THE CHARACTERISTICS AND ANALYSIS OF DAMAGES OF SINGLE STOREY R.C. INDUSTRIAL BUILDINGS DURING THE TANGSHAN EARTHQUAKE

Wang Zuang Sun[I] Ju Ming Chuan[II]
Chen Zhong[III] Tung Wei Ming[II]

SYNOPSIS

In this paper damages of various precast R.C. structural members in single storey industrial buildings during Tangshan earthquake are introduced, and analysis are made to interpret causes of such damages theoretically. Typical damages are illustrated, including skylight frames protruding out of the roof, roofing systems, R.C. columns, bracings and joints. Based upon experience summerized afterwards, essentials regarding designing such buildings under strong seismic loadings are deduced.

INTRODUCTION

Epicenter intensity of Tangshan Earthquake in 1976 was as high as 11°. As located in the main industrial areas, very serious damages were resulted toward single storey factory buildings. After the earthquake, investigations have been made by the authors in those areas on buildings of single storey with reinforced concrete column constructions, in which including 10 buildings under 11° intensity, 40 under 10°, and large numbers under $9\text{-}7^{o}$.

Historically, Tangshan region had seldom recorded to subject to heavy earthquake, thus design intensity for this area had been assigned to be 6°. Therefore, almost all the buildings investigated have not been designed to withstand earthquake.

MAIN EARTHQUAKE DAMAGES AND THEIR ANALYSIS

Precast Π-shaped skylight frames protruding out of the roof often suffer heavy damages either in the epicenter or in the near-by areas. Even in 7° region, there are some causalities. The weak sections on those frames are their vertical bracings and their joints. Direction of the failure is chiefly along the longitudinal of the building. Failures consist of buckling of the bracings, breakdown of the joints, crack or incline or downfall of the stubs. In the most severe case, downfall of the whole roof might occur.

Roof slabs at the end of gabled roof and at the section of the

---

I Deputy Director, Office of Earthquake Resistance, The 1st Ministry of Machine Building Industry, China, Beijing.
II Engr., The General Institute of Plant Design, The 1st Ministry of Machine Building Industry, China, Beijing.
III Engr., The 8th Design Institute, The 1st Ministry of Machine Building Industry, China, Changsha.

building where vertical bracing between columns are existing, often concentrated to be damaged. This is due to the reason that stiffness of the gable wall is far more than those of the column row, thus earthquake loading is concentrated there. On the other hand, welding seams between the roof slabs and the roof trusses on the same section is the weakest. Therefore, even in 8° regions, roof slabs on such sections happen to be displaced or rotated, which indicate that the weak welding seams have been already broken. Column bracings are the structural members used to transmit horizontal seismic load acting on the whole roof trusses, thus earthquake load acting there are higher than others. If the roof bracing systems on there have not been reinforced, heavy damage would be expected. On the contrary, those with suitable roof bracing systems established on those sections such damage could be avoided.

Vertical bracings are the main measures to take the longitudinal load for stabilizing the roof systems, especially for those with higher end members. Photo 1 shows a certain building that declined longitudinally due to unsufficient vertical bracing. There are two nearby buildings in the same area of 10° intensity. Both are in the same structural construction basically. After the earthquake, the one without vertical bracings falls down totally with its roof, while the other still remains in good condition because it is well braced, thus forming a distinct contrast.

Generally, columns are stepped in factory buildings for travelling of the overhead crane. The main members for resisting lateral seismic load are these columns in single storey factory buildings. Except at 11° intensity, for few such buildings with heavy roof construction, breakage appears on the bottom portion of these columns. For the rest intensities, damages are not very serious. From 8° up, 0.2mm residue visible cracks appear on bottoms of the columns with their widths increase with the intensity. Based upon tests made on models, if ductility factor, μ, lies between 2 and 3, the width of the residue cracks is about 0.1 — 0.2mm. It is deduced that in the 8° intensity regions, seismic force acting on the columns might exceed its yielding strength. In 10° intensity regions, owing to unreasonable arrangement of column bracings, columns of a few buildings are damaged seriously with their main reinforcement buckling, protecting cover of concrete spalling off (Photo 2).

Damage often occur seriously at the junction where stepped columns change their sectional areas. Statistics shows that whenever inertia of the upper section differs the lower section by more than 5 times, damage would occur and would be on the increase with the ratio. Photo 3 shows a typical example of certain factory building with columns broken on its upper section. Owing to the fact that a crane of heavy class is provided in that factory, inertial of the lower section is made 10 more times than its upper. Calculation shows that under horizontal seismic load, yielding strength of the lower section is 2 more times more than its upper, thus bottom of the upper section arrived at the plastic stage earlier during earthquake. Thus, ductility of the whole building is decreased, causing downfall of the roof. Damages on the junction between spans with different heights are caused by the

higher mode of vibration during earthquake. Analysis has been made on 204 buildings with spans of different in heights. Results show the larger the difference in height, the higher the internal stress induced by the higher mode, which coincides basically with the marco damages observed.

Bracings between columns are the important members to withstand longitudinal seismic load. From 8° on, various signs of damages appeared on them (Photo 4). Analysis indicates that whenever buckling appeared on those cross bracings made by steel angles after earthquake, the bracings worked in the elastic-plastic stage with a ductility factor of about 3-4. Moreover, observation on large amount of earthquake damages shows that if cross bracings between columns are made strong, generally, serious damages would happen on the joints. On the other hand, if the bracings are not strong, buckling would happen on themselves.

For buildings without cross bracings between columns, serious damages occur even at 8° intensity. Generally, corners of the columns were subjected to be spall off and buckling of main reinforcements. Analysis shows that strength of the columns is weak in the diagonal direction of its cross-section.

In the 10° intensity regions, failure of joints atop columns are the main reason to cause downfall of the roof. Therefore, special attention must be paid to the reliability of the joints of precast R.C. buildings to withstand earthquake. As observed from downfall of factory roofs on site at 10° regions, the roofs have been fallen down together with their embedded steel plates welded to them, while legs attached to the plates were pulling out from the concrete into which they are embedded due to lower anchorage strength. The main reason to cause such failure of the joints is due to the weakness of the joints. During earthquake, certain amount of flexural moment would be induced on such joints. Meanwhile, there are axial loads and shear existing due to seismic load, thus such joints are subjected to complicated actions of several kinds. The strength and deformability of the joints is relatively low, thus damage occurs when those complicated actions apply. Should the joints be bolted, such damage would be eliminated, because the bolt cannot transmit complicate stress. Therefore, the result as regarding to withstand the earthquake is better.

CONCLUSION

Based upon actual observations on site and investigations made above, the authors consider that the followings should be taken into consideration in designing single storey factory buildings.

1. Even in 6° intensity regions, certain measures must be taken toward the buildings to withstand earthquake. For buildings having been designed in accordance with the basic requirement of their respective seismic intensity measures should also be made to prevent them from downfall when subjected to unexpected strong shock.

2. Total weight of the factory building should be made less, and their integrity should be made better. Arrange the various bracings

rationally throughout the building, especially enforce the longitudinal bracings.

3. Try to avoid Π-shape skylights. If this skylight is necessary, bracings should be increased to enhance the longitudinal capacity of earthquake resistance.

4. Special attention should be paid to design joints between precast structural members. Use bolted joints or others which are advantageous to withstand earthquake. Try to avoid welded joints between main members.

5. Strength and ductility of the columns should be carefully enhanced, especially the junction between stepped columns. Moreover, junction between high and low spans should be carefully designed, where stepped columns are to be used.

6. For buildings without bracings between columns, the strength in the diagonal direction requires to be checked to withstand the earthquake.

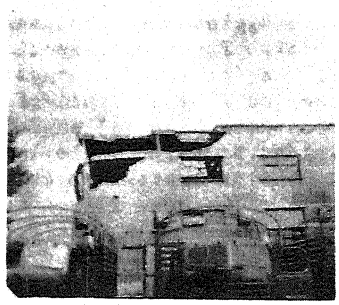

Photo 1

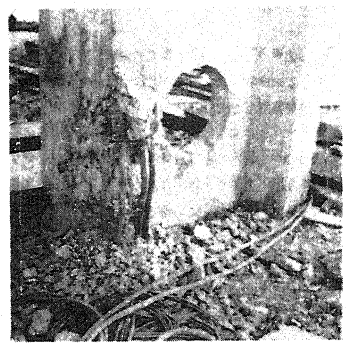

Photo 2

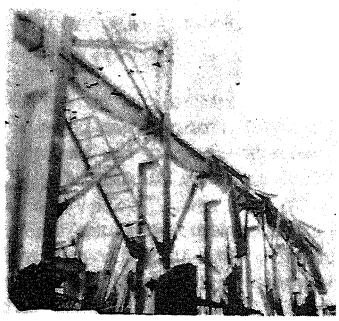

Photo 3

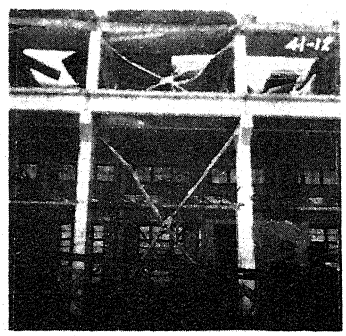

Photo 4