NEW SEISMIC DESIGN PROCEDURE FOR BUILDING STRUCTURES

WEI Lian

1 Institute of Earthquake Engineering, China Academy of Building Research, Beijing, China

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.

![Probability Density Curve](image)

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 exceedance 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 exceedance of about 2% as shown in Fig. 1.

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

Approximate relationship among the three could be written in the following

$$I_o - I_m = 1.55^0$$

$$I^* - I_o = 10 + I^{*0}$$

in which $I^{*0}$ is a modification value according to intensity probability analysis results and varies with different basic intensity values.

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

<table>
<thead>
<tr>
<th>Basic Intensity</th>
<th>Strength Design (minor earthquake)</th>
<th>Anticollapse Checking (under major earthquake)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$7^0$</td>
<td>0.08</td>
<td>0.50</td>
</tr>
<tr>
<td>$8^0$</td>
<td>0.16</td>
<td>0.90</td>
</tr>
<tr>
<td>$9^0$</td>
<td>0.32</td>
<td>1.40</td>
</tr>
</tbody>
</table>

**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 $i$th mass for $j$th mode

$$P_{ji} = \alpha(j) \nu_i x_{ji} W_i$$

(3)

SRSS combination is accepted.

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

$$P_{jix} = \alpha(j) x_{jix} W_i$$

(4)

$$P_{jiy} = \alpha(j) y_{jiy} W_i$$

(5)

$$M_{jix} = \alpha(j) x_{jix} \phi_{jix} W_i$$

(6)

in which

$$\gamma_{jx} = \frac{\sum_{i=1}^{n} x_{ji} W_i}{\sum_{i=1}^{n} W_i (x_{ji}^2 + y_{ji}^2 + \phi_{ji}^2 r_i^2)}$$

(7)

$\alpha(j)$ — Earthquake influence factor corresponding to $j$th natural period $T_j$.

$$x_{ji}^2 = \frac{J_i}{W_i}$$

(8)

$J_i$ — Torsional momentum of mass of $i$th story;

$x_{ji}$, $y_{ji}$, $\phi_{ji}$ — Mode displacements for $j$th mode at $i$th story mass.

CQC combination is suggested.

Fig. 2 Seismic Load for $j$th Mode

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

$$1.2E^+_E + 1.3E^+_K + 0.5E^+_v + 0.2 \times 1.4W_K \leq R'_{D/E}$$

(8)
in which

$$E^+_E = G + 0.3 \quad 0.8L_K + 0.5S_K$$

(9)

$\gamma_{RE}$ — 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.

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

$$i_{min} = \left( \frac{Q_{yi}}{Q_{ei}} \right)_{min}$$

(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 $\frac{\Delta P_i}{h_i}$ should not be greater than $\frac{\Delta P}{h_i} = 1/50$ for ductile frame so as to keep the structure safe against collapse.

$$\frac{\Delta P_i}{h_i} \leq 1/50$$

(11)

For Structural Walls  Weak story is identified by minimum value of either story yield shear ratio $i_{Q}$ or story yield moment ratio $i_{im}$.

$$i_{Q} = \left( \frac{Q_{yi}}{Q_{ei}} \right)_{min}$$

(12)

$$i_{im} = \left( \frac{M_{yi}}{M_{ei}} \right)_{min}$$

(13)

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

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

In case of flexural failure \((\delta_{1m})_{\text{min}}\)
\[
(\Delta_{F1}/h_1) \leq 1/100
\]  \hspace{1cm} (14)

In case of shear failure \((\delta_{Q})_{\text{min}}\)
\[
(\Delta_{F1}/h_1) \leq 1/200
\]  \hspace{1cm} (15)

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

For frames with quite uniform story stiffness distribution and \(\delta_i\) value \((\delta_i > 0.8(\delta_1 + \delta_2 + \ldots + \delta_n)/n\) along the structure height elasto-plastic story drift \(\Delta P\) is found by

\[
\Delta P = \eta_P \Delta e
\]  \hspace{1cm} (16)

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

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

<table>
<thead>
<tr>
<th>Number of Stories</th>
<th>(\delta_y)</th>
<th>0.5</th>
<th>0.4</th>
<th>0.3</th>
<th>0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-4</td>
<td></td>
<td>1.30</td>
<td>1.40</td>
<td>1.60</td>
<td>2.10</td>
</tr>
<tr>
<td>5-7</td>
<td></td>
<td>1.50</td>
<td>1.65</td>
<td>1.80</td>
<td>2.40</td>
</tr>
<tr>
<td>8-12</td>
<td></td>
<td>1.80</td>
<td>2.00</td>
<td>2.20</td>
<td>2.60</td>
</tr>
</tbody>
</table>

In case of only story rigidity being uniform and \(\delta_{1}\) value located in
\[
\delta_{1} < 0.5(\delta_1 + \delta_2 + \ldots + \delta_n)/n
\]  \hspace{1cm} (17)

We have \(\Delta_{P1}\) at weak story

\[
\Delta_{P1} = 1.5\eta_P \Delta e_1
\]  \hspace{1cm} (18)

When \(\delta_{1}\) value stands in between the above cases, interpolation method could be applied.

If both story rigidity and \(\delta_{1}\) factor are nonuniform, the approach of redistribution of plastic internal force offers the following formula:

\[
\Delta_{P1} = 0.85\Delta e(n) - A_P - B_P
\]  \hspace{1cm} (19)

in which
\[ \Delta_0(n) \] — 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

\[ \Delta_{P_i} = 0.9 \Delta_0(n) - A_s - B_s \]  \hspace{1cm} (20)

In case of story flexural failure

\[ \Delta_{P_i} = \Delta_s^{i+1} + \left( \sigma_{P,i+1}^{SM} - \sigma_{E,i+1}^{SM} \right) h_{i+1} \]  \hspace{1cm} (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.

**REFERENCES**