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DAMAGE ANALYSIS ON BUILDINGS IN TOWNS AND VILLAGES AROUND THE JUNCTION AREA OF SICHUAN AND GANSU IN WENCHAUN EARTHQUAKE

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ABSTRACT: Based on the site investigation of building damage in towns and villages around the junction area of Sichuan and Gansu province caused by Wenchuan earthquake in 2008, the damage characteristics of buildings are studied and the damage phenomena are analyzed in the paper. Considering the construction situation of buildings in towns and villages in China, the key issues about seismic design of building are discussed and several seismic fortification measures and suggestions on seismic design of buildings in towns and villages are proposed.

Key Words: Wenchuan earthquake, buildings in town and village, damage phenomena, seismic design

Introduction

On May 12, 2008, an Ms 8.0 earthquake occurred in Wenchuan, Sichuan province, China. Until May 27, 67183 people were killed, 361822 people were injured, and all kinds of buildings, especially buildings in villages and towns were damaged seriously. Since the earthquake occurring in a mountainous region of Western China, the earthquake presents many new damage characteristics of buildings in towns and villages, which brings many new problems to earthquake disaster prevention and mitigation.

Since the focal depth of the earthquake is only 10 to 20 kilometers, the earthquake belongs to inland shallow earthquake. The released great energy was widely spread by seismic waves, and the earthquake was felt in most of provinces and cities of China, such as Beijing, Gansu, Guizhou, Ningxia, Shanxi, Shanxi, Henan, Hubei, Shanghai, etc. Because Gansu province is close to the Sichuan province, the earthquake disasters were very serious. In the present paper, based on site investigation on the buildings in towns and villages in Longnan city, which is situated in the junction area of Sichuan and Gansu province, the damage characteristics of buildings are studied.

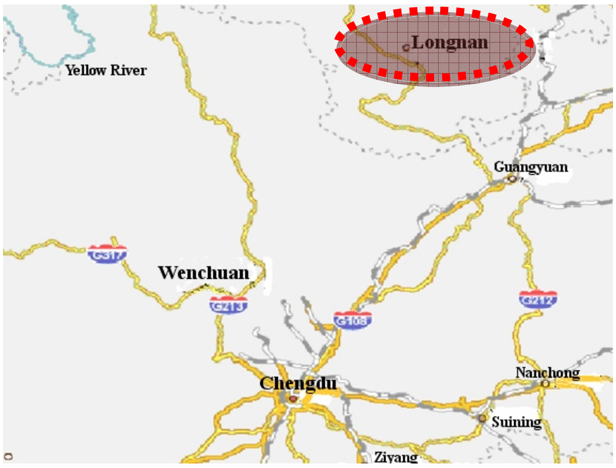

Fig.1 The geographic position of Longnan city

Longnan city is about 200 kilometer far away from Wenchuan, as shown in Fig.1. The seismic fortification intensity of Longnan city is 8 degrees and the design earthquake acceleration is 0.20g, which is equal to the intensity of Wenchuan earthquake. The typical building damages in towns and villages in Longnan city were analyzed in the paper.

Earthquake damage investigation of buildings in Longnan, Gansu province

In the site investigation of building damages, more than hundreds of residence buildings and 99 public buildings were investigated. In the mountain area, most residence buildings were made of raw-soil structure buildings, timberwork buildings, bricks timberwork buildings and masonry concrete structures and so on. The investigated public buildings were main irregular structure buildings and large span structure buildings. The raw-soil structure buildings and timberwork buildings were damaged seriously, and the heavy damaged buildings accounted for 78%. The main support walls collapsed, wooden frames collapsed and tilt, the transverse and longitudinal joints of wooden frame loosed, tenon structures were damaged seriously, and the span purline and tile of roofs felled down. The masonry concrete structures without constructional column were also damaged seriously, especially the ground floor, where the walls were shear failure, containing diagonal cracks, ‘X’ form cracks and horizontal cracks. The masonry concrete structures of large span multi-ribbed slab frame structure were also damaged seriously. Although obvious cracks on most of the reinforced concrete structures can not be seen, the damages were obviously on non-structural bodies such as infilled wall.

The raw-soil structure buildings and timberwork buildings

The raw-soil structure buildings and timberwork buildings were the main types of buildings in towns and village, which were basically built before 1970s with single layer and the beams were placed on the walls directly. So the type of buildings were designed without considering aseismic ability and damaged seriously during the earthquake as shown in Fig.2 and Fig.3. Because the raw-soil structure buildings are weak in integrity, if there are not connected structures between the walls, the buildings will be easy to crack and collapse subject to horizontal seismic forces. Though it is specified that the junctions of outer wall and inner wall should set a layer of bamboo muscle, batten and so on, in design of raw-soil structure buildings in Code for Seismic Design of Building (GB50011-2010), the damaged buildings were lack of connection structures, even some buildings were without foundations, the walls were too high and the span were too large comparing with the specifications in the code on the site investigation. So the raw-soil structure buildings collapsed because the shaking crack was too large in the earthquake. The purline and crossbeam were set on the wall directly, and they were not subject to concentrated loads. Because the strength of walls was insufficient, the walls always crack in using. So when the earthquake occurred, the purline and crossbeam collided with walls, which caused the cracks increasing.

The main problems of timberwork buildings were that the components corroded and decayed, the section of timberwork weakened, the strength of components connection was insufficient, and the floor height was too high. The important reasons of buildings in towns and villages collapsed in the earthquake were that the building were not designed according the seismic design codes and the building materials did not meet the requirements. So in high seismic fortification intensity town area, it is important to strengthen the legality of building construction and the supervision to improve the quality of buildings.

Fig.2 The collapsed timberwork buildings

Fig.3 The collapsed raw-soil structure buildings

The masonry timber buildings

Besides the raw-soil structure buildings and bricks timberwork buildings, masonry timber buildings are also another common type of local dwellings houses. The main support wall were most brick walls with thickness 120mm, 180mm or 240mm, and the roof were triangle wooden frame. The masonry timber buildings were designed without seismic measures and lack of connection components, and the roof trusses were installed on the brick wall directly, so the type of the buildings were always with bad integrity. Under vertical loads, the structures usually relative stable, but subject to horizontal earthquake, the maintenance walls were easy to incline, which leads to severe earthquake damage such as local collapsed or overall collapse. In the earthquake, most masonry timber buildings were damaged seriously and some buildings built relative early completely collapsed as shown in Fig.4. The masonry timber structures have the same problems with the raw-soil structure buildings, such as the purline put on the brick wall directly. The improper constructions and connections made the masonry timber structures loss the aseismic ability.

Fig.4 The destroyed masonry timber buildings

The masonry concrete buildings

The masonry concrete buildings were a new type of buildings adopted by local residents in recent years, most of which were with two layers. The buildings usually set ring beams at the ground and at top of first floor, but rarely at the top of second roof, and did not set constructional columns. In the earthquake, the damages of the type of buildings contain cracks on the walls, damage at the connection of vertical walls and horizontal walls, damage at doors and windows, walls incline and collapse and so on. Some buildings adopted the improper force transmission structures, which caused some buildings were damaged seriously as shown in Fig.5. It can clearly be seen that the second layer column was cut off. The loads acting on upper layer column can not transfer to the foundation via a proper force transmission path, but directly acted on the lower beams, which caused big concentrated forces and ‘X’ form cracks on masonry structure under the beams. The second layer bearing structures were equal to three large bays, and the walls between windows of the three large bays were damaged with ‘X’ form cracks. The irregular structures are easy to be damaged in an earthquake, so it should be avoided in the design.

Fig.5 The building with improper force transmission path

The irregular buildings

Irregular construction was one type of the seriously damaged buildings in the earthquake. In order to get the novel appearance, many buildings adopted the irregular construction shape, such as split-level building, plane protruding building, and so on. Due to the force transmission pass abrupt change, the change points of the structure are easy to be damaged and lead to the damage of the whole building during an earthquake. The Fig.6 shows a meteorological agency building whose main structures are three layers and local structures are four layers. The three layers part and four layers part were connected together without setting aseismic joint, which leads the top column completely fracture as shown in Fig.6. The top floor of another irregular building was also badly damaged, shown in Fig.7 (a), and the change point of a building cracked in the earthquake, as shown in Fig.7 (b). Because of improper design, the plastic hinges occurred at the end of the columns of irregular building structures in the earthquake, shown as Fig.8. The building damages showed the phenomenon of ‘strong beam-week column’, which is opposite with the design goal of ‘strong column-weak beam’.

Fig.6 the damages of Meteorological Bureau building in gansu province

(a) Irregular building in planar direction (b) Irregular building in planar direction and façade

Fig. 7 The damaged irregular buildings

Fig.8 The phenomenon of ‘strong beam-week column’

The school buildings with large spans

In the investigation of building damages, the large span buildings were also damaged seriously. The Longnan middle school building was an octagonal masonry concrete structure with four floors. The destruction features of the school building with large span showed that the vertical wall of the classroom with cantilevered corridor in one side occurred ‘X’ form shear cracks, as shown in Fig.9. The cross wall of large span classroom occurred diagonal cracks, which was about 45 degrees, as shown in Fig.10.

Fig.9 The ‘X’ form shear cracks of vertical wall

Fig.10 The diagonal cracks of cross wall

Seismic damage analysis on buildings in towns and villages

Site investigation also showed that improper location was an important reason of buildings damaged in the earthquake. A large number of buildings were built in bad geological location, such as slope surface area formed by landslide and debris flow as shown in Fig.11.

Fig.11 The buildings built on landslide zone

The local buildings were designed considering the proper location little, such as the meteorological agency shown in Fig.6, was built on a raised soil, which is 50 meters higher than normal ground. The raised soil has a magnifying effect on seismic responses and the magnifying coefficient can be 1.3-1.5. So the building was damaged seriously not only in the irregular point and but at another side of the building which is shown in Fig.6. So the improper location will bring great hidden dangers to buildings, and it should be avoid in building design.

In the earthquake, some buildings were seldom damaged since the adopting of seismic measures. The Fig.12 provided by Gansu civil engineering science research institute shows an apartment building which adopts rubber bearing shown in Fig.13. There did not present any cracks in the apartment building, and also the vase on the air conditioner did not fall. It showed that the proper isolation measures are an effective way to improve the aseismic ability of buildings.

Fig.12 The building with rubber bearing Fig.13 The rubber bearing

Recommendations on design of buildings in towns and villages

Because of relative lagging economy, the countryside buildings had some problems of building materials, structural styles and traditional customs, which made the casualties and damaged building in villages more serious than that in cities. Through the survey, we found that adopting proper structural measures in countryside buildings is an effective way to mitigate the building damage in 6 degrees and 7 degrees fortification area, for reinforce concrete frame structures.

For raw-soil buildings and timberwork buildings, it is necessary to strengthen the integrity of buildings and the connection of components. And all of the used irons, clinchers, straws and wooden poles only value 2%~5% of the total cost of buildings. Especially for timberwork buildings, walls and timber structures should connect reliably, and the masonry walls should not completely surround the wood column and should be built outside of the column. (Ge, 2005, Wang, 2004, etc)

For masonry structures, the proper constructional columns and ring beams are necessary. The quantity and position of constructional columns should be proper, and avoid the following cases, the longitudinal bars of the constructional columns in building nooks insufficient, the anchorage length of longitudinal bars of constructional columns and ring beams insufficient, the stirrup of constructional columns at the position of up and down the floors not encryption, the anchorage length of steel tie bars between constructional column and brick walls insufficient or the spacing improper.

The stairway is the part suffering earthquake seriously of the masonry structures and the aseismic ability of stairway is week. So the stairway must be set properly. According the Code for Seismic Design of Building (GB50011-2010), the stairway can not be set in end and nook of the building, also can not set too large window. It should strengthen the connection of each component, and well dispose the relation of nonstructural components and major structure. For constructional column setting, according its influence on integral structure, it can set the four corners of the building as first class, the four corners of the stairway as second class, and the junction of inner walls and outer walls as the third class. The roof house and additional structures protruding the roof should be paid more attention. Because of the influence of ‘whipping effect’ in an earthquake, the structures protruding the roof are always damaged more seriously than the lower major structures. So, unless special requirements and adopting reliable measures, the protruding structures should be avoided in design (Tang, 2007).

For reinforced concrete structures, adopting proper structural measures can ensure that the parts where likely occur plastic hinges will have enough ductility, that is to say, the structures have enough plastic rotational capacity and plastic energy dissipation capacity. For beams, we always expect that the plastic hinges occur at the end of beams, so we should ensure the beam end with good ductility and energy dissipation capacity in design. Except meeting some requirements for calculation, it also needs set a series of structural measures, such as controlling the ratio of reinforcement, the beam with a certain number of compression reinforced bars, the proper quantity and usage of stirrups and the well designed sectional dimensions of beams. The structural measures of columns are basically the same as the beams. But the columns not only bear the flexural moments and shear forces, also endure the axial forces, so there are sill requirements for ratio of axial compressive force to axial compressive ultimate capacity of section. (Zhong, 2008, Yu, 2008, etc)

For new structural system, performance-based seismic design (PBSD) should be used. Accompanying with development of PBSD, the building design should meet the requirements for multistage seismic design, shown as Fig.14. The mechanical properties of large complex structures should be determined by using time history seismic analysis and the complex structures should design by using performance-based seismic design method to control the position of the major structure where plastic hinges occur and the precedence of plastic hinges.

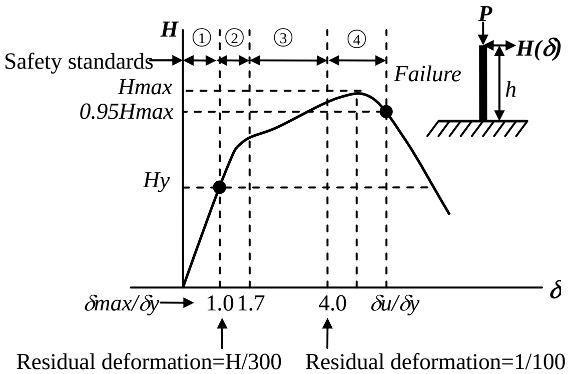

Fig. 14 The multistage seismic design

Conclusions

Combining with the damage characteristics of buildings in towns and villages at the junction areas of Sichuan and Gansu in Wenchuan earthquake, the key points on aseismic ability of buildings were discussed and the following recommendations were made.

The site selection of buildings should avoid bad geological location, such as landslide, dilapidation, subsidence, river valley edge, ground fracturing debris flow and seismogenic zone. The foundation should be reinforced according the bearing capacity, deformation characteristics and structural characteristics of buildings to ensure that the building will not be damaged due to instable foundation.

Considering the economy, buildings in towns and villages can be constructed with different grades and levels. In a certain period, raw-soil structure buildings can still be the main residence houses, with the economy developing, brick buildings should be encouraged to be built. And irregular structures also need to be avoided and set proper constructional column and ring beam to strengthen the seismic capacity of buildings.

The construction of town buildings should be more standardized, and all of the design, construction and supervision should be paid more attention and ensure that they meet the requirements of the related laws and regulations.

For the countryside buildings, we should analyze the characteristic of seismic damage, and adopt some simple and effective construction measures to improve the aseismic ability of buildings considering construction cost. It also needs to propose seismic strengthening methods suitable to countryside buildings to mitigate the earthquake damage of old buildings.

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