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LESSONS LEARNT FROM DAMAGE TO BUILDINGS BY BOHOL EARTHQUAKE AND TYPHOON YOLANDA 2013 IN THE PHILIPPINES

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ABSTRACT

The authors conducted surveys on damaged reinforced concrete (RC) buildings by Bohol Earthquake and Typhoon Yolanda (Haiyan internationally)in the Philippines, and found heavy damage in non-structural members, huge difference in degree of damage among buildings in similar situation, and each of heavily damaged buildings has its own specific causes. 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 works. This report introduces overview of damage and causes, considers the background and presents some recommendation on basic policy to improve the situation as 1) creation of common understanding of designs, 2) improvement on designs and description/documentation, 3) comprehensive capacity development of relevant stakeholders .

1. BACKGROUND, OBJECTIVES AND OUTLINE

1.1 Background and objectives

The Philippines experienced two natural disasters in succession in 2013, namely the Bohol Earthquake on October 15 and the Typhoon Yolanda (Haiyan internationally) November 6-9. Both caused serious damage to the Philippines in various aspects in wide area. Among them buildings are one of the most heavily damage infrastructures. JICA dispatched experts to grasp the damage, causes, social background of causes and draw lessons which could contribute to mitigate disaster in future. This paper summarizes results of the field surveys, analyses causes and the background, and presents recommendation based on the surveys. Targeted buildings of this report are reinforced concrete (RC) buildings and most of them are public building because those were buildings the authors could rapidly obtain permissions to conduct detail survey. Please refer to other reports regarding to other types such as historical buildings of masonry structure and detached houses of concrete block masonry structure.

1.2 Outline of research

1.2.1 The first field survey

The first survey was conducted as follows,

- **Cebu and Bohol**

1 Japan International Cooperation Agency
2 Expert Advisor, Public Buildings Association (PBA), Advisor, Penta- Ocean Construction Co ltd
3 Osaka University
4 Tokyo Polytechnic University
5 Polytechnic University
6 Nagoya Institute of Technology

Date: November 29 to December 2, 2013
Members: Dr. T. Narafu, D. Y. Sanada, Dr. S. Takahashi, Mr. H. Nakamura and staff of Department of Public Works and Highways (DPWH), staff and consultants of the World Bank

- **Leyte and Samar**

Date: December 4-6, 2013
Members: Dr. T. Narafu, Ms. A. Itsuki and staff and consultants of JICA

1.2.2 The second field survey

It is observed in the first field survey that damage occurred not only in structural members like columns and beams but also in various members like shelter walls, partition walls, ceilings and roofing. The members of buildings other than structural members are called "non-structural members" and usually designed by architects. Causes of damage also vary in wide range from design, to workmanship and materials. Damage in Bohol was caused by shaking motion and that of Leyte, by strong wings and inundation. These facts require survey team members with wider expertise in addition to structural engineering. Therefore the second survey team was organized to consist of experts from construction engineering, construction management, workmanship, materials, and wind engineering as follows,

- **Bohol**

Date: January 7-8, 2014
Members: Dr. T. Narafu, Mr. T. Shimizu, Dr. N. Mita, Mr. H. Nakamura, staff and consultants of JICA, and staff of Department of Public Works and Highways (DPWH)

- **Leyte and Samar**

Date: January 9-11, 2014
Members: Dr. T. Narafu, Mr. T. Shimizu, Dr. N. Mita, Dr. Y. Tamura, Dr. Y. Sanada, Ms. A. Itsuki, staff and consultants of JICA, and staff of Department of Public Works and Highways (DPWH)

1.2.3 Analysis, discussion and elaboration of recommendation

During the field surveys the survey team analyzed causes of damage from various point of views with the wide range of expertise of the team members. The survey team also conducted survey on construction practice in the Philippines such as preparation of drawings and specification for procurement of construction service, usual procedures of construction management on site by staff of DPWH. Based on the results of the survey, the team discussed social background of causes and concluded that most of the background of two different natural disasters is common even though the natural hazards (the earthquake and the typhoon) and actions to buildings by the hazards (shaking motion, pressure by strong winds, and inundation) are different. Based on this finding, the team elaborated recommendation in the context of actual construction practice in the Philippines.

1.3 Overview of previous reports/papers and features of this report

1.3.1 Overview of previous reports/papers

Every time large scale natural disasters occur, engineer and researcher community usually conduct field surveys in affected areas to grasp damage, analyze causes and draw lessons to mitigate damage by future disasters. Many reports/papers of field reports on damage by earthquakes were presented at international conferences like World Conference of Earthquake Engineering (WCEE, one of the largest world conference on earthquake engineering held every four years. The last one held in 2012 in Lisbon, Portugal, had about 4,000 participants and about 3,400 papers were presented.). Among papers presented at 15th World Conference of Earthquake Engineering 2012 (15WCEE), several different approaches were found as a) management or planning point of view dealing with numbers of affected people, analysis of damage including response/behavior of people to hazards, analysis by social groups like gender, age, disabled, influential factors like preventive measures, preparedness, etc., b) socio economic point of view dealing with impacts to local economy, households and so on, and c) engineering point of view. Ones from engineering point of view (approach c) could be categorized into three groups as below. Several typical papers are listed for each of the groups. (source: Proceedings of

15WCC in USB with index search by names of authors, titles of paper or keywords)

Group 1 on Earthquakes: to grasp total damage

H. Kit MIYAMOTO and Amir SJ Gilani, Urban Earthquake Damage Assessment and Reconstruction: 2010 Haiti Earthquake

Satoshi TANAKA and Kishie SHIGEKAWA, Analysis of the Building Damage Evaluation for the 2011 Great East Japan Earthquake

Group 2 on Earthquakes: to focus on specific aspects, types of buildings, members and so on

Masaki Maeda et al. Damage Survey on Reinforced Concrete School Buildings in Miyagi after the 2011 East Japan

I. Senaldi, G. Magenes and J. M. Ingham, The seismic performance of unreinforced stone masonry buildings during the 2010-2011 Canterbury earthquake sequence

Masatoshi Yamazoe, Joji Sakuta, Kazuya Mitsuji, and Masaki Maeda, Field Investigation and Dynamic Analysis of Damaged Structure on Pile Foundation during the 2011 off the Pacific Coast of Tohoku Earthquake

Group 3 on Earthquakes: to analyze behavior of structure, causes of failure etc. on specific buildings

J. Sherstobitoff, P. Cajiao and P. Adebar, Analysis and Repair of an Earthquake-Damaged High-rise Building in Santiago, Chile

YAN Peilei and SUN Baitao, The Analysis of Non-Linear Seismic Response between a Collapsed and a serious damage Infilled Frame Structure in Yingxiu Town–the Heavy Disaster Areas of Wenchuan Earthquake

The categorization above can be applied for reports/papers on field surveys on areas affected by typhoons, cyclones and similar disasters. Typical ones are listed below. Reports/papers of group 6) on this disasters are not so many because of characteristic of damage to buildings with similar materials in similar construction methods are usually also similar and analysis on specific buildings is not so significant compared with cases of earthquakes.

Group 1 on Typhoons: to grasp total damage

G. Davenport, The impact of structural damage in Jamaica due to hurricane Gilbert and the prospects for disaster reduction, Journal of Wind Engineering and Industrial Aerodynamics, Vol. 36, Part 1, pp.53-62. , 1990

A.M. Goliger, J.V. Retief, Severe wind phenomena in Southern Africa and the related damage, Journal of Wind Engineering and Industrial Aerodynamics, Vol.95, Issues 9–11, pp.1065-1078. , 2007

M. C. McCullough, A. Kareem, A. S. Donahue, J. J. Westerink, Structural Damage Under Multiple Hazards in Coastal Environments, Journal of Disaster Research, Vol.8, No.6, pp.1042-1051. , 2013

Group 2 on Typhoons: to focus on specific aspects, types of buildings, members and so on

A.M. Cruz, E. Krausmann, Damage to offshore oil and gas facilities following hurricanes Katrina and Rita: An overview, Journal of Loss Prevention in the Process Industries, Vol. 21, Issue 6, pp.620-626. , 2008

H. Liu, H. S. Saffir, P. R. Sparks, Wind Damage to Wood‐Frame Houses: Problems, Solutions, and Research Needs, Journal of Aerospace Engineering, Vol.2, No.2, pp.57-70. , 1989

P. R. Sparks, H. S. Saffir, Mitigation of wind damage to non-engineered and marginally engineered buildings, Journal of Wind Engineering and Industrial Aerodynamics, Volume 36, Part 2, pp.957-966. , 1990

Group 3 on Typhoons: to analyze behavior of structure, causes of failure etc. on specific buildings

D. Henderson, C. Williams, E. Gavanski, G. A. Kopp, Failure mechanisms of roof sheathing under fluctuating wind loads, Journal of Wind Engineering and Industrial Aerodynamics, Volume 114, pp.27-37. , 2013

O. Mahrenholtz, H. Bardowicks, Aeroelastic problems at masts and chimneys, Journal of Wind Engineering and Industrial Aerodynamics, Vol.4, Issues 3–4, pp.261-272. , 1979

1.3.2 Features of this report

This report is written on damage by recent two disasters in the Philippines from view point of engineering focusing on reinforced concrete buildings and should be categorized in approach c and

Group 2 on Earthquakes and Group 2 on Typhoons according to the categories in the previous section. This report has specific features of being comprehensive and practical as below thanks to very wide fields of expertise of the eight co-authors with practical experiences.

- covering damage by two different types of natural disasters (earthquake and typhoon) with three types of actions (shaking motion, pressure by strong winds and inundation by water), which reveal different types of vulnerability of actual buildings in the Philippines
- covering damage to both structural members which are designed by engineers, and non-structural members (partition walls, ceiling boards, roofing and so on) by architects, whereas most of previous reports/papers are prepared by engineers on structural members
- analyzing causes of damage in whole procedures of construction from design, procurement, construction works on site including workmanship and materials, to management and supervision

2. Overview and analysis of damage

2.1 Overview of damage

2.1.1 Overview of damage by two disasters

Overview of damage by the two natural disasters is shown in Table 1. The damage occurred both in structural members and non-structural members. Total design of buildings is managed by architects and that of structural members is usually by engineers, which appears in drawings for practical use in review stated Section 3.2. (Drawings are consisted of four kinds of architectural, structural, mechanical or electrical) stated in 3.2. It should be noted that architects and engineers graduate from different department of universities in the Philippines whereas both from the same, "architectural engineering" in Japan. Qualification scheme for design profession managed by Professional Regulatory Commission (PRC) also follows the same division.

Table 1 Overview of damage by the two natural disasters

portion/parts of buildings		damages by types of hazards		
		earth quakes	inundation	strong winds
non-strctural members	shelter/partition walls	often	often	several
	parapets	often	rare	several
	ceiling boards	often	often	often
	ornaments/sign boards	often	rare	often
	roofing	rare	rare	often
structural members	columns and beams	several	rare	several
	roof truss/post and beams	rare	rare	often

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 (Figure 1) on October 15, 2013 (Philippine Institute of Volcanology and Seismology PHIVOLUCS) and caused serious damage in Bohol and Cebu islands as below (NDRRMC update SitRep No. 33 issued on October 31, 2013),

Dead: 222 people

Missing: 8 people

Injured: 796 people

Affected: 671,103 families, 3,221,248 people

Damaged houses: 13,249 houses totally, 53,683 houses partially

Figure 1.　Epicenter of Bohol Earthquake 2013

Table 2 Overview of damage to RC buildings

Municiparity	buildings	Use	Damage				Pictures in Figures
			Structure	Non-stractural walls	Ceilings	Others	
Tagbilaran	Municiparity office	X	Slight	Slight	Medium	Medium	
	University Hospital	X	–	Medium	Heavy		
	School of nursing	X	–	Extreme	Heavy (most fell down)	Slight	
Sagbayan	Municipal office	X	Medium	Extreme	Heavy	Extreme	2,4(lower), 11, 19(right), 22, 23(left)
	District Health care center	X	Medium (damage in beam, cracks in columns)	Medium	Heavy		12
	School	X	Slight	Slight	No ceilign boards		
Catigbian	Municipal office	X	Medium (damage in columns)	Extreme	Medium		16
Loon	Market building	X	Medium (failure in beams, etc.)	Extreme	Extreme	Extreme	17, 18, 19(left), 21, 22(right)
	Hospital building 1	X	–	Heavy (most fell down)	Medium		
	Hospiral building 2	X	Slight	Extreme	Extreme		
	Hospiral building 3	X	Slight	Extreme	Extreme	Heavy	
Antequera	Municipal office building 1	X	Slight	Medium	Extreme	Heavy	
	Municipan builiding 2	50%	–	Medium	Medium (2nd fl.)		4(upper)
	Barangay office	10%	Heavy (2nd fl. Tilted)	Extreme	Extreme		13, 20(right)
	District Health care center	20%	–	Medium	Medium		

The highest intensity of the shaking motion is reported VII in PHIVOLCS Earthquake Intensity Scale (PEIS) (smallest I to largest X, http://www.phivolcs.dost.gov.ph/index.php? option =com_ content &task = view&id=45&Itemid=100) Many totally collapsed buildings are found to have furniture withstanding inside them. Figure 2 shows an example of Municipal building of Sagbayan, Bohol. Left photo shows heavy damage to shelter walls, partition walls, ceiling boards and so on in spite that damage to structure is limited (Orange circle shows position related to Figure 11 and 22). Right photo shows inside the buildings where most of cabinets, lockers and other furniture were found withstanding. Usually in developed countries buildings may collapse by far strong shaking motion than ones causing furniture fall (Figure 3). This implies buildings in the affected areas are very vulnerable. Table 2 shows all the RC buildings which are heavily damaged and investigated in detail (steel structures are excluded). In spite of none or slight damage to structural members (like cracks or others), 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-structural members.

Huge difference in degree of damage is observed. Figure 4 shows huge Difference among municipal buildings of Antequera and Sagbayan, Bohol. Upper left photo shows Municipal office of Antequera (Building 2) suffered little and upper right shows the conditions of the first floor of the upper left that it suffered little and started operation soon after the earthquake. Lower left photo shows exterior view of Municipal office of Sagbayan (refer to Figure 2). Lower right photo shows heavy damage to non-structural members of partition walls and ceiling boards, etc. On the other hand damage to structure is limited. It will be demolished due to the damage.

Another significant finding is that each of heavily damaged buildings has its own specific causes which seemed to invite the heavy damage. The causes can be categorized into 1) improper design, 2) poor/insufficient quality of materials, 3) poor workmanship/improper construction works, and 4) lack of maintenance works

Figure 2. Municipal building of Sagbayan, Bohol: (Left) Heavy damage to shelter walls and so on, and (Right) Inside the buildings

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/ Heavy	Heavy	Very heavy
PEAK ACC (%g)	< 0.17	0.17 – 1.4	1.4 – 3.9	3.9 – 9.2	9.2 – 18	18 – 34	34 – 65	65 – 124	> 124
PEAK VEL (cm/s)	< 0.1	0.1 – 1.1	1.1 – 3.4	3.4 – 8.1	8.1 – 16	16 – 31	31 – 60	60 – 116	> 116
INSTRUMENTAL INTENCITY	I	II – III	IV	V	VI	VII	VIII	IX	X

MMI VII or higher: some furniture may fall down

MMI X or higher: vulnerable buildings may collapse such as stone masonry

Figure 3 Descriptive Table of Modified Mercalli Intensity (USGS)

Figure 4 Huge Difference among municipal buildings of Antequera and Sagbayan, Bohol (Upper left) Municipal office of Antequera (Building 2), (Upper right) First floor of Upper right (Lower left) Municipal office of Sagbayan (Lower right) Interior view of Lower left

2.1.3 Damage by Typhoon Yolanda

The Typhoon Yolanda went through in the middle of the Philippines November 6-9, 2013 (Figure 5) and caused heavy damage in large area along its track. It is reported that the hazards were extreme. Severe Weather Bulletin (SWB) No. 6 issued by National Disaster Risk Reduction and Management Council of Philippine Government reported the highest maximum sustained winds of 235 km/h and gustiness 275 km/h (recorded highest sustained wind speeds reported by Philippine Atmospheric, Geophysical & Astronomical Services Administration (PAGASA): 160 km/h and gustiness: 195 km/h both at Guiuan, East Samar). National Structural Code of the Philippines (NSCP) defines wind loads in terms of gustiness as 250 km/h for Zone I, 200 km/h for Zone II, 150 km/h for Zone III). Heavily damaged areas by the typhoon locate in Zone I (Samar Island) and II (Leyte Island).(Figure 6) Maximum depth of sea water above ground level by storm surge is estimated 5-8 meters estimated by an expert group of Japan Disaster Relief Team (JDR). The strong winds and the storm surge caused extraordinary heavy damage as below (SWB No. 104 issued on January 29, 2014).

Dead: 6,201 people
Missing: 1,785 people
Injured: 28,626 people
Affected: 3,424,593 families, 16,078,181 people
Damaged houses: 550,928 houses totally, 589,404houses partially

Damage to buildings is caused by two different actions of pressure by strong winds (Figure 7) and inundation by water (Figure 8). Table 3 shows buildings which are analyzed in Section 2.2. Most of buildings suffered from both strong winds and inundation. Huge difference is also observed in degree of damage among buildings even in similar condition. Typical examples are shown in Figure 9 and 10. Figure 7 shows comparison of damage of large buildings by the typhoon. Left is Leyte Convention Center in Palo, which total collapsed. On the other hand, Toyota showroom in Tacloban (Right) got limited damage to roofs and ceilings and started operation about one month after the disaster.

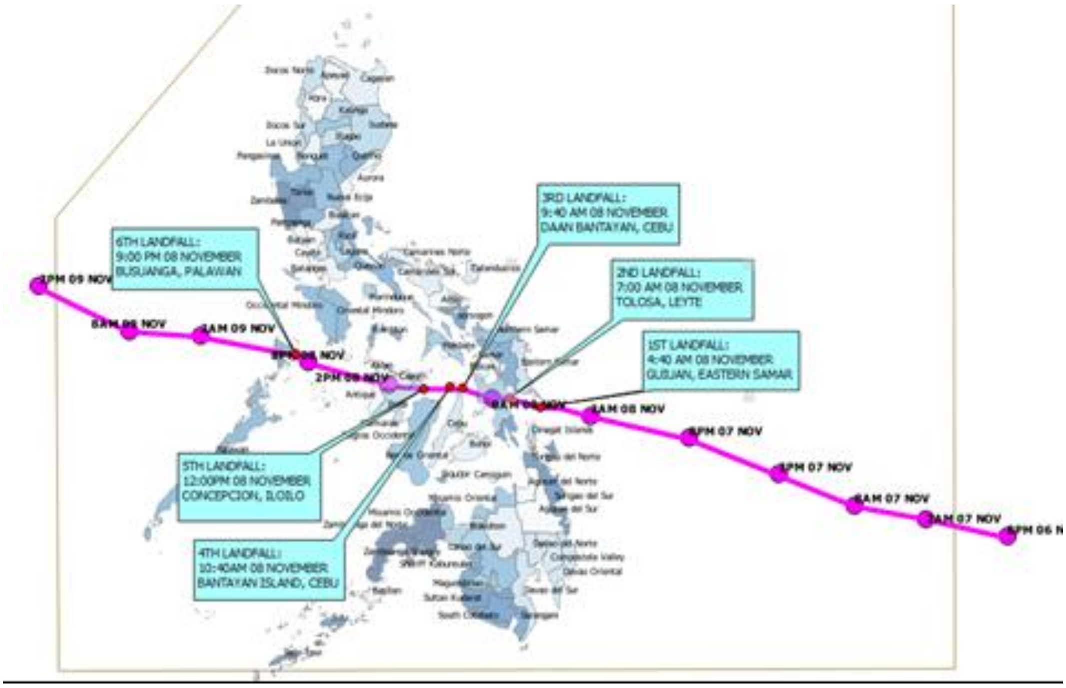


Figure 5 Track of Typhoon Yolanda (Philippine Atmospheric, Geophysical & Astronomical Services Administration: PAGASA)

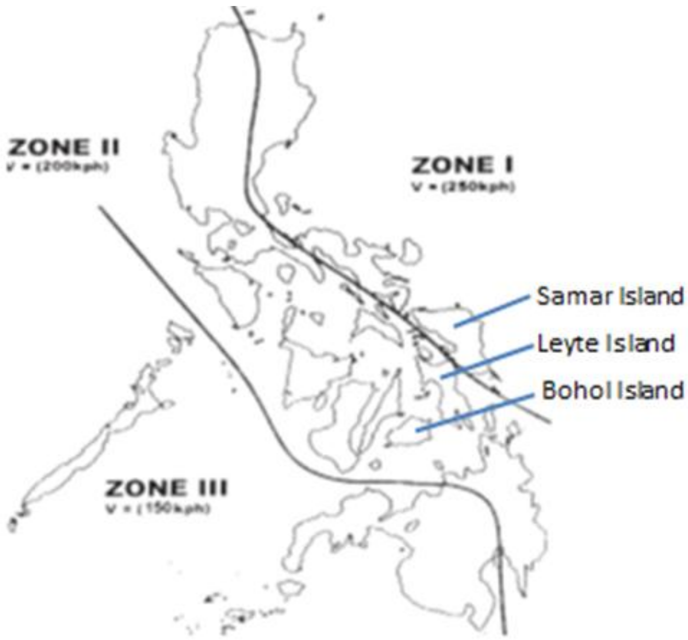


Figure 6 Wind Zone Map of National Structural Code of the Philippines (NSCP)

Figure 7 Typical damage by strong winds by the typhoon: (Left) Heavy damage in roofing: Customers' center of private company in Palo, Leyte, (Right) Damage to both roofing and roof trusses. Sagkahan National High school, Tacloban, Leyte

Figure 8. Typical damage by storm surge caused by the typhoon in coastal area of Tacloban city, Leyte

Table 3 Overview of damage buildings by the typhoon analyzed in this paper

Municipality	buildings	Use	Damage				Pictures in Figures
			Structure (including roof truss)	Roofing	Ceilings	Others	
Tacloban	Sagkahan National High School 1(grant aid by Japan)	X	None	slight	slight	Medium (windows)	10(upper right)
	Sagkahan National High School 2	X	None	slight	slight	Medium (windows)	10(lower left)
	Sagkahan National High School 3	X	Collapse	Collapse	Collapse	Collapse	7(right) 10(lower right)
	Sagkahan National High School 4	X	slight	slight	slight	Medium (windows)	25(left)
	Toyota Showroom	X	None	slight	slight	Medium (doors, shutters)	
Palo	Leyte Convention Center	X	Collapse	Collapse	Collapse	Collapse	9(left)
	Customers' Center	X	slight	Extreme	Extreme	Extreme	7(left)
	Supermarket Metro	X	Collapse	Collapse	Collapse	Collapse	15
Tanauan	Tanauan National High School 1	X	Collapse	Collapse	Collapse	Collapse	14(left)
	Tanauan National High School 1	X	Collapse	Collapse	Collapse	Collapse	14(right)

Figure 9. Comparison of damage of large buildings: (Left) Leyte Convention Center in Palo (Right) Toyota showroom in Tacloban

Figure 10. Comparison of damage of school buildings in Sagkahan National High School in Tacloban, Leyte: (Upper left) Overview of the school, (Upper right) a building by Grant Aid project by Japan, (Lower left) a building with limited damage (Lower right) a building with heavy damage

Figure 10 is an example of school buildings in Sagkahan National High School in Tacloban, Leyte. Upper right is a building by Grant Aid project by Japan which suffered little. Lower left is another one with limited damage to roof flash and ceiling boards. Lower right is one with heavy damage of blown away of roofing and failure of roof trusses

It is also observed that each of heavily damaged buildings has its own specific causes which seemed to invite the damage. Most of 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 works just same as those on the earthquake.

2.2 Analysis of damage

2.2.1 Improper designs

Several cases of damage by improper structural design were found during the field surveys. Typical ones are shown in Figure 11-15. Figure 11,12 and 13 are similar type that structural designs are not regular which invited unexpected force and stress. Irregularities are, Figure 11: beams of canopy were not attached to main structure in consistent manner and were connected to a beam at points without support of columns, Figure 12: levels of beams differ to each other, which caused unexpected stress in columns, Figure 13: irregular configuration of columns and imbalanced layout of non-structural walls might invite torsional force to the total structure.

Figure 14 is an example of damage in gable walls and roof trusses. This might be caused by improper designs (load estimation or design strength is not appropriate) or construction might not comply with the designs. Figure 15 is an example of a steel structure. Many failures occurred in connection where welding without gusset plates were applied. Such direct welding may damage parent/base materials and reduce strength of connecting sections. In both cases of Figure 14 and 15, the authors could not clarify the real causes (improper designs or incorrect construction works) as they could not examine drawings and specifications for the buildings.


Figure 11. An example of improper structural design in Municipal building of Sagbayan, Bohol (by the earthquake) (Exterior view: refer to Figure 2) (Left) damaged connection of beams of canopy and main structure (Right) Detail of the damage


Figure 12. An example of improper structural design (by the earthquake) (Left) Exterior view of District Health Care Center of Sagbayan, (Right) connection of a column and beams

Figure 13 An example of improper structural design in Barangay office in Antequera (by the earthquake): (Left) exterior view, (Right) damaged columns by irregular configuration

Figure 14 Tanauan National High School in Leyte (by the typhoon): (Left) Collapsed gable walls of CHB. (Right) Roof truss heavily damaged without sufficient reinforcement in longitudinal direction

Figure 15 Supermarket Metro in Leyte (by the typhoon): (Left) Roof truss was completely destroyed, (Right) Welding without gusset plates.

2.2.2 Poor/insufficient quality of materials

As stated in 2.1.1, damage to non-structural members is dominant by the two disasters. Among them concrete hollow block (CHB) walls are one of the most common damage. One of the major causes of the damage is poor strength of CHB. It is often observed that rebar in wall and mortar filled in hollows remains but most of CHB disappears due to extremely low strength like in Figure 16 .Regarding damage to ceilings, use of usual type of nails to fix ceiling boards is one of the causes of heavy damage. Appropriate nails for fixing ceiling boards or nails with washers should be used.

2.2.3 Poor workmanship/improper construction works

Poor workmanship/improper construction works seems to be another dominant causes both in Bohol and Leyte. The authors find various types of defects shown in Figure 17-21. In a case of Figure 17, several improper construction works are identified. Longitudinal rebar is positioned inaccurately (placed inside than the designed position). All the overlap splices of longitudinal rebar locates at the same level of a critical position, the bottom of the columns. (A red pipe in right photo is a pipe for electric wire installation) In a case of Figure 18 failures of concrete occurred at the one of the most critical part of structures, panels (crossing parts of columns and beams), where hoops are absent (right photo). Honeycomb caused by insufficient compaction of concrete are often found (Left photo of Figure 19). There found some cases that pieces of board penetrate into columns which might be used to prevent fresh concrete coming out through gap between form panels (Right photo of Figure 19). Figure 20 shows improper rebar works. The left photo is a case that spacing of hoops is too large, which might allow inside concrete coming out (Barangay Office in Antequera) and the right photo has several improper rebar works: bending of hooks of hoops is 90 degree, all the overlap splices of longitudinal rebar locate at the bottom of a column.

Figure 21 shows examples of improper anchorage of CHB walls to RC members in Market Building of Loon. The left photo is a case that horizontal rebar in a wall is not correctly anchored to a column and the right is a case that anchorage to a beam seems not work well. Figure 22 shows improper installation of concrete gutters in Sagbayan Municipal Office that a precast concrete gutter fell down to ground by shaking motion (exterior view and original position of the the gutter: refer to Figure 2).

Figure 23 shows cases of ceiling boards. The left photo shows extreme damage that most of ceiling boards were damaged in Sagbayan Municipal Building and the right is a case ceiling of second floor fell down onto a stairway in Market Building in Loon.

Figure 16 An example of poor quality of concrete hollow blocks (CHB) (by the earthquake): (Left) Damaged non-structural walls in Municipal Office of Catigbian, (Right) Details of a damaged wall.

Figure 17 Examples of improper rebar works in Market Building in Loon (by the earthquake): (Left) Heavy damage at the bottom of most of columns, (Right) Detail of the damage.

Figure 18 An example of improper rebar works in Market Building in Loon (by the earthquake): (Left) Failures at panels, (Right) Detail of damaged part

Figure 19 Examples of improper concrete placing (by the earthquake): (left) Market Building in Loon, (Right) Sagbayan Municipal Office

Figure 20 Examples of improper rebar works (by the earthquake): (left) Barangay Office in Antequera, (Right) A building under construction, Basey National High School

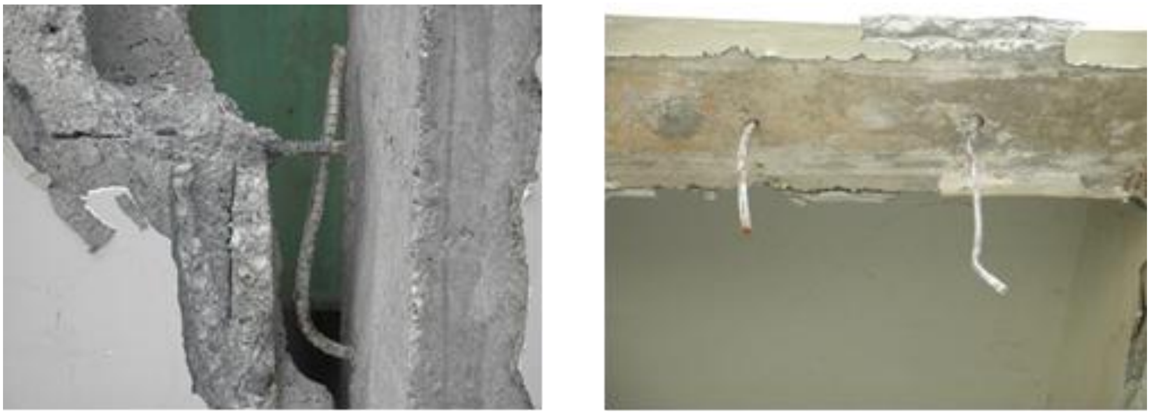


Figure 21 Examples of improper anchorage of CHB walls to RC members in Market Building of Loon (by earthquake): (Left) a case of horizontal rebar, (Right)a case of vertical rebar

Figure 22 An example of improper installation of concrete gutters in Sagbayan Municipal Office (by the earthquake)

Figure 23 Examples of improper fixing of ceiling boards (by the earthquake): (Left) Sagbayan Municipal Building, (Right) Market Building in Loon.

2.2.4 Lack of maintenance works

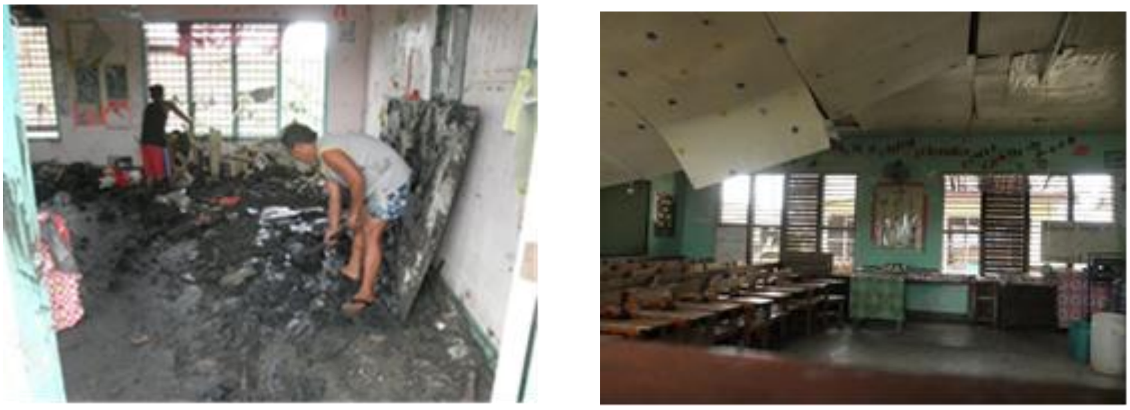
Lack of maintenance works invited heavy damage in several situations. Corrosion of steel members by rusting, damage to woods by termites, fatigue of roofing sheets by cycles of expanding and shrinking by sunlight are the typical examples. Figure 24 left photo shows a case of a wood column heavily damaged by termites at St. Joaquin Central Elementary School, Palo, Leyte (by the typhoon), and the right, a heavily corroded steel column at Cogon Norte Elementary School, Loon, Bohol (by the earthquake).

Figure 24 Examples of failures by lack of maintenance: (Left) St. Joaquin Central Elementary School, Palo, Leyte (by the typhoon), (Right) Cogon Norte Elementary School, Loon, Bohol (by the earthquake)

2.2.5 Damage by inundation

Most of buildings are designed without consideration of inundation and do not use water-proof materials except roofing. Therefore various inundated materials got damage shown in Figure 25. The left photo of Figure 25 shows situation that the storm surge brought much mud into builidngs, Basey National High School, Samar, and the right photo is an example of damage to ceiling boards by inundation（Sagkahan National High School in Tacloban, Leyte. Figure 26 is a case of Municipal Health Office of Basey, Samar, which employ simple finishing of concrete walls with durable painting and ceiling without boards. It allows easy recovery and quick restart of operation within several weeks by just washing of finishing.



Figue 25 Examples of damage by inundation (by the typhoon): (Left) Basey National High School, Samar, (Right) Sagkahan National High School in Tacloban, Leyte

Figue 26 Municipal Health Office of Basey, Samar (Left) exterior view, (Right) interior view of the first floor

3. Consideration on background of damage and recommendation

The authors conducted studies on legal and technical framework on building control in the Philippines as well. The National Building Code of the Philippines (NBCP), and revised implementing rules and regulations are basic legal documents and the National Structural Code of the Philippines (NSCP) is a technical standard on structures (Figure 27). Several examples of drawings for practical use were also reviewed and interviews/discussion with Philippine engineers was organized for better understanding on situation and practice concerning building construction. Several recommendations are elaborated based on these activities.

3.1 Study on legal and technical framework on building control in the Philippines

The Basic legal document in the Philippines is the National Building Code of the Philippines. It was issued as Presidential Decree No. 1096 in 1977. Many of technical standards are prepared by each of organizations of specific expertise. As to structure, Association of Structural Engineers of the Philippines (ASEP) prepares standards. Current standard on structure for buildings is National Structural Code of the Philippines (NSCP) 6th edition Volume 1: Buildings, towers, and other vertical structures, approved by Department of Public Works and Highways (DPWH) as a referral code of NBCP. The preface of 6th edition of NSCP states that it is referenced from Uniform Building Code

UBC-1997, International Building Code IBC-2009, America Society of Civil Engineers ASCE/SEI 7-05 and other 7 codes/standards/handbooks in the United States. Philippine engineers state that most of Philippine engineers use reference information and tools such as structural calculation software from the United States.

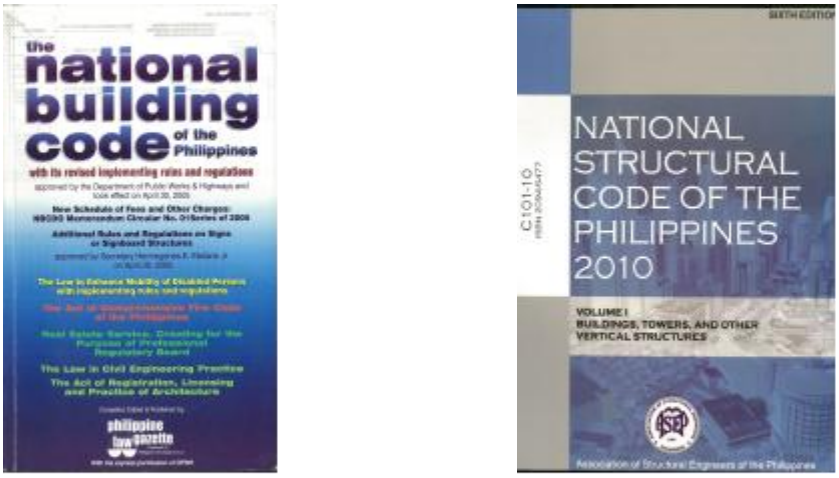


Figure 27 Documents concerning building control in the Philippines: (Left) National Building Code of the Philippines(NBCP) and revised implementing rules and regulations, (Right) National Structural Code of the Philippines (NSCP) 6th edition Volume 1

3.2 Review of drawings for practical use

The authors reviewed examples of drawings of several buildings. They found most of them would have certain level of performance when they are constructed in compliance with description of drawings, and in following usual practice in the US in cases where detailed information is not described on drawings. In other words detailed information on designs and specification is not enough on drawings in practice. In most of countries like the US or Japan, detailed information on design, material/parts/components, construction methods are provided with reference technical documents like standard detail design drawings and standard specifications. During the survey they could not find standard detail drawings and did find a document on standard specifications in a dusty book shelf which has not been used for a long time.

3.3 Consideration on background of damage

3.3.1 Lack of common understanding among relevant groups

Basis of constructing buildings of good quality is common understanding of design among all the relevant groups such as designers, supervisors, contractors, foremen, workers and so on. The authors observe that lack of common understanding is one of the most crucial situations in the Philippines. Documents for construction of buildings shown in Figure 28 are tools to create common understanding in Japan. The review of drawings in practice reveals 1) information provided by documents by designers (drawings, detail drawings, specifications) is not sufficient, 2) reference documents (standard detail drawings, standard specifications) in not prepared/utilized, 3) practice of preparing shop drawings are not usual, and 4) supplemental documents are not prepared/utilized. These situations result lack of common understanding on what kind of construction works should be implemented on site. Typical examples of damage caused under the conditions are described below.

<Position of longitudinal rebar>

As to design of section of columns or beams, most of them have no description on position of rebar (Figure 29). The designed position could be figured out only when description of concrete cover thickness in another sheet of drawings is referred. These may lead workers without enough technical knowledge to think number of rebar is significant but position in not in that way, which might invite the defects and damage like in Figure 17. (The positioning of longitudinal rebar and bending work of hoops are consistent, which supports the supposition) Another possible way to avoid this kind of problems could be training to make standard coverage of concrete to be common knowledge to all the workers.

<Fixing of ceiling boards>

As to design of ceiling boards. description on drawings is usually only on type and quality of materials, not on design of ceiling frames and hungers, and fixing methods like type of nails and spacing. Therefore workers could not understand proper way of fixing and might fix them in a way they like, which might invite the defects and damage like in Figure 23.

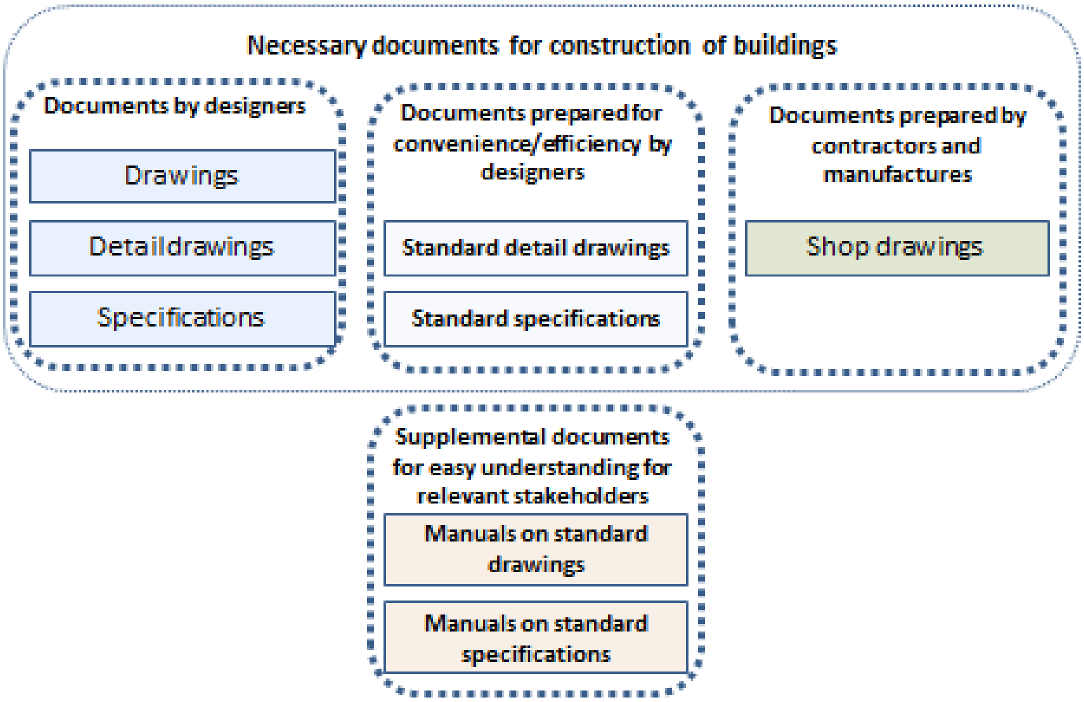


Figure 28 Various documents usually prepared for construction of buildings in Japan

Figure 29 Description of design of section of beams in usual drawings

3.3.2 Design of structures

The Philippine structural code adopts "capacity design" with structural members of smaller section areas especially in columns, which expects large ductility and allows large deformation of structure. This type of design with slender portion of structural members requires precise construction works in various phases like 1) lot of rebar of complicated bending schedule both in longitudinal and ties, 2) precise positioning of rebar, 3) complete compaction of concrete especially in parts with congested rebar. More redundant design is recommendable which could avoid serious damage even when

buildings have certain level of inaccurate construction works. For the purpose push-over analysis could be an effective tool in addition to usual method, which provides with deformation of structure by push-over loading (large deformation may cause serious crack in concrete and failure of cover concrete of rebar). It provide with 1) 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) types of failure (shear failure or flexure one) at each point, which suggest effective way of improving resilience of total structure, and 3) deformation of each of stories, which might indicates possible soft story collapse. All these information could contribute to realize redundant designs by avoiding vulnerable types of failures and increasing resilience.
Another important point is application of types of values of wind load for structural designs for roof trusses and others. In the Philippines, jalousie or other type of opening for ventilation is commonly used. Appropriate wind force coefficients for walls and roofs should be applied in accordance with condition of openings. Wind loads for buildings with openings can be larger than those for usual closed-type buildings.

3.3.3 Design and construction of non-structural members

<CHB walls>
CHB non-structural walls (shelter walls and partition walls) are one of the most vulnerable parts especially by shaking motion. It has several issues to be solved such as 1) quality/strength of CHB, 2) filling/compaction of mortar in hollows, 3) installation of reinforcing rebar in CHB walls, 4) connection/anchorage of CHB walls to columns and beams.
<Roofing> Roofing is the parts which suffer most from the strong wind by Typhoon Yolanda. Most of damage is caused by local negative (uplift) pressures caused by rapid flow of air. There is description on wind load in the Structural Code of the Philippines but usually calculation based on wind load is applied only to structural members of roof trusses and other structural members, not to roofing materials, purlins, rafters, nails and others in the Philippines. Materials and detail design of roof and related members have to be designed considering the wind loads and properly described in drawings or other documents. In this case application of appropriate value of wind load in accordance to types of opening is important as well as in structural design.
It is clearly proved that eaves or ends of roofing are the most critical parts for damage from strong winds and additional reinforcement and appropriate finishing worked well, which is shown in the building by Grant Aid project in Figure 10. This could be a good practice for prevention of damage from strong winds.
<Ceiling>
Ceiling is another most heavily suffered parts. Damage is caused both by strong wind (pressure by air flow coming into roofs, etc.) and shaking motion (damage of nail fixation by shaking motion, collision of ceiling boards to adjacent boards or walls) It seems usual in the Philippines that there is statement only on materials of ceiling boards on drawings, not frames, hangers, nails and spacing. These should be designed considering possible hazards and described clearly for foremen and construction workers to show how to construct ceilings on design documents.

3.4 Recommendation on basic policy for strategies to reduce damage

Since the causes of damage and the background are wide and diverse, 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, administration and research community(Figure 30). Therefore inter-sectoral and inter-disciplinary approach is necessary. The authors elaborate basic policy stated below for strategies to reduce damage in context of practice in the Philippines based on the surveys and the studies.

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. For the purpose, provision of more detail information in easy and user-friendly manner is a basic way. Usual tools of communication are drawings, specifications, shop drawings, supplemental documents shown in Figure 28. Every possible dissemination/communication activities like briefings, lectures, guidance on site should follow it. Inspection on site could be categorized in this activity. Capacity development for those groups would create a basis because it will enhance capacity to understand designs, which are further to be stated in 3.4.3.

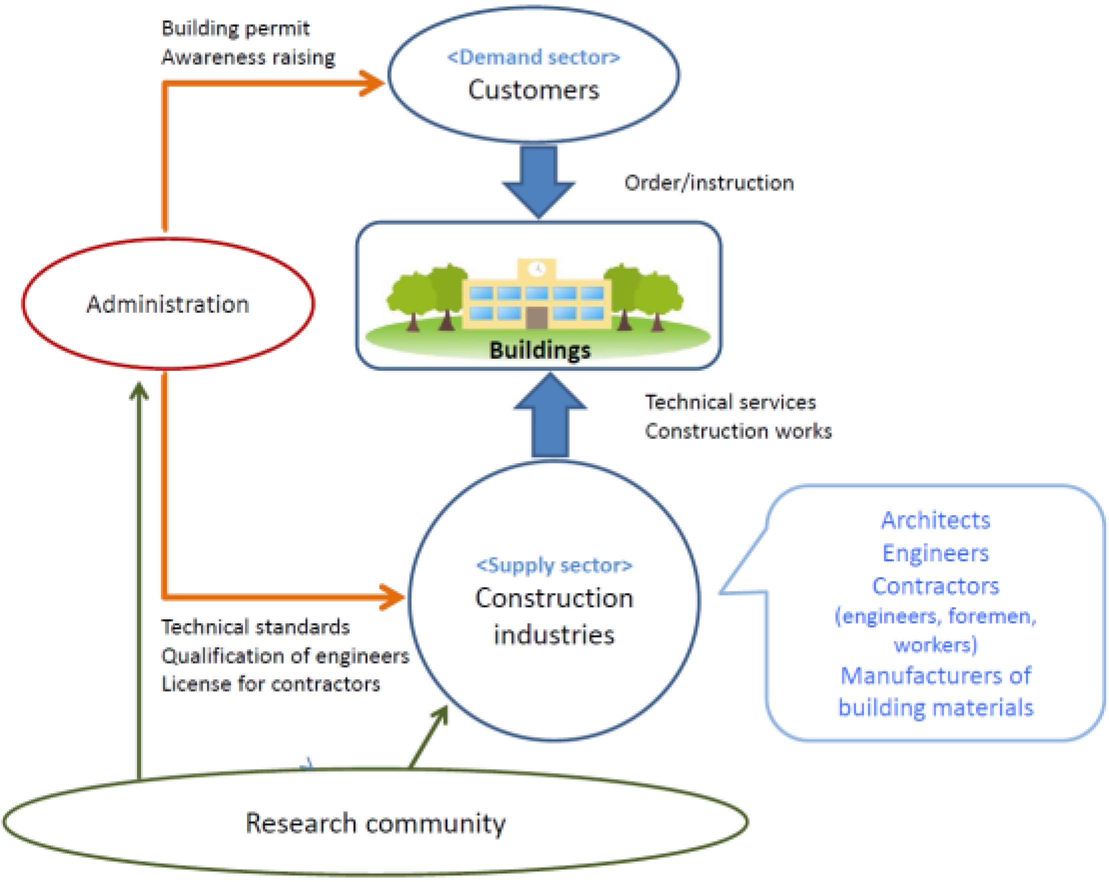


Figure 30 Construction sector and relevant groups for construction of buildings

3.4.2 Improvement of designs and description/documentation

Appropriate design both on 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, cost effectiveness and others. For structural design, more redundant design is recommended in 3.3.2. As to non-structural members, more intervention of engineering is required as stated in 3.3.3. In these cases, feasibility on site and acceptability by workers should be taken into consideration as all the construction works are conducted by workers on site. Buildings of good quality could not be realized when design and detailing requires complicated or difficult works on site so as that workers became reluctant to follow the design. Appropriate description/documentation of the design is also necessary for better understanding mentioned in the previous section.

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 actors. In addition, engineers, foremen

and workers working in contractors should be focused considering the situation in the Philippines that improper construction works are one of most prevailing causes of heavy damage. Training on construction skills for workers needs special consideration as they usually have limited engineering knowledge and need specific trainings methods, which should be different from that for engineers. Concerning non-structural members, architects are key players in designs and manufactures are the other ones in manufacturing.
Besides the supply sector mentioned above, demand sector of customers should be also target group, who are responsible to decide quality of buildings by order/instruction to supply sector. Administration is another important group, especially officials in local governments who work in practice.
Both supply and demand sector usually pay little attention to maintenance works. Awareness raising of engineers and architects on importance of maintenance should be the first step, who are the most appropriate people to disseminate it to customers.

CONCLUSIONS

The two natural disasters in 2013 revealed vulnerability of buildings in the Philippines. Vulnerability exists not only in structural members but also in various non-structural members like shelter walls, partition walls, ceiling, roofing, ornaments and so on. The causes of damage are identified as 1) improper designs, 2) poor/insufficient quality of materials, 3) poor workmanship/improper construction works and 4) lack of maintenance works. Based on the survey, study and analysis, the authors recommend 1) creation of common understanding of design among relevant groups, 2) improvement of designs and description/documentation, 3) comprehensive capacity development of construction sector and relevant groups. Lessons learnt from disasters with “very expensive fees” have to be fully utilized to mitigate future damage.

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