Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.V)

8-1-9

NEW SEISMIC DESIGN PROCEDURE FOR BUILDING STRUCTURES

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SUMMARY

This paper presents a newly developed seismic design approach for building structures. In this approach, different design intensities are defined for strength design and collapse checking based upon seismic risk analysis results done in China. The structural influence factor C which were widely used for seismic load hence disappears. Collapse checking is carried out through elasto-plastic story drift checking at the weak story of the structure under quantitative major earthquake load and expressions for evaluation of elasto-plastic story drifts are offered.

INTRODUCTION

In the past, seismic design for building structures only took into account strength checking under seismic load corresponding to basic intensity elastic earthquake load multiplied by structural influence factor C with its value ranging from 0.25-0.50 depending upon different type or material structures according to China Seismic Design Code currently enforced. The C value less than 0.50 implies that the elastic load reflecting structures working within elastic range under earthquakes is relevant to their intensity much lower than the basic one. Since C value varies with different sorts of structures the reduced intensity value is changing. This seems not reasonable for structures to be seismically designed in the same region.

On the other hand, no checking to be done against collapse under certain quantitative major earthquake. Designers do not know or could not estimate the damage state or whether collapse will take place under a major earthquake with intensity higher than basic intensity. But the 1976 Tangshan Earthquake tragedy clearly taught us that the main reason causing such a sad event was the collapse of the buildings.

The urgent need rises to develop a new procedure that will concretely embodies the basic principle of earthquake resistance design. No damage versus minor earthquake and no collapse against major earthquakes.

DESIGN INTENSITY DETERMINATION

Fig. 1 shows the probability density curve for design intensity for buildings with 50 years as reference period. This was obtained based upon seismic risk analysis results over more than 70 seismically active cities, towns and regions in the past five years in China.

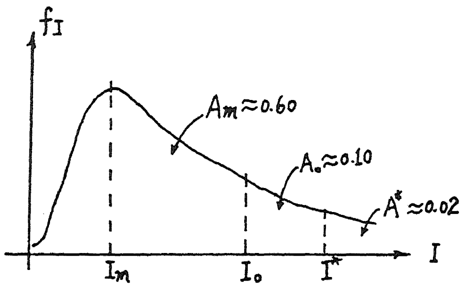

Fig. 1 Probability Density Curve for Design Intensity

Strength design is then to be done under a minor earthquake load, leading to the structure working within elastic stage and no damage turning up. The so called minor earthquake is defined as earthquake of "Mode Intensity" I_m with probability excedance of about 60% as shown in Fig. 1.

No collapse to building structures is demanded for design under major earthquakes. The so called major earthquake is defined as earthquake of big intensity I* with probability excedance of about 2% as shown in Fig. 1.

The basic intensity I_o has a probability excedance of about 10 and no irrepairable damage is to be expected for design under such intensity earthquakes.

Approximate relationship among the three could be written in the following

$$I_o - I_m \doteq 1.55^\circ \tag{1}$$

$$I^* - I_o \doteq 1^\circ \pm I^{*o} \tag{2}$$

in which I^{*o} is a modification value according to intensity probability analysis results and varies with different basic intensity values.

The maximum values of earthquake influence factor α_{max} for different basic intensity to be used for seismic design in the new procedure are listed below:

Table 1 α_{max} Values

Basic Intensity	Strength Design (minor earthquake)	Anticollapse Checking (under major earthquake)
7°	0.08	0.50
8°	0.16	0.90
9°	0.32	1.40

SEISMIC LOAD FORMULAE

For strength design, we ordinarily use code response spectrum and mode analysis approach. The seismic load are calculated according to the following formulae:

1. Planar systems of multi-degree of freedom (Fig. 2) subjected to horizontal earthquake action.

Earthquake load at ith mass for jth mode

$$P_{ji} = \alpha_j \gamma_j X_{ji} W_i \tag{3}$$

SRSS combination is accepted.

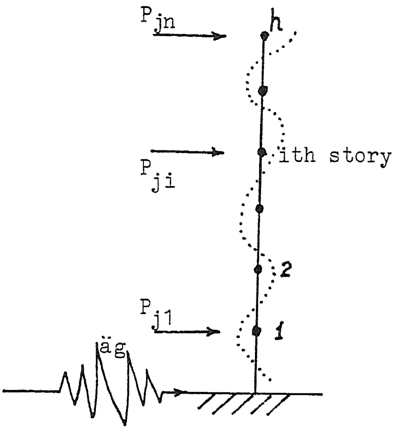

Fig. 2 Seismic Load for jth Mode

2. Asymmetrical structure subjected to horizontal earthquake action along X-axis (Fig. 3).

$$P_{jix} = \alpha_j \gamma_{jx} X_{ji} W_i \tag{4}$$

$$P_{jiy} = \alpha_j \gamma_{jx} Y_{ji} W_i \tag{5}$$

$$M_{jit} = \alpha_j \gamma_{jx} \phi_{ji} r_i W_i \tag{6}$$

in which

$$\gamma_{jx} = \frac{\sum_{i=1}^{n} X_{ji} W_i}{\sum_{i=1}^{n} W_i (X_{ji}^2 + Y_{ji}^2 + \phi_{ji}^2 r_i^2)} \tag{7}$$

α_j — Earthquake influence factor corresponding to jth natural period T_j.

$$r_i^2 = \frac{J_i}{W_i} \tag{8}$$

J_i — Torsional momentum of mass of ith story;

X_{ji}, Y_{ji}, ϕ_{ji} — Mode displacements for jth mode at ith story mass.

CQC combination is suggested.

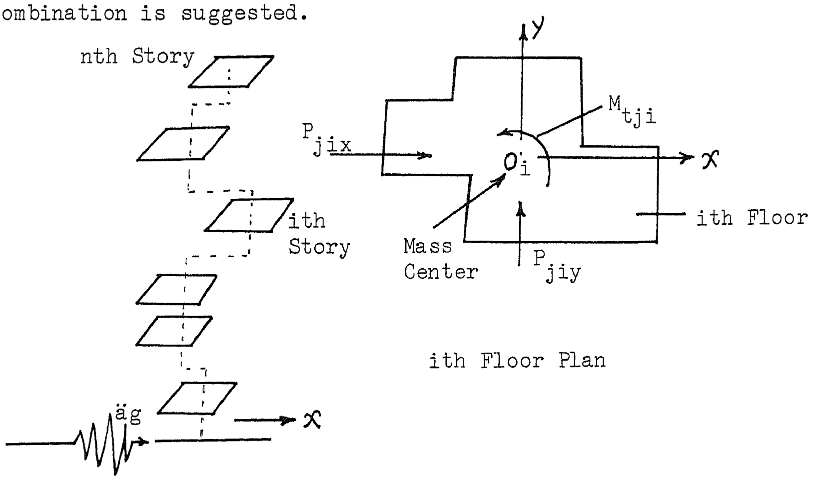

Fig. 3 Seismic Load for Asymmetric Building Structure

STRENGTH DESIGN

Reliability based expression for strength design under mode intensity I_m seismic action is expressed by

$$1.2G_E + 1.3E_{hK} + 0.5E_{vK} + 0.2 \times 1.4W_K \leq R_D/\gamma_{RE} \quad (8)$$

in which

$$G_E = G_K + 0.3 \quad 0.8L_K + 0.5S_K \quad (9)$$

γ_{RE} — Seismic modification factor.

All coefficients are obtained based on probability theory and reliability analysis.

It is seen that strength checking expression has been converted from one single safety factor K used in the past into multi-coefficient form which are reliability-based.

It is pointed out that the seismic response E_{hK} or E_{vK} is calculated according to elastic analysis under mode intensity earthquake load as shown in Table 1.

WEAK STORY IDENTIFICATION AND COLLAPSE CHECKING

In the new design procedure, collapse checking should be carried out for reinforced concrete structures through the elasto-plastic story drift checking at the weak stories under a major earthquake with $_{max}$ values listed in Table 1.

<u>For Ductile Frames</u> Weak story is identified by minimum value of story yield shear ratio $_{i_{min}}$.

$$\xi_{i_{min}} = (Q_{yi}/Q_{ei})_{min} \quad (10)$$

in which

Q_{yi} — Yield shear strength at ith story;

Q_{ei} — Elastic shear at ith story under major earthquake load assuming structure working elastically.

At weak story, the elasto-plastic story drift $\Delta P_i/h_i$ should not be greater than θ_P = 1/50 for ductile frame so as to keep the structure safe against collapse.

$$\left(\frac{\Delta P_i}{h_i}\right) \leq 1/50 \quad (11)$$

<u>For Structural Walls</u> Weak story is identified by minimum value of either story yield shear ratio $_{iQ}$ or story yield moment ratio $_{im}$.

$$(\xi_{iQ})_{min} = (Q_{yi}/Q_{ei})_{min} \quad (12)$$

$$(\xi_{im})_{min} = (M_{yi}/M_{ei})_{min} \quad (13)$$

Weak stories might appear when their ξ_i value allocates less than the average value of ξ_{i-1} and ξ_{i+1}. That means a concave point of ξ_i value occurs there.

Collapse checking at weak story should be done according to the following expression.

In case of flexural failure $(\xi_{im})_{min}$

$$(\Delta P_i/h_i) \leq 1/100 \quad (14)$$

In case of shear failure $(\ _{iQ})_{min}$

$$(\Delta P_i/h_i) \leq 1/200 \quad (15)$$

ELASTO-PLASTIC STORY DRIFT EVALUATION AT WEAK STORY UNDER MAJOR EARTHQUAKES

For Frames For frames with quite uniform story stiffness distribution and ξ_i value $(\xi_i > 0.8(\xi_1 + \xi_2 + \ldots + \xi_n)/n$ along the structure height elasto-plastic story drift Δp is found by

$$\Delta_P = \eta_P \Delta_e \quad (16)$$

Δ_e — Elastic story drift of the frame under major earthquake (I*) assuming the structure kept in elastic range;

η_P — Amplification factor of elasto-plastic deformation which is closely related to yield shear strength factor ξ_y (see the following list).

Table 2 η_P Value of Uniform Story Rigidity and factor R.C. Frames

Number of Stories \ ξ_y	0.5	0.4	0.3	0.2
2-4	1.30	1.40	1.60	2.10
5-7	1.50	1.65	1.80	2.40
8-12	1.80	2.00	2.20	2.60

In case of only story rigidity being uniform and ξ_i value located in

$$\xi_i < 0.5(\xi_1 + \xi_2 + \ldots + \xi_n)/n \quad (17)$$

We have Δ_{Pi} at weak story

$$\Delta_{Pi} = 1.5\eta_P \Delta_{ei} \quad (18)$$

When ξ_i value stands in between the above cases, interpolation method could be applied.

If both story rigidity and ξ_i factor are nonuniform, the approach of redistribution of plastic internal force offers the following formula:

$$\Delta_{Pi} = 0.85\Delta_e^{(n)} - A_f - B_f \quad (19)$$

in which

$\Delta_e(n)$ — Top elastic displacement of the frame under a major earthquake assuming structure kept in elastic scope.

For Structural Walls

In case of story shear failure

$$\Delta_{Pi} = 0.9\Delta_e^{(n)} - A_s - B_s \quad (20)$$

In case of story flexural failure

$$\Delta_{Pi} = \Delta^{s}_{P,i+1} + \left(\theta^{sm}_{P,i+1} - \theta^{sm}_{e,i+1}\right) h_{i+1} \quad (21)$$

The above expressions are derived out using the procedure of the redistribution of plastic internal force and could be found in detail in the author's paper (Ref. 2).

CONCLUDING REMARKS

The new design procedure seems improved in the following points:

1. Omission of structural influence factor C brings about clearer conception in design.
2. Available for asymmetric building structure design.
3. Anti-collapse checking against major earthquake has been provided and the practical quantitative approach to do it presented in the paper is easy to be grasped by average engineers.

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