A Proposal on the Simplified Structural Evaluation Method for Existing Reinforced Concrete Buildings with Infilled Brick Masonry Walls

Matsutaro Seki, Masaki Maeda and Hamood Al-Washali

Abstract The developing countries in the earthquake prone regions in the world are still suffering a lot of casualties as well as building damage. These damages might be caused by inadequate structural design by engineers and/or poor quality control of construction works. In order to contribute to disaster mitigation for existing reinforced concrete (RC) buildings in developing countries, the simplified structural evaluation method based on the philosophy of Japanese evaluation standard; JBDPA (The Japan building disaster prevention association. Standard for seismic evaluation of existing reinforced concrete buildings, 2001) vis-a-vis the international seismic code; IBC (International Code Council, Inc. International Building Code, 2000) was developed by Seki (J Earthq Sci Eng, 2015). However, this evaluation method doesn't consider the infilled brick masonry wall inside the beam and column. The usual RC building has many infilled brick masonry walls but these are not considered in the structural seismic design. They have the benefit in the strength capacity and the disadvantage in the brittle failure mode. For the structural evaluation of existing RC buildings, the consideration of the infilled brick masonry wall is quite important to get the actual behavior during the strong earthquake. The main objective of this study is to take the infilled brick masonry wall into the structural evaluation for the existing RC building in developing countries.

Keywords RC existing buildings · Developing country · Seismic index
Service load index

M. Seki (✉)
Building Research Institute, 1-Tachihara, Tsukuba, Ibaraki, Japan
e-mail: sekimatsutaro@yahoo.co.jp

M. Maeda · H. Al-Washali
Faculty of Architecture and Building Science, Graduate School of Engineering, Tohoku University, Aobayama 6-6-11, Aoba-Ku, Sendai, Japan
e-mail: maeda@archi.tohoku.ac.jp

H. Al-Washali
e-mail: Hamood@rcl.archi.tohoku.ac.jp

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1 Introduction

The proposed evaluation method is based on JBDPA (2001). The seismic index of structure Is shall be calculated by E_0, S_D and T at each story and in each principal horizontal direction of a building. The irregularity index S_D in the first level screening and the time index T may be used commonly for all stories and directions. The basic and most important structural index E_0 is calculated from C * F formula. The back ground of this formula is based on Blume et al. (1961). This proposed method of this paper is developed for the preliminary screening among buildings, so Is index is basically calculated by the structural and architectural drawings without in situ survey, then it corresponds to the first level screening procedure in JBDPA (2001) (Fig. 1).

2 Proposed Evaluation Method

2.1 Simplified Seismic Index: I_{SS}

$$I_{SS} = E_{SS} * S_{SD} * T_S \tag{1}$$

where,

E_{SS} Simplified structural index
E_{SS} Maximum values of following three index;

$$\begin{aligned} &\text{(i)}\ (C_{SSW} + 0.7 * C_{SSB}) * F_W \\ &\text{(ii)}\ C_{SSB} * F_B \\ &\text{(iii)}\ \surd(C_{SSW} * F_W)^2 + (C_{SSB} * F_B)^2 \end{aligned} \tag{2}$$

S_{SD} Simplified Irregularity Index (here assumed to be S_{SD} = 1.0)
T_S Simplified Time Index (here assumed to be T_S = 1.0).

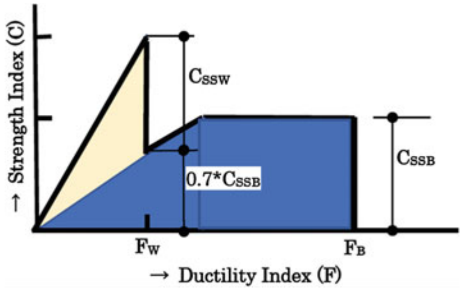

Fig. 1 Strength index (C) vs. ductility index (F) (JBDPA 2001)

2.1.1 C_{SSB} and C_{SSW} Index; Strength Index

(i) Bare frame

$$C_{SSB} = \tau_c * \Sigma A_C / W \tag{3}$$

where,

τ_c	Average shear strength of column (N/mm^2) (after JBDPA standard)
$h_0/D > 6$	$\tau_c = 0.7$ N/mm^2
$h_0/D \leqq 6$	$\tau_c = 1.0$ N/mm^2
h_0	Clear height of column (mm)
D	Depth of column section (mm)
ΣAc	Total area of columns (mm^2)
W	Total weight of building (N)

(ii) Frame with infilled brick wall

$$C_{SSW} = (2 * \tau_c * \Sigma A_C + \alpha * \tau_w * \Sigma A_w)/W \quad \text{(Commentary A)} \tag{4}$$

where,

τ_c	Average Shear Strength of Column (N/mm^2) (JBDPA 2001)
ΣA_c	Total area of culumns (mm^2)
τ_w	Averag shear strength of infilled brick wall (mm^2)
τ_w	0.2 N/mm^2
ΣA_w	Total area of walls (mm^2)
α	Opening reduction factor of infilled brick wall (BSAO 2007)
α	$1-\sqrt{\gamma}$ here, $\alpha \geqq 0.6$
γ	Opening factor defined in Fig. 2.

2.1.2 F_B and F_W Index; Ductility Index

$$\begin{aligned} F_B &= R_B/\Omega_{0B} \quad \text{(Commentary B)} \\ F_W &= R_W/\Omega_{0W} \end{aligned} \tag{5}$$

F_B	Ductility index of bare frame
F_W	Ductility index of frame with infilled brick wall
R_B	Response modification factor of frame
R_W	Response modification factor of infilled brick wall
	Based on the structural type: Defined in the concerned country's seismic design code.

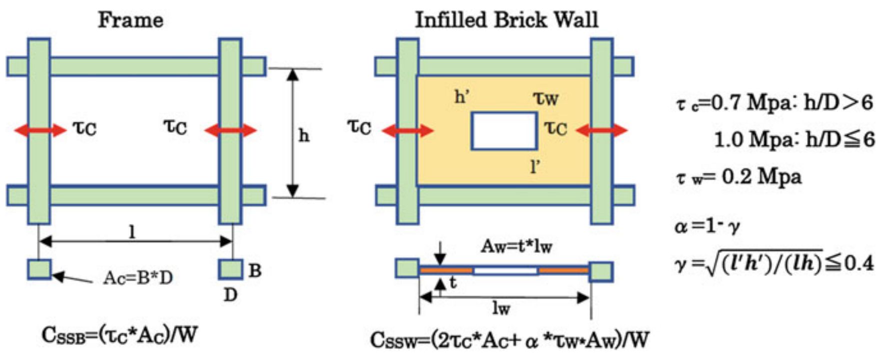

Fig. 2 Definition of C_{SSB} and C_{SSW}

Ω_{0B} Over strength factor of frame.
Ω_{0W} Over strength factor of infilled brick wall
Based on the structural type: Defined in the concerned country's seismic design code.

2.2 Simplified Service Load Index: I_{SD} (N/mm^2)

$$I_{SD} = W/\Sigma Ac \tag{6}$$

where,

W Total weight of building (N)
ΣA_C Total sectional area of columns (mm^2)
In case of infilled brick wall, Ac is the column's area except the brick wall area.

3 Judgment Index

3.1 Simplified Seismic Judgment Index: ISS0

$$I_{SS0} = S_{Da} * I_S \quad \text{(Commentary C)} \tag{7}$$

where,

I_{SS0} Simplified seismic judgement index
S_{Da} The design spectral response acceleration
I_S The occupancy importance factor.

3.2 Simplified Service Load Judgment Index: ISD0 (N/mm²)

$$
\begin{aligned}
I_{SD01} &= 0.4 * Fc \quad \text{(Commentary D)} \\
I_{SD02} &= 0.7 * Fc
\end{aligned} \tag{8}
$$

where,

Fc Designed concrete strength (N/mm²).

4 Judgment Method

4.1 Simplified Seismic Capacity

$$
\begin{aligned}
I_{SS} &\geqq I_{SS0} : \text{Higher than seismic capacity demand (SA)} \\
0.5I_{SS0} \leqq I_{SS} &< I_{SS0} : \text{Lower than seismic capacity demand (SB)} \\
I_{SS} &< 0.5I_{SS0} : \text{Remarkably lower than seismic capacity demand (SC)}
\end{aligned} \tag{9}
$$

4.2 Simplified Service Load Capacity

$$
\begin{aligned}
I_{SD} &< I_{SD01} : \text{Higher than service load capacity demand (DA)} \\
I_{SD01} \leqq I_{SD} &\leqq I_{SD02} : \text{Lower than service load capacity demand (DB)} \\
I_{SD02} &< I_{SD} : \text{Remarkably lower than service load capacity demand (DC)}
\end{aligned} \tag{10}
$$

4.3 Final Rank Based on Combination of Seismic Capacity and Service Load Capacity

Final structural rank based on combination of seismic capacity and dead load capacity can be obtained as following Table 1.

Table 1 Final capacity rank of simplified structural evaluation

Final capacity rank	Combination of seismic capacity and service load capacity	Recommendation
A	SA-DA	Safe
B	SA-DB, SB-DA, SB-DB	Detail evaluation recommended
C	SA-DC, SB-DC, SC-DA, SC-DB, SC-DC	Immediately detail evaluation recommended

5 Commentary

5.1 Commentary A

5.1.1 Strength Index of Frame with Infilled Brick Wall

$$C_{SSW} = (2 * \tau_c * \Sigma A_C + \alpha * \tau_w * \Sigma A_w)/W \quad (11)$$

where,

τ_c Average shear strength of column (N/mm^2) (JBDPA 2001)
ΣA_c Total area of culumns (mm^2)
τ_w Averag shear strength of infilled brick wall (mm^2)
τ w = 0.2 N/mm^2
ΣA_w Total area of walls (mm^2)

The shear strength of infill panel (τ_w) was assumed as 0.2 MPa in Fig. 3. As this estimation procedure is basically performed by structural and architectural drawing, in-site material test is not carried out, therefore the minimum and conservative value was decided based on the various research works and seismic codes. The shear strengths in terms of the prism strength (fm) presented by AlWashali et al. (2017) and Sudhir et al. (2014) are shown for the comparison. In case of the strength less than 5 MPa, the proposed 0.2 MPa of shear strength might overestimates the real shear strength of infill wall panel.

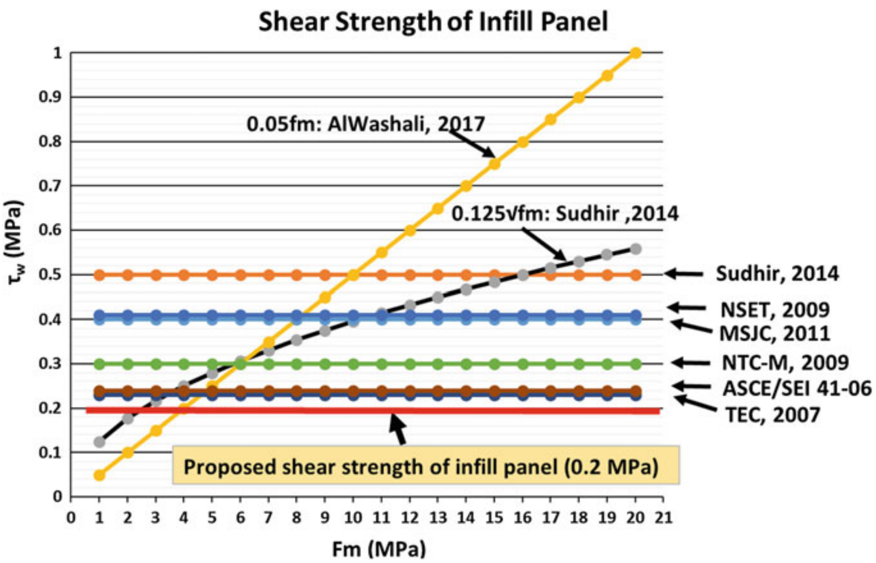

Fig. 3 The shear strength of infill panel (τ_w)

5.1.2 Opening Reduction Factor (α) (BSAO 2007)

$\alpha = 1-\gamma$; (here, $\alpha \geqq 0.6$)
$\gamma = \sqrt{(\text{area of opening})/(\text{area of infilled brick masonry wall})}$, (here, $\gamma \leqq 0.4$).

Figure 4 shows the comparison of opening reduction factor between BSAO (2007) and AlWashali et al. (2017). α factor in vertical axis is defined by BSAO (2007) and λ_{OP} factor of horizontal axis is defined by AlWashali et al. (2017). The factor of BSAO (2007) is more conservative than experimental data. According to the experimental data, the effective zone of resisting seismic zone by BSAO (2007) should be less than 0.6. There are many types of infill wall as shown in Fig. 5, therefore this factor's evaluation needs more discussion.

5.2 *Commentary B*

The relation of lateral seismic force V and lateral deformation (drift) Δ is shown in Fig. 6. Also response modification coefficient R, system over strength factor Ω_0 and deflection amplification factor Cd are shown. These values for the reinforced concrete frame defined in IBC (2000) are shown Table 2. In case of infilled wall frame, ordinary reinforced masonry shear walls (E) may be recommended in Table 2.

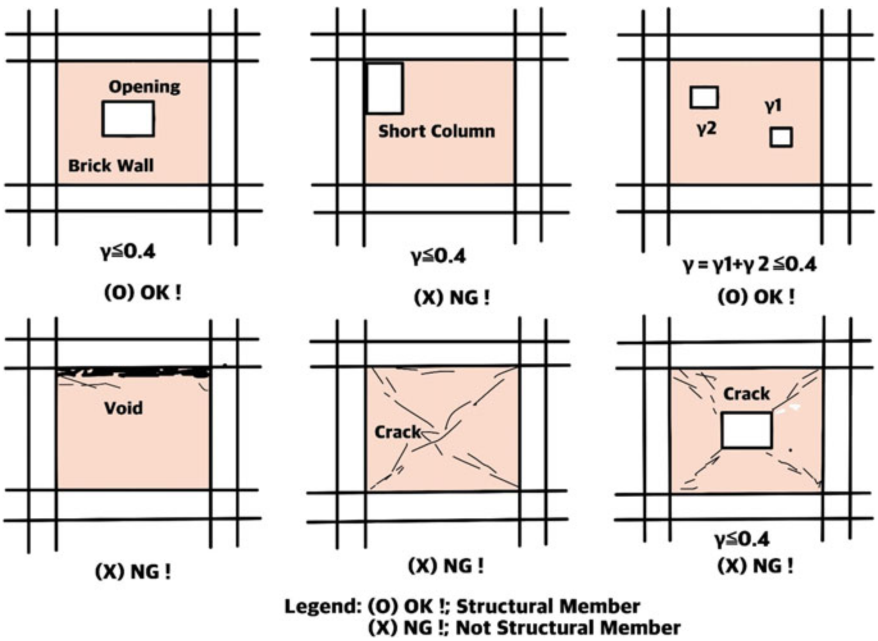

Fig. 4 Reduction factor of shear strength of infilled panel

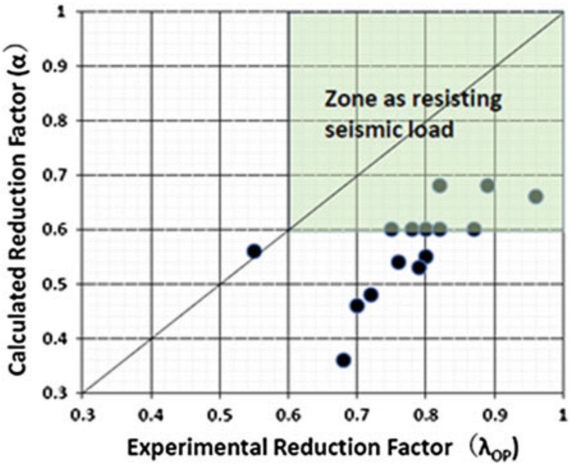

Fig. 5 Various type of the frame with infilled brick wall

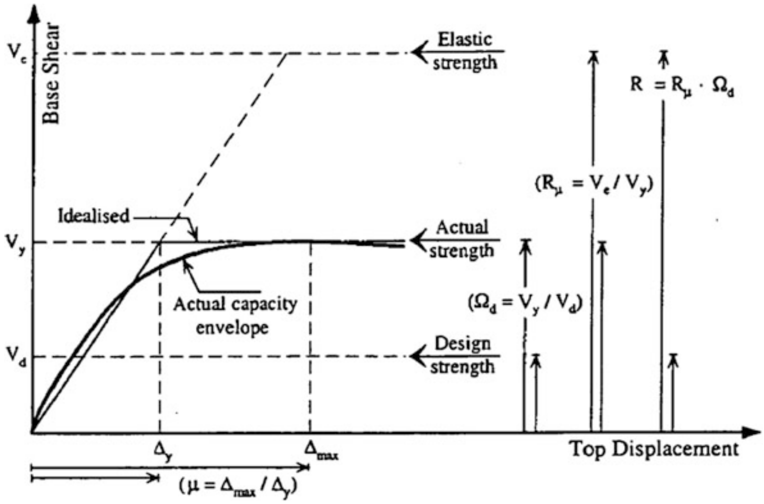

Fig. 6 Relationships between response modification coefficient R and structural over strength factor Ω_d and ductility reduction factor R_μ (Mwafy 2002)

For the seismic evaluation, as Japanese standard JBDPA (2001) is based on the inelastic behavior, ultimate inelastic lateral deformation should be defined. In Fig. 7 the relationships between R factor and Fs factor based on IBC (2000) is shown. R is reduction factor which is the same as ductility factor for elastic design and Fs is the ductility factor for inelastic design. In this proposed simplified seismic evaluation Fs should be used. The relationship between R and Fs can be obtained as Formula 12.

Table 2 Design coefficients and factors for basic seismic-force-resisting system for reinforced concrete moment frames (IBC 2000) (extract)

Basic seismic—force—resisting system	Response modification coefficient (R)	System over strength factor (Ω_0)	Deflection amplification factor (Cd)
Special reinforced concrete moment frames	8	3	5 1/2
Intermediate reinforced concrete moment frames	5	3	4 1/2
Ordinary reinforced concrete moment frames	3	3	2 1/2
Dual system with special moment frames			
E. Special reinforced concrete shear walls	8	2 1/2	6 1/2
L. Special reinforced masonry shear walls	7	3	6 1/2
M. Intermediate reinforced masonry shear walls	6 1/2	3	5 1/2
Dual system with intermediate moment frames			
D. Ordinary reinforced concrete shear walls	5 1/2	2 1/2	4 1/2
E. Ordinary reinforced masonry shear walls	3	3	2 1/2
F. Intermediate reinforced masonry shear walls	5	3	4 1/2

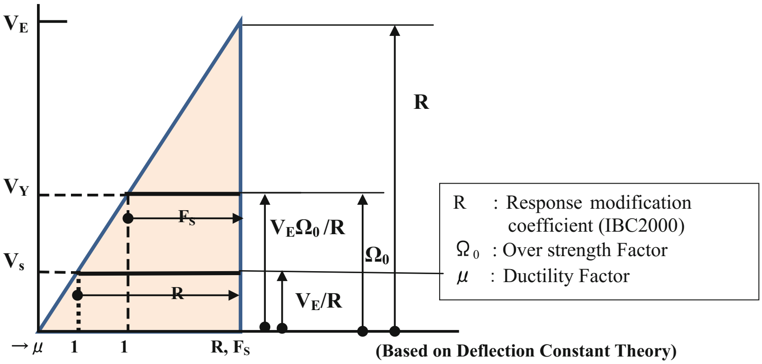

Fig. 7 Response acceleration (v)—ductility index (F_S) relations (IBC 2000)

From Fig. 7, ductility index F_S can be obtained by the following relationships;

$$
\begin{aligned}
V_Y/V_E &= 1/\mu \\
\therefore V_Y &= V_S * \Omega_0 = \Omega_0 * V_E/R \\
\therefore V_Y/V_E &= 1/\mu = \Omega_0/R \\
\therefore \mu &= Fs = R/\Omega_0
\end{aligned}
\tag{12}
$$

5.3 Commentary C

The design base shear coefficient S_{Da} in Eq. (7) is usually calculated by the design spectral response acceleration based on the characteristic of building, site soil condition, seismic intensity corresponding to the seismic zone and the occupancy importance factor, etc. These values will be decided considering the concerned country's seismic design code.

5.4 Commentary D

Simplified dead load judgment index I_{SD0} is defined as I_{SD01} is 0.4 * Fc (N/mm^2) based on the JBDPA (2001). From this standard, in the region above 0.4 N_S/(bDF_C), the ultimate horizontal deflection angle remarkably decrease and is defined as 0.005 of quite small value. In this evaluation method, as for critical limited value I_{SD01} for the service load judgment of column is assumed as 0.4 N_S/(bDF_C) and as for the most critical value I_{SD02} is assumed as 0.7 N_S/(bDF_C), respectively.

6 Conclusions

In this paper, a simplified seismic evaluation method based on the structural and architectural drawings was discussed and proposed for utilizing to the preliminary screening stage for the developing countries. The target building is the reinforced concrete moment resisting frame building with infilled brick walls. Seismic evaluation is basically based on the philosophy of The Japan Building Disaster Prevention Association (JBDPA 2001) and International Building Code 2000 (IBC 2000). This evaluation method will be discussed for applying to more advanced in situ simplified evaluation.

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