EARTHQUAKE DAMAGE ANALYSIS AND STRENGTHENING OF THE MAIN BUILDING OF NATIONAL AGRICULTURAL EXHIBITION CENTER

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SUMMARY

Based on the experimental study, a dynamic analytic model of the main building of National Agricultural Exhibition Center for earthquake response analysis is set up and an analysis of earthquake damage during Tangshan earthquake of 1976 is presented in this paper. Besides, on the basis of nonlinear earthquake response analysis, the effect of strengthening scheme is also discussed.

INTRODUCTION

The National Agricultural Exhibition Center was built in 1959 in Beijing. The main building of this exhibition center has an internal reinforced concrete frame with external bearing brick wall structural configuration. All the reinforced concrete beams, slabs and columns are casting members. The middle part of the building has three stories with plan of 35×49 m and there are two single-story buildings on its both sides. The plan view and side view are shown in Fig. 1 and Fig. 2. On the top of the building roof there are four small and one big pavilions, as shown in Fig.2.

During Tangshan earthquake of 1976, the main building of the exhibition center suffered local seismic damage. Therefore, the main building must be strengthened. The research work in connection with this paper is carried out as follows:

1. The dynamic characteristics of the damaged main building were investigated by means of ambient vibration survey, the results of which were used to set up a lumped mass model taking account of the torsional vibration and to identify the initial stiffness of whole system.

2. Considering a trilinear stiffness degrading model for restoring force, a computer program was developed for the analysis of nonlinear earthquake response of the main building.

3. On the basis of nonlinear seismic analysis, the adjustment of interstory stiffness in main building was recommended for strengthening of this building.

4. Based on the above-mentioned study, a viable strengthening scheme is presented.

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AMBIENT VIBRATION SURVEY AND ANALYTIC MODEL FOR STRUCTURE

In order to provide survey data to determine the analytic model of structure, an ambient vibration survey for main building was carried out. After inputting the information into micro-computer, the dynamic parameters such as frequencies, vibration modes and damping ratios can be obtained by analysing response spectrum and transfer function spectrum.

The results of the survey work can be summarized as follows:

1. From the survey points arranged along the height of the building at each floor as shown in Fig.2, it was obtained that the natural frequency of the building is 3.66 HZ in X direction and 3.90 HZ in Y direction. The first translational vibration mode in each direction is shown in Fig.3 and damping ratio is about 0.051~0.067.

2. From the survey points arranged symmetrically at the roof elevation 14.90 m, it was obtained that the first torsional frequency of the building is about 4.88~5.27 HZ by analysing phase angle variation in each survey point.

3. From the survey points, as shown in Fig.2, arranged at the roof beams of the five pavilions, it was found that during the ambient vibration the small pavilions vibrated simultaneously as the same body, but the big one did not vibrate synchronously with the small pavilions.

In order to set up an analytic model for the structure of the building, according to above-mentioned survey results, the following factors should be considered.

1. Because the mass center does not coincide with the stiffness center, the torsional vibration effect should be taken into account in the model.

2. Because the vibration of the big pavilion is different from that of the four small pavilions, the big one and the four small ones should be concentreted as two lumped masses respectively.

3. Because the main aseismic members are arranged in X and Y direction, the seismic resistant capacity of the building in two directions must be considered in the model.

Based on the above considerations, a lumped mass shear-torsion model was set up, as shown in Fig.4 and Fig.5.

The calculated results of the dynamic characteristics of the building with the shear-torsion model show that the natural frequency of main building is 3.665 HZ in X direction, 3.916 HZ in Y direction and 4.854 HZ in rotation. The calculated vibration modes are also shown in Fig.3. The comparison between the results of calculation and those of survey shows that the dynamic model is reasonable.

EARTHQUAKE DAMAGE ANALYSIS OF MAIN BUILDING

During Tangshan earthquake on 28th of July in 1976, the main building suffered seismic damage to that extent: serious diagonal cracks appeared in one external column of the big pavilion and some visible cracks occurred in three interal columns. The small pavilions also had a minor damage. Besides, the brick masonry wall of (J) axis in X direction (Fig.2) at elevation 10.10~14.90 m had diagonal and horizontal cracks as well as brick masonry walls of (11), (13), (31) and (33) axes in Y direction at the same elevation also cracked severely, and a few brick window piers had horizontal cracks.

By inputting earthquake ground motion recorded at Beijing Hotel on 28th of July,1976 (after-shock of Tangshan earthquake into the above-mentioned model and using the restoring force model (Ref.4, semi-degrading trilinear model) shown in Fig.6, it was found that the big pavilion and the small ones cracked first and next the brick wall of (J) axis in X direction cracked at the elevation 10.10~14.90 m; after a moment, the brick walls of (11), (33), (13) and (31) axes in Y direction at the same story cracked gradually. The calculated results are in agreement with the seismic damages.

On the basis of nonlinear earthquake response analysis, the reasons of the local seismic damages may be cited as follows:

1. The structural stiffness is of a significant nonuniform distribution shown in Fig.7, so apparent whiplash effect took place and caused cracks in the pavilions during earthquake.

2. The brick walls at elevation 10.10~14.90 m are of large opening ratio and their section are weakened, so the story shift was large enough to cause cracking, and because of the torsional effect shown in Fig.8, the story shift of (J) axis in X direction was larger than that of (B) axis (Fig.9), the wall of (J) axis also cracked earlier.

3. Owing to the amplification effect of torsional vibration along the height of the building (see Fig.8), the shift of upper member far from the stiffness center increased rapidly and resulted in cracking.

STRENGTHENING SCHEME FOR MAIN BUILDING

Based on the survey results and theoretical analyses and in order to reduce the earthquake response of building structure, the following view-points for strengthening scheme of main building should be considered.

1. Because the strengthening design should be done on the basis of original condition and some expensive ornaments must be preserved, the stiffness variation along the height of the building has to be reduced and the whiplash effect and deformation concentration should be reduced as much as possible.

2. In order to reduce the torsional vibration effect, the stiffness of some main structural members should be increased.

3. Owing to the fact that the existing structure does not satisfy the requirement of current code to resist the earthquake corresponding to design

intensity (Fig.10), the strength of some structural members must be increased reasonably.

According to the above view-points and considering architectural function, investment of the project and convenience of construction, the following main measures can be recommended:

1. The external and internal columns of the big pavilion are strengthened to form reinforced concrete combined columns.

2. The columns of the four pavilions are strengthened to become L-section columns.

3. The brick walls at elevation $10.10 \sim 14.90$ m and all the damaged walls are strengthened by cement mortar reinforced with steel mesh.

4. The walls under the roof of the center hall at the four corners are strengthened by additional reinforced concrete shear walls.

5. Some reinforced concrete shear walls are added in Y direction of the two side single-story buildings in order to reduce its torsional effect.

Considering the above main measures and inputting several earthquake ground motion accelerograms (all peak values are equal to 200 gal), the nonlinear earthquake responses of the structure are obtained as shown in Fig.11. These results show that the shift of the building is reduced significantly, and all the members work at the first and second stiffness regions of the restoring force model (Fig.6) except the columns of the big and small pavilions, columns of which work at the third stiffness region, but only with slight damage. It means that the strengthening scheme is reasonable.

CONCLUSIONS

1. The shear-torsion model can be taken for nonlinear earthquake response analysis and the seismic action should be considered in two directions of the building.

2. The reason of local seismic damage of the building mainly is that the nonuniform distribution of mass and stiffness results in the torsional vibration of building and whiplash effect of the pavilions.

3. The strengthening measures suggested in this paper are reasonable and can reduce the earthquake response when the building meets the earthquake corresponding to design intensity.

ACKNOWLEDGMENT

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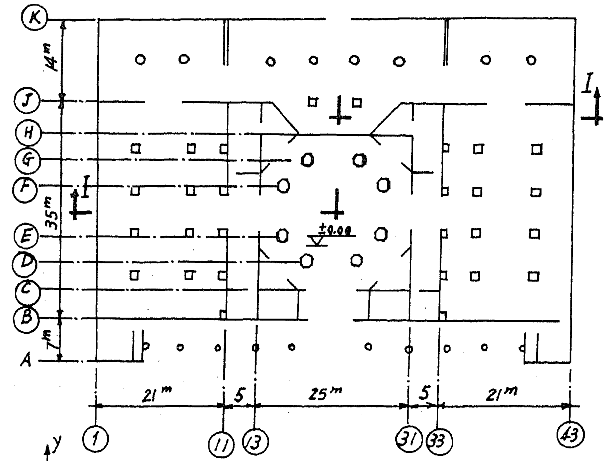


Fig. 1 Plan view

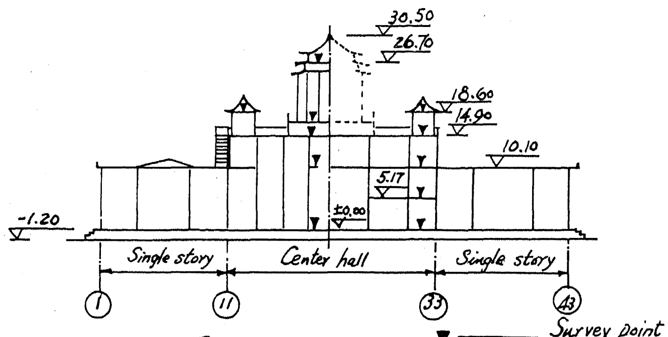


Fig. 2 Section I-I

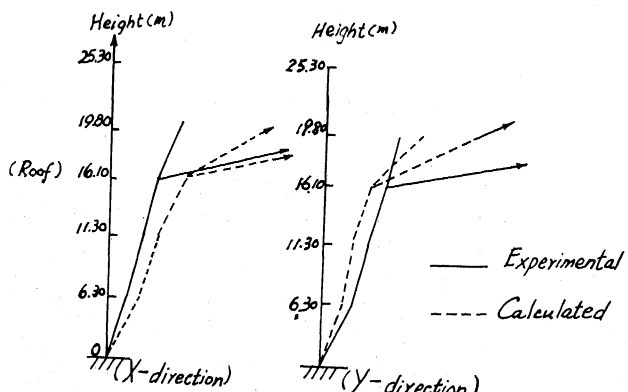


Fig. 3 Vibration modes

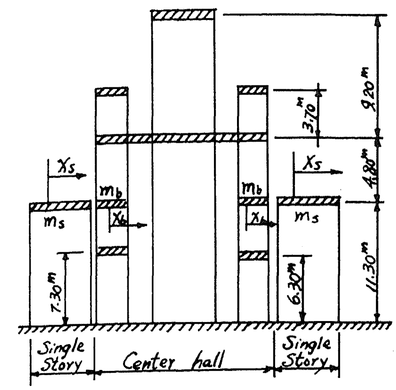


Fig. 4 Analytical model

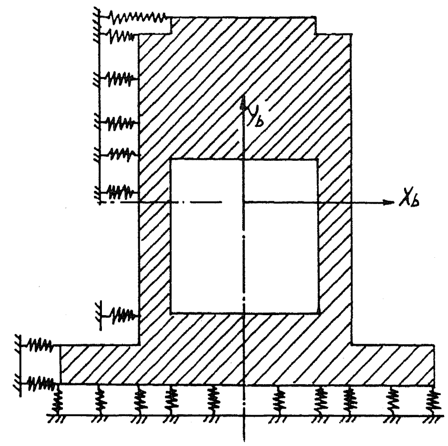
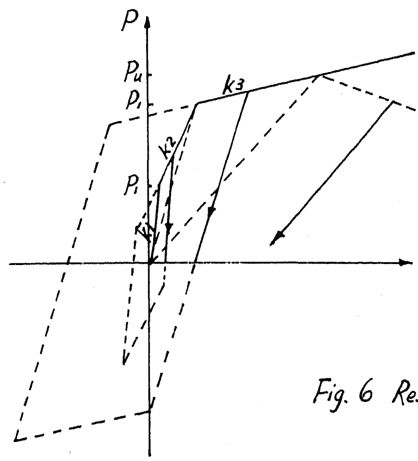


Fig. 5 Plan of mass m_b



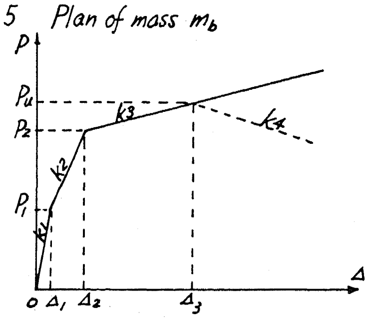


Fig. 6 Restoring force model

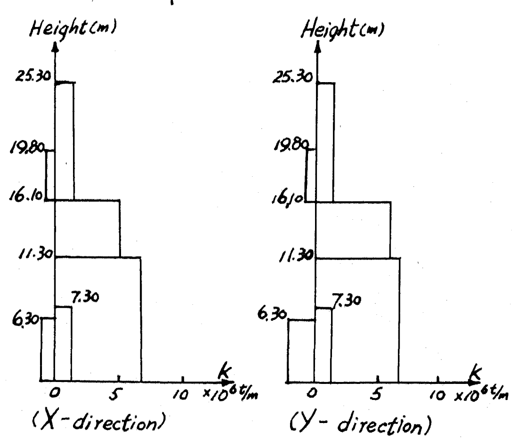


Fig. 7 Story stiffness

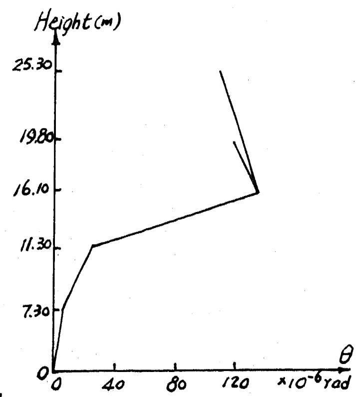
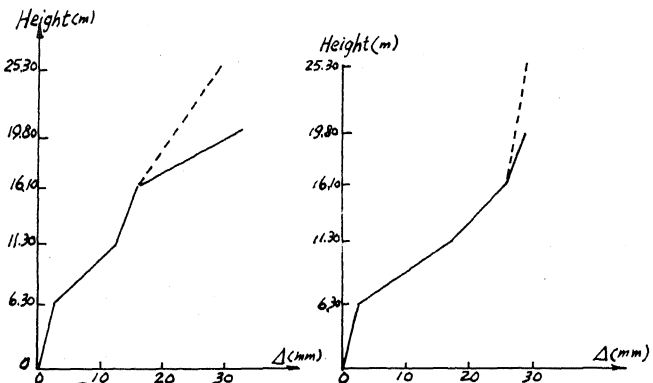
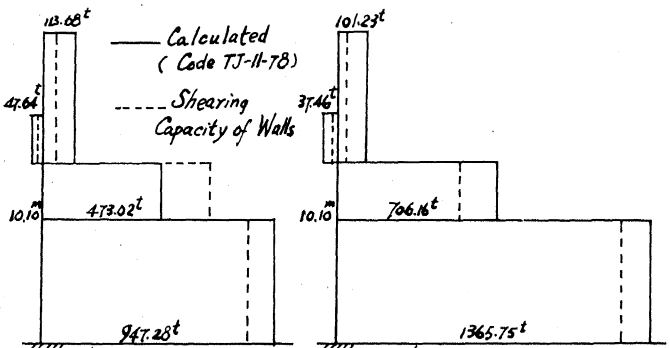


Fig. 8 Envelope of torsional angle
(nonlinear)



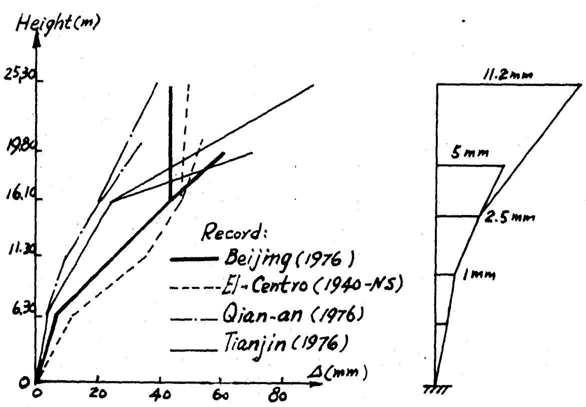
(At Ⓑ axis in X-direction) (At Ⓙ axis in X-direction)

Fig. 9 Envelope of story shift (nonlinear), Peak value: 73gal.



(X-direction) (Y-direction)

Fig. 10 Story shear force



(Before strengthening) (Prediction after strengthening)

Fig. 11 Envelope of story shift (nonlinear), Peak value: 200gal.