Seismic Design Force for Buildings in Taiwan

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SUMMARY:
The current seismic design code for buildings in Taiwan was minor revised and issued in 2011. The objective of this paper is to point out the revision compared with the previous version, and further, to express the static and dynamic procedures to determine the seismic demand specified by the new code. For the design level with a return period of 475 years, the design spectral response acceleration can be developed for general sites, near-fault sites and Taipei Basin. In addition, in order to avoid the collapse of building during the extremely large earthquake and the yield of structural components and elements during the frequently small earthquakes, the required seismic demands at maximum considered earthquake level (MCE, 2%/50 years) and operational level are also included in the new seismic design code. For the dynamic analysis procedures, both the response spectrum method and the time history method are specified in the current seismic design code.

Keywords: seismic design code, basin effect, near-fault demand

1. GENERAL INTRODUCTION

Taiwan is located in the circum-Pacific earthquake belt, and most building designs are controlled by seismic loads. Seismic design codes have to be periodically revised to reflect the latest findings from both research and practice. In 1974 Taiwan implemented, seismic force requirements (SFR) for building structures based on the format of the US Uniform Building Code. In 1982, the important factors for various building occupancy categories were further incorporated into the SFR. After the Mexico Earthquake in 1985, the importance of the fundamental vibration of the Taipei Basin was recognized and a specific acceleration response spectrum was incorporated into the SFR in 1989.

In 1997, the SFR underwent major changes. These changes include the dynamic analysis procedures using the response spectrum method, the number of seismic zones increased from 3 to 4, and the zoning factor directly represents the design peak ground acceleration associated with a hazard level of 10% chance of exceedance in 50 years (10/50 event). In addition, the force reduction factors associated with any one specific structural system follow the Newmark and Hall recommendations. Hence, the force reduction factor varies depending on the fundamental vibration periods of a given structural system. Three months after the 1999 Chi-Chi Earthquake, a change in the building codes was released that temporarily reduced the number of Taiwan seismic zones from 4 to 2. Based on the 1997 version of seismic design code, the elastic seismic demand is defined by the spectral acceleration as $S_A(T)=ZC(T)$, where $C(T)$ is the normalized response spectrum coefficient, and Z is the zoning factor that means the design ground acceleration corresponding to a return period of 475 years. However, in 2005 version, instead of the zoning factor Z, the mapped design spectral response acceleration parameters are determined directly based on the uniform hazard analysis at a return period of 475 years. The 5%-damped spectral response acceleration for short periods and at 1.0 second are prescribed for each municipal unit such as a village, town or city. In addition, the site-adjusted spectral response acceleration parameters for short periods and 1.0 second structures can be defined by multiplying the mapped values with the site coefficients to incorporate the local site effects. The design spectral response acceleration can then be computed on the basis of the site-adjusted spectral response acceleration parameters. Thus, it can be used to determine the design base shear.

In recent years, people have learned that near-fault ground motions have many different characteristics from the far-field ones, and the near-fault ground motions will cause much more damage. Prior to the 1994 Northridge earthquake, the near source effects were particularly addressed by SEAOC for the UBC97. In Taiwan, more and more studies related to the near-fault effect are developed after the Chi-Chi earthquake (1999). The so-called near-fault factors N_A and N_V are introduced to consider the near-fault effect (Chai *et al.*, 2000; Chai *et al.*, 2001). Two near-fault factors defined for the short period (acceleration control) and long period (velocity control) domains are needed because the effect is substantially greater at longer periods. In the 2005 version of seismic design code, the values for the near-fault factors N_A and N_V are defined for several active faults. It should be noted that the near-fault factors are determined by the characteristic earthquake model as well as the seismic hazard analysis for Taiwan area, and they are functions of the distance from the fault.

For Taipei Basin, based on the 1997 version of seismic design code, the zoning factor Z=0.23g and the normalized response spectrum coefficient is defined by C=2.5 and C=3.3/T for the short and moderate period range, respectively. However, the uniform seismic demand can not reflect the real basin effect due to the varied thickness of the sedimentary soil layers in Taipei Basin. Therefore, in 2005 version, four seismic micro-zones were defined for the Taipei Basin to reflect the observed basin effects. The specific value of the corner period T_0 between the short and the moderate period ranges of the design response spectrum were defined for each micro-zone. Thus, applying the uniform hazard analysis, design spectral response acceleration values for structures in Taipei Basin can be determined directly from the design spectral response acceleration for short period structures as well as from the corner period T_0 prescribed for each micro-zone. In 2011, the microzonation for Taipei Basin was modified, and the number of seismic micro-zones was reduced from four to three (Chang *et al*, 2008).

In addition to the seismic demand considered for the 10/50 hazard, the seismic demand imposed by the maximum considered earthquake (MCE) was also incorporated into the current seismic building provisions in order to avoid the collapse of buildings during an extremely large earthquake. In the current seismic building code, the MCE hazard level is defined as a seismic hazard level of 2% probability of exceedance within 50 years (2/50 hazard or a return period of 2500 years). Furthermore, in order to avoid any nonlinear demand on the structural elements during a frequently occurring small earthquake, a minimum seismic force (MSF) requirement is prescribed in the current seismic code. The final base shear for the elastic structural design is governed by the larger of the base shears determined at the design level (using a reduced ductility capacity against the 10/50 hazard) and the MCE level (using the full system ductility against the 2/50 hazard). Nevertheless, it should never be less than the MSF requirement. For the dynamic analysis procedures, both the response spectrum method and the time history method are specified in the new seismic design code for buildings in Taiwan.

2. STATIC ANALYSIS PROCEDURES

2.1 Seismic design base shear for general sites

In the current seismic building code in Taiwan, the elastic seismic demand is represented by the design spectral response acceleration, S_{aD}, corresponding to a uniform seismic hazard level of 10% probability of exceedance within 50 years. Based on the uniform hazard analysis, the mapped design 5%-damped spectral response acceleration at short periods (S_S^D) and at 1 second (S_1^D) have been tabulated for each municipal unit of village, town or city level. For the sake of simplicity, only four levels of S_S^D and S_1^D were defined for both the 10/50 and the 2/50 hazard levels as shown in Table 2.1, and the distribution is shown in Fig.1.

The mapped spectral response acceleration parameters must be modified using the site coefficients in order to include the local site effects. Thus, the site-adjusted spectral response accelerations at short periods (S_{DS}) and at 1.0 second (S_{D1}) are expressed as:

$$S_{DS} = F_a S_S^D \quad ; \quad S_{D1} = F_v S_1^D \tag{2.1}$$

where site coefficients F_a and F_v are given in Table 2.2. These coefficients are functions of the soil type and the mapped spectral response acceleration parameters, S_S^D for F_a and S_1^D for F_v, respectively. From the above provisions it is evident that the non-linear amplification effects of soil layers have been considered. Based on the soil structure in the upper 30 meters below the ground surface, a given site can be classified into S1 (Hard site) with V_{S30}>270 m/s, S2 (Normal site) with 180≤ V_{S30}≤270 m/s and S3 (Soft site) with V_{S30}<180 m/s, respectively. As specified in the 2011 version, the site class parameter V_{S30} is defined as the averaged shear wave velocity for all soil layers in the top 30 meters, and is determined by:

$$V_{S30} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \left(d_i / V_{si} \right)} \tag{2.2}$$

where V_{si} is the shear wave velocity, and d_i is the thickness of any soil layer in the top 30 meters ($\sum_{i=1}^{n} d_i = 30$ m). The shear wave velocity at any soil layer can be obtained from the PS logging data, or estimated by the following equations:

$$\text{for a cohesive soil layer:} \quad V_{si} = \begin{cases} 120 q_{ui}^{0.36} & ; \quad N_i < 2 \\ 100 N_i^{1/3} & ; \quad 2 \le N_i \le 25 \end{cases} \tag{2.3.a}$$

$$\text{for a cohesionless soil layer:} \quad V_{si} = 80 N_i^{1/3} \quad ; \quad 1 \le N_i \le 50 \tag{2.3.b}$$

where N_i is the standard penetration resistance as measured in the field without corrections, and q_{ui} is the unconfined compression strength (in kgf/cm^2).

Table 2.1. Values of mapped spectral response acceleration parameters

10%/50 year					2%/50 year				
S_S^D (g)	0.8	0.7	0.6	0.5	S_S^M (g)	1.0	0.9	0.8	0.7
S_1^D (g)	0.45	0.40	0.35	0.30	S_1^M (g)	0.55	0.50	0.45	0.40

Table 2.2. Values of site coefficients F_a and F_v

Site Class	Values of F_a					Values of F_v				
	S_S≤0.5	S_S =0.6	S_S =0.7	S_S =0.8	S_S ≥0.9	S_1≤0.3	S_1 =0.35	S_1=0.4	S_1=0.45	S_1 ≥0.5
Hard site	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Normal site	1.1	1.1	1.0	1.0	1.0	1.5	1.4	1.3	1.2	1.1
Soft site	1.2	1.2	1.1	1.0	1.0	1.8	1.7	1.6	1.5	1.4

Note: S_S and S_1 may be S_S^D, S_S^M, $N_A S_S^D$ or $N_A S_S^M$ and S_1^D, S_1^M, $N_V S_1^D$ or $N_V S_1^M$ for different cases.
Straight-line interpolation is used for the intermediate values of S_S and S_1.

Based on the site-adjusted spectral response acceleration parameters S_{DS} and S_{D1}, the design spectral response acceleration S_{aD} for a given structure can be developed by using the following:

$$S_{aD} = \begin{cases} S_{DS}\left(0.4 + 3T/T_0\right) & ; \quad T \le 0.2T_0 \\ S_{DS} & ; \quad 0.2T_0 < T \le T_0 \\ S_{D1}/T & ; \quad T_0 < T \le 2.5T_0 \\ 0.4 S_{DS} & ; \quad T > 2.5T_0 \end{cases} \qquad \text{with} \qquad T_0 = \frac{S_{D1}}{S_{DS}} \tag{2.4}$$

where T is the structure's fundamental period given in seconds. The shape of the design response spectrum is illustrated in Fig. 2.

The fundamental period can be determined by the following approximate equations:

(1) Moment resisting frame systems not enclosed or adjoined by more rigid components that will

prevent the frames from deflecting under seismic forces:

Steel moment-resisting frame: $T = 0.085 h_n^{3/4}$

RC or SRC moment-resisting frame: $T = 0.07 h_n^{3/4}$

(2) Eccentrically braced steel frames: $T = 0.07 h_n^{3/4}$

(3) Others: $T = 0.05 h_n^{3/4}$

where h_n is the height (in meters) of the building above the base. In addition, the fundamental period can also be estimated by a properly substantiated analysis. However, the estimated period shall not exceed the product of the approximate fundamental period and the coefficient for the upper limit of the calculated period, and as specified in the 2011 version, the coefficient is defined by a constant C_u=1.4.

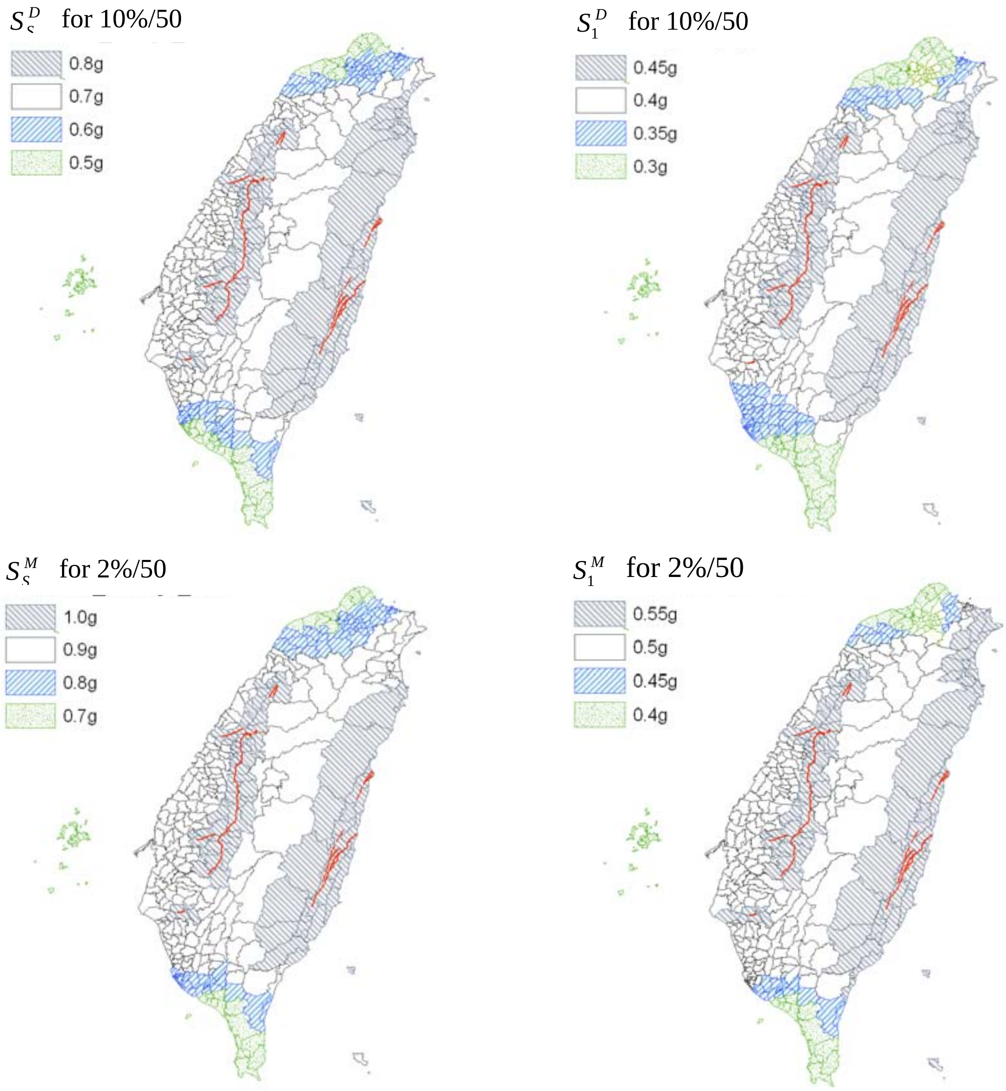

Figure 1. Mapped spectral response acceleration parameters for both 10%/50 and 2%/50 hazard levels

The structure system ductility capacity R of the structural system for most basic types of seismic-force-resisting system can be found in the seismic design code. For example, the R values for a special moment steel frame and a special concentrically braced frame are 4.8 and 4.0, respectively. However, in order to control the damage level under the design base earthquake (DBE), only two-thirds of the ultimate inelastic deformational capacity of the structural system is considered in the design. Therefore, the allowable ductility capacity R_a shall be defined according to the ductility capacity R as:

$$R_a = 1 + (R-1)/1.5 \quad \text{(for general sites and near-fault sites)} \tag{2.5}$$

In addition, the seismic force reduction factor F_u for the structural system can be defined by the allowable ductility capacity R_a and the fundamental period T of the structure as:

$$F_u = \begin{cases} R_a & ; \quad T \geq T_0 \\ \sqrt{2R_a - 1} + \left(R_a - \sqrt{2R_a - 1}\right) \times \dfrac{T - 0.6T_0}{0.4T_0} & ; \quad 0.6T_0 \leq T \leq T_0 \\ \sqrt{2R_a - 1} & ; \quad 0.2T_0 \leq T \leq 0.6T_0 \\ \sqrt{2R_a - 1} + \left(\sqrt{2R_a - 1} - 1\right) \times \dfrac{T - 0.2T_0}{0.2T_0} & ; \quad T \leq 0.2T_0 \end{cases} \tag{2.6}$$

This is based on the equal displacement principle between the elastic and the EPP systems for the long period range and the equal energy principle for short periods. As shown in Eq. (2.6), the structural period larger than T_0 is viewed as the long period range with T_0 being the corner period of the design response spectrum as defined by Eq. (2.4). On the other hand, the constant acceleration range is divided into two equal parts. The structural period in the range of $0.2T_0$ to $0.6T_0$ is defined as the short period range, and the linear interpolation is defined for the other part ($0.6T_0$ to T_0) between short and long period ranges. The linear interpolation is also adopted for a structural period less than $0.2T_0$, such that the reduction factor F_u will be equal to one when the structural period becomes zero. This is because there is no ductility capacity considered for a rigid body. Thus, the seismic design base shear is expressed as:

$$V = \frac{I}{1.4\alpha_y} \left(\frac{S_{aD}}{F_u} \right)_m W \tag{2.7}$$

and

$$\left(\frac{S_{aD}}{F_u} \right)_m = \begin{cases} S_{aD}/F_u & ; \quad S_{aD}/F_u \leq 0.3 \\ 0.52\left(S_{aD}/F_u\right) + 0.144 & ; \quad 0.3 < S_{aD}/F_u \leq 0.8 \\ 0.70\, S_{aD}/F_u & ; \quad S_{aD}/F_u > 0.8 \end{cases} \tag{2.8}$$

where I is the important factor, W is the total gravity dead load of the structure, α_y is defined as the first yield seismic force amplification factor that is dependent on the structure types and design method. For example, α_y=1.2 for steel structures using the allowable stress design method, and α_y=1.5 for RC structures using the strength design method. In addition, the constant 1.4 means the over-strength factor between the ultimate and the first yield force. This is somewhat dependent on the redundancy of the structural system, but is treated as a constant for the sake of simplicity. The modified ratio of $(S_{aD}/F_u)_m$ is defined to reduce the seismic demand, because a damping ratio higher than 5% can be considered due to the soil-structure interaction for short period structures.

2.2 Seismic design base shear for near-fault sites

In order to take the effects of near-fault ground motions into consideration in the seismic design of structures, the near-fault factors N_A and N_V are defined for several active faults in Taiwan. Within the proximity of these specific near-fault sites, the near-fault effects should be considered at the design level to improve the seismic design force requirements of these structures against near-fault ground motions. For these specific near-fault sites, the site-adjusted spectral response acceleration parameters S_{DS} and S_{D1} can be computed from:

$$S_{DS} = F_a N_A S_S^D \quad ; \quad S_{D1} = F_v N_V S_1^D \tag{2.9}$$

It should be noted that the associated site coefficients F_a and F_v must be evaluated from Table 2.2 on the basis of the near-fault spectral response acceleration parameters $N_A S_S^D$ and $N_V S_1^D$, respectively. The near-fault factors N_A and N_V are determined on the basis of the characteristic earthquake model as well as the seismic hazard analysis for the Taiwan area. They are expressed as functions of the distance between the building site and the interesting nearby fault.

Ultimately, the site-adjusted spectral response acceleration parameters must be applied to determine the design spectral response acceleration S_{aD} using Eq. (2.4). Then the near-fault design base shear can be determined by the same procedure as prescribed for general sites.

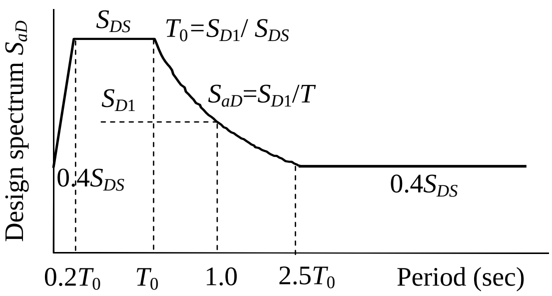

Figure 2. Design response spectrum developed by site-adjusted parameters S_{DS} and S_{D1}

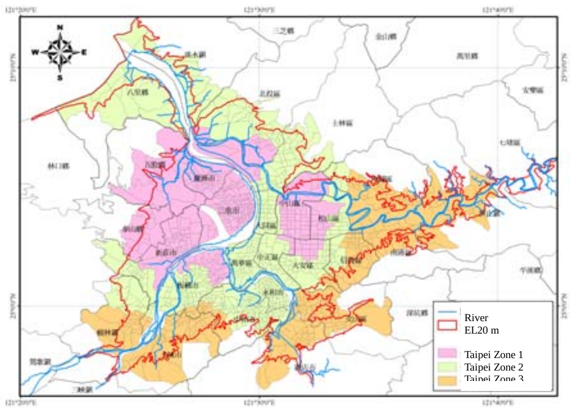

Figure 3. Distribution of the micro-zones and in Taipei Basin

2.3 Seismic design base shear for Taipei Basin

Due to the basin effects, the corner periods noted in the response spectra associated with the earthquake data observed in Taipei Basin are generally larger than 1.0 second. This implies that the aforementioned parameters S_{DS} and S_{D1} prescribed in the design response spectrum for general sites can not be applied directly for sites in the Taipei Basin. Therefore, it is based on the parameters of C=2.5 and $C=C_v/T$ for the normalized design response spectrum within the short and moderate period ranges, respectively. Parameter C_v and the associated corner period ($T_0=C_v/2.5$) can be determined from the observed strong ground motions from each observation station within the Taipei Basin. Then, based on the contours of parameter C_v and the boundaries of the municipal units, three seismic micro-zones are defined in Taipei Basin. The representative values of corner period T_0 between short and moderate period ranges of the design response spectrum are shown in Table 2.3.

In addition, based on the uniform hazard analysis, the design spectral response acceleration S_{aD} for an interesting site can be developed directly from the design spectral response acceleration at short periods S_{DS} (S_{DS}=0.6g) as well as the corner period T_0 for each seismic micro-zone in Taipei Basin, and can be expressed as:

Table 2.3. Representative values of corner period for each microzonation in Taipei Basin

Microzonation	S_{DS}	S_{MS}	T_0 (sec.)
Taipei Zone 1	0.6	0.8	1.60
Taipei Zone 2	0.6	0.8	1.30
Taipei Zone 3	0.6	0.8	1.05

$$S_{aD}=\begin{cases} S_{DS}\left(0.4+3T/T_0\right) & ; \quad T\le 0.2T_0 \\ S_{DS} & ; \quad 0.2T_0<T\le T_0 \\ S_{DS}T_0/T & ; \quad T_0<T\le 2.5T_0 \\ 0.4S_{DS} & ; \quad T>2.5T_0 \end{cases} \tag{2.10}$$

The distribution of the three micro-zones and the shapes of the corresponding design response spectrum in Taipei Basin are shown in Fig. 3. It should be noted that the distribution of the three micro-zones is in accordance with the basin shape and reflects the thickness of the sedimentary soil layers in the basin.

Due to the basin effects, the duration that the ground shakes will be longer in the Taipei Basin than in any other region. Accordingly, the number of the cyclic loads imposed on the structures is likely to be greater during an earthquake. Therefore, only one-half (not two-third as suggested for general sites) of the ultimate inelastic deformation capacity has been incorporated into the computation of the seismic force reduction factors for buildings located in Taipei Basin. That is, the allowable ductility capacity R_a for a given site within Taipei Basin is:

$$R_a = 1 + (R-1)/2.0 \quad \text{(for Taipei Basin)} \tag{2.11}$$

Therefore, the design base-shear for any given site within the Taipei Basin can be determined using the same procedures prescribed for general sites.

2.4 Seismic demand for MCE hazard level and minimum force requirement

In order to avoid the collapse of a building during an extremely large earthquake, the seismic demand during a maximum considered earthquake (MCE) has been taken into consideration in the current code. For general sites, the site-adjusted spectral response acceleration at short periods (S_{MS}) and at 1.0 second (S_{M1}) has been defined using the mapped spectral response acceleration parameters S_S^M and S_1^M at the MCE level as

$$S_{MS} = F_a S_S^M \quad ; \quad S_{M1} = F_v S_1^M \tag{2.12}$$

In which the mapped spectral response acceleration parameters S_S^M and S_1^M at the MCE level are determined from the seismic hazard level of 2% probability of exceedance within 50 years. Similar to the design level (10/50 hazard level), only four levels of S_S^M and S_1^M have been implemented as given in Table 2.1. For the near-fault sites, the site-adjusted spectral response acceleration parameters S_{MS} and S_{M1} are prescribed as:

$$S_{MS} = F_a N_A S_S^M \quad ; \quad S_{M1} = F_v N_V S_1^M \tag{2.13}$$

The site coefficients F_a and F_v in Eqs. (2.12) and (2.13) must be evaluated from Table 2.2 on the basis of the mapped spectral response acceleration parameters S_S^M and S_1^M, and the near-fault spectral response acceleration parameters $N_A S_S^M$ and $N_V S_1^M$, respectively. Then, the required spectral response acceleration S_{aM} for the general sites and the near-fault sites at the MCE level can be computed from:

$$S_{aM} = \begin{cases} S_{MS}\left(0.4 + 3T/T_0^M\right) & ; \quad T \le 0.2T_0^M \\ S_{MS} & ; \quad 0.2T_0^M < T \le T_0^M \\ S_{M1}/T & ; \quad T_0^M < T \le 2.5T_0^M \\ 0.4S_{MS} & ; \quad T > 2.5T_0^M \end{cases} \qquad \text{with} \qquad T_0^M = \frac{S_{M1}}{S_{MS}} \tag{2.14}$$

At the same time, the spectral response acceleration S_{aM} for Taipei Basin at the MCE level can be computed using the spectral response acceleration at short periods S_{MS} (S_{MS}=0.8g) as well as the corner period T_0^M (defined in Table 2.3) for each seismic micro-zone in Taipei Basin. This is expressed as:

$$S_{aM} = \begin{cases} S_{MS}\left(0.4 + 3T/T_0^M\right) & ; \quad T \le 0.2T_0^M \\ S_{MS} & ; \quad 0.2T_0^M < T \le T_0^M \\ S_{MS}T_0^M/T & ; \quad T_0^M < T \le 2.5T_0^M \\ 0.4S_{MS} & ; \quad T > 2.5T_0^M \end{cases} \tag{2.15}$$

In addition, at the MCE hazard level, the system ductility demand is permitted to reach full capacity R, instead of the allowable ductility capacity R_a as prescribed for the design base earthquake (10/50 hazard level). Therefore, the seismic force reduction factor F_{uM} of the structural system at the MCE level is defined as:

$$F_{uM} = \begin{cases} R & ; \quad T \geq T_0^M \\ \sqrt{2R-1} + \left(R - \sqrt{2R-1}\right) \times \dfrac{T - 0.6T_0^M}{0.4T_0^M} & ; \quad 0.6T_0^M \leq T \leq T_0^M \\ \sqrt{2R-1} & ; \quad 0.2T_0^M \leq T \leq 0.6T_0^M \\ \sqrt{2R-1} + \left(\sqrt{2R-1} - 1\right) \times \dfrac{T - 0.2T_0^M}{0.2T_0^M} & ; \quad T \leq 0.2T_0^M \end{cases} \tag{2.16}$$

Thus, the required base shear demand at the MCE level is defined as:

$$V_M = \frac{I}{1.4\alpha_y} \left(\frac{S_{aM}}{F_{uM}} \right)_m W \tag{2.17}$$

and

$$\left(\frac{S_{aM}}{F_{uM}} \right)_m = \begin{cases} S_{aM} / F_{uM} & ; \quad S_{aM} / F_{uM} \leq 0.3 \\ 0.52\left(S_{aM} / F_{uM}\right) + 0.144 & ; \quad 0.3 < S_{aM} / F_{uM} \leq 0.8 \\ 0.70\, S_{aM} / F_{uM} & ; \quad S_{aM} / F_{uM} > 0.8 \end{cases} \tag{2.18}$$

Furthermore, in order to avoid any nonlinear demand on the structural elements during a frequently occurring small earthquake, a minimum seismic force (MSF) requirement is prescribed as well in the current seismic code. The corresponding base shear demand is defined as:

$$V^* = \begin{cases} \dfrac{IF_u}{4.2\alpha_y} \left(\dfrac{S_{aD}}{F_u} \right)_m W & ; \text{(for general sites and near-fault sites)} \\ \dfrac{IF_u}{3.5\alpha_y} \left(\dfrac{S_{aD}}{F_u} \right)_m W & ; \text{(for Taipei Basin)} \end{cases} \tag{2.19}$$

It should be noted that no near-fault effects are considered for the frequently occurring small earthquakes, and hence, the near-fault factors are defined as N_A=N_V=1.0 for the near-fault sites.

The final base shear for the elastic structural design is governed by the larger of the base shears determined at the design level (using a reduced ductility capacity against the 10/50 hazard) and the MCE level (using the full system ductility against the 2/50 hazard). Nevertheless, it should never be less than the MSF requirement. In other words, the required base shear to be used for the structural design is defined as:

$$V_D = \max\left[V, \quad V_M, \quad V^*\right] \tag{2.20}$$

3. DYNAMIC ANALYSIS PROCEDURES

Buildings with any one of the following conditions shall be designed by following the dynamic analysis procedures:

(1) The building is 50m high or higher, or has more than 15 stories.
(2) The building is higher than 20m or has more than 5 stories, and it has vertical mass, stiffness or configuration irregularities, or it has torsional irregularity in any one of the stories.
(3) The building is higher than 20m or has more than 5 stories, and its structural system is non-uniform throughout its height.

For the dynamic analysis procedures, both the response spectrum method and the time history method are specified in the current version of the seismic design code.

3.1 Response spectrum method

When the response spectrum method is used, peak modal responses of sufficient modes have to be calculated in order to capture at least 90% of the participating mass of the building in each of the two orthogonal principal horizontal directions of the building. Based on the modal period T_m of the m^{th} mode of the structure, the corresponding modal spectral response acceleration S_{aD}^{m} can be developed for general sites and near-fault sites as follows.

$$S_{aD}^{m}=\begin{cases} S_{DS}\left[0.4+\left(\dfrac{1}{B_S}-0.4\right)\dfrac{T_m}{0.2T_{0m}}\right] & ;\quad T_m \le 0.2T_{0m} \\ S_{DS}/B_S & ;\quad 0.2T_{0m}<T_m\le T_{0m} \\ S_{D1}/(B_1T_m) & ;\quad T_{0m}<T_m\le 2.5T_{0m} \\ 0.4S_{DS}/B_S & ;\quad T_m>2.5T_{0m} \end{cases} \quad \text{with} \quad T_{0m}=\frac{S_{D1}B_S}{S_{DS}B_1} \tag{2.21}$$

Herein, the site-adjusted spectral response acceleration at short periods (S_{DS}) and at 1.0 second (S_{D1}) are determined from Eq. (2.1). The damping coefficients B_S and B_1 are defined in Table 3.1, expressed in terms of the effective modal damping ratio ξ. We then find that B_S=B_1=1.0 if the damping ratio is equal to 5%, and Eq. (2.21) will be reduced to Eq. (2.4) for this special case.

Table 3.1. Damping Coefficients B_s and B_1

ξ (%)	≤2	5	10	20	30	40	≥50
B_s	0.80	1.00	1.33	1.60	1.79	1.87	1.93
B_1	0.80	1.00	1.25	1.50	1.63	1.70	1.75

Note: The damping coefficient should be based on linear interpolation for effective modal damping ratios other than those given.

On the other hand, the modal spectral response acceleration S_{aD}^{m} for Taipei Basin can be developed as:

$$S_{aD}^{m}=\begin{cases} S_{DS}\left[0.4+\left(\dfrac{1}{B_S}-0.4\right)\dfrac{T_m}{0.2T_{0m}}\right] & ;\quad T_m \le 0.2T_{0m} \\ S_{DS}/B_S & ;\quad 0.2T_{0m}<T_m\le T_{0m} \\ T_0S_{DS}/(B_1T_m) & ;\quad T_{0m}<T_m\le 2.5T_{0m} \\ 0.4S_{DS}/B_S & ;\quad T_m>2.5T_{0m} \end{cases} \quad \text{with} \quad T_{0m}=\frac{T_0B_S}{B_1} \tag{2.22}$$

Herein, T_0 is the representative corner period (5% damping) for each micro-zone in the Taipei Basin.

Peak member forces, story displacements, story drifts, story forces, story shears, and base reactions for each mode of response shall be combined by either the SRSS (square root sum of squares) rule or the CQC (complete quadratic combination) rule.

3.2 Time history analysis

When the time history method is applied, building responses can be computed at discrete time steps using synthetic time histories as the base motion input. No fewer than three time history analyses shall be performed. Each input ground motion shall have magnitude, fault distance, and source mechanisms that are consistent with those that control the design earthquake ground motion. Furthermore, the input ground motion shall be compatible with the design response spectrum. The synthetic time history shall be scaled such that the associated 5%-damped spectral response acceleration for each period between $0.2T$ and $1.5T$ (where T is the fundamental period of the building) does not fall below 90% of the value specified by the design response spectrum. The average value in this period range shall be larger than or equal to the value averaged from the design response spectrum as prescribed by the code.

Response parameters shall be calculated from each time history analysis, and the maximum value of each response parameter may be used for the design.

3.3 Adjustment by base shear

The force and the deformation determined by the dynamic analysis procedures shall be adjusted according to the base shear as specified below:

(1) For irregular buildings, the base shear determined by the dynamic analysis shall be adjusted to 100% of the required base shear V_D as defined by Eq. (2.20).
(2) For regular buildings, the base shear determined by the dynamic analysis shall be adjusted to 90% of the required base shear V_D as defined by Eq. (2.20).
(3) For irregular and regular buildings, if the base shear determined by the dynamic analysis exceeds 100 % and 90% of the required base shear V_D, respectively, the response determined by the dynamic analysis shall be used for the design without any adjustment.

4. CONCLUSIONS

In the current issued seismic design code for buildings in Taiwan, based on the uniform hazard analysis at a return period of 475 years, the mapped 5%-damped spectral response acceleration at short periods and at one second are prepared for each administration unit of village, town or city level. Furthermore, the site-adjusted spectral response acceleration parameters at short periods and at 1 second can be defined by multiplying the site coefficients to include the local site effects. Then, the design spectral response acceleration can be developed and used to determine the design base shear.

To consider the effect of near-fault ground motions in seismic design, the so-called near-fault factors N_A and N_V are defined for several active faults. Within these specific near-fault sites, the near-fault effect should be considered at the design level to increase the seismic resistance capacity of structures against near-fault ground motions. For Taipei Basin, the representative value of the corner period T_0 is defined for each one of the four microzonations. Then, combined with the uniform hazard analysis, the design spectral response acceleration for Taipei Basin can be developed directly by the design spectral response acceleration at short periods as well as the corner period T_0 for each microzonation. In addition, in order to avoid the collapse of building during the extremely large earthquake and the yield of structural components and elements during the frequently small earthquakes, the required seismic demands at maximum considered earthquake level (MCE, 2%/50 years) and operational level are also included in the new seismic design code. For the dynamic analysis procedures, both the response spectrum method and the time history method are specified in the current issued seismic design code for buildings in Taiwan. The synthetic input ground motion is expected to be compatible with the design response spectrum and further perform the same waveform characteristics as the control earthquake ground motions.

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