STRATEGIES TO REDUCE EARTHQUAKE DAMAGE IN DEVELOPING COUNTRIES

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OVERVIEW OF CONTENTS

1. **Realty of damage in developing countries and the major causes**

- The fact that damage in developing countries are far more serious than in developed countries is explained as well as some of major causes of the fact

2. **Typical damage in developing countries**

- Three typical damage as below are shown,

  - structural members, failure of which leads total collapse of buildings

  - non-structural members which are often damaged by moderate shaking motions

  - global keen issue of non-engineered construction, which is the major cause of human casualties

3. **Strategies to reduce the damage**

- Since the damage and causes are different from current situation of developed countries, specific strategies for developing countries are required

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I. REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND THE MAJOR CAUSES

- Not so strong shaking motion causes serious damage in developing countries
- This is clearly shown by the facts that furniture in seriously damaged buildings often withstood (Shaking motions were not strong enough to make furniture tumbled)

An elementary school damaged by the Central Java EQ 2007, Indonesia

A municipal government office building damaged by the Bohol EQ 2013, the Philippines

REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND THE MAJOR CAUSES

EARTHQUAKE INTENSITY SCALE

- **MMI Scale (Modified Mercalli Intensity)**

- **MMI VII** or larger: furniture fall
- **MMI X** or larger: some of buildings collapse (such as stone masonry)

- JMA Scale

- JMA 5- or stronger: furniture fall
- JMA 6+ : some of buildings collapse

Ordinary situation in developed countries:
Collapse are caused by far stronger shaking than one which causes tumbling of furniture such as MMI VII

Buildings in developing countries:
Collapse occurs even when furniture withstand (not tumble)

Descriptive table of Modified Mercalli Intensity (USGS)

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)	<.17	.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 INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND MAJOR CAUSES
VULNERABLE BUILDINGS IN DEVELOPING COUNTRIES AND THE REASON

- Judging from this fact, **damaged buildings** in developing countries are **far vulnerable** compared with those in developed countries

- **What are the reasons?**

Structural code?

Most of those countries have **already introduced own structural codes** referencing the codes of US or Europe, **which requires resilience** just like the referenced codes

Damage in developing countries is **often caused by smaller shaking motion** than that **the code assumes**

This implies that in many developing countries **the codes are not fully complied** with

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REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND MAJOR CAUSES

TYPICAL DAMAGE IN DEVELOPING COUNTRIES <STRUCTURAL MEMBERS>

- Examples of recent disasters: building collapse in Turkey and Bangladesh
- The failures occurred at joints of columns and beams, which leaded to total collapse

Buildings in Izmir damaged by the Turkey offshore EQ 2020

Rana Plaza Building collapse without impacts in Bangladesh

REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND MAJOR CAUSES

TYPICAL DAMAGE IN DEVELOPING COUNTRIES ＜STRUCTURAL MEMBERS＞

- The both buildings showed the similar behavior of **sudden collapse** in several seconds
- This behavior is **strictly prohibited** by most of structural codes in the world because it gives no time for people to escape and cause many casualties

Start

2 seconds later

4 seconds later

9 seconds later

REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND MAJOR CAUSES

TYPICAL DAMAGE IN DEVELOPING COUNTRIES <STRUCTURAL MEMBERS>

- Failures at joints are commonly observed in many countries

A school building affected by Wenchuan EQ 2008 in **China**

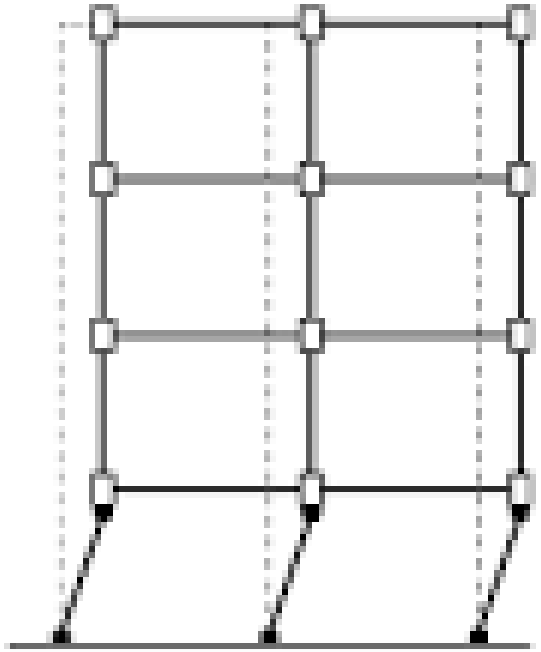
A dental hospital in Muzaffarabad affected by Kashmir EQ 2005m **Pakistan**

A market building affected by Bohol EQ 2013 in **the Philippines**

Failure mechanism for less serious failure

- Most of the structural codes **allow failures** when **very strong impact** hits buildings such as a strong earthquake
- **The least serious failure: failures at beams**, which allow the structure **to keep standing** (If failure occurs at columns or joints, it would lead the structure to collapse)
- For the purpose, there are several key items in structural codes to avoid failures in columns and joints

Failures in beams
Buildings could keep standing



Failures in columns
Collapse will occur and very dangerous

Failures in columns on the ground floor

Typical vulnerable failures of RC buildings in Japan

Shear failure in columns

A typical example of **vulnerable and unpreferable** failures by the Great East Japan EQ, 2011

No injuries because people could **escape before the collapse**

Typical failures of RC buildings in Japan

Failure in the middle of the column

One of typical vulnerable types of RC structure failures: shear failure

- Even the vulnerable shear failure, it gives **several minutes** to allows people to escape
- It also gives **space for people to survive**
- Main cause: insufficient shear reinforcement

STRUCTURAL MEMBERS AND **NON-STRUCTURAL** MEMBERS

Columns and beams:
structural members

Partition walls:
non-structural members

Shear walls:
structural members

REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND MAJOR CAUSES

ANOTHER TYPICAL DAMAGE <NON-STRUCTURAL MEMBERS>

- **Many non-structural walls** in developing countries are constructed by non-/insufficiently reinforced masonry
- They often suffered serious damage even when structural members suffered little

Most of high rise apartment houses in Kathmandu got heavy damage in non-structural walls by Gorkha EQ 2015

A municipal government building lost most of cladding walls by Bohol EQ 2013, in the Philippines

REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND MAJOR CAUSES

GLOBAL KEEN ISSUE <NON-ENGINEERED CONSTRUCTION>

- What is "non-engineered construction"?

"spontaneously and informally constructed in various countries in the traditional manner without any or little intervention by qualified architects and engineers in their design":

Source: Guidelines for Earthquake Resilient Non-engineered construction published by UNESCO

- They are quite vulnerable and often kill many people

Adobe houses in Peru

Stone masonry house in Nepal

A stone masonry house in Pakistan

REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND MAJOR CAUSES

GLOBAL KEEN ISSUE <NON-ENGINEERED CONSTRUCTION>

- The other types of non-engineered constructions in the world

Unreinforced brick masonry in Indonesia

Confined brick masonry houses in Indonesia

A concrete hollow block (CHB) house in the Philippines

REALTY OF DAMAGE IN DEVELOPING COUNTRIES AND MAJOR CAUSES

GLOBAL KEEN ISSUE <NON-ENGINEERED CONSTRUCTION>

COMPARISON OF ENGINEERED AND NON-ENGINEERED

- Conventional/non-engineered constructions are different in many aspects from engineered constructions
- It is very tough to reduce damage in non-engineered constructions

Aspects/items	Conventional/non-engineered	Engineered
Materials	Available in the area No control	Usually controlled in size, quality, etc.
Construction workers	Non/semi-skilled workers	Skilled workers
Technical intervention	No/little intervention	Intervention in design, construction procedures, etc.
Users/residents	Low/middle income people	Middle/high income people

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3. STRATEGIES TO REDUCE THE DAMAGE IN DEVELOPING COUNTRIES
ON STRUCTURAL MEMBERS TO PREVENT TOTAL COLLAPSE OF BUILDINGS

- One of the high priority issues is to prevent total collapse of buildings which causes human casualties
- The total collapse is caused by failures at columns or joints
- Major causes of those failures are identified by field surveys of damaged buildings as below

- inappropriate **concrete casting** such as throwing from high places
- insufficient concrete **compaction**
- improper setting of **longitudinal rebar and overlap splice**
- absence of **hoops at the joints**

- Good **workmanship** and precise **supervision** is the key to improve the Situation

3. STRATEGIES TO REDUCE THE DAMAGE IN DEVELOPING COUNTRIES STRATEGIES FOR STRUCTURAL MEMBERS <CONCRETE CASTING>

- **Concrete casting** is one of the most critical work for structural safety
- **Typical poor practice** in developing countries: just throwing concrete into form panels and insufficient compaction
- Since the damage and the causes in developing countries are different from those of developed countries, **strategies appropriate to developing countries** are required

A poor practice in developing countries:
workers just throw concrete into form panels

Ordinal practices in developed countries:

Left: casting concrete using “shoot panels” to prevent segregation of mortar and aggregates

Right: compaction of concrete by sticking

- Poor construction practice drastically reduce the strength of concrete

・**insufficient compaction**: by more than **50%** (re: table below and photos)

・**inappropriate curing** after casting: by **10 - 30%** (re: table on the right)

Effects of curing of concrete to compression strength

specimens	water/cement ratio (%)	flow value (mm)	curing	compression strength at 28days (N/mm2)	**ratio (%)**
cement made in Japan	50	195	in water (standard)	64.4	**100**
	50	195	in air after 3 days	58.9	**91**
			in air after 1 day	49.1	**76**
cement made in Indonesia	50	188	in water (standard)	51.7	**100**
	50	187	in air after 3 days	48.2	**93**
			in air after 1 day	37.7	**73**

Effects of compaction of concrete to compression strength

Influence of compaction of concrete		
Specimens	Compression strength (N/mm2)	Ratio
following standards	(A) 64.9	100%
one time sticking	(B) 30.7	**(B/A) 47%**

3. STRATEGIES TO REDUCE THE DAMAGE IN DEVELOPING COUNTRIES
STRATEGIES FOR NON-STRUCTURAL WALLS

- Dangerous situation of non-structural walls

- **no reinforcement** inside the walls

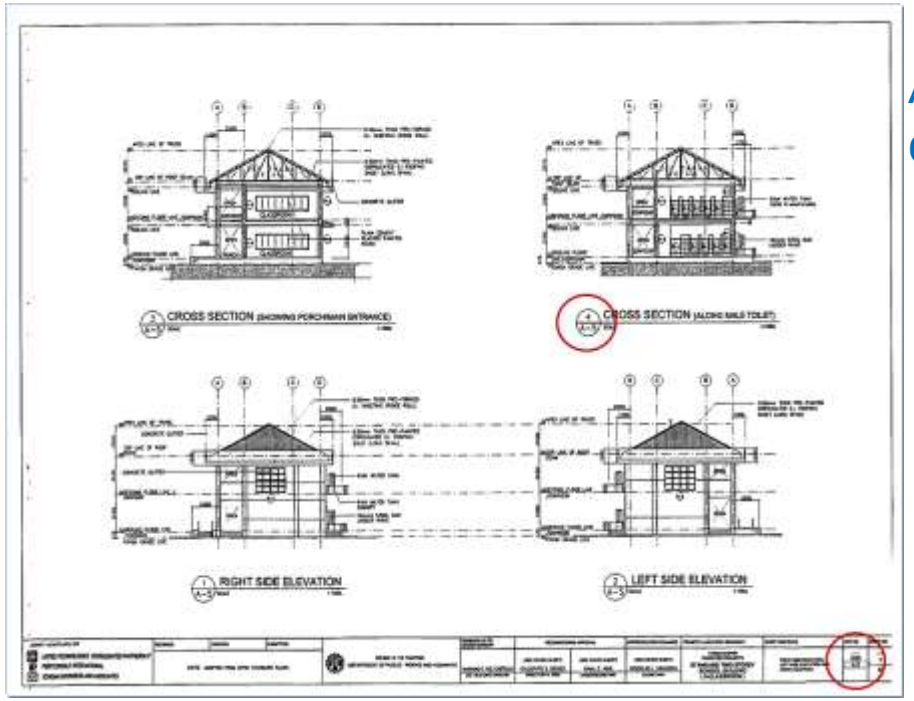
- improper **anchorage** of reinforcement to structural members

Partition walls of unreinforced brick masonry in Bangladesh

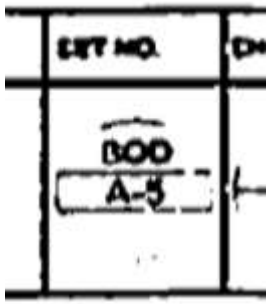
Improper anchorage of reinforcement to columns in non-structural walls in the Philippines (overlap splice must be straight)

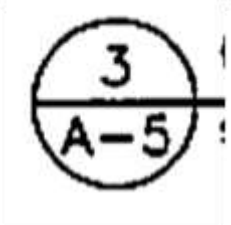
3. STRATEGIES TO REDUCE THE DAMAGE IN DEVELOPING COUNTRIES
STRATEGIES FOR NON-STRUCTURAL WALLS

- In many countries, **technical guidelines/standards** on non-structural members have **not created yet** (Structural codes usually do not cover non-structural members)
- Creation of technical documents is the first step
- Decision/definition of **responsible person** on design and supervision on non-structural members is another key issue (usually structural engineers bear responsibility only on structural members)

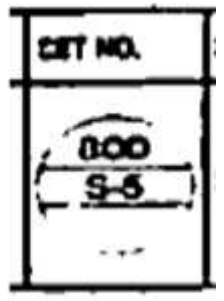


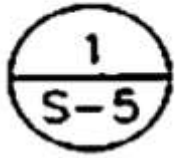
An example of drawing





An example of architectural drawing





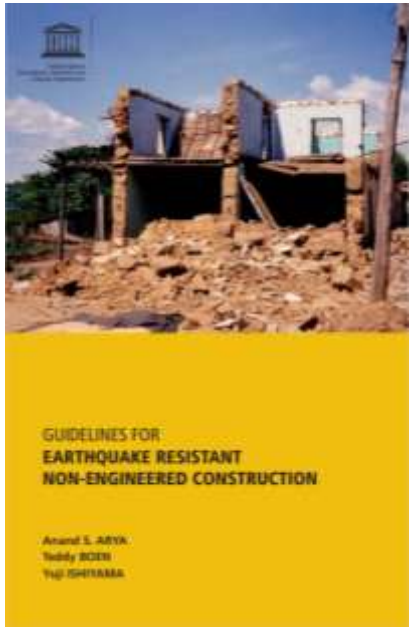
An example of structural drawing

3. STRATEGIES TO REDUCE THE DAMAGE IN DEVELOPING COUNTRIES
STRATEGIES FOR NON-ENGINEERED CONSTRUCTION

- Most countries have **not created official technical documents** on non-engineered construction and non-engineered constructions are **constructed informally** (out side of building regulation)
- **Formalization** of non-engineered construction is difficult issue and approaches for it may be different from country to country depending on social, political and economical conditions in each country
- **UNESCO** prepared **two guidelines** on technical and policy making to support and encourage these approaches, in which you can obtain **some clues** to improve the situation in your countries

'Guidelines for Earthquake Resistant Non-Engineered Construction'

https://unesdoc.unesco.org/ark:/48223/pf0000229059



'Towards Resilient Non-Engineered Construction – Guide for Risk0informed Policy Making'

https://unesdoc.unesco.org/ark:/48223/pf0000246077

Chap.1 Perspective for safer Non-engineered Construction

Chap.2 Earthquake Risks and Perceptions by People

Chap. 3 Characteristics of Non-engineered Construction

Chap,4 Technical Approaches for Structural Improvement

Chap,5 Dissemination of Technologies

Chap.6 Towards Resilient Non-engineered Construction

- Thank you for your attention