ON THE GENERALIZED RELIABILITY OF REINFORCED CONCRETE SHEAR WALL UNDER SEISMIC LOADINGS

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SUMMARY

In this paper, some indeterminate informations in structural design of reinforced concrete shear wall under seismic loadings is discussed. These major indeterminate factors are indeterminateness of seismic loadings, fuzziness of guide rule for safety, classification of shear wall, failure model and the boundary of eccentric compression. Then, based on the concept of structural generalized reliability the calculation and evaluation of generalized reliability for reinforced concrete shear wall are presented by use of a simple example.

INTRODUCTION

Usually, the steps of cross-section design for reinforced concrete shear wall under horizontal earthquake loadings are as follows: At first, the category of shear wall is determined according to its openings and the internal forces and displacements corresponding to assigned design earthquake intensity can be obtained. Then, the strength and stiffness of shear wall are checked as the eccentric compression or tension members and the shear members. In this process of designing reinforced concrete shear wall, a engineer will confront with many random and fuzzy factors which lead to indeterminateness of strength and stiffness.

The concept and methods which had been suggested by Chinese scientist—Prof. Wang Guangyuan can be used to study the generalized reliability of reinforced concrete shear wall (Ref.1).

The major indeterminate factors considered in this paper are:
1. Indeterminateness of seismic loadings (random and fuzzy).
2. Fuzziness of seismic response and corresponding permissible range reflected by the fuzziness of guide rule for the safety and failure model of reinforced concrete shear wall.
4. Fuzzy boundary between large eccentric member and small one.

FUZZINESS OF SEISMIC LOADINGS

In structural design we usually use simplified method to calculate the seismic loadings. Chinese Design Standard J2102-79 (Ref.2) stipulates: For the n-storeys reinforced concrete shear wall or frame—shear wall, in which n≤50, If
the weight and rigidity are well-distributed along the height, the horizontal seismic loading which acts on ith storey are

$$P_i = \frac{W_i H_i}{\sum_{i=1}^{n} W_i H_i} (1 - \xi) \alpha \sum_{i=1}^{n} W_i$$  

(1)

where, $W_i$ and $H_i$ are the concentrated weight and height in the ith storey respectively, $\xi$ is the adjustable coefficient of the seismic loadings along structural height, $\alpha$ the structural influence coefficient, and $\alpha$ seismic effect factor, satisfies

$$\alpha_{j\min} \leq \alpha = \zeta \alpha_{j0} = \frac{\alpha_{j\max}}{T} \leq \alpha_{j\max}$$  

(2)

de the value of $\zeta$ is 0.2 sec., 0.3 sec. and 0.7 sec. for the 1st, 2nd and 3rd category of soil in site respectively and $\alpha_{j\max} = 0.23$, $\alpha_{8\max} = 0.45$, $\alpha_{9\max} = 0.90$; $\alpha_{\min} = 0.2 \alpha_{\max}$.

When the structural height is higher or the distribution of weight and rigidity is uneven, the seismic loadings should be calculated by accuracy methods.

It can be seen that the indeterminate factors of design earthquake intensity and classification of soil in site determine the magnitude of seismic loadings by means of the seismic effect factor.

Generally, the earthquake intensity not only is random, but also fuzzy. Although it is divided into 12 dispersive grades, the discussed region of earthquake intensity should be continuous. Every earthquake intensity grade should posses fuzzy boundary and continuously cover a certain region, transit gradually from one earthquake intensity grade to the next one.

To stipulate discussed region of earthquake intensity is the closed interval $V = (I | I \in [0,12]) = [0,12]$ in real number axis, one fuzzy earthquake intensity grade $I_j$ in dispersive discussed region of earthquake intensity is a fuzzy interval in continuous discussed region $V$, its membership function is (is shown in Fig.1)

$$\mu_{\alpha_j}(I) = \frac{1}{2} \left[ \sin \left( I - I_j + \frac{1}{2}\pi \right) + 1 \right] \quad (I_j \in [I_{j-1}, I_{j+1}])$$  

(3)

From Eqn. (2) we know the membership function of $\alpha_j$ is shown in Fig.2 when fuzzy grade of earthquake intensity is $I_j$ and discussed region of soil in site is
\[ Y_{s} = (v_{1}, v_{2}, v_{3}) \]  

Here \( v_{1} \) is the classification of soil in site.

Fuzzy grade for the classification of soil in site can be determined by use of a comprehensive evaluation for multiple factors (Ref. 3). Let the obtained vectors of fuzzy grade \( Q = (d_{1}, d_{2}, d_{3}) \), in which \( d_{i} \) is the membership degree of grade \( v_{i} \) relative to fuzzy grade \( Q \). Then, \( Z \) can be calculated by weighted average. Finally, the membership function of earthquake effect factor \( \alpha \) is shown in Fig. 3. Its expression is

\[
\mu_{\alpha}(\alpha) = \begin{cases} 
\frac{1}{2} \left( 1 + \frac{2 \alpha \frac{T}{\alpha_{\text{max}}} - \frac{3}{2}}{\pi} \right) & \frac{0.5 \alpha_{\text{max}}}{T} \leq \alpha \leq \frac{\alpha_{\text{max}}}{T} \\
\frac{1}{2} \left( 1 + \frac{2 \alpha \frac{T}{\alpha_{\text{max}}} - 1}{\pi} \right) & \frac{\alpha_{\text{max}}}{T} \leq \alpha \leq 2 \frac{\alpha_{\text{max}}}{T} 
\end{cases}
\]

(4)

**Fig. 3 Membership Function of \( \alpha \)**

**Fig. 4 Membership Function of \( u_{\text{fw}} \)**

**Fig. 5 Membership Function of \( J_{A}/J_{u1} \)**

**FUZZINESS OF CLASSIFICATION OF R.C. SHEAR WALL**

When the outside shapes of reinforced concrete shear wall and sizes of opening in it are different, not only distribution of stress in the cross-section of wall-limb but also the changeable law of bending moment along the height of wall are different, meanwhile the analytical method of internal force is different too. Hence we divide the shear wall into 3 categories based on Ref. 2:

1. If the whole coefficient of shear wall \( g \geq 10 \), and ratio of moment of inertia for shear wall \( J_{a}/J \leq Z_{0} \), the reinforced concrete shear wall like this is the small openings wall;
2. If \( g \geq 10 \) and \( J_{a}/J > Z_{0} \), is the wall-frame;
3. If \( g \leq 10 \) and \( J_{a}/J \leq Z_{0} \), double-limb wall.

Moreover, it is defined, there should be a fuzzy transiting boundary between two different categories of shear wall.

Suppose the discussed region of shear wall category \( Y_{w} = (u_{1}, u_{2}, u_{3}) \), here, \( u_{i} \) is indicated small openings wall, double-limb wall and wall-frame respectively. Grade vector of fuzzy category is \( \bar{E} = (e_{1}, e_{2}, e_{3}) \) in which \( e_{i} \) is the membership degree of grade \( u_{i} \) which is relative to fuzzy classification grade \( \bar{E} \). \( \bar{E} \) can be determined by a comprehensive evaluation for multiple factors and also obtain from Fig. 4 and Fig. 5.

**FUZZY BOUNDARY BETWEEN ECC. COMPRESSION CONDITION OF WALL-LIMB**

Generally, we regard the compressive wall-limb of reinforced concrete shear wall as eccentric compressive member to calculate. When the height of compressive
zone $x \leq (0.55-0.1u_s)h$, this is large eccentric compression member, at this time reinforcement in tension (compression) $Ag$ ($A_g^t$) all reach yield strength $R_g$ ($R_g^t$) and the radial value of concrete compressive stress in compressive zone is $R_w$, the vertical distributing reinforcement beyond 1.5x are still valid. When $x \geq (0.55-0.1u_s)h$, it is small one, stress of $A_g$ in compressive zone can reach yield strength $R_g$, but that of $A_g$ in other side does not reach the yield point or still tensioned and its influence is usually neglected.

In boundary, maybe there are contradictions in calculating results for different working states. This shows us to divide the wall-limb into two working state which are very different by one cut is not enough rational. Transition from large to small eccentric compression should be gradual and its boundaries fuzzy.

Suppose discussed region for large and small eccentric compression of the wall-limb cross-section is $Ye = (w_1, w_2)$, here $w_1$, $w_2$, is indicated large and small eccentric compression respectively. Classification vector $F_1 = (f_1^t, f_2^t)$ for fuzzy working state, $f_1^t$ is the membership degree of $W_1$ relative to $F_1$, The membership function (shown in Fig.6) is

$$\mu_{Ag} = \begin{cases} 0 & (\frac{x}{h} \leq 0.5-0.1u_s) \\ \frac{1}{2} \sin ((10 \frac{x}{h} + u_s -5.5)\pi + 1) & (0.5-0.1u_s < \frac{x}{h} < 0.6-0.1u_s) \\ 0 & (\frac{x}{h} \geq 0.6-0.1u_s) \end{cases}$$

(5)

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(6)

**FUZZY GUARD RULE OF SAFETY**

Safety guide rule of reinforced concrete shear wall used today is constraints $S_i \leq R_i$, here, $S_i$ is the maximum value of response ith of shear wall; $R_i$ is a permissible value of $S_i$; according to this stipulation, shear wall is either safety or failure. There is no transition between the two states, this does not conform to practice. In practice of engineering, failure degree of structural permission is a fuzzy conception, no failure, a slight failure, moderate failure and serious failure etc. are all fuzzy. Hence the fuzzy guide rule of safety is used in shear wall:

$$Q_i \text{ } \Delta \text{ } (S_i \subseteq R_i)$$

(7)

here, $Q_i$ is a fuzzy event that the fuzzy maximum response $S_i(\overline{Y}, \overline{x})$ can satisfy the safety requirement, the permissible interval $R_i(\overline{Y}, \overline{x})$ of maximum response $S_i$ constitutes a fuzzy subset in the discussed region of response such as bending moment $N$, axial force $N$, and shear $Q$.

We equivalently regard fuzzy interval $R_i(\overline{Y}, \overline{x})$ as fuzzy number $R_i(I_p)$ in discussed region $I_p$, their membership functions $\mu_{R_i}$ can be written and usually adopt the form of Fig.7. In figure there is a transitional stage with length $m_1$ from complete not-permission to complete permission. Sometimes simply regard this

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transition curve as a inclined straight line. And like this, we can regard the maximum value of response \( S_i(\bar{y}, \bar{x}) \), its membership function \( \mu_{S_i}(\bar{y}, \bar{x}, i) \) is shown in Fig.8. The satisfactory degree of fuzzy guide rule is

\[
\beta_1(\bar{y}, \bar{x}) = \frac{\int_{-\infty}^{\infty} \mu_{R_i}(\bar{y}, \bar{x}, i) \mu_{S_i}(\bar{y}, \bar{x}, i) \, di}{\int_{-\infty}^{\infty} \mu_{S_i}(\bar{y}, \bar{x}, i) \, di} \quad (i=M, N, Q) \tag{8}
\]

**FUZZY EFFECTIVE REGION**

Under different conditions, there could happen many forms of failure for reinforced concrete shear wall, such as tensioned failure which happens due to longitudinal reinforcement yield in the large eccentric compression conditions; compressed failure, in which concrete in compressive zone has been crushed in the small eccentric compression conditions; shear-compression failure and oblique—tension failure etc. In reinforced concrete shear wall design, the failures of oblique compression or tension are usually prevented by use of construction measures, and in calculation are not considered, so that calculation can be reduced. So in normal designing of reinforced concrete shear wall, there are only two failures forms: the failure of normal section and shear-compression one of oblique section.

This fuzzy event of shear wall regular work means that the fuzzy constraints given in Eqn. (7) can be satisfied in several level, that is fuzzy maximum response \( S_i(1) \) \((i=M, N, Q\) etc.) drops in its corresponding permission interval \( R_i(1) \).

in the meaning of different satisfactory degrees. At this time fuzzy constraints Eqn. (7) will constitute effective subregion which possesses fuzzy boundaries in the character space of structural response, corresponding satisfactory degree \( \beta_1 \) \((i=M, N, Q\) and others) can be calculated by Eqn. (8). For every reinforced concrete shear wall, fuzzy effective subregion only have a corresponding one which satisfies all constraints in Eqn. (7), therefore, effective region of shear wall is

\[
\Omega = \Omega_1 \cap \bigcap_{i=1}^{\Omega_1}
\]

and

\[
\mu_{\Omega} = \text{Min} \left( \mu_{\Omega M}, \mu_{\Omega N}, \mu_{\Omega Q}, \ldots \right) \tag{10}
\]

**GENERALIZED RELIABILITY OF R.C. SHEAR WALL**
Random and fuzzy reliability of structure can be calculate by use of below-mentioned

$$\psi = F(\Omega) = \int f_q(G) \mu_{R_o}(G, \bar{x}) d\bar{x}$$  \hspace{1cm} (11)

When only consider fuzzy indeterminate factors which influence the strength of shear wall, there are fuzziness and no radom for the maximum response $s_i$ and corresponding permission interval $B_i$. At this time $\mu_{R_o}(G, \bar{x})$ will convert into $u_R(\bar{x})$, which does not include radom parameter $G$ or its realizing $\bar{y}$, then the fuzzy reliability of reinforced concrete shear wall is:

$$\psi(\bar{x}) = \mu_{R_o}(\bar{x})$$  \hspace{1cm} (12)

To calculate the fuzzy reliability of reinforced concrete shear wall is to solve Eqn. (12).

By using this method the fuzzy reliability of a 4-storeys of reinforced concrete shear wall, which has symmetrical openings (shown in Fig.9), is calculated.

$$\psi(\bar{x}) = 1.00 \times 0.85 + 1.00 \times 0.10 + 0.5959 \times 0.05 = 0.98$$

The calculating procedure is shown in Tab. 1.

<table>
<thead>
<tr>
<th>Table 1 Calculation of Membership Degree</th>
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<td>$I_s$</td>
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<td>$F(I_s)$</td>
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<td>$F(I_s)$</td>
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</tbody>
</table>

Fig.9 A 4-Storeys Shear Wall

REFERENCES

2. Regulations For Reinforced-Concrete High Rise Building Structure Design ( JZ 102-79 ), Published in Beijing, (1980)