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Proposal to Adopt a Simplified Seismic Evaluation Method Based on the Japanese Standard for Existing Reinforced Concrete Buildings in Northern Thailand

Suppachai Sinthaworn[1, 2,*] and Wasan Teerajetgul[1, 2]

[1]Department of Civil Engineering, Faculty of Engineering, Srinakharinwirot University, Thailand

[2]Research Unit in Sustainable Innovation in Civil and Environmental Engineering, Srinakharinwirot University, Thailand

Abstract

In Northern Thailand, small to moderate earthquakes occurred quite often which have caused damages to houses and buildings. Hence, mitigation of the earthquake disaster, seismic evaluation and retrofitting of the existing buildings is very necessary. Thai Ministry of Interior has issued a standard of seismic evaluation and rehabilitation of existing buildings in the earthquake prone areas. This standard provides pseudo-lateral force for structural model in order to start structural analysis and finally to get internal force and displacement. To follow this standard an expert with specific software is required which is difficult to find in most of Thailand. On the other hand the Japanese's standard (JBDPA first level) is a rapid approach of screening the existing RC buildings. It simplifies the structural system and then calculates the ratio of seismic force and capacity of the structure. Hence, we propose an alternative simplified Japanese method for evaluation of existing reinforced concrete buildings in northern Thailand with adoption of the spectral acceleration values from Thailand hazard maps as the target seismic force.

Keywords: Seismic Evaluation; Reinforced Concrete Building, Earthquake

*Corresponding author.E-mail address: suppachai@g.swu.ac.th (S. Sinthaworn).

1. Introduction

Some parts of Thailand are earthquake prone areas, especially the northern part of Thailand as shown in the seismic hazard map (Fig. 1) (Warnitchai 2011). The latest earthquake was Mae Lao earthquake of May 5, 2014 which had 6.1 Mw and caused damages to infrastructure (i.e. school buildings), private buildings and one victim from this earthquake (Bureau of Geotechnology 2014, Ornthammarath et al. 2015).

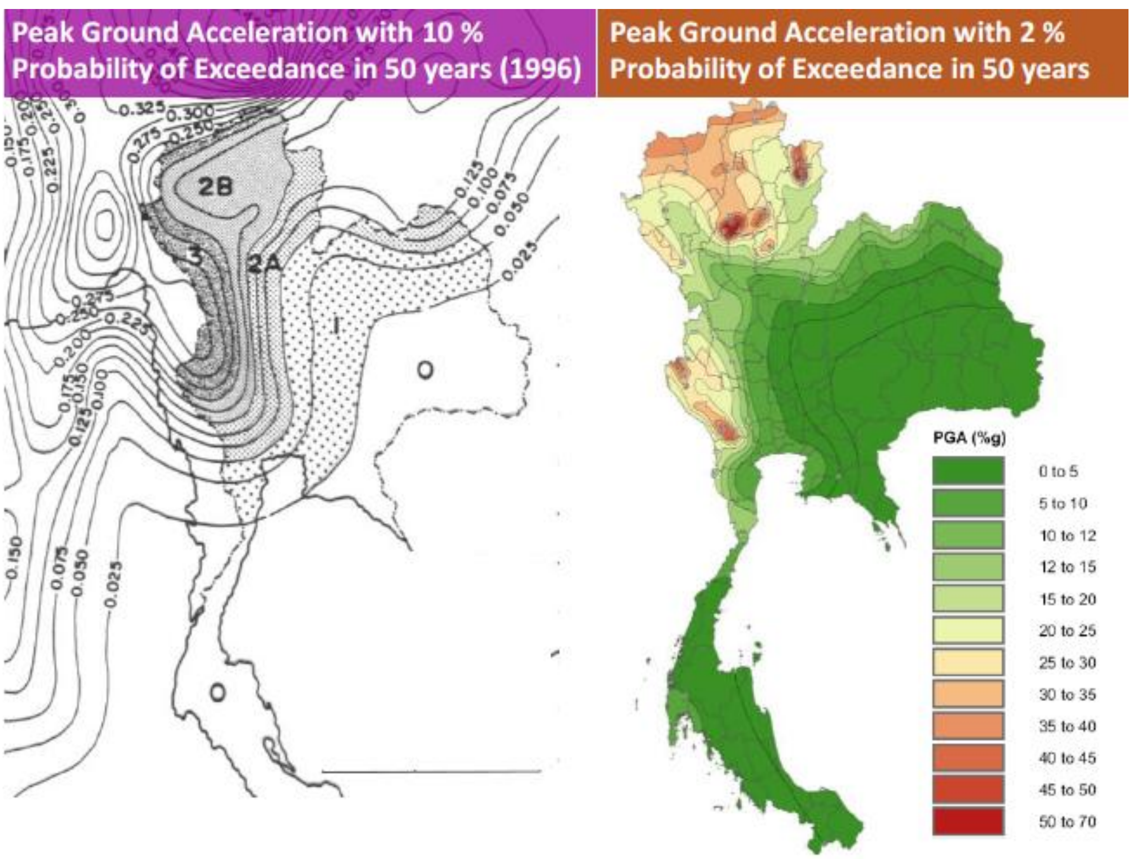

Figure 1. Seismic hazard maps of Thailand in 1996 and 2009(Warnitchai 2011)

The ground shaking caused damages to more than 10,000 buildings, affecting about 500,000 people in Chiang Rai which is located in the northern part of Thailand. Some school buildings were damaged as shown in Fig. 2. This earthquake is the most recent incidence which again raises an awareness of the effect of earthquakes in Thailand.

(a) Four stories school building

(b) Two stories school building (Ornthammarath et al. 2015)

Figure 2. Damage to school buildings due to Mae Lao earthquake of 2014

Thailand has only a few ground motion data and most of peak ground accelerations are quite small. The earthquake catalog used in Thailand and adjacent areas has been prepared by Thailand Meteorological Department. Due to paucity of local data, Thai design codes for buildings are being developedusing data of other seismic prone countries such as USA and Japan.

In 1997, the Ministry of Interior of Thailand issued the first regulation of building code (Ministry Regulation No.48-97) which is based on UBC code in order to provide seismic resistance of new buildings in the earthquake prone areas. Subsequently, the building code was revised again in 2007 in order to cover the long distance earthquake in central area of Thailand (Ministry of Interior 2007). In late 2014, the first standard for seismic evaluation and retrofitting of existing structures in earthquake prone areas was issued by Ministry of Interior. This standard is mainly based on ASCE/SEI 41-06: Seismic Rehabilitation of Existing Buildings (Department of Public Works and Town & Country Planning 2014).

The Thai seismic evaluation standard provides pseudo-lateral force for buildings from acceleration response spectra(Department of Public Works and Town & Country Planning2014). For compliance to this Standard the evaluator (i.e. engineer) must compute internal force of structural members usually by structural analysis software which is normally quite expensive and requires familiar user. However, most earthquake prone areas of Thailand (such as the north and the west sides) comprise small cities which normally have many low-rise reinforced concrete buildings and few medium or high rise buildings. In addition, those areas have a lack of professional people in earthquake engineering. Hence, the first suggested standard of seismic evaluation and rehabilitation of existing buildings is out of reach for the local inhabitants.

In Japan, the Japan Building Disaster Prevention Association (JBDPA) standard (Umemura 1980, JBDPA 2001)for seismic evaluation of existing reinforced concrete (RC) buildings is applicable to the buildings constructed based on older design standards. This standard provides three levels of screening procedures. The first two levels of the procedures could be applied to low-rise and medium-rise reinforced concrete buildings whereas the third level procedure is for frame structures. The first level procedure is a simplified method which can normally be calculated without any structural analysis softwares. The objective of this article is to adopt the first level of the screening procedure of Japan (JBDPA, 2001) with the existing standard of Thailand (Department of Public Works and Town & Country Planning 2009, Department of Public Works and Town & Country Planning 2014) in order to evaluate structural characteristics of the existing building in Northern Thailand.

2. The First Level of the Screening Procedure of JBDPA Standard

JBDPA(first level) is one of the rapid approach of screening the existing RC buildings. The seismic capacity of the structures is evaluated based on the performance of the vertical element on the assumption that girders are strong enough, not to fail (Seki 2015). The screening procedure applicable to low and medium-rise RC buildings of up to about six stories uses a basic structural seismic performance index (E_0), which is modified by multiplying factors related to building irregularities, degree of deterioration in strength and ductility, and local geology. The Is-index (as shown in Eq. 1) is calculated at each floor in each direction of the building. This value corresponds to the maximum elastic response shear coefficient that the floor can resist. A larger 'Is' indicates better seismic performance of the building.

$$I_S = E_0 . S_D . T \qquad (1)$$

Where E_0 is basic structural performance index calculated based on the ultimate strength, ductility and story level, S_D is structural design index to modify E_0 due to degree of irregularity of the building shape and the distribution of stiffness, T is time index to modify E_0 due to the degree of deterioration of strength and ductility. The time index (T) and S_D index are equal to 1 when the investigated buildings are non-deteriorate and the stiffness of the building is balanced.

The basic seismic index of structure (E_0) for the first level screening methodis calculated with Eq. (2) or (3).

$$E_0 = \frac{n+1}{n+i}(C_w + \alpha_1 C_C). F_W \qquad (2)$$

$$E_0 = \frac{n+1}{n+i}(C_{SC} + \alpha_2 C_w + \alpha_3 C_C). F_{SC} \qquad (3)$$

Table 1. The av. shear stress (for compressive strength of concrete, f_c' = 20 MPa) and ductility index.

Type of Member	Clear height/column width (h/d)	Average Shear Stress, τ (N/mm^2)	Ductility Index, F
Column	h/d ≥ 6	0.7	1.0
Column	6 > h/d > 2	1.0	1.0
Short Column	2 ≥ h/d	1.5	0.8
Wall	-	1.0	1.0

Where $\frac{n+1}{n+i}$ isthe story-shear modification factor, α is effective strength factor (α_1 = 1.0, α_2 = 0.7 and α_3 = 0.5), Cis the strength index which is calculated by Eq. 4, and F is the ductility index as shown in Table 1. In addition, subscripts C, SC, and W represent column, short column and wall, respectively. For the first level, relationship of C and F is shown in Fig. 3

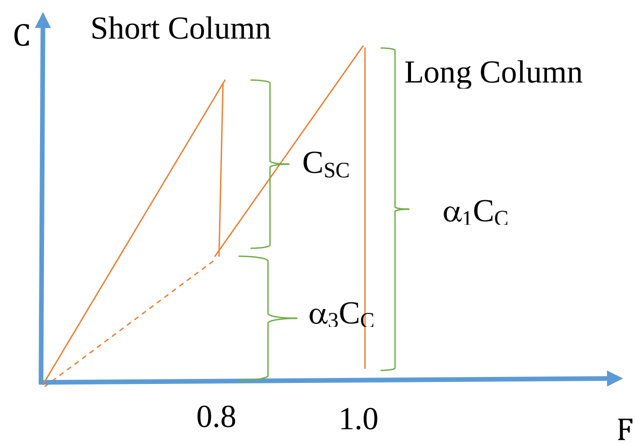

Figure 3. C-F relations in the first level of the screening procedure without wall

$$C = \frac{\sum \tau A}{\sum W} \beta \qquad (4)$$

Where $\tau$is average shear as defined in Table 1, A is cross sectional area of member, W is weight of the floor above the investigated floor and β is modification factor of concrete strength.

The critical value (I_{so}) of 0.8 is recommended for first level of the screening procedure as determined from correlation studies from damaged buildings of past severe earthquakes in Japan. The flow diagram of the simplified structural evaluation is shown Fig. 4.

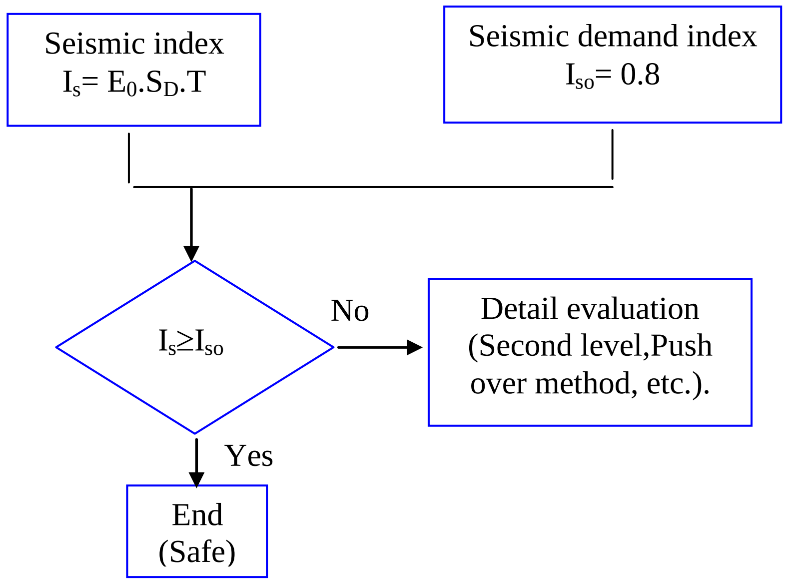

Figure 4. Flow Diagram of Simplified Structural Evaluation of RC buildings

3. The Current Thai Standard, DPT 1303-14(Department of Public Works and Town & Country Planning 2014).

There are four analysis procedures that can be used in the Thai standard, including the Linear Static Procedure(LSP), Linear Dynamic Procedure (LDP), Nonlinear Static Procedure(NSP), and Nonlinear Dynamic Procedure(NDP).Thus, structural analysis is needed in all procedures such as static as well as dynamic analysis.

However, this article discusses only the LSP which seems to be the easiest procedure and could be used for concrete moment-resisting frame as performance based design concept. This procedure is intended to provide a conservative estimate of building response and performance in an earthquake. The LSP provides pseudo-lateral force (V in Eq. 5) to calculate the deformation of the building (U_{inel}) as shown in Fig. 5.

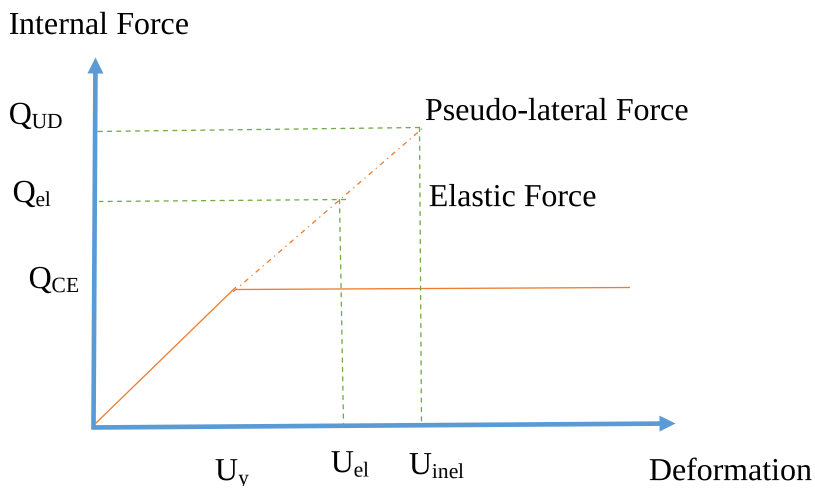

Figure 5. The relationship between internal force and deformation of investigated building

$$V = C_1 C_2 C_m S_a W \qquad (5)$$

Where V is pseudo-lateral force, C_1 is modification factor to relate expected maximum inelastic displacements to displacements calculated for linear elastic response, $C_2$is modification factor to represent the effects of pinched hysteresis shape, stiffness degradation, and strength deterioration on maximum displacement response, C_m is effective mass factor to account for higher mode mass participation effects, S_a is response spectrum acceleration at the fundamental period and damping ratio of the building in the direction under consideration, and W is effective seismic weight of the building.

The vertical distribution of the pseudo lateral load for RC buildings is similar to the Ministry Regulation No.49 and DPT 1302 standard. The lateral load applied at any floor level x (F_X) could be determined in accordance with Eq. 6 to 7.

$$F_X = C_{VX} V \qquad (6)$$

$$C_{VX} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k} \qquad (7)$$

Where C_{VX} is vertical distribution factor, w_i is the portion of the total building weight W located on or assigned to floor level i while w_x is the portion of the total building weight W located on or assigned to floor level x, h_i is the height from the base to floor level i whereas h_x is the height from the base to floor level x, k value is an adjust factor (the value between 1.0 and 2.0) which depends on the period of the building.

For the force-controlled member, its internal force (Q_{UF}) could be adjusted by the modification factors as shown in Eq. 8.

$$Q_{UF} = Q_G \pm \frac{Q_E}{C_1 C_2 J} \qquad (8)$$

Where Q_G is the action due to design gravity loads, Q_E is the action due to design earthquake loads, C_1 is the expected maximum inelastic displacements to displacements calculated for linear elastic response, C_2, the effect of pinched hysteresis shape, cyclic stiffness degradation and strength deterioration on maximum displacement response, and J is the force-delivery reduction factor.

Coefficients C_1 and C_2 were the amplification factors for the design base shear to achieve a better estimate of the maximum displacements expected for buildings responding in the inelastic range.
On the other hand, for deformation-controlled actions, Q_{UD}(in Fig. 5) shall be calculated in accordance with Eq.9.

$$Q_{UD} = Q_G \pm Q_E \qquad (9)$$

Therefore, the force Q_{UD} (the deformation-controlled design action due to gravity loads and earthquake loads) results in an equivalent deformation (U_{inel}) of building in inelastic range while U_y is the deformation at yield point as shown in Fig. 5.

The acceptance criteria of DPT 1303standard is that the components shall be classified as primary or secondary, and actions shall be classified as deformation-controlled or force-controlled. The Components and elements analyzed using the linear procedures shall satisfy the requirements of either deformation-controlled or force-controlled. The flow chart of DPT 1303 standard is shown in Fig. 6.

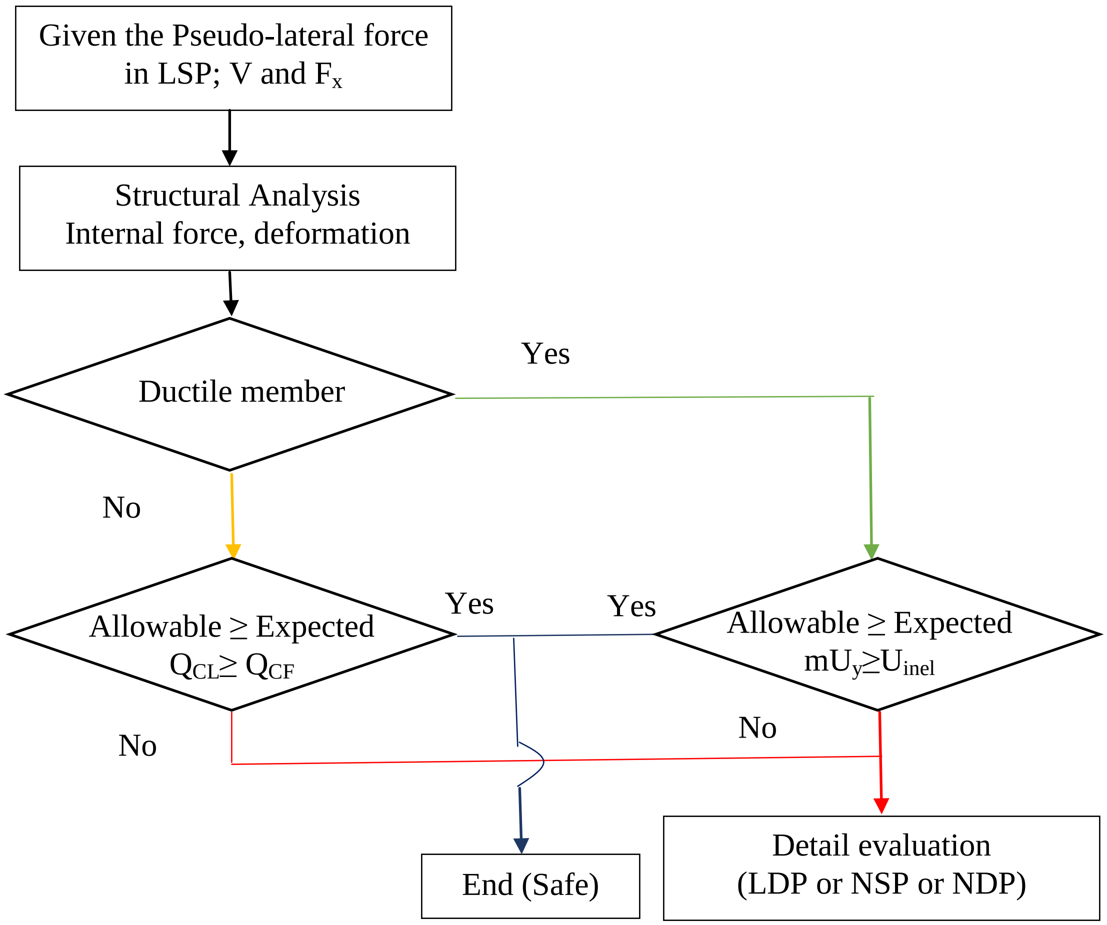

Figure 6. Flow Diagram of DPT 1303-14 standard of RC buildings.

In the case of deformation-controlled actions, the primary and secondary components and elements must satisfy with Eq.10 or Eq.11 which assume equal stiffness of structure (k).

$$m\kappa U_y \geq U_{inel} \qquad (10)$$

$$m\kappa Q_{CE} \geq Q_{UD} \qquad (11)$$

Where m is component or element demand modifier (factor) to account for expected ductility associated with this action at the selected Structural Performance Level (m-factor), $Q_{CE}$is the expected strength of the component or element at the deformation level under consideration for deformation-controlled actions (k*U_y) and κ is knowledge factor which relate whit accurately of obtained data (normally this value is between 0.75 to 1.00).

In the case of force-controlled actions, the primary and secondary components and elements shall satisfy with Eq. 12.

$$\kappa Q_{CL} \geq Q_{UF} \qquad (12)$$

Where Q_{CL} is the lower-bound strength of a component or element at the deformation level under consideration for force-controlled actions.

4. The Proposed Method of Simplified Seismic Evaluation of Existing Reinforced Concrete Buildings of Northern Thailand.

The proposed simplified structural evaluation method aims to be used as the first screening of the seismic evaluation before using LSP. This procedure is based on the following assumption;

1. Seismic evaluation was adopted basically based on the philosophy of the DPT 1303 and JDBPA standard.
2. The target building is 4-storied reinforced concrete moment resisting frame building which is assumed to have weak columns and strong beams behavior.
3. The necessary information such as material strength and detail of drawing should be determined and could be adjusted by knowledge factor.
4. In Thailand, the buildings are normally constructed with enough capacity for gravity load. Then, this proposal will be used only to evaluate or to check the seismic force.

4.1 Level of Seismic Force

The seismic hazard map of Thailand was developed based on the location of buildings with respect to the causative faults, the regional and site-specific geologic characteristics (Ornthammarathet al. 2010). The peak ground acceleration derived on the probabilistic and deterministic basis is shown in Fig.1. Seismic hazard due to ground shaking is defined as acceleration response spectra (S_a)for design engineer. The required spectral accelerations (S_a) are at 0.2 s, and 1.0 s natural periods with 2 % probability of exceedance in 50 years for defining Maximum Considered Earthquake (MCE). The DPT 1302specifies S_a($S_{0.2}$ and $S_{1.0}$) at all areas in Thailand but the building damage level index (which is similar to the critical value (I_{so}) in JBDPA standard) is not available. This paper aims to converse the existing spectral accelerations in Thai standard to the critical building damage level index as the proposed principle of Seki (2015).

The design standard of DPT 1302 for new building defines two basic earthquake hazards, Design Basis Earthquake (DBE) and Maximum Credible Earthquake (MCE) which is expected to occur, on average, about once every 1,000 and 2,500 years. Normally, response accelerations of DBE (S_{DS}, S_{D1}) are approximately two-third of MCE (S_{MS}, S_{M1}).However, the level of used response acceleration for existing building according to DPT 1303 is basic safety earthquake (BSE). Return period is 225 years on average, which has the response acceleration approximately equal to one-third of S_a (S_{as}, S_{a1}) or ½ of S_D (S_{DS}, S_{D1}).. Therefore, S_a(S_{as}, S_{a1}) value from DPT 1302 should be modified to be the critical value similar to I_{so} as Eq. 13.

$$I_{SO} = S_a . I/R \qquad (13)$$

Where S_a is one-half of S_D from DPT 1302, I is importance factor of building (in this case, I = 1 for normal building) and R is response modification factor (in this case, R = 3 for ordinary reinforced concrete). The hint to converse S_a to I_{SO} is illustrated in Fig. 7.

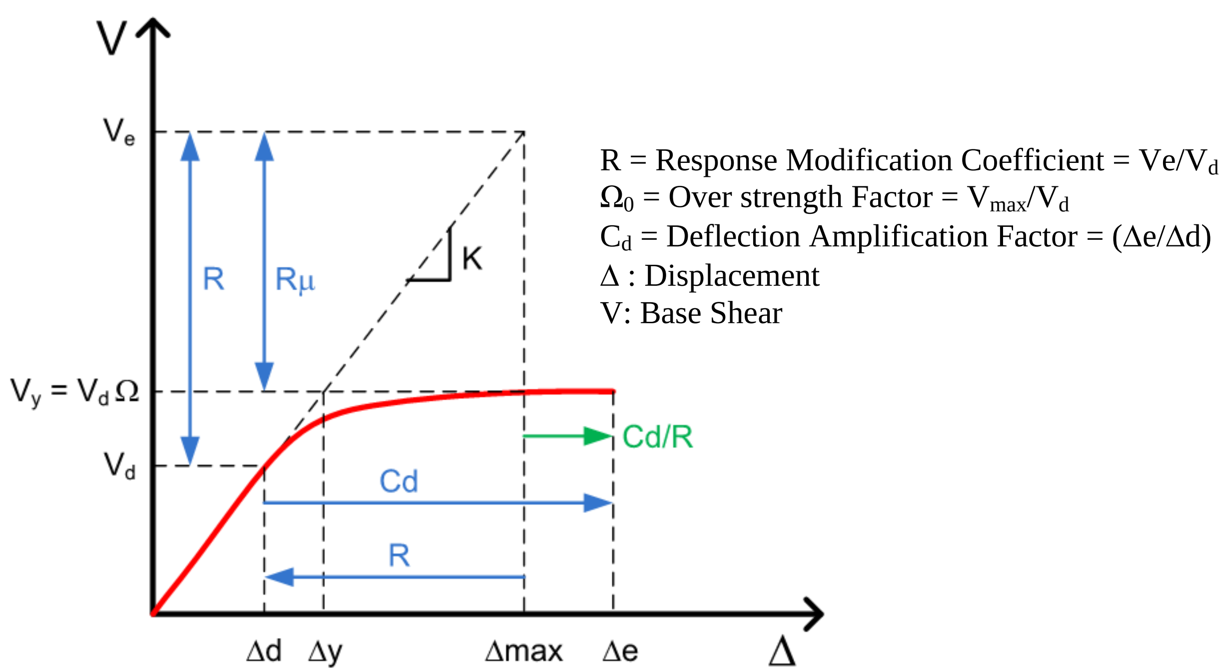

Figure 7.The relationship between response acceleration (V) and displacement (Δ) adopted from Seki (2015)

4.2Relationship between the Story-Shear Modification Factors and the Vertical Distribution of the Pseudo Lateral Load

Although, earthquake ground motions exert seismic forces to buildings not only horizontally but also vertically. Usually existing RC buildings in Thailand have strong capacity against vertical motions. Therefore, horizontal seismic force parameters will be discussed in this section.

In Thai code, the response displacements increase linearly from base to the top. The seismic force increases linearly. Typically, RC buildings in Thailand are four stories or lower. The first level of professional civil engineers is licensed to design buildings up to four stories. Therefore, the proposed method aims to evaluate only those existing RC building. The relationship between story-shear modification factors and floor of a four stories building is shown in Fig. 8 as JBDPA legend whereas the cumulative vertical distribution of the pseudo lateral load is also shown as DPT. In Fig. 8, these two lines are not directly correlated. Story-shear modification factor is a factor to reduce the capacity while another line is the ratio of represented force to the building.

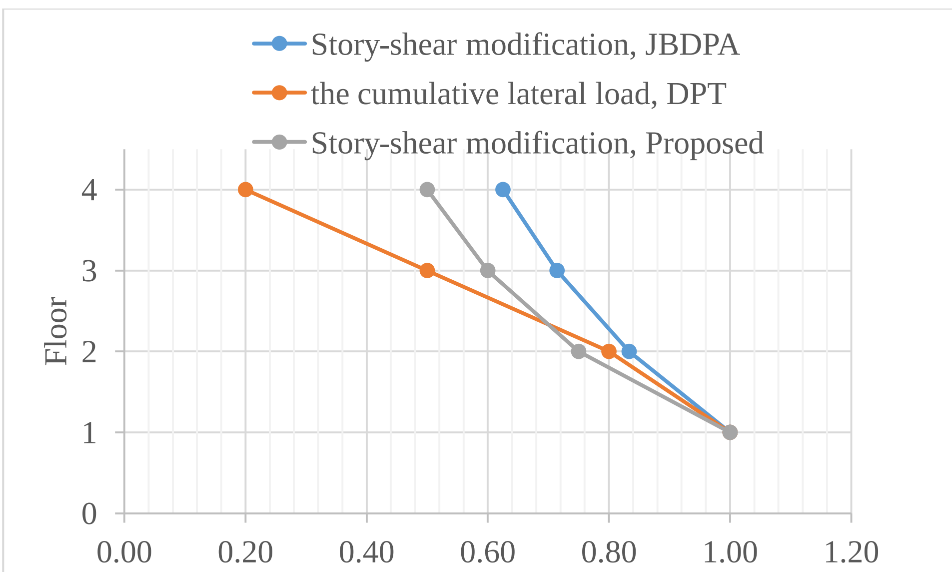

Figure 8.The story-shear modification factors (JBDPA, Proposed) and a cumulative vertical force of a building (DPT).

Rewrite Eq. 1 to 4 and 13 in Eq. 14.

$I_{SO} = S_a.\frac{I}{R} \leq I_S = [\frac{n+1}{n+i}\left(\frac{\sum \tau A}{\sum W}\beta\right).F].S_D.T$ (14)

Substituting $\beta.F.S_D.T$ = Co and $\frac{n+1}{n+i}$ = F_{SSM} and $\left[S_a.\frac{I}{RCo}\right] = A$, re-write Eq.14 in Eq. 15.

$A.(\frac{1}{F_{SSM}}) \leq \left(\frac{\sum \tau A}{\sum W}\right)$ (15)

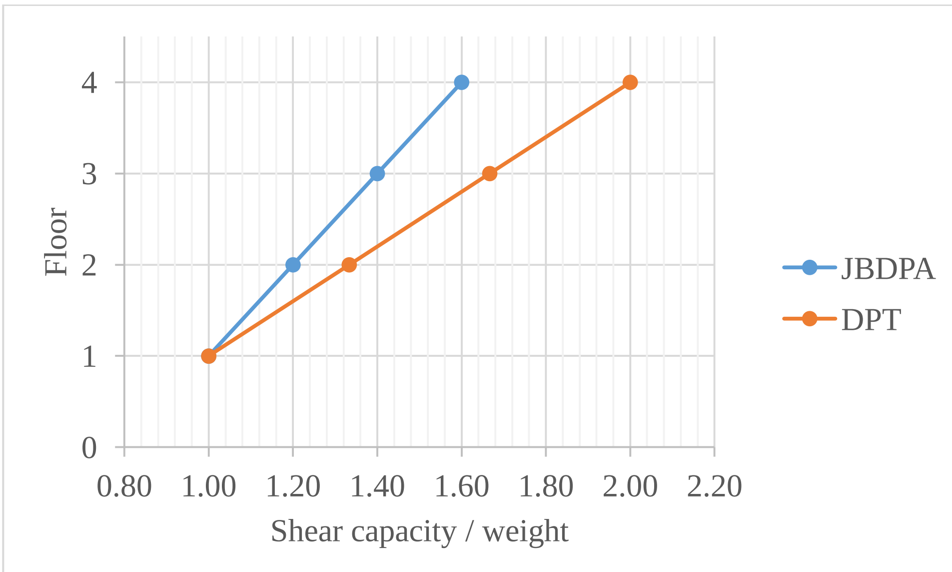

Figure 9. Shear capacity per weight of JBDPA and DPT.

From Eq. 15, the factor of shear capacity by weight $(1\ /F_{SSM})$ could be obtained as shown in Fig. 9. In order to compare the shear modification factor of JBDPA with lateral force in DPT 1302, Eq. 7 is considered as lateral force of each floor per cumulative weight and also plot into Fig.9

From Fig. 9, the DPT standard provides higher value of shear capacity per weight than JBDPA. However, the DPT standard needs more details to compute this value. Probably, equivalent shear modification factor $(\frac{n+1}{n+i}{}')$ could calculate by cumulative weight divided by cumulative shearforce of each floor from the vertical distribution of the pseudo lateral load as shown in Fig. 8 (Story-shear modification, Proposed line)

4.3 Strength and Ductility Index

The shear strength of column is the main parameter to evaluate in the first level screening in JDBPA standard. This value depends on the slenderness of column as illustrated in Table 1 and Fig. 3. For this part, the experimental data of Thai's building should be prepared in the near future. The average shear strength should follow the JDBPA standard as shown in Table 1. However, ductility index is always equal to 1.0 for ordinary reinforced concrete in Thailand while equal to 0.8 for brittle short column.

Finally, the proposed procedure is presented as flow diagram in Fig.10.

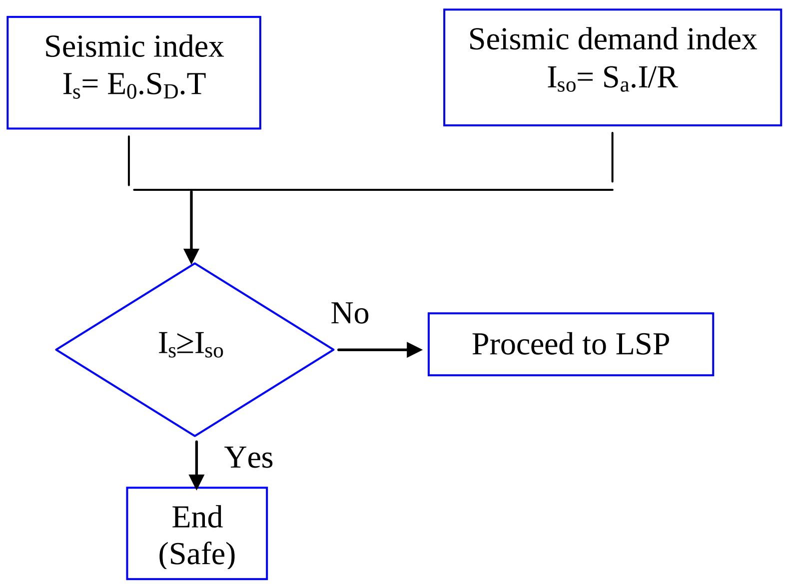

Figure 10. Flow diagram of the proposed seismicscreeningof existing RC buildings.

5. Conclusion

Based on this study, the following conclusions can be drawn:

1. The structural properties such as strength and ductility index follow the JDBPA standard while story-shear modification factors could be computed by using cumulative weight divided by cumulative shear-force of each floor from the DPT's vertical distribution of the pseudo lateral load.

2. The seismic force is estimated by the DPT 1302 standard while the intensity is based on the DPT 1303 standard. However, the Seismic Demand Index is adjusted by response modification coefficient of the DPT 1302 standard as described in this article. However, to obtain such actual critical values for Thailand may be obtained by collecting the field data in future.
3. To mitigate the earthquake disaster, an alternative rapid method for seismic evaluation of existing reinforce concrete buildings in Thailand is more cost effective.

The proposed simplified seismic evaluation method is applied to the earliest screening stage before proceeding to the Linear Static Procedure(LSP) in the northern Thailand. The target building is the reinforced concrete moment resisting frame building of up to four stories. Seismic evaluation is basically based on the performance as per the Thai DPT 1303 standard.

5. Acknowledgements

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