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SOME EXPERIENCE OF SEISMIC DESIGN FROM TANGSHAN EARTHQUAKE

WU Yucai[1] YUAN Yueming[2] XUE Zonghui[2]

1 Design and Research Institute of State Commission of Machine-Building Industry, Beijing, China.
2 Beijing Polytechnic University, Beijing, China.

SUMMARY

In this paper, 106 single-story mill buildings with reinforced concrete columns are analyzed dynamically as a member system by means of random vibration theory using actual or artifical earthquakes. From comparison of calculated results and actual seismic damege, the calculated results are in good agreement with the observed seismic damage. It also shows that the calculated results are reliable and enables us to reveal some preliminary conclusions.

THE ANALYSIS OF EARTHQUAKE RESPONSE

When the cross wall intervals exceed a certain value, the workshop is simplified as a plane system. Every column with the same section, is regarded as an eccentric compression member. The roof is regarded as a cross girder with infinite stiffness, and the masses of the roof, column, etc. lump at the top of the column. The material behavior is assumed to be bilinear and the strain hardening coefficient is represented as p. The columns of a single-story mill building are thinner and longer, and the deformations are greater during an earthquake, consequently, the p-delta effect, which results from the structural weight, can not be neglected. It's influence can be considered in the analysis by superposing a geometric matrix to the structural stiffness matrix.

Divide the displacement components into two parts U_1 U_2 which respectively include and exclude inertia force. Assuming the variation of the acceleration is linear in a time interval Δt, the increments of acceleration and velocity can be expressed by the displacement increment Δu. Based on the initial velocity $\dot{u}_1(t)$ and the initial acceleration $\ddot{u}_1(t)$ at the same time, the instantaneous displacement, velocity and acceleration can be obtained, and the internal force and displacement of every member end can be obtained. Finally, we can determine the safety of every member.

In this programme, a switch variable is set. It can be used to adjust the acceleration amplitude, the time stepwise and the duration of seismic waves. It can output capacity, seismic maximum elastic and elastoplastic responses at both ends of member, and the moments when they happen respectively. It can also give the maximum displacement at every lumped mass, the moments when the displacements happen, and the seismic elastic and elastoplastic responses of every member when the displacements happen.

THE ANALYSIS OF THE CALCULATED RESULTS

After setting the programme mentioned above, we input the NINGHE earthquake and several artifical earthquakes. Our study leads to four preliminary conclusions.

Explaining the Seismic Damage Phenomena The programme can be given the capacities My and the seismic elastic responses Me for every member. Let My/Me=C_1. In the calculating form, the value C_1 corresponds to the value C in the code. It represents the safety reserve of a member. The greater it is, the safer this member is. When it falls to a certain value, the member will have seismic damage. When the damage degree caused by an earthquake just meets the threshold level of the seismic code, the value C_1 is equal to the value C of the code. Where there is a minimum value C_1 in a structure, there is the weakest place of this structure.

We collected 76 samples in TIANJIN and found that there were 39 samples which incurred seismic damage. Among the 39 samples, there are 37 samples which have damage at the locations having the minimum value C_1. There are two exceptions: one has damage at the places where there are 2nd and 3rd lowest values of C_1, the other has damage in the upper-column which supports the roof structure at different levels and this column has the 2nd lowest value of C_1. It is obvious that these two exceptions don't deny this fact that the smaller the value C_1 is, the lower the aseismic capacity is, and when there is the smallest value C_1, the seismic damage will become most serious and most likely to happen at that location.

The samples are divided into three groups: (1) The 19 samples of the first factory. There are 10 samples with the residual cracks of width not larger than 0.2mm, the other two samples have residual cracks of width not larger than o.3mm. (2) The 25 samples of the 2nd factory. Although there are only 9 samples developing seismic damage, which are residual cracks of width about 3~4mm, and with concrete shattered and longitudinal bar buckled. There is also a corner column broken. It is obvious that this factory is damaged more seriously than the first factory. (3) The remaining 32 samples occur in 9 factories. Among these factories, one is next to the first factory, and some are near the second factory. Only a few are more seriously damaged than the second factory. The average degree of the earthquake damage of the 3rd group is between these of the above 2 groups. The average C_1 of these 3 groups are 0.278, 0.155, 0.236 in turn. These average values indicate that the smaller the value, the greater the damage; conversely, the larger the value, the lighter the damage.

The above facts indicate that the value of C_1 and the average of the values of C_1 represent the safety reserve of a member or a structure and the structures of a group. So we can see that the calculated results correspond to the reality of seismic damage and can also explain the occurrence of the seismic damage.

The Slope of the Standard Response Spectrum In the Ref[4], we have once offerred that if the response spectrum of the code is applied to a single-story mill building, we can obtain the result that the building with a heavy roof is safer than the building with a light roof under the same conditions; or the thinner or the higher the column is, the sater it is, under the same conditions. The result is the contradiction in both macroscopic observation of seismic damage and static designs and is not easy to be accepted either. We call this phenomenon as an "abnormal phenomenon."

In order to make a statistical analysis, we divided the samples of TIANJIN into 2 groups. The first group is made up of the samples from the first factory that has slight damage as mentioned earlier. The factory is a heavy machinery factory that has a larger static capacity of the member and this factory is based on site soil II. The second group is made up of the remaining samples. And most of these samples are from the factories that are based on site soil III. These samples have damage as serious as these in the second and third groups mentioned. Because these two groups of samples have different characteristics, we had to make separate statistical analyses. The programme can also give the largest accelerations A at the positions of the lumped mass of the buildings. Multipling A by the value C_1 at the place where it has the most serious damege, we can obtain the term corresponding to the base shear force ceefficient $C\alpha$ given by the code. One group of samples has a group of values C_1A. After we find the C_1A-T curve by the regression analysis, and compare the curve to the value $C\alpha$, we obtain the data of Table-1 according to the range of the natural period of the semples.

Table-1 Comparision of C_1A and $C\alpha$

T		0.7	1.0	1.3	1.5	1.7	2.0
Data of First Group	$\eta_i = C_1A/C\alpha$	3.21	3.24	3.33	3.40	3.47	3.60
	$\eta_i / \eta_{2.0}$	0.89	0.90	0.92	0.94	0.96	1.00
Data of Second Group	$\eta_i = C_1A/C\alpha$	2.66	3.03	3.38	3.60	3.82	4.12
	$\eta_i / \eta_{2.0}$	0.65	0.74	0.82	0.87	0.93	1.00

The data of Table-1 indicates two points: (1) The practical earthquake response is two to three times larger than the earthquake response given by the code. This is consistent with the analyses given by Ref.[5],[6]. The main reason for this is that the earthquakes poses problems is stochastic instantaneous and the code offers the equivalent static force. Many documents [Ref.5,7,8,9] also directly or indirectly show that there are great differences between them. Clearly understanding this problem will hopefully result in a great reform in seismic design. (2) η_i in Table-1 expresses the ratio between the earthquake responses both derived from the samples of the past events and given by the code at the moment T=i. $\eta_i/\eta_{2.0}$ expresses the ratio of two curves at every point T=i while these two curves are coincide at T=2.0 sec. The ratio is a decimal and expresses that the slope of the former curve is more even than that of the later curve. The earthquake response given by the curve of the samples of the past events must make a fundamental change to the abnormal phenomenon mentioned above. It coincides with the conclusion given by our past analyses of two sets of brick column industrial buildings[10] and approaches the slopes of the curves given by the present revision draft of the code. The approving of the revision code will be a great advance in design practice.

<u>The Lower-end of Upper Part of Step-column is the Weakest Place in Earthquake.</u> Dividing the TIANJIN samples into three groups as mentioned above: The first group has 19 samples. (1) There are 14 samples in this group which have minimum value C_1 at their upper parts, ("upper part" denotes "the lower-end of upper part" in the following) and 10 of them have residual cracks at this position. The other 5 samples in this group which have minimum value C_1 at their lower parts, have no residual cracks at their lower parts but 2 of them still have residual cracks at their upper parts. (2) Dividing the average of the values C_1

of all lower parts by that of all upper parts, we get 0.95; dividing the average of the values C_1 of all lower parts of the samples which have seismic damage by that of all upper parts of same samples, we get 0.93. These results indicate that the safety reserve of upper part is slightly larger than that of lower part. The samples of this group have no residual cracks at the lower parts but 12 samples of them still have residual cracks at the upper parts. (3) There are 59 ranked columns in this group of samples and 20 of them have residual cracks at their upper parts. In the elastoplastic analysis these 20 ranked columns are characterised by yielding at both upper and lower parts and only at upper parts. But when they are characterised by yielding only at lower parts, neither upper parts nor lower parts have not this type of cracks. This three results prove that although the safety reserve of upper part is slightly larger than that of lower part, it is still easy to have seismic damage in the upper part.

The second group has 25 samples. They also explain the phenomena as indicated above from three aspects: (1) There are 8 samples from this group which have residual cracks and 3 samples only to have this cracks at upper parts. 2 of these 3 samples have minimum values C_1 at lower parts. (2) Among the samples with residual cracks in the upper and lower parts or only in the lower parts, the average of the values C_1 of lower parts are one quarter less than that of their upper parts. Otherwise, seismic damage only occurred in the upper parts. (3) In the elastoplastic analysis, that only lower parts or both the upper and lower parts have cracks when only lower parts are characterised by yielding. And then only the upper part cracking would occur in these conditions, when the lower parts or the upper parts, or simultaneously the upper and lower parts are characterised by yielding.

The 3rd group samples, reveal the same fact: (1) In the elastic analysis, the phenomena that only upper parts have cracks occur in the columns where the ratios of the values C_1 of lower parts divided by the values C_1 of upper parts is between 1.2~0.8. Most of these ratios are approaching 0.8 and the average is about 0.9. It explains that the safety reserve of the lower parts is 10~20% less than that of their upper parts, it is still only to have the residual cracks in the upper parts. When only the lower parts have the residual cracks, the ratio mentioned above is about 0.6. (2) In the elastoplastic analysis, the results are same as (3) of the second group of samples.

The results of these three groups explain that the upper part of step-column is the most weakest in earthquake [11].

<u>Deformation Calculation</u> From the lesson of 1976 TANGSHAN earthquake. We draw the design philosophy that a structure should resist minor earthquakes without damage and have sufficient capacity to avoid collapse in the event of a severe earthquake. It is unquestionable that this is an advance in the quide idea of seismic design. During a severe earthquake, many members have entered well into the elastoplastic state. Although a loading capacity may include the deformation factors, it is not proper in conception to judge the safety by it, and it is better to represent the safety of a structure by using the deformations.

Because the elastoplastic calculation are very complicated, it is seldom used in design. The elastic calculation is not only reliable but also convenient. We assume that we can calculate the elastic and elastoplastic deformations in the same condition and can find out the statistical relations between two kinds of deformations. Through the calculation of 106 samples, we can get the elastic and elastoplastic deformations of each member in turn. The records of samples include only whether concrete has been shattered and logitudinal bars have buckled, and also the size of cracks. We have made the pseudo-static test of the step-column and obtained the elastic and elastoplastic deformations corresponding to the broken phenomena as mentioned above. We obtain the data of two capacity states of member: yield and limit. They correspond, respectively, with the two instances that (i) the members have residual cracks of about 0.2mm wide and (ii) the concrete shattered or longitudinal bar buckled. The deformations of two states are about L/60 and L/10, in turn. When the degree of seismic damage apprcaches the two states as mentioned about, the deformations given by the samples distribute around L/40 and L/10, in turn. This analysis indicates that our calculated results are in good agreement with the test results. So we can say that our calculated results are convincing. According to the data given by our calculation and considering the concept of the equality of energies, we deduce semi-empirical formula of elastoplastic deformation as follows:

$$\Delta\rho = \eta\,\Delta e = \frac{1}{5\sqrt{\xi}}(0.3+2.2\sqrt{\xi}) + (\xi + \frac{1}{\xi})\Delta e \tag{1}$$

where, Δp, Δe denote the deformations of a member in the elastoplastic and elastic state in turn; η, the conversion coefficient between elastic and elastoplastic deformations; ξ, the ratio of the capacity, $\xi = My/Me$; and My,Me,the capacity and seismic elastic response, in turn.

Based on the data from the calculations of the samples during the past events and pesudo-static test and considering some satety reserve, we suggest that the permissille deformation values should be as follows: (i) For the instance that a structure does not collapse in a severe earthquake, L/30. This value corresponds to the cracks width of 1.5mm. (ii) In the instance that a structure has no damage in a minor earthquake, L/120. This value is used as a limit deformation of the column that has a deformation demand. This value corresponds to the crack width of 0.1mm [12].

The above calculation offers some quentitive values and explains some phenomena of seismic damage. Although it is a initial work, it is very concrete and can solve some problems in quantity.

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