Structure Earthquake Demand Importance Analysis Based on Variance Importance Analysis

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Abstract. Under the action of Taft ground motion records, the dynamic nonlinear time history analysis of the reinforced concrete frame structure were carried out. The earthquake demands of the reinforced concrete frame structure were given, the importance index of each random variable was obtained by variance importance analysis method of this reinforced concrete frame structure which was solved by Monte Carlo numerical simulation method. The results show that: The importance sorting of random variables, such as yield strength, damping ratio and structural quality was ahead and elasticity modulus of concrete was in the end for most earthquake demands. When analyzing the earthquake demand of reinforced concrete frame structure, we can consider the influence of several random variables, such as the yield strength of steel bar, the damping ratio and the structural quality. The calculation and analysis above may be helpful for improving the calculation efficiency of the analysis of earthquake demands.

Introduction

In structural earthquake calculation, the analysis of structural earthquake demand is an important aspect. In recent years, the research of structural earthquake demand is also more. The earthquake demand is influenced by the randomness of the random variable and the ground motion intensity in the structure. The randomness of the ground motion intensity has a great influence on the earthquake demand of the structure[1]. At the same time, the random variables in the structure also have a great influence on the earthquake demand of the structure. Therefore, the random variables in the structure should be considered when the earthquake demand of the structure is analyzed.

In this paper, variance importance analysis method is applied to analyze the importance of reinforced concrete frame structures, than random variables with significant influence and smaller influence were selected separately.

Analysis of Variance Importance

The importance measure $\delta^v_i$ of the random variable $X_i$ based on variance refers to, the ratio of mathematical expectation of the conditional variance $\text{Var}(E(Y|X_i))$ to unconditional variance $\text{Var}(Y)$ of the response quantity $Y$[2-3]:

$$\delta^v_i = \frac{\text{Var}(E(Y|X_i))}{\text{Var}(Y)} = \frac{\text{Var}(Y) - E(\text{Var}(Y|X_i))}{\text{Var}(Y)}$$

(1)

where: $X_i$ is a random variable, $E(\text{Var}(Y|X_i))$ represents the mathematical expectation of the conditional variance of $Y$.

In the solution (1), when the $N$ unconditional samples of the random variable $X_i$ were extracted, the $N$ unconditional sample values $Y_i$ were obtained by the nonlinear time history analysis. According to the law of large numbers, the unconditional variance $\text{Var}(Y)$ of $Y$ is as follows:

$$\text{Var}(Y) = \frac{\sum_{i=1}^{N_i} (Y_i - \bar{Y})^2}{N_i - 1}$$

(2)
When the conditional variance $\text{Var}(Y | X_i)$ of $Y$ is calculated, first of all, the mean of random variable $X_i$ was taken as implementation value, according to the probability density function of other random variables, $N$ samples were sampled randomly, and $N$ sample values were obtained. Input the realization value of $X_i$ and $N$ sample values into the nonlinear time history analysis model, the $N$ response values were got, that are, the conditional sample values when $X_i$ was fixed. The conditional variance $\text{Var}(Y | X_i)$ of the response amount $Y$ is as follows:

$$\text{Var}(Y | X_i) = \sum_{j=1}^{N} (Y_{i,j} - \bar{Y}_{X_i})^2 / (N - 1)$$  \hspace{1cm} (3)

Substituting formula (2) and (3) into formula (1), that is, the variance importance measure index $\delta_i^v$.

### Reinforced Concrete Frame Structure Model

A reinforced concrete frame structure is 3 span 7 story, the bottom layer height is 4.2m, the other layer height is 3.6m. The plane schematic diagram is shown in Figure 1. All column spacing are 6.0m, steel grade is HRB335, concrete grade is C40. The details of the random variables are shown in Table 1, and the section information of the beams and columns are shown in Table 2.

![Diagram](image)

**Figure 1.** Standard layer schematic diagram.

<table>
<thead>
<tr>
<th>Random variable</th>
<th>Distribution type</th>
<th>Symbol</th>
<th>Mean value</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete elastic modulus/Mpa</td>
<td>Normal</td>
<td>$E_c$</td>
<td>33904</td>
<td>0.08$^{[4]}$</td>
</tr>
<tr>
<td>Concrete compressive strength/Mpa</td>
<td>Normal</td>
<td>$f_c$</td>
<td>34.82</td>
<td>0.14$^{[5]}$</td>
</tr>
<tr>
<td>Steel bar elastic modulus/Mpa</td>
<td>Normal</td>
<td>$E_s$</td>
<td>228559</td>
<td>0.033$^{[6]}$</td>
</tr>
<tr>
<td>Steel bar strength/Mpa</td>
<td>Log-normal</td>
<td>$f_y$</td>
<td>384</td>
<td>0.078$^{[4]}$</td>
</tr>
<tr>
<td>Damping ratio</td>
<td>Normal</td>
<td>$D_A$</td>
<td>0.05</td>
<td>0.2$^{[7]}$</td>
</tr>
<tr>
<td>Structure quality/kN·m$^{-2}$</td>
<td>Normal</td>
<td>$M_s$</td>
<td>6</td>
<td>0.1$^{[5]}$</td>
</tr>
</tbody>
</table>

Note: the structure quality in the table is the representative value of the gravity load.
Table 2. Section information.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Beam section (mm×mm)</th>
<th>Beam section reinforcement/mm²</th>
<th>Column section (mm×mm)</th>
<th>Column section reinforcement/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bottom</td>
<td>Top</td>
<td></td>
<td>Edge</td>
</tr>
<tr>
<td>1</td>
<td>300×600</td>
<td>1256</td>
<td>1964</td>
<td>600×600</td>
</tr>
<tr>
<td>2~4</td>
<td>300×600</td>
<td>1017</td>
<td>1520</td>
<td>600×600</td>
</tr>
<tr>
<td>5~7</td>
<td>300×600</td>
<td>804</td>
<td>1017</td>
<td>500×500</td>
</tr>
</tbody>
</table>

In this paper, Taft ground motion record was adopted, and OpenSees was used for dynamic nonlinear time history analysis. Columns and beams were made of nonlinear fiber beam column element, concrete adopts Concrete02 unit, and steel bar adopts Steel02 unit material model.

**Importance Analysis Results**

We choose the 4 earthquake demands of the top displacement, maximum drift angle, the maximum floor acceleration and base shear to analysis the influence of each random variable. The importance measure index are shown in Figure 2, we can see from Figure 2, The damping ratio, the structure quality and the compressive strength of concrete have great influence on the 4 earthquake demands, but the elastic modulus of concrete has little influence.

**Summary**

(1) Damping ratio, structural quality and compressive strength of concrete have great influence on different earthquake demands, while the influence of elastic modulus of concrete is the smallest.
(2) The impact of each random variable on the same earthquake demand in the transverse and longitudinal structure of the reinforced concrete frame structure is basically the same.

Acknowledgement
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References