AN OUTLINE OF DAMAGES TO SCHOOL BUILDINGS IN DUJIANGYAN BY THE WENCHUAN EARTHQUAKE ON MAY 12, 2008

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ABSTRACT:

The great Wenchuan Earthquake on May 12, 2008, caused serious damages to buildings in major cities of Sichuan Province, Mid China, due to which more than several ten thousand people were reportedly killed. It is also reported that school buildings consisting of several thousand classrooms collapsed, which resulted in death toll of several thousand students and teachers. In the middle of June, one month after the Earthquake, the authors carried out a post-earthquake quick observation on damages to school buildings in Dujiangyan. A total of about eighty school buildings in Dujiangyan, almost all the schools in the city area, were surveyed. Structural damage rates of the buildings are classified based on the Japanese standard, such as into no damage, slight, minor, moderate, severe, and collapse, so that the damage rates based on the inventory survey for the schools in the region could be derived. The results of investigation are summarized in this paper analyzing the damage rates statistically in relation to the structural properties and construction year.

KEYWORDS: Wenchuan earthquake, inventory survey, damage evaluation, damage rates

1. INTRODUCTION

The great Wenchuan Earthquake of M8.0 on May 12, 2008 destroyed major cities in Sichuan Province, Mid China. Three and half millions of houses were reportedly damaged and more than sixty-nine thousand people were killed, and eighteen thousand people were missing, mostly due to the collapse of buildings. It is also reported school buildings consisting of several thousand classrooms collapsed, which resulted in death toll of several thousand students and teachers.

In the middle of June, one month after the Earthquake, the authors carried out a post-earthquake quick observation on damages to school buildings in Dujiangyan. The objective of the investigation is to classify the damages to all the school buildings in the region, to identify structural properties as detailed as possible, and to document and analyze the damage rates in academic viewpoint. Because the school buildings have been designed and constructed based on a standard with similar structural plan and their locations are spread in proportion to the population and houses, damage rates based on the inventory survey on them could be representative measure of damages in the region. The actual seismic performance of existing school buildings could also be verified through the investigation, which are often different from even sophisticated calculation using on idealized models.

A total of more than eighty school buildings in Dujiangyan, almost all the schools in the city area, were surveyed as a result. Structural damage rates of the buildings are classified based on the Japanese standard, such as into no damage, slight, minor, moderate, severe, and collapse, so that the damage rates based on the inventory survey could be derived. Location, number of stories, and structural types are also identified. Construction year is also identified for most of the buildings. The results of the investigation are summarized as the damage rates analyzed statistically in relations to the structural properties and construction year.

2. METHOD OF SURVEY:

2.1 Damage Evaluation Method

The authors' team performed the following types of site investigations in two days in Dujiangyan City. An inventory survey on the damages to all the school building structures was performed in the city area, to record detailed damage ratios and their spatial distribution. Location, construction age, number of stories, direction, type of structure system were surveyed as well as observed damage level, which was classified into five grades and no damage according to the Japanese standard of post-earthquake damage level evaluation[JBDPA, 2001]. The classification of the damage grades is judged quickly by the authors, based on the overall observation on the buildings from outside and into inside mostly as well. The detailed classification judgment should be based on the damage indices of each member following the standard rigorously. However, we did not rigorously follow the standard but the quick judgment was done instead due to limited observation time or occasion. The structural damages were classified into (Grade 0) No damage, (Grade 1) slight, (Grade 2) minor, (Grade 3) moderate, (Grade 4) severe or heavy, or (Grade 5) collapse or near collapse. Construction year was identified by hearing to the officers or from the records on the building. Structural type is estimated, judged and identified by the authors. The damage grade was judged each for longitudinal and transverse directions. Detailed investigation on the design, construction and the detailed measuring was also carried out for selected buildings. Sectional sizes were measured and damage indices of members were observed in detail.

2.2 Surveyed School Buildings

The damage investigation was carried out for all the school buildings in the central areas of Dujiangyan, as shown in Figure 1, although there might be more school buildings in the suburb areas. A total of 78 buildings in 27 schools were investigated as listed in Table 1, which includes three kindergartens, eighteen elementary schools, ten junior high school, two foreign language schools, two colleges and two universities. A few schools could not be surveyed due to limited entrance into the site. Also the buildings in the colleges and universities are only part of the buildings, which could be surveyed occasionally. Each school has several buildings mostly for functional use of classrooms, while mostly each has a building of attached residential house for the teachers located also in the school sites, which are also included in the statistical results below.

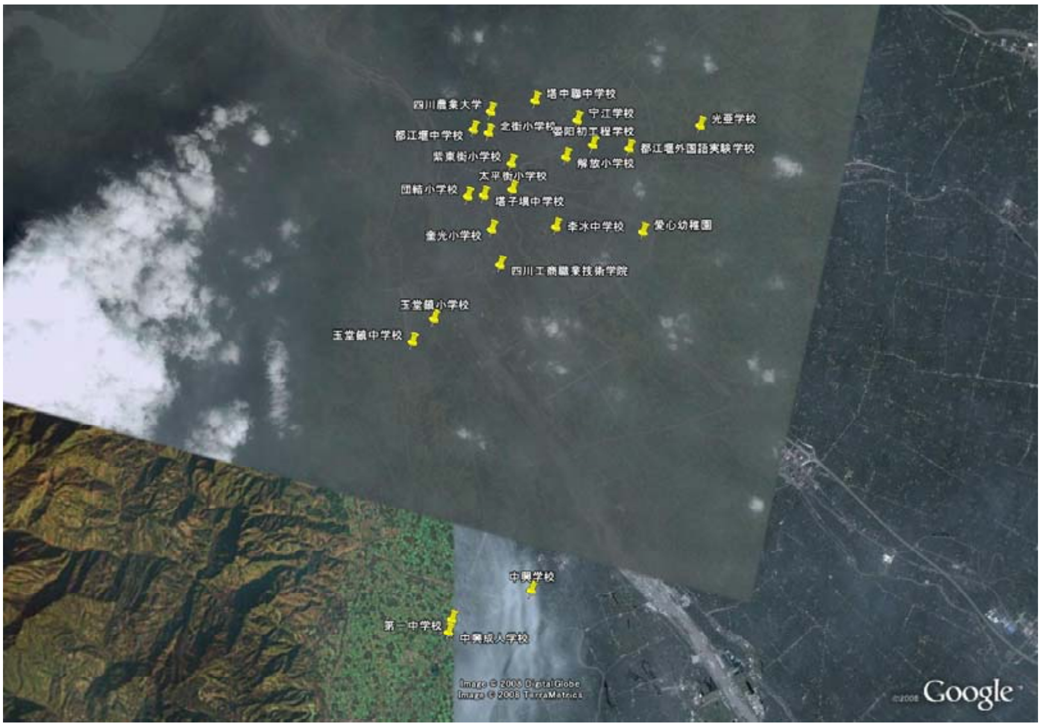

Figure 1 Location of school buildings investigated in Dujiangyan City

Table 1 List of surveyed schools and buildings

Kindergarten	3	Classrooms	65
Elementary school	10	Library	2
Junior high school	8	Lunch room	3
Foreign language school	2	Residence	7
University	2	Entrance Piloti	1
College	2		
Number of schools	27	Number of buildings	78

3. RESULT OF INVENTORY SURVEY

3.1 Structural Sytem

The structural systems of the surveyed buildings were estimated and identified by the authors (see Figure 6 later), although some of them remained as unknown. 40 buildings were identified as masonry structures, where there are no reinforced concrete frames as the vertical members around the typical classrooms, except for the limited part such as the staircase and so on. The beams and slabs mostly seemed to be reinforced concrete, probably precast concrete, in these masonry structures. 23 buildings were identified as reinforced concrete frame building with hollow brick walls or masonry walls. The rest 15 buildings remained as not identified. Therefore, more than half or two-thirds are estimated to be masonry structures without reinforced concrete frames.

3.2 Overall Damage Ratios

The overall statistics for the damage rates, the heavier rate of two directions, are shown in Figure 2. The ratios of the classified damage grades to the total number were (0)10%, (1)27%, (2)26%, (3)18%, (4)13%, and (5)6% for (0) No damage, (1) slight, (2) minor, (3) moderate, (4) severe, and (5) collapse or near collapse, respectively. About 20% of the school buildings were collapsed or severely damaged and 20% were moderate, while 60% were minor, slight or no damage. Photos of typical damage examples in each grade are shown in Figure 3.

The post-earthquake recovery is also recorded as shown in Figure 2, which are classified as (1) functional for continuous use, (2) repair/strengthening and reuse, and (3) demolish and reconstruction. As for the demolishment, a few of them had been executed, some of them decided and marked on the buildings by the administrators. The authors judged possible execution in the other cases. As for the repair/strengthening, the authors estimated the probable judgment in most cases. The relations between the damage grades and the post-earthquake recovery are also shown in Figure 4.

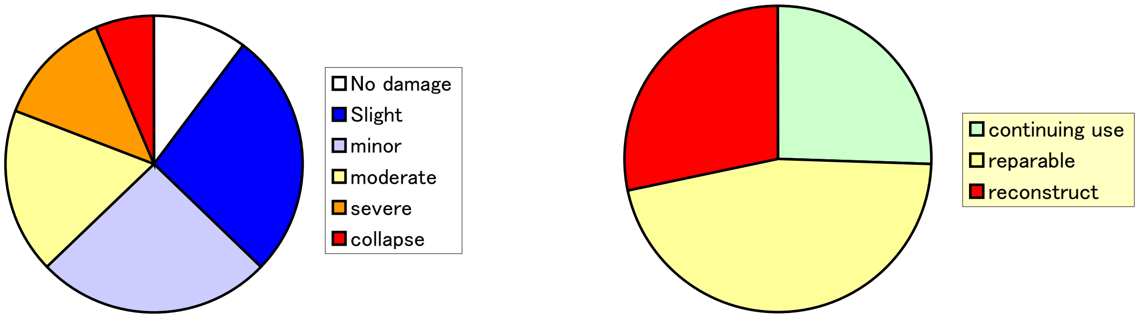

Figure 3 Overall damage rates and post-earthquake functionality


(Grade 0) No damage


(Grade 1) Slight damage


(Grade 2) Minor damage


(Grade 3) Moderate damage


(Grade 4) Severe damage


(Grade 5) Collapse or near collapse

Figure 2 Photo of school buildings typically with the damage grades

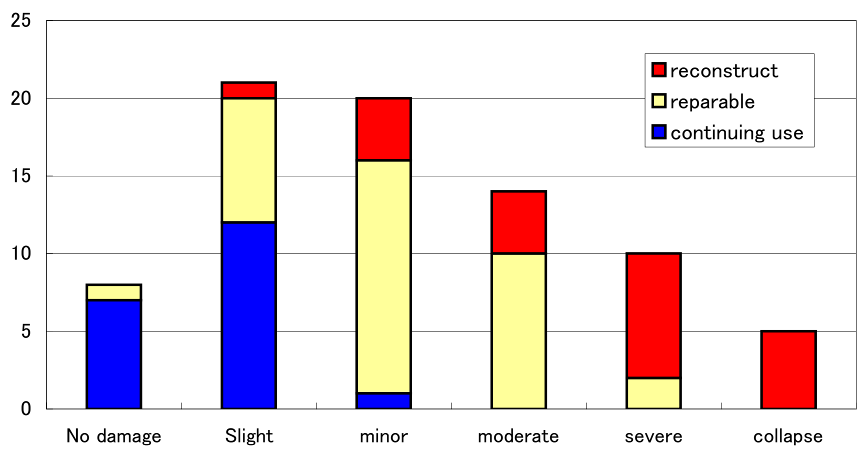

Figure 4 Damage rates and post-earthquake use

3.3 Damage Ratios vs Number of Story

The damage rates were analyzed with the number of story of the buildings as shown in Figure 5. Buildings in one or two story had relatively slight damage rates, only one high story-height piloti building was severely damaged out of 13 buildings. Only three buildings (one is for damage of base foundation, two are already taken away) were severe or collapse out of 43 buildings in three or four story buildings, while half, 11 of 22, were severe or collapse in five to seven story buildings. It may be concluded that the heavy damage rates are apparently higher for higher buildings.

3.4 Damage Ratios vs Construction Year

The transition of the damage rates with construction year of the buildings is shown in Figure 6. The rates were shown each for the half decade. More than half of the buildings constructed in 1980 to 85 were collapsed or severe, while the heavy damage rates decrease for buildings constructed in later years. There were no severe nor collapse for the buildings constructed after 2001, and two thirds of these were slight or no damage. It may be concluded that the damage rates of recently constructed buildings were apparently slight or minor, while serious damages such as collapse and severe were observed in older buildings.

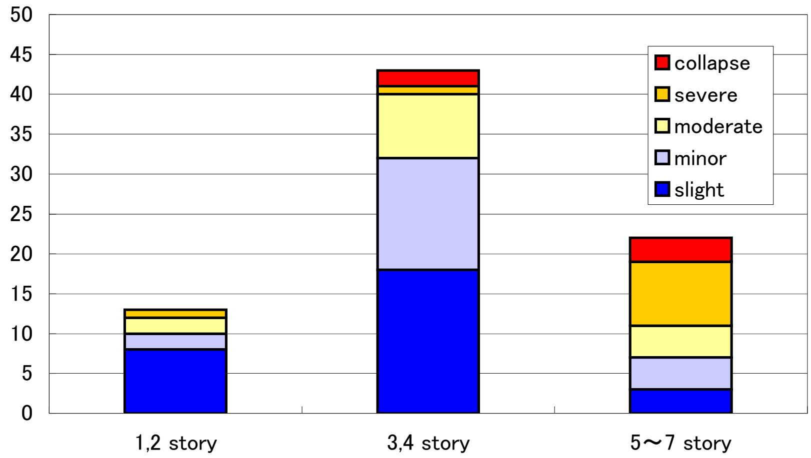

Figure 5 Damage rates and story number

3.5 Damage Ratios vs Structural System

The damage rates were compared for the type of structural systems, the masonry structures or the reinforced concrete frame with brick or masonry infill walls. As shown in Figure 7, there were no obvious differences between the damage rates of the buildings in the two structural systems. It should be noted that the damage rates of the masonry structures are not higher than those of the reinforced concrete frames, probably owing to relatively thick masonry walls and relatively larger amount of sectional dimensions of the vertical members.

3.6 Damage Ratios and Direction

The longitudinal direction of the school buildings was located either in EW-direction or in NS direction. Therefore, the damage rates judged for the longitudinal direction were analyzed with the location of longitudinal directions of the buildings, as shown in Figure 8. Relatively heavier damages are observed in case the longitudinal direction was in EW direction, so that the intensity of the ground motion in EW direction might be higher due to the directivity of the motion, which is orthogonal to the direction of the source fault line.

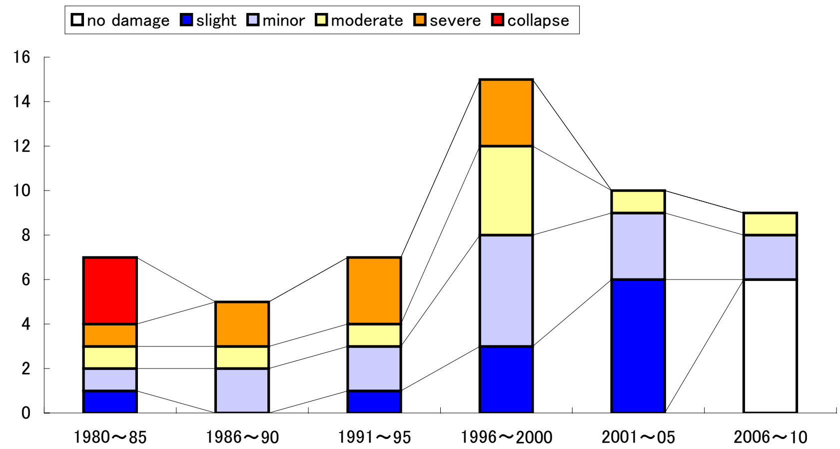

Figure 6 Damage rates and construction year

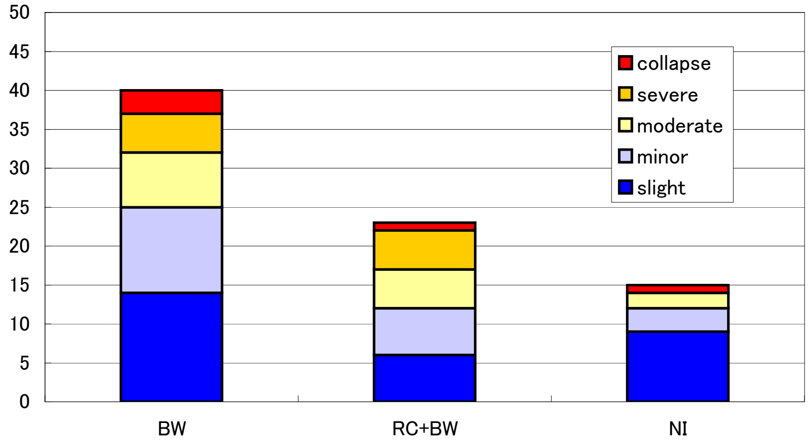

Figure 7 Damage rates and construction type

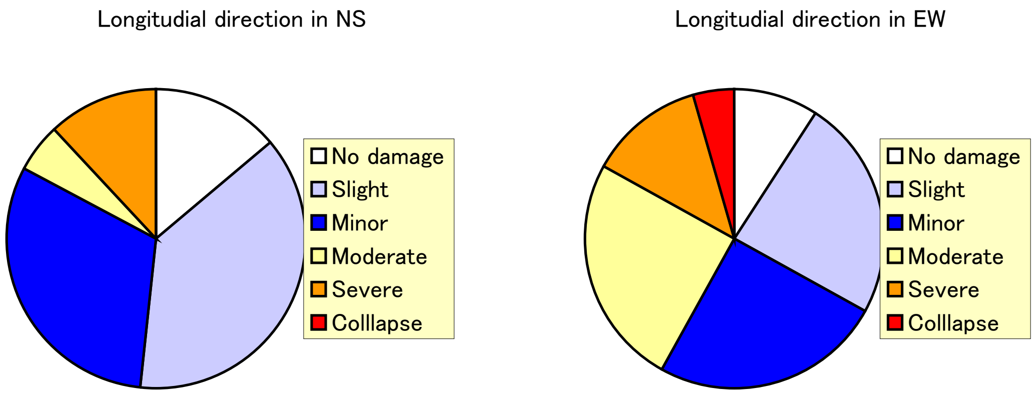

Figure 8 Damage rates and longitudinal direction of buildings

4. RESULT OF DETAILED SURVEY

4.1 Typical Structural Plan

Dimensions of the structural members are also recorded for some of the typical buildings. Two buildings were investigated in detail to measure the sectional dimensions. The number of buildings is limited due to the tight schedule of investigation and more should have been investigated. However, most of the design and construction practice seems to be similar to the surveyed type as typical. Dimensions of the buildings, such as location of columns, spans, arrangement of nonstructural walls, sizes of columns and beams, were basically measured, so that the typical plans was drawn by the authors, (1) one for three-story reinforced concrete frame buildings with thick masonry wall and with thin reinforced concrete columns, and (2) another for a four-story building masonry building, as shown in Figures 9 and 10, respectively.

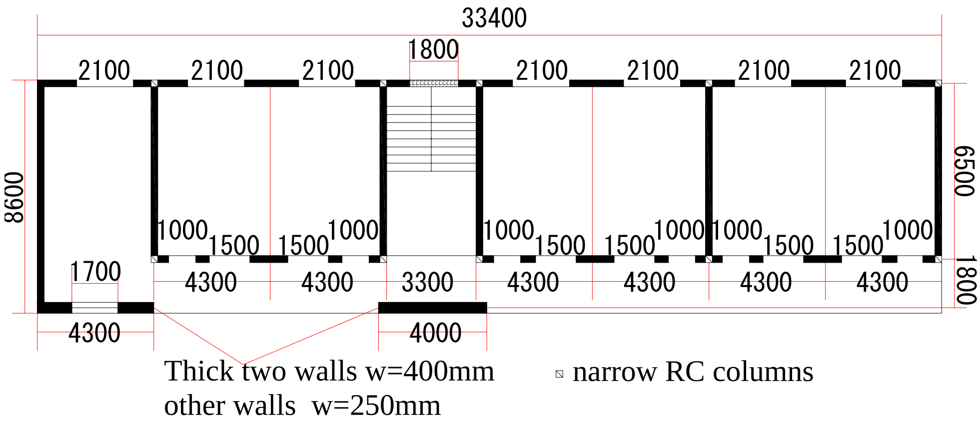

Figure 9 A typical floor plan of a three-story building in an elementary school

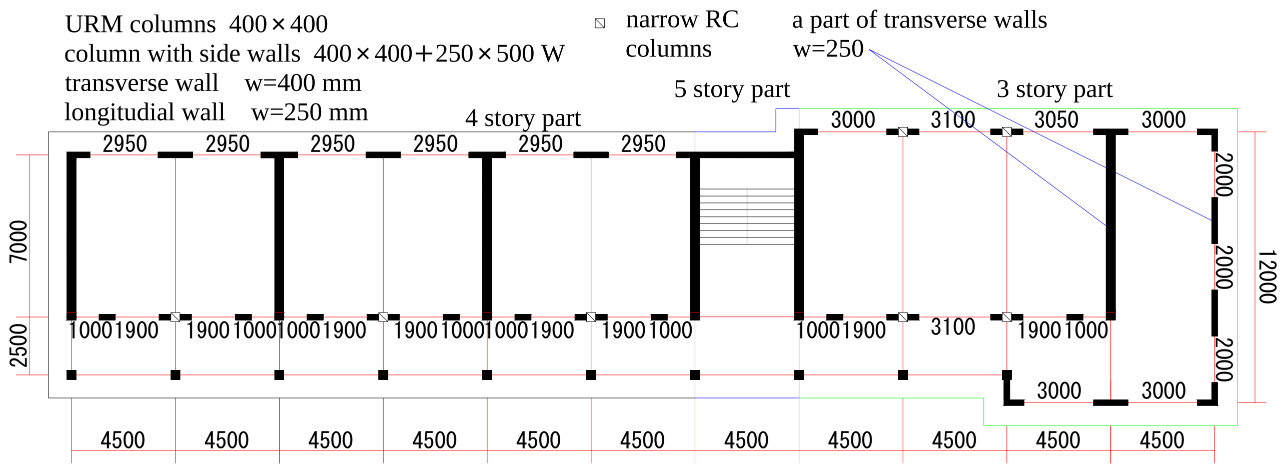

Figure 10 A typical floor plan of a five-story building in a junior high school

4.2 Estimated Lateral Strength

The lateral load carrying capacity and weight of above buildings are estimated from the dimensions referring to the past test data of similar structural members. Horizontal load-carrying capacity was defined as the sum of ultimate strength of all columns and walls in the first floor. Referring to the past experimental data (Sanada, 2006) and design standard for masonry structures (CEN, 2005), the averaged shear stress at the ultimate strength of the brick walls are assumed as 0.5N/mm^2 to estimate the shear strength from sectional area. The ultimate averaged stress of reinforced concrete columns is assumed as 1.0N/mm^2. The weight of the structure was calculated from the floor area using 12kN/m^2 as averaged per unit floor area. Then the ultimate lateral load carrying capacities, which are expressed in terms of the base shear coefficient, are estimated as: (1) 0.55 in longitudinal direction and 0.67 in transverse direction for the first three-story building in Figure 9, and (2) 0.39 in longitudinal direction and 0.58 in transverse direction for the second four-story building in Figure 10.

It is reported by CEA, although not yet officially, that the intensity of the ground motion in Dujiangyan was estimated as IX in terms of the Chinese intensity scale, while the design earthquake level in the region was VII. The responses of the buildings to the ground motion and the correlations with observed damages need be analyzed further in detail when the recorded data are available and the ground motion on the sites could be estimated by an earthquake simulation.

5. CONCLUSIONS

Post-earthquake survey was carried out on the damages to the school buildings in Dujiangyan after the great Wenchuan Earthquake on May 12, 2008. The damage rates could be derived from the inventory survey on about eighty school buildings in the region. The following conclusions may be drawn from the preliminary statistical observation data:

(1) 20% of the school buildings were collapsed or severely damaged, while 20% were moderate, 60% were minor, slight or no damage.
(2) The structural system of more than half, about two thirds of the surveyed buildings, seemed to be masonry system without reinforced concrete, while the rest one third seemed to be reinforced concrete frame system with infill walls.
(3) The heavy damage rates were apparently higher for higher buildings.
(4) The damage rates of recently constructed buildings were slight or minor, while serious damages such as collapse and severe were occurred in older buildings.
(5) The damage rates of the masonry structures are not higher than those of the reinforced concrete frames with infill walls.
(6) The lateral load-carrying capacities are estimated from the typical design of the buildings as 0.39 and 0.55 in longitudinal direction and 0.58 and 0.67 in transverse direction.

ACKNOWLEDGEMENT

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