

Fig. 6 Process to determine performance level

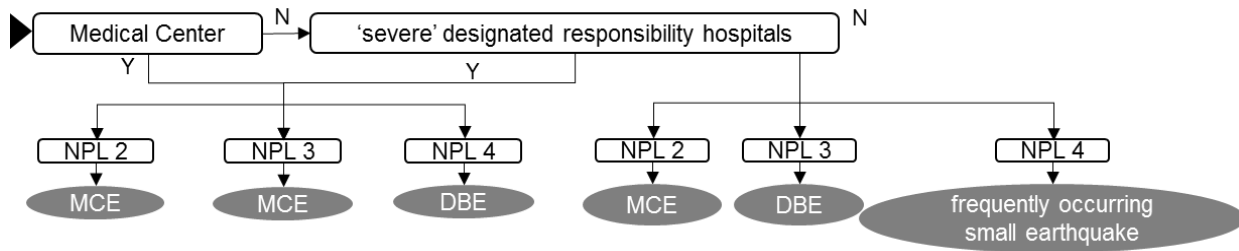


Fig. 7 Process to determine earthquake hazard level for seismic evaluation

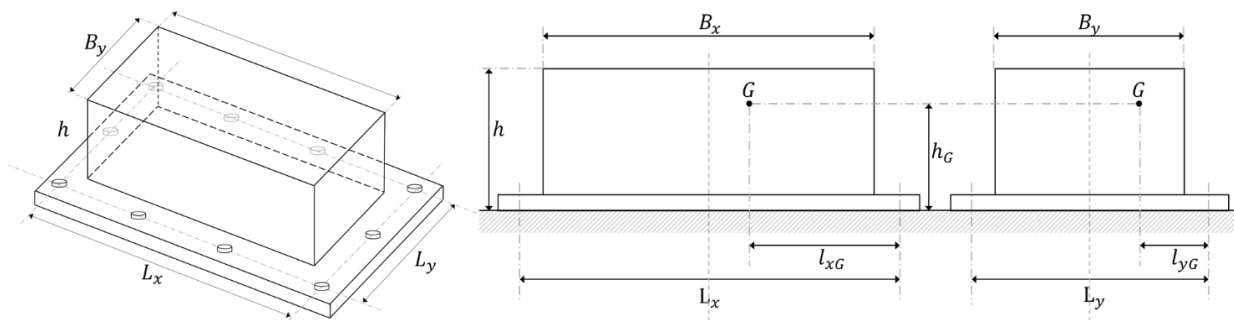


Fig. 8 Notes for rigid rectangular equipment

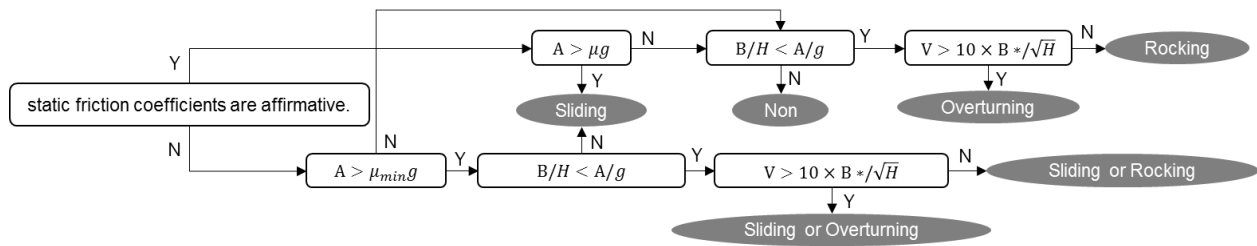


Fig. 9 Process to determine seismic response

The algorithms mentioned previously are all used in the background of spreadsheet for equipment placed on the floor. For equipment mounted on the wall, the process to determine the performance level and earthquake hazard level are also used, the earthquake hazard level decides the seismic demand for each equipment to calculate the seismic ability of the original anchorage.

5. SEISMIC EVALUATION CRITERIA FOR ANCHOR BOLTS

5.1 Seismic Demand on the Rigid Equipment

For equipment places on the floor, in general and based on the rigid body assumption, Eq.(4) and Eq.(5) are adopted to calculate the tension and shear demands (T_{ua} and V_{ua} , respectively) that act on one anchor bolt.

$$T_{ua} = [F_{ph} \times h_G - (W_p - F_{pv}) \times l_G] / (L \times n_t) \quad (4)$$

$$V_{ua} = F_{ph} / n \quad (5)$$

Herein, n is the total number of bolts and n_t is the number of bolts along one side. Other symbols are shown in Fig.8. The dead load (W_p) and seismic force (F_{ph} and F_{pv}) are combined to determine the tension force. For shear demand V_{ua} , it is assumed that the horizontal seismic force is equally borne by all bolts.

5.2 Modification Coefficients for Real Equipment

As aforementioned, Eq.(4) and Eq.(5) are defined under the rigid equipment assumption without considering the response of the equipment's structure. In addition, it is noted that only one component of the horizontal seismic force is considered in the simplified equation, and then the maximum values determined from seismic force in the x- or y-direction are used for the design. Therefore, in order not to underestimate the critical seismic demands on the bolt, the tension and shear demands in the proposed program are defined by:

$$T_{ua} = 0.9 \times \varphi_{TW} \times T_W \pm \varphi_{TE} \times T_E \quad (6)$$

$$V_{ua} = \varphi_{VE} \times V_E \quad (7)$$

where under the rigid body assumption, T_w , and T_E are the calculated tension forces caused by the dead load and seismic loads, respectively, and V_E is the shear force caused by the seismic load. The generic equations to calculate T_w , T_E and V_E are defined by:

$$T_w = \min\left(\frac{W_p \times \min(l_{xG}, L_x - l_{xG})}{L_x \times n_y}, \frac{W_p \times \min(l_{yG}, L_y - l_{yG})}{L_y \times n_x}\right) \quad (8)$$

$$T_E = \max(T_{QX} + 0.3T_{QY} + T_{QZ}, 0.3T_{QX} + T_{QY} + T_{QZ}) \quad (9)$$

$$V_E = \sqrt{\left(\frac{F_{ph}}{n}\right)^2 + \left(\frac{0.3 \times F_{ph}}{n}\right)^2} \quad (10)$$

where T_{QX} , T_{QY} , and T_{QZ} are the tension demands caused by a seismic force F_{ph} in the x- and y-directions (Eq.(11) to Eq.(13)), and F_{pv} in the z-direction, respectively, and they are defined by:

$$T_{QX} = \frac{F_{ph} \times h_G}{L_x \times n_y} \quad (11)$$

$$T_{QY} = \frac{F_{ph} \times h_G}{L_y \times n_x} \quad (12)$$

$$T_{QZ} = F_{ph} \times \max\left(\frac{\max(l_{xG}, L_x - l_{xG})}{L_x \times n_y}, \frac{\max(l_{yG}, L_y - l_{yG})}{L_y \times n_x}\right) \quad (13)$$

where n is the total number of bolts, and n_x and n_y are the number of bolts located on one side along x- and y-directions, respectively. It is noted that the loading combination 0.9D+1E is adopted to determine the tension demand for an anchor bolt. In addition, the 100-30 rule is adopted to consider the effect caused by two horizontal directions, i.e., 100% of the effect in one direction is combined with 30% of the effect in the other orthogonal direction. The seismic base shear V_E in Eq.(10) is defined by the vector sum of the two horizontal components following the 100-30 rule.

5.3 Coefficients for Modification

In order to determine the modification coefficients ϕT_w , ϕT_E , and ϕV_E , the finite element software SAP2000 was adopted to determine the reaction forces at the supporting points of real equipment. The parameters included aspect ratio, bolt-installation location, and eccentricity affect each other, all parameters should be considered simultaneously to calculate the results. In this study, only some conditions in each parameter were selected for analysis. For example, the aspect ratio 1:10 was considered as a critical situation. To

