行政院國家科學委員會專題研究計畫 成果報告

大地與結構監測資料於設計地震需求及結構健康診斷之應用--子計畫:以強震監測資料及結構模擬評估建築物於地震中之層間變位及 RC 結構之損害潛勢(I)

研究成果報告(完整版)

計 畫 類 別 ： 整合型
計 畫 編 號 ： NSC 99-2625-M-027-003-
執 行 期 間 ： 99 年 08 月 01 日至 100 年 07 月 31 日
執 行 單 位 ： 國立臺北科技大學土木工程系

計 畫 主 持 人 ： 黃昭勳
共 同 主 持 人 ： 段永定
計畫參與人員： 碩士班研究生-兼任助理人員：鄭秉昀
碩士班研究生-兼任助理人員：陳勝恩

報 告 附 件 ： 出席國際會議研究心得報告及發表論文

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2011 International Conference on Structures and Building Materials

January 7-9 2011, Guangzhou, China

Notification of Paper Acceptance

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The Scientific Committee has completed its review of your paper submitted for International Conference on Structures and Building Materials (ICSBM 2011). The final decision is made base on the peer-review reports, the scientific merits and the relevance.

We are pleased to inform you that your paper as follow has now been accepted by the Scientific Committee of ICSBM 2011 and will be published in international journal "Advanced Materials Research", and will be indexed by EI COMPENDEX and Thomas ISTP.

Manuscript Number	H7478
Authors	Chao Hsun Huang, Yungting Alex Tuan, Chun Ying Huang
Title	Lateral Force Demand of Essential Equipment in Hospital Buildings for Earthquakes

Notes:

1. Please revise your manuscript according to the detailed comments and suggestions from the referees. And make sure that your paper is in strict accordance with the format of Advanced Materials Research journal.

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2010-9-14

Lateral Force Demand of Essential Equipments in Hospital Buildings for Earthquakes

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Keywords: medical equipments, component amplification factor, height adjustment factor.

Abstract. To deliver the badly need medical services for the victims, major regional hospitals are expected to remain operational after an earthquake. In order to provide continuing services, these hospitals not only have to secure the structural safety of the buildings, but need to ensure the functionality of essential equipments. In this study, a finite element analysis was performed on equipments attached in a series of reference buildings to examine the structural demand of hospital equipments during an earthquake. It was found out that the current code provides a good estimation for equipment with a short period of vibration. For those with longer periods, however, the component amplification factor should be obtained from the design spectrum.

Introduction

In most disaster responding systems, the medical section is always considered a critical element. For this reason, the ability to provide continuing services after major earthquakes strongly affects the government's ratings on regional hospitals. During both 1994 Northridge and 1999 Chichi Earthquakes, numbers of hospitals failed to provide such services due to damages in medical or other essential equipments, causing the loss of a life and immediate evacuation of hospital patients after the earthquakes. Since most building codes specify higher (usually by 25%~50%) design seismic load for medical facilities than ordinary structures, hospital buildings are now less likely to suffer serious structural damages during earthquakes. As the building structure gets secured, the availability of medical services after an earthquake would depend on the structural integrity of the equipment itself.

To discover potential threats to hospital operation after earthquakes, Ray-Chaudhuri and Shinozuka [1] performed a fragility analysis on primary mechanical and electrical systems in a 4-story hospital building. They found out that during an earthquake, the possibility of getting damaged for most equipment increases with the peak ground acceleration; for the power and piping systems, however, story drift becomes the main factor. To identify the most critical components, Myrtle et al. [2] ranked the essential elements equipment in hospitals in the order of seismic vulnerability as piping systems, electrical, communications, medical monitors, ventilators, defibrillators, HVAC, suspended ceilings, and fire sprinklers based on a survey conducted by on hospitals suffering from the 1994 Northridge (USA), 1995 Kobe (Japan), 1999 Kocaeli (Turkey), and 1999 Chichi (Taiwan) Earthquakes. And in a study on seismic retrofit of the hospital equipment, Chuan [3] further concluded that the seismic resistance of the equipment is often determined by the strength of the anchorage. Therefore, the anchorage often dominates the seismic design of hospital equipment.

To ensure the safety of equipment during earthquakes, the International Building Code [4], ASCE 7 [5], FEMA 450-1 [6], as well as the (Taiwan) Seismic Design Code for Buildings [7] all specify a design horizontal seismic load of

$$F_p = \frac{0.4 a_p S_{DS} W_p}{R_p / I_p}\left(1 + 2\frac{z}{h}\right) \quad (1)$$

for equipment attached to buildings, in which

F_p = seismic design force
S_{DS} = spectral acceleration at short period
W_p = component operating weight
a_p = component amplification factor due to possible resonance effects (see Table 1)
R_p = component response modification factor (see Table 1)
I_p = component importance factor
z = height in structure of point of attachment of component with respect to the base. For items at or below the base, z shall be taken as 0. The value of z/h need not exceed 1.0
h = average roof height with respect to the base

The load calculated in Eq. 1 is not required to be taken as greater than 1.6 $S_{DS}\, I_p\, W_p$ and shall not be taken as less than 0.3 $S_{DS}\, I_p\, W_p$. In this equation, factors that affect the seismic response of the equipment such as the ductility, resonance, site, and relative height effects are all taken into account. However, as the dynamic property of equipment varies, the a_p values given in Table 1 might not represent the correct response. On the other hand, as the height and configuration of hospital buildings may be complete different, whether or not the height adjustment factor, 1 + 2 z/h, reveals the actual height effects is to be examined. In this study, a finite element analysis was performed on a series of reference buildings to investigate the dynamic response of hospital equipment during an earthquake.

Table 1 Seismic coefficients for mechanical and electrical components [6]

Mechanical or Electrical component or Element	a_p	R_p
General Mechanical		
Broilers and Furnaces	1.0	2.5
Pressure vessels on skirts and free-standing	2.5	2.5
Stacks	2.5	2.5
Cantilevered chimneys	2.5	2.5
Other	1.0	2.5
Piping Systems		
High deformability elements and attachments	1.0	3.5
Limited deformability	1.0	2.5
Low deformability elements and attachments	1.0	1.5
HVAC System Component		
Vibration isolated	2.5	2.5
Non-vibration isolated	1.0	2.5
Mounted in-line with ductwork	1.0	2.5
Other	1.0	2.5
Elevator Components	1.0	2.5
Escalator Components	1.0	2.5
Trussed Towers (free-standing or guyed)	2.5	2.5
General Electrical		
Distribution systems (bus ducts, conduit, cable tray)	1.0	5
Equipment	1.0	2.5
Lighting Fixtures	1.0	1.5

Finite Element Analysis

Considering that the major equipments in a hospital are mostly rigid, the analysis was performed on four different types of equipments with fundamental periods of vibration, T_p, of 0.01, 0.02, 0.05, and 0.10 sec. respectively. The structural model of the equipment is shown in Fig. 2. To study the height effect, a series of reference structures with heights of one to fourteen stories were used as the hospital models. (See Fig. 3) Dimensions of structural components in the reference buildings are given in Table 2, and the (concrete) compressive strength of these elements is assumed as 28 MPa.

The design acceleration spectrum specified for stiff soil at Hu-Wei, Yun-Lin County, by the current Taiwan Seismic Design Code for Buildings is selected as the ground motion input in the analysis, as indicated by the dashed line in Fig. 4.

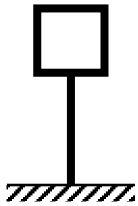
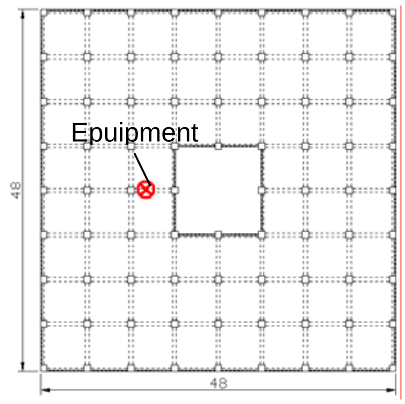
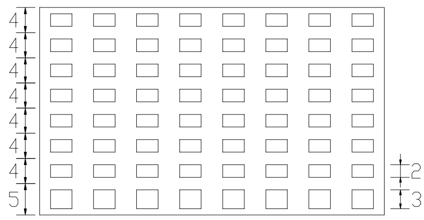


Fig. 2 Typical structural model for equipment





(a) plan (b) elevation (8-story model)

Fig. 3 Plan and elevation of the reference building(s)

Table 2 Dimensions of structural components in the reference buildings

Element	Column	Beam	Slab	Wall
Dimension(s)	90 cm x 90 cm	50 cm x 70 cm	20 cm	20 cm

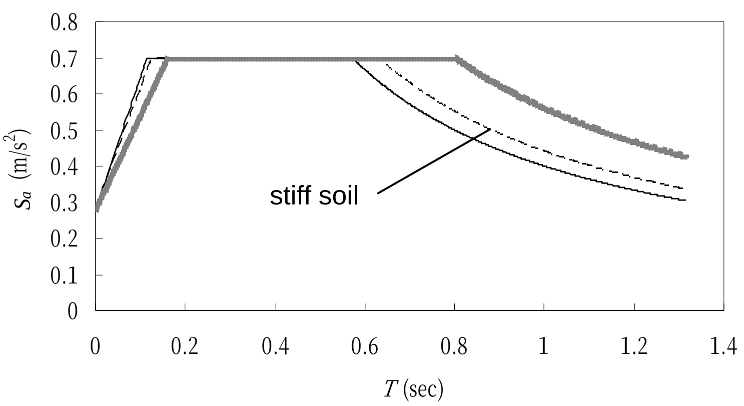


Fig. 4 Design spectrum for at Hu-Wei, Yun-Lin County

Fig. 5 shows the component amplification factor for equipment with T_p equal to 0.02 sec. obtained in the finite element analysis, and the average factors for equipments with T_p of 0.01, 0.02, 0.05, and 0.10 sec were obtained as 1.15, 1.21, 1.58, and 1.91, respectively. It can be seen that the component amplification factors do vary for different equipments instead of stay at the lower and upper bound of 1.0 and 2.5, as specified in Table 2. On the other hand, these factors, when normalized by multiplying

$0.4S_{DS}$, are comparable to the spectral acceleration S_{aD} specified by the code. (See Fig. 6.) Therefore when the fundamental period of the equipment is known, it is recommended that the designer should obtain the component amplification factor directly from the design spectrum.

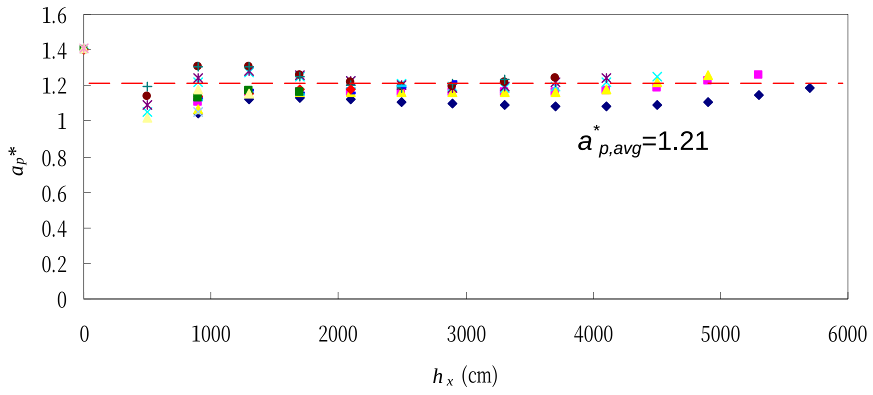


Fig. 5 Component amplification factor for equipment with T_p = 0.02 sec.

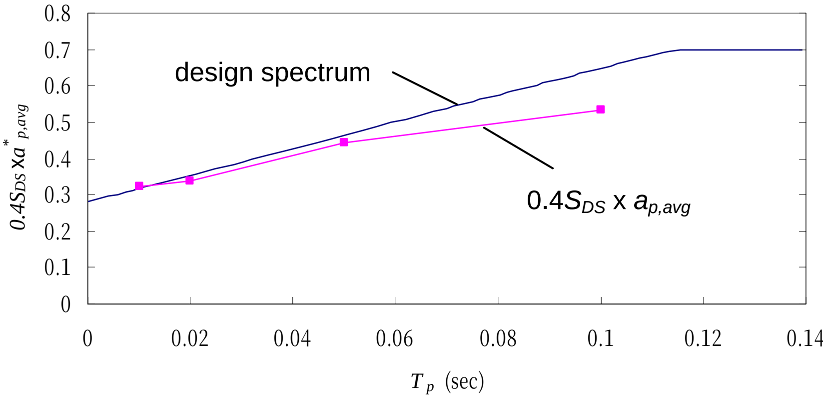


Fig. 6 Comparison between the normalized component amplification factor with the design spectrum

As for the height adjustment, it was investigated by changing the total height of the reference building and the height at which the equipment is attached for all four types of equipments. Figs. 7 and 8 show the height effect on lateral force action on equipments attached on the 7-story and 14-story reference buildings, respectively. It is found that for equipments with lower T_p, the rate at which the seismic load increases with the relative equipment height is close to the code formula, $1 + 2z/h$; however, for equipment with T_p equal to 0.05 and 0.10 sec., the seismic load does not rise as fast. Therefore, if the equipment is rigid enough, the code formula will give a good adjustment to account for the height effect.

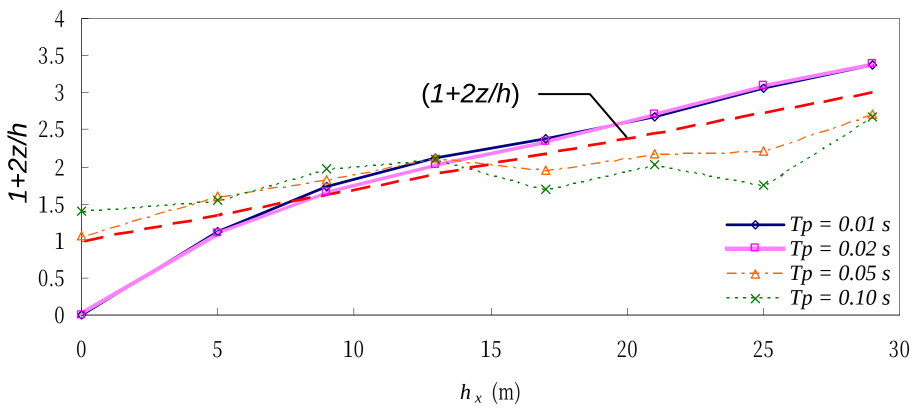


Fig. 7 Height adjustment factor for equipments attached in the 7-story building

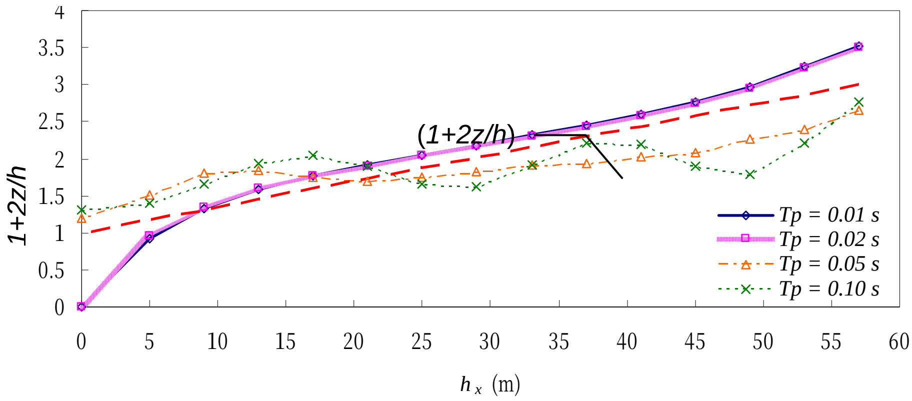


Fig. 8 Height adjustment factor for equipments attached in the 14-story building

Summary

By comparing the equipment forces at various floor heights and building configurations, the following conclusions can be made:

1. The average component amplification factors for all four types of equipments are comparable to the spectral acceleration S_{aD} specified by the code when normalized with respect to the PGA. Therefore, designers could get the component amplification factor from the spectral acceleration if higher accuracy is desired.
2. The current code does provide a reasonable adjustment method for equipments attached at different elevations in the same building. However, the force increase becomes less sensitive to the floor height when the fundamental period of equipment rises.

Acknowledgement

The financial support provided by the National Science Council of Taiwan to this research (Grant # NSC 98-2625-M-027 -004 and NSC 99-2625-M-027 -003) is gratefully acknowledged by the authors.

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2010-9-14

國科會補助計畫衍生研發成果推廣資料表

日期:2011/10/24

國科會補助計畫	計畫名稱: 子計畫:以強震監測資料及結構模擬評估建築物於地震中之層間變位及RC結構之損害潛勢(I)
	計畫主持人: 黃昭勳
	計畫編號: 99-2625-M-027-003- 學門領域: 永續發展研究-工程技術

無研發成果推廣資料

99 年度專題研究計畫研究成果彙整表

計畫主持人：黃昭勳	計畫編號：99-2625-M-027-003-
計畫名稱：大地與結構監測資料於設計地震需求及結構健康診斷之應用--子計畫:以強震監測資料及結構模擬評估建築物於地震中之層間變位及 RC 結構之損害潛勢(I)	

成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	1	1	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	2	1	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	1	1	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	1	1	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	本研究之初步成果已於 100 年 6 月 9-10 日國家地震工程研究中心舉辦之 International Workshop on Structural Health Monitoring and Damage Assessment 中發表

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

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1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

   ■達成目標

   □未達成目標（請說明，以 100 字為限）

   □實驗失敗

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   說明：

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   論文：□已發表 □未發表之文稿 ■撰寫中 □無

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