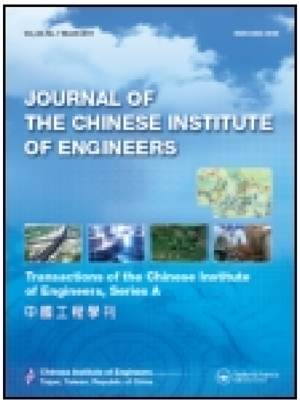
This article was downloaded by: [National Chiao Tung University 國立交通大學]
On: 27 April 2014, At: 21:27
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Journal of the Chinese Institute of Engineers
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tcie20

Roles of non-structural walls in Chi-Chi earthquake

Gin-Show Liou [a], Yi-Feng Chiu [a] & Fu-Ping Cheng [a]

[a] Department of Civil Engineering, Chiao-Tung University, Hsingchu, Taiwan 300, R.O.C.

Published online: 03 Mar 2011.

To cite this article: Gin-Show Liou, Yi-Feng Chiu & Fu-Ping Cheng (2002) Roles of non-structural walls in Chi-Chi earthquake, Journal of the Chinese Institute of Engineers, 25:4, 473-477, DOI: 10.1080/02533839.2002.9670722

To link to this article: http://dx.doi.org/10.1080/02533839.2002.9670722

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

Journal of the Chinese Institute of Engineers, Vol. 25, No. 4, pp. 473-477 (2002)

ROLES OF NON-STRUCTURAL WALLS IN CHI-CHI EARTHQUAKE

Gin-Show Liou*, Yi-Feng Chiu, and Fu-Ping Cheng
Department of Civil Engineering
Chiao-Tung University
Hsingchu, Taiwan 300, R.O.C.

Key Words: non-structural wall, earthquake analysis, Chi-Chi Earthquake, ductile failure

ABSTRACT

Presented are some close observations of failure modes of building structures after the Chi-Chi Earthquake, which occurred on September 21, 1999, and some numerical analysis of building structures that proves the conclusions of these close observations. According to the observations and analysis results, one can conclude that non-structural walls play a major role in the damage and collapse of building structures in strong earthquakes. Therefore, some suggestions are made for the structural design industry and academic research in order to improve the earthquake resistance of existing and future building structures.

I. INTRODUCTION

On the early morning of Sept. 21, 1999, a catastrophic earthquake attacked the central part of Taiwan, which caused more than two thousand casualties, the collapse of tens of thousands of buildings and damage to hundreds of thousands of buildings. Most of the human lives were lost in the collapsed buildings. Therefore, the causes of building collapse should be investigated in great detail in order to upgrade design practices for better seismic resistant buildings in the near future and to know how to improve the seismic resistant ability of existing buildings. After a tour of the earthquake stricken area, the causes of building damage and collapse, in general, can be categorized into two groups. One is lousy construction practice. For example, adding excess water in concrete in order to obtain better workability, which will reduce the strength of concrete, overlapping all the main reinforcement of columns at the same location which is against building code provisions, and not following the construction specifications for seismic resistant structures. The other is malpractice by structural designers, for example, using an oversimplified analysis method to design very complicated structures, little care about feasibility of construction (e.g. too much reinforcement at beam-column joints), and neglecting some design factors which are important. To some degree, all of these causes may contribute to the collapse or damage of buildings.

However, after closer examination of the earthquake stricken area, it seems that non-structural RC or brick wall, whose influence on structural behavior is always overlooked in design and construction practice, was one of the major culprits in causing the collapse of or damage to building structures during the earthquake. Therefore, this paper will

---

*Correspondence addressee

investigate some patterns of structural failure of buildings due to non-structural walls (brick wall or thin R.C. wall) that are a common feature of buildings in Taiwan. After some in-depth investigations of collapsed buildings, one finds that this kind of failure pattern was quite common in the 921 Chi-Chi earthquake.

II. NON-STRUCTURAL WALL PERFORMANCE

In reinforced concrete buildings, heavy non-structural brick walls (24cm in thickness) or R.C. walls are often used as partitions between two adjacent residential units in order to avoid interference between the two residential units. Also, in Taiwan, one building is often used for both residential and commercial purposes. For low rise buildings, similar to condos or town houses, the ground story is used for commercial purposes and upper stories are used for residential purposes. For high-rise collective apartment buildings, the ground or lower stories are usually used for a lobby or a department store. Therefore, the number of walls on lower stories is much less than on upper stories. This creates a soft story effect. Unfortunately, in the past fifteen years, using ductile moment resistant frames to resist horizontal seismic loads has been favored by structural engineers in Taiwan for R.C. structures without considering the influence of heavy brick or R.C. walls. This situation creates serious problems in earthquakes. The following investigation shows how the soft story effect dramatically increases the moment and axial loads at certain columns.

To investigate a specific building structure, the commercialized computer program ETABS Version 6.2 was used. Linear static and dynamic analyses were performed (ETABS, 1997). However, in the analyses, the actual weight of the building was also considered in order to understand the wall effect on structural behavior more precisely. The Chi-Chi earthquake record (accelerograms) at the location close to the specific building with similar geological condition is chosen for the dynamic analyses. The structural damping ratio was assumed to be 0.05.

The building was 14 stories in height with a 2-story underground basement. The basement was used as a parking garage, the ground and first floors were used for commercial purposes and the second to fourteenth floors were used for residential purposes. The plan of the building with column number indicated is shown in Fig. 1. Fig. 1 also shows the locations of non-structural walls with ×'s. In the 921 Chi-Chi earthquake, the left two rows of columns (column Nos. 51~70) at the ground floor were crushed, and the non-structural walls above the first floor were found almost intact.

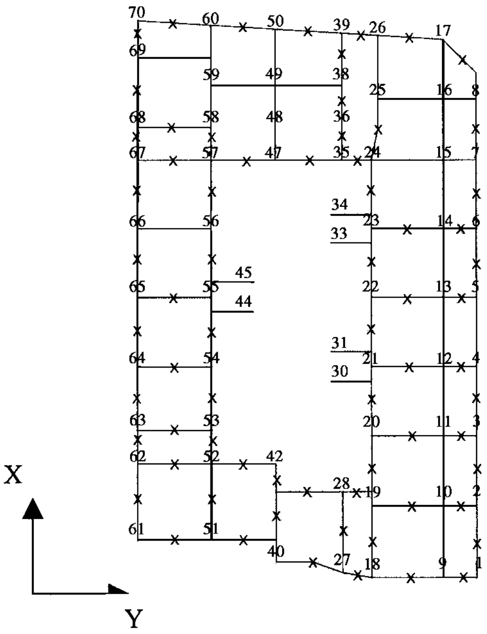
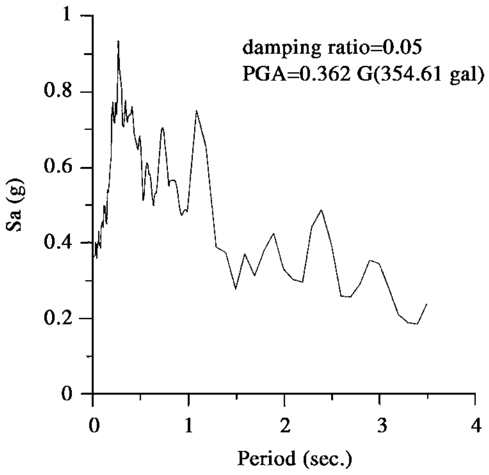
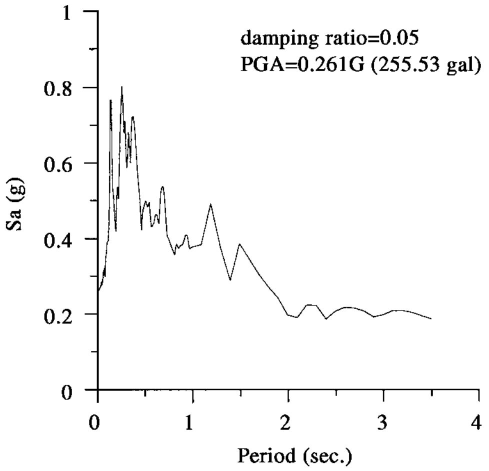


Fig. 1 The plane of building with column numbers and wall location (Marked with ×)

Three seismic analyses were performed in order to compare results in different conditions. The first was a quasi-static analysis with horizontal seismic loads according to the seismic provisions of the building code published in 1992 (code, 1992), which the design of the building was required to follow. In the code, the horizontal seismic force is calculated by the formula $V=ZKCIW$, where Z=0.8 for the seismicity zone of the region, K=1.0 for the structural type, C=0.143 for X-direction and C=0.129 for Y-direction which depend on structural first periods in X and Y directions respectively, I=1.0, and W is the weight of the structure. The second analysis was a dynamic time history analysis without considering the effect of non-structural walls. This is what the design practice usually assumes. The third analysis was also a dynamic time history analysis considering the stiffness effect of the non-structural walls above the first floor in order to obtain the influence of the soft story effect. The locations of non-structural walls are indicated in Fig. 1 with ×'s. The reason for simulating the building structure without non-structural wall at the ground level is that the number of walls at the ground floor is much smaller than the number of walls above the first floor and the walls at the ground floor mostly collapsed after the earthquake while the walls above the first floor were relatively intact. Although the existence of walls at ground level will stiffen the structure and induce larger seismic forces, this increase due to a decrease of the structural



(a) EW direction

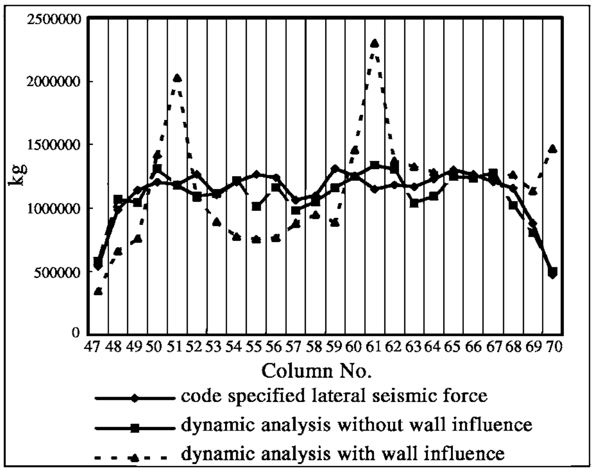


(b) NS direction

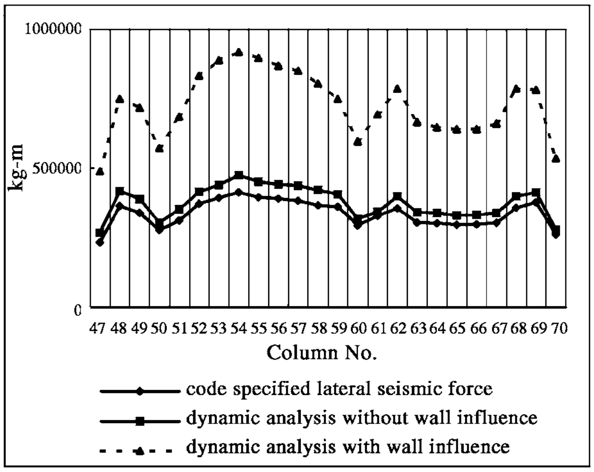
Fig. 2 Acceleration response spectra of free-field accelerograms recorded at chung-hshin university

period is usually insignificant (e.g. the decrease of structural period is less than 5% in this case), and most importantly, the walls will confine the columns and share a large part of the axial force due to seismic force. The input accelerogram used for our analysis was recorded near the building with similar characteristics and geological situation. The response spectrum of the accelerogram for EW and NS directions is shown in Figs. 2 (a) and (b). In order to reflect the real situation, both *X* and *Y* direction seismic forces were applied simultaneously. In the dynamic analysis, EW is the *Y*-direction and NS is the *X*-direction according to the orientation of the structure shown in Fig. 1.

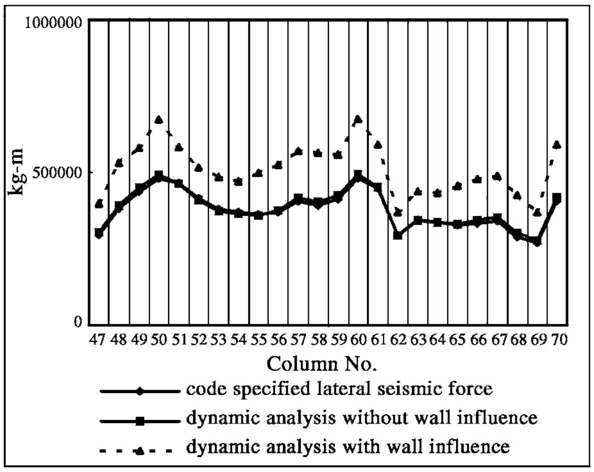
Figures 3 (a), (b), (c) show the comparisons of the results of the three analyses for columns 47~70 at the ground floor. From these figures, one can observe that the results due to the code specified lateral seismic force is similar to that due to the Chi-Chi earthquake, if one assumes the non-structural walls do not influence the dynamic behavior of the structure. This is because the distribution of horizontal



(a) Axial Force



(b) Moment in X-direction



(c) Moment in Y-Direction

Fig. 3 Comparison of three analyses

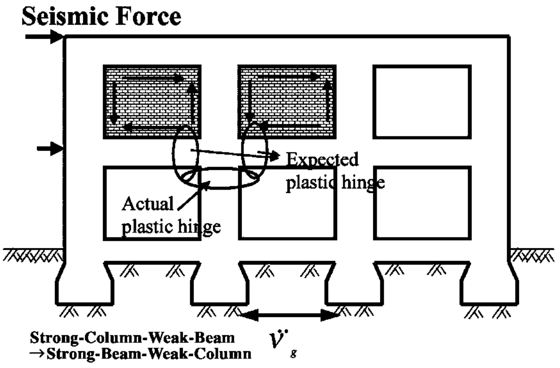


Fig. 4 Soft story effect

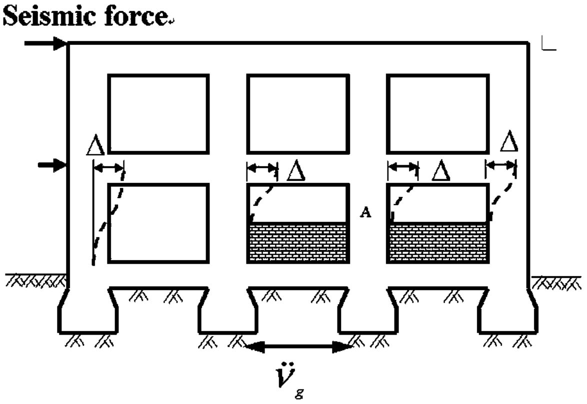


Fig. 5 Short column effect

seismic force to all the columns is similar for the dynamic analysis without the influence of non-structural walls and the quasi-static analysis without the influence of non-structural walls. This gives some evidence that if the walls did not influence the structural behavior, the structure would have withstood the Chi-Chi earthquake. However, if one takes the influence of non-structural walls into account, the results change dramatically as shown by the dashed-lines on these figures. From Figs. 3(b) and (c), one can see that the column moment is greatly increased (almost doubled) in both directions, if wall effects are taken into account. The reason for this phenomenon, is that the structure becomes more stiff if walls are considered. For this specific structure, if wall stiffness is considered, the periods (T) of the first and second modes of the structure are 0.77 sec. and 0.71 sec., respectively. The periods (T) are increased to 2.38 sec. and 2.12 sec., respectively, if wall effects are not considered. Referring to the response spectra of Figs. 2 (a) and (b), one can obtain much larger responses with T=0.77 sec. and 0.71 sec. respectively. Also, observing Fig. 3 (a) with reference to Fig. 1, one can see that the axial force at the external columns (or corner columns) increases dramatically and the axial forces in other interior columns do not change much, if the wall effect is considered. This occurs because the walls will act like shear panels and attract a larger share of horizontal seismic load in the story. This condition in turn will create huge axial forces in the adjacent columns in order to balance the overturning moment due to the shear in wall, and this axial force will be transmitted down to the ground floor column without distributing to other frames or columns as shown in Fig. 4. This is the reason why the axial forces in Column Nos. 51 and 61 are so large, as shown in Fig. 3(a). For interior columns having walls at both sides, these increases of axial force will cancel out each other. This axial force may create a problem for exterior columns, since the ductility of a column with a large axial force (gravity load plus earthquake load) will be difficult to be taken into account in design practice.

From the analyses above, one can conclude that the soft story effect will not only increase the total seismic horizontal load, which will induce huge moments in the columns, but also could increase the axial force in some columns. This situation will create very serious problems for columns. Also, as shown in Fig. 4, the design philosophy for the earthquake resistant frames should be strong-column-weak-beam design. The first reason for this philosophy is that it is much easier to design a beam with high ductility, since the axial force in beams is very small and no P–Δ effect occurs in beams. The second reason is that the failures of beams would not create a catastrophic situation. However, from Fig. 4, we can conclude that the plastic hinge will occur at the column first, since the beams have been strengthened by the walls. This means the strong-column-weak-beam design breaks down and the actual structural behavior is strong-beam-weak-column.

Also, another situation causing column failure by non-structural walls is the well-known short-column effect. The short-column situation, as shown in Fig. 5, is created by large window openings. In the Chi-Chi earthquake, a lot of column failure was observed due to the short column effect, especially for the columns in school buildings. Referring to Fig. 5, the short column effect causes column failure in two ways. The first is the well-known reason in which the shorter columns have a large stiffness compared to the longer columns in the same story as Fig. 5 indicated. This situation will increase shear and moment in the shorter columns. The second reason is that point A in Fig. 5 is located at the middle part of the column which needs less tie reinforcement in the original design. But, if the short column effect is included, point A should be at the end part of the column which needs more tie reinforcement to confine the concrete core and to increase the ability to resist the shear force as specified in the building code. Therefore, shear cracks of × pattern are observed quite commonly in the region close to point A in short columns in the Chi-Chi earthquake.

III. CONCLUDING REMARKS AND SUGGESTIONS

In the Chi-Chi earthquake, one interesting scenario is observed. Most collapsed buildings with the loss of one or two stories had walls comparatively intact at the unfailed stories, while a lot of buildings with severe damage to the non-structural walls (including the walls in upper stories) were intact. This means that the building structures that lost all the walls act more in accord with design expectations. Therefore, structural failure during a strong earthquake may not be expected, if most of the walls are severely damaged first.

After a thorough tour of the earthquake stricken area and some analysis of failed buildings, it seems that non-structural walls change the structural behavior dramatically during strong earthquakes. However, the wall effect is always neglected in structural design practice, and the research on the interaction of walls and frames is sometimes ignored just as if the effect did not exist. Therefore, the design industry at present should avoid the combination of heavy walls with ductile moment resistant frames. In academic, more research should be focused on nonlinear interaction behavior of brick walls and frames. This research should be directed at both experimental and theoretical aspects, and research on seismic retrofits of existing wall-frame structures should also be done in order to determine how to improve the earthquake resistant ability of existing structures.

REFERENCES

1. Computer & Structures Inc., 1997, ETABS Version 6.2.
2. Ministry of the Interior, 1992, Code and Specification for Building Design and Construction in Taiwan.

Manuscript Received: Sep. 20, 2000
Revision Received: Jun. 25, 2001
and Accepted: Aug. 14, 2001

集集大地震非結構牆對構架之影響

劉俊秀　邱奕峰　鄭復平

交通大學土木工程學系

摘　要

本文旨在探討於1999年9月21日集集大地震中部分房屋結構之破壞模式。其中主要是先經由現地勘查，然後再輔以線性靜力與動力分析，藉由分析之結果驗證現地勘查之結果。而在這些勘查與分析後，吾人發現非結構牆對韌性構架之結構行爲影響甚鉅，因此結構設計者應注意非結構牆對韌性架構之影響。同時，學界也應仔細研究非結構牆與構架間之互制行爲及研究如何補強現有之具有非結構牆之構架以作爲將來之參考。

關鍵詞：非結構牆，地震分析，集集大地震，韌性構架。