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

**June 2017**

**Building Research Institute, Japan**

**Matsutaro Seki**

# Objective

1. The simplified structural evaluation method based on the philosophy of Japanese evaluation standard; JBDPA (2001) vis-a-vis the international seismic code; ASCE 7-05 was developed by Seki (2015).

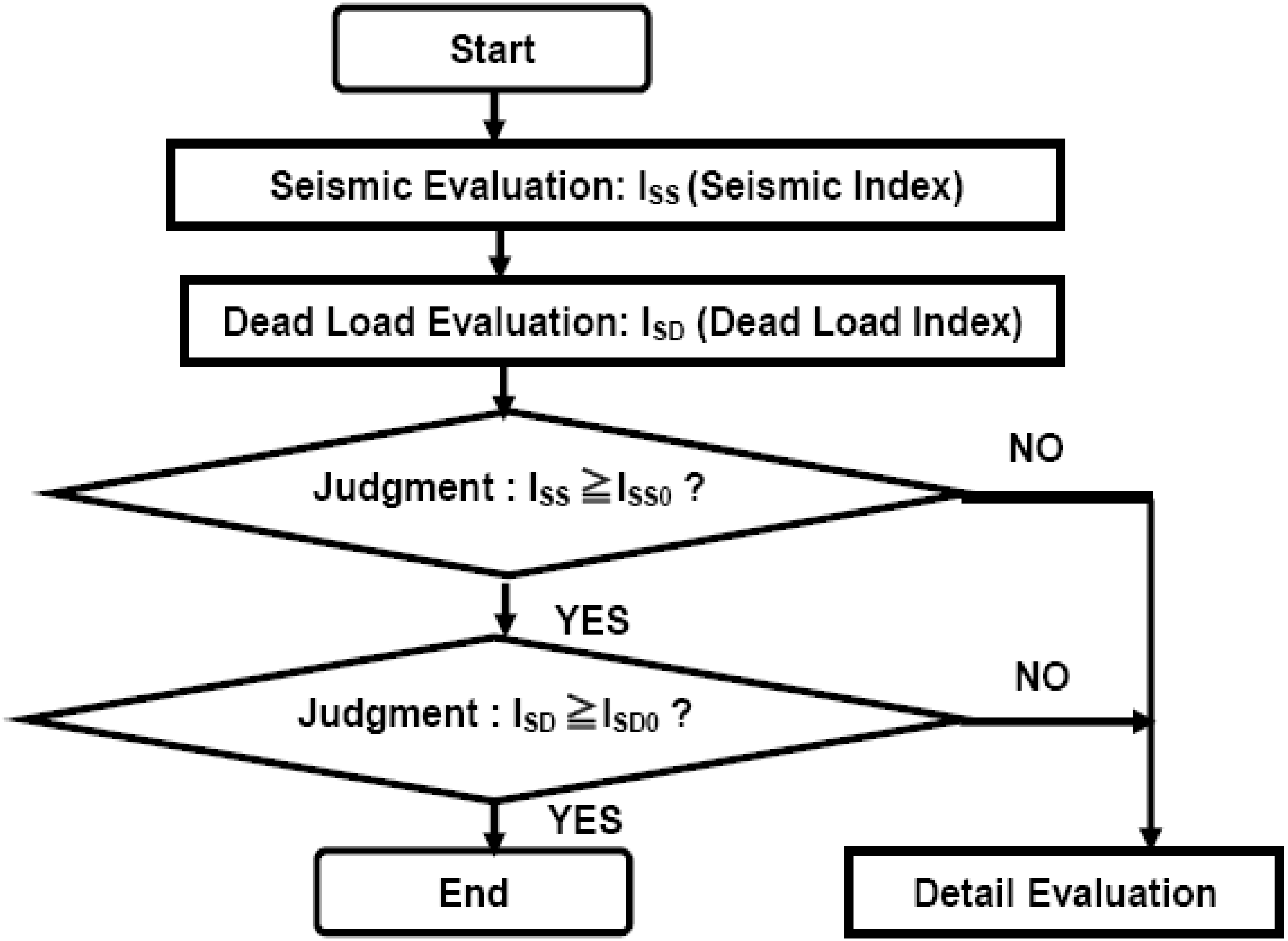
2. However,  this evaluation method doesn’t consider the infilled brick masonry wall inside the beam and column.

3. The main objective of this study is to take the infilled brick masonry wall into the structural evaluation for the existing RC buildings in developing countries.

# Structural evaluation procedure for existing reinforced concrete buildings

CNCRP JICA Project in Bangladesh

| Evaluation Method | Simplified structural evaluation | Advanced simplified structural evaluation | Detail structural evaluation |
| --- | --- | --- | --- |
| Objective | Average ultimate capacity for lots of buildings (Screening) | Between Simplified structural evaluation and Detail structural evaluation(Screening) | Ultimate capacity for individual building |
| Resource data | Structural drawing | Structural drawing & brief site investigation (Non-destructive tests) | Structural drawing & detail site investigation (destructive tests) |
| References | Seki(2015) [1], Seki(2015) [7] | | Public Works Department (2011-2015)[3] |




**Flow Diagram of Simplified Structural Evaluation for Existing Reinforced Concrete Buildings**

Seki M. ,2CNISS & 6CNIS, 2017 14-15, June , Bucharest Romania

2001Revised version

## Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings, 2001


2001

The Japan Building Disaster Prevention Association (JBDPA)

# JBDA Seismic Evaluation of Existing RC buildings in Japan

JBDA: Japan Building Disaster Prevention Association

$$I_s = E_o * S_D * T \quad (1)$$

Where,

$E_o$ : Basic seismic index of structure

$S_D$ : Irregularity index

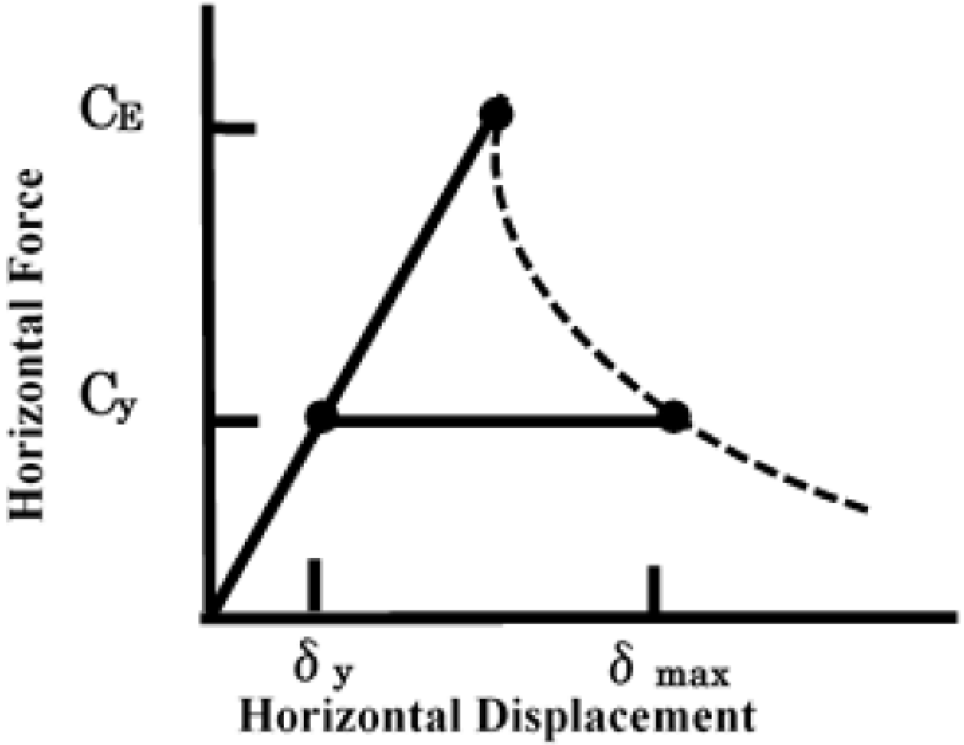
$T$ : Time index

$$E_o = C * F \quad (2)$$

Where,

$C$ : Strength capacity index

$F$ : Ductility index




$C_E$: Maximum elastic response force

$C_y$: Yielding force

$\mu=\delta_{max}/\delta_y$: Ductility factor

$C_y/C_E=1/\sqrt{2\mu-1}$

**Concept of prediction of nonlinear earthquake response after J.A. Blume, N.M. Newmark, and L.H. Corning**

# Basic seismic index *Eo*

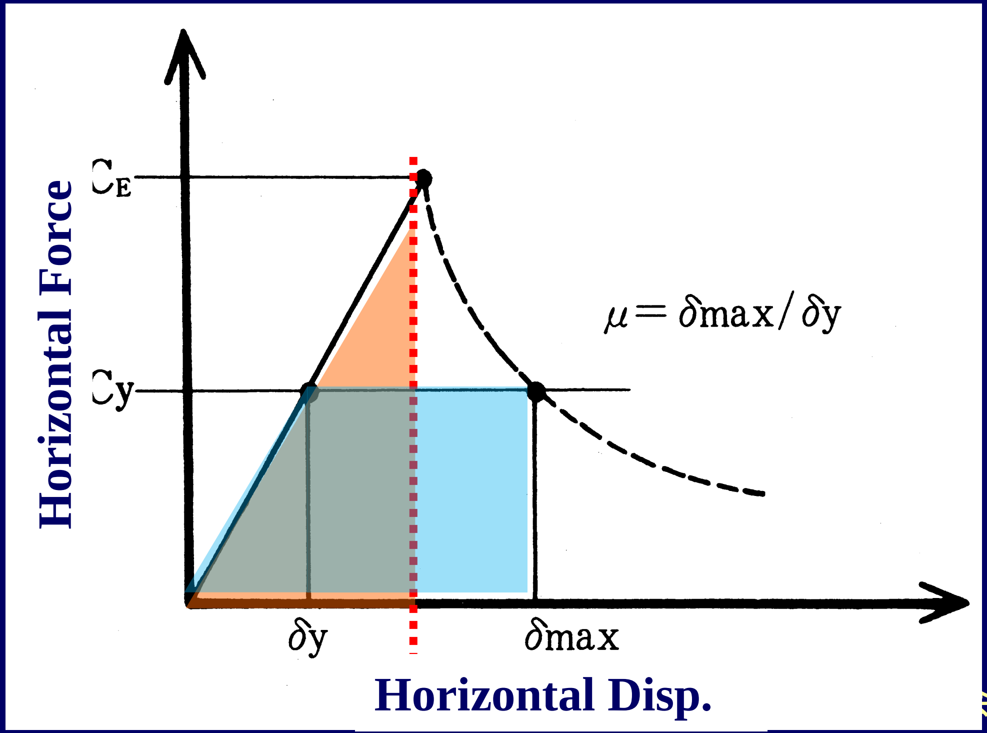
$Is = Eo \times S_D \times T$

$Eo = C \times F$

- Basic seismic index: *Eo*

$$Eo = C \text{ [strength index]} \times F \text{ [ductility index]}$$

$$cf. \quad Ce = Cy \times \sqrt{2\mu - 1}$$

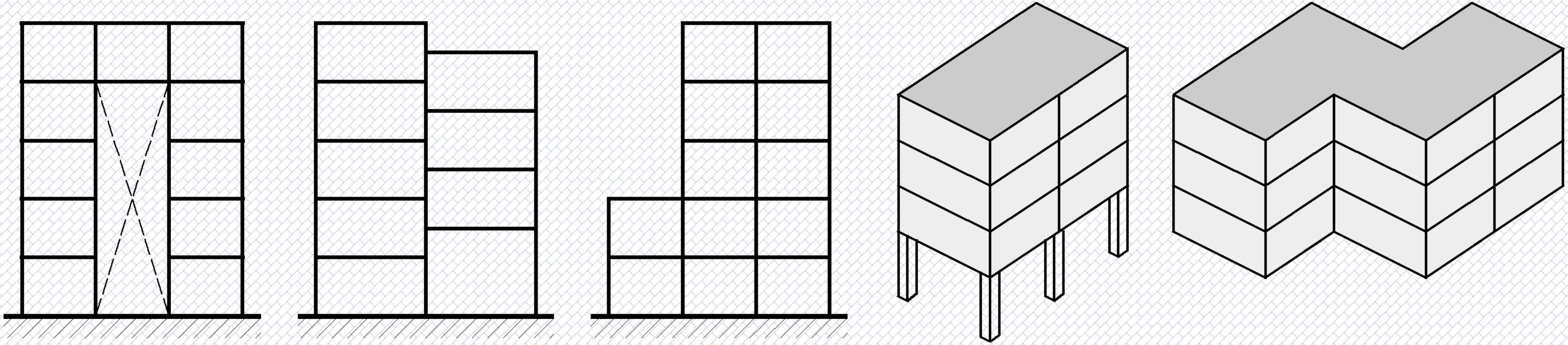



Newmark:

Energy constant theory

JBDPA seminar note

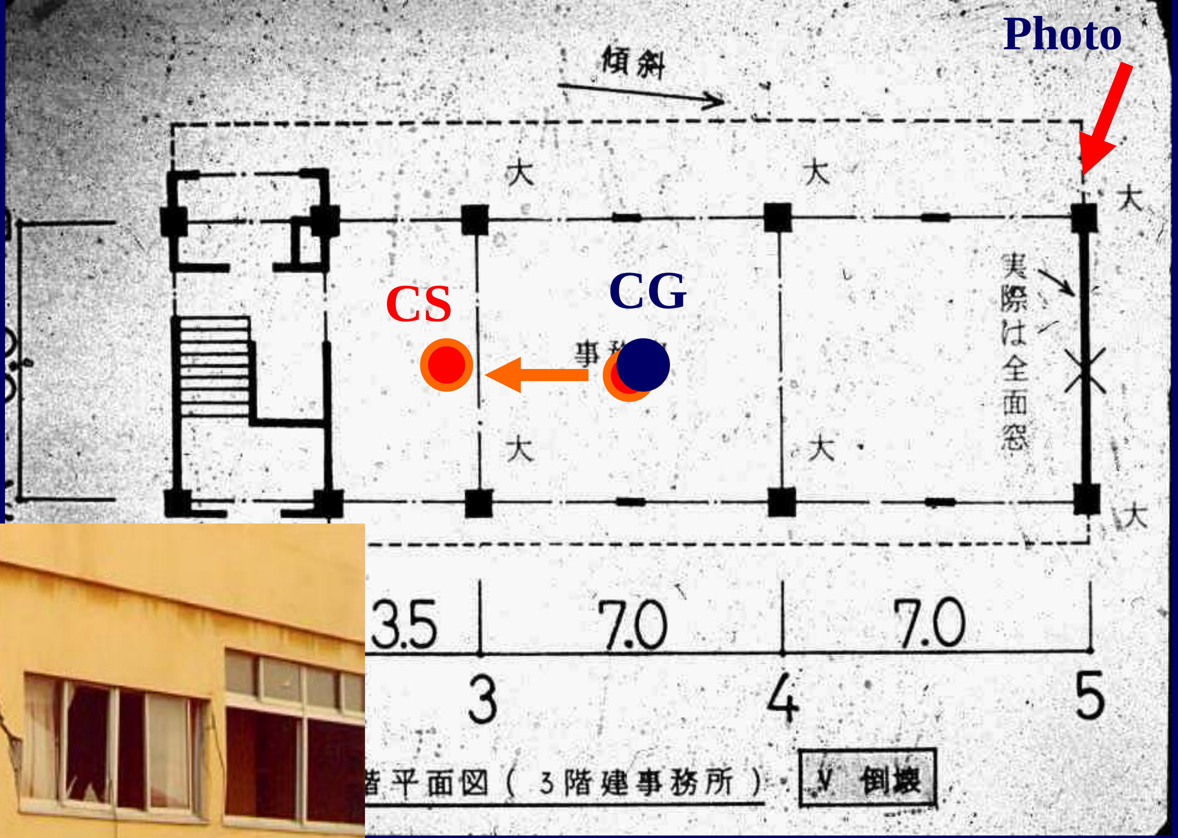
# $S_D$ index



Wellhole style    Different level    Setback    Piloti    Irregular shape

## Irregularity of existing building

# 1978 Miyagiken- oki EQ.

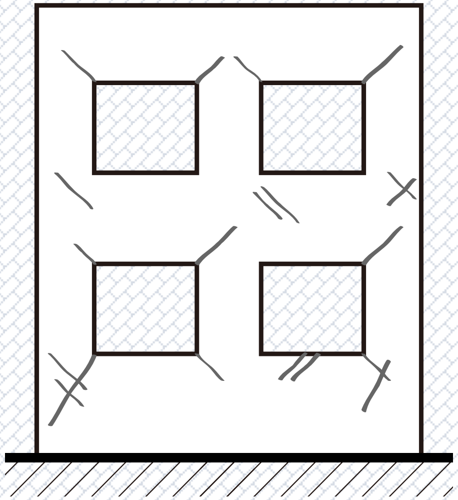




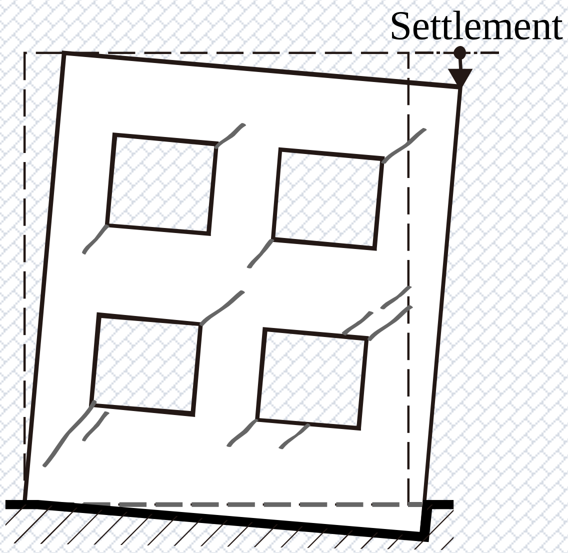
**Torsional vibration**

JBDPA seminar note

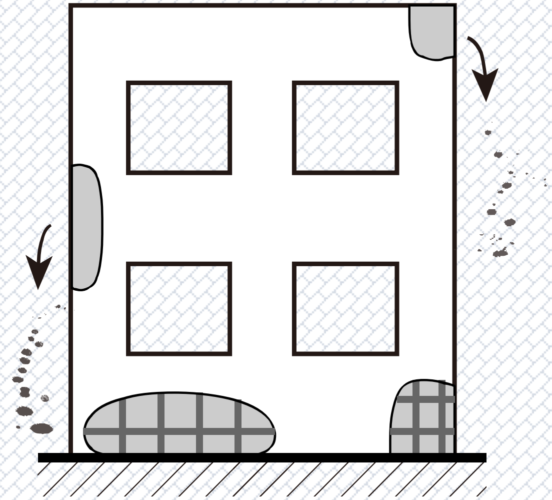
# T index:



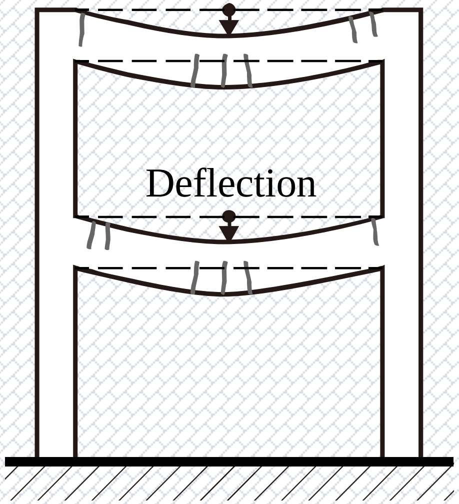
Cracking




Uneven settlement



Rust of rebar
Spalling off of finishing




Deflection of
slab and beam

**deterioration with time of existing building**

## 2. Proposed Evaluation Method

### 2.1. Simplified Seismic Index: $I_{SS}$

$$I_{SS} = E_{SS} * S_{SD} * T_S \quad (1)$$

**Where,**

$E_{SS}$: Simplified structural index

$E_{SS}$ = Maximum values of following three index;

(i) $(C_{SSW}+0.7*C_{SSB})*F_W$ (2)

(ii) $C_{SSB}*F_B$

(iii) $\sqrt{(C_{SSW}*F_W)^2+(C_{SSB}*F_B)^2}$

$S_{SD}$ : Simplified Irregularity Index (here assumed to be $S_{SD}$=1.0)

$T_S$ : Simplified Time Index (here assumed to be $T_S$=1.0)

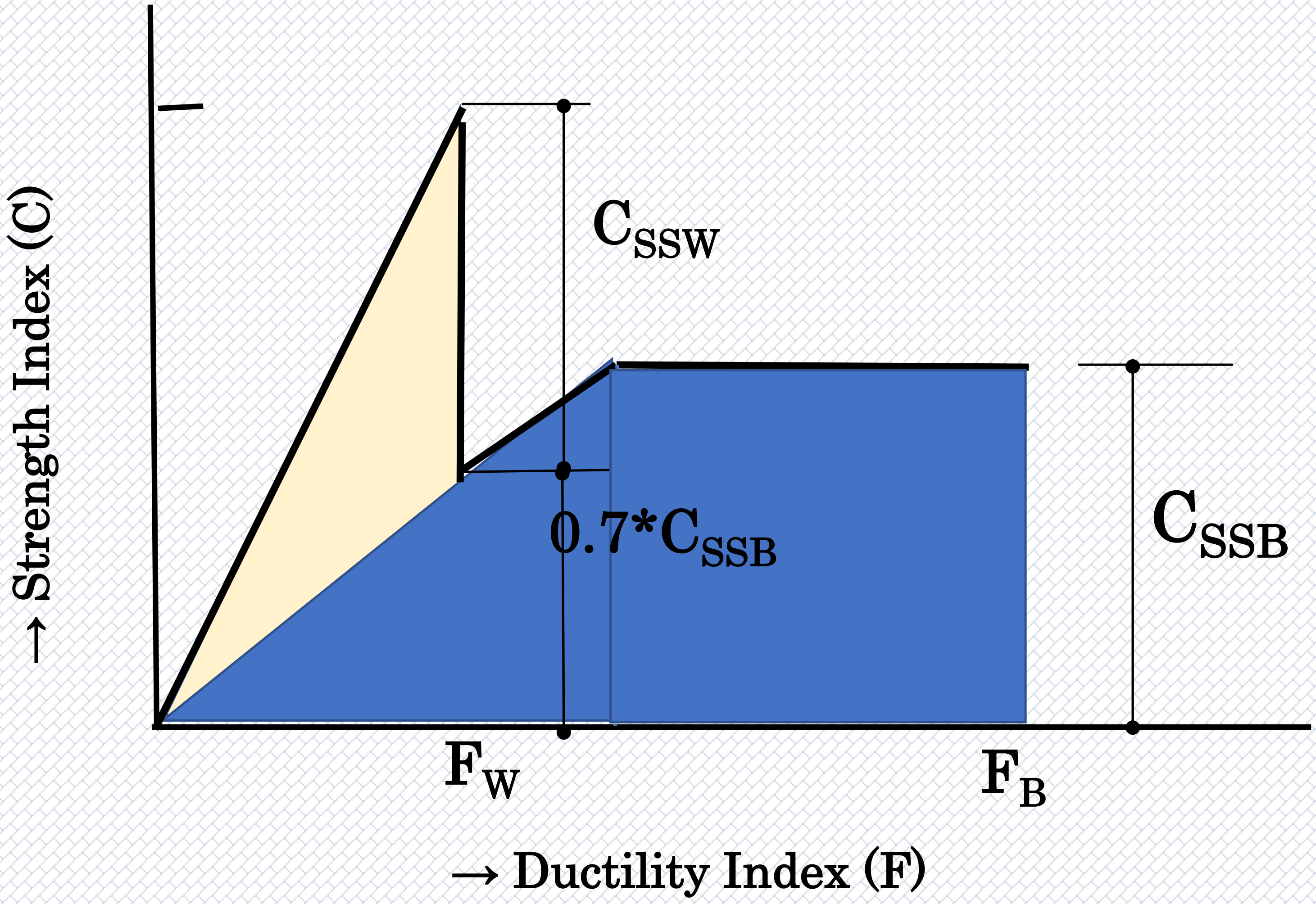



**Figure 1. Strength index (C) vs. Ductility index (F) (JBDPA,2001)**

### *2.1.1. $C_{SSB}$ and $C_{SSW}$ index; Strength index*

**(i) Bare frame**

$$C_{SSB} = \tau_c * \Sigma A_C / W \qquad (3)$$

**Where,**

**$\tau_c$: 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)**

**$\Sigma Ac$ : Total area of columns ($mm^2$)**

**W: Total weight of building (N)**

**(ii) Frame with infilled brick wall**

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

**Where,**

$\tau_c$ : Average Shear Strength of Column ($N/mm^2$) ( JBDPA ,2001)

$\Sigma A_c$ : Total area of columns ($mm^2$)

$\tau_w$ : Average shear strength of infilled brick wall ($mm^2$)

$\tau_w = 0.2\ N/mm^2$

$\Sigma A_w$ : Total area of walls ($mm^2$)

$\alpha$ : Opening reduction factor of infilled brick wall (BSAO,2007)

$\alpha = 1 - \sqrt{\gamma}$ here, $\alpha \geqq 0.6$

$\gamma$ ： Opening factor defined in Figure 2

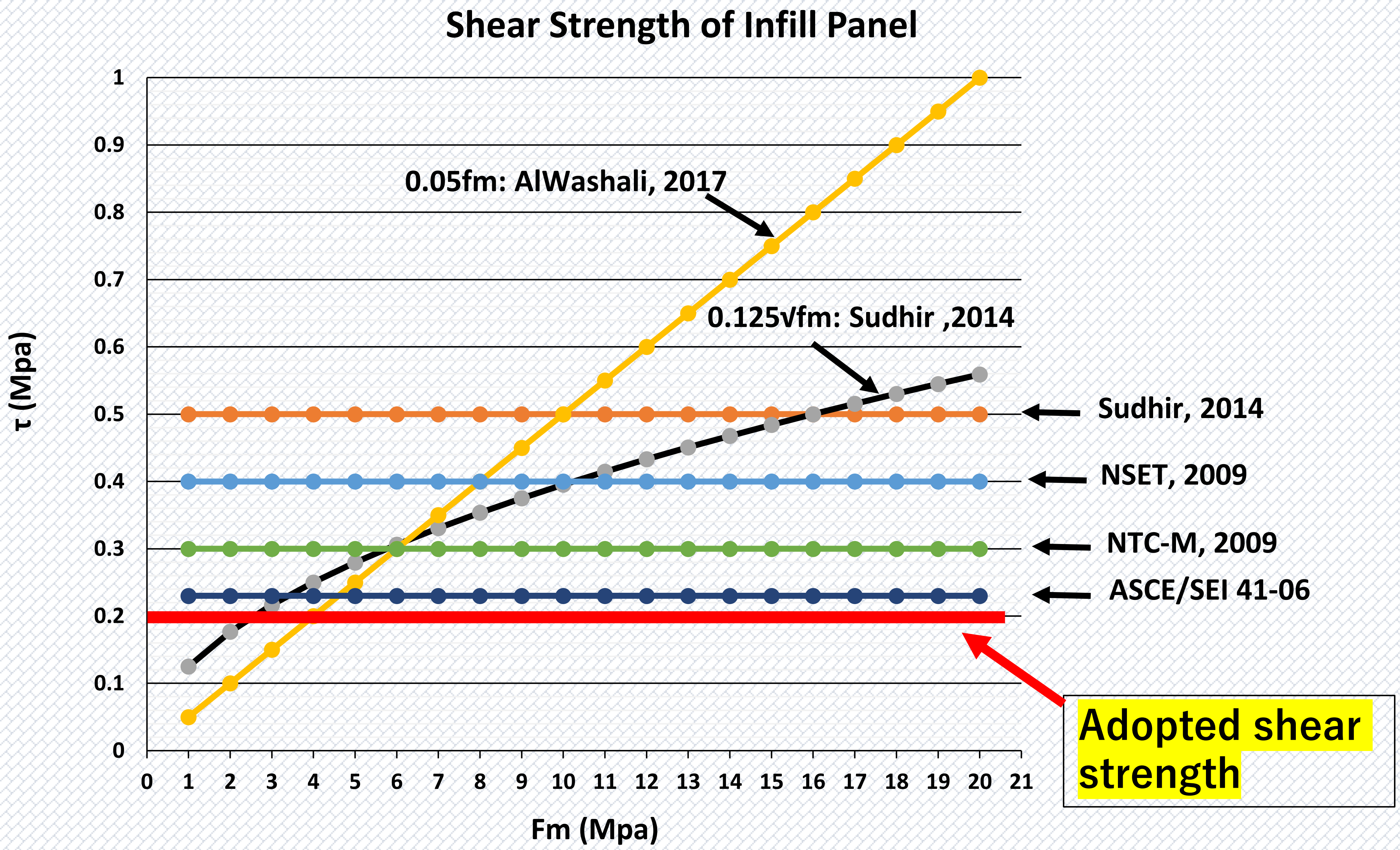



**Figure C1 The shear strength of infill panel ( $\tau_w$ )**

### *4.1.2. Opening reduction factor (α) (BSAO,2007)*

**$\alpha = 1 - \gamma$ ;     (here, $\alpha \geqq 0.6$)**

**$\gamma = \sqrt{}$(area of opening)/(area of infilled brick masonry wall),   (here, $\gamma \leqq 0.4$)**

**Figure C2 shows the comparison of opening reduction factor between BSAO (2007) and AlWashali, 2017. The factor of BSAO (2007) is more conservative than experimental data.**

**Based on BSAO (2007), the effective zone as resisting seismic zone should be not less than 0.6.**

***BSAO,2007: The Building Standard Act Enforcement Order (BSAO), No.594, Ministry of Land, Infrastructure, Transport and Tourism, Japan, May 8, 2007.***

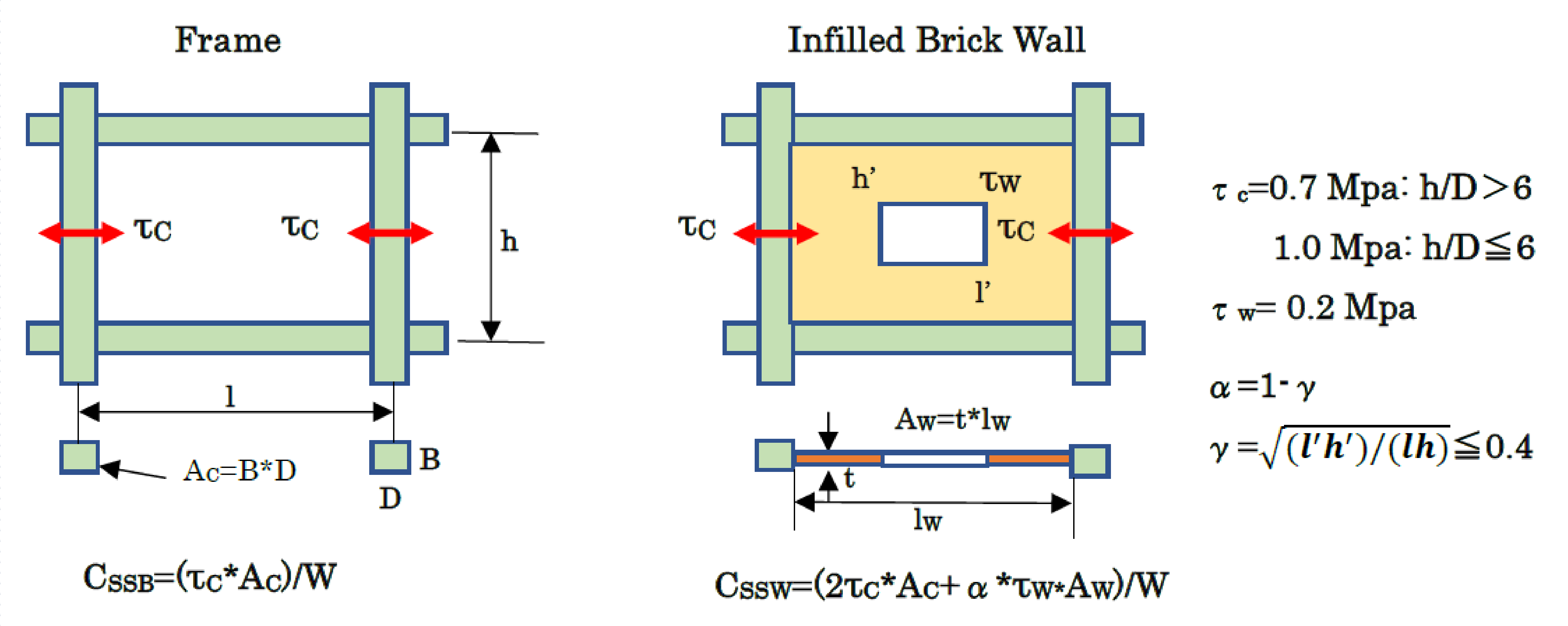



**Figure 2. Definition of $C_{SSB}$ and $C_{SSW}$**

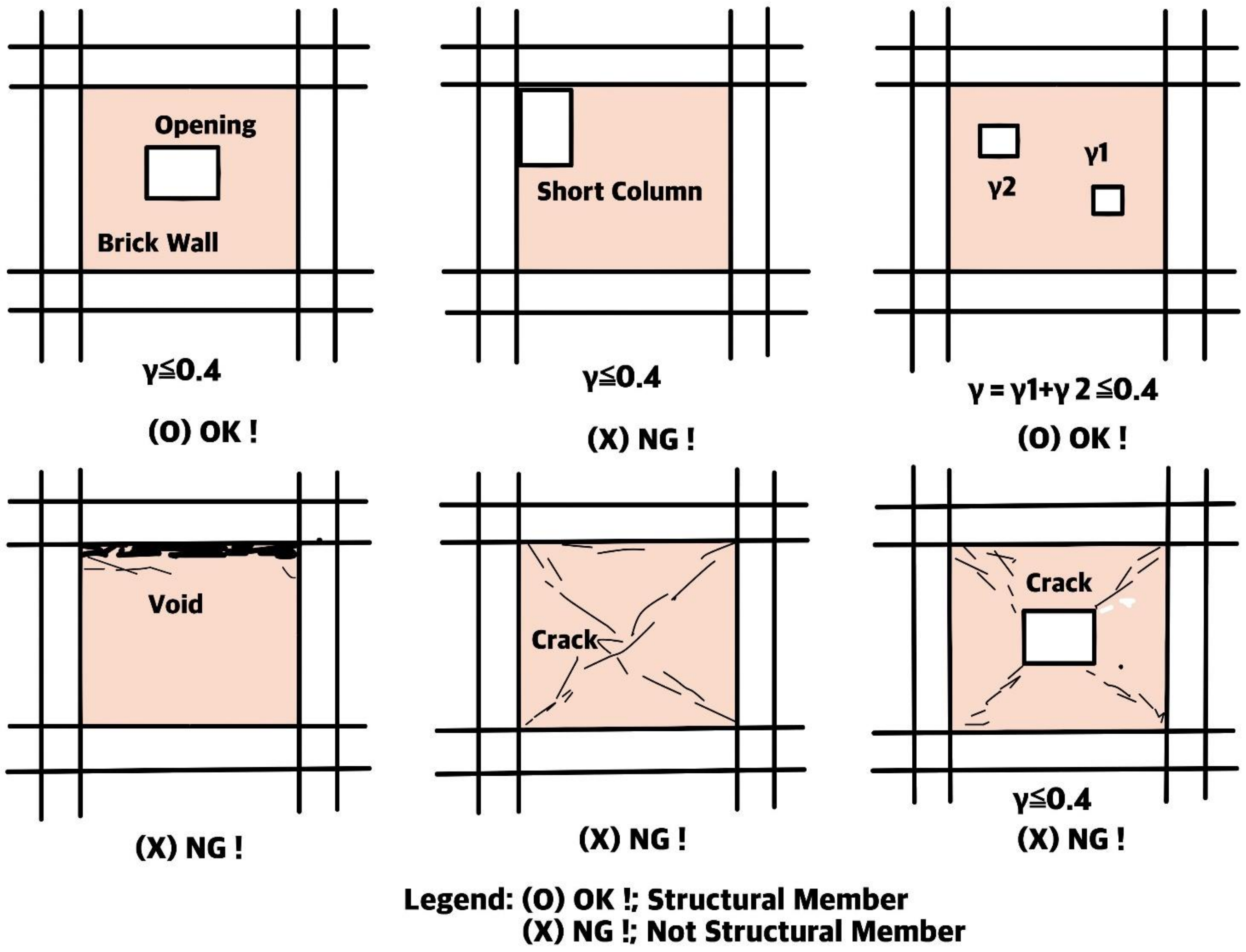



Figure C3. Various type of the frame with infilled brick wall

## Comparison of Opening Reduction Factor between BASO (2007) and AlWashali (2007)

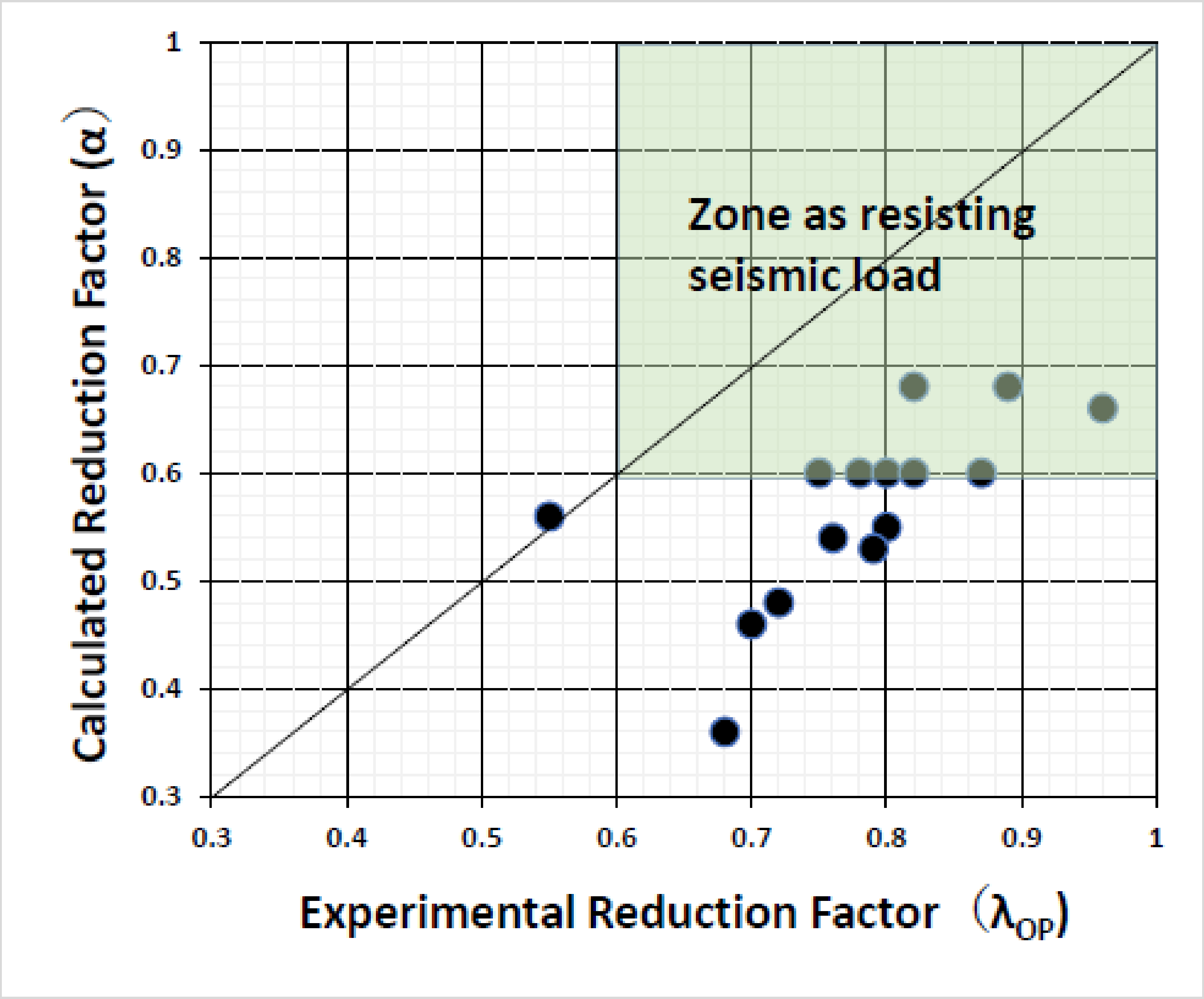
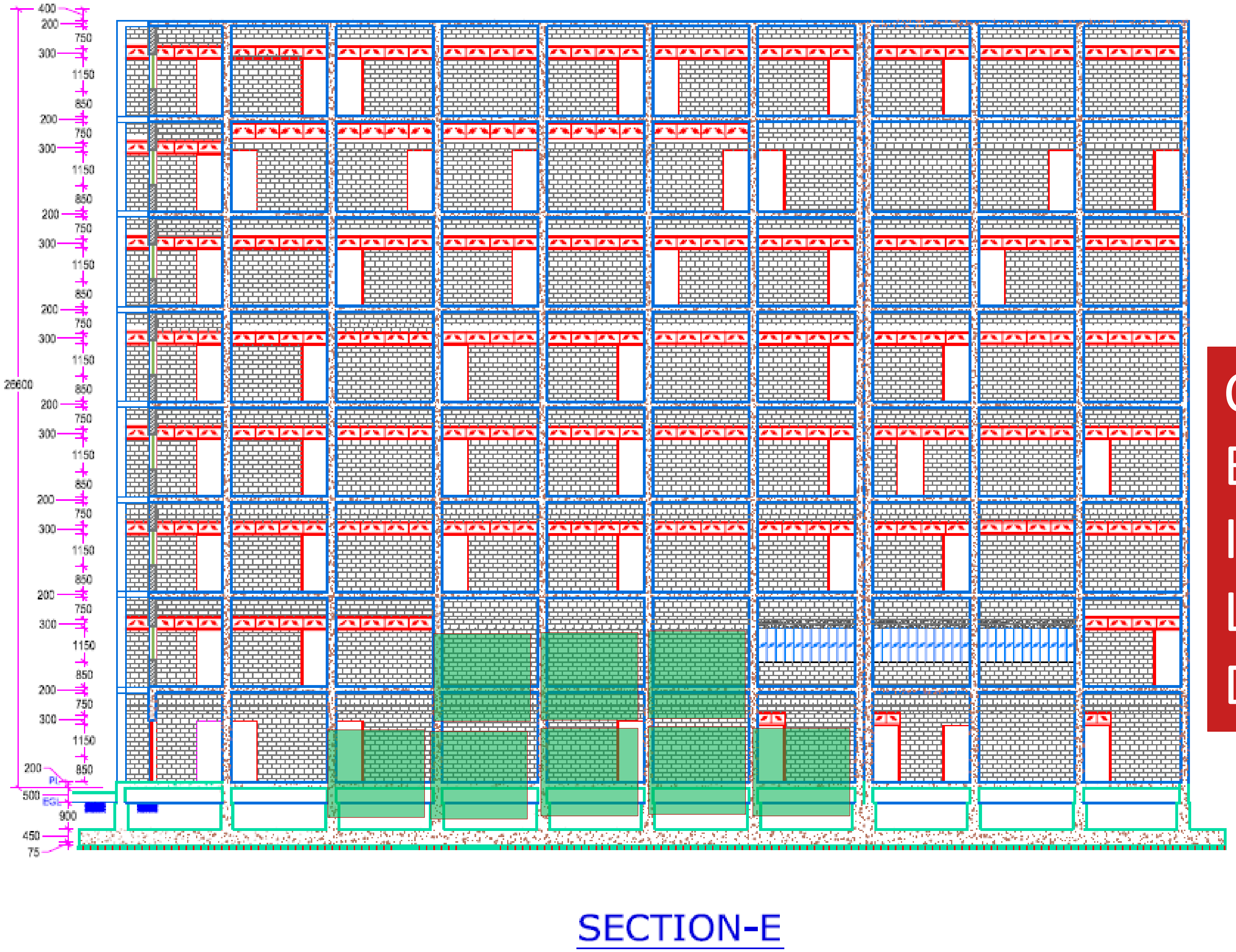


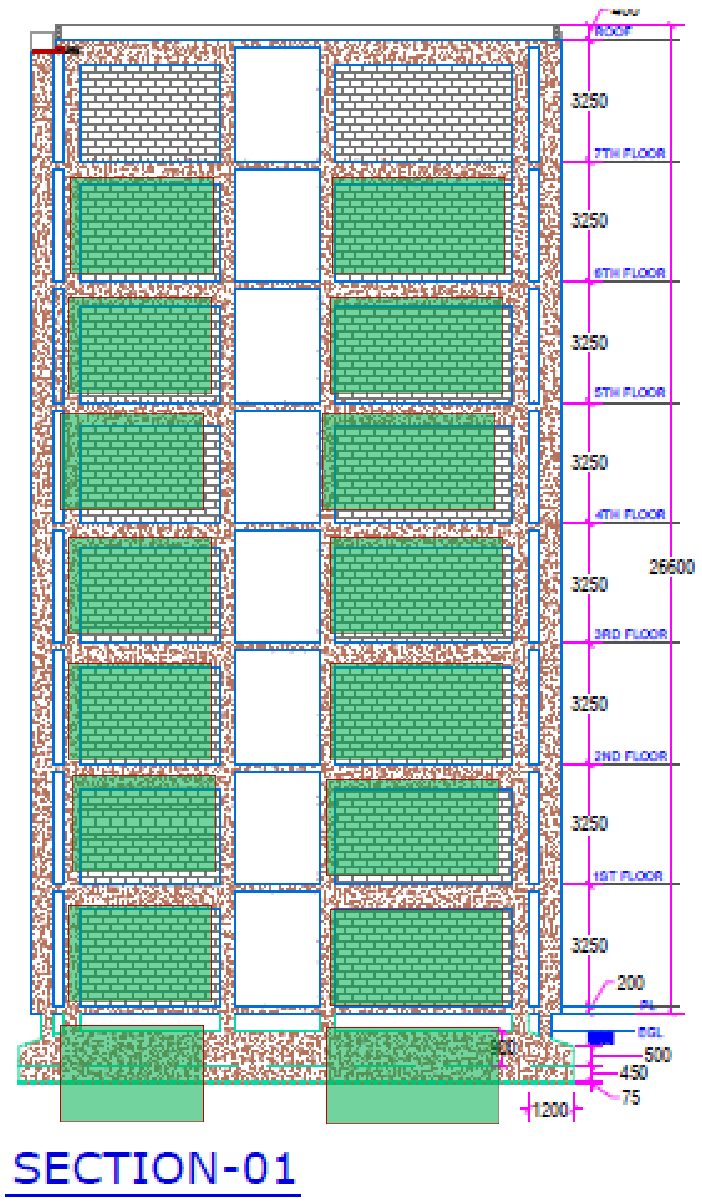

**Figure C2. Reduction factor of shear strength of infilled panel**

# An example




Consideration of Brick Masonry Infill Frame in Longitudinal Direction

# An example




Consideration of Brick Masonry Infill Frame in Transverse Direction

Seki M. ,2CNISS & 6CNIS, 2017 14-15, June , Bucharest Romania

### *2.1.2. $F_B$ and $F_W$ index; Ductility index*

**$F_B = R_B/\Omega_{0B}$** **(5) (Commentary B)**

**$F_W = R_W/\Omega_{0W}$**

**$F_B$ : 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**

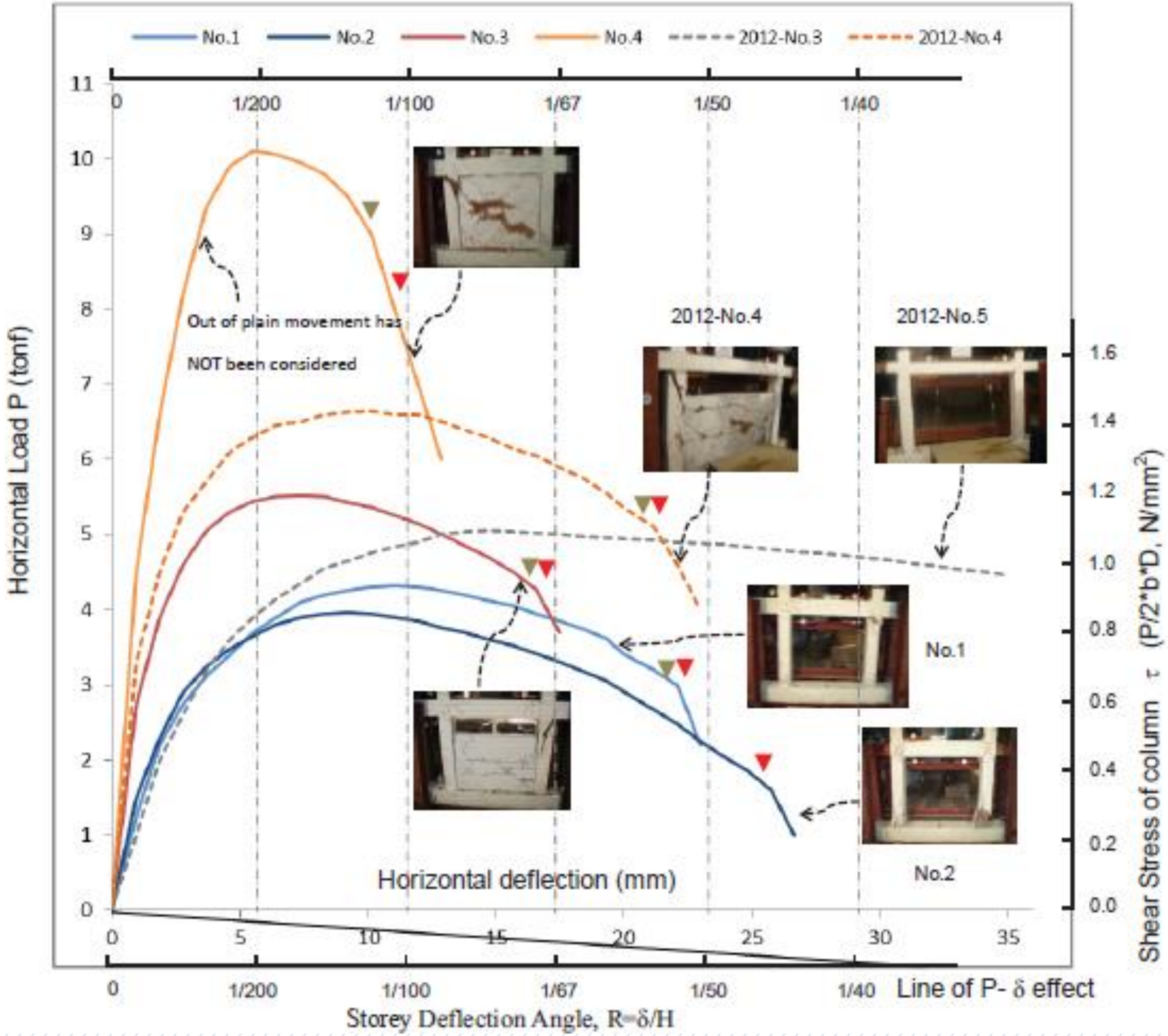
**Based on the structural type: Defined in the concerned country's seismic design code**

**$\Omega_{0B}$ : Over strength factor of frame**

**$\Omega_{0W}$ : Over strength factor of infilled brick wall**

**Based on the structural type: Defined in the concerned country's seismic design code**

# CNCRP Experimental Result on Infill Brick Masonry




Seki M. ,2CNISS & 6CNIS, 2017 14-15, June , Bucharest Romania

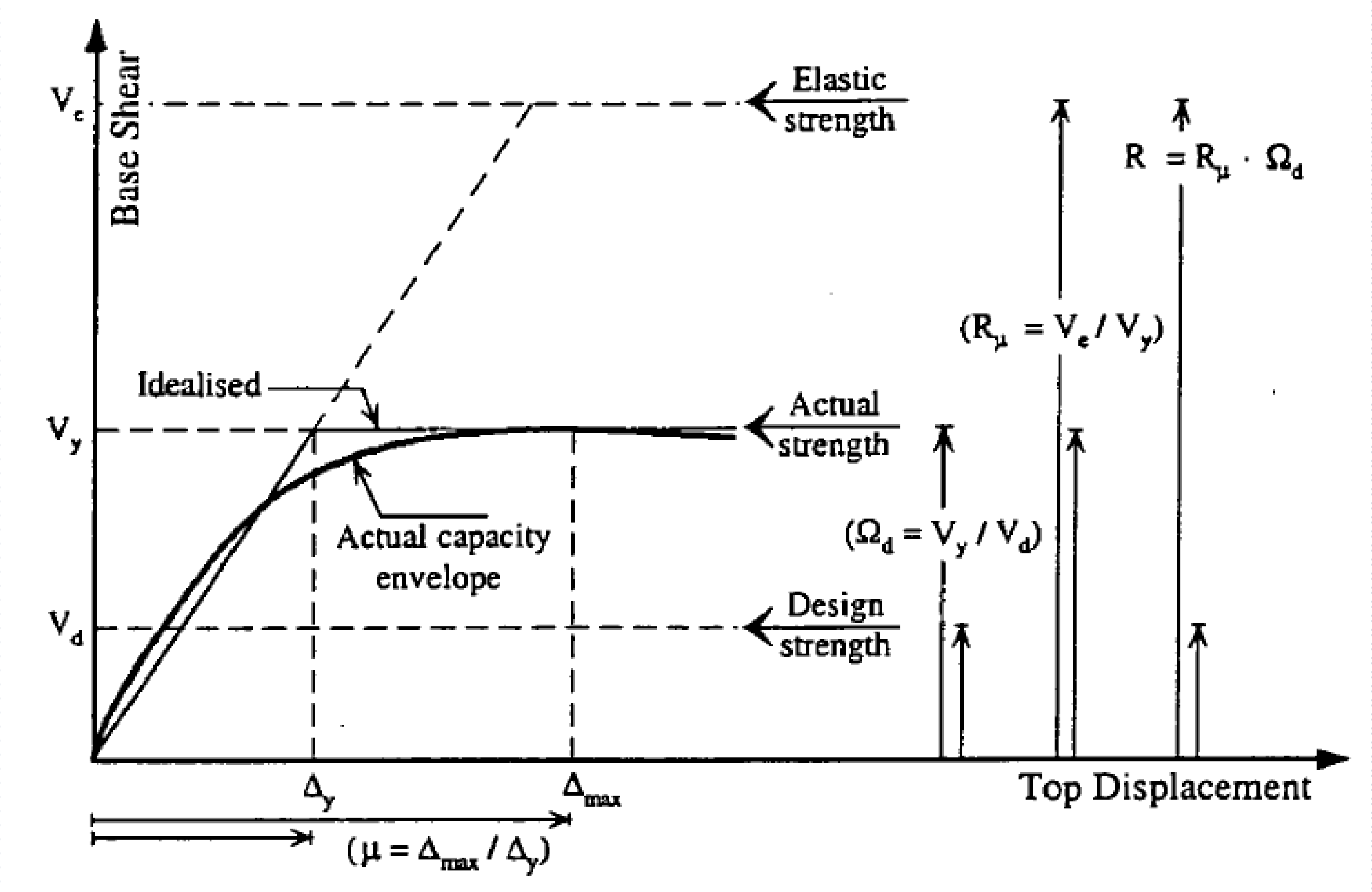
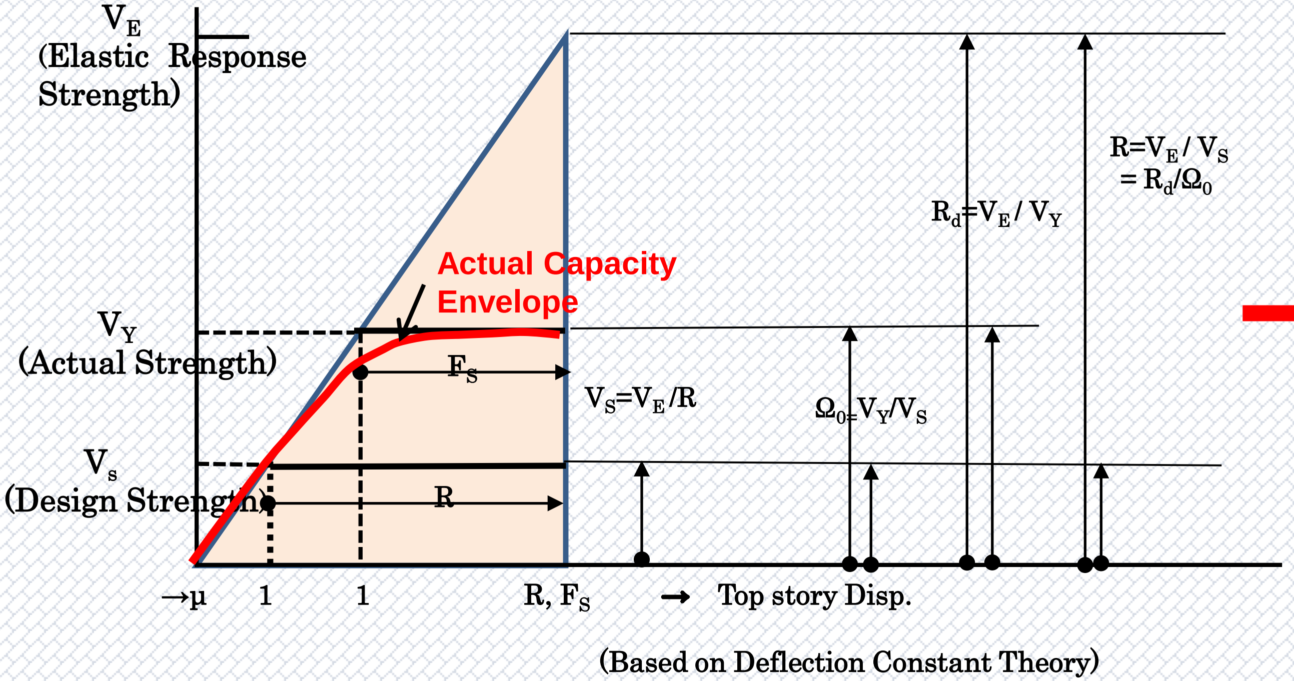



Figure C4. Relationships between Response Modification Coefficient R and Structural Over Strength Factor $\Omega_d$ and Ductility Reduction Factor $R_\mu$ (Mwafy, 2002)




$$Fs = R/\Omega_0$$

Here ;(Legend)
R : Response Reduction Factor
$R_d$: Ductility Reduction Factor (=$F_S$) (not defined in the Code)
$\Omega_0$ : Over strength Factor
μ : Ductility Factor
$F_S$ : Actual Ductility Index

Figure C5. Response Acceleration (V) – Ductility Index ($F_S$) Relations (IBC, 2000)

Table C1. Design Coefficients and Factors for Basic Seismic-Force-Resisting System for Reinforced Concrete Moment Frames ASCE 7-05 (extract)

| Basic Seismic - Force – Resisting System | Response Modification Coefficient, R | System Over strength Factor, $\Omega_0$ | 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 | 5 1/2 |
| L. Special reinforced masonry shear walls | 5 1/2 | 3 | 5 |
| M. Intermediate reinforced masonry shear walls | 4 | 3 | 3 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 | 3 1/2 | 3 | 3 |

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

$$I_{SD} = W / \Sigma Ac \qquad (6)$$

**Where,**

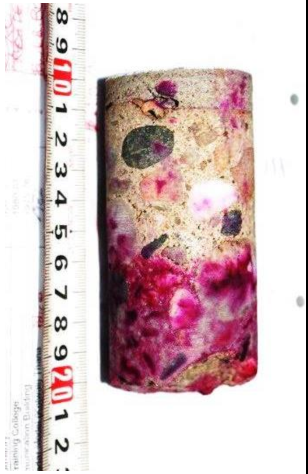
**W : Total weight of building (N)**

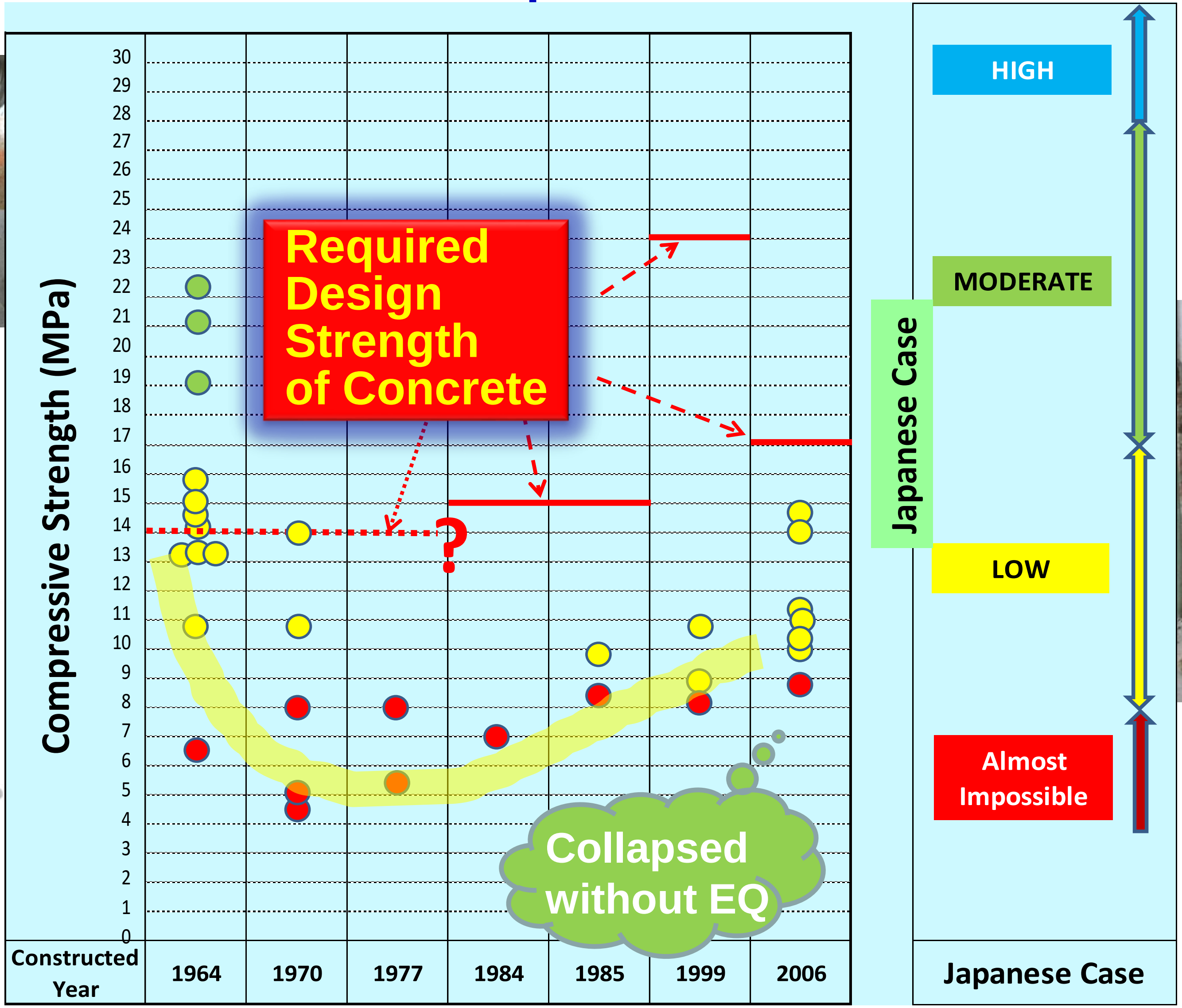
**$\Sigma A_C$ : Total sectional area of columns ($mm^2$)**

**In case of infilled brick wall, Ac is the column’s area except the brick wall area.**

CNCRP
Project for Capacity Development on Natural Disaster Resistant Techniques of Construction and Retrofitting for Public Buildings

# Concrete Strength is almost "Half of Required"








Seki M. ,2CNISS & 6CNIS, 2017 14-15, June , Bucharest Romania

## 3. Judgment index

### 3.1. Simplified Seismic Judgment Index: $I_{SS0}$

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

Where,

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

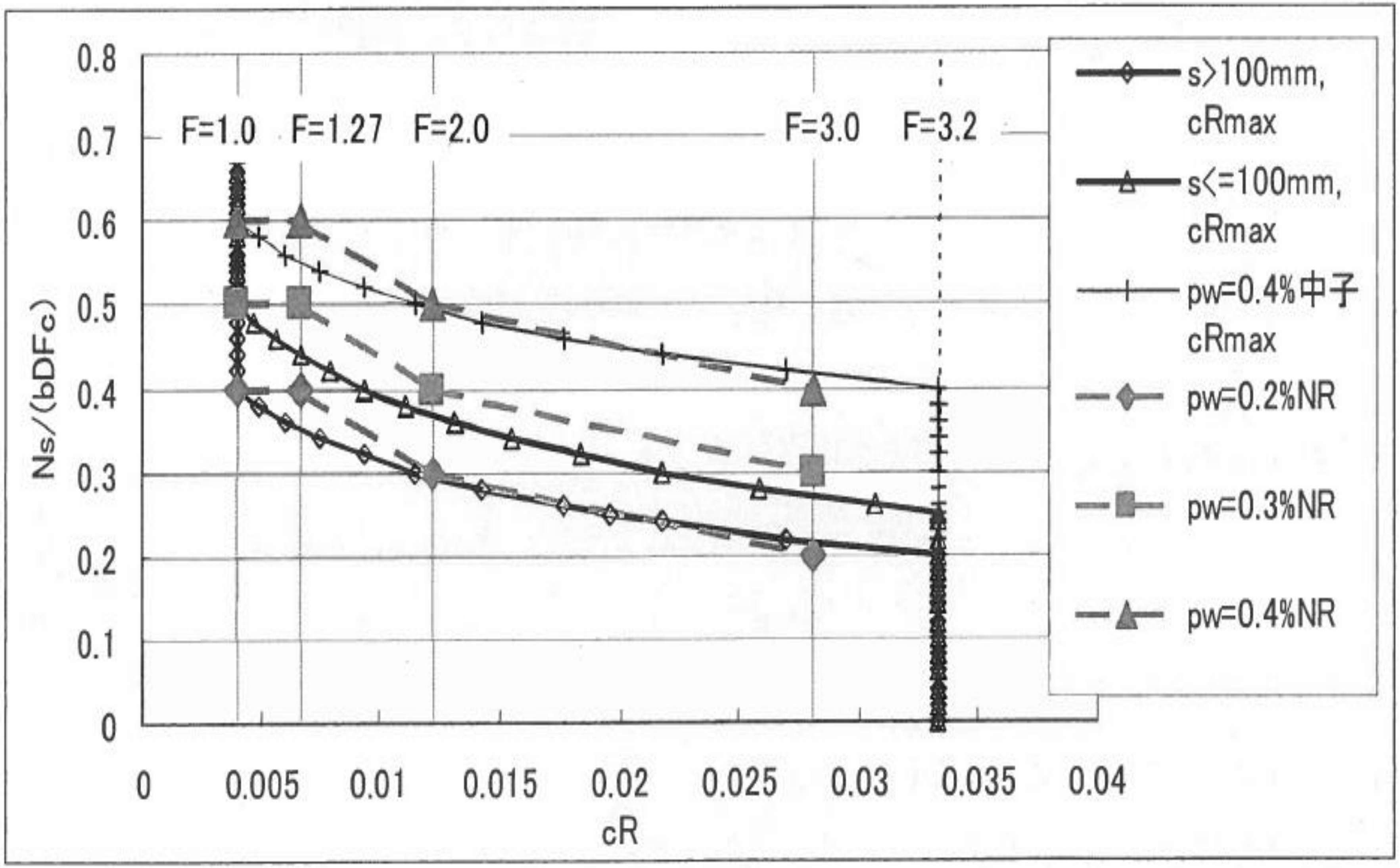
### 3.2. Simplified Service Load Judgment Index: $I_{SD0}$ ($N/mm^2$)

$$I_{SD01} = 0.4 * Fc \quad (8)\ \text{(Commentary D)}$$

$$I_{SD02} = 0.7 * Fc$$

Where,

- Fc : Designed concrete strength ($N/mm^2$)




**Dead Load Capacity - Ultimate Horizontal Deflection Angle Relations (JBDPA, 2001)**

Seki M. ,2CNISS & 6CNIS, 2017 14-15, June , Bucharest Romania

# 4. JUDGMENT METHOD

## 4.1. Simplified Seismic Capacity

$I_{SS} \geqq I_{SS0}$ : **Higher than seismic capacity demand (SA)** (9)
$0.5I_{SS0} \leqq I_{SS} < I_{SS0}$ : **Lower than seismic capacity demand (SB)**
$I_{SS} < 0.5I_{SS0}$ : **Remarkably lower than seismic capacity demand (SC)**

## 4.2. Simplified Service Load Capacity

$I_{SD} < I_{SD01}$ : **Higher than service load capacity demand (DA)** (10)
$I_{SD01} \leqq I_{SD} \leqq I_{SD02}$ : **Lower than service load capacity demand (DB)**
$I_{SD02} < I_{SD}$ : **Remarkably lower than service load capacity demand (DC)**

# 4.3. Final Rank based on Combination of Seismic Capacity and Service Load Capacity

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 |

| | | Seismic Capacity | | |
|---|---|---|---|---|
| | | SA | SB | SC |
| Service load capacity | DA | | | |
| | DB | | | |
| | DC | | | |

## 5. Conclusions

1. 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.

2. 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 American Society of Civil Engineers (ASCE 7-05)

3. This evaluation method should be more discussed for applying to the advanced in-situ simplified evaluation, especially on the evaluation of infill brick masonry panel.

# Thank you for your attention