REPAIR AND STRENGTHENING OF BUILDINGS DAMAGED BY EARTHQUAKES

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SUMMARY

One of the most important steps in the method used to repair damaged buildings was to identify the causes of the failure, to be able to eliminate them in the strengthening projects.

Analysis of the statistical information on more than 100 reinforced concrete buildings and approximately 3000 brick dwellings which were repaired in Peru in the last decade, indicates that 4 or 5 structural defects (short columns, for example) were responsible for more than 80% of the damages. Local conditions also had strong influence on damage distribution.

Damage from future earthquakes may be reduced drastically by avoiding these particular structural weaknesses and by studying damage patterns caused by local conditions.

INTRODUCTION

Preparing this paper for the VII WCEE gave the authors the opportunity to review their reports and drawings of the repair and strengthening projects of 125 reinforced concrete buildings, 19 masonry-bearing wall constructions, and nearly 3000 brick dwellings, which were constructed during the last decade (1970-79). These buildings were damaged by the Peruvian earthquakes of Ancash (May, 1970), Lima (Oct, 1974) and Arequipa (Feb, 1979).

Methods developed to repair and strengthen reinforced concrete and brick buildings are presented, as well as statistical information on the more common types of damages observed and their causes. Influence of local conditions is also examined. This information was taken from soil and geological investigations which were made in each case, and were complemented by excavation underneath the buildings to reinforce their foundations.

REPAIRING METHODS

It is necessary to distinguish between the repair procedures for brick dwellings and those for reinforced concrete buildings. Dwelling repairs were carried out as a social service to the affected families by a Reconstruction Committee set up by the Peruvian Government, with the cooperation of the National University of Engineering, and the participation of one of the authors and more than 20 graduate students. The owners were given free technical assistance and low-interest loans.

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Shortly after the May 1970 earthquake (67,000 victims), the macroseismic area was surveyed to study the economic and engineering feasibility of repairing the damaged dwellings. It was decided that the brick ones were to be repaired, but not those of adobe. Almost 3000 units were repaired, of which more than 2000 were concentrated in Chimbote City.

The results of the damage survey of brick houses are given in Fig. 1. This illustration shows how effectively the reinforced concrete columns reduce damages. It also demonstrates the influence of wall density, especially in the non-reinforced houses. When the wall density was very low (less than 5 cm/m^2), damages in doors and windows also were found.

Fig 1 also suggests the strengthening method employed for brick houses which is to add rectangular reinforced concrete columns with their longer dimension parallel to the direction of the lower wall density. First, the walls and part of the foundation are cut. After placement of the reinforcing bars, fresh concrete is poured, creating monolithic structures. The system is complemented by the use of tie beams. (See photo 1).

The repaired brick-bearing-wall buildings (other than dwellings) were old unreinforced constructions, 4-5 stories high. The damages were shear cracks and flexure failure in the upper part of the same elements when the roofs were made of light material. To strengthen these buildings, some of which had sentimental or historical value, new spatial R.C. structure with columns, beams and shear walls was added.

Other types of damaged masonry construction had originally been built with bricks having two 2" vertical holes in each piece. During construction, these holes were filled with a # 3 steel bar and cement mortar. During the damage survey, many empty spaces were found inside these holes. The walls failed by shear. To strengthen them, R.C. shear walls were added adjacent to the critical walls and/or situated at appropriate locations to eliminate excentricity and other structural defects.

To repair R.C. buildings, a more sophisticated method was used:

- Structural and non-structural damages were surveyed,plotting them on appropriate scales. This information was also used to figure the total repair cost, and thus is very detailed. (i.e. see photo 3).

- Computer seismic analysis of the buildings in the pre-earthquake stage was performed.

- Comparison of these findings made it possible to establish the cause of the failures.

- New rigid structural elements (shear walls) were added to the buildings by trial and error, with the main purpose of eliminating the structural defects which caused the failure (i.e., short columns, horizontal torsion, etc). (See photo 4). The solution also took into consideration the architectural aspects, the final stress level of the undamaged elements, and the cost.

- For important structures, special site investigations were carried out, not only to verify to soil supporting capacity, but also to determine the level and shape of the design spectra.

- Structural details were designed with the aim that the original structures and the new elements would form a monolithic system through the use of epoxy and welding of the reinforcing bars. (See photos 7, 10, 12 & 13).

- Budgets were prepared based on technical specifications.

- Inspection was carried out during construction.

COMMENTS ON THE STATISTICAL DATA AND EXPERIENCE DURING REPAIR ACTIVITIES

During the 1970's, 144 buildings, of up to 12 stories were repaired, most of them in the range of 2-4 stories. 125 (87%) were of R.C., and 19 (13%) of masonry-bearing walls.

The uses of the repaired buildings are indicated in Table 1. A high percentage (47%) are school buildings, which may be explained by the fact that classrooms need good illumination and ventilation, but privacy from the corridor. Architects solve this problem by placing large windows on the outside and high windows on the hallway, resulting in short columns aligned along the critical axis between these spaces.

Of the hospitals included in Table 1, some were repaired and strengthened only. In a number of the hospital buildings, however, remodeling was done to introduce new techniques used in modern medicine, the structures were brought up to date with the current seismic code and structural defects were eliminated.

From Table 2, it is apparent that a high percentage of the damages (more than 80%) was caused by stress concentration (i.e., short columns, see photo 2). These buildings were not designed to withstand horizontal forces efficiently and has obvious structural defects. (Examples, see photos 5 & 6). With good coordination between architects and structural engineers, such defects may be easily eliminated and damages from future earthquakes reduced drastically.

Inspection during repair construction uncovered some problems:

- When R.C. shear walls longer than 4-5 meters and about 3 m. high were built inside a frame, cracks appeared in the border of the shear walls due to the concrete retraction. To solve the problem, 3" bands were leveled on the top and side borders. Then dry concrete was poured and compacted (see photo 13).

- Simple methods had to be developed, in cooperation with the contractors, to lift the settled columns. (See photo 11).

- Epoxy resin is very expensive in Peru. To make efficient use of it, simple tests were conducted. Concrete Cylinders (those used for compression tests) were cut along their diameters and stuck together.

After drying, the cylinders were compressed along the cemented plane. In this way the drying time and amount of epoxy necessary were determined. To check the adherence between old and new concrete, half of the cylinder was put back to the steel form, the empty space was poured with fresh concrete and then tested in the same way.

The cost of repair and strengthening ranged, in most cases, from 15 to 35% of the buildings' total cost, depending on the extent of the damages. This includes items that may be considered as maintenance, such as painting. The item most difficult to calculate was demolition but, over all, this cost was not significant.

INFLUENCE OF THE LOCAL CONDITIONS

Most of the buildings repaired after the 1970 earthquake were concentrated in Chimbote City. The R.C. buildings were spread all over the city and influence of local conditions was not noted. Damage to brick dwellings was more severe (about 30%) on eolic dry sand over rock than on slightly humid sand (10%). On saturate, with the water table about 0.5 m below ground level, damage reached 90%. Those constructions were not repaired and the area will be used as park in the future. At present that area remains a ghost town.

The buildings repaired after the 1974 Lima earthquake were located at the edge of the Rimac valley in which Lima is situated. During the earthquakes that have affected Lima in this century, intensities have been 1-3 MM degrees higher at the locations along the edge of the valley than in the central portion, in spite of the fact that these areas are located only a few kilometers apart. In the dry conglomerate of the Rimac valley, there are many R.C. buildings with clear structural defects, and old adobe constructions, more than a hundred years old, that have not been damaged in past earthquakes.

A clear microzoning effect was observed in an area of very erratic soils about 300 m by 500 m on the campus of the Peru Police Academy. (see Fig. 2). A portion of a 3-story R.C. building was damaged beyond repair. The rest of that building, other 3-story building, and two one-story buildings suffered heavy damages. Identical types of buildings located only about 200 m. away were practically undamaged during that earthquake.

After the 1979 Arequipa earthquake several school buildings were repaired in Camana City, which is located more than 100 Kms. from the epicentral area. The soils in Camana consist of saturated clay over conglomerate. Camana is surrounded by rice fields which require plenty of water to grow.

In the epicentral area, heavy destruction of adobe constructions was reported. In Aplao City, located on firm ground, light damage to adobe was observed, and a two story R.C. building with short columns remained undamaged'

CONCLUDING REMARKS

When repairing and strengthening buildings damaged by earthquakes, it is very important to eliminate the cause of the failures, when possible.

To get monolithically repaired buildings it is important to design the details carefully and to be sure that specifications are followed during construction.

Most of the damages to R.C. buildings and brick dwellings have been due to stress concentration caused by the use of inadequate structure to take horizontal forces. These defects may be easily eliminated and reduce drastically the damages in future earthquakes. This may also be true for other developing countries.

ACKNOWLEDGMENT

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TABLE 1.

USE OF REPAIRED BUILDINGS		
USE	NUMBER	%
- SCHOOLS	68	47
- OFFICES	30	20
- HOSPITALS	14	10
- HOTELS	9	6
- INDUSTRIAL	8	6
- OTHERS	15	11
TOTAL	144	100%

TABLE 2.

TYPES OF DAMAGES IN THE REPAIRED BUILDINGS (INTENSITY VIII & IX, MM)		
PRIMARY TYPE OF DAMAGE*	NUMBER	%
- SHORT COLUMNS & OTHERS STRUCTURAL DEFECTS WHICH CAUSED STRESS CONCENTRATION (SUDDEN CHANGE OF RIGIDITY, IN PLANT, AND/OR ELEVATION).	100	69.0
- SHEAR CRACKS IN WALLS	18	12.5
- FAILURE OF THE COLUMN BEAM JOINT	8	5.5
- FLEXION IN WALLS	7	5.0
- POOR CONSTRUCTION QUALITY	5	3.5
- BEAM FAILURE BY LATERAL FLEXION OR SHEAR	4	3.0
- IMPACT BETWEEN ADJACENT BUILDINGS	2	1.5
TOTAL	144	100.0%

* In 13 buildings, foundation settlement occurred increasing the damages.

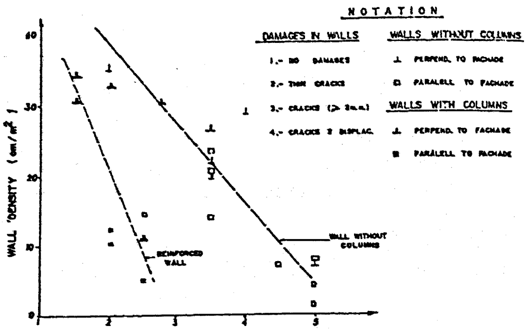

FIG. 1

CAMPUS OF THE PERU POLICE-ACADEMY (SHOWN - PARTIALLY). LA CAMPIÑA-CHORRILLOS

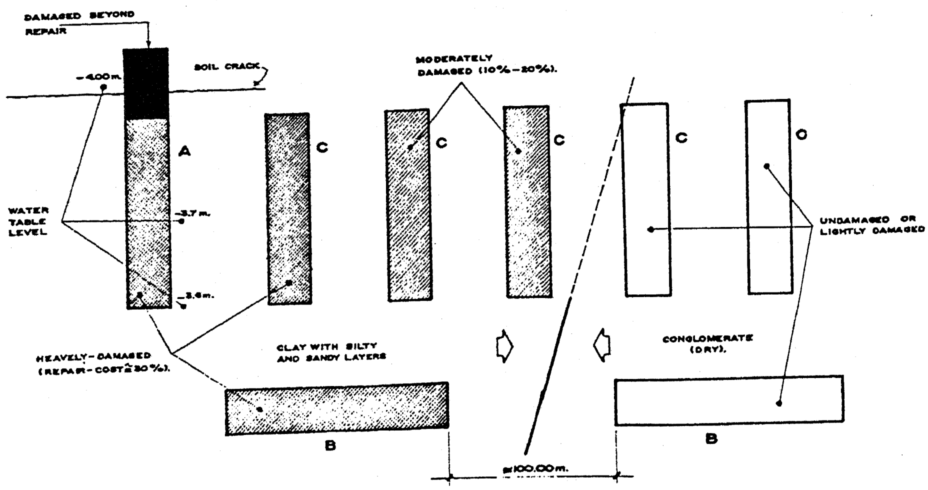

FIG. 2

Photo 1. Brick building. Note that from the post to the left has been reinforced

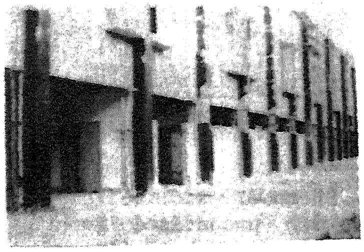

Photo 2. Damages in short columns

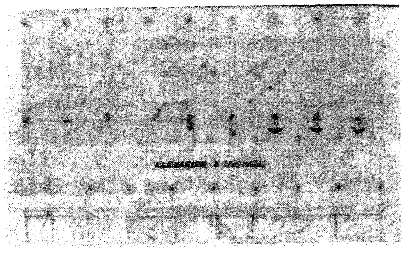

Photo 3. Plotting of damages

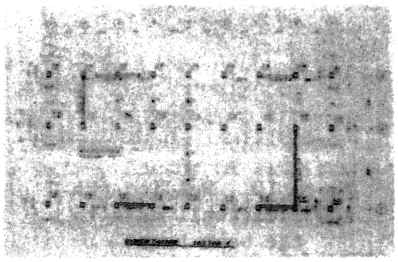

Photo 4. Note the 6 shear walls added to the building

Photo 5. Joint damage

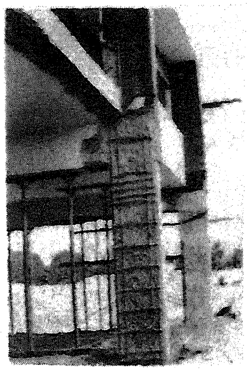

Photo 6. Unconfined joint

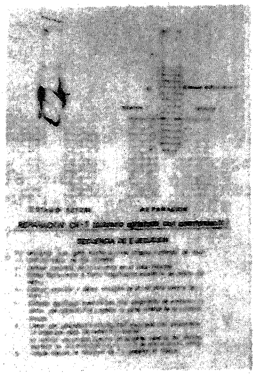

Photo 7. Example. Details to repair a column

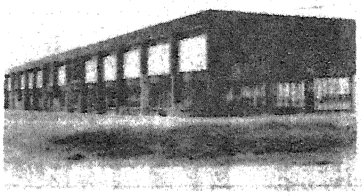

Photo 8. R.C. building with unconfined joint (see photo 6)

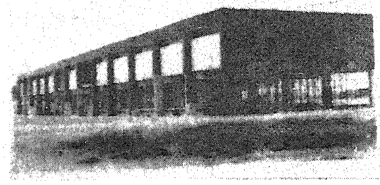

Photo 9. Photo 8 building with new shear walls

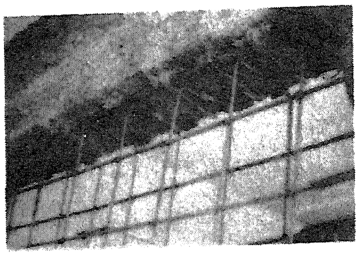

Photo 10. Welding the new shear wall bars to the beam bars

Photo 11. Lifting a settled column

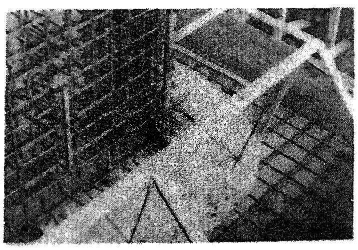

Photo 12. The steel mesh shown was welded to the existing bars. The footing high was increased

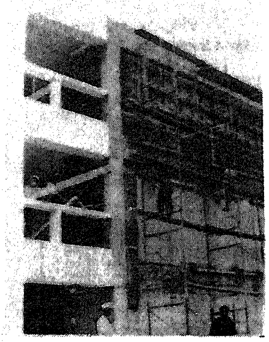

Photo 13. Shear wall Note that the left end and the top are filled separately with dry concrete