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Contents

Editorial

In this issue there is just one article. It describes observations and additional research after the damaging Philippines Bohol Earthquake in 2013. Its findings are likely to be relevant to many developing countries where there is a desire to improve the seismic performance of buildings. This article, although describing earthquake damage, goes well beyond most such reconnaissance reports. It discusses the review of the working drawings and specifications of some typical buildings, while noticing the absence of working drawing details and contract documentation, like standard specifications and details that are taken for granted in more developed countries. As such, we are presented with a holistic understanding of why damage occurred and what needs to be done to improve the future seismic performance of buildings.

The authors note that the seismic code of the Philippines has adopted the now internationally-accepted "capacity design" approach. This means designers have to ensure a careful and rigorous hierarchy of strength in structural members. For example, columns must be stronger than beams and there should not be any shear failure in any members in the event of seismic overload. But such a relatively sophisticated design approach not only needs highly skilled structural engineers, whose training and expertise is not commented upon in the article, but also a high level of detailing and construction and quality control. None of these can be taken for granted, as the authors demonstrate. They observe incomplete contract documentation, including inadequate steel reinforcement detailing.

The content and recommendations of this article need to be discussed and adopted by professional engineering institutions. Structural engineers need to provide better documentation so that their design intentions are realized and the seismic performance of their buildings is improved. Some aspects mentioned in the article could also be introduced in the curricula of colleges of engineering as well as technical training courses. If current practice is deficient, then future practitioners need to be taught a better way of design and construction. It would also be valuable for this material to be disseminated more widely. Building owners, one of the key stakeholders when it comes to seismic performance, should be aware of the current situation in order they can use their influence to improve standards of design and construction. The most concerned owners will not be developers whose interest in a building is generally short-lived, but long-term owners of institutional properties and the like.

Just before going to print we have heard about the recent devastating Nepal earthquake. Our sympathy goes out to all those affected by this tragedy and we hope we can make even a very small contribution to the rebuilding of the many damaged and collapsed buildings.

A Summary of the paper "Lessons Learnt from Damage to Buildings by Bohol Earthquake and Typhoon Yolanda 2013 in the Philippines,"

by Tatsuo Narafu, Toyokazu Shimizu, Yasushi Sanada, Yukio Tamura, Noriyuki Mita, Susumu Takahashi, Hayato Nakamura, Atsuko Itsuki. From Bulletin of IISEE 49, 39 – 61, 2015.
Note that this summary only considers damage from the Bohol Earthquake.

ABSTRACT

The authors conducted surveys on reinforced concrete (RC) buildings damaged by the Bohol Earthquake in the Philippines. They found heavy damage in non-structural elements and huge differences in the degree of damage among buildings in similar situations, with each of the heavily damaged buildings having its own specific causes of damage. The causes could be categorized into: 1) improper design, 2) poor/insufficient quality of materials, 3) poor workmanship/improper construction works, and 4) lack of maintenance. This report introduces an overview of damage and causes, considers the background and presents some recommendations for basic policy to improve the situation. That is: 1) creation of common understanding of designs between designers and builders, 2) improvement of designs and their documentation, and 3) comprehensive capacity development of relevant stakeholders.

1. BACKGROUND, OBJECTIVES AND OUTLINE

1.1 Background and objectives

The Philippines experienced the Bohol Earthquake on October 15 2013, causing serious damage. Buildings were one of the most heavily damaged structures. This paper summarizes results of the field surveys, analyses the causes and the background of the damage and presents recommendation based on the surveys. Targeted buildings of this report are RC buildings and most of them are public buildings because the authors could rapidly obtain permission to conduct detailed surveys.

2. OVERVIEW AND ANALYSIS OF DAMAGE

2.1.2 Damage by Bohol Earthquake

A large scale earthquake of Mw 7.2 (depth of focus: 12 km) hit central part of the Philippines on October 15, 2013 and caused serious damage in Bohol and Cebu islands. 222 people died, 796 people were injured and 3,221,248 people affected. 13,249 houses were totally damaged and 53,683 houses partially damaged.

The highest intensity of the shaking motion reported was VII in PHIVOLCS Earthquake Intensity Scale (PEIS). Many totally collapsed buildings were found to have furniture standing inside them. Figure 1 shows an example of Municipal building of Sagbayan, Bohol. The left photo shows heavy damage to exterior walls, partition walls, ceilings and other elements in spite of limited damage to the structure. The right photo shows inside the buildings where most of cabinets, lockers and other furniture were found standing. Usually in developed countries, buildings collapse in far stronger shaking motions than those that cause furniture to fall. This implies buildings in the affected areas are very vulnerable.

In spite of none or slight damage (like cracks) to structural members, many buildings were still out of use at the end of November (one and a half months after the earthquake), mainly because of heavy or extreme damage to non-

Figure 1. Municipal building of Sagbayan, Bohol. (Left): Heavy damage to partition walls and other elements, and (Right): inside the buildings.

Figure 2. Huge differences in damage among municipal buildings of Antequera and Sagbayan, Bohol. (Upper left): Municipal office of Antequera (Building 2). (Upper right): First floor. (Lower left): Municipal office of Sagbayan. (Lower right): Interior view of Lower left.

structural members. Huge differences in the degrees of damage were observed. Figure 2 shows differences among municipal buildings of Antequera and Sagbayan, Bohol. Upper left photo shows the Municipal office of Antequera (Building 2). It suffered little and the upper right shows the conditions of the first floor of the upper left that enabled it to start operation soon after the earthquake. The lower left photo shows the exterior view of the Municipal office of Sagbayan. Lower right photo shows heavy damage to non-structural members such as partition walls and ceilings while damage to the structure was limited. This building will be demolished due to the damage.

2.2 Analysis of damage

2.2.1 Improper designs

Several cases of damage from improper structural design were found during the field surveys. Typical ones are shown in Figures 2, 3, 4 and 5. The irregularities shown in Figure 3 are beams of the canopy not attached to the main structure in a consistent manner and were connected to a beam without support from columns. In Figure 4 levels of beams differ, causing unexpected stress in columns. Figure 5 shows irregular configuration of columns and imbalanced layout of non-structural walls which invite torsion on the total structure.

2.2.2 Poor quality of materials

Damage to non-structural members dominated. Among them, concrete hollow block (CHB) walls were one of the most commonly damaged. One of the major causes of the damage is the poor strength of CHB. It was often observed that rebar and mortar filled the cavities, but most of the CHB disappeared due to its extremely low strength like in Figure 6. Regarding damage to ceilings, use of usual types of nails to fix ceilings is one of the causes of heavy damage. Appropriate nails with large diameter heads or nails with washers should be used.

2.2.3 Poor workmanship

Poor workmanship seemed to be another dominant cause of damage in Bohol. The authors found various types of defects shown in Figures 7 - 12. In the case of Figure 7, several improper construction practices were identified. Longitudinal rebars were positioned inaccurately (placed inside rather than in the designed position). All the overlap splices of longitudinal rebars were located at the same level

Figure 3. An example of improper structural design in Municipal building of Sagbayan, Bohol (For exxterior view: refer to Figure 1). (Left): damaged connection of beams of canopy and main structure, (Right): Detail of the damage.

Figure 4. An example of improper structural design. (Left): Exterior view of District Health Care Center of Sagbayan, (Right): connection of a column and beams.

Figure 5. An example of improper structural design in Barangay office in Antequera. (Left): exterior view, (Right): damaged columns by irregular configuration.

Figure 6 An example of poor quality of concrete hollow blocks (CHB). (Left): Damaged non-structural walls in Municipal Office of Catigbian. (Right): Details of a damaged wall.

at a critical position, the bottom of the columns. (A red pipe in right photo is for electric wire installation). In the case of Figure 8, failure of concrete occurred at one of the most critical structural areas, beam-column joints, where hoops were absent (right photo). Honeycomb caused by insufficient compaction of the concrete was often found (Left photo of Figure 9). There were some cases where pieces of board penetrated into columns in order to prevent fresh concrete coming out through gaps between formwork panels (Right photo of Figure 9). Figure 10 shows improper rebar bending. The left photo shows spacing of hoops that is too large, which reduces their ability to confine the concrete and the right photo has several poor rebar details: bending of the hooks of hoops is only 90 degrees, and all the overlap splices of the longitudinal rebars are located at the bottom of a column.

Figure 11 shows examples of poor anchorage of CHB walls to RC members in the Market Building of Loon. The left photo shows a horizontal rebar in a wall that is not correctly anchored to a column and on the right an anchorage to a beam seems inadequate.

Figure 12 shows damage to ceilings. The left photo shows the extreme damage to most of the ceilings damaged in the Sagbayan Municipal Building, and the right is a case of a ceiling of the second floor that fell down onto a stairway in the Market Building in Loon.

2.2.4 Lack of maintenance

Lack of maintenance invited heavy damage in several situations.

3. CONSIDERATION ON BACKGROUND OF DAMAGE AND RECOMMENDATION

The authors conducted studies on the legal and technical framework of building control in the Philippines. The National Building Code of the Philippines (NBCP), and revised implementing rules and regulations are basic legal documents. The National Structural Code of the Philippines (NSCP) is a technical standard on structures. Several examples of working drawings were also reviewed and interviews with Philippino engineers were organized for better understanding the situation and practice of

Figure 7. Examples of improper rebar works in Market Building in Loon: (Left) Heavy damage at the bottom of most of columns, (Right) Detail of the damage.

Figure 8. An example of improper rebar works in Market Building in Loon: (Left) Failures at panels, (Right) Detail of damaged part.

Figure 9. Examples of improper concrete placing: (left) Market Building in Loon, (Right) Sagbayan Municipal Office.

Figure 10. Examples of improper rebar works: (left) Barangay Office in Antequera, (Right) A building under construction, Basey National High School.

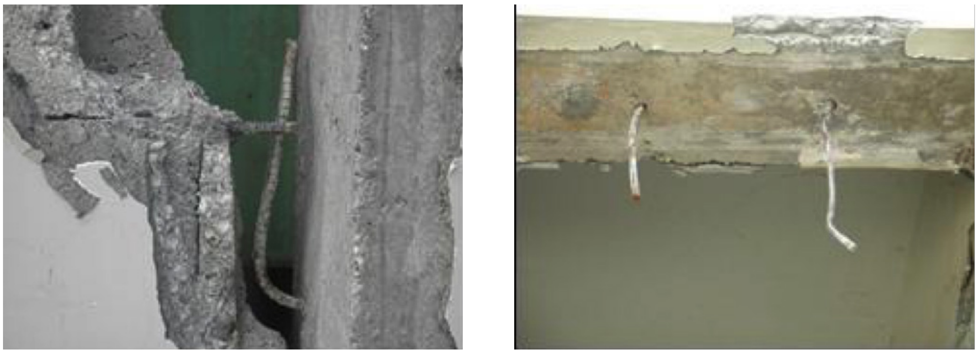

Figure 11. Examples of improper anchorage of CHB walls to RC members in Market Building of Loon: (Left) a case of horizontal rebar, (Right) a case of vertical rebar.

Figure 12. Examples of improper fixing of ceiling boards: (Left) Sagbayan Municipal Building, (Right) Market Building in Loon.

building construction. Several recommendations are elaborated based on these activities.

3.2 Review of working drawings

The authors reviewed examples of drawings of several buildings. They found most of them would have a good level of performance if constructed in compliance with the drawings, but in most cases the detailed information on the designs and specification was insufficient for working drawings. In most countries, like the US or Japan, detailed information on design, material/parts/components and construction methods are provided with reference technical documents like standard detail design drawings and standard specifications. During the survey the authors could not find standard detail drawings.

3.3 Background of the damage

3.3.1 Lack of common understanding among relevant groups

A basic requirement for constructing buildings of good quality is a common understanding of the design among all the relevant groups, such as designers, supervisors, contractors, foremen, and workers. The authors observed that a lack of common understanding is one of the most crucial problems in the Philippines. The review of working drawings revealed: 1) information provided by the designers (drawings, detail drawings, specifications) is insufficient, 2) reference documents (standard detail drawings, standard specifications) are not prepared, 3) the practice of preparing shop drawings is not usual, and 4) supplemental documents are not prepared. These situations result in a lack of common understanding on what kind of construction works should be implemented on site. Typical examples of damage caused due to these lacks are described below.

Position of longitudinal rebar:
Regarding the sections of columns or beams, most of them have no description about the position of rebars. The designed position could be figured out only when the concrete cover thickness on another sheet of drawings was referred to. Workers without enough technical knowledge, who think the number of rebars is significant but their position is unimportant, might cause defects and damage like in Figure 7. Another possible way to avoid this kind of problem could be training to make standard coverage of concrete detailing to be common knowledge to all workers.

Fixing of ceiling panels:
For design of ceilings, descriptions on drawings usually only covers type and quality of materials and not the design of ceiling frames and hungers, and fixing methods like the type of nails and their spacing. Therefore workers might not understand the proper way of fixing, and fix them in a way which might result in the defects and damage shown in Figure 12.

3.3.2 Design of structures

The Philippine structural code adopts "capacity design" with small section columns, and large assumed ductility to allow large deformation of the structure. This type of design with slender structural members requires precise construction in the various phases like: 1) lots of complicated rebar bending both in longitudinal and tie bars, 2) precise positioning of rebar, and 3) complete compaction of concrete especially in parts with congested rebar.

More redundant design is recommended which could avoid serious damage even when buildings have a certain level of inaccurate construction. A push-over analysis could also be an effective tool in addition to the usual design method. It provides the deformation of the structure by push-over loading (large deformations that cause serious cracks in the concrete and failure of the cover concrete). It provides: 1) the failure mechanism of total structures which informs possible vulnerable types of failure such as failures at ends of columns, which might lead to total collapse of structure, 2) the types of failure (shear failure or flexural) at each point, which suggests an effective way of improving the resilience of the total structure, and 3) deformation of each of the storeys, which might indicate possible soft story collapse. All this information could contribute to realizing more redundant designs by avoiding vulnerable types of failures and increasing resilience.

3.3.3 Design and construction of non-structural members

CHB walls:
CHB non-structural walls (cladding walls and partition walls) are one of the most vulnerable of all building elements to ground shaking motion. Several issues need to be solved such as: 1) strength of the CHB, 2) filling and compaction of grout in the cavities, 3) installation of reinforcing rebar in CHB walls, and 4) connection of CHB walls to columns and beams.

Ceilings:
Ceilings are other heavily damaged elements. Damage is caused both by the shaking motion affecting nail fixings and collisions of adjacent ceiling boards or against walls.

Supporting frames, hangers, nails and spacing all need to be described clearly so foremen and construction workers know how to construct ceilings as shown on design documents.

3.4 Recommendations on strategies to reduce damage

Since the causes of damage and their backgrounds are wide and diverse, a comprehensive approach is necessary. Another important aspect is that many groups are involved in construction of buildings such as designers (architects and engineers), contractors (engineers, foremen, and workers), manufactures of materials, administrators and researchers. Therefore an inter-sectoral and inter-disciplinary approach is necessary.

3.4.1 Creation of common understanding of design among relevant groups

Creation of common understanding of designs among all the relevant groups should be the first basic policy. Provision of more detailed information in an easy and user-friendly manner is a basic way forward. Usual tools of communication are drawings, specifications, shop drawings, and supplemental documents. Every possible dissemination activity like briefings, lectures, or guidance on site should follow. Inspections on site could be categorized in this activity. Capacity development for those groups would enhance their ability to understand designs.

3.4.2 Improvement of design and documentation

Appropriate designs both of structural and non-structural members should be the next basic policy. Designs must be reviewed from various points of view, like safety against every possible hazard, as well as functionality and cost effectiveness. For structural design, more redundant design is recommended. As for non-structural members, more engineering intervention is required. In these cases, construction feasibility on site and acceptability by workers should be taken into consideration. Buildings of good quality cannot be realized when design and detailing requires complicated or difficult work on site, making workers reluctant to follow the design.

3.4.3 Comprehensive capacity development of relevant stakeholders in both supply and demand sector

Capacity development of all the relevant groups would create a basis of common understanding of designs. Engineers working in design and supervision are key players. In addition, contractors' engineers, foremen and workers should be focused, given the situation in the Philippines that improper construction is one of most prevailing causes of heavy damage. Training on construction skills for workers needs special consideration. They usually have limited engineering knowledge and need specific training methods, which should be different from those for engineers. Concerning non-structural members, architects and manufactures are key players. Besides the supply sector mentioned above, the demand sector of customers should be also target group. They decide the quality of buildings by instruction to the supply sector. Administration is another important group, especially officials in local governments who work in the construction area.

Both the supply and demand sector usually pay little attention to maintenance. Awareness raising of engineers and architects on the importance of maintenance should be the first step. They are the most appropriate people to disseminate it to customers.

CONCLUSIONS

The natural disaster in 2013 revealed the vulnerability of buildings in the Philippines. Vulnerability exists not only in structural members but also in various non-structural members like cladding walls, partition walls, ceilings, roofing, and ornaments. The causes of damage are identified as: 1) improper designs, 2) poor quality of materials, 3) poor workmanship, and 4) lack of maintenance. The authors recommend: 1) creation of a common understanding of design among relevant groups, 2) improvement of designs and documentation, and 3) comprehensive capacity development of the construction sector and relevant groups. Expensive lessons learnt from disasters have to be fully utilized to mitigate future damage.

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries

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