Seismic Vulnerability Assessment Method of Low-Rise RC Buildings With Masonry Infill

後積み組積造壁を有する低層 RC 造建物の耐震診断法

ハモード　アルワシャリ（リハビリテーション工学分野）
Hamood ALWASHALI

Abstract:

後積組積造壁を有する鉄筋コンクリート造骨組の耐震性能評価を行った。まず，既往の基準を用いた調査として，ヨルダンに実際に立地する建物に対し，日本の耐震診断基準及び米国の耐震診断基準である ASCE31 を用いて耐震性能評価を行い，両者について比較した。続いて，後積組積造建物の簡便な耐震性能評価法を提案した。本手法は，志賀マップを後積組積造建物に適用可能にするため，複数の建物モデルに対して解析を行い，これらの建物モデルの被害との関係を図示した。

Keywords ： *Seismic Evaluation, Masonry infill walls, Existing RC Buildings, Buildings in Jordan.*
耐震診断，後積み組積造壁，ヨルダンの鉄筋コンクリート建物，

1. Introduction:

RC buildings with masonry infill are a common practice in many developing countries. Poor performance of RC buildings with masonry infill was noticed in many earthquakes, recently in China 2008 Wenchuan earthquake and Haiti earthquake 2010.The performance of these buildings could be improved by special detailing of frames, strengthen walls by reinforcement and other retrofitting techniques. However, the problem is that existing buildings makes a huge considerable number therefore seismic evaluation method is necessary to screen vulnerable buildings.

The main objective of this study is to evaluate seismic capacity of RC buildings with masonry infill using existing seismic evaluation methods and to propose a simpler and more practical method that could be used in developing countries. To make this study more realistic, existing RC buildings with masonry infill walls in Jordan is taken as an example.

2. Investigation of existing seismic evaluation methods

This part (chapter 2 in Thesis) takes buildings in Jordan as a case study and the ASCE (ASCE31, 2003) and Japanese (JBDPA 2001b) methods will be applied to selected existing buildings. The ASCE method and Japanese method were chosen because they are the most well known evaluation methods.

Jordan is a Middle East country located along the seismically active Dead Sea Transform Fault that extends 1000 km from the Red Sea to Turkey (see figure 1). The seismicity in Jordan is thought to be moderate. Current estimates predict a major earthquake in the region roughly every 200 years.

Fig. 1 Location of Jordan and Dead Sea fault

RC structures with masonry infill walls are widely used in Jordan. The exterior infill walls are of thickness 300~350 mm and are composed usually of 3 layers; stone facing, plain concrete and in some cases hollow concrete blocks.. These walls are bounded by weak RC frames. It is not until 2005 that a seismic code for buildings based on UBC code 1997 was implemented. Existing buildings have not experienced a major earthquake recently therefore the seismic performance of buildings in Jordan is still an unclear.

8 existing buildings are chosen with different floor areas and stories ranging 1~4 . The 1st story of the 8

selected buildings is checked using both methods.

2.1 Results:

7 of the 8 building in failed using both the second screening of JBDPA method and the Tier 1 of ASCE 31 method. An exception is building No. 7 which only a 1 story building. Comparison of results between the two standards is shown in Fig. 2. The results are normalized by the criteria standard of both standards which Is index of 0.6 in JBDPA and 0.48 Mpa (70 psi) in the ASCE 31 standard.

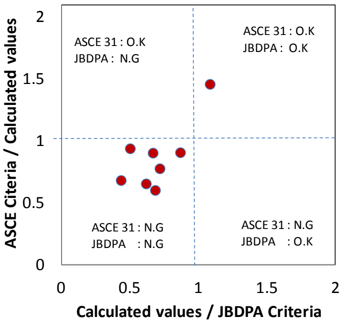


Fig. 2 Comparison of results of ASCE 31 and JBDPA standard

From the results of previous section, it appears that almost all buildings are unsafe and the government should start screening and seismic retrofitting plans. Professional engineers and the time needed to seismically evaluate a whole city will be of a high cost. In addition, if almost all buildings are considered unsafe then the possible action of the Jordan government and people is no action because building a new city seems much easier. From the above points it is concluded that a simple, low cost and fast seismic screening method is needed as a first screening method.

3. Proposal of seismic evaluation method:

The original concept of the method proposed in this study is not new and was introduced first by Shiga (Shiga 1968) for the Japanese buildings. The Shiga map screens the buildings into zones with different vulnerability levels according to 3 parameters: column sectional area, wall sectional area and floor area. The seismic capacity could be checked easily using only these 3 parameters. However, the problem is that the Shiga`s method is only applicable to its region because of different seismicity level, material properties and structural details. Actual earthquake damage data is needed to construct Shiga map. As for countries with infrequent earthquakes damage data is usually unavailable. Waiting for an earthquake to construct such method is not an option.

The proposed method is a recalibration of Shiga`s method to be suitable to RC buildings with infill walls in different seismic regions. A Case study of RC buildings with masonry infill walls in Jordan is presented as an example.

3.1 Flowchart of the proposed method:

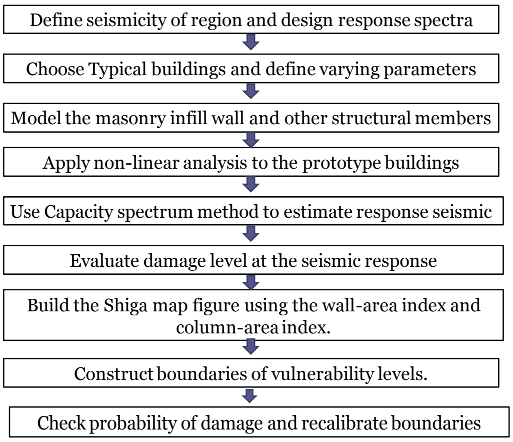


Fig. 3 Flowchart of the proposed method

A brief explanation of each step of the proposed method is presented here, for more details refer to the main thesis.

3.2 Define seismicity of Jordan:

Different regions have different seismicity levels in Jordan. In this study, two design response spectra of the region of the main cities in Jordan are considered. The design response spectrum for seismic zone 2B and two soil types for soil type S_B (rock) and soil type S_c (very dense soil and soft rock) are shown in Fig. 4.

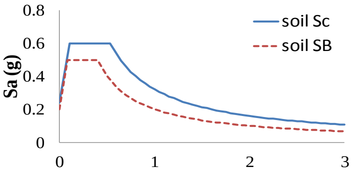


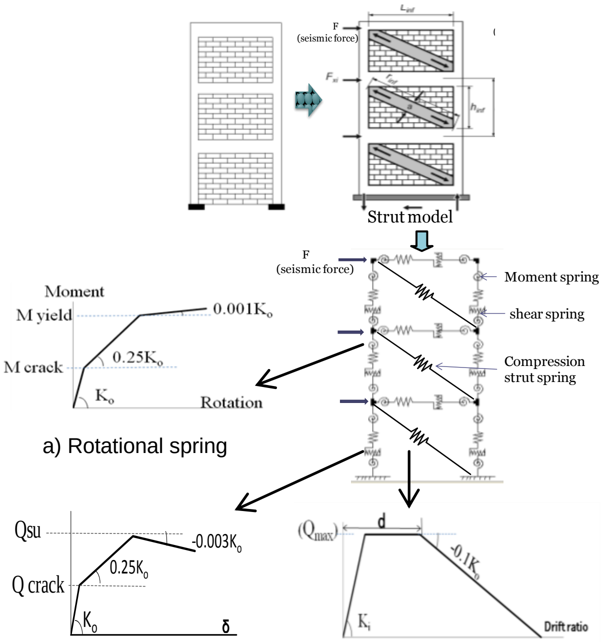
Fig. 4 Design response spectra for zone 2B and two soil types

3.3 Prototype buildings:

3 prototype buildings with different floor areas were used for analysis. Different cases were assumed for each building, assuming number of stories ranging from 1 till 4 stories and varying the places and number of masonry infill walls. Since exterior facings of buildings have usually many opening, exterior infill walls with opening of $1m^2$ in each wall were assumed.

3.4 Modeling of structure

A two-dimensional pushover analysis using computer program SNAP and a mathematical model shown in figure 5 is carried out. Beams and columns are idealized by two nonlinear rotational springs at their ends, a nonlinear shear spring in the middle and a linear axial spring, shown in figure 5a) and 5b). The infill wall is modeled as an equivalent diagonal compression strut and figure 5c) shows its backbone curve. The d value shown in the figure 5c) is taken using Table 7-9 in (FEMA 2000) for assumed ratio of frame to infill strengths ≤ 0.7 (the frame is assumed to have smaller strength compared to the infill panel). The influence of openings to the stiffness and strength of masonry infill walls were considered.



a) Rotational spring

b) Shear spring of columns c) Strut spring back bone

Fig. 5 Mathematical model used for non-linear analysis

3.5 Seismic response and damage evaluation:

The seismic response of the structure is calculated using methodology for calculating target displacement given in (FEMA 2000).

The damage evaluation is judged by approximating the amount and level of damage in the infill walls and columns in the first and second story of each building at the seismic response displacement given by the pushover analysis. In figure 6 a suggested figure for damage evaluation of masonry infill wall is proposed. This proposed damage evaluation figure were compared to experimental test carried by other researchers and had quite well agreement with some conservativeness.

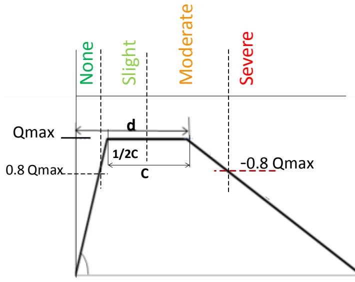


Figure 6 Proposed damage states of masonry infill

3.6 Shiga`s map and boundaries of vulnerability levels:

The Column index, Wall index (WI) and damage expected of each building using response spectra of Soil Sc are shown in figure 7.

The Column index, CI, is percentage ratio of the cross sectional area of columns in 1st story to the total floors area of the prototype buildings. The Wall index, WI_{inf}, is the percentage ratio of the cross sectional area of infill walls (the length of the openings in infill walls are deducted from the total infill length) of the total of 1st floor to the total floors area of the prototype buildings. Vulnerability Zones are divided into 3 zones, for which zone A is the most vulnerable and zone C is the least.

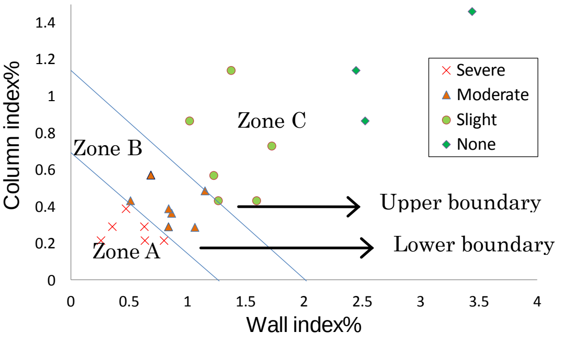


Fig.7 Proposed evaluation map for Jordan`s zone 2B &Soil S_c

Thinking of results as capacity provided by the building versus seismic demand by earthquake, then capacity is thought to be provided by columns and infill walls strength, which is product of the shear stress and cross sectional area of columns and walls shown of the left side of Eq (1).

$$\text{Capacity} \geq \text{Demand}$$

$$\tau_c . A_C+\tau_w . A_W \geq W. C_a .D_s \qquad (1)$$

Where A_c: is the area of columns(mm²), τ_c : is the shear strength of columns (N/mm²), A_w: is the area of masonry infill (mm²), τ_w : is the shear strength of masonry infill walls (N/mm²) , W: is total weight of building, Ca: response acceleration coefficient of earthquake. Total weight of the buildings (W) is the product of total area of floors (A_f) and average weight per unit area. Taking 13 kN/m² as the average weight per unit area, assuming reduction factor Ds=1 and response acceleration coefficient C_a for Soil S_C spectra for buildings with short periods (low-rise buildings) is 0.6g. Therefore:

$$\tau_c \cdot CI+\tau_w \cdot WI_{inf} \geq 0.78 \text{ N/mm}^2 \qquad (2)$$

The column shear strength τ_c and Wall shear strength τ_w of lower boundary is :

$$1\text{N/mm}^2 \cdot CI+0.6\text{N/mm}^2 \cdot WI_{inf} \geq 0.78 \text{ N/mm}^2 \qquad (3)$$

The Eq(2) is constructed for response spectra of seismic zone 2B-soil Sc. Similar equations are proposed for response spectra of Soil S_B .

4. Probability of damage:

The probability of damage of each case in figure 7 is investigated using the fragility curves of RC buildings with masonry infill suggested by HAZUS. The probability of severe damage are shown in figure 8 where x-axis represents the seismic capacity of building calculated using the column shear strength τ_c and Wall shear strength τ_w shown for lower boundaries shown in Eq(3). The probability of severe damage for each building can be roughly estimated based on it Column index CI and Wall index WI_{inf}. For example if the seismic capacity of building is 0.78 N/mm², then the probability of severe damage is about 24%.

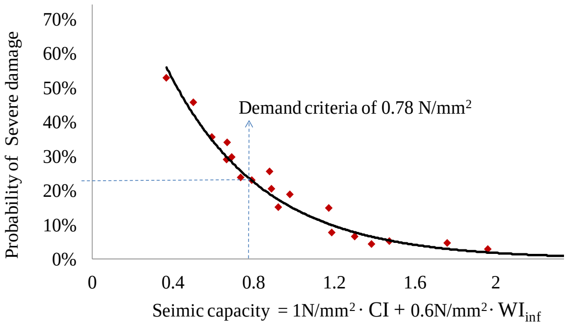


Fig. 8 Severe damage probability of the lower boundary

Figure 9 shows the relation between severe damage probability and amplification factor α of lower boundary, where seismic capacity of lower boundary:

$$= \alpha \cdot (1N/mm^2 \cdot CI + 0.6N/mm^2 \cdot WI_{inf}).$$

Based on the probability of damage in figure 9, the lower and upper boundaries could be modified based on the philosophy of the acceptable damage in the risk mitigation project and also based on the available resources for seismic evaluation and retrofit. For example if the acceptable severe damage is taken as 10%, then from figure 9 the appropriate α = 0.7. and the values of shear strength τ_c and Wall shear strength τ_w in Eq(3) is taken as 0.7N/mm² and 0.42 N/mm² ,respectively.

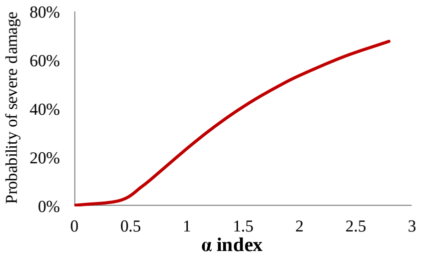


Fig. 9 Severe damage probability and amplification factor α

5. Comparison with earthquake damage:

There is no recent major earthquake in Jordan. The nearest country with earthquake damage data is Turkey. The proposed method are compared and plotted with data of damaged buildings by Erzincan earthquake 1992 in Turkey in figure 10. The damaged buildings data are collected by METU (Middle East Technical University) and AIJ and were mentioned by (Hasan1997). The boundaries from the proposed buildings showed good agreement with damage of the Erzincan`s buildings. However, the Erzincan`s response spectra (about 1g) is much larger than the response spectra in Jordan (about 0.6g). The difference of Damage states definition used in the proposed method and the damage building data are thought to be one of reasons for such agreement. In addition, short duration and few displacement cycles of large amplitudes in the Erzincan earthquake helped to show good performance and the degradation of masonry walls was not significance.

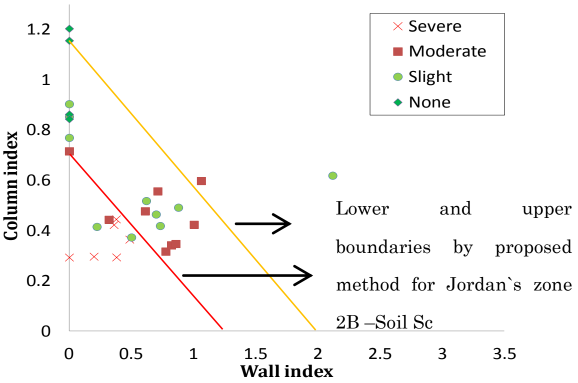


Fig. 10 Comparison of the proposed method with actual damage

Conclusion:

1) Selected existing buildings of Jordan were checked using the Japanese standard JBPDA and American standard ASCE 31. Almost all buildings failed using both methods.

2) Due to economical and time problems, a first screening method that is more practical and simple was introduced. The vulnerability boundaries of the method could be modified based on the probability of damage and budget of risk mitigation project.

3) Further improvements are needed in future research to increase accuracy, such as increasing the number of prototypes and varying parameters of buildings.

Reference:

American Society of Civil Engineers , *"Seismic Evaluation of Existing Buildings ASCE/SEI 31-03. "* Published in 2003.

(FEMA) (1999), HAZUS99 Technical Manual by Washington, DC,

Federal Emergency Management Agency (FEMA) (2000), *"Prestandard and Commentary for the Seismic Rehabilitation of Buildings,"*,

Japan Building Disaster Prevention Association (JBDPA). (2001b). "*Standard for Seismic Evaluation of Existing RC Buildings*".

Hassan, A.F., and. Sozen, M.A. "*Seismic Vulnerability Assessment of Low-Rise Buildings in Regions with Infrequent Earthquakes.*"ACI Structural Journal, Jan-Feb 1997;

Shiga, T., Shibata, A. and Takahashi, T., *"Earthquake Damage and Wall Index of Reinforced Concrete Buildings,"* Proceedings, Tohuku District Symposium, Architectural Institute of Japan, No. 12, Dec.1968.