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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.
3. Fuzziness of classification of reinforced concrete shear wall.
4. Fuzzy boudary 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 JZ102-79 (Ref.2) stipulates: For the n-storeys reinforced concrete shear wall or frame——shear wall, in which $n \leq 50$, If

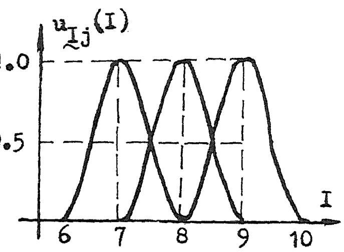

Fig.1 Membership Fuction of Fuzzy earthquake Intensity

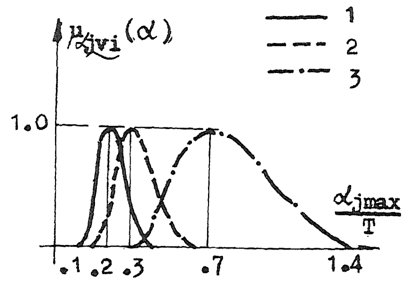

Fig.2 Membership Fuction $\mu_{\underset{\sim}{\alpha}jvi}$

the weight and rigidity are well-distributed along the height, the horizontal seismic loading which acts on ith storey are

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

where, W_i and H_i are the concentrated weight and height in the ith storey respectively, ξ is the adjustable coefficient of the seismic loadings along structural height, C the structural influence coefficient, and α seismic effect factor, satisfies

$$\alpha_{jmin} \leqslant \alpha = \zeta\alpha_{j0} = \frac{\zeta\alpha_{jmax}}{T} \leqslant \alpha_{jmax} \tag{2}$$

here, the value of ζ is 0.2 sec., 0.3 sec. and 0.7 sec. for the 1st,2nd and 3rd category of soil in site respectively and $\alpha_{7max} = 0.23$, $\alpha_{8max} = 0.45$, $\alpha_{9max} = 0.90$; $\alpha_{min} = 0.2\,\alpha_{max}$.

When the structural height is higher or the distribution of weight and rigidity is unever, 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 continously 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 $V=(\,I \mid I\in[0,12]\,)=[0,12]$ in real number axis, one fuzzy earthquake intensity grade $\underset{\sim}{I}_j$ 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)

$$\mu_{\underset{\sim}{I}j}(I) = \tfrac{1}{2}\left[\sin\,(I-I_j+\tfrac{1}{2})\pi + 1\right] \qquad (\,I_j \in [I_{j-1},\, I_{j+1}]\,) \tag{3}$$

From Eqn.(2) we know the membership function of α_j is shown in Fig.2 when fuzzy grade of earthquake intensity is $\underset{\sim}{I}_j$ and discussed region of soil in site is

$Y_s = (v_1, v_2, v_3)$, here v_i 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 $\underset{\sim}{D} = (d_1, d_2, d_3)$, in which, d_i is the membership degree of grade v_i relative to fuzzy grade $\underset{\sim}{D}$. Then, ζ can be calculated by weighted average. Finally, the membership function of earthquake effect factor α is shown in Fig.3. Its expression is

$$\mu_{\underset{\sim}{\alpha} j} = \begin{cases} \frac{1}{2}\left(\sin\left(\frac{2\alpha T}{\zeta\alpha_{jmax}} - \frac{3}{2}\right)\pi + 1 \right) & \left(\frac{0.5\zeta\alpha_{jmax}}{T} \leqslant \alpha \leqslant \frac{\zeta\alpha_{jmax}}{T} \right) \\ \frac{1}{2}\left(\sin\left(\frac{\alpha T}{\zeta\alpha_{jmax}} - \frac{1}{2}\right)\pi + 1 \right) & \left(\frac{\zeta\alpha_{jmax}}{T} \leqslant \alpha \leqslant \frac{2\zeta\alpha_{jmax}}{T} \right) \end{cases} \quad (4)$$

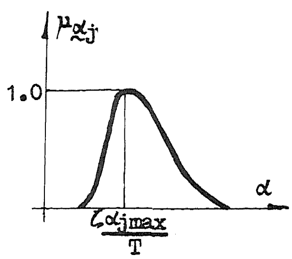

Fig.3 Membership Fuction of α

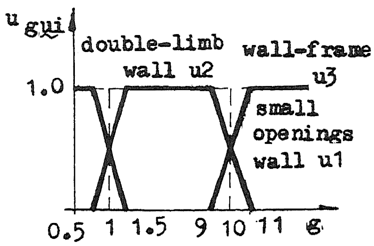

Fig.4 Membership Fuction $u_{\underset{\sim}{gui}}$

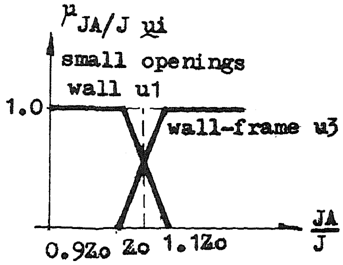

Fig.5 Membership Fuction $u_{JA/J\underset{\sim}{ui}}$

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 $g \geqslant 10$, and ratio of moment of inertia for shear wall $J_a/J \leqslant Z_0$, the reinforced concrete shear wall like this is the small openings wall;
2. If $g \geqslant 10$ and $J_a/J > Z_0$, is the wall-frame;
3. If $g \leqslant 10$ and $J_a/J \leqslant Z_0$, 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 $\underset{\sim}{E} = (e_1, e_2, e_3)$ in which e_i is the membership degree of grade u_i which is relative to fuzzy classification grade $\underset{\sim}{E}$. $\underset{\sim}{E}$ 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 conpressive 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 (Ag') all reach yield strength Rg (Rg') and the madial value of concrete compressive stress in compressive zone is Rw, 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 Ag in compressive zone can reach yield strength Rg, but that of Ag' in other side does not reach the yield point or still tensioned and its influence is usually neglected.

In boundary, maybe there are contradations 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 $\underset{\sim}{F} = (f_1, f_2)$ for fuzzy working state, f_i is the membership degree of W_i relative to $\underset{\sim}{F}$. The membership function (shown in Fig.6) is

$$\mu_{\underset{\sim}{le}} = \begin{cases} 0 & (\frac{x}{h} \leq 0.5-0.1u_s) \\ \frac{1}{2}\sin((10\frac{x}{h}+u_s-5.5)\pi+1) & (0.5-0.1u_s < \frac{x}{h} < 0.6-0.1u_s) \\ 0 & (\frac{x}{h} \geq 0.6-0.1u_s) \end{cases} \tag{5}$$

$$\mu_{\underset{\sim}{se}} = \begin{cases} 0 & (\frac{x}{h} \leq 0.5-0.1u_s) \\ \frac{1}{2}\sin((10\frac{x}{h}+u_s-5.5)\pi+1) & (0.5-0.1u_s < \frac{x}{h} < 0.6-0.1u_s) \\ 0 & (\frac{x}{h} \geq 0.6-0.1u_s) \end{cases} \tag{6}$$

FUZZY GUIDE 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 ect. are all fuzzy. Hence the fuzzy guide rule of safety is used in shear wall:

$$\underset{\sim}{\Omega}_i \triangleq (\underset{\sim}{S}_i \subset \underset{\sim}{R}_i) \tag{7}$$

here, $\underset{\sim}{\Omega}_i$ is a fuzzy event that the fuzzy maximum response $\underset{\sim}{S}_i(\bar{y}, \bar{x})$ can satisfy the safety requirement, the permissible interval $\underset{\sim}{R}_i(\bar{y},\bar{x})$ of maximum response $\underset{\sim}{S}_i$ constitutes a fuzzy subset in the discussed region of response such as bending moment M, axial force N, and shear Q.

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

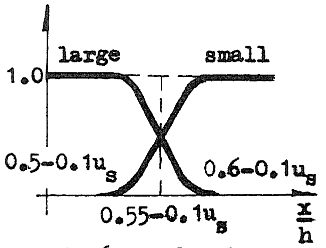

Fig.6 Membership Function of Ecc. Compression Condition

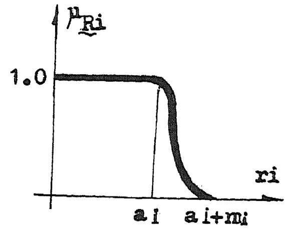

Fig.7 Membership Function of $\underset{\sim}{R}_i(\bar{x})$

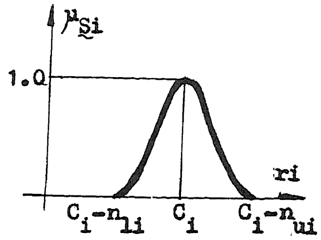

Fig.8 Membership Function of $\underset{\sim}{S}_i(\bar{x})$

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

$$\beta_i(\bar{y},\bar{x})= \mu_{\underset{\sim}{\Omega}\,i}(\bar{y},\bar{x})= \frac{\int_{-\infty}^{+\infty}\mu_{\underset{\sim}{R}i}(\bar{y},\bar{x},i)\,\mu_{\underset{\sim}{S}i}(\bar{y},\bar{x},i)\, di}{\int_{-\infty}^{+\infty}\mu_{\underset{\sim}{S}i}(\bar{y}, \bar{x}, i)\, di} \qquad (i=M,\ N,\ Q) \qquad (8)$$

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 ect.. 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 $\underset{\sim}{S}_i(i)$ (i= M, N, Q ect.) drops in its correponding permission interval $\underset{\sim}{R}_i(i)$, 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 β_i (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), therefor, effective region of shear wall is

$$\underset{\sim}{\Omega} = \underset{\sim}{\Omega}_1 = \bigcap_i \underset{\sim}{\Omega}_i \qquad (9)$$

and

$$\mu_{\underset{\sim}{\Omega}} = \mathrm{Min}\,(\mu_{\underset{\sim}{\Omega}M},\ \mu_{\underset{\sim}{\Omega}N},\ \mu_{\underset{\sim}{\Omega}Q},\ \cdots) \qquad (10)$$

GENERALIZED RELIABILITY OF R. C. SHEAR WALL

Random and fuzzy reliability of structure can be calculate by use of below-mentioned

$$\psi \triangleq P(\underset{\sim}{\Omega}) = \int_{-}^{+} f_{\eta}(\bar{y}) \mu_{\underset{\sim}{\Omega}}(\bar{y}, \bar{x}) d\bar{y} \qquad (11)$$

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

$$\psi(\bar{x}) \triangleq \mu_{\underset{\sim}{\Omega}}(\bar{x}) \qquad (12)$$

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

By using this methed the fuzzy reliability of a 4-storeys of reinforced concrete shear wall, which has symmertrical openings (shown in Eig.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 .

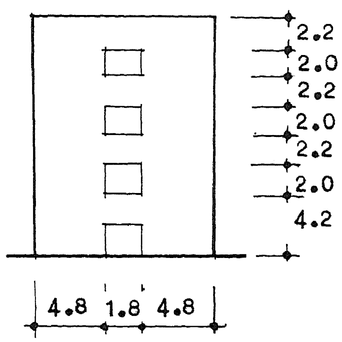

Fig.9 A 4-Storeys Shear Wall

Table 1 Calculation of Membership Degree

I_s			7	8	9
$P(I_s)$			0.85	0.10	0.05
μ	1	M	1.0000	1.0000	1.0000
		Q	1.0000	1.0000	1.0000
	2	M	1.0000	1.0000	1.0000
		Q	1.0000	1.0000	1.0000
	3	M	1.0000	1.0000	1.0000
		Q	1.0000	1.0000	0.9965
	4	M	1.0000	1.0000	0.5959
		Q	1.0000	1.0000	0.9089
$\mu(I_s)$			1.0000	1.0000	0.5959

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