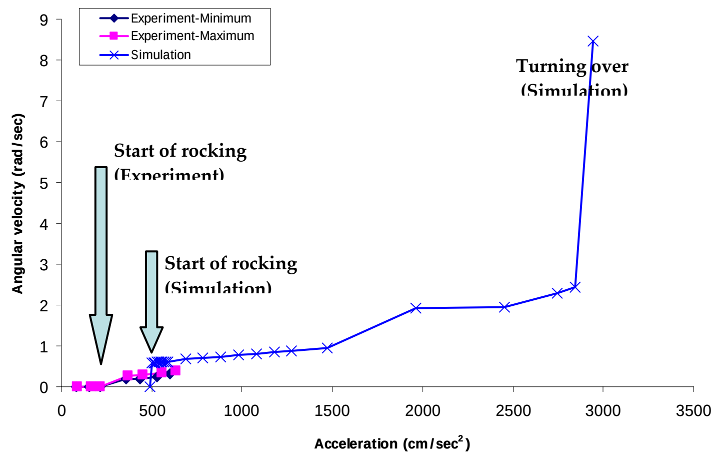


Figure 4.60 (e)- Results of 6Hz

Figure 4.60- Relationship angular velocity and acceleration

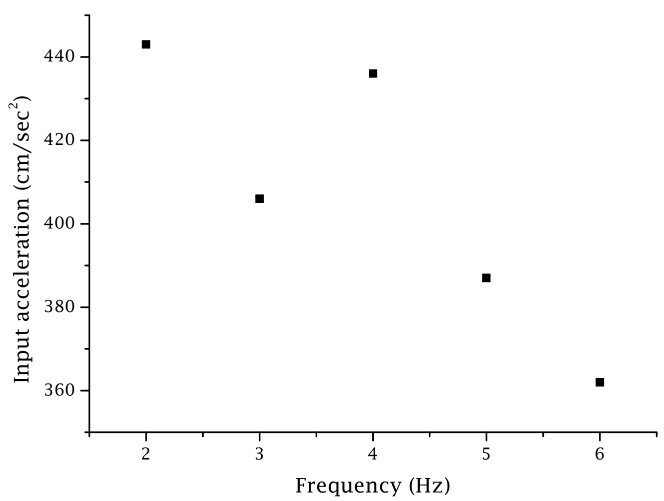


Figure 4.61- Relationship acceleration starting the rocking and frequency

Two more cases were considered during our experiments but unfortunately could not be deeply investigated even though we believe that they are extremely important cases. For that reason we present the experimental results that we have reached and we hope to consider these two cases in the future in more detail.

3.3.4 Case I-3: Two wheels locked

We asked some personnel of Matto Public Hospital in Hakusan City in Japan about the number of wheels that they usually lock. We were told that two wheels is the norm for those items of equipment that are rarely moved. Considering this, we carried out experiments using the shaking-table shown in Photo 4.5 as it is larger than the other one. The wheels were able to turn around the vertical axis which makes them able to move in both directions; X and Y. Only three frequencies were considered in this case; 1Hz, 3Hz and 5Hz. The locked wheels stop the equipment from sliding, but when the acceleration induced load exceeds the friction force the equipment moves very fast in the direction of the unlocked wheels as the friction force is about 10 times lower than the locked ones, see Figure 4.62. The equipment does not start sliding only when the friction of the locked wheels is exceeded. Figure 4.63 shows the absolute response acceleration and the amplification versus the input acceleration; the figure on the left is the response toward the X-direction, while the one on the right is the response toward the Y-direction. The acceleration was high in both directions as is seen in both figures 4.63 (a) and (b) this resulted in large displacement of the table which, unfortunately, was not possible to measure. The amplification AMP2, shown in Equation 4.32, depends on the frequency. APM is about seven times in the case of 3Hz and six times for the case of 5Hz as Figure 4.63 (c) illustrates. This might be because of the low natural frequency that the system has; however we cannot confirm this now as we don't have the sufficient information to decide. The present case can be treated as two-dimensional model if we consider that the wheels cannot rotate around the vertical axis. This makes the analysis much easier than a three-dimensional model.

$$AMP2 = \frac{\sqrt{\ddot{x}_{mes}^2 + \ddot{y}_{mes}^2}}{a} \tag{4.32}$$

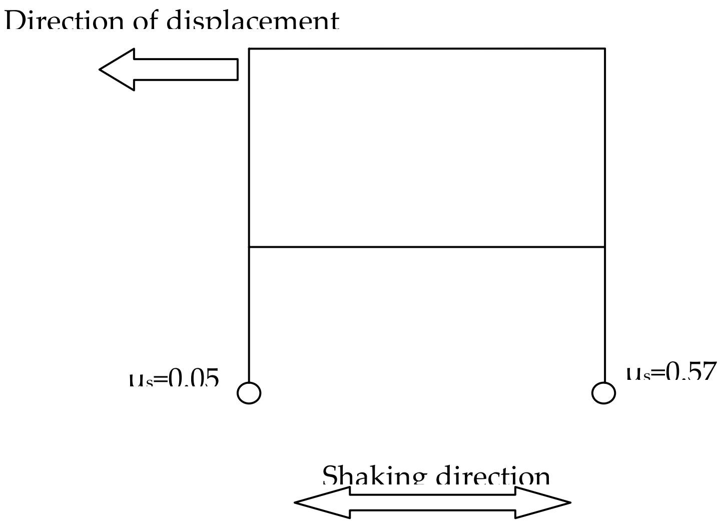


Figure 4.62- State of table with two wheels lacked

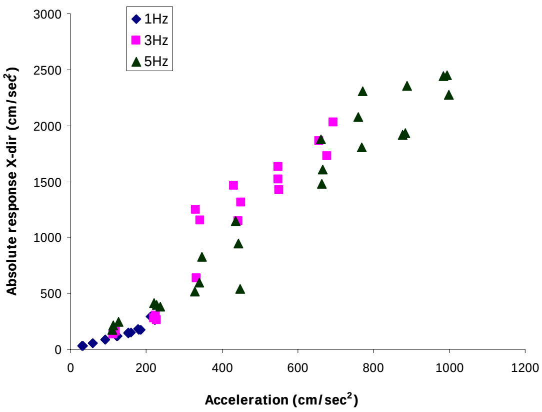


Figure 4.63 (a)

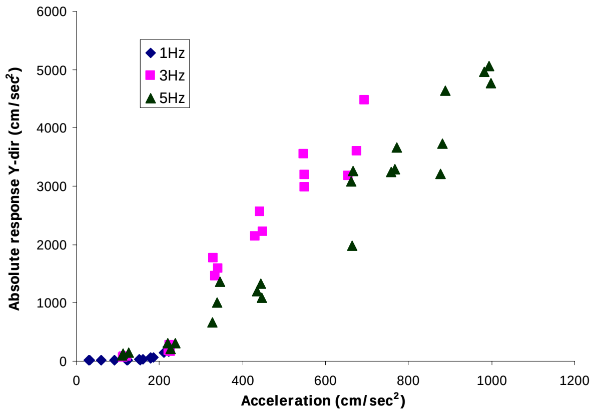


Figure 4.63 (b)

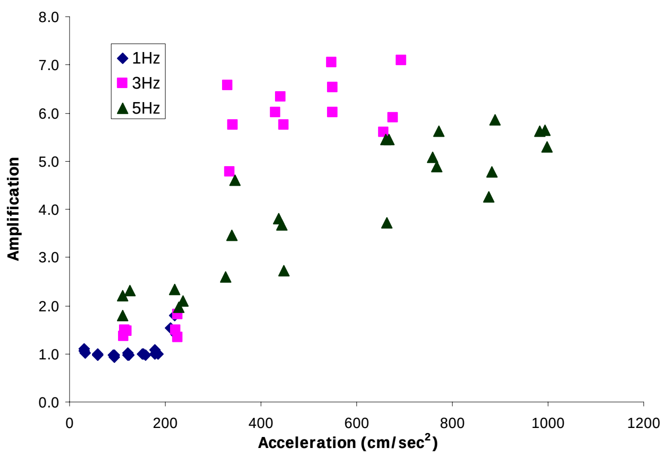


Figure 4.62 (c)

Figure 4.63- Response of Two-wheel-locked case

4.3.4 Case I-4: One wheel locked

When a wheel is locked it becomes like a rotating centre about which the equipment rotates. The rotation occurred because the unlocked wheels are free to rotate around the vertical axis given that their friction is very low. This made the entire system work as a base isolation system until the load induced by the acceleration exceeded the friction force to make the equipment slide. Figures 4.64 (a) and (b) show that the response acceleration is always increasing in both directions; however Figure 4.64 (c) shows that the amplification AMP2 is decreasing until a certain level then starts increasing. Similarly to previous case, Case I-3, the response to 3Hz is higher than that of 5Hz. It is difficult to use a two-dimensional model for the present case as the sliding occurs in the plane XY, i.e. plane of the shaking table or floor.

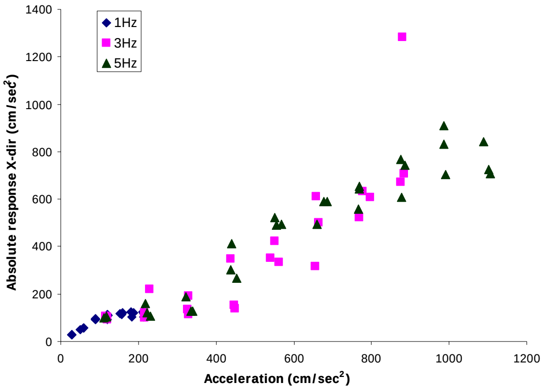


Figure 4.64 (a)

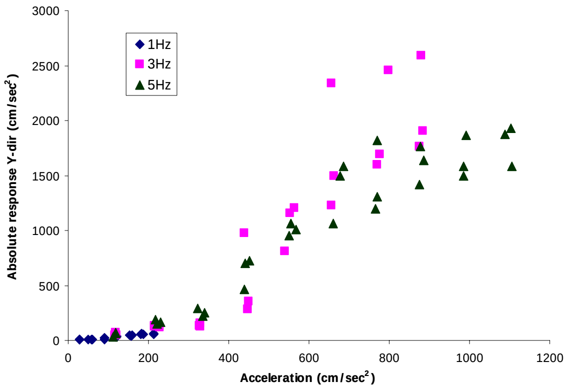


Figure 4.64 (b)

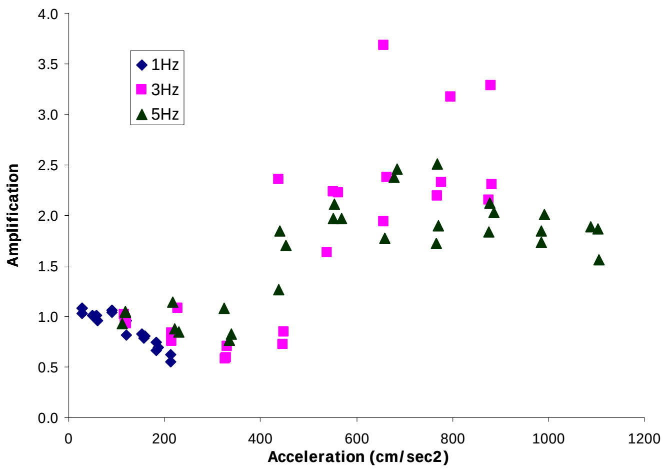


Figure 4.64 (c)

Figure 4.64- Response of One-wheel-locked case

4.4 Response of shelves

4.4.1 Overview

Shelves are the second elements to be considered in this study because of the enormous amount of medicine and equipment that they store. After visiting some facilities we found that there is large variety of shelving, they are of various sizes, methods of connection to their supports vary and others. For that reason, we considered a model with a variety of connections. Some shelves were attached to the structure with bolts, see Photo 4.14, others are built-in structures as shown in Photo 4.15, while some others were connected with flexible connections, such as bolt + rubber, or freely standing as Photo 4.16 shows. In this section we considered four different cases of shelf connections; a) shelf connected at the bottom, b) top and bottom, c) bottom and side and d) half fixed and half flexible. The freely standing shelves have the same response as Case I-2 in which all the wheels of the table are locked. The response therefore is rocking; the friction and the geometry of the shelf lead to rocking and not sliding. The fixed anchorage was later changed by flexible anchor which created four more cases to be considered. The model considered in this study is a five-storey shelf with a uniform square cross section with 1.5cm dimension of each side and 0.15cm uniform thickness; Figure 4.65 and Figure 4.66 represent the model and the cross section considered in the study respectively.

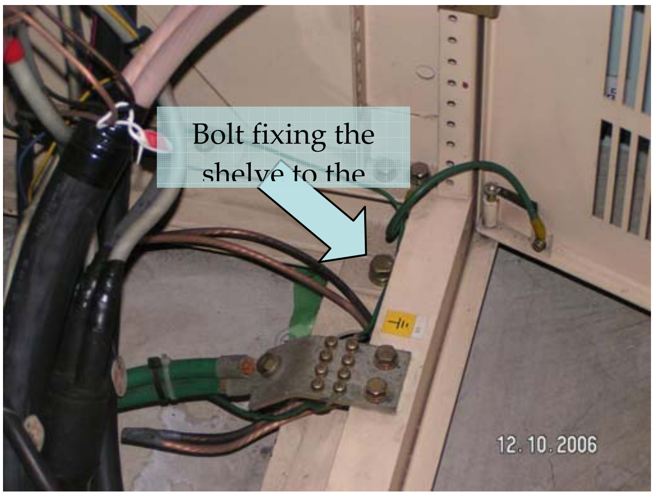


Photo 4.14- Shelf connected with bolts

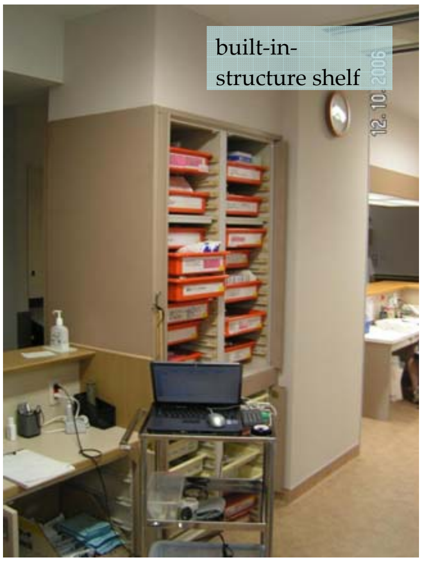


Photo 4.15- Built-in-structure shelf

Photo 4.16- Freely standing shelves

In some cases a layer of rubber is used to reduce the vibration of shelves, see Figure 4.67. We modelled this connection by a spring of stiffness k_1=50kg/cm and k_2=500kg/cm, see Figure 4.67. Table 4.35 illustrates the name of cases that are considered during this study. The stiffness of the spring depends on the stiffness of the rubber, and the way that the bolt is fastened; the more the bolt is tightened, the greater the stiffness.

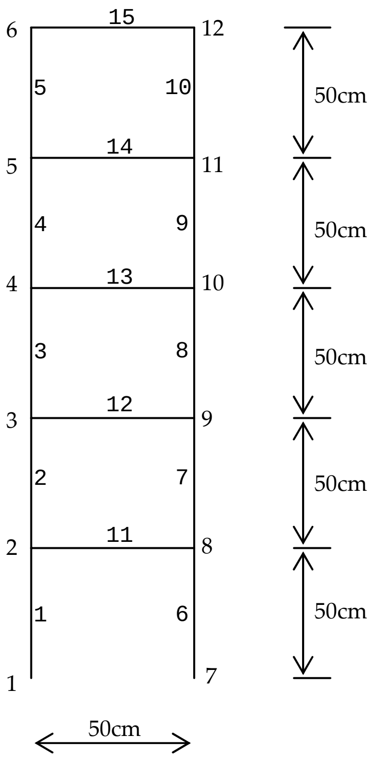


Figure 4.65- Model of shelf

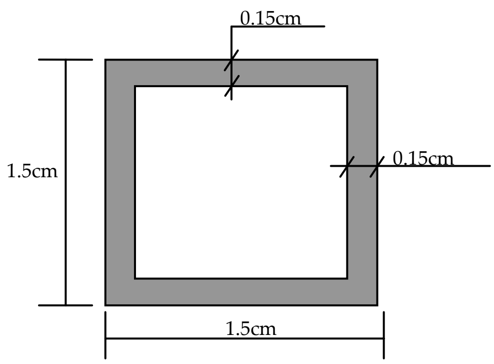


Figure 4.66- Cross section used for shelves

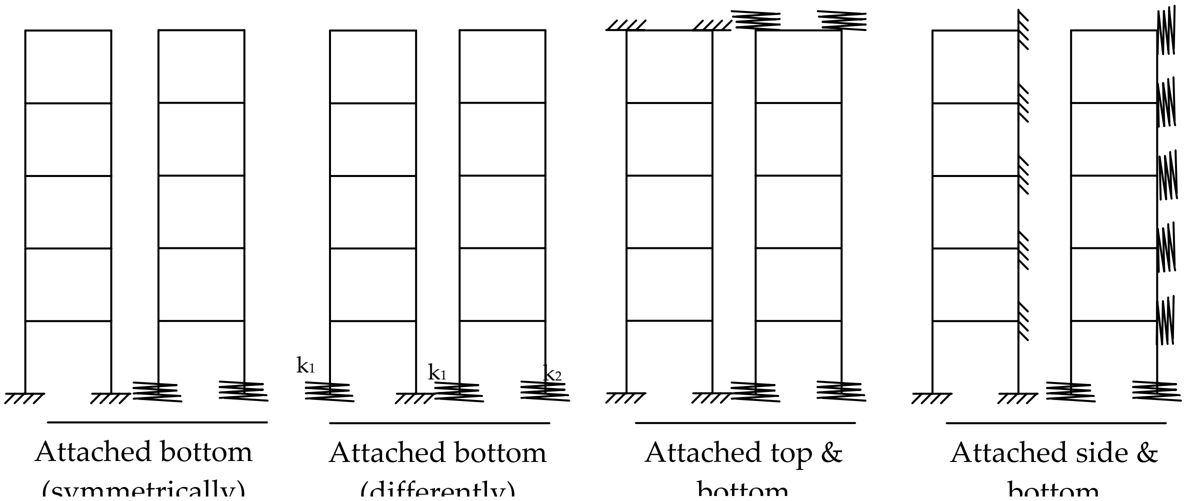


Figure 4.67- Connection Models

It was hoped to carry out an experimental study which could then be confirmed with a theoretical model, but unfortunately that was not possible because of several limitations. Only a simulation using software SAP2000® is considered. The software uses a finite element methodology which makes the results very detailed and given at each node of the structure. The equation of motion of the structure is shown in Equation 4.33. The damping is defined in Equation 4.34 (CSI, 2005); in which c_M is the mass coefficient and it is considered equal to zero, and c_K is the stiffness coefficient considered as constant equal to 2%. The finite element methodology, provided in the software, helps greatly in practice as medicines are usually placed at the level of nodes 2, 3, 4 and 5. All what is required from this study is finding the time history of response acceleration at each of the précised nodes to be used in the next step, i.e. studying the stability of small equipment.

The shelves were considered to undergo the same loadings as the previous equipment, i.e. the nurses table; sinusoidal wave with frequency variable between 1-10Hz and acceleration variable between 100 and 1000cm/sec^2. The structure was under loading for 30seconds.

$$M\ddot{X} + C\dot{X} + KX = Ma \qquad (4.33)$$

Where

a: Input acceleration (sinusoidal wave)

M: Mass matrix, determined automatically by the software considering the material and the length bar

K: Stiffness matrix, determined automatically by the software according to bar sections

C: Viscous damping matrix, defined as follows

$$C = c_M M + c_K K \tag{4.34}$$

4.4.2 Results of simulation

4.4.2.1 Case II-1 and Case-II-2

The results showed that the flexibility given to the shelf reduces the natural frequency; for the fixed shelf the first mode is about 7Hz, while for the flexible model it is about 6Hz, Table 4.36 shows the modes of both cases. The spring stiffness is relatively large that makes the structure very close to being fixed; this in turn made both models similar and therefore respond similarly. The shelf is supposed to respond linearly for the purpose of simplifying the analysis and achieving the purpose faster.

Table 4.35- Detail of considered connections

Case	**Fixed nodes**	**Flexible nodes**	**Stiffness** (Kg/cm)
Case II-1	1 and 7	-	-
Case II-2	-	1 and 7	500
Case II-3	7	1	50
Case II-4	-	1 and 7	50 and 500 (respectively)
Case II-5	1, 6, 7 and 12	-	-
Case II-6	-	1, 6, 7 and 12	500
Case II-7	1, 7, 8, 9, 10, 11 and 12	-	-
Case II-8	-	1, 7, 8, 9, 10, 11 and 12	500

As previously considered, the amplification factor AMP1, shown Equation 4.11, was used as the parameter to analyse the response. When the shelf is fixed it responds less than when it is flexible, the structure is able to move more than when it is fixed to the floor. The results show that the response may reach 1.75 times the input acceleration for a fixed shelf, see Figure 4.68 (a), and it may become twice the input acceleration if the connection is flexible, see Figure 4.68 (b). This was translated in larger displacement of the flexible model as the maximum displacement was about 0.125cm for an acceleration of 100cm/sec^2 for a flexible connection; while it was about 0.075cm for the same acceleration if the connection is fixed see Figure 4.69 (a) and Figure 4.69 (b) respectively. The flexibility causes the shelf to move more but it releases the bars internal constraint.

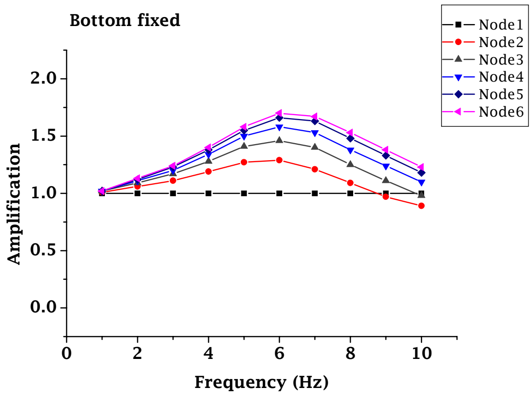


Figure 4.68 (a)

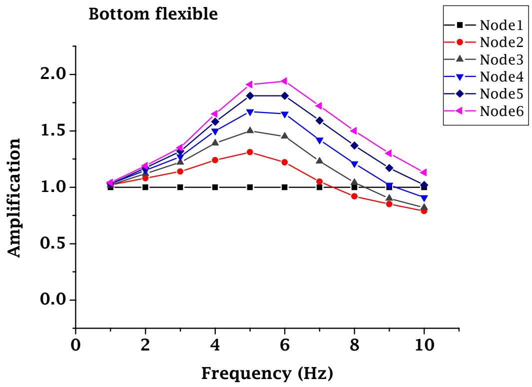


Figure 4.68 (b)

Figure 4.68- Relationship between the amplification and the frequency, Case II-1 and Case II-2

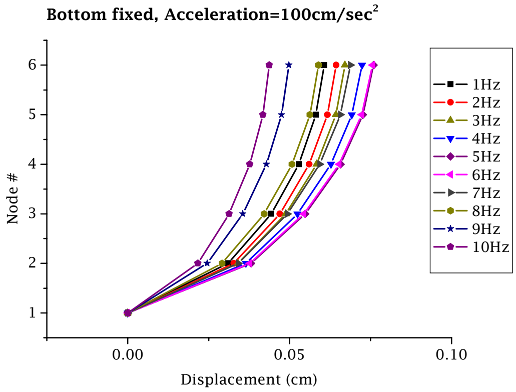


Figure 4.69 (a)

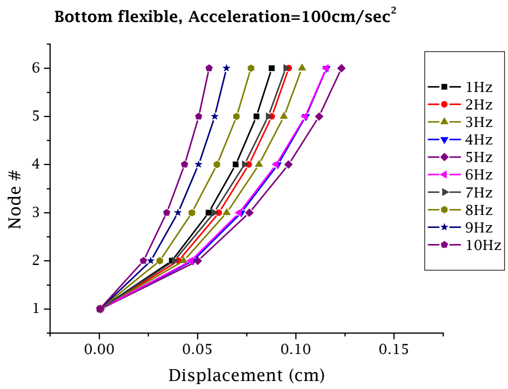


Figure 4.69 (b)

Figure 4.69- Deformation of shelves, Case II-1 and Case II-2

3.4.2.2 Case II-3 and Case-II-4

Simulation showed that first natural modes are not so different. Case II-3 resonates at 4.2Hz while Case II-4 resonates at 4.1Hz as seen in Table 4.37. At this level of frequency the shelf starts rocking, however because of the difference of stiffness the weakest spring allows the motion of the node to which it is attached to while the stronger does not allow larger movements. For high frequencies, higher or equal to 8Hz, the response of the structure changes as the frequency gets closer to Mode 2; Figure 4.70 illustrates in high frequencies the amplification becomes very low. In the same way as the previous case, the flexibility did not change much in the modes of the structure. The natural frequency is reducing given that the stiffness is reducing too; in comparison to the previous cases the structures are less connected to their support, i.e. low stiffness.

Table 4.36- Natural modes of shelves in cases II-1 and II-2

Case #	Mode #	Period (sec)	Frequency (Hz)	Circular Frequency (rad/sec)	Eigen value (rad2/sec^2)
Case II-1	Mode 1	0.141773	7.054	44.32	1964
	Mode 2	0.040812	24.503	153.96	23702
	Mode 3	0.021468	46.581	292.67	85659
	Mode 4	0.014160	70.622	443.73	196900
	Mode 5	0.010919	91.582	575.42	331110
	Mode 6	0.002518	397.190	2495.60	6228000
	Mode 7	0.002491	401.490	2522.70	6363800
	Mode 8	0.000867	1153.100	7245.20	52492000
	Mode 9	0.000866	1154.500	7253.90	52620000
	Mode 10	0.000556	1797.900	11296.00	127610000
	Mode 11	0.000556	1798.700	11301.00	127720000
	Mode 12	0.000539	1855.100	11656.00	135870000
Case II-2	Mode 1	0.164997	6.061	38.08	1450
	Mode 2	0.044187	22.631	142.20	20220
	Mode 3	0.021562	46.378	291.40	84914
	Mode 4	0.014523	68.859	432.65	187190
	Mode 5	0.014046	71.197	447.34	200120
	Mode 6	0.011004	90.875	570.99	326020
	Mode 7	0.010734	93.162	585.35	342640
	Mode 8	0.003549	281.740	1770.20	3133700
	Mode 9	0.003544	282.170	1772.90	3143300
	Mode 10	0.001224	817.000	5133.30	26351000
	Mode 11	0.001221	818.710	5144.10	26462000
	Mode 12	0.000647	1545.200	9709.00	94265000

The amplification factor *AMP1*, defined as previously in Equation 4.11, is used to analyse the results of simulation. The amplification reaches 2.75times the input acceleration. This high acceleration encourages the instability of medicine and small equipment that are placed on shelves. In comparison to Case II-1 and 2 these cases, Case II-3 and 4, are more unstable as the amplification is larger than the former. The maximum displacement was found at the top node, Node 6. An acceleration of 100cm/sec^2 caused a maximum displacement of 0.375cm when Node 1 is fixed and 0.475cm when it is flexible, k_2=500kg/cm. Figures 4.71 (a) and (b) show the deformation of the structures; in comparison to the previous cases, the shape of the structure does not change.

Table 4.37- Natural modes of shelves in cases II-3 and II-4

Case #	Mode #	Period (sec)	Frequency (Hz)	Circular Frequency (rad/sec)	Eigen value (rad2/sec^2)
Case II-3	Mode 1	0.239344	4.178	26.25	689
	Mode 2	0.050978	19.616	123.25	15191
	Mode 3	0.022534	44.377	278.83	77746
	Mode 4	0.020841	47.982	301.48	90889
	Mode 5	0.014056	71.144	447.01	199820
	Mode 6	0.011041	90.573	569.08	323860
	Mode 7	0.010269	97.376	611.83	374340
	Mode 8	0.002504	399.360	2509.30	6296400
	Mode 9	0.001231	812.210	5103.30	26043000
	Mode 10	0.000867	1153.800	7249.60	52556000
	Mode 11	0.000648	1542.800	9693.70	93968000
	Mode 12	0.000556	1798.300	11299.00	127660000
Case II-4	Mode 1	0.246724	4.053	25.47	649
	Mode 2	0.051145	19.552	122.85	15092
	Mode 3	0.024605	40.641	255.36	65208
	Mode 4	0.021582	46.334	291.13	84754
	Mode 5	0.014614	68.427	429.94	184850
	Mode 6	0.011574	86.403	542.89	294730
	Mode 7	0.011028	90.677	569.74	324600
	Mode 8	0.010262	97.443	612.25	374850
	Mode 9	0.003547	281.960	1771.60	3138500
	Mode 10	0.001231	812.080	5102.50	26035000
	Mode 11	0.001223	817.980	5139.50	26415000
	Mode 12	0.000648	1542.700	9693.40	93961000

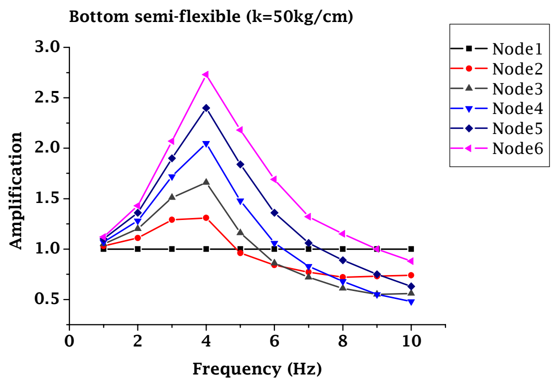


Figure 4.70 (a)

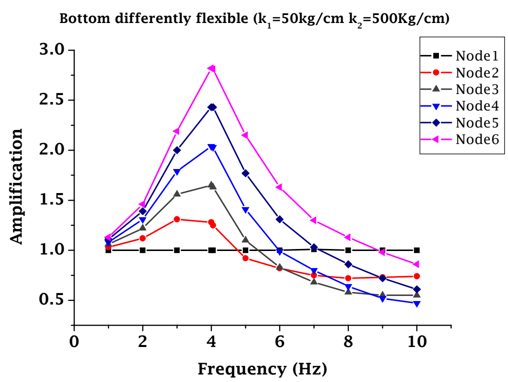


Figure 4.70 (b)

Figure 4.70- Relationship between the amplification and the frequency, Case II-3 and Case II-4

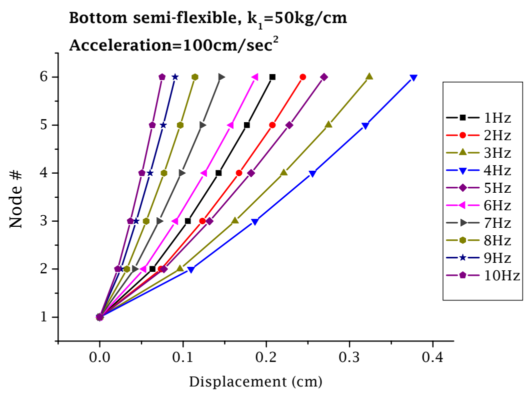


Figure 4.71 (a)

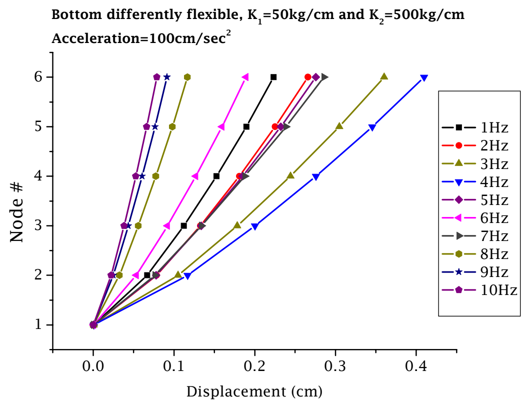


Figure 4.71 (b)

Figure 4.71- Deformation of shelves, Case II-3 and Case II-4

3.4.2.3 Case II-5 and Case-II-6

The structure has, evidentially, become stronger by strengthening its stiffness, which made the first mode around 16Hz for both cases fixed and flexible, see Table 4.38. The table shows also that springs do not change much in the first natural modes which is the same as the first four cases. The fact of having the first mode at 16Hz reduces the response of the structure and therefore gives more stability to medicine and small equipment.

The shelf is almost stable as the amplification AMP1 did not reach even 1.2 times the input acceleration in both cases; fixed and flexible as shown in Figure 4.72 (a) and (b). Unlike the previous cases, Node 3 is the most unstable node as it is located in between both connected nodes, Node 1 and Node 6. In other words, equipment placed at the level of Node 3 is the most unstable among those on the other levels. The flexibility did not affect the response of the shelf, at least at the level of this study; the maximum displacement was about 0.012cm in both cases, Figure 4.73 (a) and (b) illustrate the deformation of Case II-5 and Case II-6 respectively.

Table 4.38- Natural modes of shelves in cases II-5 and II-6

Case #	Mode #	Period (sec)	Frequency (Hz)	Circular Frequency (rad/sec)	Eigen value (rad2/sec^2)
Case II-3	Mode 1	0.061183	16.34	102.70	10546
	Mode 2	0.025834	38.71	243.22	59155
	Mode 3	0.015301	65.35	410.63	168620
	Mode 4	0.011128	89.87	564.64	318820
	Mode 5	0.001233	810.71	5093.90	25947000
	Mode 6	0.001230	812.73	5106.50	26076000
	Mode 7	0.000648	1542.10	9689.10	93879000
	Mode 8	0.000648	1543.00	9695.20	93997000
	Mode 9	0.000539	1855.10	11656.00	135870000
	Mode 10	0.000539	1855.40	11658.00	135900000
	Mode 11	0.000539	1856.00	11662.00	136000000
	Mode 12	0.000538	1857.10	11669.00	136160000
Case II-4	Mode 1	0.062645	15.96	100.30	10060
	Mode 2	0.026152	38.24	240.25	57722
	Mode 3	0.015474	64.62	406.04	164870
	Mode 4	0.011173	89.50	562.37	316260
	Mode 5	0.009857	101.45	637.44	406320
	Mode 6	0.008638	115.76	727.35	529040
	Mode 7	0.004917	203.37	1277.80	1632800
	Mode 8	0.003549	281.74	1770.20	3133700
	Mode 9	0.003544	282.17	1772.90	3143300
	Mode 10	0.001215	823.22	5172.50	26754000
	Mode 11	0.001212	824.93	5183.20	26865000
	Mode 12	0.000646	1548.4	9729.00	94654000

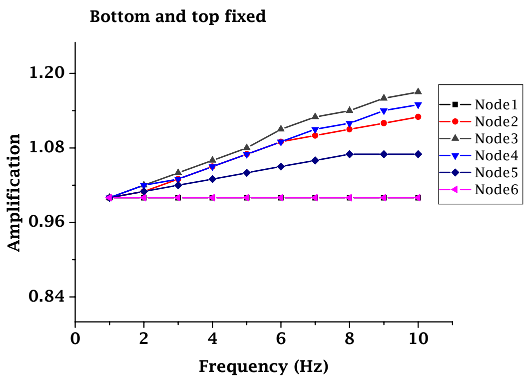


Figure 4.72 (a)

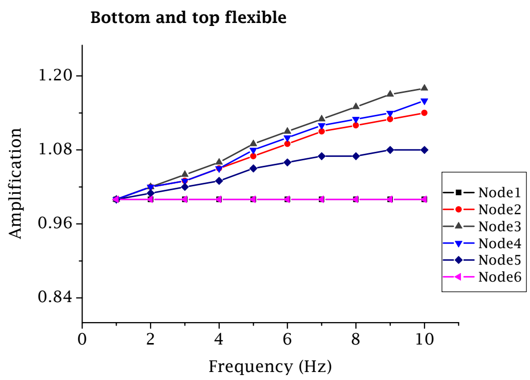


Figure 4.72 (b)

Figure 4.72- Relationship between the amplification and the frequency, Case II-5 and Case II-6

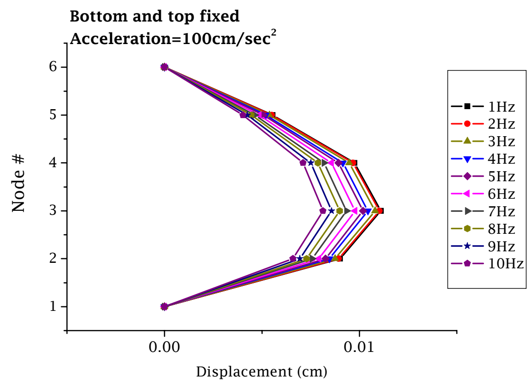


Figure 4.73 (a)

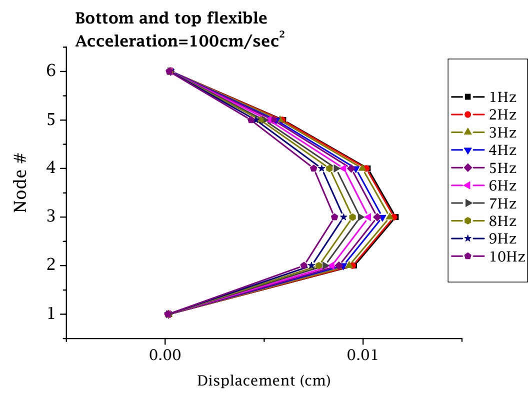


Figure 4.73 (b)

Figure 4.73- Deformation of shelves, Case II-5 and Case II-6

3.4.2.4 Case II-7 and Case-II-8

Evidentially the present cases are the most stable cases among all those seen previously cases II-1 to 6. The connection of 7 nodes, out of 12, to their support makes the structure very strong and responds with the building. Table 4.39 shows the natural modes of Case II-7 and Case II-8. It is impossible to put the shelves into resonance simply because the frequency is extremely high, about 400Hz for fixed connections and 80Hz for flexible connections. The damage that the shelves may go through is then that of the building; if the structure is damaged then the shelves will be too, and if the structure is provided with special devices to protect it, i.e. base isolation etc., then it is not possible that the shelves will be damaged. The stability if the equipment then depends only on its characteristics, i.e. geometry, weight, friction etc.

After looking at the natural modes of both cases it can be expected that the amplification will not be different from the unity, i.e. response is equal to input acceleration. The simulation confirms the speculation and it can be seen clearly in Figure 4.74 (a) and (b); the amplification AMP1 is equal to unity in all the nodes and under all the frequencies. These cases are the safest among all the others, Case II-1 through Case II-66, as equipment placed on them would fall after the others fall. The unconnected nodes could displace but with very low values which can be neglected. The maximum attained displacement was 7.10^{-6} cm, Figure 4.75 (a), for the fixed connection case, and 2.10^{-4} cm, Figure 4.75 (b), for the flexible case.

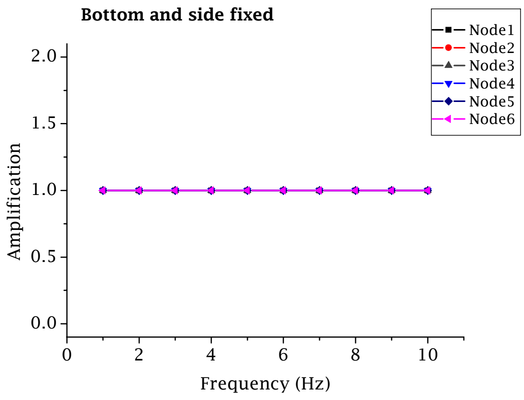


Figure 4.74 (a)

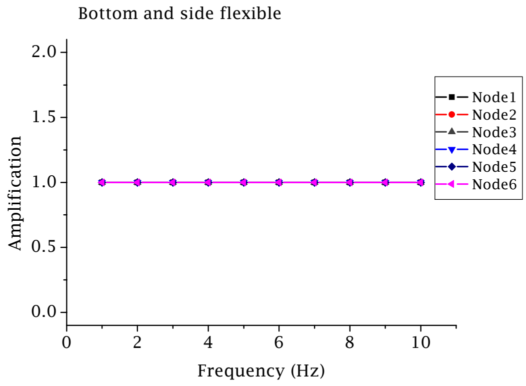


Figure 4.74 (b)

Figure 4.74- Relationship between the amplification and the frequency, Case II-7 and Case II-8

Table 4.39- Natural modes of shelves in cases II-7 and II-8

Case #	Mode #	Period (sec)	Frequency (Hz)	Circular Frequency (rad/sec)	Eigen value (rad2/sec^2)
Case II-3	Mode 1	0.002504	399.33	2509.10	6295500
	Mode 2	0.000867	1153.80	7249.50	52556000
	Mode 3	0.000762	1311.80	8242.50	67939000
	Mode 4	0.000762	1312.20	8245.00	67981000
	Mode 5	0.000761	1313.20	8251.20	68083000
	Mode 6	0.000761	1314.70	8260.70	68240000
	Mode 7	0.000622	1607.10	10098.00	101960000
	Mode 8	0.000556	1798.30	11299.00	127660000
	Mode 9	0.000440	2272.30	14277.00	203840000
	Mode 10	0.000393	2542.80	15977.00	255260000
Case II-4	Mode 1	0.012422	80.50	505.80	255830
	Mode 2	0.008697	114.98	722.46	521950
	Mode 3	0.008356	119.68	751.96	565440
	Mode 4	0.007724	129.46	813.44	661680
	Mode 5	0.007027	142.30	894.10	799420
	Mode 6	0.006600	151.52	952.00	906300
	Mode 7	0.005509	181.52	1140.50	1300700
	Mode 8	0.003549	281.74	1770.20	3133700
	Mode 9	0.003544	282.18	1773.00	3143500
	Mode 10	0.001223	817.81	5138.40	26404000
	Mode 11	0.001199	833.68	5238.20	27439000
	Mode 12	0.000647	1545.60	9711.50	94314000

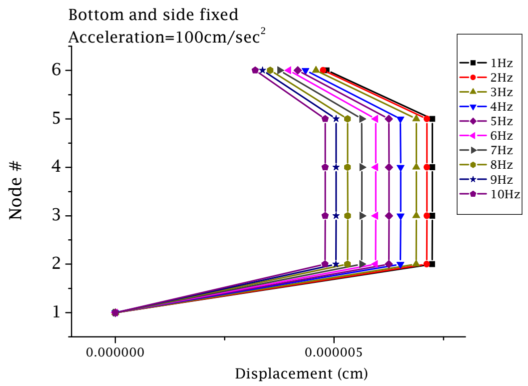


Figure 4.75 (a)

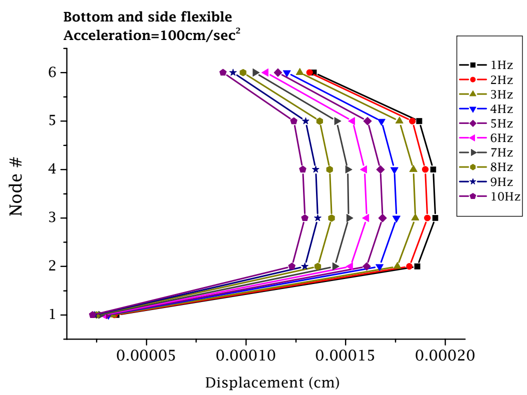


Figure 4.75 (b)

Figure 4.75- Deformation of shelves, Case II-7 and Case II-8

5. CONCLUSION

The questionnaire, while very specific and therefore perhaps limited has served well to highlight some of the problems that were faced during emergencies. It is clear that it is not just internal systems that are important for the functioning of hospitals but also external installations. The importance of electricity was clarified by the equation and verified by the previous experiences and other studies done for cases around the world. It should be stressed that our study is done using a limited amount of data from three particular earthquakes this makes Equation 4.3 true only for the presented data. The equation can be generalized but it is difficult with the data that we have, so more information is needed and it is hoped that this can be done as future research.

This study has shown that the use of PV technology is economically profitable for healthcare as an alterative source and showed that it can also be used as a main source in some locations in the world. The solar system has many benefits mainly: independence, eco-friendliness and reliability. Even if the cost of the PV system is still high, once installed there are no more expenses. Equations 4.7 and 4.8 are limited only to the six considered panels; the general case will be considered in future studies. The seismic study proved the system is safe to be installed and that the supports are strong enough to withstand very strong earthquakes.

The relation between the type of injuries and their causes could not be found because of shortage of data. However, it was possible to roughly classify the patients and therefore determine the most required service to treat the majority of patients.

The response of equipment mounted on wheels modifies according to locking or unlocking wheels and the number of wheels to be locked or unlocked. The summary is presented in the following:

- Unlocked wheels is the best case for high accelerations and/or frequencies, but it is not recommended for low frequencies and mainly in high accelerations, i.e. in base isolated buildings it maybe safer to lock all wheels,

- All wheels locked case is not recommended in high frequencies and high accelerations, i.e. it maybe safer to unlock all wheels when a building is not provided with an isolation system, and

- Preliminary results show that the cases of one and two wheels locked are not stable as the equipment is able to move and the risk of damage is very high.

Further studies are required to find relation between the frequency and the start of rocking, also the case of one or two wheels locked have to be investigated more and special models should be considered.

To stabilize a shelf it is better to attach it as much as possible to the structure, because that makes the natural frequency very high and therefore it is impossible for the shelf to resonate, i.e. get damaged.

To summarise all that has been achieved so far. The purpose was in studying the most important lifelines, and the services that ensure the best treatment to the majority of injuries. The evaluation showed that electric power is the most important lifeline. The study of the medical service was done by considering two pieces of equipment which are common to the majority of the cases which can be found at any service. To further study the vulnerability of systems we need to use the response acceleration of each case discussed in this chapter and use it as the input for small equipment such as medicines or any other type of small equipment. This will be the focus of the next chapter.

CHAPTER 5

EVALUATION OF FRAGILITY

1. INTRODUCTION

In the last two chapters we have seen 1) the factors that affect a healthcare facility's operation; structure, lifelines, equipments, personnel and others, 2) the performance of lifelines through the consideration of electric power system and 3) the response of some equipment (nurse table and shelves) which hold medicine containers and such like. The third point was about finding the response of equipment which are freely standing on the floor, mounted on wheels and attached to their support with or without flexible connection. If we consider that all systems, mounted on wheels or freely standing, as rigid bodies we can therefore use the same models to find out the level at which the small size equipments and medicine containers get damaged. Systems which are attached to their supports might be easier as they are classical structures. In other words we can study the stability of each of the systems, i.e. their fragility of each system.

The present chapter discusses the fragility of some systems within a healthcare facility. Here we considered two main systems; lifeline and equipment. As it was impossible for us to study all lifeline systems, we studied only the electric power system and water supply system using some results found by researchers.

The following sections discuss the fragility of each of the systems considered in the study. As mentioned before the only lifeline and equipments are considered. The fragility of structure is not considered, however it can be easily added

2. FRAGILITY OF SYSTEMS

2.1- Lifeline

2.1.1- Water supply

The fragility of water system is supposed to be the occurrence of the first leakage in the piping system. Because of their geometry, pipelines are still very vulnerable to earthquakes; Photo 5.1 shows damage to some pipelines after the occurrence of the 2003 Tokachi-Oki Earthquake, Japan. Several researchers worked on the damage to pipelines such as Ishida et al (2000) and Kuwata et al (2003) who presented Equation 5.1 that is able to predict the number of leakages in 1km of pipelines. The damage depends on the kind of tube C_p, its diameter C_d, the topography of its installation C_g and the possibility of liquefaction C_l. Two types of tubes were considered DIP-ф75 and CIP-ф100-150 installed in a building, i.e. others for topography, and in non-liquefied soil.

It should be noticed that the considered assumptions do not have any real meaning as we could not consider a real case to study this part.

The fragility of the system is considered to be the fragility of the pipes as they are the most fragile elements in the water supply system, for that we assumed that the fragility of water installation is that of the pipes. The result of the evaluation is shown in Table 5.2 in which the probability of damage is defined as the first appearance of the first leak. The best fit was found using Origin v7 software by OriginLab Corporation; Figure 5.1 illustrates the fragility curves after fitting. A Sigmoidal function, which has the form shown in Equation 5.3, was found to be the best for fitting the data. The parameters of fitting are shown in Table 5.3.

Table 5.1- Pipes information (Source: Kuwata et al., 2003)

Tube Kind C_p		**Tube Diameter** C_d		**Topography** C_g		**Liquefied conversion** C_l	
DIP	0.3	Φ75	1.6	Alteration mountain region	1.1	None	1
CIP	1	Φ100-150	1	Terrace	1.5	Partially	2
VP	1	Φ200-450	0.8	Valley, Old water section	3.2	Entirely	2.4
SP	0.3	Φ500-	0.5	others	1		
ACP	1.2				0.4		

$$S_i = f(a) \times C_{pi} \times C_{di} \times C_{li} \tag{5.1}$$

Where

f(a): number of leaks/km defined in Equation 5.2

a: Input acceleration

$$f(a) = 2.88 \times 10^{-6} \times (a - 100)^{1.97} \tag{5.2}$$

$$y = V_{max} \frac{x^n}{k^n + x^n} \tag{5.3}$$

_2.3_

Photo 5.1- Pipe damage, Kushiro Urinary Clinic

Table 5.2- Damage to pipes

Acceleration (cm/sec^2)	***f(a)* (leak/km)**	**Probability of damage DIP**	**CIP**
0	0.000000	0.000000	0.000000
100	0.000000	0.000000	0.000000
200	0.025084	0.012040	0.025084
300	0.098270	0.047170	0.098270
400	0.218435	0.104849	0.218435
500	0.384991	0.184796	0.384991
600	0.597535	0.286817	0.597535
750	1.001917	0.480920	1.000000
800	1.159406	0.556515	1.000000
900	1.508272	0.723971	1.000000
1000	1.902174	0.913043	1.000000
1100	2.340952	1.000000	1.000000
1200	2.824464	1.000000	1.000000

Table 5.3- Parameters of the fitting

Parameter	**DIP**	**CIP**
V_{max}	1.0	1.0
k	730	529
n	4.6	6.3
χ^2 /DOF	0.002	0.004
Coefficient of determination R^2 (%)	97.9%	97.9%

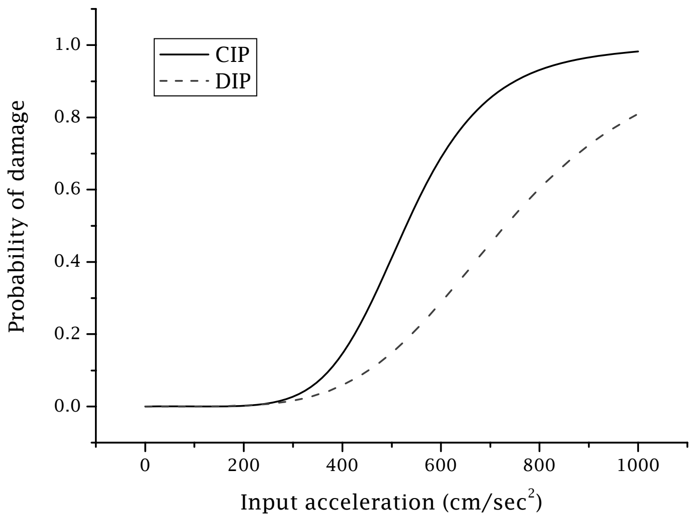


Figure 5.1- Fragility of water system

The fragility of the water system depends on the way the pipelines are used. In other words, many factors should be considered to find the fragility of the water system such as the importance of each pipe for the functioning of the system. Here we consider that both pipelines have the same impact on the system and therefore the most fragile pipe, i.e. CIP, represents the fragility of the water system.

2.1.2- Electric power

The fragility of electric installation considers only the case of the alternative source as the commercial power is usually turned off automatically for security measures or because of damage outside of the hospital. In general electric installations are very large, extremely flexible, because of the electric wires, and attached to the building structure which makes their damage dependant on the structural damage. Moreover batteries are very well attached to each other and placed in shelves placed on the floor, i.e. they can be considered as a part of the structure of the building as well. The only element that may have the possibility to be damaged, therefore, is the supports of panels. For that the fragility of electric power installation will be considered as the stability of the support of its panels. The removal of the panel supports from their connections is then considered as the damage to the electric power system. Using the results found during the simulation in Chapter 4, the reaction does not depend on the frequency. Thus the maximum reactions will be considered, i.e. F_x=18.84kgf, F_z=15.19kgf for Model 1 and F_x=40.81kgf, F_z=45.53kgf for Model 2. Bolts type M20 were used for Model 1 while bolts M22 were used for Model 2. Figure 5.2 shows the resistance of bolts M20 and M22 (PBA, 2003), to simplify the problem we considered that the minimum force for the bolt to be removed is equal to the horizontal resistance as it is the lowest force. The probability for the panels to be damaged then is equal to the reaction of the support divided by the resistance of 1 bolt. The reaction R is defined as square root of the squared value of each reaction: horizontal F_x and vertical F_z, see Equation 5.4. The results are shown in Table 5.4 then fit with using the software Origin V7; the results fragility curves are shown in Figure 5.3. The same fitting model, Sigmoidal function, was taken which parameters are shown in Table 5.5. The support is extremely strong as well as the bolts. The result confirms what was found during the simulation in Chapter 4; it is almost impossible that the support will fall over, i.e. the system is safe. We believe that other factors should be considered such as the age of the support and building structure which be the focus in future studies.

$$R = \sqrt{F_x^2 + F_z^2} \tag{5.4}$$

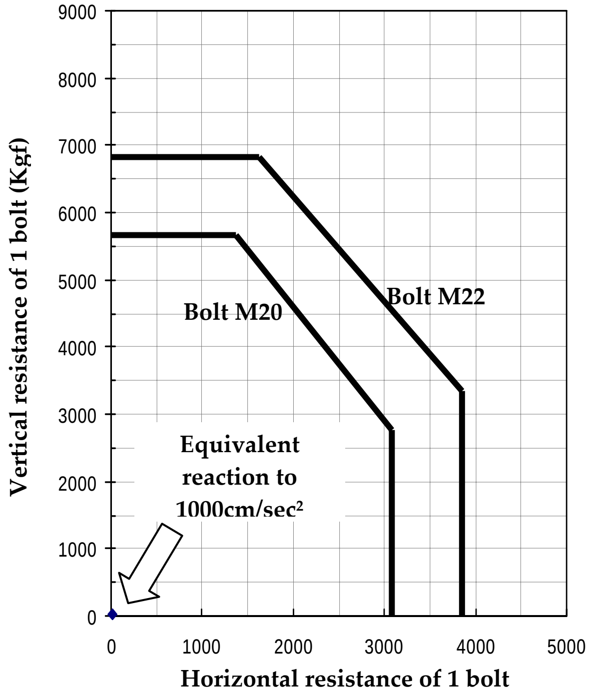


Figure 5.2- Resistance of bolts and maximum reaction

Both supports are considered with the same power of impact on the malfunction of electricity. The fragility of the electric power installation is therefore is equal to the most fragile support, i.e. Model 1.

Table 5.4- Total reaction and probability of damage

	Model 1		**Model 2**	
Acceleration (cm/sec^2)	**F1** (kgf)	**Probability** (%)	**F2** (kgf)	**Probability** (%)
100	2.4201	0.0756	5.2945	0.1655
200	4.8402	0.1513	10.5890	0.3309
300	7.2603	0.2269	15.8835	0.4964
400	9.6803	0.3025	21.1780	0.6618
500	12.1004	0.3781	26.4725	0.8273
600	14.5205	0.4538	31.7670	0.9927
700	16.9406	0.5294	37.0615	1.1582
800	19.3607	0.6050	42.3560	1.3236
900	21.7808	0.6806	47.6505	1.4891
1000	24.2009	0.7563	52.9450	1.6545

Table 5.5- Parameters of the fitting

Parameter	**Model 1**	**Model 2**
V_{max}	1.0	1.0
k	128446.8	57160.5
n	1.0	1.0
χ^2 /DOF	0.0	0.0
R^2(%)	100	100

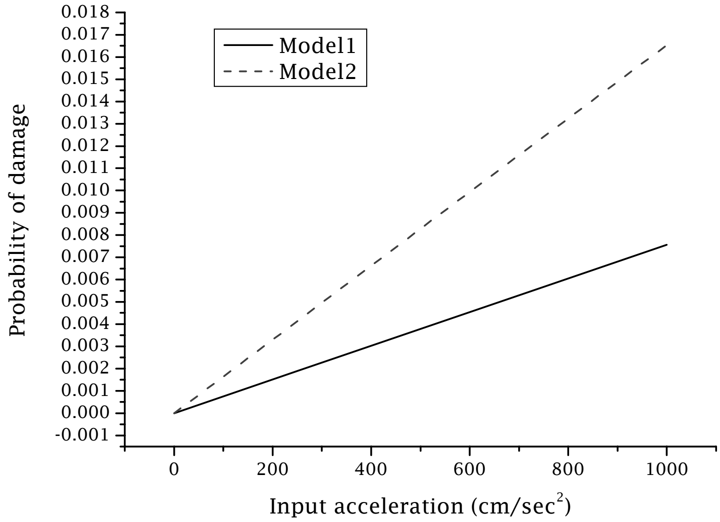


Figure 5.3- Fragility of the solar system

2.2- Equipment

2.2.1 Introduction

Four different types of medicine container (e.g. bottle) or any other small size equipment were considered to be placed on wheeled tables, and shelves. The four models have the same shape and size as shown in Figure 5.4, different weight, m=100grammes and m=500grammes, and different frictions, μ_{s1}=0.15 and μ_{s2}=0.45, see Table 5.6 contains the summary of all factors that will be considered in this section. The difference of weight is for the purpose of covering several pieces of equipment as well as to consider the case of bottles being full or half full. The difference of friction is the purpose of making the model slide when the friction is low and rock when the friction is high.

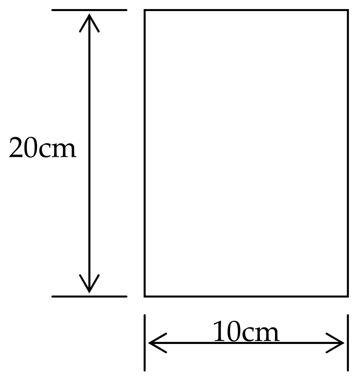


Figure 5.4- Model of the small equipment/medicine

Table 5.6- List of the cases of medicine containers

Case	Mass (Kg)	Static Friction
Case III-1	0.100	0.150
Case III-2	0.100	0.450
Case III-3	0.500	0.150
Case III-4	0.500	0.450

2.2.2 Conditions of damage

2.2.2.1 Sliding

The same theoretical models used in Chapter 4 were used to analyse the response and find out when the damage is likely to occur. For the low friction the equipment slides until it reaches the edge of the table or shelf and falls down. The goal then is finding the maximum displacement that the container reaches during the shaking. Figure 5.5 and Figure 5.6 show the case of container placed on table and shelf respectively. The container is assumed to be placed at the furthest location from both edges.

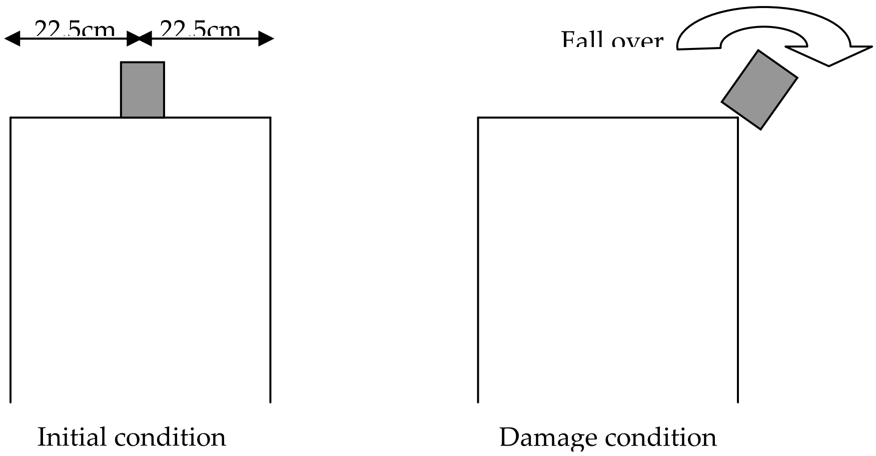


Figure 5.5- Conditions of damage for equipment placed on table

2.2.2.2 Rocking

For the case of high friction the container rocks until it turns over and therefore becomes damaged; Figure 5.7 illustrates the case placed on a wheeled table and Figure 5.8 the case of containers placed on shelves. Some of the equipment may have been padded to not be broken but that case is not considered as it is only some particular types which are not spread in all hospitals around the world. Equation 4.31 was used again for the parameters of the containers. Both containers have the same response as the weight does not affect the results. For the results it is used for both cases; m=100grammes and m=500grammes.

The container starts rocking at about 500cm/sec^2. In low frequencies, $f \leq 4$Hz, it falls at the start of rocking. While in high frequencies it stabilizes more than low frequencies. Figure 5.9 illustrates the fitting of the fragility of the container's response. The fitting was done by Origin version 7, Sigmoidal model was used which parameters are shown in Table 5.7.

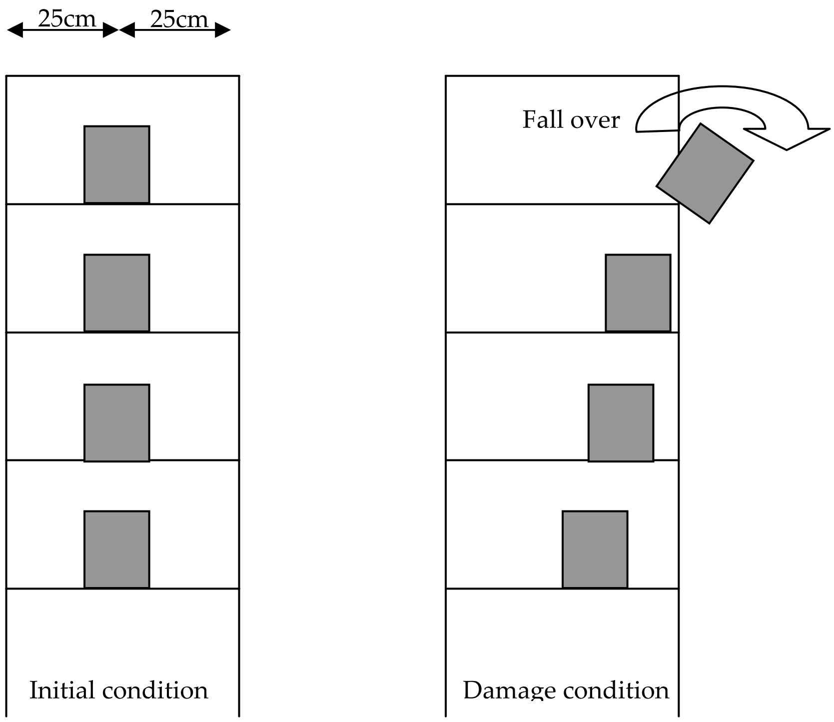


Figure 5.6- Conditions of damage for equipment placed on shelves

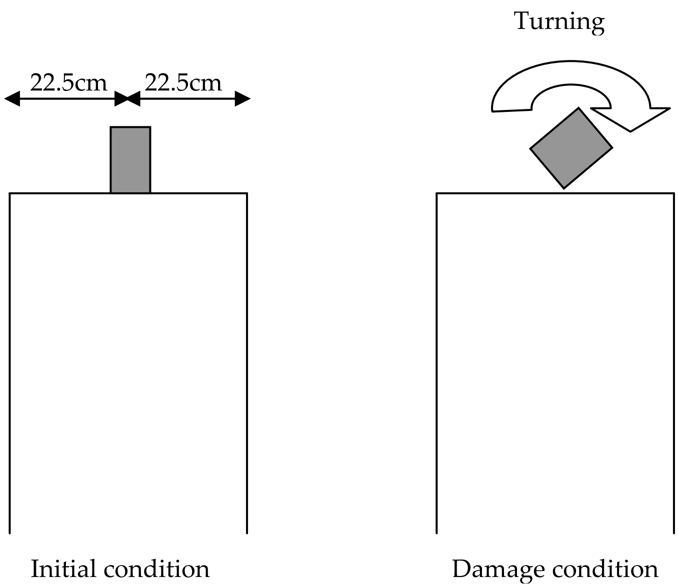


Figure 5.7- Conditions of damage for equipment placed on table

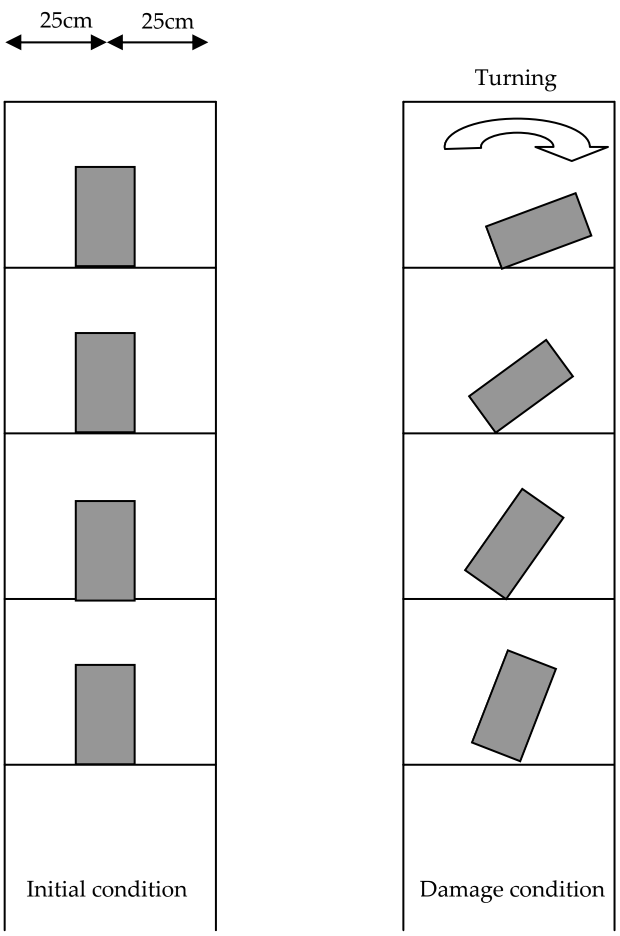


Figure 5.8- Conditions of damage for equipment placed on shelves

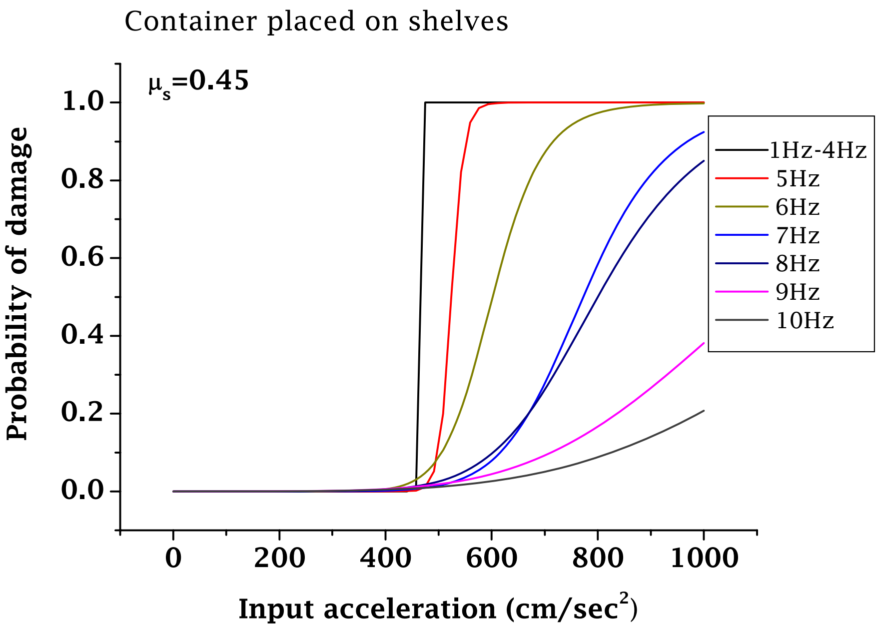


Figure 5.9- Fragility of container

Table 5.7- Parameters of the fitting of container's fragility

Parameter	1Hz-4Hz	5Hz	6Hz	7Hz	8Hz	9Hz	10Hz
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	462.8	524.3	601.8	772.6	800.0	950.0	1150.0
n	397.6	45.1	12.7	9.8	7.9	7.9	7.8
χ^2 /DOF	0.000	0.011	0.007	0.006	0.027	0.009	0.017
R^2 (%)	100	95.0	95.6	97.2	85.5	92.8	86.3

2.2.3 Considered cases

In Chapter 4 two sets of cases where considered; a nurse's table and shelves. Each of the four medicine containers considered were placed on the nurse table and shelves. Thus a total of forty cases are considered for the equipment as illustrated in Table 5.8. The following paragraph discusses all cases.

2.2.3.1 Equipment placed on wheeled table

2.2.3.1.1 Unlocked wheels (Case IV-1 through Case IV-4)

To move the medicine container the horizontal force should exceed the friction force. According to the experiment and simulation in Chapter 4, in low frequencies the table seems to respond stronger than in higher frequencies as the equipment has very low natural frequency. Table 5.9 illustrates the maximum acceleration achieved on top of the table as well as the minimum acceleration required for the medicine to start moving. The medicine container cannot slide except in the case of 1Hz where the exciting acceleration slightly exceeds the minimum required acceleration to start moving. In low friction, i.e. Case IV-1 and Case IV-3, the container is able to move which makes its probability of being damaged high as shown in Figure 5.10 and Figure 5.11. Containers of high friction, i.e. Case IV-2 and Case IV-4, do not move as the acceleration does not reach the minimum acceleration required to make them move as shown in Figure 5.12.

Fragilities relevant to 1Hz in Case IV-1 and Case IV-3 were fit with Sigmoidal model using Origin version 7. The detail of fitting is shown in Table 5.10.

Table 5.8- Fragility cases

Case	Combination
Case IV-1	Case III-1 and Case I-1
Case IV-2	Case III-2 and Case I-1
Case IV-3	Case III-3 and Case I-1
Case IV-4	Case III-4 and Case I-1
Case IV-5	Case III-1 and Case I-2
Case IV-6	Case III-2 and Case I-2
Case IV-7	Case III-3 and Case I-2
Case IV-8	Case III-4 and Case I-2
Case IV-9	Case III-1 and Case II-1
Case IV-10	Case III-2 and Case II-1
Case IV-11	Case III-3 and Case II-1
Case IV-12	Case III-4 and Case II-1
Case IV-13	Case III-1 and Case II-2
Case IV-14	Case III-2 and Case II-2
Case IV-15	Case III-3 and Case II-2
Case IV-16	Case III-4 and Case II-2
Case IV-17	Case III-1 and Case II-3
Case IV-18	Case III-2 and Case II-3
Case IV-19	Case III-3 and Case II-3
Case IV-20	Case III-4 and Case II-3
Case IV-21	Case III-1 and Case II-4
Case IV-22	Case III-2 and Case II-4
Case IV-23	Case III-3 and Case II-4
Case IV-24	Case III-4 and Case II-4
Case IV-25	Case III-1 and Case II-5
Case IV-26	Case III-2 and Case II-5
Case IV-27	Case III-3 and Case II-5
Case IV-28	Case III-4 and Case II-5
Case IV-29	Case III-1 and Case II-6
Case IV-30	Case III-2 and Case II-6
Case IV-31	Case III-3 and Case II-6
Case IV-32	Case III-4 and Case II-6
Case IV-33	Case III-1 and Case II-7
Case IV-34	Case III-2 and Case II-7
Case IV-35	Case III-3 and Case II-7
Case IV-36	Case III-4 and Case II-7
Case IV-37	Case III-1 and Case II-8
Case IV-38	Case III-2 and Case II-8
Case IV-39	Case III-3 and Case II-8
Case IV-40	Case III-4 and Case II-8

Table 5.9- Acceleration affecting the medicine container

Frequency (Hz)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Acceleration at the top of the table (cm/sec^2)	151	134	124	124	105	98	92	93	83	78
Min. required acceleration (cm/sec^2), μ_s=0.15							147			
Min. required acceleration (cm/sec^2), μ_s=0.45							441			

Table 5.10- Parameters of the fitting

Parameter	Case IV-1	Case IV-3
V_{max}	1.0	1.0
k	1100	1200
n	4.0	3.3
χ^2 /DOF	0.003	0.002
R^2(%)	76.4	86.6

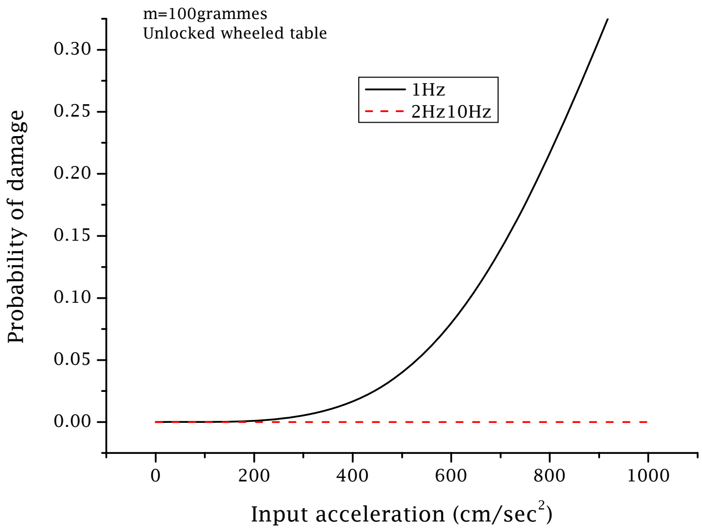


Figure 5.10- Fragility of Case IV-1

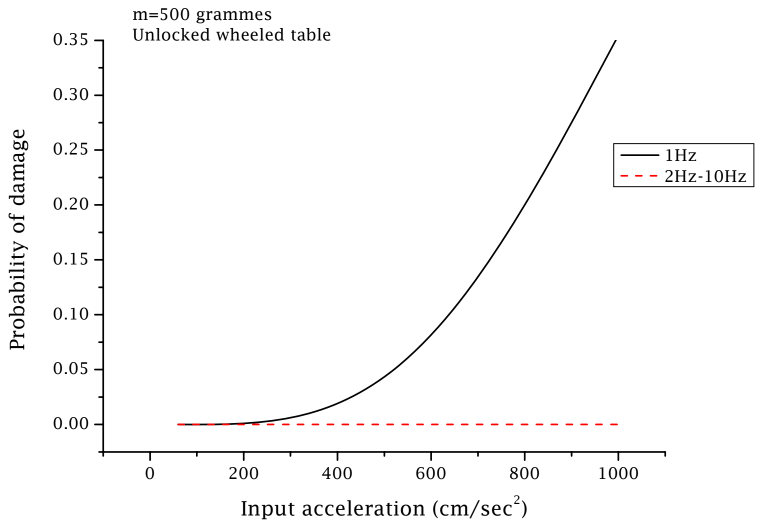


Figure 5.11- Fragility of Case IV-3

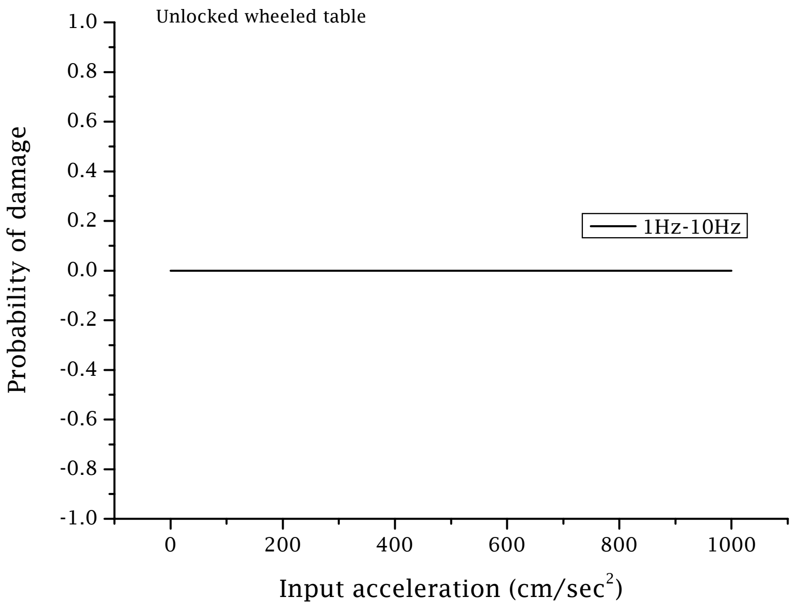


Figure 5.12- Fragility of Case IV-2 and Case IV-4

The fragility of equipment placed on top of a wheeled table is equal to the average of fragilities of all containers. Containers are considered to have the same importance for the functioning of the facility. The original data were used for the purpose of reducing the errors. Results then were fit using the same methodology and model as in previous sections. Figure 5.13 illustrates the fitting of fragility of equipment placed on top of wheeled tables. The parameters of fitting are shown in Table 5.11.

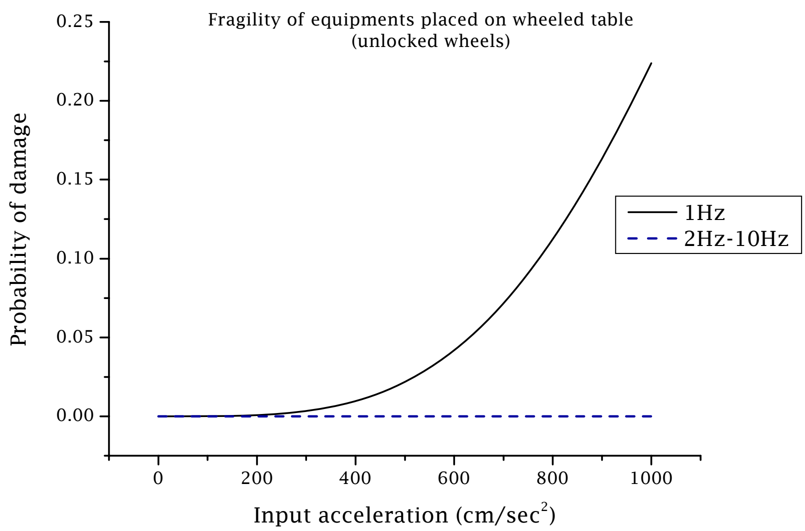


Figure 5.13- Fragility of equipments placed on top of wheeled table

Table 5.11- Parameters of the fitting

Parameter	Equipment placed on wheeled table
V_{max}	1.0
k	1400
n	3.7
χ^2 /DOF	0.001
R^2(%)	80.4

2.2.3.1.2 All wheels locked (Case IV-5 through Case IV-8)

In Case IV-5 and Case IV-7 the containers slide until the table starts rocking, given that the friction is high, μ_{table}=0.57. The table passes through two main stages; the first is stability, i.e. no response, and the second is rocking. During the first the stage the container slides without falling down as the friction is low, $\mu_{container}$=0.15. Once the table starts rocking, the container will fall down and is therefore damaged. Figure 5.14 and Figure 5.15 show the results of evaluation before the fitting. The fitting was done by the same method as the previous curves; the new figures are shown in Figure 5.16 and Figure 5.17 relevant to Case IV-5 and Case IV-7 respectively. The parameters of fitting are shown in Table 5.12.

A heavy container tends to fall before the rocking starts as the friction is low, i.e. easy motion, and the weight is high, i.e. stronger horizontal force. This can be clearly seen in the case of 1Hz in figures 5.14 through 5.17.

Table 5.12- Parameters of the fitting of Case IV-5

	Case IV-5									
Parameter	**1Hz**	**2Hz**	**3Hz**	**4Hz**	**5Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	414.7	415.9	416.0	416.1	416.1	416.1	416.2	416.2	416.2	416.1
n	24.2	55.3	72.2	85.8	93.8	101.1	107.4	113.6	118.4	125.8
χ^2 /DOF	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	97.6	99.8	99.9	100	100	100	100	100	100	100
	Case IV-7									
Parameter	**1Hz**	**2Hz**	**3Hz**	**4Hz**	**5Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	365.5	415.2	415.9	416.0	416.0	416.1	416.1	416.1	416.0	416.2
n	5.96	47.4	65.7	81.1	89.3	97.3	104.2	111.9	114.6	121.8
χ^2 /DOF	0.007	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	96.5	99.6	99.91	99.97	99.98	100	100	100	100	100

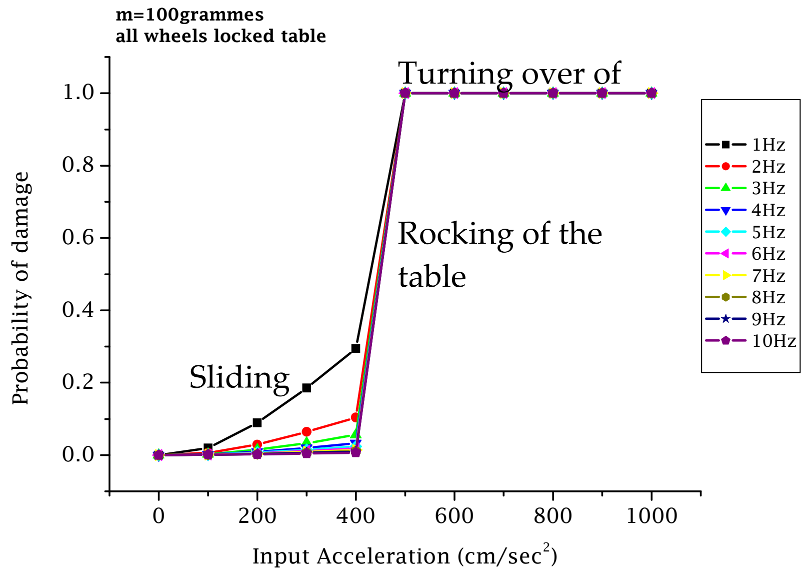


Figure 5.14- Fragility of Case IV-5 before fitting

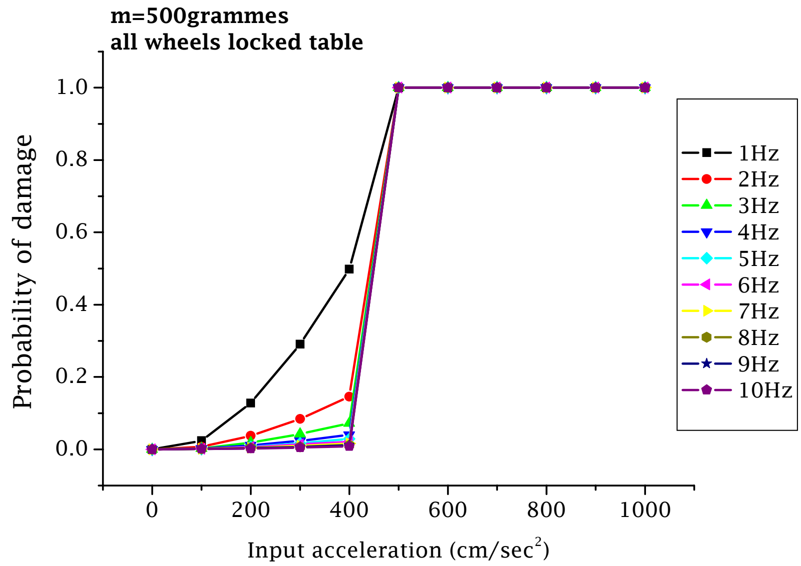


Figure 5.15- Fragility of Case IV-7 before fitting

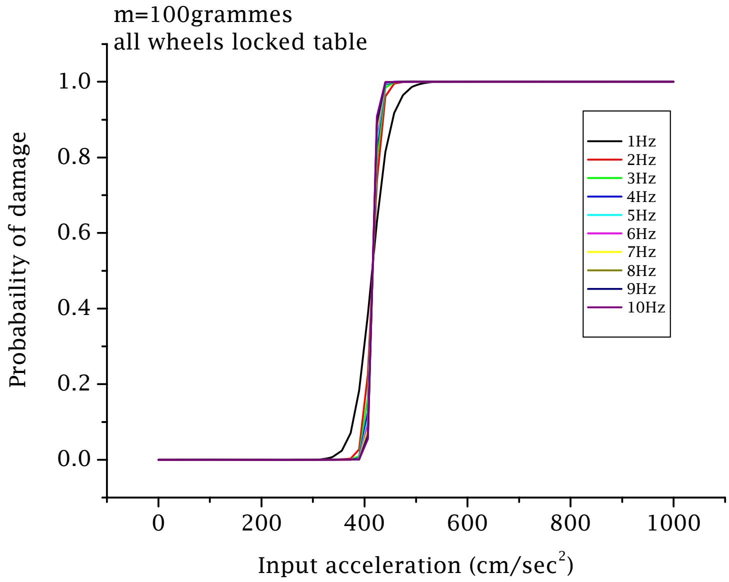


Figure 5.16- Fragility of Case IV-5

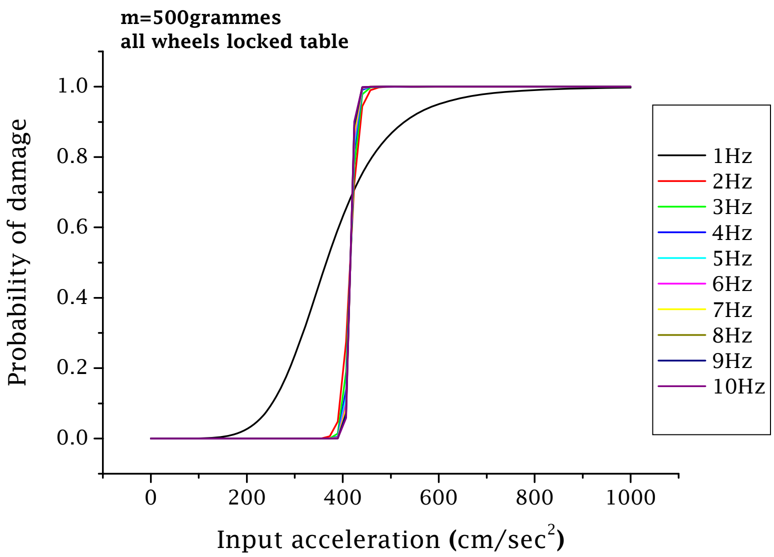


Figure 5.17- Fragility of Case IV-7

In Case IV-6 and Case IV-8 both the table and containers are stable before the rocking starts at around the same acceleration, 500cm/sec^2. Once the table starts rocking the container is considered as damaged as it is not stable anymore because of its light weight, which makes it easily toppled. The container then passes from stability, 0% of damage, to total damage, 100%, at 500cm/sec^2. The fragility of Case IV-6 and Case IV-8 is then shown in Figure 5.18.

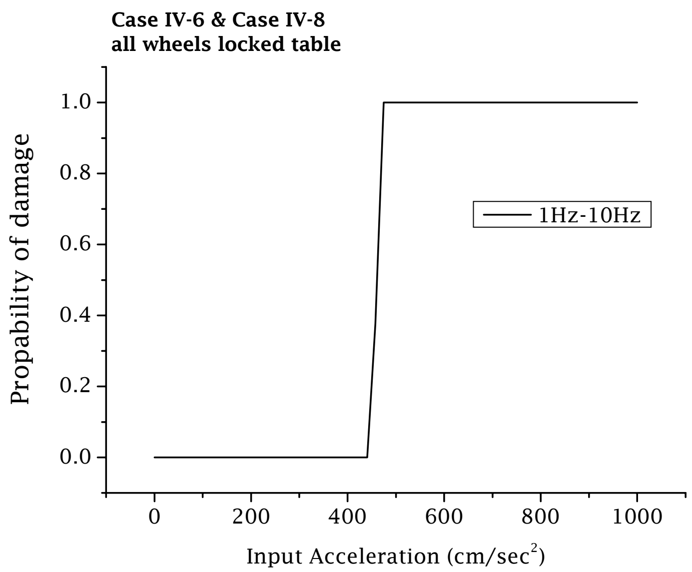


Figure 5.18- Fragility of Case IV-6 and Case IV-8

The fragility of equipment placed on top of a free standing table, including tables mounted on locked wheels, is equal to the average of fragilities of all containers. Containers are considered to have the same importance for the functioning of the facility. The original data was used for the purpose of reducing errors. Results then were fit using the same methodology and model as in previous sections. Figure 5.19 illustrates the fragility of equipment placed on top of free standing tables. The parameters of fitting are shown in Table 5.13.

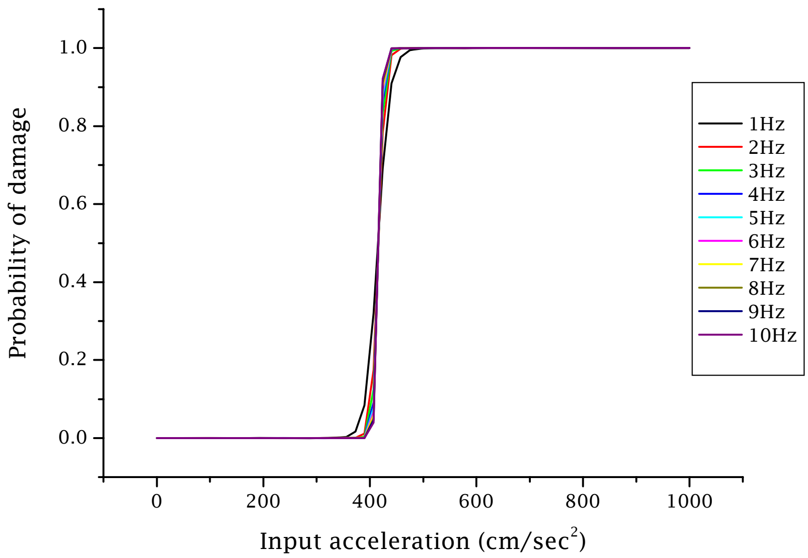


Figure 5.19- Fragility of equipments placed on top of free standing table

Table 5.13- Parameters of the fitting of Case IV-5

Parameter	1Hz	2Hz	3Hz	4Hz	5Hz	6Hz	7Hz	8Hz	9Hz	10Hz
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	415	416	416	416	416	416	416	416	416	416
n	38.3	69.4	86.7	101.3	109.6	116.4	121.8	128.7	134.1	138.5
χ^2 /DOF	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	99.1	99.9	100	100	100	100	100	100	100	100

2.2.2 Equipment placed on shelves

2.2.2.1 Introduction

All shelves are considered to have four levels to hold containers. Only containers of same characteristics are placed together in a single shelf. In other words, if containers of a single layer are damaged and the others are still stable the damage of the shelf is considered to be 25%. This is not true for the case of containers of different characteristics as they do not respond similarly. Particular study is needed to determine the impact of each type on the damage of the shelf; many factors are included in the study such as the friction, size, weight, number of containers in a single shelf and others. Unfortunately the time was limited for considering this case, however it will be considered in future work.

In Chapter 4 we considered eight different types of shelve connections, bottom fixed (Case II-1), bottom flexible (Case II-2), mixture between fixed and flexible (Case II-3), different bottom flexibility (Case II-4), top and bottom fixed (Case II-5), top and bottom flexible (Case II-6), bottom and side fixed (Case II-7) and bottom and side flexible (Case II-8). Each of the containers is supposed to be placed in each of the shelves which make the total number of cases equal to 32.

In the following sections the fragility of each of the shelves. The first case, Case IV-9 to Case IV-12, the methodology followed to evaluate the fragility of all shelves. Later on only the results will be shown as the same judgment was followed to reach the required results.

2.2.3.2.2 Bottom fixed shelf (Case IV-9 through Case IV-12)

In Case IV-9 and Case IV-11 the containers slide until the falling over which represent the total damage. To evaluate the displacement we used the acceleration evaluated in Chapter 4 at each of the relevant nodes, 2 3 4 and 5, as input for the computer programme, which chart-flow is shown in Figure 4.44. A container, with characteristics shown in Case III-1 placed on a shelf Case II-1 excited with sinusoidal of frequency 1Hz, has the fragility shown in Figure 5.20, Figure 5.21, Figure 5.22 and Figure 5.23 if it is placed at the level of Node 2, Node 3, Node 4 and Node 5 respectively. The figures show two curves the first is the original curve and the second is its fitting using Origin v7. The model is Sigmoidal model as shown in Equation 5.3 which parameters are shown in Table 5.14. The fragility of the shelf is assumed to be the average of all fragilities. The original data was used rather than the fitting for the purpose of reducing errors. The fragility of Case IV-9 (case of 1Hz) becomes as shown in Figure 5.24; the parameters of fitting are shown in Table 5.15. Following the same judgment the fragilities of all the rest of cases were obtained. Figure 5.25 and Figure 5.26 show the fitting of the fragilities of Case IV-9 and Case IV-11 respectively; parameters are shown in Table 5.15.

In Case IV-10 and Case IV-12 containers pass from stability to rocking. As stated previously, the weight of containers do not affect their response therefore results of both cases lead to the same result, i.e. Case IV-10 and Case IV-12 have the same response shown in Figure 5.26 and the fitting parameters shown in Table 5.16.

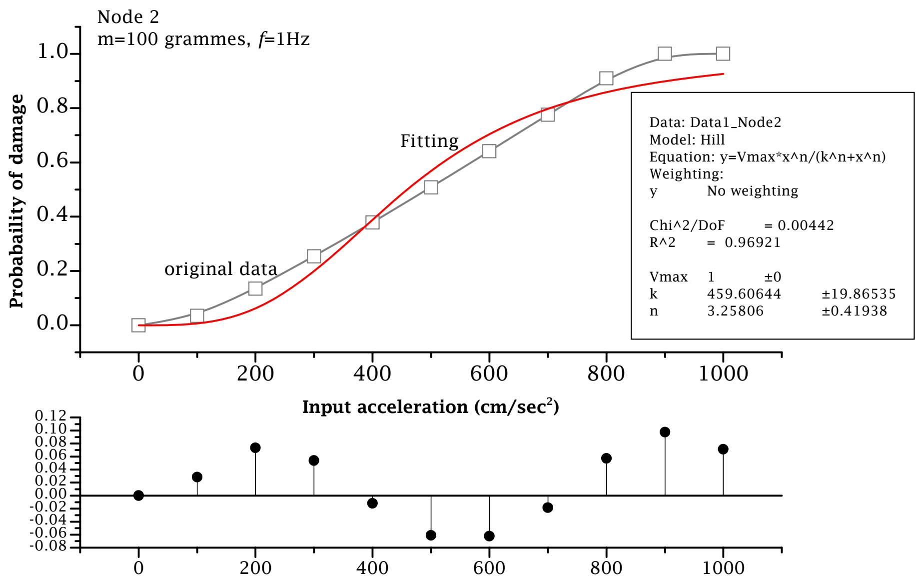


Figure 5.20- Fragility of container Case III-1 placed at the level of Node 2

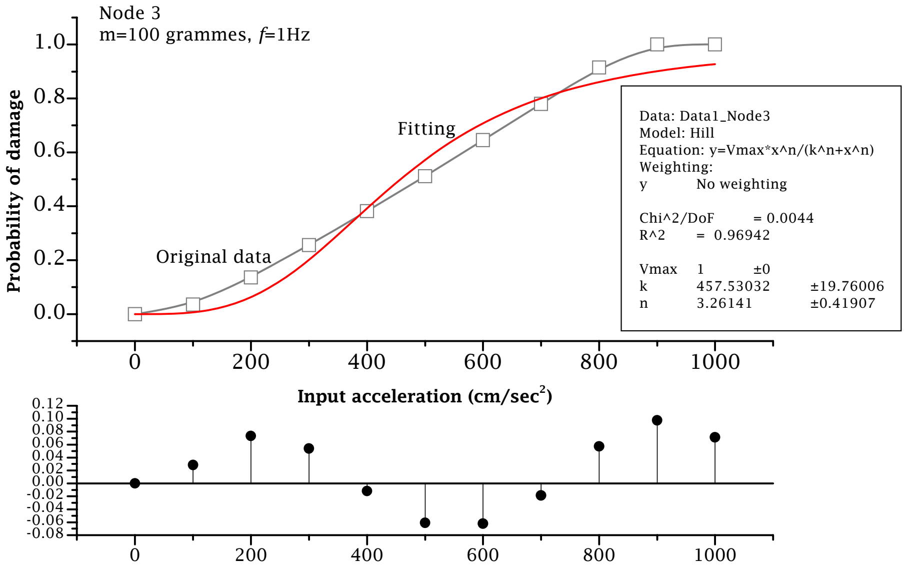


Figure 5.21- Fragility of container Case III-1 placed at the level of Node 3

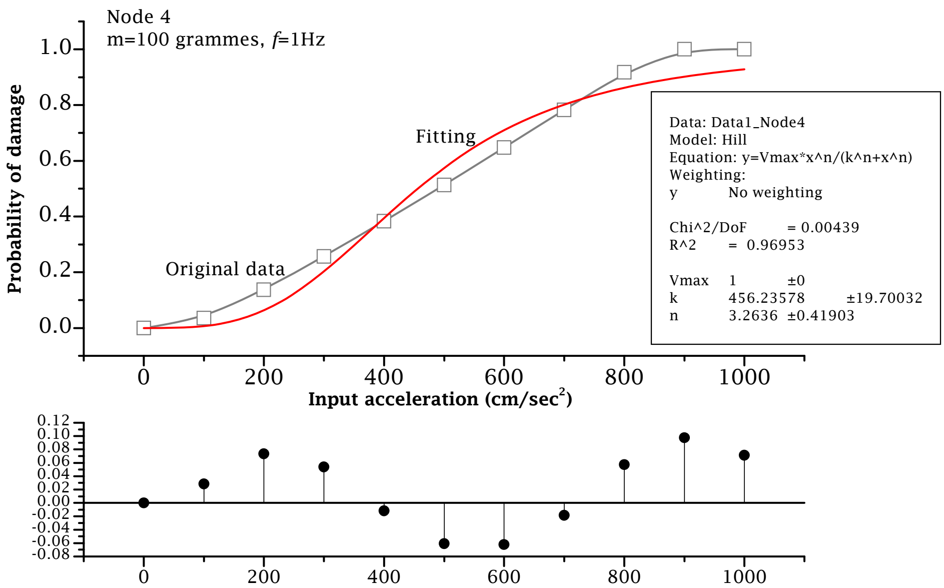


Figure 5.22- Fragility of container Case III-1 placed at the level of Node 4

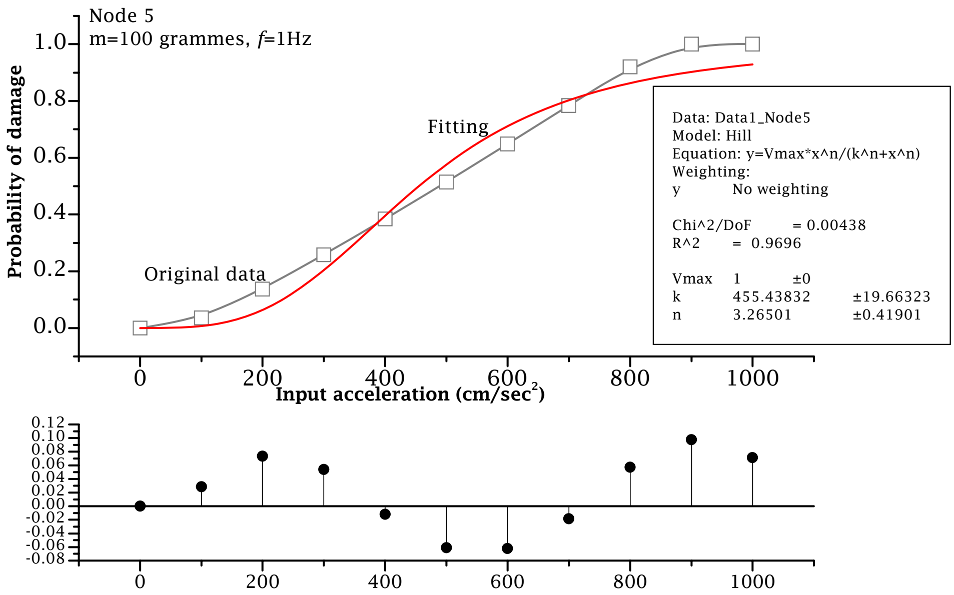


Figure 5.23- Fragility of container Case III-1 placed at the level of Node 5

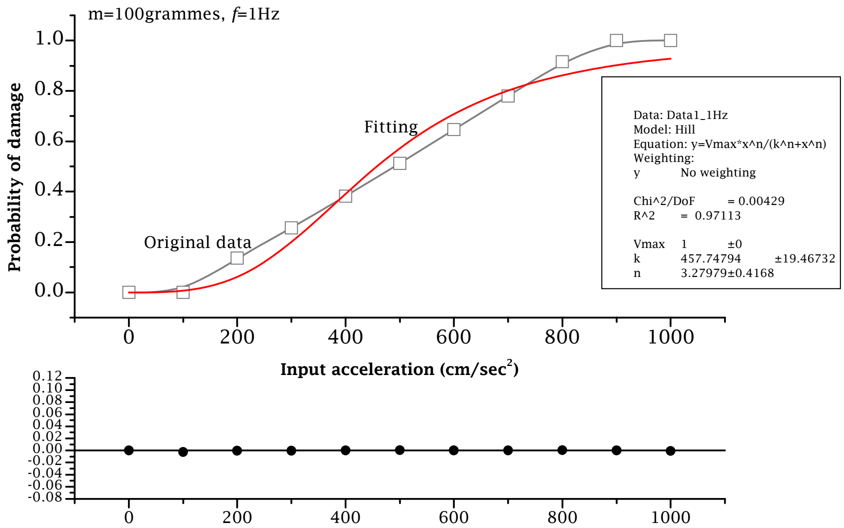


Figure 5.24- Fragility of shelf, Case IV-9 *f*=1Hz

Table 5.14- Parameters of fitting nodes of shelf type Case IV-9, *f*=1Hz

Parameter	**Node 2**	**Node 3**	**Node 4**	**Node 5**
V_{max}	1.0	1.0	1.0	1.0
k	459.6	457.5	456.2	455.4
n	3.26	3.26	3.26	3.26
χ^2 /DOF	0.004	0.004	0.004	0.004
R^2 (%)	96.9	96.9	96.9	97.0

Table 5.15- Parameters of fitting Case IV-9

Parameter	1Hz	2Hz	3Hz	4Hz	5Hz	6Hz	7Hz	8Hz	9Hz	10Hz
Case IV-9										
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	457	1053	1090	2559	3251	4231	4642	5871	6743	8086
n	3.28	1.87	1.65	1.60	1.60	1.62	1.57	1.53	1.57	1.57
χ^2 /DOF	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00 0	0.000
R^2 (%)	97.11	99.8	99.9	99.9	99.8	99.9	99.9	99.7	99.7	99.7
Case IV-11										
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	284	596	1071	1538	2048	3123	2971	3491	4136	6024
n	4.30	3.52	2.22	2.01	1.94	1.79	1.82	1.84	1.86	1.71
χ^2 /DOF	0.00 2	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	98.5	96.8	99.7	100	99.9	100	100	100	99.9	99.8

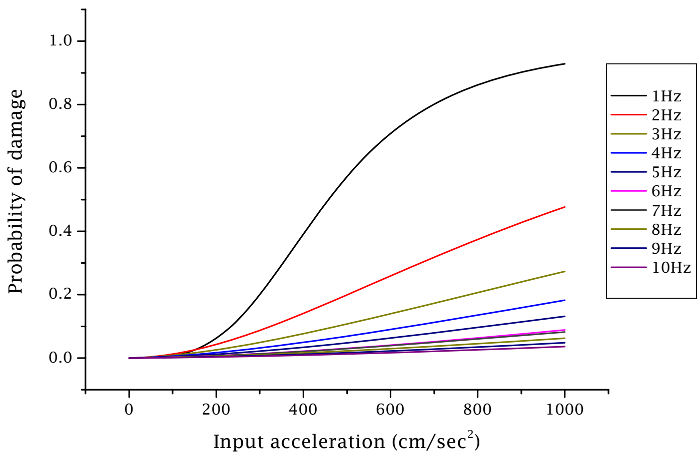


Figure 5.25- Fragility of Case IV-9

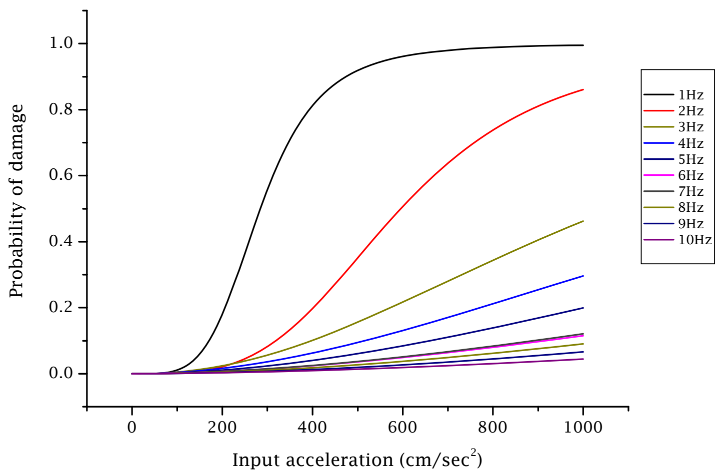


Figure 5.26- Fragility of Case IV-11

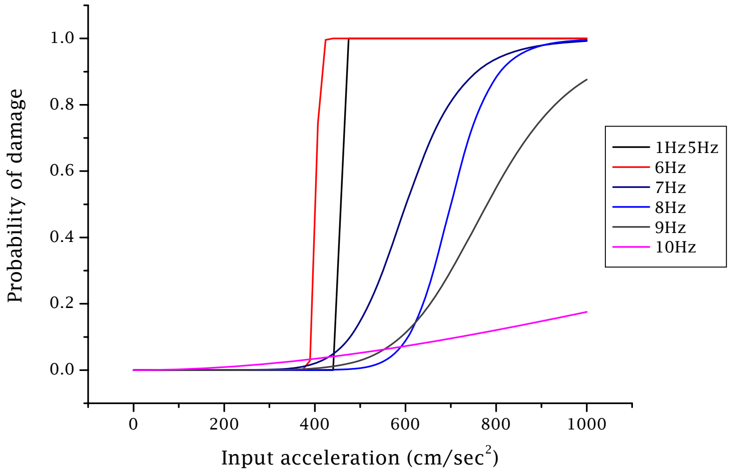


Figure 5.27- Fragility of Case IV-10 and Case IV-12

Table 5.16- Parameters of fitting Case IV-10 and Case IV-12

Parameter	1Hz-5Hz	6Hz	7Hz	8Hz	9Hz	10Hz
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0
k	457.6	402.7	601.6	700.0	780.0	2200.0
n	421.5	107.5	9.5	15.1	7.9	1.7
χ^2 /DOF	0.000	0.000	0.000	0.017	0.015	0.000
R^2 (%)	100	100	91.2	91.4	85.0	88.2

2.2.3.2.3 Fragilities of all cases

According to Case IV-9 through Case IV-12 results can be classified into three classes; two classes of sliding and the third is rocking. The response of sliding depends on the weight of the container while the response of rocking is the same for all cases. The results are presented in the following three sections; the first presents the results of m=100grammes, the second section presents the case of m=500grammes and the third is the case of rocking. The figures show the fitting of the original results which parameters are shown the relevant tables that follow each set of figures.

2.2.2.3.1 Case of m=100grammes

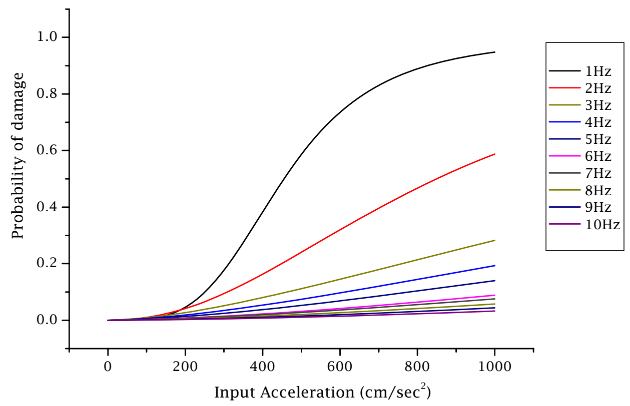


Figure 5.28- Fragility of Case IV-13

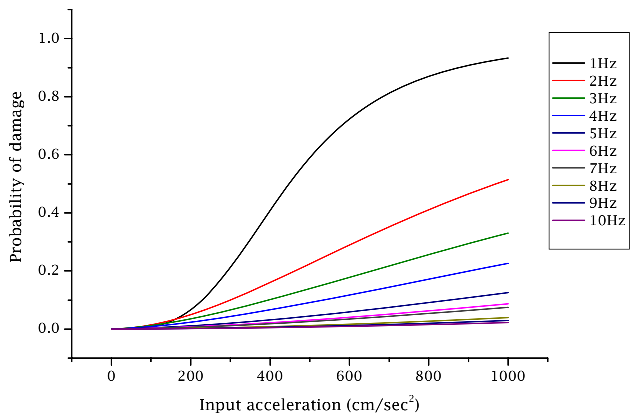


Figure 5.29- Fragility of Case IV-17 and Case IV-21

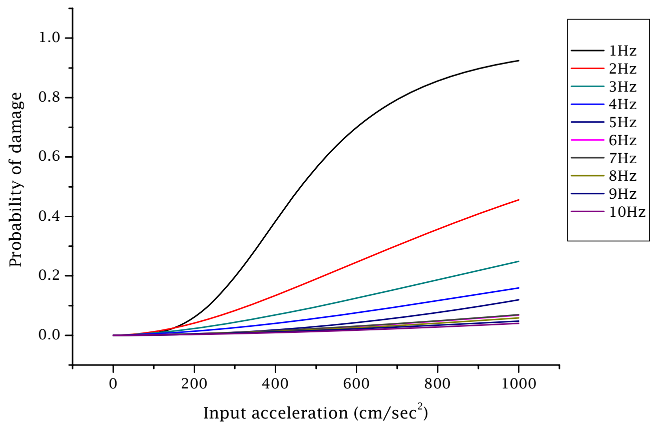


Figure 5.30- Fragility of Case IV-25

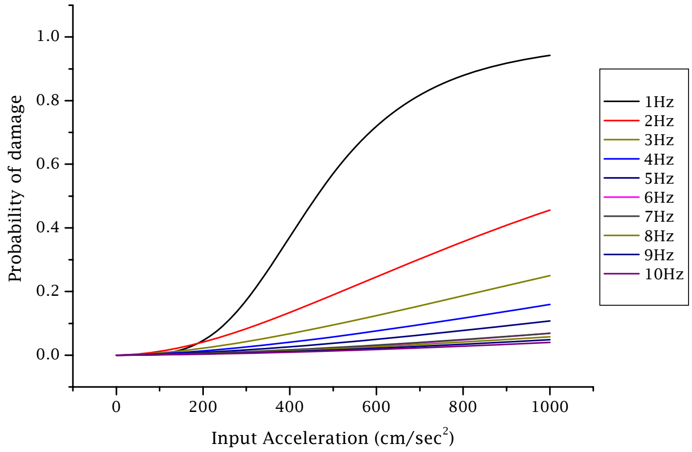


Figure 5.31- Fragility of Case IV-29

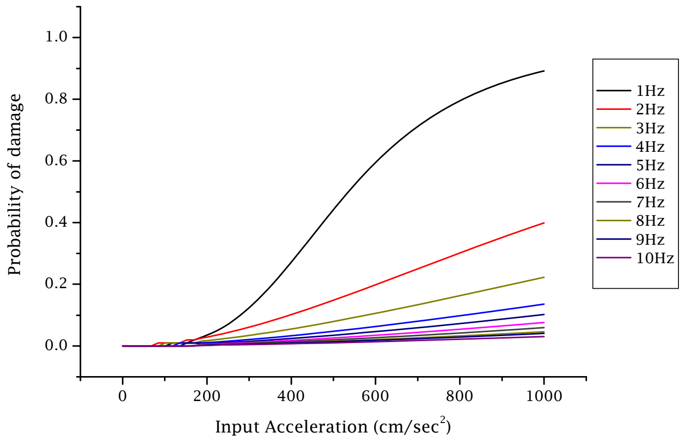


Figure 5.32- Fragility of Case IV-33 and Case IV-37

Table 5.17- Parameters of fitting m=100grammes and μ_s=0.15

Parameter	1Hz	2Hz	3Hz	4Hz	5Hz	6Hz	7Hz	8Hz	9Hz	10Hz
	Case IV-13									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	455	850	1763	2468	3208	4427	5175	6206	6956	8392
n	3.7	2.2	1.6	1.6	1.6	1.6	1.5	1.5	1.6	1.6
χ^2 /DOF	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	92.2	99.4	100	100	100	99.8	99.9	99.9	99.9	99.6
	Case IV-17 & Case IV-21									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	448	970	1546	2207	3352	4384	4713	6203	6875	8157
n	3.3	1.9	1.6	1.6	1.6	1.6	1.6	1.7	1.8	1.8
χ^2 /DOF	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	97.0	99.8	100	100	99.9	99.9	99.8	99.9	100	99.9
	Case IV-25									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	463	1101	1960	2759	3644	4760	5181	5674	6377	7309
n	3.3	1.8	1.6	1.6	1.6	1.7	1.6	1.6	1.6	1.6
χ^2 /DOF	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	96.9	99.9	100	100	100	99.9	100	100	99.9	99.9
	Case IV-29									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	462	1101	1929	2759	3644	4611	5215	5517	6212	6985
n	3.6	1.8	1.7	1.6	1.6	1.7	1.6	1.6	1.6	1.6
χ^2 /DOF	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	92.9	99.9	100	100	100	100	99.9	100	99.9	100
	Case IV-33 & Case IV-37									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	448	970	1546	2207	3352	4384	4713	6202	6875	8157
n	3.3	1.9	1.6	1.6	1.6	1.6	1.6	1.8	1.8	1.8
χ^2 /DOF	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	97.0	99.8	100	100	99.9	100	99.8	99.9	100	99.9

2.2.2.3.2 Case of m=500grammes

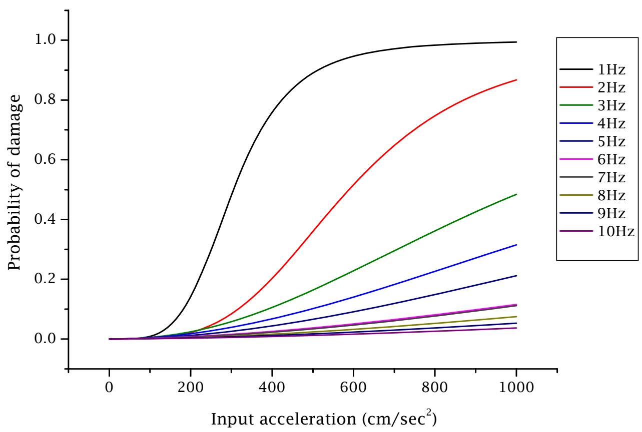


Figure 5.33- Fragility Case IV-15

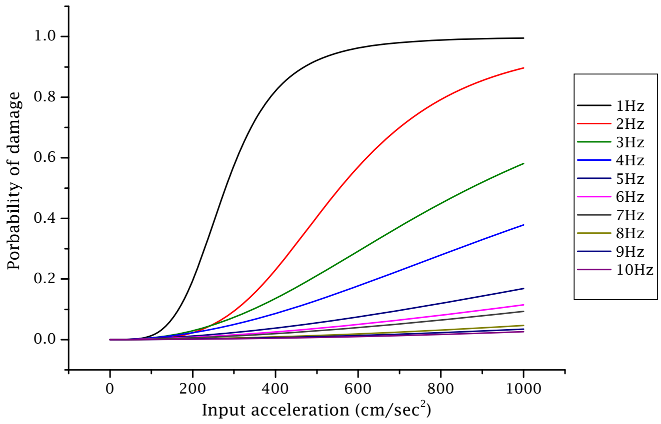


Figure 5.34- Fragility Case IV-19 and Case IV-23

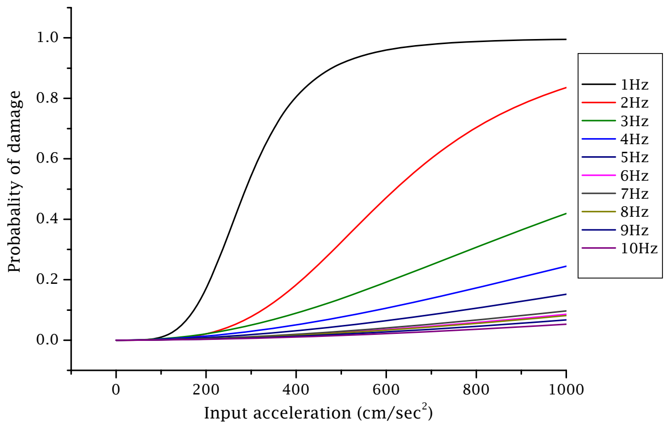


Figure 5.35- Fragility of Case IV-27

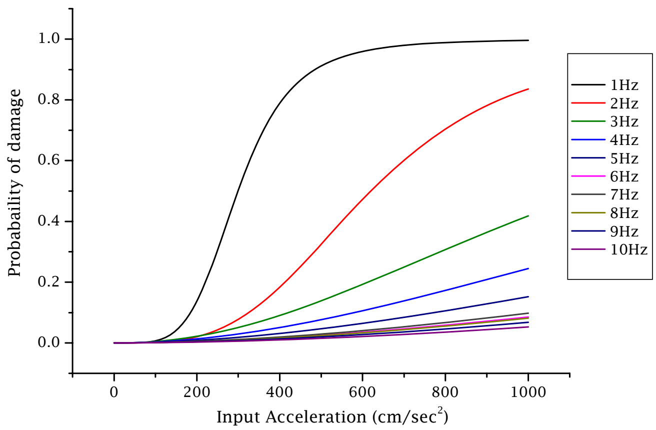


Figure 5.36- Fragility of Case IV-31

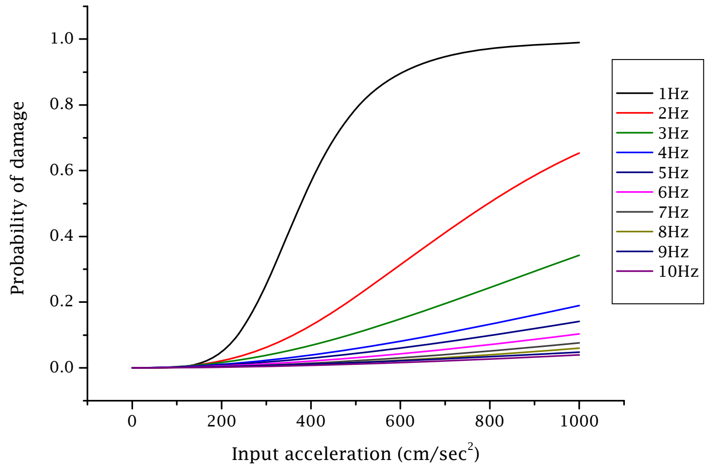


Figure 5.37- Fragility of Case IV-35 and Case IV-39

Table 5.18- Parameters of fitting m=500grammes and μ_s=0.15

	Case IV-15									
Parameter	**1Hz**	**2Hz**	**3Hz**	**4Hz**	**5Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	306	589	1028	1469	1973	3203	3087	4163	5512	7046
n	4.3	3.5	2.3	2.0	1.9	1.7	1.8	1.8	1.7	1.7
χ^2 /DOF	0.003	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	98.1	96.3	99.6	99.9	99.8	99.9	100	99.9	100	99.8
	Case IV-19 & Case IV-23									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	279	556	871	1275	2455	3202	3573	5136	5766	6423
n	4.2	3.7	2.4	2.0	1.8	1.8	1.8	1.8	1.9	1.9
χ^2 /DOF	0.002	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	98.6	96.7	2.4	99.9	100	100	100	100	100	100
	Case IV-27									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	288	621	1162	1771	2495	3636	3342	3688	4184	4878
n	4.3	3.4	2.2	2.0	1.9	1.8	1.8	1.9	1.8	1.8
χ^2 /DOF	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	98.4	97.4	99.9	100	100	100	100	100	100	100
	Case IV-31									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	299	620	1166	1772	2506	3644	3310	3702	4218	4665
n	4.5	3.4	2.2	2.0	1.9	1.8	1.9	1.8	1.8	1.9
χ^2 /DOF	0.004	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	97.7	97.4	99.7	100	100	100	100	100	100	99.9
	Case IV-35 & Case IV-39									
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	378	796	1357	2138	2674	3229	3676	4188	6305	5731
n	4.7	2.8	2.1	1.9	1.8	1.8	1.9	1.9	1.6	1.8
χ^2 /DOF	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R^2 (%)	97.9	99.3	99.9	99.9	99.8	99.4	98.7	98.7	97.2	96.2

2.2.2.3.3 Case of rocking

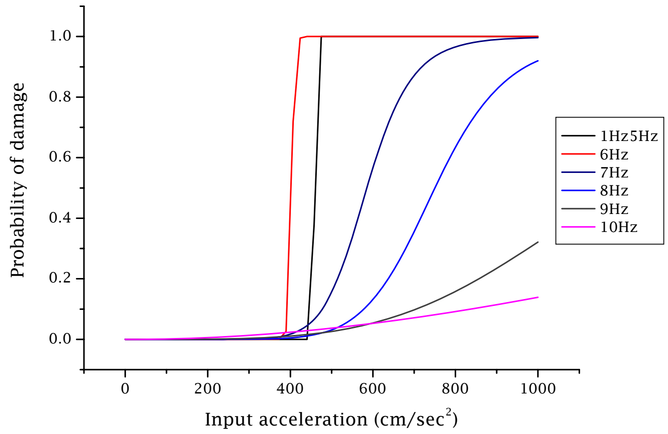


Figure 5.38- Fragility of Case IV-14 and Case IV-16

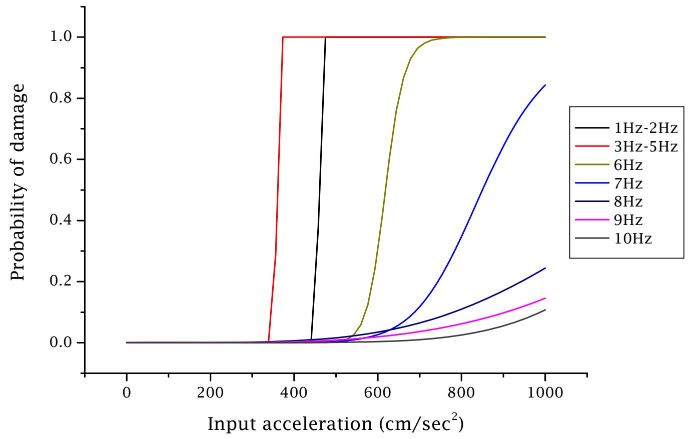


Figure 5.39- Fragility of Case IV-18 and Case IV-20

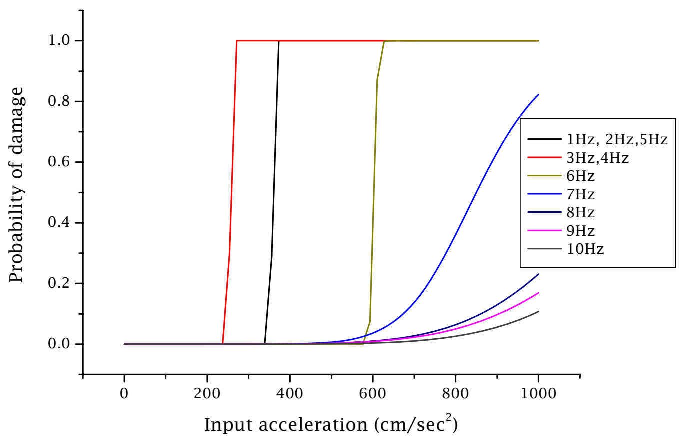


Figure 5.40- Fragility of Case IV-22 and Case IV-24

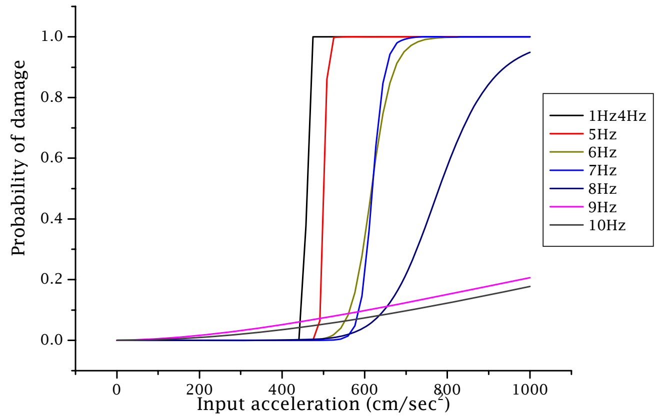


Figure 5.41- Fragility of Case IV-26, Case IV-28, Case IV-30 and Case IV-32

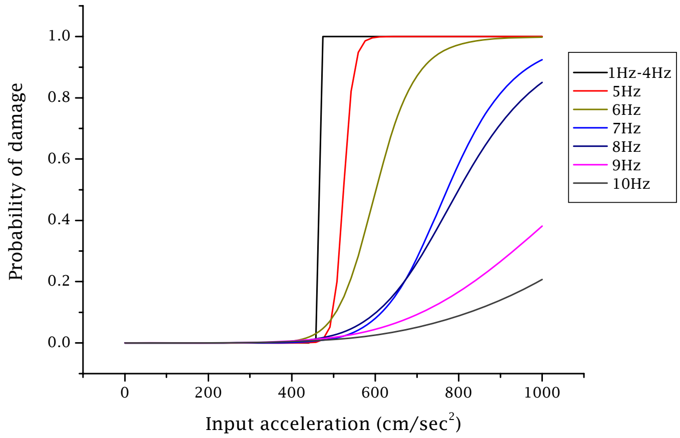


Figure 5.42- Fragility of Case IV-34, Case IV-36, Case IV-38 and Case IV-40

Similarly to previous systems, equipment are supposed to have the same importance for the functioning of the facility. The fragility of equipment placed on shelves, therefore, is equal to the average fragility of all containers. For the purpose of reducing errors, the original data, without fitting, was used to determine the fragility. After that we applied the same model, Sigmoidal function, to find the fragility shown in Figure 5.43 which parameters are shown in Table 5.20.

Table 5.19- Parameters of fitting

	Case IV-14 and Case IV-16					
Parameter	**1Hz-5Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0
K	458.2	403.2	585.6	750.0	1196.9	2399.3
N	421.7	107.6	10.7	8.5	4.2	2.1
χ^2 /DOF	0.000	0.000	0.008	0.029	0.002	0.001
R^2 (%)	100	100	96.8	81.2	89.3	84.7

	Case IV-18 and Case IV-20						
Parameter	**1Hz-2Hz**	**3Hz-5Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0
K	458.2	356.9	618.1	850.0	1300.0	1515.5	1360.1
N	421.7	327.8	27.8	10.4	4.3	4.3	6.90
χ^2 /DOF	0.000	0.000	0.010	0.012	0.001	0.001	0.000
R^2 (%)	100	100	96.2	88.4	81.1	85.5	85.7

	Case IV-22 and Case IV-24						
Parameter	**1Hz,2Hz,5Hz**	**3Hz,4Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	356.9	255.2	602.8	850.0	1200.0	1300.0	1367.7
n	327.8	237.9	157.8	9.4	6.6	6.1	6.8
χ^2 /DOF	0.000	0.000	0.000	0.021	0.001	0.001	0.000
R^2 (%)	100	100	100	78.2	74.1	81.8	84.7

	Case IV-26, Case IV-28, Case IV-30 and Case IV-32						
Parameter	**1Hz-4Hz**	**5Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	458.2	501.5	616.6	618.6	780.0	2191.5	2200.0
n	421.7	132.4	24.7	42.3	11.8	1.7	1.9
χ^2 /DOF	0.000	0.000	0.008	0.005	0.021	0.001	0.001
R^2 (%)	100	100	96.8	98.2	86.3	87.4	84.9

	Case IV-34, Case IV-36, Case IV-38 and Case IV-40						
Parameter	**1Hz-4Hz**	**5Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	462.9	524.3	601.8	772.6	800	1100	1350
n	388.9	45.1	12.7	9.7	7.8	5.1	4.5
χ^2 /DOF	0.000	0.012	0.007	0.007	0.032	0.002	0.001
R^2 (%)	100	94.6	95.1	95.5	75.8	82.2	79.8

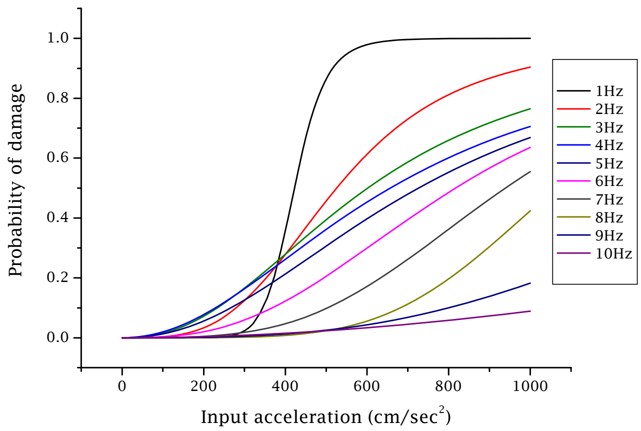


Figure 5.43- Fragility of all equipment placed on shelves

Table 5.20- Parameters of fitting of equipment placed on shelves

	Case IV-13									
Parameter	**1Hz**	**2Hz**	**3Hz**	**4Hz**	**5Hz**	**6Hz**	**7Hz**	**8Hz**	**9Hz**	**10Hz**
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	422	526	602	657	726	817.1	939	1064	1618	3135
n	10.9	3.5	2.3	2.1	2.2	2.8	3.5	4.9	3.1	2.0
χ^2 /DOF	0.058	0.008	0.009	0.010	0.008	0.005	0.001	0.000	0.000	0.000
R^2 (%)	83.7	94.6	90.9	87.9	89.8	93.0	98.3	98.2	97.4	96.5

3. FRAGILITY OF HEALTHCARE FACILITY

The fragility of a healthcare facility is the summation of fragilities of each of the systems that it contains multiplied by a coefficient that depends on the importance of the system to the functionality of the facility. The importance, of each system, depends on many factors such as the availability of the system at the facility, the availability of its alternative system and other factors. It should be noticed that the importance depends also on the impact that the system in question has on other systems if it is damaged; e.g. damage to all systems can be damaged by the structural damage such as what happened in India, Algeria and Iran after the Bhuj Earthquake of 2001, Boumerdes Earthquake of 2003 and Bam Earthquake of 2003 respectively. Another example is equipment that can cause damage to structure such as that happened in Japan or Taiwan where damage to equipment, water tank and electric power engine caused the closure of the entire facilities after the Hyogo-ken Nambu Earthquake 1995 and Chi-Chi Earthquake of 1999 respectively. Equation 5.5 represents the fragility of a facility composed of N systems. F is bounded between zero and unity; a null value means that the facilities is functioning perfectly without any damage while value 1 means that the facility cannot function and it has to be closed.

$$F = \sum_{i=1}^{N} \alpha_i F_i^{sys} \tag{5.5}$$

Where

$F^{sys}{}_i$: Fragility of system i, $0 \leq F^{sys}{}_i \leq 1$

α_i: a coefficient of importance of system i

Unfortunately, it was not possible for us to study the coefficient of each system as a large amount of information is required. For that reason we considered that all systems have equal importance to the functioning of the facility. The coefficients, α_i, are all equal to 1/5 as we have five different systems; *electric power system*, *water supply system*, *equipment* *mounted on wheels*, *equipment mounted on free standing tables* and *equipment placed on shelves*. The fragility of the healthcare facility was fit with the same way as the systems' fragilities and shown in Figure 5.44. Table 5.21 illustrates the parameters of fitting. Finally, the coefficient of importance will be considered in our future studies to make the accuracy of the results higher.

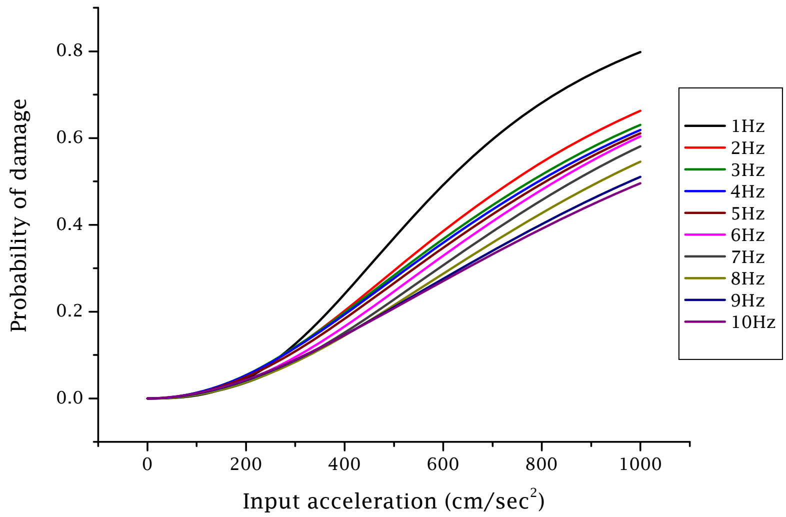


Figure 5.44- Fragility of healthcare facility

Table 5.21- Parameters of fitting of healthcare facility

Parameter	1Hz	2Hz	3Hz	4Hz	5Hz	6Hz	7Hz	8Hz	9Hz	10Hz
V_{max}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
k	607	739	776	793	808	828	864	918	979	1009
n	2.8	2.2	2.1	2.1	2.1	2.2	2.2	2.1	2.0	1.9
χ^2 /DOF	0.004	0.007	0.007	0.007	0.007	0.006	0.004	0.004	0.005	0.005
R^2 (%)	96.5	90.9	89.7	89.0	89.4	60.5	92.3	92.3	89.4	88.2

4. CONCLUSION

The fragility of the water supply system and electric power system does not depend on frequencies. A water system is likely to be damaged more easily than an electric power system, given that the geometry of both systems is different. Water systems are composed with rigid long elements, i.e. pipes, which are very weak. While an electric power system is a mixture of very flexible elements, i.e. wires, and very strong elements, i.e. support of solar panels, this makes it very difficult to be damaged. Unconnected equipment response depends on frequency as their natural frequencies are low, less than 1Hz; low frequencies cause their damage easier than high frequencies.

The results show that low frequencies are the most dangerous for the malfunctioning of a facility. All non-connected equipment has very low natural frequencies and therefore exciting them with low frequencies makes them resonate and therefore become unstable. This leads us to conclude that hospitals with base isolation systems suffer damage to their unconnected equipment more than facilities built with usual structure.

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CHPATER 6

CONCLUDING REMARKS

CONCLUSION

This dissertation presents a new methodology to estimate the malfunction of healthcare facilities following an earthquake with the purpose of saving human life. Several researchers have been working on similar studies but this methodology offers better results which make it very particular. The methodology provides detailed fragility determinations 1) of each element of a system, 2) of each system, 3) each facility and 4) of the healthcare system. The first two points, 1) and 2), help engineers to reduce the vulnerabilities of elements and therefore the entire system. The third point mainly helps doctors in dispatching the injured during an earthquake-related emergency. This leads to reduced transfer of the injured from one facility to another and therefore fewer traumas and higher chance to survival. This also helps the administration of the hospital to find out wich system needs attention most urgently and thus helps them take measures to reduce its vulnerability. The fourth point provides the decision makers with a clear idea of the situation of each hospital in the health system. This helps them to take the necessary measures in preparing for an earthquake. Finally the proposed methodology is universal, i.e. valid for any hospital or healthcare system around the world which makes it unique and useful for developed and developing countries.

Chapter 2 pointed out a) the different systems of a healthcare facility and b) the factors that may affect the treatment of an injured person. A healthcare facility is composed mainly of two categories; the human category (composed of patients, medical staff, mainly doctors and nurses, administrative and support staff) and the physical category (composed of structural and non-structural category as well as lifeline and equipment category). Several factors affect the treatment of an injury. Some of them are related to traffic and road conditions and others are related to the healthcare facility. The latter depends on internal and external factors such as structural and non-structural elements as well as lifeline and equipment conditions.

Chapter 3 provides general idea about damage experienced in health facilities following previous earthquakes around the world. Damage was classified into three main types; 1) structural and non-structural damage, 2) lifeline damage and 3) damage to equipment. Other types were found such as crisis management but they were not considered in the study. Damage to structural and non-structural elements was found to be very different from one case to another; some were very strong and could withstand very high seismic intensity while others collapsed under low intensities. Several factors were found to cause the difference; some of them were related to the age of buildings, others to the material used, reinforced concrete or masonry, others to the type of structures, with base isolation or without base isolation among others.

The damage to lifelines was found to be somehow comparable between the cases as lifelines are similar everywhere; similar elements are being used around the world and obviously similar causes, i.e. earthquakes, applied to similar systems, i.e. lifelines, would cause similar damage. The difference was found to be in the level of alternative sources. Facilities with alternative sources have a higher chance to withstand emergency situations, while facilities without alternative sources are in risk of malfunction given an earthquake. Internal lifeline system malfunction depends on both the ground motion and external lifeline system. Lifeline shortage greatly affects the functionality of equipment which in turn affects the operation of the facility.

A hospital is home to large amount of equipment; some are connected to the structure, others are free standing which can be mounted on wheels or not etc. The past events highlighted the problem of equipment instability and the damage that they can cause; damage to structure, lifelines, other equipment and people.

Chapter 4 discussed the main problems found in hospitals; lifeline and equipment stability. Electric power was found to be the most important lifeline for the functioning of a facility. Emergency power generators, which are used as alternative sources in hospitals, were found to be vulnerable. To reduce this vulnerability and strengthen the lifeline system solar panels were proposed. A comparison between both systems, considering energetic delivery, economic and environmental issues, was completed. The solar system has many benefits mainly: independence, unlike the generators, they are eco-friendly and reliable. The system was also studied with relation to dynamic loads, i.e. earthquakes, and found to be safe. The study showed that a solar system is able to be installed as an alternative and even main source in some cases.

A couple of equipment categories were studied; a) connected and not connected to their supports. Eight types of shelves were considered; each type was connected in a particular way which can be fixed or flexible. The results showed that the more the shelf is attached to the structure the more stable it becomes. The most unstable types of shelves are those which are connected only by their bottoms. Simulation and experimental determination response of wheeled equipment was finalised. The wheels are equipped with brakes and this causes a difference in response according to the brakes being in a locked or unlocked position; rocking or sliding respectively. An unlocked setting was found to be stable while the locked setting was unstable. Low frequencies seem to make the equipment unstable while high frequencies seem to stabilize it.

Chapter 5 is a study of the fragility of some systems. The fragility of water supply and electric power systems was finalised. The frequency does not affect their fragilities. Electric systems are stronger than water supply systems. Water supply system is more easily damaged as its elements are more fragile than the electric system's elements. The fragility of equipment depends on the frequency. Low frequencies tend to make the highest damage to systems and therefore to healthcare facilities. Hospitals with base isolation systems suffer damage to their unconnected equipment more than facilities without base isolation system.

This dissertation shows a feasible methodology to estimate malfunction in critical facilities, mainly hospitals. Its simplicity makes it remarkable and accurate. The study has opened the door for more research. In the future, the methodology will be improved by considering more factors such as the importance of each system and other considerations.

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APPENDIX I

BOUMERDES EARTHQUAKE; SUGGESTIONS

This section represents some suggestions that we thought they might be helpful for those who are concerned about the situation of healthcare system in Algeria.

1. SUGGESTIONS SOLUTIONS

The three issues, structural, lifeline and organizational, need to be protected by reconstructing new stronger structures or strengthening the actual structures, providing the necessary lifelines and protecting them from any damage and organizing the functioning of the facilities to have better response capabilities in the case of an emergency. However, it is difficult to have all these issues done at the same time because of the high cost that is needed. For that, we propose the following solutions classified according to their priority and taking into consideration the economical aspects of the country.

1.1 Management issue

Training seminars and lectures are two of the main activities that should be conducted to help personnel understand the situation of an emergency. They can be prepared based on the previous experiences of such disasters as the Boumerdes earthquake, or any other more serious situation that can be expected. The personnel performed well after the Boumerdes disaster and so their experiences can be used to educate other staff members based on what they went through. Only they have the details of the rescue and the many problems that they faced. Their experiences can be used as the basis of the training sessions as well as becoming the goal of what they would like to improve. In the following paragraphs we propose some guidelines that the trainers may need.

After the occurrence of an earthquake the personnel can be divided into three main groups; the first group is onsite (*affected area*), the second is the transport team and the third is the treatment team that is present at the hospital. The onsite group is asked to access the patients, provide preliminary care and dispatch the victims who need special treatment and send home those that do not need medical treatment. This group is asked to know: the situation of hospitals, to which victims will be transferred; also they should know the ability of the hospital to receive patients (*no damage, not crowded*). The transport group is asked to know perfectly the roads that lead to hospitals. The roads to be taken should be neither damaged nor crowded and they should be the fastest. Among them some members of a medical team should be ready to provide the victim with the necessary treatment until they reach the hospital. The group based in hospitals should be ready to accept the victims as well as dispatch them to the necessary department in the shortest possible time.

1.2 Structural issue

Algerian investigators have declared that many factors contributed to the structural damage. Some of those factors are architectural and structural design problems; poor quality of design as well as low quality materials used such as the concrete; poor inspection during the construction and poor construction techniques; and inadequate building maintenance (Belazougui et al., 2003). As has been stated previously, the main causes of structural damage that we found during our visit were the age and the type of the structure, which was masonry. Two solutions are possible to fix such problems; the first is to retrofit the actual structures and the second is to rebuild completely new structures. Retrofitting should be carried out by adding new structural elements to the masonry. The retrofitting must cover the foundations as well as the roof. This has the effect of making the charge distribution smoother. However, this type of retrofitting is very costly, it can cause malfunction to the hospital and the quality of the retrofitting may not be as good as is needed. Therefore the best option is to build a new structure considering some measurements to have the needed strength and quality. The new facilities should be built step by step to not hamper the functioning of the actual facilities and to not affect the economy. There are three main factors of consideration; architecture, design and construction. We strongly recommend that the construction of a newer, stronger structure be seriously considered.

There are several errors that are being committed during the construction of any building in the North African area and these should be avoided during the construction of the new facilities. The majority of buildings have frame-type-structures filled with bricks or masonry. In some cases concrete walls or concrete cages, which can be used for elevators or escalators, are needed for the structure. The location of those elements should be chosen very carefully so as to avoid or at least minimise any problems in structural response. For example, the location of an elevator cage can cause eccentricity between the centre of mass and the centre of stiffness, that eccentricity can cause torsion during the buildings response to seismic waves. The same type of problem was described by the PAHO and the solution was to have symmetrical shaped structures (PAHO, 2000). Some other types of problems should be investigated and avoided during the design of new health care facilities.

Concerning construction, it is important to check the quality of materials such as concrete, the type of steel used and the method that is followed during the construction. The characteristics considered during the design should conform to those used in the construction. Finally, it is highly recommended that architects and engineers consider the problems stated herewith during their design to avoid unnecessary damage to vital hospital structures.

1.3 Lifeline issue

To protect lifelines some measurement should be well thought-out. In reality lifeline preparedness depends on the type of lifeline itself. The lifeline should be protected always from any danger that can harm its functioning. There are some common problems such as attachment of the equipment to their supports. The attachment should be strong enough to not allow the equipment to fall down and it should be flexible enough to not damage the support itself. It is obvious that the type of attachment depends on the equipment itself since some equipment needs to be mobile. Pipeline joints should be flexible to provide the different pipes with the necessary movement during seismic shaking.

The facilities should be equipped with alternative sources that may be needed during an emergency, electricity, water and telecommunications. Those sources should be permanently present in the hospital and should be in operation immediately after the loss of the main source. To be sure about their functionality they should be tested regularly. It should be noted also that dividing the lifeline systems into subsystems would help to restrict any malfunction to that particular subsystem rather than leaving the entire facility without the use of that lifeline, like we found in Algeria.

2. DEDUCTION

Simply by looking at the presented pictures and tables, the level of preparedness of Algeria's health care facilities for any disaster, but particularly earthquakes, can be clearly understood. Thousands of buildings collapsed and no alternative sources were provided or available in hospitals.

The table that presents Hospital Damage Distribution, while being useful in viewing clearly the damage to structural elements, is not so useful for the case of health care facilities. A study has shown that structural elements represent 10-15% of the whole cost of a hospital and the remaining percentage is representative of the non-structural elements including medical equipment (PAHO, 2000). Health care facilities, with all their types (fixed or mobile) are the only locations where a patient can receive complete treatment. Therefore their importance cannot be judged by their structural elements without taking into consideration the rest. Algeria, as well as many other countries import medical equipment; that import has a direct affect on the national economy of the country.

Therefore such types of equipment should be very carefully protected. The colour coded classifications of Green1- Red5 do not serve any role within a hospital because even if a vital piece of equipment is displaced and damaged, this can result in one or many patients not having access to the necessary treatment that they require. Therefore a better classification is necessary, one that is more relevant to life saving.

The types of structural problems encountered are common in developing countries. There are many reasons behind these problems. Some of them are as follows; - the technical problems: since engineers and constructors do not pay attention to the quality of the materials used as well as the correct design. – Lack of knowledge of seismic problems: many architects look for the aesthetics of the structure more than the strength of it. Unfortunately, some countries are ignorant to such disasters by using the seismic history as the main reason to show that earthquakes do not occur in their areas.

The presented solutions may not be very detailed so as to provide the protection of the facilities; however, they do give the main guidelines that the Algerian engineers, architects and medical staff may need to prepare for future disasters. The proposed solutions take into consideration the economical difficulties of the country by depending on the human resources more than material resources. It is possible to change the proposed ideas according to the cases that were faced by the staff and according to the available possibilities during the final preparation, but it is important to follow the sequence of the main steps: i.e. referring always to organizational issues, structural issues then lifeline issues. The best way to make a good method is the one in which all specialities share in its operation. Therefore, engineers, architects and medical staff should gather and discuss the architectural drawings as well as the location of the equipment and try to find the best solution to make the hospital strong enough to resist against earthquakes.

Lastly, what can be learned from the presented disaster is the importance of health care facilities and the obligation to protect them through the correct preparation of their structural, non-structural and organizational aspects. They should be able to face any type of emergency, particularly natural disasters such as earthquakes.

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APPENDIX II

BAM EARTHQUAKE; SUGGESTIONS

Similarly to the Algerian case, this section focuses on particular issues that were found during the investigations. Some suggestions are proposed for those who are interested in the Iranian case.

1. DISCUSSION AND SUGGESTIONS

Damage to health care facilities depends from country to country, in another word depending on the level of preparedness in each country. Usually it starts with the structural and it ends with lifelines and organization; for that Iran should take in consideration the experience of other countries such as Algeria, following the Boumerdes earthquake of 21st May 2003. Additionally, the preparedness should be done according to trustful systems, such as the case of Japan. Japan could reduce greatly the number of victims even if some problems are still being found during emergencies. The preparedness should be done to all the categories; structure, lifeline and organization.

The following section deals with the different hospital categories, some suggestions are presented to help the decision makers to prepare their health care facilities to save as many as possible lives. The section is divided into three main sub-sections are shown in the following; structural planning, lifeline planning and management of the facilities.

1.1 Structural and non-structural issues

It is clear that Iran needs a total reform to its structures, two possibilities exist and can be applied; *a)* retrofitting the existent facilities and rebuild the parts that totally collapsed, *b)* rebuild the whole facilities. The author recommends the second solution since the first can be very costly and may not able to give the expected strength. It is important to notice that many studies have shown the vulnerabilities of structures that should be taken in the design phase; hereby we remind that the difficult shapes may be able to concentrate the strain and therefore can cause the damage of the structure; some of the structures that should be avoided are shown in Figure II.1 and Figure II.2. The location should be well chosen; it is advisable to have hospitals far from seismic faults, at the same time it highly recommended to have facilities near the concentration of inhabitants. When facilities are close to residential area it may be easier for the victims to reach them, hospitals, when they need them the most; close facilities save the patients time and reduce the risk of trauma or death while travelling. The facility buildings should be built according to the newest building codes since they consider new factors that were not considered in the old ones.

1.2 Lifeline issues

The difference between any commercial/living building and health care building is the lifeline/equipment that exists in both of them. Healthcare facilities are equipped with very particular equipment that are used to treat patients. Hospitals' equipment are related to each other with very complicated ways. The main problems that were found in Iran and in many other facilities in the world can be classified into three categories; *alternative sources*, *topple and damage of equipment* and *malfunction*.

As their name indicates “alternative sources” have to be always in the hospitals; an alternative source is a source that would be used in case of loss of the main source therefore it has to exist with the main source. A health care facility cannot function if it doesn’t have electricity or water or any other lifeline. The Khomeini hospital did not have any emergency electric generators, did not have any water supply and therefore it had to be closed. The facilities could not use their landline phones and even the mobiles were not functioning, this was because of damage to external problems. To reduce this risk it is highly recommended to have different sources of lifelines so that if one cannot be used the other(s) will be.

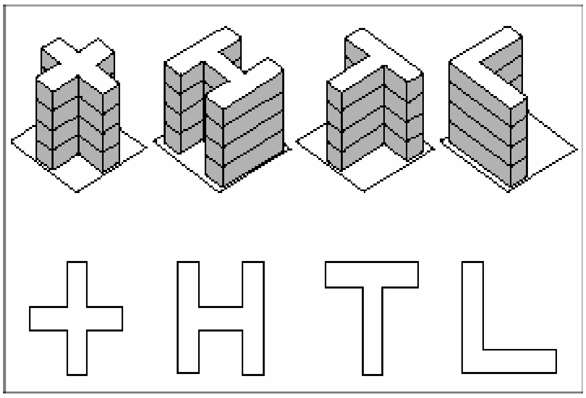

Figure II.1- Shapes, in plan, that should be avoided during the design (Source: PAHO, 2000)

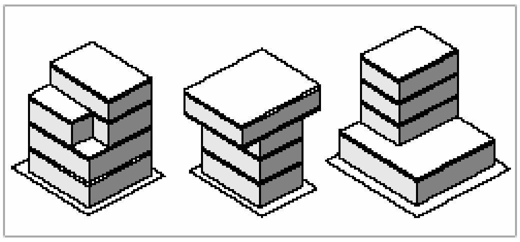

Figure II.2- Vertical shapes to be avoided (Source: PAHO, 2000)

1.3 Management issues

Management and planning are the main issue that has two different edges; the first is the correct behaviour during the emergency, and the second is dealing with the actual condition of the facilities. In other words management represents saving the lives with the lowest cost.

Managing for disasters deals with many issues; number of personnel and their education, choosing the right location of equipment, providing the facility with the necessary equipment needed for treating causalities. The number of personnel should be well studied according to the number of inhabitant within the same area, and the average number of patient per year. Also the personnel should be always aware of the emergencies situation. Special activities such as training and lectures can be organized to make the personnel aware of the situation. The Aflatoonian hospital already started teaching its personnel which helped them during the emergency. The situation is the more or less the same as Algeria, therefore we propose the same idea proposed about the Algerian earthquake.

Healthcare facilities should have always emergency manuals that explain to the personnel in detail the situation of emergencies with very easy way. The Aflatoonian hospital had emergency manuals but unfortunately it does not consider the case of earthquakes.

The location of equipment should be well chosen since during earthquakes equipment move and may make the area inaccessible, see Photos II.1, II.2 and II.3. Noting that this issue is related directly to the previous section, *lifeline issues*, since the problem of anchorage imposes itself; also it is related to the decision of the location which depends on the medical and administrative personnel.

Finally, we propose some ideas that might inspire Iranian engineers, as well as those who are living in countries that are facing the same danger.

1- Building strong structures that can resist disasters.
2- Organizing the inside and the outside of the facilities to avoid any equipment from falling and harming displacement inside and outside the facility. Equipment should be well attached to their support with flexible couplings.
3- Providing the health care facilities with the necessary number of personnel.
4- Providing the medical staff as well as the rest of the staff with special emergency response lectures and training to help them to behave correctly during a disaster.
5- Providing the hospitals with the necessary medical products that are needed in the case of an emergency.
6- Providing the hospitals with alternative sources that can be used immediately after the lack of the principal lifeline such as electric generators for the case of a blackout.

1.4 Other issues

Management and economical issues are still one the main problems for health facilities around the world. Each country has its own specific problems but in total they are similar. It is known that public hospitals are not beneficent from treatment. The public facilities are built using the tax of the citizen, for that the cost of treatment cannot be advantageous. On the other hand, hospitals must have very particular equipment which is very expensive. The possibility of affecting the national economy is very high and mainly in countries such as Iran seeing that they have to buy these types of equipment from other countries. The Aflatoonian Hospital had to close because of some problems with its insurance company; therefore economical problems. The government can encourage the providers of the hospitals and the technical services to take maintain the facility with the necessary service, maintenance of the equipment, with a reduction of certain amount from the taxes that have to pay. This way will save the government expenses on health care facilities after the occurrence of disasters and will make sure the operation of the equipment when they are needed the most; and finally saving more lives.


Photo II.1- Falling over of a gas cylinder


Photo II.2- Displacement of equipment


Photo II. 3- Topple of medical equipment

2. DEDUCTION

Iran is in high risk of having earthquakes, yet it still has not prepared for them. Many problems were faced during the emergencies and it should be noticed that they are not particular only to Iran because many countries are suffering from the same problems. However, the situation in Iran can be made much better using the resources that the country has. It has to be mentioned that this is the best time to organize correctly its health care facilities by building new facilities and equipping them with the necessary equipments. The preparedness of personnel is very necessary since they are the most important people who are able to treat injuries and therefore save lives.

An important lesson shall be learned from the rescue nuisance; the planning and the organization are very important and should be done always even if the risk of having disasters is low. If preparedness was done the situation would be much better and the numbers would be less than they are as well as the economy losses would not be as they are.