A New Earthquake Resistant Design Standard for Buildings in Thailand

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***Abstract*— The first seismic regulation in Thailand was issued in 1997 and followed by the design standard which has been published since 2009. Recent understandings of regional seismic hazard and new findings from researches have identified some key amendments for the standard. This paper presents major revisions of the 2018 standard as following contents; updated probabilistic seismic hazard assessments, new design spectral acceleration for Bangkok and vicinity area considering deep basin effects, seismic detailing requirements for concrete moment frames, recommendations for RC frames with masonry infill walls, seismic load for foundation design, revision of seismic detailing requirements, modification of response spectrum analysis procedure and miscellaneous amendments.**

Keywords—Earthquake Resistant design standard, reinforced concrete, building, Thailand

I. Introduction

Thailand is situated in low to moderate seismicity area. Seismic risks in the country can be classified as two main categories; medium scale earthquakes from active faults in the northern and western parts of the country and large scale distant earthquake from highly active subduction zone in Andaman Sea. Occasional earthquakes have indicated substantial risks in several parts of the country. The seismic regulation for buildings was firstly issued in 2540 B.E. (A.D. 1997) as the Ministerial Regulation No. 49 [1] and it was superseded later by the revision version in 2550 B.E. (A.D. 2007). These regulations were established based on the model code of the Uniform Building Code (UBC) 1985 edition. The regulation is enforced only in some areas and the calculation of seismic load by equivalent static force procedure is only enacted without other requirements for the design such as structural detailing and configuration. In 2009, the Department of Public Works and Town & Country Planning (DPT) issued the first edition of seismic design standard for buildings in Thailand [2] to provide detailed descriptions and modern procedures. The framework in the standard was based on the ASCE-7, 2005 edition. The standard has been officially approved as an alternative of the Ministerial Regulation 2550 B.E. After the standard has been issued, Thailand has experienced a number of moderate earthquakes which increased public awareness for seismic safety. These events include the 24 March 2011 Mw 6.8 Tarlay earthquake in Myanmar, the 4.3 Magnitude earthquake in Phuket on 24 March 2012 and the 5 May 2014 Mw 6.1 Mae Lao earthquake in Chiangrai which caused extensive losses to the community. In addition, better understandings of seismic hazard of the country including updated earthquake records from national and regional seismic network stations, more studies of crustal faults in and near Thailand from recent paleoseismic investigation carried out mainly by Department of Mineral Resources and research developments for particular characteristics of Thailand's seismic risks have indicated some necessary amendments to the standard which had not been considered in the first edition. Consequently, there is an important need for amendment of the standard to be appropriate with the recent information. Therefore, the Department of Public Works and Town & Country Planning has arranged a working research team for conducting studies and provide rational supports for the amendment of the standard. The following sections describe the main studied activities and results for the revision.

II. Updated Probabilistic Seismic Hazard Assessment

In the first part of the study, probabilistic seismic hazard maps are updated to account for new data that have been obtained since the maps in DPT 1302-52 were released [3], applying the Frankel (1995) [4] approach with crustal fault and subduction zone models. An earthquake catalogue for the study region which has been extended from 1912 to 2007 by including recent events from 2008 to 2014 was compiled comprehensively. By increasing observation time, recent damaging tremors have also been included, e.g. 24 March 2011 Mw 6.8 Tarlay earthquake in Myanmar and 5 May 2014 Mw 6.1 Mae Lao earthquake in Chiangrai. The observed ground motions were acquired from Thai

Metrological Department (TMD), Department of Mineral Resources (DMR), Royal Irrigation Department (RID) for data across Thailand and international organizations such as USGS and ISC-GEM for regional data. Subsequent processing of catalogue data and reviewed of new crustal faults in and near Thailand is mainly obtained from recent paleoseismic investigation carried out by several agencies, e.g. Department of mineral resources (DMR) 2012 [5], Earth Observatory of Singapore (EOS) 2013 [6]. The results of the analysis present the spectral acceleration (SA) at 0.2 second and 1.0 second with 2 % probability of exceedance in 50 years for defining Maximum Considered Earthquake (MCE) ground motions [7]. The updated ground motion hazard maps are provided for all districts in the country, excluding Bangkok and vicinity area where the designed SA is incorporated with site effects from soft sediments and the contents will be discussed in the next topic. The updated SA at 0.2 second shows that the highest hazard zone is in the northern and western parts of Thailand due to ongoing observed seismicity and local active faults. In addition, the 2018 seismic hazard in the southern part of Thailand increase the SA at 0.2 second to be at a similar value of the north-eastern part such as Loei, Nong Khai or Bueng Kan provinces. Changes in hazard is mainly due to observed series of earthquake near Ranong and Khlong Marui faults. On the other hand, there is no significant change for seismic hazard map for SA at 0.2 second for other areas, as well as SA 1.0 second for the entire country. Figure 1 shows the updated SA at 0.2 second and at 1.0 sec with 2 % probability of exceedance in 50 year.

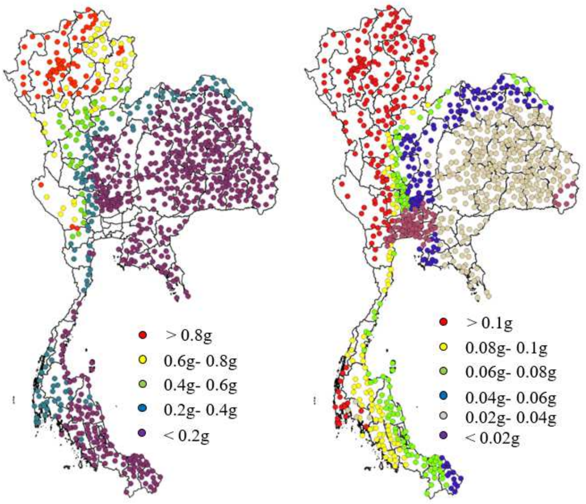

Fig. 1. *Maps of new design SA at 0.2 sec (left) and at 1.0 sec (right) with 2 % probability of exceedance in 50 year*

III. NEW DESIGN SPECTRAL ACCELERATION FOR BANGKOK AND VICINITY AREA CONSIDERING DEEP BASIN EFFECTS

The problem of soil amplification of ground motions due to soft sediments has been observed in several past earthquakes. Bangkok and the vicinity areas are situated on a large plain underlain by the thick alluvial and deltaic sediments of the Chaophraya Basin, and therefore the areas are susceptible to the large magnitude-teleseismic earthquakes. The design SA specified in the DPT 1302-52 standard [2] were established based on the data of site characteristics available in the past. However, recent studies [8,9] have revealed several key features of site characteristics which are important for improving the current standard. In this part, seismic site effects of Bangkok and the vicinity area focusing on deep basin structures were examined in order to establish the SA appropriate for design of structures. The areas of study cover Bangkok, Nonthaburi, Pathumthani, Samut Prakan, Samut Sakhon, Samut Songkram and some parts of Phra Nakhon Si Ayutthaya, Nakhonpathom, Chachoengsao, Nakhon Nayok, Prachinburi, Petchaburi, Ratchaburi and Chonburi. Investigations of site characteristics were conducted by microtremor observations to explore shear wave velocity profiles from surface to bedrock. The array microtremor technique employed was the Centerless Circular Array (CCA) method [10], which could provide long detectable wavelength and deep exploration depth. Then, site response analysis was conducted in order to examine the ground response and to propose seismic microzonation accordingly.

The representative ground motions from the updated seismic hazard assessment in the first part were input as rock outcrop acceleration time history and the propagations through the model of soil profiles were analyzed by an equivalent linear analysis [11]. From strong motion database, the input motions having the same mechanism of occurrence were selected and scaled to match response spectra with the conditional mean spectrum (CMS) at 0.2, 0.5, 1.0, 2.0 and 3.0 second, for 2475 years return period. Then the average spectral accelerations were used to evaluate the Maximum Credible Earthquake (MCE) design spectrum for each site. The average SA were compared with the valued specified in the DPT 1302-52 standard [2] and significant differences could be observed in several areas. For example, the new SA of Bangkok is about 25% higher at period of 1.0 second but it is lower for 28% at long period of 6.0 second. The results of spectral accelerations for neighboring sites were considered for their similarity and consequently the area was sub-divided into 10 different zones. The shape of the spectral accelerations were the key indications for the seismic microzonation. The updated design spectral accelerations are then proposed in the revised standard. Figure 2 and 3 show the proposed boundary of 10 zones and their design SA, respectively.

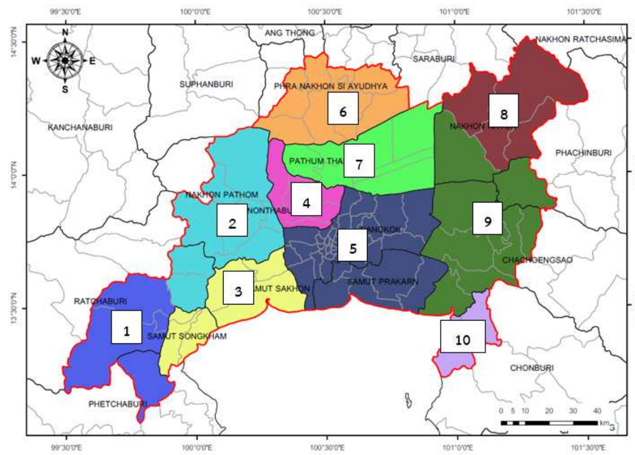

Fig. 2. *Microzonation map based of the design SA for Bangkok and vicinity area*

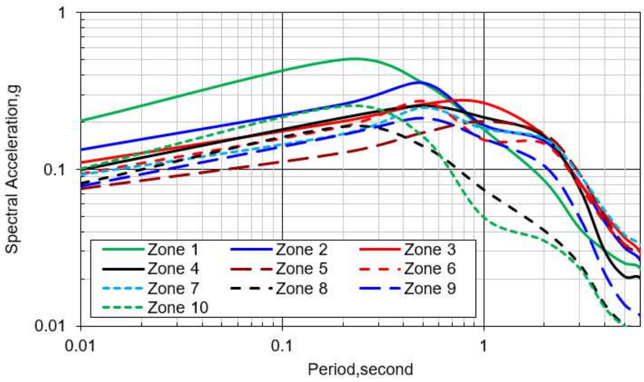

Fig. 3. *New design spectral acceleration for 10 zones in Bangkok and vicinity area*

IV. SEISMIC DETAILING REQUIREMENTS FOR CONCRETE MOMENT FRAMES

Reinforced concrete moment frames and walls in most building codes can be broadly classified into three categories namely ordinary, with limited ductility, intermediate, with moderate ductility, and special, with considerable ductility. Specific detailing requirements and available ductility vary among the codes. In general, the major differences in the design of these structures lie in the level of design forces (the higher the available ductility, the lower the design forces), detailing requirements, and capacity design provisions for critical elements such as columns, beam-to-column joints, etc. The limitations on the use of these structures also vary among various codes. Some codes restrict the use of structures with intermediate ductility to only the areas with moderate seismic hazard while some codes allow them to be used in areas with higher seismic hazard levels. The current DPT 1302-52 [2] follows the former type where structures with intermediate ductility are only allowed in the moderate seismic areas defined by Seismic Design Category (SDC) C. The seismic hazard level in the Thai standard is defined based on the SDC similar to the one given in the ASCE 7 [12]. For the design of regular building structures in many areas near the major faults in Thailand as well as the design of important building structures in Bangkok fall into SDC D. As such, structures with intermediate ductility are not allowed in these cases.

In revising the standard, the restrictions on the use of structures with intermediate ductility are reviewed and revised to allow them to be used in areas with higher seismic hazard. Based on this study, it was found that some standards allow for the wider use of structures with intermediate ductility in areas with higher seismicity defined by the current SDC D in DPT 1302-52 [2]. Therefore in this revision, the limitations on the application of structures with intermediate ductility have been modified. It is possible to use structures with intermediate ductility under wider circumstances. However, these requirements apply.

a) In areas with high seismicity, the structures with intermediate ductility detailing are allowed (but are not encouraged). In these areas, structures with intermediate ductility are allowed up to the height of 40 meters for moment frames and 60 meters for shear walls. However, the structures must be designed with 40% higher forces (corresponding to lowering the response modification factor (R) value to 70% of the specified values.)

b) In cases where taller structures with intermediate ductility are used, in-depth calculation and performance assessment must be carried out to ensure that compressive strain, shear force, etc., in critical elements do not exceed the required limits corresponding to the provided level of detailing both for the Design Basis and Maximum Considered Earthquakes. The evaluation can be based on the use of an established procedure or from cyclic testing.

V. RECOMMENDATIONS FOR RC FRAMES WITH MASONRY INFILL WALLS

RC frames with masonry infill walls account for the largest building stocks in Thailand particularly for low- to medium-rise buildings. Based on past research results and response of such buildings in past earthquakes, it is well known that the interaction between the frame and the infill walls can have significant effects on the response of the structure even though these infill walls are generally considered as non-structural elements. Research carried out in Thailand on the response of an RC frame with infill wall constructed using local practice and materials has indicated that the infill wall can increase the strength and stiffness of the frame by more than 3 times. More significantly it has shown that the interaction between the wall and the frame can lead to an undesirable failure mode such as column shear failure. The current DPT 1302-52 standard [2] does not explicitly specify how the infill masonry walls should be considered. Infill walls are treated differently in various national building codes. In general, the code approaches for considering the infill walls fall into two categories, those that consider the strength and stiffness of the infill wall and those require the infill walls to be isolated from the main frames. For this revision, studies were carried out to review various approaches to handle masonry infill walls and also to obtain data on the key design parameters as well as local material properties. Based on these studies, the revised standard now provides the following.

a) Minimum detailing requirement for frame members, especially the columns, surrounding an infill wall. Ductile detailing is now required when infill walls are present either on one side or both sides of the column

b) Recommendations for collapse prevention including explicit shear calculation in the column due to compression strut force from the infill wall, captive column failure prevention, and design against soft story collapse due to irregularity caused by infill walls.

c) Recommendations for suitable modelling techniques that can capture wall-frame interaction in case an in-depth performance evaluation is required.

VI. SEISMIC LOAD FOR FOUNDATION DESIGN

In seismic design of structure, the lateral force is based on an inelastic behavior of a structure. The behavior of super-structure is to deform beyond elastic limit and allows yielding in the plastic hinge region of beams where the hysteretic energy is absorbed and dissipated under inelastic behavior. When the applied force is transferred to the foundation, the foundation shall be able to resist the same lateral force and it may absorb some hysteretic energy as well as the super-structure. The important step of seismic design of foundation is to determine the load combination imposed to the foundation due to gravity and earthquake loads. However, the DPT Standard 1302-52 [2] does not provide a procedure to calculate the lateral force and load combinations for the design of foundation. In this revision, the concept of inelastic foundation is adopted. A study of seismic performance of the inelastic foundation was conducted. A four-storey building that is the standard school building of the Ministry of Education in Thailand was selected as a case study. The structure has been designed as ductile/special reinforced concrete moment resisting frame (SMRF) based on the equivalent static force procedure according to the DPT 1302-52 [2]. In the analysis of seismic performance, the structure and foundation system were modeled by using Ruaumoko [13]. The inelastic behavior of beam and column members was modeled to allow yielding at one or both ends of the members. For the foundation model, the tie beam between the foundations was modeled to absorb and dissipate energy, the same as the beams of the super-structure. The soil-structure interaction effect was taken into account by applying the horizontal and the vertical springs with the stiffness proposed by Wolf (1994) [14]. The seismic performance of the structure and foundation was analyzed by using Nonlinear Static Analysis (Pushover Method). The result was compared with Nonlinear Time History Analyses (NTHA) with seven pairs of ground motions. It was found that the seismic capacity based on the ultimate base shear was much greater than the design base shear. An over-strength factor Ω_0 of 3.72 was obtained from the ratio of the ultimate base shear and the design base shear. This value is about 24% greater than the over-strength factor (Ω_0 =3.0) as suggested by DPT 1302-52 [2] and ASCE-7 [12]. Therefore, the foundation is to resist this ultimate base shear under the actual earthquake loading. For the seismic design, the design base shear has to be multiplied by an over-strength factor to resist the actual base shear.

To adopt this concept in the improved DPT 1302 standard, detailed procedures of foundation design have been added as follows:

a) The procedure to determine the load combination due to gravity and earthquake loading for foundation design. Special emphasis in the determination of the lateral shear force was taken into account. The design shear force shall be multiplied by an over-strength factor to account of the actual base shear.

b) The foundation shall be evaluated for the safety against the load carrying capacity, the sliding shear, the overturning moment, including the shear strength of the pedestals and piles.

In addition, a detailed design example of pile foundations and tie beams of a four-storey building is used to illustrate the seismic design of foundation in the guideline.

VII. Revision of Seismic Detailing Requirements

The DPT 1302-52 standard [2] has introduced several types of structural system and different design factors accordingly such as Response modification factor (R), Overstrength factor $\left(\Omega_0\right)$ and Deflection amplification factor $\left(C_d\right)$. These factors are determined based on ductility as well as structural detailing in member components. However, in the DPT standard, the seismic detailing requirements are provided only for the intermediate RC moment-resisting frame system. The DPT 1302-52 [2] is also applicable for the special reinforced concrete moment-resisting frame and the special reinforced concrete shear wall but the seismic detailing requirements for these structures are not presented in the standard. Moreover, for important building structures such as a hospital in Bangkok area, the DPT 1302-52 [2] does not allow to use the ordinary RC shear wall but special RC shear wall system.

Therefore, this revision adds the seismic detailing of for the special reinforced concrete moment-resisting frame and the special reinforced concrete shear wall. The revised contents of the seismic detailing are as follows:

- Provisions for beams of special moment frames
- Provisions for columns of special moment frames
- Provisions for joints of special moment frames
- Provisions for special structural walls and coupling beams

In addition, recommendations for design of RC wall, from recent researches and observed damages from 2010 Maule Chile earthquake are provided in an appendix to prevent some possible scenarios of damage.

VIII. Modification of Response Spectrum Analysis Procedure

Many previous researchers have demonstrated the problem of shear force demands in shear walls by using nonlinear response history analysis (NLRHA), which is the most accurate seismic analysis method, such that shear force demands computed from NLRHA are larger than design shear forces computed from response spectrum analysis (RSA) procedure.

Blakeley et al. (1975) [15] observed that shear forces in shear walls of tall buildings determined by such RSA procedure are much lower than those computed by NLRHA. Many research works have confirmed this observation and proposed modifications to RSA procedure for computing shear forces in shear walls of tall buildings, for example, Eibl and Keintzel (1988), Priestley (2003) [16], Rejec et al. (2012) [17], Calugaru and Panagiotou (2012) [18]. Munir and Warnitchai (2012) [19] explained that the flexural yielding at the base of shear wall is effective in limiting seismic demands of the first mode, but not for higher modes, so using factor to reduce elastic demands is valid for the first mode but not for higher modes. Typically, higher-mode contributions to seismic responses are significant in tall buildings. This implies that the RSA procedure currently stipulated in ASCE 7 [12] and DPT 1302-52 [2] could significantly underestimate seismic forces in tall buildings because factor is used to divide elastic force demand due to all modes.

Although ASCE 7 [12], which is the model code of DPT 1302-52 [2], has not yet addressed this shear demand problem in shear walls, however Eurocode 8 [20] of Europe, NBCC (2010) [21] of Canada, and NZS 3101 (2006) [22] in Appendix D1 of New Zealand have already addressed this problem by multiplying design shear forces with an amplification factor to account for higher-mode effects and flexural over-strength factor inherent in design. One of reasons that the US practice has not included this problem in

ASCE 7 [12] for design of tall buildings could be that NLRHA is directly used for verification of the design of tall buildings according to Tall Building Initiative (PEER, 2017) or an Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region (LATBSDC, 2017).

However, most structural engineers in Thailand are not familiar with time history analysis and still prefer the RSA procedure to analyze and design of tall buildings. Hence, the design of shear resistance in structural walls is not safe if the conventional RSA procedure is used. Therefore, it is necessary to improve the calculation method for computing shear forces for use in design of vertical structural members. The column sections in tall buildings in Thailand usually have long aspect ratio similar to walls, so it is suggested to use the improved method with vertical structural members both columns and walls. The improved method involves calculation of shear forces for use in the design of shear resistance of each vertical structural members in a building. In the improved method, shear forces from the fundamental mode are multiplied with the over-strength factor and divided by the response modification factor (R), whereas shear forces in higher modes are not divided by R, and the total design shear forces are obtained by combining shear forces from the first few modes in the same way as the conventional RSA method. The improved method has the same basic concept as that used in the shear magnification factor in Eurocode 8 [20] and as that suggested by Priestley and Amaris (2003) [16]. The improved method is called Modified RSA (MRSA), which provides design shear forces more accurate and larger than the conventional RSA method and is safe to use.

The accuracy of the conventional RSA and the proposed MRSA procedures was evaluated by comparing the computed demands with NLRHA results. Six tall RC shear wall buildings of 15 to 39 stories and four RC frame buildings of 3 to 15 stories subjected to earthquake ground motions in two different cities, Bangkok and Chiang Mai, were used. It was found that RSA could be used to compute floor displacements and story drifts. With ductile detailing locations estimated from the proposed MRSA method, bending moments computed from RSA could be used for design. Shear forces from MRSA method should be used for design as it significantly improves the underestimation of RSA method and generally provides good accuracy when compared to NLRHA for all case-study buildings.

In addition, the revised standard DPT-1302 proposes a method to estimate inelastic strains that are likely to occur due to the design earthquake by considering combined effect of axial force and bending moment in the vertical structural member. The proposed method uses axial forces and bending moments from elastic analysis which is convenient and readily available for design engineers.

The procedure of the proposed MRSA method is summarized as follows:

1. Compute design bending moment from (1), design shear force from (2), design displacement from (3), and design drift from (4).

$$M = \frac{S_F \times I}{R}\sqrt{{M_{1e}}^2 + {M_{2e}}^2 + {M_{3e}}^2 + \cdots} \tag{1}$$

$$V = I\sqrt{\left(\frac{S_F \Omega_0 V_{1e}}{R}\right)^2 + {V_{2e}}^2 + {V_{3e}}^2 + \cdots} \tag{2}$$

$$\delta = \frac{C_d}{R}\sqrt{{\delta_{1e}}^2 + {\delta_{2e}}^2 + {\delta_{3e}}^2 + \cdots} \tag{3}$$

$$\Delta = \frac{C_d}{R}\sqrt{{\Delta_{1e}}^2 + {\Delta_{2e}}^2 + {\Delta_{3e}}^2 + \cdots} \tag{4}$$

2. Determine maximum strain of the wall and column by (5) and (6). Ductile detailing is required at the locations where the computed strain exceeds elastic limit, 0.002.

Tensile strain: $$\varepsilon_t = \frac{P}{E_c A_g} + \frac{M}{E_c I_{eff}}(c + \tfrac{1}{3}c_{\text{long}}) \tag{5}$$

Compressive strain: $$\varepsilon_c = \frac{P}{E_c A_g} - \frac{M}{E_c I_{eff}}(c - \tfrac{1}{3}c_{\text{long}}) \tag{6}$$

where I is the important factor; M_{ie} , V_{ie} , δ_{ie} and Δ_{ie} are the elastic bending moment, shear force, displacement, and drift contributed by mode i , respectively; S_F is the scaling factor computed by $0.85 V_s / V_t$ and is not less than one; V_s is base shear computed from ELF, and V_t is modal base shear computed from conventional RSA, not from MRSA.

ε_t and ε_c are the maximum tensile and compressive strains, respectively; M and P are the elastic bending moment and axial force computed from linear RSA combined with factored gravity load, respectively; c is the distance from elastic neutral axis to the location where strain is being computed; c_{long} is defined as the longer distance measured from elastic neutral axis to either edge of the wall or column; A_g is the gross cross-section of the wall or column; E_c is the Young's modulus of concrete; I_{eff} is the effective moment of inertia of cross-section of the wall or column computed by (7), which is taken from Table 6.6.3.1.1(b) of ACI 318M-14 [23].

$$0.35 I_g \le I_{eff} = \left(0.80 + 25\frac{A_{st}}{A_g}\right)\left(1 - \frac{M_u}{P_u h} - 0.5\frac{P_u}{P_0}\right) I_g \le 0.875 I_g \tag{7}$$

Where I_g is the gross moment of inertia; A_{st} is the area of vertical reinforcement in the wall or column; M_u and P_u are the design bending moment and axial force of the wall or column that produce the least value of I_{eff} ; h is the depth of the column or the length of the wall; and P_0 is the nominal axial strength at zero eccentricity.

IX. Miscellaneous Amendments

The new DPT 1302 standard is amended in the followings issues to clarify the design procedures and provisions with an aim to provide clear understandings for practices.

- The contents of examples are amended according to the updated contents and new examples and explanations are added.
- The standard provides recommendations for good practices of the design such as recommendation for design of RC wall, recommendation for seismic design of non-structural components and recommendation for model and analysis of infill wall-structure interactions.
- The DPT 1301-54 (standard for structural detailing and configurations) [24] is combined into this updated DPT 1302 standard in order to unify the seismic design standard for building and to facilitate the use of the standard.
- The ground motions based on the Maximum Creditable Earthquake (MCE) are provided for time history analysis procedure. For Bangkok and vicinity area, the ground motions are specified by Conditional Mean Spectrum (CMS) concept at period of 0.2, 0.5, 1.0, 1.5, 2.0 and 3.0 second. For other area, the ground motions for moderate, high and very high seismicity are provided at 0.2 and 1.0 second.

X. Concluding Remarks

This paper presents progress of earthquake resistant design standard for Buildings in Thailand. The seismic provisions have been developing over the period since the first regulation in 1997. Recent understandings of the regional seismicity and structural performance have resulted in these developments. This paper presents main activities for the current revision of the seismic design standard. These take into account several issues; from probabilistic seismic hazard assessment to structural detailing design, and proposes new concepts of the standard from comprehensive studies. In spite of this state-of-the-art development, since the Thailand's seismicity is at low to moderate level, lack of complete information is a major obstacle. In addition to a rational standard, law enforcement and construction inspection are yet to be more encouraged. For practicing engineers, education and training are very much important.

Acknowledgment

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