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# DAMAGE OF BUNKERS AND SILOS IN TANGSHAN EARTHQUAKE AND HAICHENG EARTHQUAKE

Chunqiu JIANG[1]

[1] China Coal Mine Planning & Disigning Inst, Beijing, China

## SUMMARY

This paper reviews the earthquake damages of 71 R.C. bunkers and silos during the Haicheng and Tangshan earthquakes in China and puts forward some proposals for improving the aseismic design philosophy of R.C. bunkers and silos.

## INTRODUCTION

Haicheng earthquake (1975, M=7.3) and Tangshan earthquake (1976, M=7.8) were the two earthquakes which had strongest impacts on industrial cities in China. Many industrial structures in the two regions confronted strong seismic action. The behavior of the 71 R.C. bunkers and silos (411 cells) during these two earthquakes have been investigated. These bunkers and silos were located in the regions of intensity 9,10 and 11 based on New China Scale (similar to the Modified Mercalli Scale). Before the earthquakes, Haicheng and Tangshan used to be classified as regions of intensity 6, so these bunkers and silos were designed without consideration of earthquake resistance.

## THE MAIN CHARACTERISTICS OF EARTHQUAKE DAMAGE

Foundation  A bunker or silo may consist of four parts, i.e. foundation, bottom supporting structure, cell wall and upper structure (Fig.1). Foundations and columns below ground surface on ordinary soil conditions were slightly damaged or basically undamaged, but those on soft soil or liquified soil conditions were seriously damaged. Take a coal bunker of Kailuan Coal Mine for example (Fig.2). Located in the region of intensity 9, it was a 30 m high, 7-storey R.C. frame structure (its upper structure was 4-storey), covering a plane area of 14 x 63 m, 28 m in width locally. The distance between columns was 7 m. This bunker was damaged seriously due to the sand liquification. All its 37 ground floor columns (external columns with dimensions of 80 x 80 cm, internal columns with dimensions of 90 x 90 cm) were broken or dislocated at 2.0-2.8 m below the ground surface. The settlement amount of this bunker was 410-1035 mm, 28 columns were seriously displaced or dislocated, the max. horizontal displacement at level 4.850 m was 240 mm.

After restored and strengthened with the settled-down columns lifted and put back into the original positions, this seriously damaged coal bunker was put into used again and has been under good conditions up to now. Of all the industrial structures of Kailuan Coal Mine, except 27% which collapsed by the earthquake, 73% which had been subjected to different damages (including 26% were seriously damaged, 17% moderately damaged, 30% slightly damaged or basically undamaged) were mostly restored and strengthened afterwards and put into used again. Thus, we've gained rich experience in the restoration and strengthening of different industrial structures damaged in earthquake, a work that not only can result in cut-down expenditures, but also can speed up the rehabilitation as compared with dismantlement of the old and construction of new ones instead. These advantages are very important for mines and industrial enterprises.

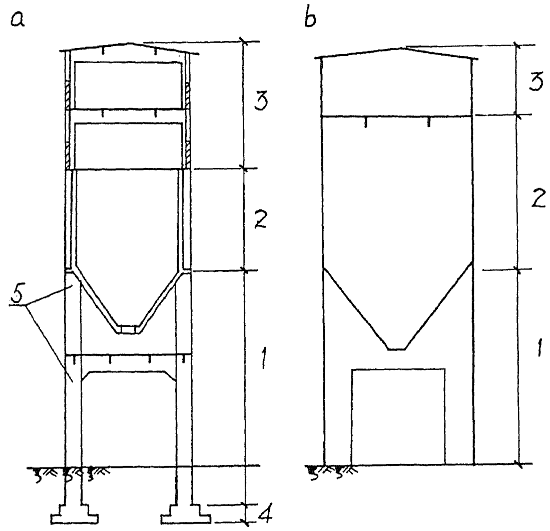


**Fig. 1**

a -- column supported system; b -- wall supported system;
1 -- bottom supporting structure; 2 -- cell wall; 3 -- upper structure;
4 -- foundation; 5 -- major damages occured

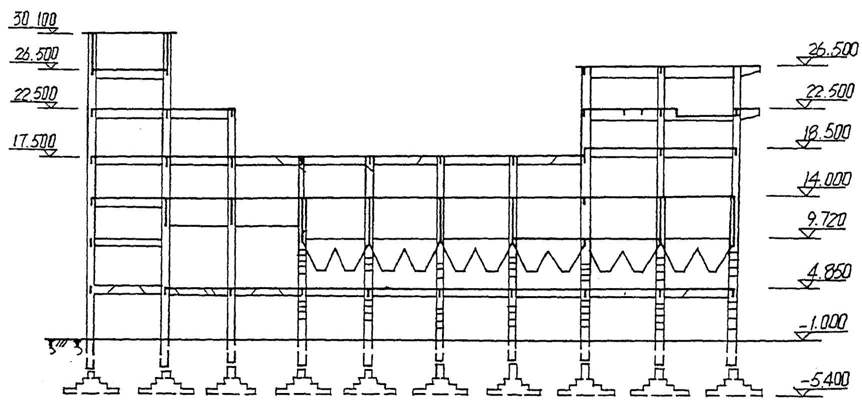


**Fig.** 2

Bottom supporting structure The bottom supporting structures may be divided into two kinds: column-supported system and wall-supported system. For column-supported system, major damages occured at the cap of columns under the cell walls and at the cap of ground columns, which were characterized as follows: horizontal or diagonal cracking when slightly damaged; concrete spalling or buckling when moderately damaged; rupture of diagonal section, crushing of concrete or lantern shape of principal reinforcing steel when seriously damaged, resulting in breaking of columns and collapse of the bunker at last.

For wall-supported system, the section of the gate hole at ground floor for passing of the transpotational facilities was the weak part — horizontal and diagonal corner cracking were found there.

<u>Cell wall</u> No damages or only slightly damages such as local horizontal and diagonal cracking were found in the cell walls.

<u>Upper structure</u> For brick-wall structure, the destruction of wall was the main damage. For R.C. frame structure, the cracking of beams and columns was the main damage which did not turn out to be serious except that when the connection of column foot and cell walls was not strong enough, the upper strucure would prone to being seriously tilted. For steel or timber structure, the connecting joints were subjected to serious damage and deformation, but without the risk of collapse.

<u>The others</u> (1) In the earthquake, local damages occured to some bunkers and silos as a result of impacting against adjoined buildings or between two parts of the bunker or silo. This was because of the expansion or settlement joints which had not been designed according to the requirements of earthquake resistance or had not had sufficient width. (2) Integral torsional deformations were found in some bunkers. Fig.3 shows an actually measured plan view of a coal bunker after the earthquake.

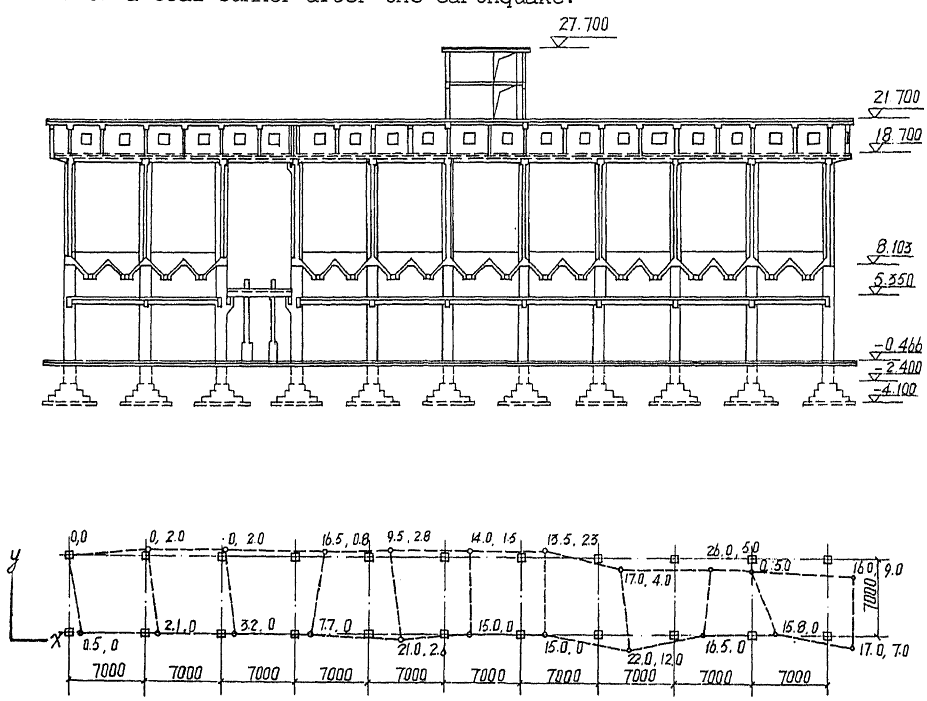


**Fig. 3**

Note: x, x -- the deformation amount of column in x, y direction respectively at level 5.350 m, cm.

## STATISTICS AND ANALYSIS OF DAMAGE

The key part of a bunker or silo is bottom supporting structure. The bottom structures of bunkers and silos which had been investigated could be divided into three kinds:

A-1: column-supported rectangular or square bunkers, the cell dimensions vary from 5x5 m to 7x7 m.

A-2: column-supported silos

A-3: wall-supported silos

The diameters of silos vary from 10 to 15 m.

The upper structure could be divided into three kinds:

B-1: one or two storey brick bearing wall structure

B-2: one or two storey steel or timber strucure

B-3: multi-storey R.C. frame structure

Damage statistics on bottom supporting structure (71 bunkers and silos) and on upper structure (58 bunkers and silos) are shown in Table 1 and 2 respectively.

Table 1

| Item | no. of investi-gation | collapse | damaged seriously | damaged modera-tely | damaged slightly | undamaged basically |
|---|---|---|---|---|---|---|
| A-1 | 45 (100%) | 10 (22%) | 12 (27%) | 8 (18%) | 9 (20%) | 6 (13%) |
| with infilled brick wall between columns in longitudinal direction | 11 (100%) | 1 (9%) | 1 (9%) | 3 (27%) | 4 (36%) | 2 (19%) |
| without infilled brick wall between columns | 34 (100%) | 9 (27%) | 11 (32%) | 5 (15%) | 5 (15%) | 4 (11%) |
| A-2 | 15 (100%) | 2 (13%) | | 3 (20%) | 10 (67%) | |
| A-3 | 11 (100%) | 1 (9%) | | 3 (27%) | 4 (37%) | 3 (27%) |
| Total | 71 (100%) | 13 (18%) | 12 (17%) | 14 (20%) | 23 (32%) | 9 (13%) |

Table 1 shows the follows:

--- The ratio of collapse and serious damage of R.C. bunkers and silos reached 35%, one of the highest in all kinds of R.C. buildings and structures during these two earthquakes.

--- The ratio of collapse and serious damage of column-supported bunkers and silos was 40%, while that of wall-supported system was 9%. It shows that the column-supported system has a poor aseismic capability.

--- The ratio of collapse and serious damage of column-supported silos was

13% (A-2), while that of column-supported rectangular or square bunkers was 49% (A-1). This partially shows the configuration has an affection on the aseismic capability of structure.

--- The ratio of collapse and serious damage of column-supported rectangular or square bunkers with infilled brick walls in longitudinal direction between columns was 18%, while that of column-supported rectangular or square bunker without infilled brick wall was 59%. This shows the infilled brick wall between columns can absorb some earthquake energy and upgrade the aseismic capability of bottom supporting structure.

Table 2 shows that the damage of upper structure was serious to brick bearing wall structure, medium to R.C. frame structure, slight to steel or timber light structure during the two earthquakes.

On the other hand, of the investigated 71 bunkers and silos, 62 were one-row layout, the other 9 were two- or three-row layout. The damage statistics are shown in Table 3. The ratio of collapse and serious damage of one-row bunkers and silos were 20% and 16% respectively, that of two- and three-row were 0 and 11% respectively. This shows that the aseismic capability of multi-row layout is better than one-row layout under same conditions.

Table 2

| Item | no.of investi-gation | collapse | damaged seriously tely | damaged modera- | damaged slightly cally | undama-ged basi |
|---|---|---|---|---|---|---|
| B-1 | 34 (100%) | 13 (38%) | 6 (18%) | 6 (18%) | 7 (20%) | 2 (6%) |
| B-2 | 10 (100%) | | 3 (30%) | 1 (10%) | 2 (20%) | 4 (40%) |
| B-3 | 14 (100%) | 2 (14%) | 3 (21%) | 3 (22%) | 3 (21%) | 3 (22%) |
| Total | 58 (100%) | 15 (26%) | 12 (21%) | 10 (17%) | 12 (21%) | 9 (15%) |

Table 3

| Item | no.of investi-gation | collapse | damaged seriously | damaged modera-tely | damaged slightly | undama-ged basi-cally |
|---|---|---|---|---|---|---|
| one-row bunkers and silos | 62 (100%) | 13 (20%) | 10 (16%) | 11 (18%) | 19 (31%) | 9 (15%) |
| two- or three-row bunkers and silos | 9 (100%) | | 1 (11%) | 3 (33%) | 4 (44%) | 1 (12%) |

## SOME PROPOSALS FOR IMPROVEMENT OF ASEISMIC DESIGN OF R.C. BUNKERS AND SILOS

1. Investigation and analysis of earthquake damages proves that the wall-supported silo has superiour aseismic behavior and should be given priority in the region of higher intensity (8 and above).

If conditions permit, multi-row layout should be adopted first.

2. If a wall-supported silo has a large sectional opening in section, it should be reinforced effectively by adding battlements on both sides of the opening to compensate the weakening of rigidity in the sectional area and to keep a uniform change of rigidity in the vertical direction.

3. The following measures may be adopted for column-supported bunkers and silos to upgrade their aseismic capability:

--- avoid short column ($H/B \leq 3$) and adopt square cross-section for the bottom supporting column;

--- limit the shearing stress in the beam and column of the bottom supporting frame structure;

--- reduce the axial compresion ratio of the bottom supporting columns and increase the amount of ties and stirrups to upgrade the lateral confinement;

--- maintain the integrity of the beam-column joints sufficiently to develop the ultimate strength and strain force of the connecting beams and columns

--- increase the design bending moment of bottom supporting column by 50% in order to delay the occurence of plastic hinge in the column.

4. In a region of intensity 7 brick bearing wall may be adopted as the upper structure of a bunker or silo with aseismic tie columns and ring beams added in the brick wall to increase ductility and deformation capability of the structure. In a region of intensity 8 or above, R.C. frame structure or steel structure should be adopted.

The dimension of the upper structure should be more or less the same as that of the cells and abrupt change of rigidity in vertical direction should be avoided. It is recommended that the silo walls be extended to form the upper structures.

5. Because the cell walls have enough strength, aseismic measures can be left out of consideration for them.

6. The uneven settlement amount of a bunker or silo constructed on soft or liquified soil must be controlled within the permitted limits.

### REFERENCES


1. Damages of Haicheng Earthquake (in Chinese). The Seismological Publishing House (1979).

2. Damages of Tangshan Earthquake (in Chinese). The Seismological Publishing House (1986).