Manual on "Retrofitting of Existing Vulnerable School Buildings- Assesment to Retrofitting"

part II

Save the Children

2009

MANUAL ON

"RETROFITTING OF EXISTING VULNERABLE SCHOOL BUILDINGS – ASSESSMENT TO RETROFITTING"

PART II

Hari Darshan Shrestha

Krishna S. Pribadi

Dyah Kusumastuti

Edwin Lim

Mission of Save the Children

To create lasting, positive change in the lives of children in need

Vision of Save the Children

A world in which every child is ensured the right to survival, protection, development and participation as set forth in the United Nations Convention on the Right of Children

This book is developed by Save the Children, Construction Quality & Technical Assistance (CQTA)

in collaboration with

Center for Disaster Mitigation - Institute of Technology Bandung (CDM -ITB)

PREFACE

Schools are institutions providing an education as well as a common place for community gatherings and meetings. They should be models in providing examples of quality education and the enhancement of the environment & physical facilities. Schools not only provide opportunities for formal education, but also for social development and personal growth.

Despite this, there are millions of schools around the world that are unsafe. There is an urgent need to create greater awareness of safer school construction in new schools, while at the same time making sure that the existing school buildings are safe. This can be done through the implementation of general practices of safe school construction and the retrofitting of existing school buildings.

Creating a culture of safe school construction is possible and need not be as complicated as some may seem. It can be implemented simply by establishing standards of design and construction of school buildings, developing a local building code and ensuring that the code and standards are met. The challenge is the thousands of unsafe existing school buildings around the globe where millions of children are at risk. Recent disasters such as the earthquake in Pakistan and China, the cyclone in Bangladesh and the infamous hurricane Katrina in the USA have caused the destruction of thousands of schools and with them the lives of many students and teachers. This shows the urgent need to make schools safer for everyone.

Save the Children initiated the creation of safe and child friendly school construction. Save the Children is conducting workshops and trainings as well as developing guidelines and manuals to support this initiative.

These documents are based on best practices in Indonesia, the most seismic prone country in the world. We believe these resources could be useful for other countries facing similar challenges as well as other organizations working on building the capacities of local authorities to effectively implement safe and child friendly school buildings.

We would like to thank Dr. Krishna Pribadi, Dr. Dyah Kusumastuti and Mr. Edwin Lim from the Center for Disaster Mitigation - Institute of Technology Bandung, and Mr. Hari Darshan Shrestha for their contributions on the development of this document.

Mike Novell

AVP, Asia Area office

Save the Children

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INTRODUCTION

Recent earthquake disasters in Indonesia have shown that casualties due to earthquake were mostly caused by damage on buildings. Therefore, a building must perform well during earthquake, i.e., strong enough to resist the earthquake force or if the building is damaged, building occupants should be safe. Considering school buildings, the design criteria require that buildings should be able to resist the earthquake force without collapse. The requirement is based on the function of school building in post-disaster measures, as well as providing protection for students as the next generation.

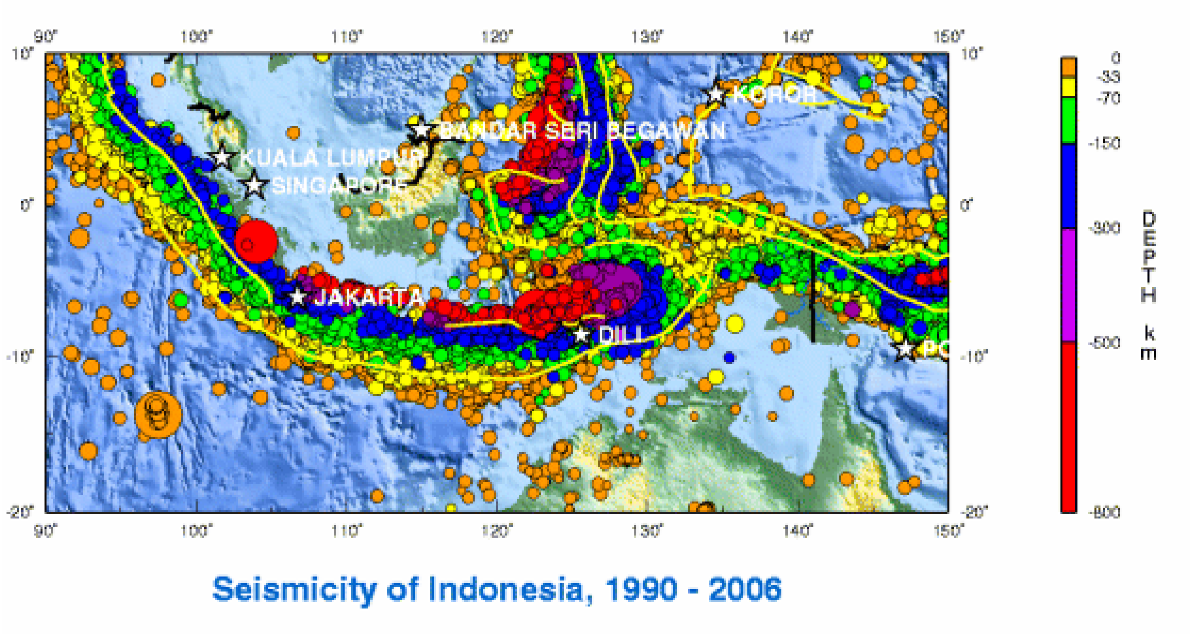


Figure 1 Seismicity Map of Indonesia

(http://earthquake.usgs.gov/earthquakes/world/indonesia/seismicity.php)

In general, buildings can be categorized into engineered buildings and non-engineered buildings. Engineered buildings are buildings designed and built with the assistance of an engineer, thus follow building codes/standards. Engineered buildings are designed to perform well for a certain level of damage, before collapsing. Typical problems found in engineered structures are insufficient detailing provided on the buildings, irregular shape in plan and elevation of building, etc.

Non-engineered buildings are buildings that were designed and constructed without assistance of an engineer. Non-engineered buildings are usually constructed without consideration of the level of damage, which makes the vulnerability assessment more difficult. For non-engineered buildings, major issues on building deficiencies are minimum reference to standards/codes, lack of structural elements (column, beam, foundation, etc), lack of detailing, poor quality of materials, and poor quality of workmanship.

Most school buildings in Indonesia, majority were built in 1970's and 1980's, can be considered as non-engineered buildings. Problems found for school buildings may vary, depend on the structural design and construction methods. Thus, vulnerability assessment is critical to determine the behavior of structure under earthquake loading, and to ensure that school building must not collapse during earthquake.

The solutions for mitigating earthquake hazard for school buildings are different for new buildings and existing buildings, with respect to the challenges faced by each category. The common procedure for earthquake mitigation of buildings is as follows:

a. For new buildings, the mitigation measures include the design and construction process. The design of the buildings must comply with the current building code, and the construction must be appropriate following design specifications and drawings.
b. For existing buildings, the mitigation measures consist of assessing the structural performance to resist design earthquake forces based on current building codes. If the assessment found that structures are not adequate, retrofitting strategies should be designed to improve the building's performance.

PRINCIPLE OF RETROFITTING

What is Retrofitting?

Retrofitting is technical interventions in structural system of a building that improve the resistance to earthquake by optimizing the strength, ductility and earthquake loads. Strength of the building is generated from the structural dimensions, materials, shape, and number of structural elements, etc. Ductility of the building is generated from good detailing, materials used, degree of seismic resistant, etc. Earthquake load is generated from the site seismicity, mass of the structures, important of buildings, degree of seismic resistant, etc.

In the design of retrofitting approach, the engineer must comply with the building codes. The results generated by the adopted retrofitting techniques must fulfill the minimum requirements on the buildings codes, such as deformation, detailing, strength, etc.

When is Retrofitting Needed?

Retrofitting is needed when the assessment of structural capacity results in insufficient capacity to resist the forces of expected intensity and acceptable limit of damages.

It is not merely poor quality of materials and damage of structural elements serves as the reasons to retrofit a building. Change of the building's function, change of environmental conditions, and change of valid building codes could also be the reasons for retrofitting.

Who Conducts Retrofitting?

Retrofitting must be conducted by experts from each field. In most retrofitting process, an engineer plays the main role. An engineer must assess and analyze the structural capacity. An engineer must also design the best retrofitting techniques to strengthen the structural deficiencies. The role of the novice is restricted to identify the possibility of insufficiency of building capacity.

What Factors should be considered for Retrofitting?

Some factors should be considered to decide whether to retrofit or not, i.e:

a) Technical aspect
b) Cost intervention
c) Importance of building
d) Availability of adequate technology
e) Skilled workmanship to implement the proposed measures
f) Duration of works.

What are the Advantages and Disadvantages of Retrofitting?

The advantages of adopting retrofitting approach, despite of reconstructing the building, are as follows:

a. When retrofitting approach is adopted, retrofitted building can still be operated.

b. Retrofitting will take relatively less construction cost with similar structural performance achievement.
c. Retrofitting will involve relatively less resources, either human resources or natural resources.
d. Retrofitting will not significantly change the building configuration and shape. It is preferable when the retrofitted building has historical values.
e. Retrofitting the building will produce less debris than reconstructing the building.

Besides the advantages, retrofitting also has several disadvantages, such as:

a. The skill of the worker must comply with the adopted retrofitting approaches

b. Limited access of the construction site, since the building could be still in function.

What is the General Process of Retrofitting?

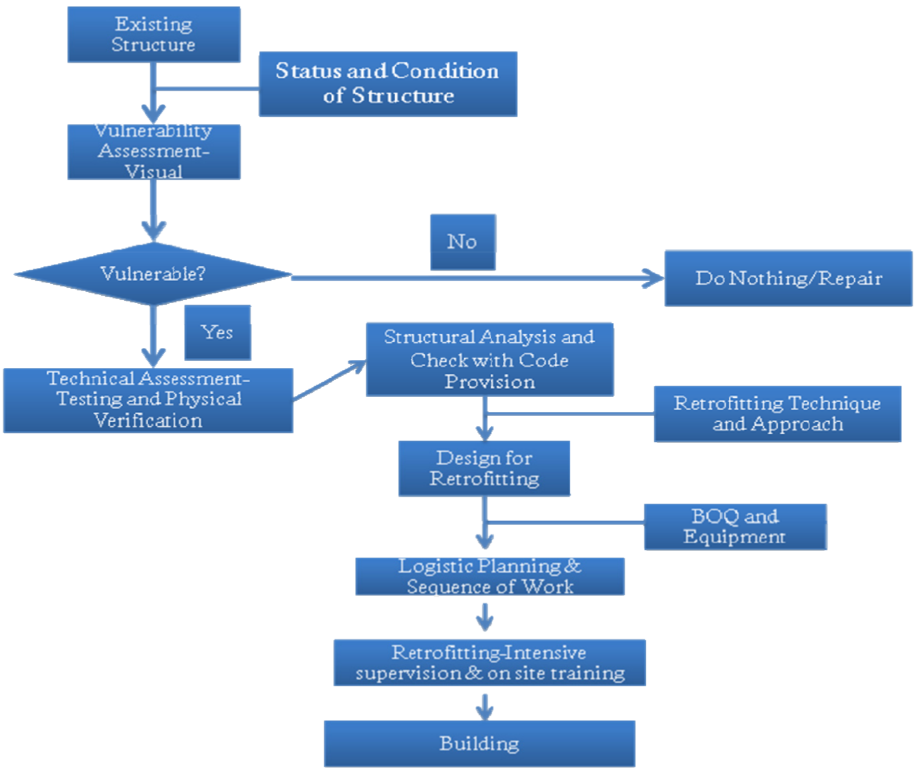
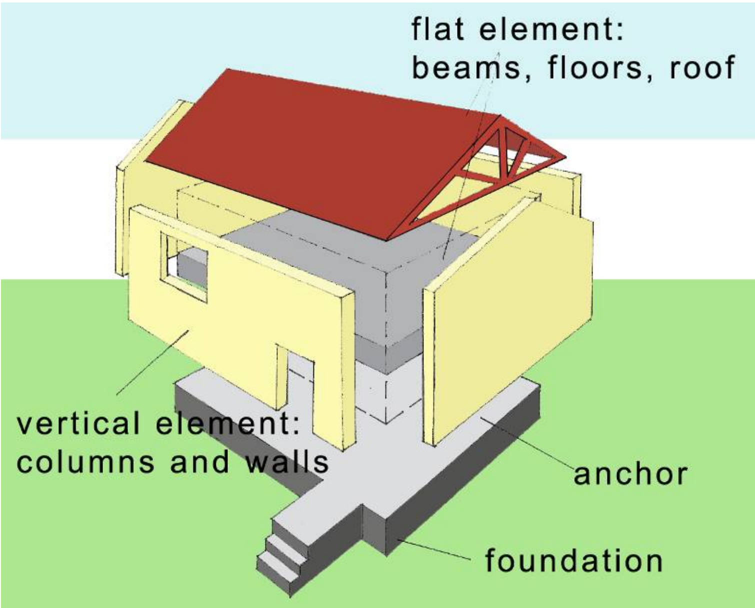


Figure 2 Retrofitting Stages

VULNERABILITY ASSESSMENT FOR A NOVICE

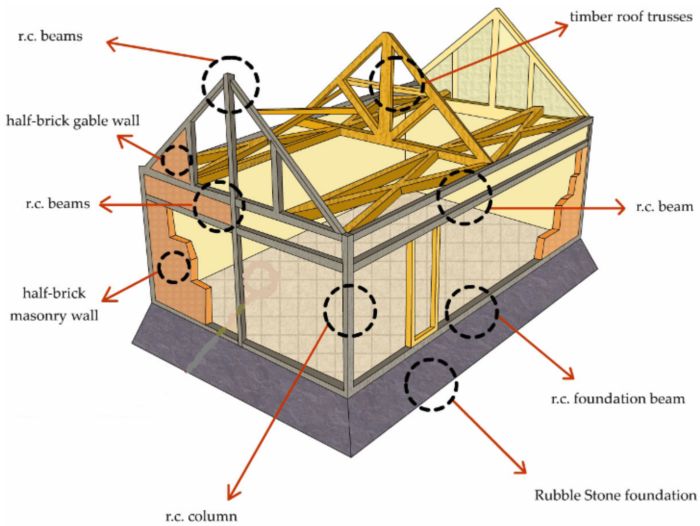
What are the Structural Elements?



- Column
- Beam
- Foundation
- Bearing Wall
- Roof System
- Floor

Figure 3 Structural Elements(Courtesy of *Panduan Konstruksi dan Perkuatan Bangunan Sekolah Tahan Gempa,* CDM-ITB 2008*)*

What are the Criteria of an Earthquake Resistant Building?



- Simple and Symmetrical Layout
- Proper Site Area
- Proper Connection on Each Structural Elements
- Proper Construction Material
- Good Quality Construction

Figure 4 Earthquake Resistant Building Criteria (Courtesy of *Panduan Konstruksi dan Perkuatan Bangunan Sekolah Tahan Gempa,* CDM-ITB 2008*)*

What Aspects should be considered for Vulnerability Assessment of Buildings?

- Site Condition
- General Planning
- General Elevation
- Structural Elements (Existence and Defects)
- Non-structural Elements (properly secured)

VULNERABILITY ASSESSMENT FOR AN ENGINEER

What are the Common Problems of Reinforced Concrete Structure?

- Insufficient lateral load resistance.
- Inadequate ductility due to insufficient confinement of longitudinal reinforcement, especially at the joint of the elements.
- A tendency of overstressing due to complex and irregular geometry in plan and elevation.
- Interaction between structural system and non-structural walls resulting in unintended torsional forces and stress concentration.
- High flexibility combined with insufficient spacing between buildings resulting in risk of neighboring structures pounding each other during shaking
- Poor quality materials or work method in the construction.

What are Common Problems of Masonry Building?

- Inadequate structural layout (unsymmetrical).
- Insufficient load-bearing capacity of the walls.
- Inadequate connection between the walls.
- Poor quality materials or work method in the construction.

What are the Stages in Vulnerability Assessment?

1) Visual investigation.
2) Structural investigation.
3) Detailed structural analysis.

What are the Activities in a Visual Investigation?

- Mapping the site condition
- Sketching the overall layout, include the structural system, dimension and geometry of elements, spacing, loading system, etc.
- Mapping the detail structural damage, e.g. spalling, pops-out, cracking and its pattern, corrosion, discoloration, etc.
- Observation of deflection and displacement on the structural elements
- Observation of the deterioration of materials.

What are the Activities in a Structural Investigation?

a) Structural investigation for upper structure

There are two types of structural investigation for upper structures, non-destructive test (NDT) and semi-destructive/destructive test (DT).

Non Destructive Test is conducted to assess the condition of the upper structure. Te NDT should be conducted as much as possible to give proper description and evaluation on material properties. In many occasions, semi-destructive/destructive test ((S)-DT) may also be conducted, if NDT does not yield satisfactory results.

Figure 5 Non-Destructive Testing Tools

b) Structural investigation for sub-structure

Structural investigation for sub-structure includes investigations for soil properties and foundation. The most common used techniques for soil investigation for a single story structure are hand boring and soil penetration test. Investigation of the foundation can be conducted by digging the soil to check the existence of the foundation, including the dimensions and the bearing area, or using a detector device.

Figure 6 Soil Penetration Test

What are the Purposes of Detailed Structural Analysis?

Detailed structural analysis is conducted to estimate the structural behavior when subjected to applicable loads. Results from structural investigations should be used for the detailed structural analysis. The results of structural analysis will be used for designing of retrofitting approaches/strategy.

VULNERABILITY ASSESSMENT FOR A PROGRAM PERSON

What Factors should be considered for Retrofitting?

- Number of affected buildings
- Acceptable level of risk, defined by selected rehabilitation performance objectives
- Duration of the program
- Number of residents in the buildings
- Cost and benefits of retrofitting or other alternatives
- Societal impacts
- Politics
- Economic impacts
- Environmental impacts

VARIOUS TECHNIQUES ON RETROFITTING

What are Possible Techniques for Retrofitting of Structural Elements?

1) Inserting structural elements

Additional structural element is needed when:

1. **Force distribution is needed to reduce**
2. **Structural stiffness is needed to increase**
3. **Total area of wall without vertical structural element > 9 m^2**

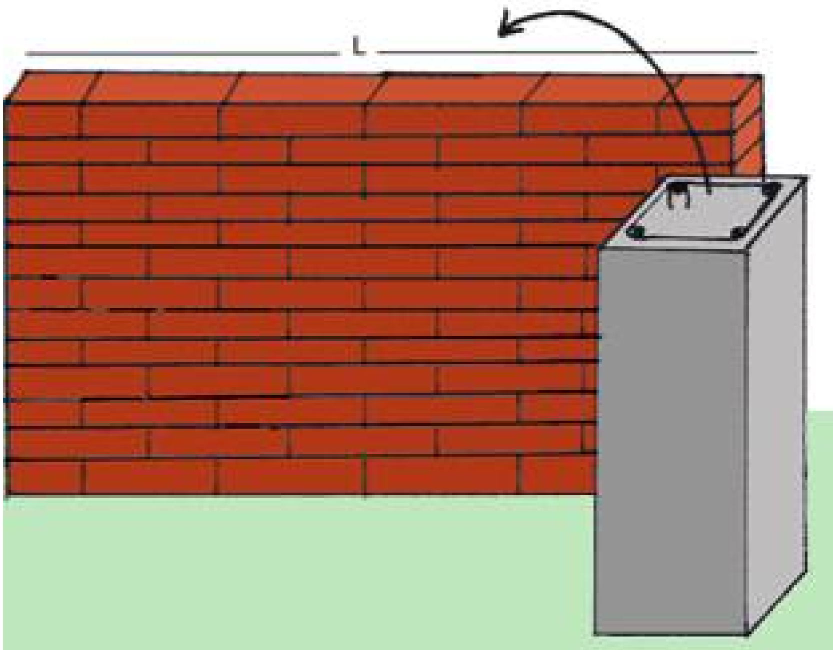


Figure 7 Addition of Reinforced Concrete Column (Courtesy of *Panduan Konstruksi dan Perkuatan Bangunan Sekolah Tahan Gempa, CDM-ITB 2008)*

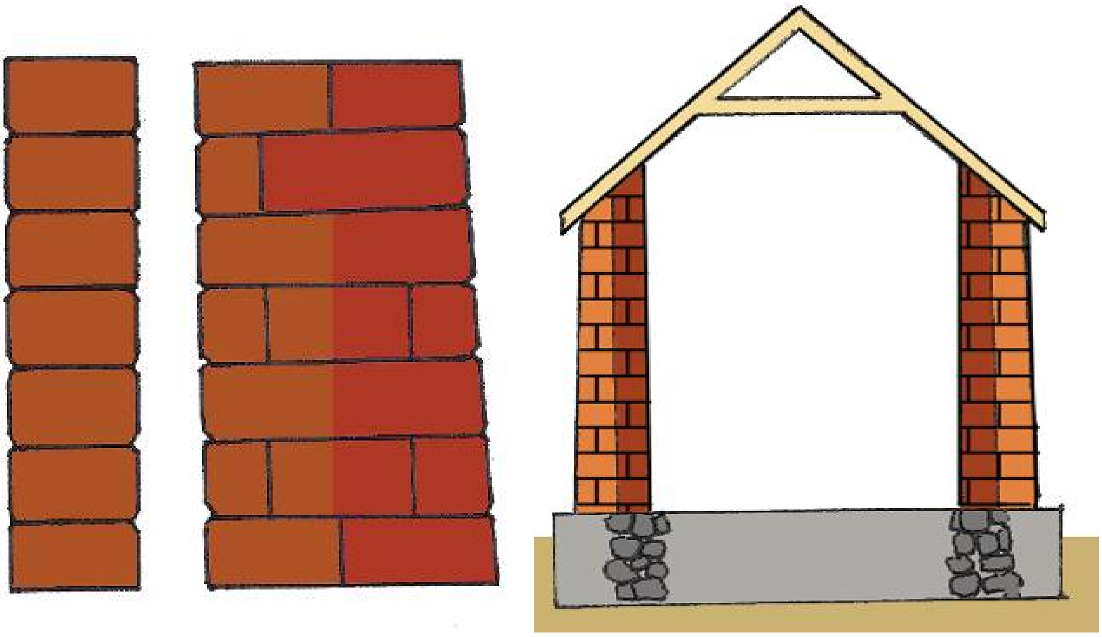


Figure 8 Addition of Buttress in Masonry Structure

2) Jacketing of structural elements

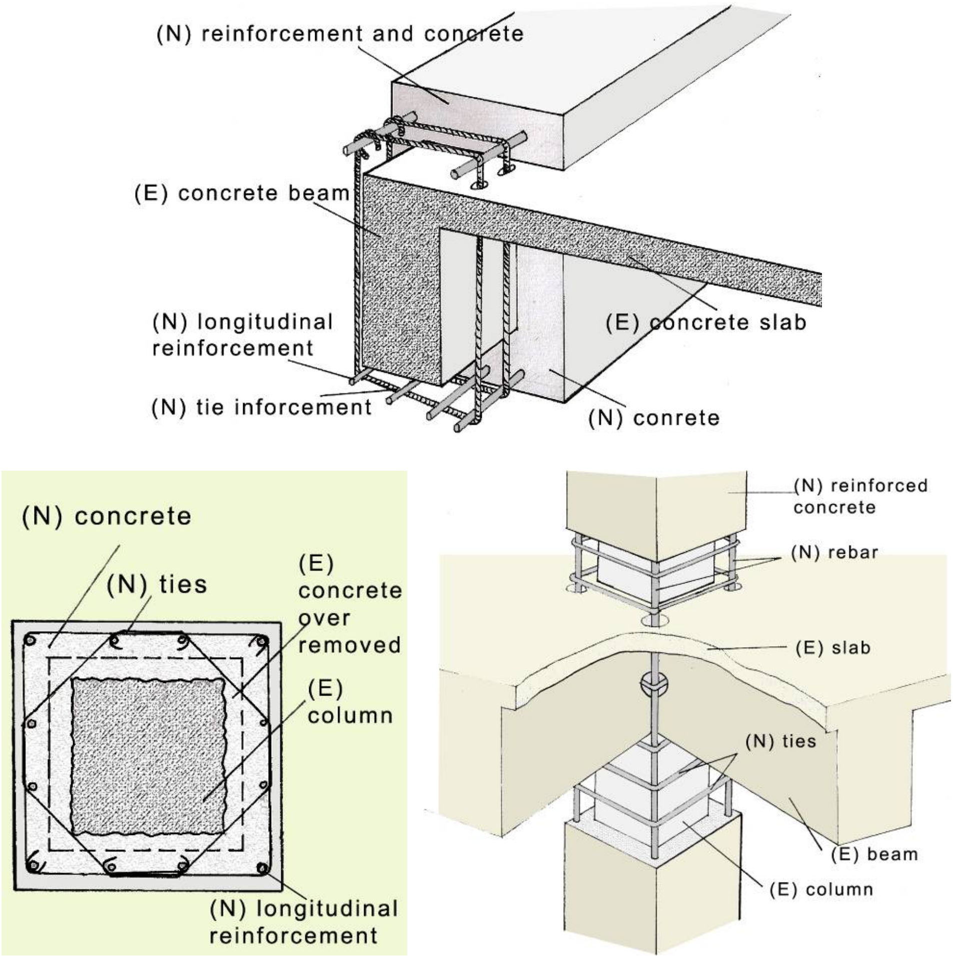


Figure 9 Concrete Jacketing

3) Implementing iron wire-mesh in masonry buildings.

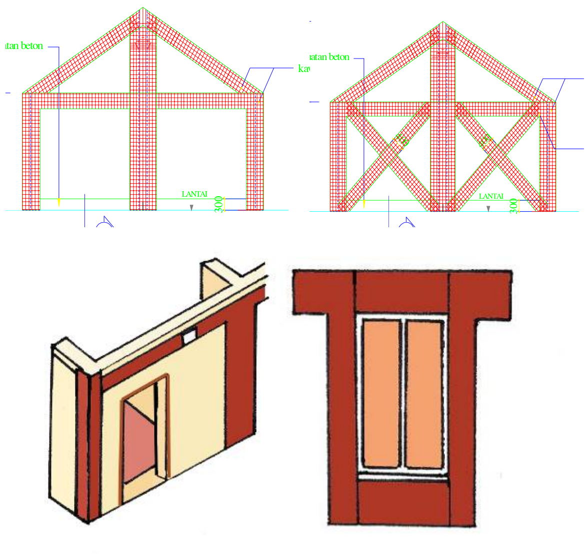
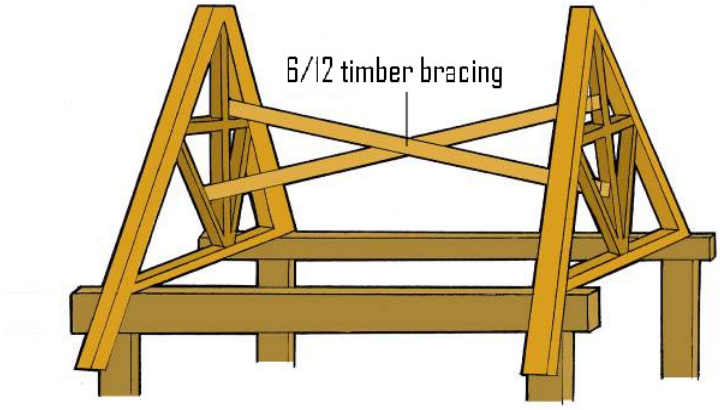


Figure 10 Strengthening with Seismic Belts

4) Strengthening of Roof Trusses and Roof Diaphragms



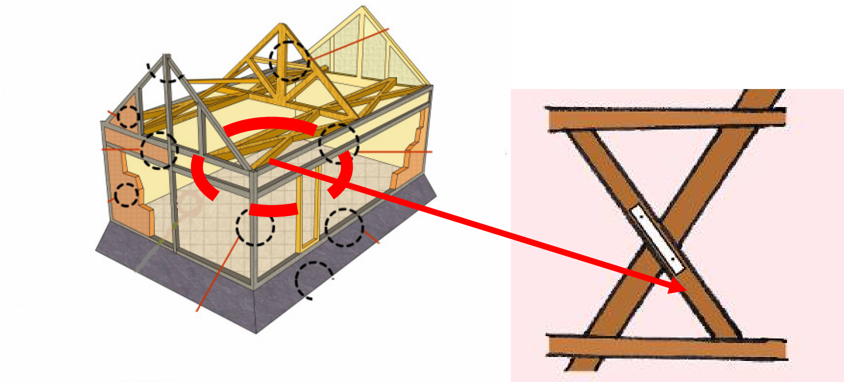


Figure 11 Strengthening Roof Trusses (top) and Roof Diaphragms (bottom) (Courtesy of *Panduan Konstruksi dan Perkuatan Bangunan Sekolah Tahan Gempa, CDM-ITB 2008)*

5) Strengthening Concrete Diaphragm.

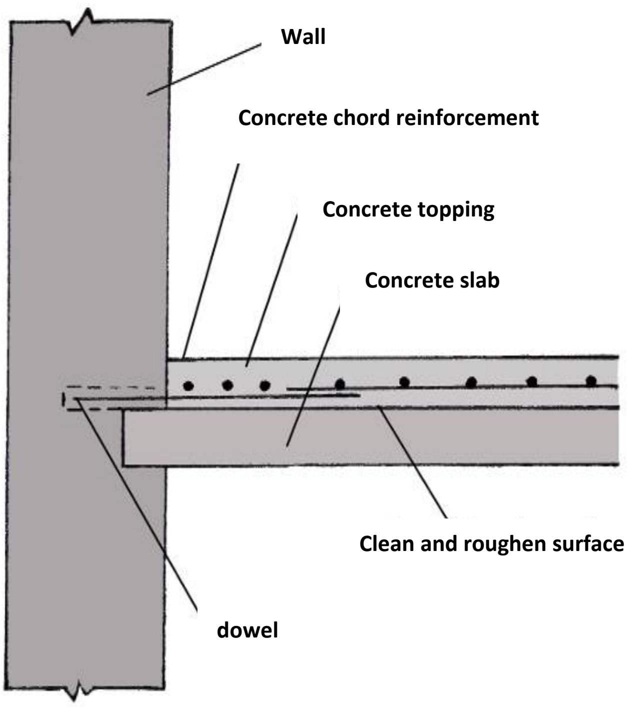


Figure 12 Strengthening Concrete Diaphragm with a New Toping Slab and Chord

6) Strengthening techniques for continuous or strip wall footings

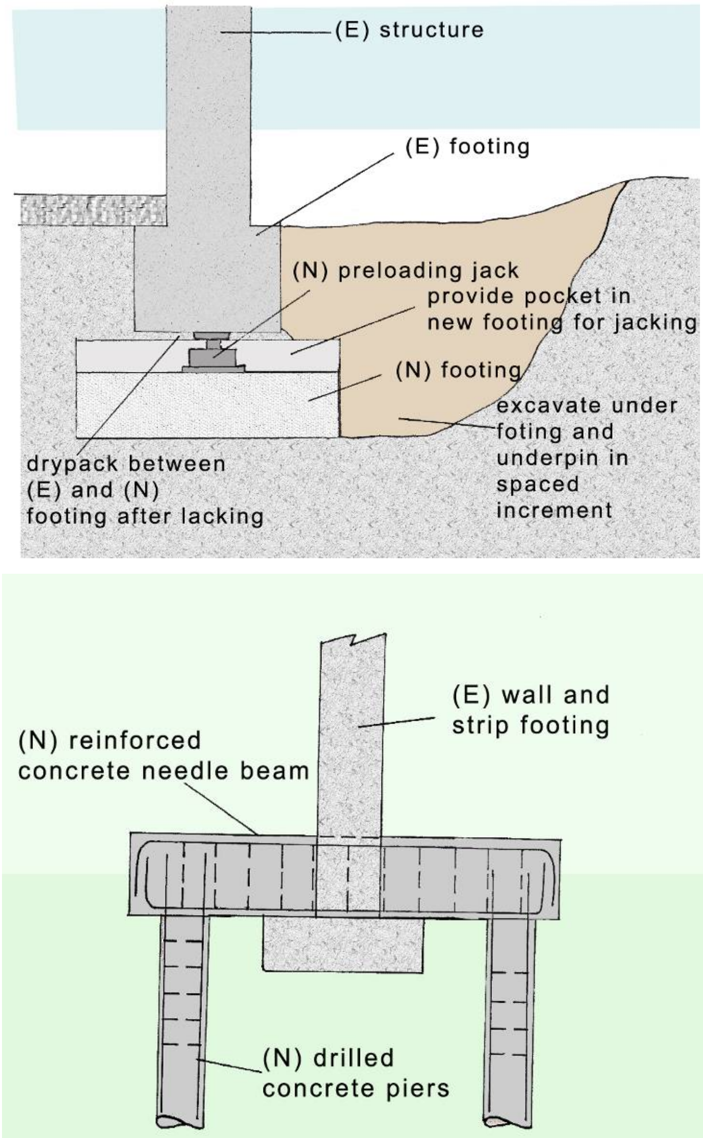
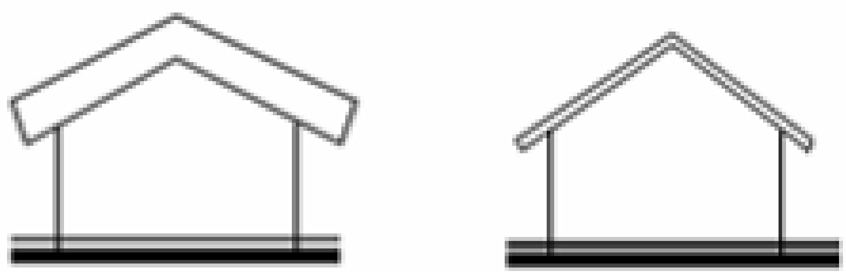


Figure 13 Underpinning of the Existing Foundation (top) and Addition of Drilled Piers (bottom)

7) Decreasing Demand on Existing Building.



Bad Good

Figure 14 Reducing the Weight of the Building by Using Light Weight Roof System

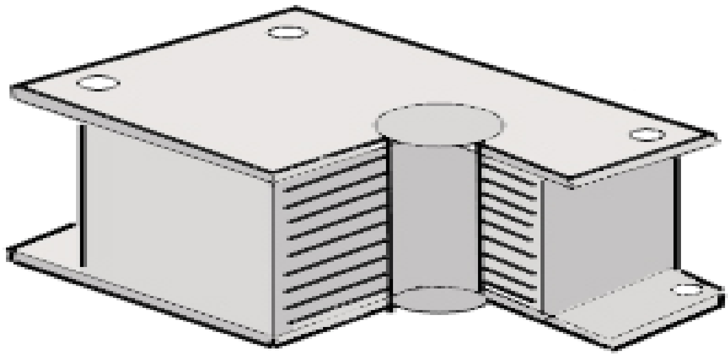


Figure 15 Lead rubber bearing used as seismic isolator and supplemental damping

What are Possible Techniques for Retrofitting of Non-structural/ Architectural Elements?

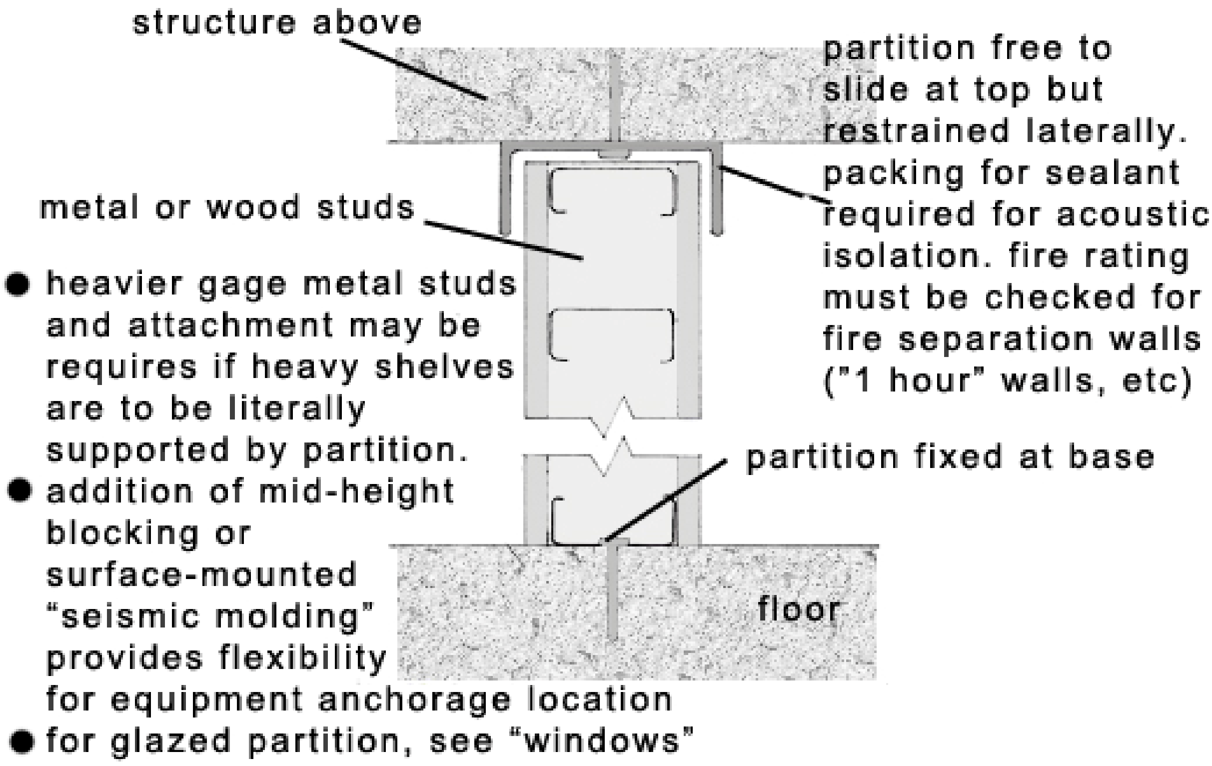


Figure 16 Built-in Full-Height Partition

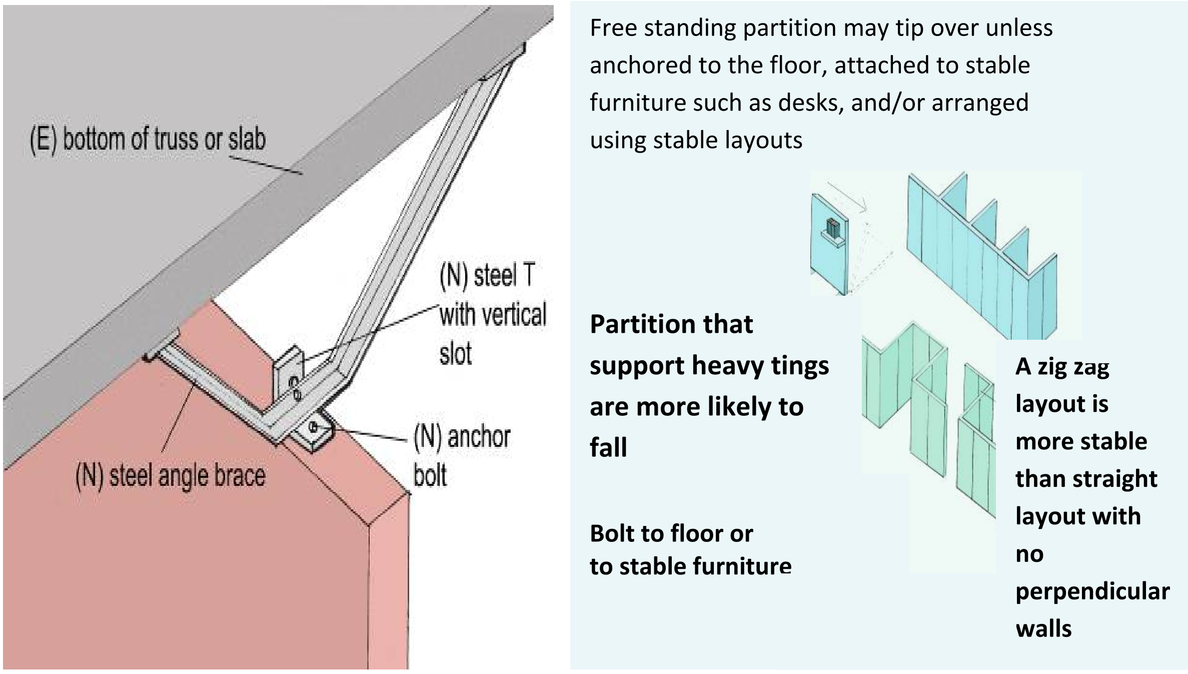


Figure 17 Built-in Partial-Height Partition

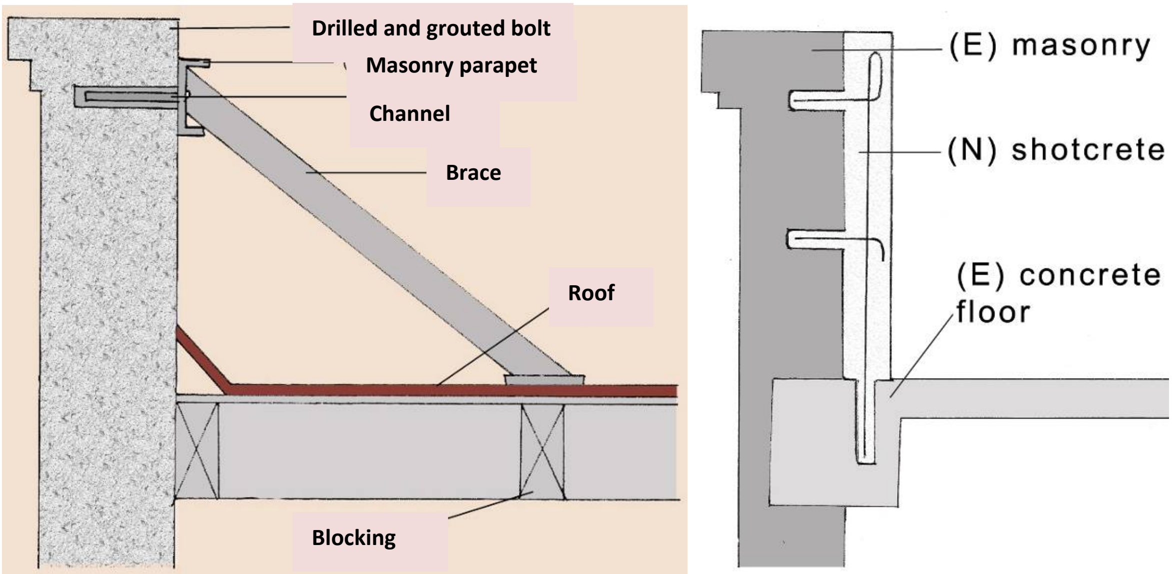


Figure 18 Parapets

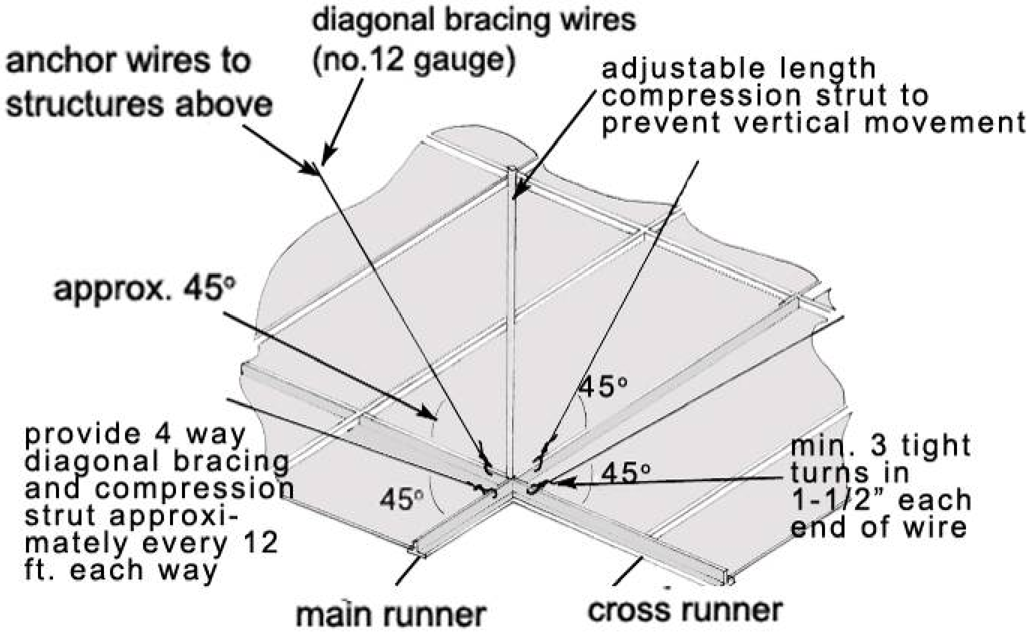


Figure 19 Ceilings

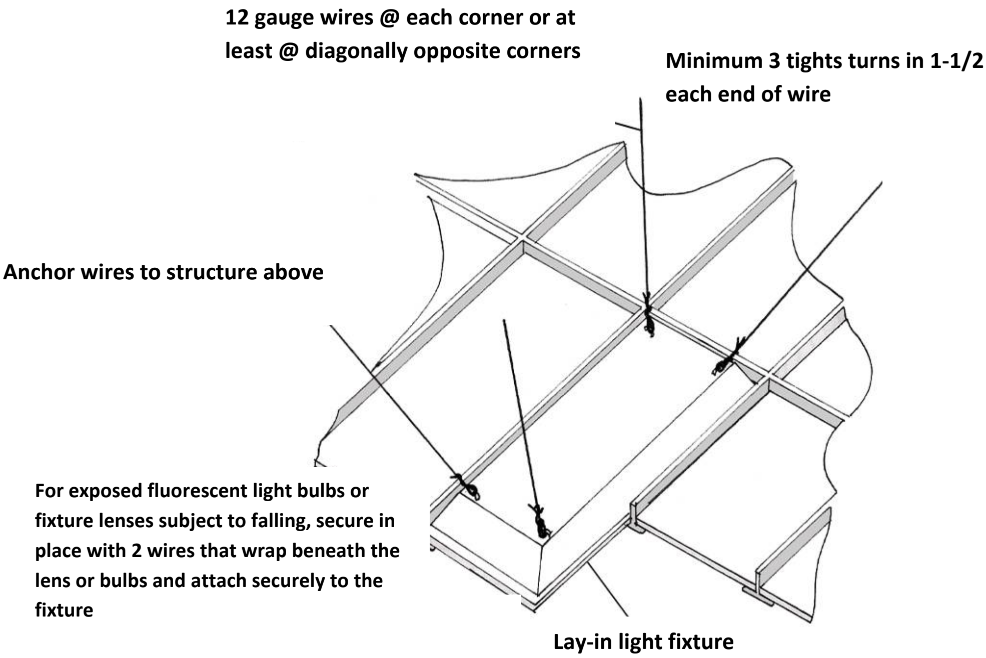
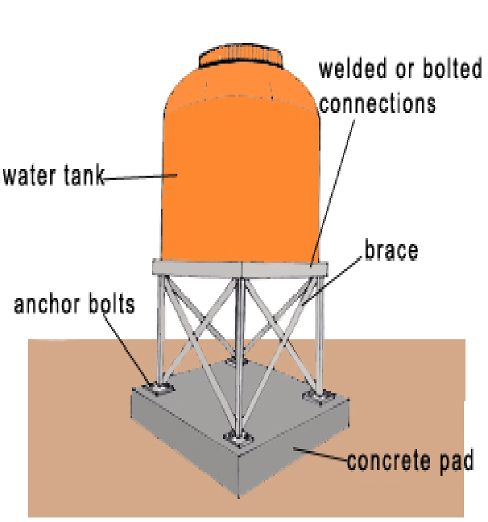


Figure 20 Lighting Fixtures

What are Possible Techniques for Earthquake Safety of Utilities?



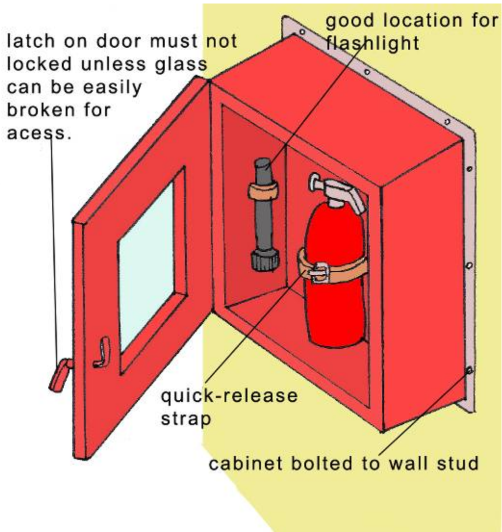
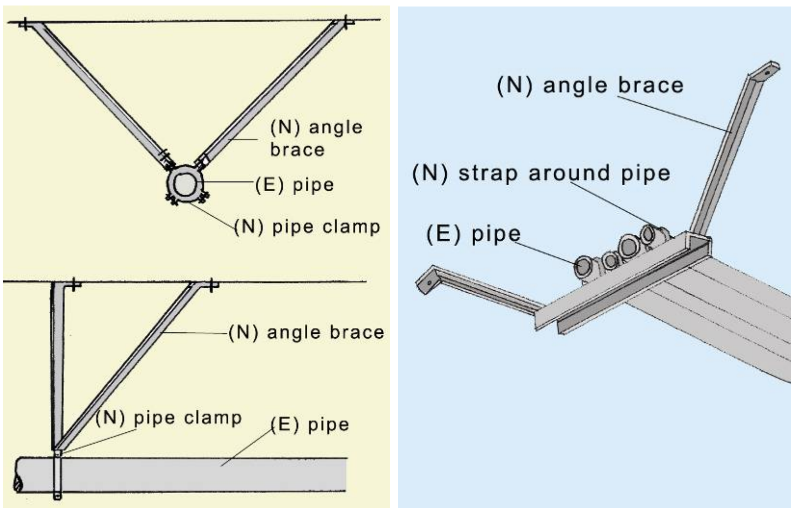


Figure 21 Tank **Figure 22 Fire Extinguisher and Cabinets**



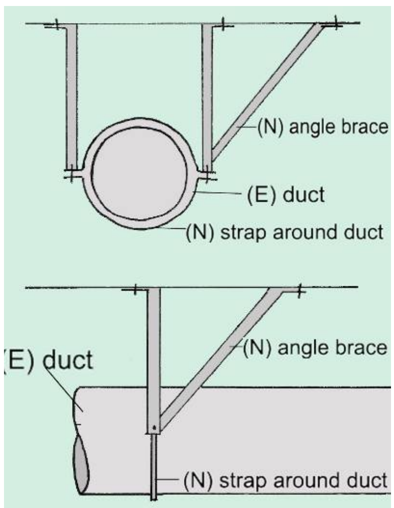


Figure 23 Piping System **Figure 24 Ducting System**

What are Possible Techniques for Earthquake Safety of Furniture and Contents?

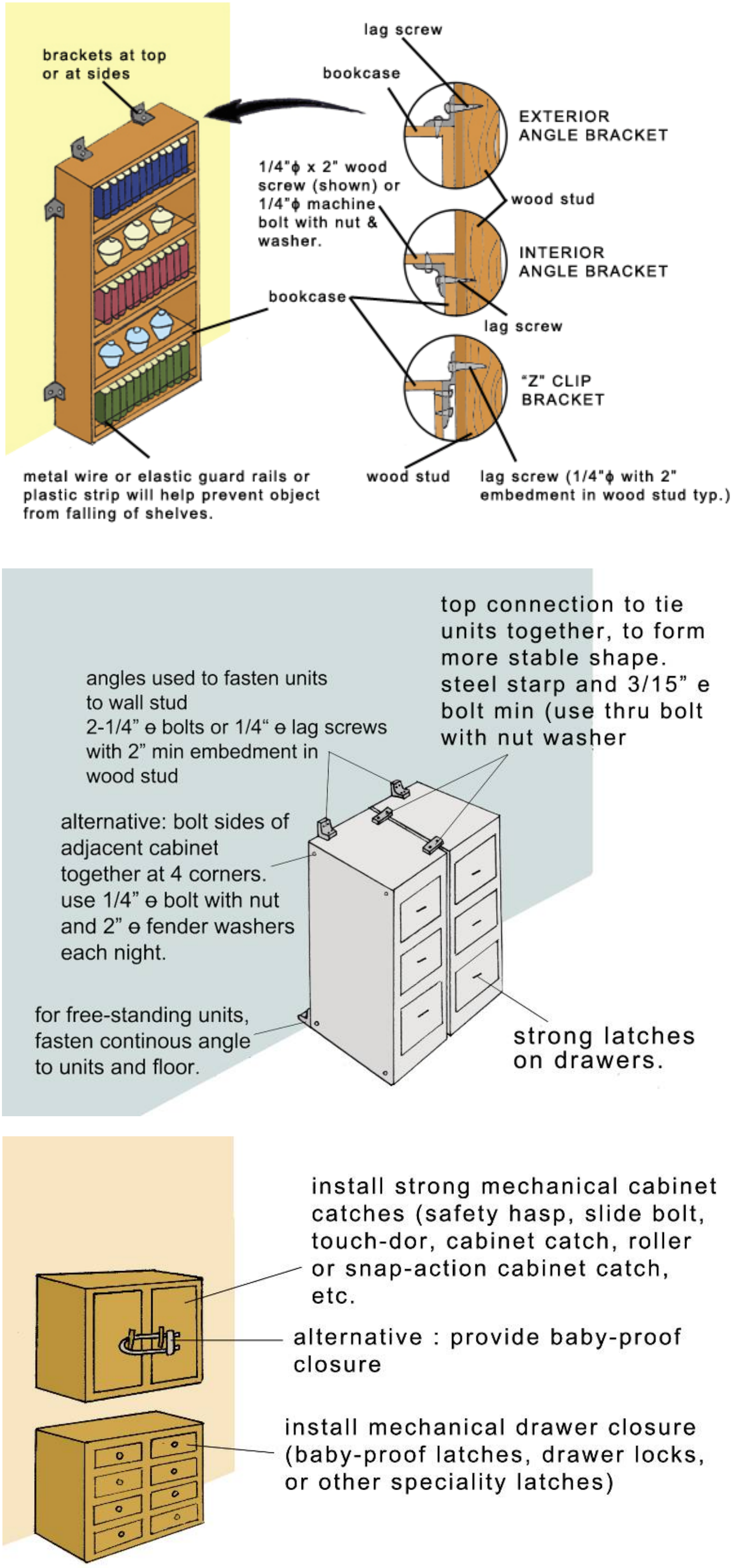


Figure 25 Tall shelving, Filing Cabinet, Drawer and Cabinet Latches

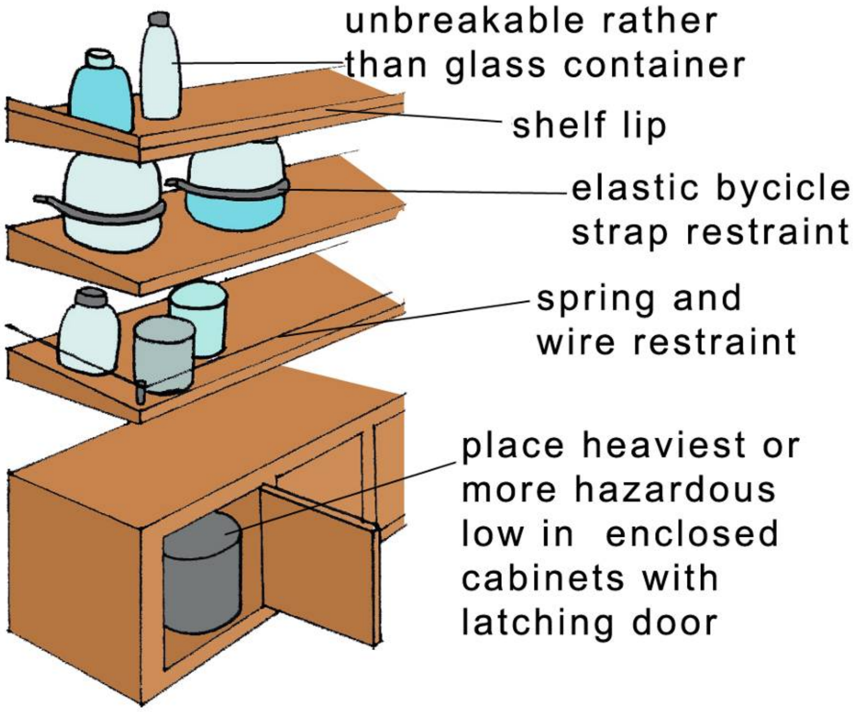


Figure 26 Containers of Hazardous Materials

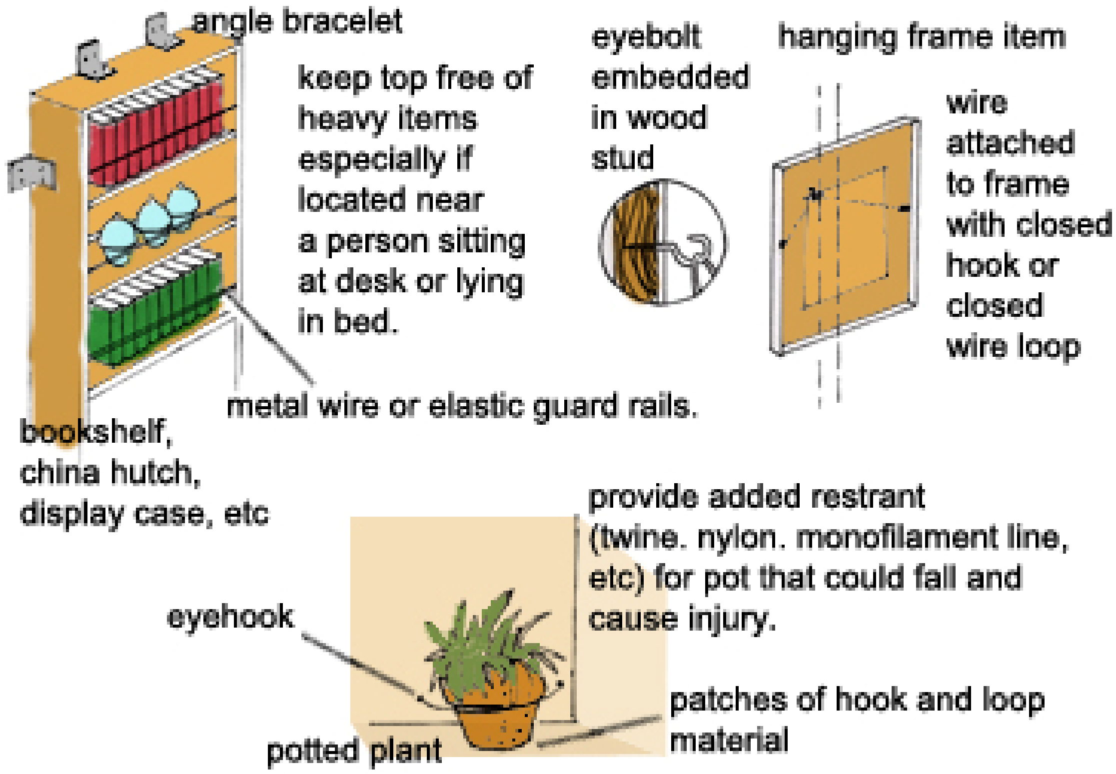


Figure 27 Miscellaneous Furniture

Case Studies: SDN PADASUKA II (UNCRD project, with technical assistance from CDM-ITB)

Introduction and Layout

United Nations Centre for Regional Development (UNCRD) and Center for Disaster Mitigation (CDM) ITB are conducting a collaborative project to reduce the vulnerability of existing school buildings in the corridor of School Earthquake Safety Initiative (SESI) project. As the pilot project, two schools were selected and one of them was SDN Padasuka II.

SDN Padasuka II is located at Kecamatan Soreang, Bandung County. The school has approximately 400 students. The school building consists of 2 buildings with four rooms each, and the total area of the school building is approximately 500 m^2. The structural system before retrofitted is reinforced concrete frames and masonry walls. The buildings were built in the early of 1990s, and still in the expected life-time.

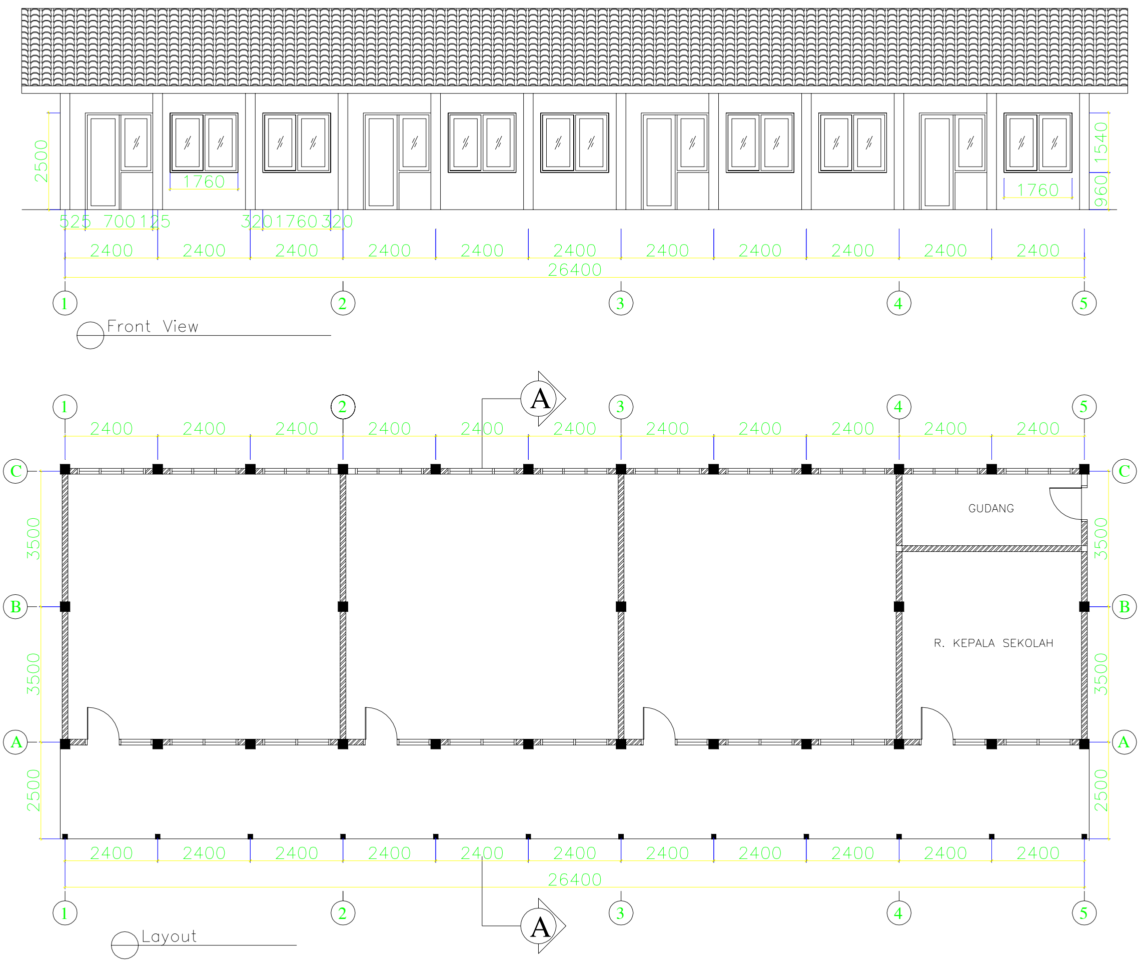


Figure 28 SDN Padasuka II

Existing Structural Condition

- Masonry structures with no columns/beams
- Inadequate foundation system → no tie beam, exposed on some places and soil eroded
- Poor roof structures → poor wall-roof connection, poor roof truss element and connection, excessive roof deformation on the top of the building
- Damage on walls, with cracks and gaps

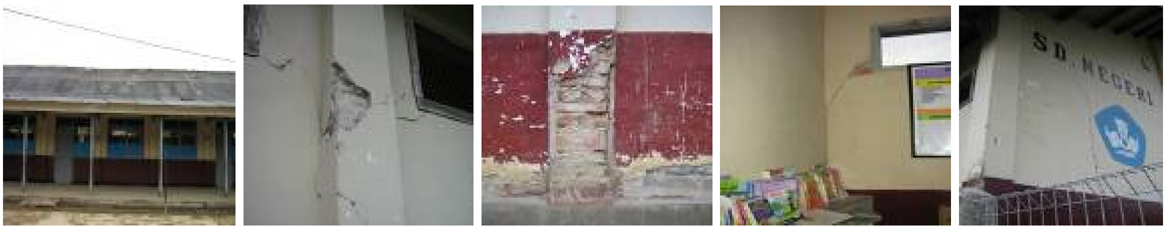


Figure 29 Existing Condition of SDN Padasuka II

Conclusions from Structural Survey

- Inadequate structural system with deficiencies in lateral load resisting elements
- Poor materials and detailing
- Required finishing/cosmetic repair and improvement on sanitation facilities

Structural Analysis Method

- Development of structural model with frame elements (beams and columns), plate elements (walls), and truss elements (roof trusses)
- Material properties were based on results from structural investigations
- Design criteria follows Performance Based Design approach, the structure was expected to have minor/limited damage under design earthquake (elastic behavior)
- Analysis was based on current building codes, with seismic design level of PGA of 0.24g

Structural Analysis and Investigation Results

- Inadequate foundation system → need of improvement
- Inadequate lateral load resistance elements
  - Very poor structure (systems and materials)
  - No R/C frames → need of new lateral load resisting frames
- Poor roof truss element and connection → need of improvement
- Inadequate wall elements → repair

Retrofitting Approach and Implementation

- Install adequate RC frames with mat footings (RC columns on the corners of the structure)
- Install wire mesh for strengthening wall elements and to replace practical columns
- Add tie beams underneath the wall for better foundation system
- Replacing roof trusses and install proper detailing of roof truss systems
- Repair of nonstructural elements, e.g. doors, windows and ceilings
- Repair of sanitary facilities

DETAIL OF COLUMN WITH IRON WIREMESH REINFORCEMENT

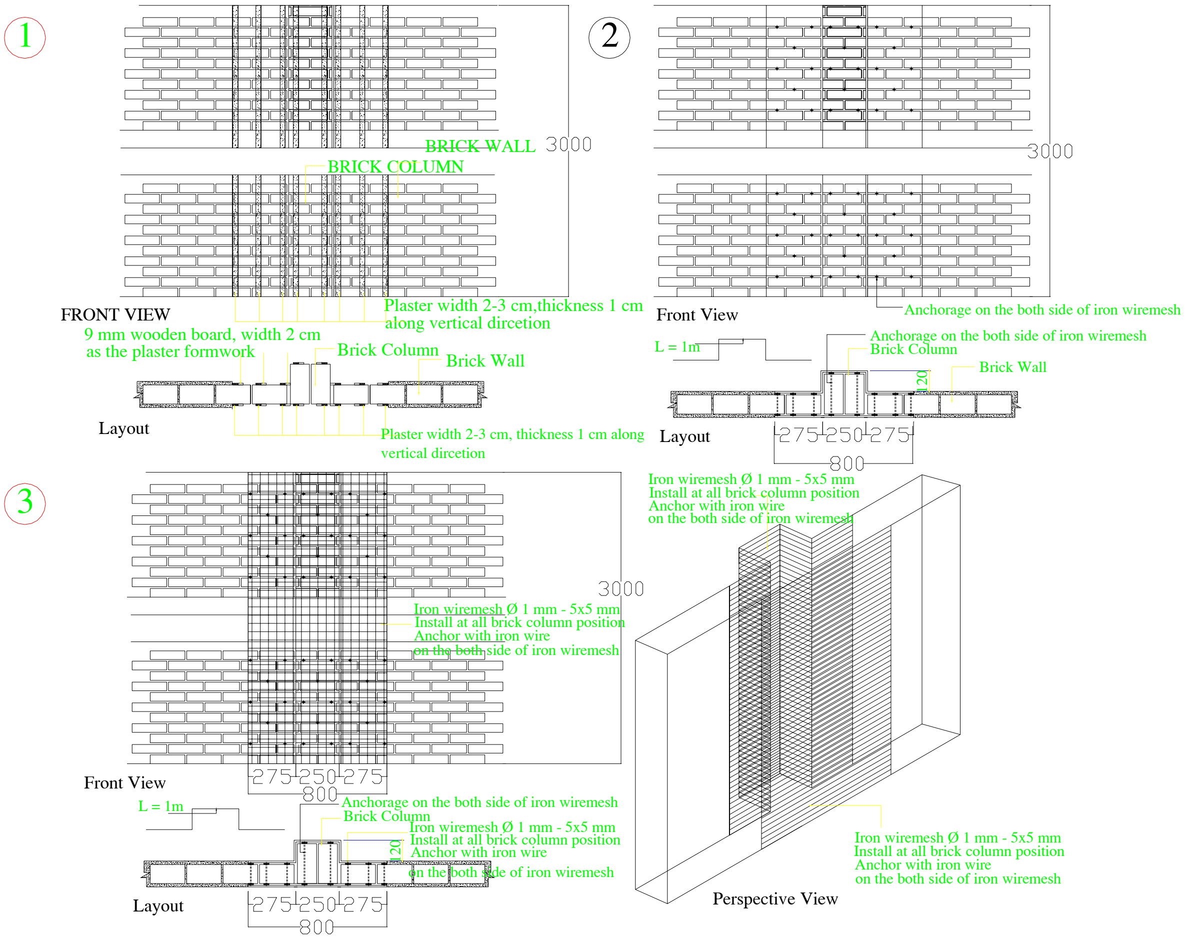


Figure 30 Retrofitting Strategy and Implementation for Column

(Courtesy PT. Teddy Boen Consultant)

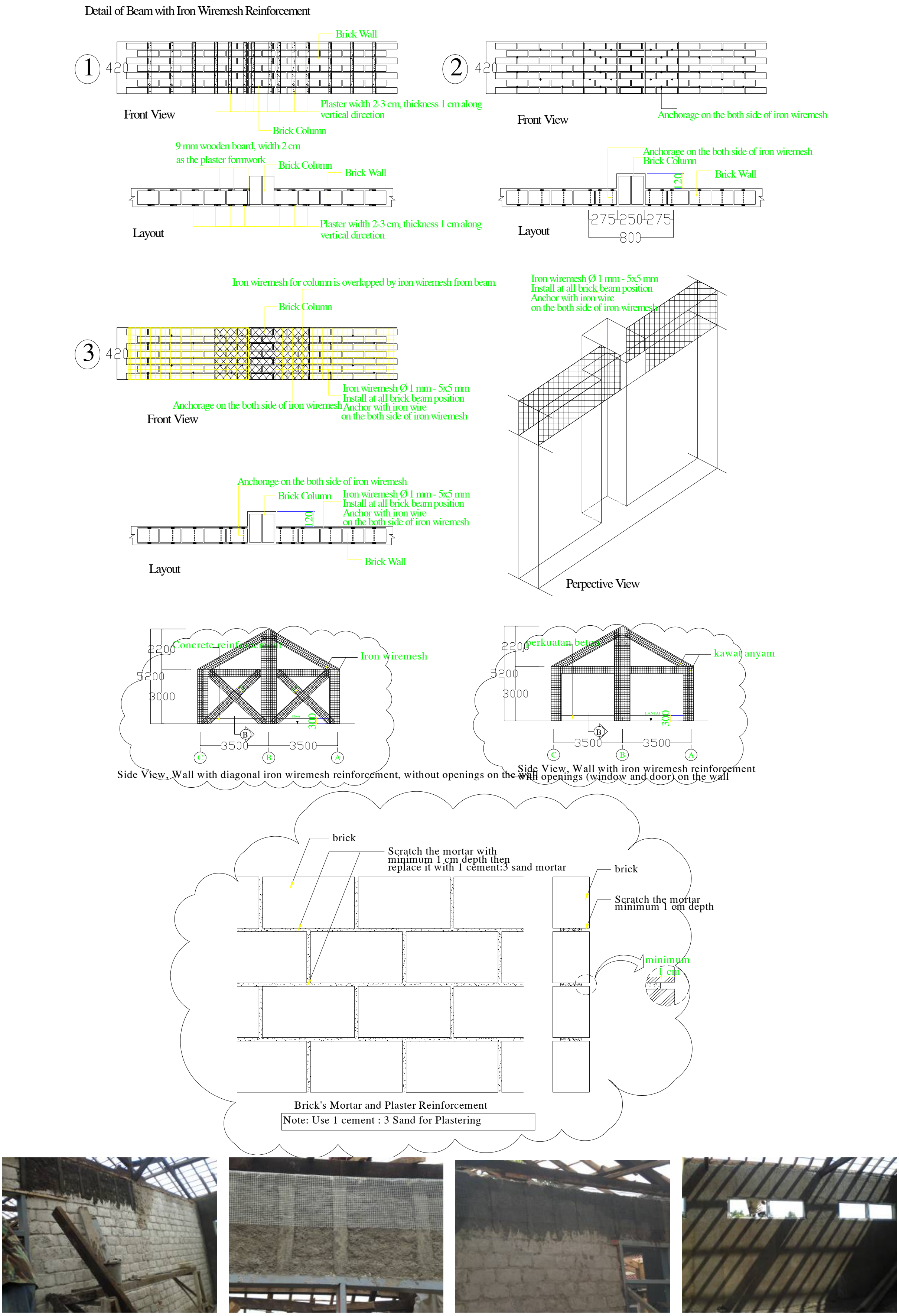


Figure 31 Retrofitting Strategy and Implementation for Beam (Courtesy PT. Teddy Boen Consultant)

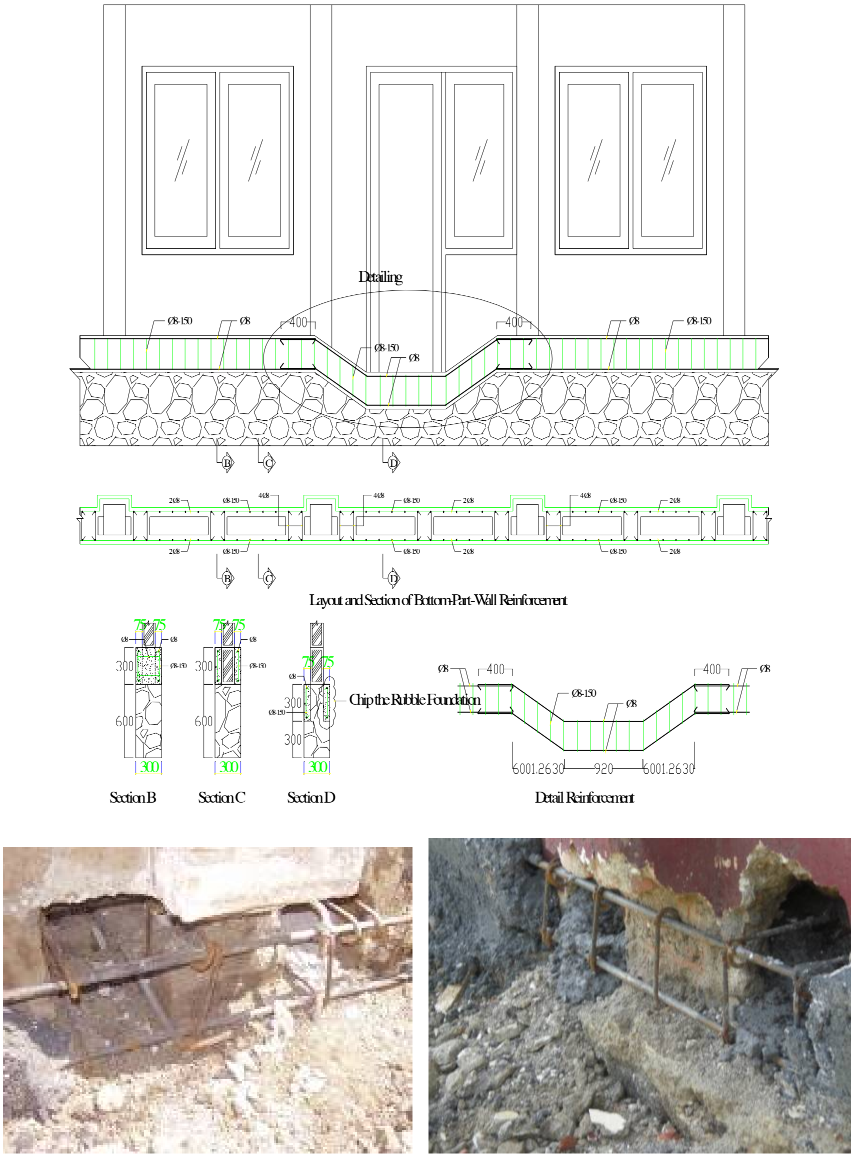


Figure 32 Retrofitting Strategy and Implementation for Tie Beams (Courtesy PT. Teddy Boen Consultant)

Figure 33 Retrofitting works for the trusses and roof

Figure 34 Finishing Works

Figure 35 Sanitary Works

Figure 36 Retrofitting of SDN Padasuka 2

How was the building performance due to earthquake?

There was no significant damage on SDN Padasuka II after earthquake. No structural damage was found on structural elements, and only a few non-structural cracks occurred. From the post-earthquake condition, it can be concluded that the retrofitting approaches adopted for SDN Padasuka II has successfully prevented the buildings from damage.

Figure 37 SDN Padasuka II Post-earthquake Condition

Case Studies: SDN 13 SYAMTALIRA ARUM (Save the Children project, with design and technical assistance from Syiah Kuala University)

Layout

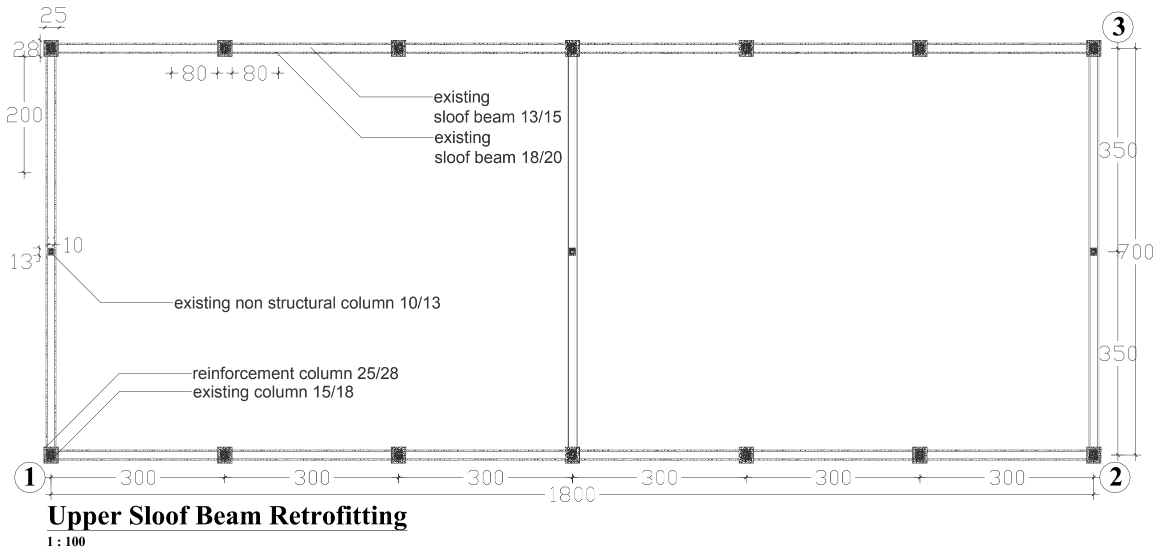


Figure 38 SDN 13 Syamtalira Arun Layout

Existing Structural Condition

1. Cracks on walls
2. Cracks on structural member
3. Poor workmanship
4. Poor quality construction

Figure 39 Existing condition of SDN 13 Syamtalira Arun

Visual Assessment

1. Rapid visual inspection and assessment
2. Collection of design and drawing

3. Topographical information of site
4. Site measurement of main structural member
5. Inspection of cracks and location
6. Judgment of quality of construction
7. Evaluation of workmanship
8. Inspection of material used and its quality

Figure 40 Visual and Technical Assessment

Design Code

- PPI 1983 – Loading standard
- SNI -03-2847-2002 – Standard for design of concrete structures
- SNI O3 – 1726 – 2003 – Standard for earthquake resistant building

Structural Analysis and Results

- Technical assessment measures consist of:
  - Review and evaluation of design, specification & drawing
  - Comparison of size and quality between design drawing and state of the structure in site
  - Check with code provision, mainly size of main structural member and reinforcement bar
- Structural analysis:
  - Structural model was based on open frame lateral resisting systems, with only frame elements (beams and columns)
  - Walls were not considered as lateral resisting elements for the analysis, which is a very conservative approach and does not reflect the actual condition
  - Material properties were based on results from structural investigations
  - Design criteria follows applicable buildings codes
- Results of assessment and analysis
  - Deficiencies on the design
  - Do not satisfy code requirement
  - Insufficient size of structural member
  - Improper site for foundation in some case
  - Poor quality of material – do not satisfy Specification
  - Poor workmanship

Retrofitting Approaches and Implementation

- Based on results from structural analysis and assessment
- Due to the approach of open frame system (walls were not considered as lateral resisting elements), the retrofitting design required that structural elements (beams and columns) to be increased in dimensions to provide larger load resistance capacity
- Concrete jacketing of beams and columns were selected for retrofitting approach, which result in large column and beam sizes, which is uncommon for one-story structure

Retrofitting of Column

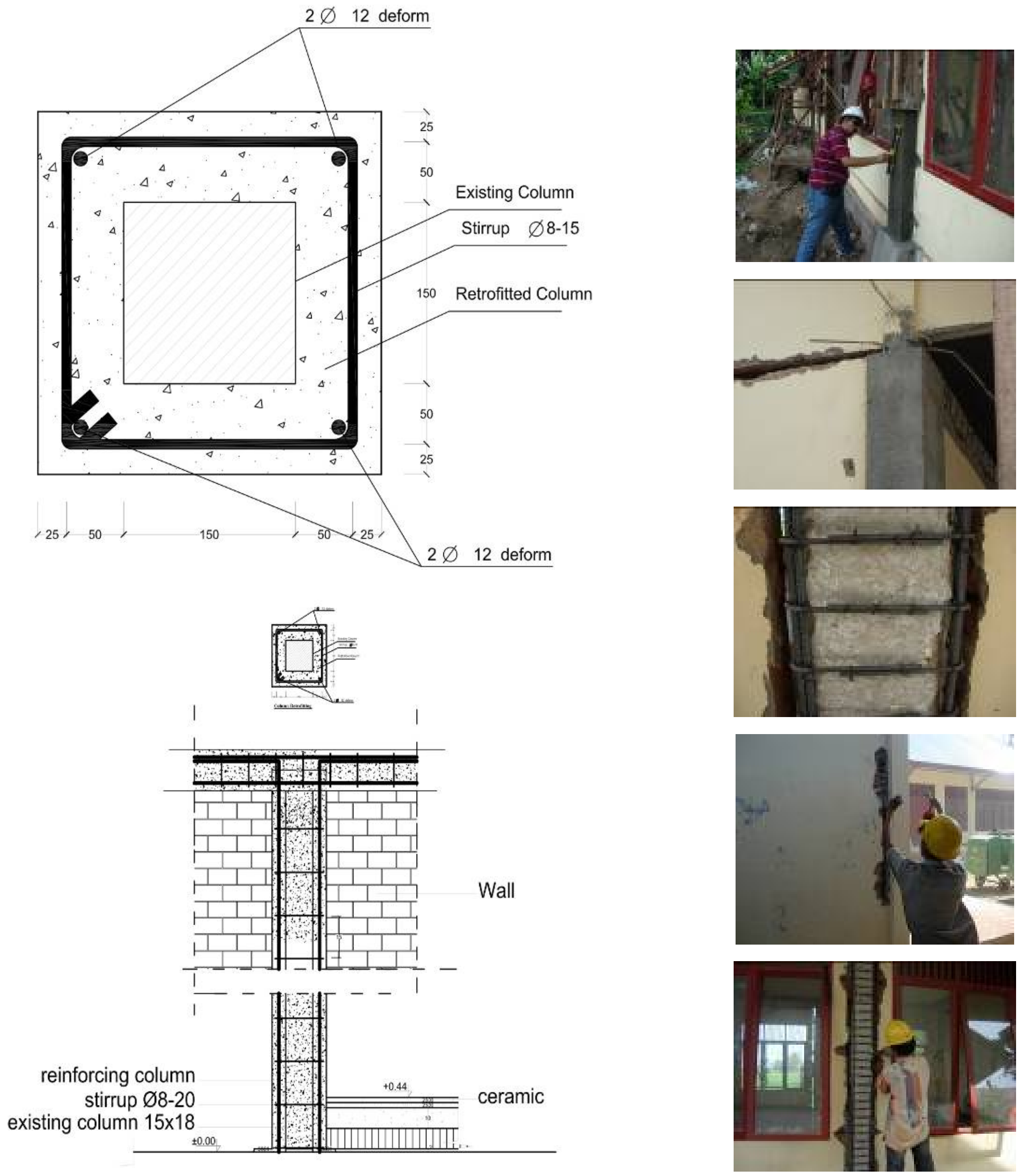


Figure 41 Retrofitting of Column

Retrofitting of Beam

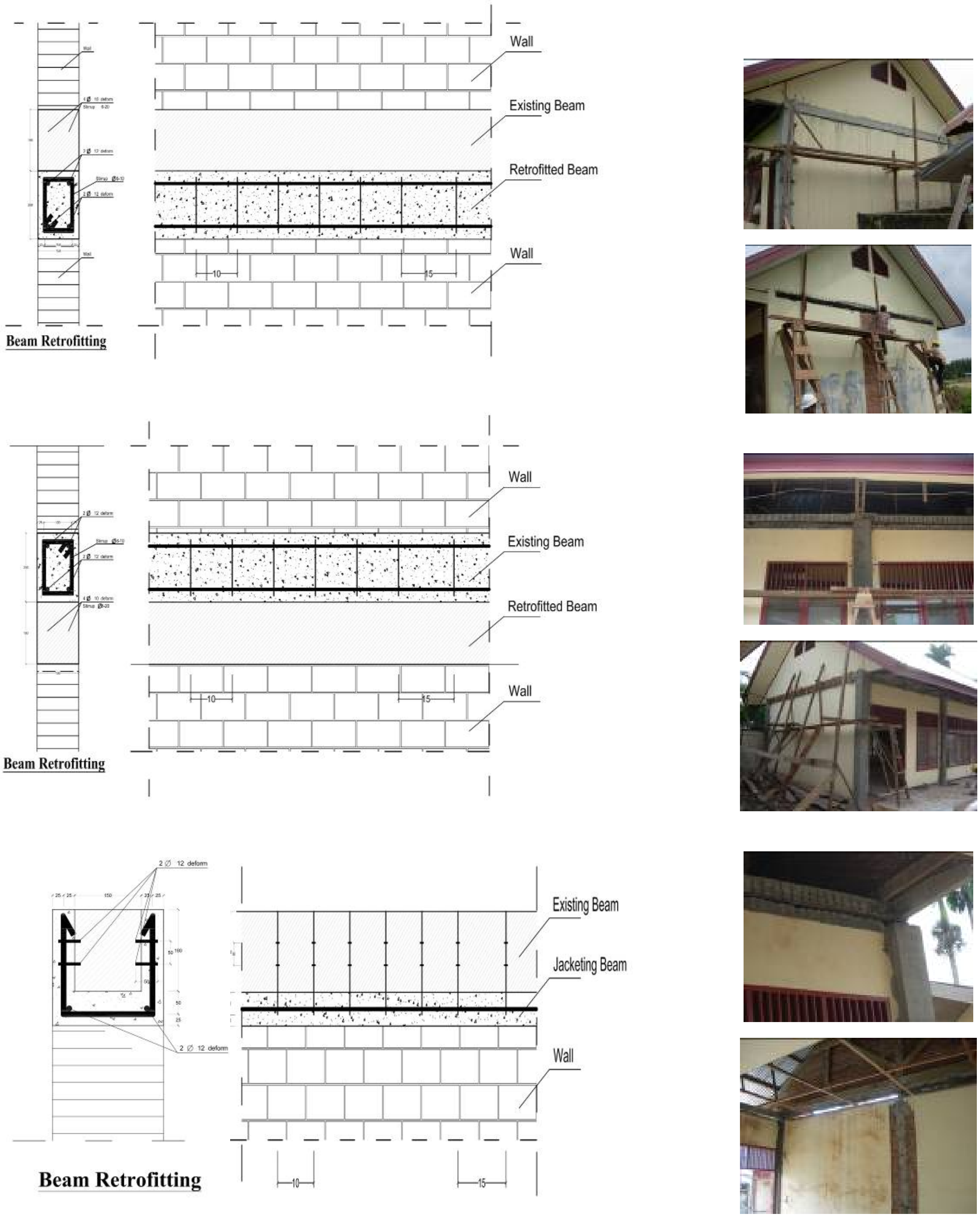


Figure 42 Retrofitting of Beam

Retrofitting for Foundation

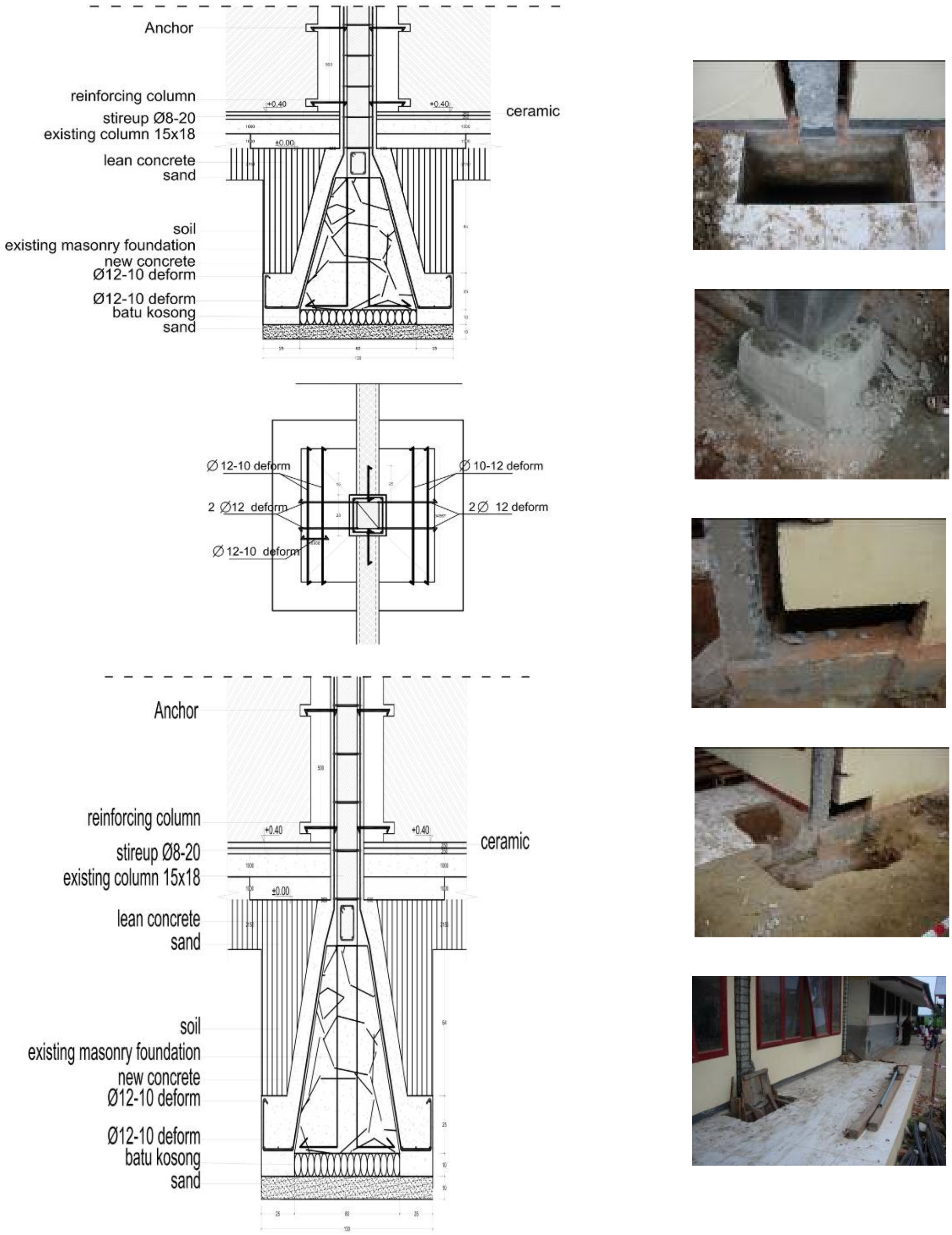


Figure 43 Retrofitting of Foundation

Retrofitting between Wall and Column

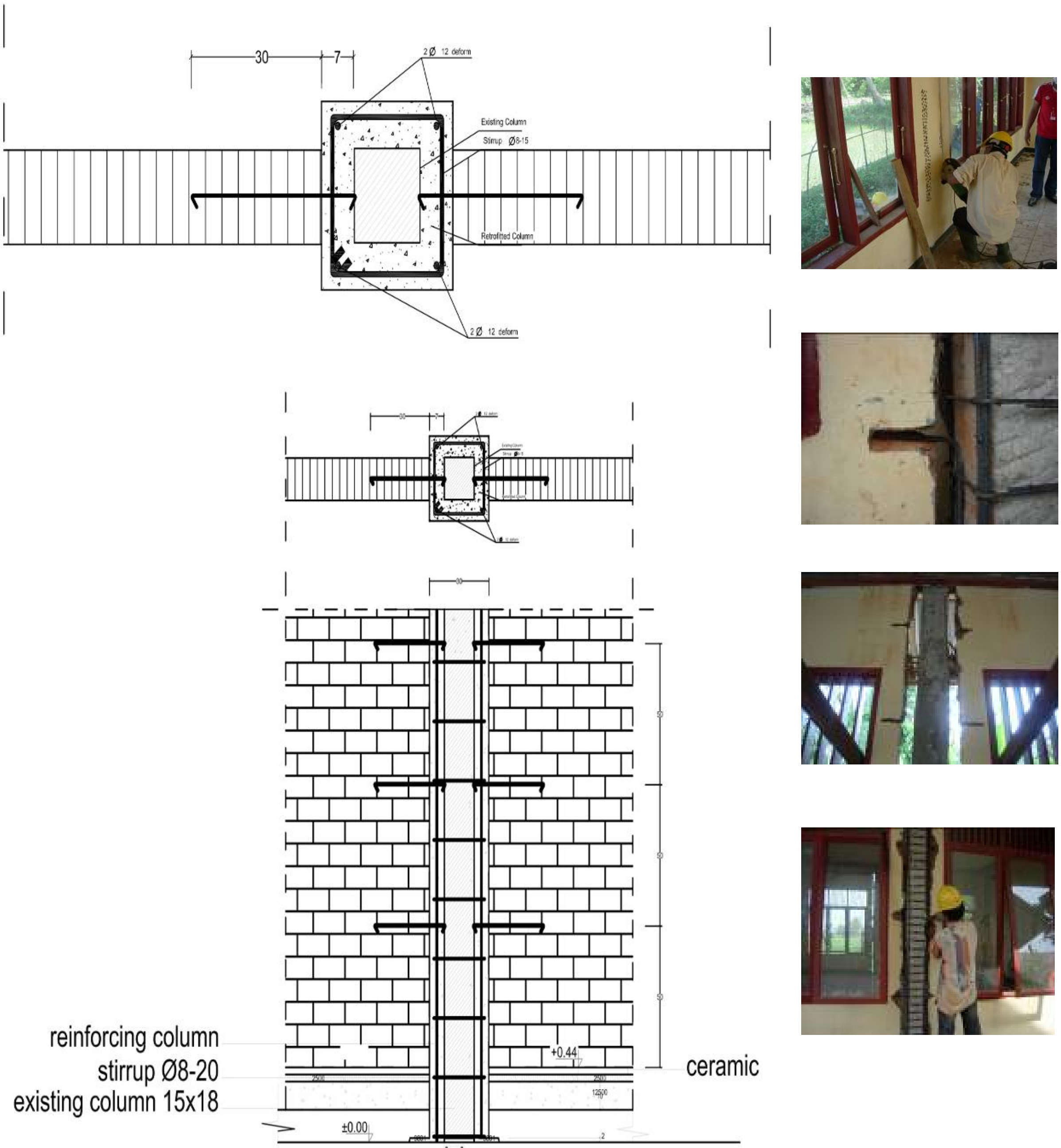


Figure 44 Retrofitting between Walls and Columns

Corrective measure on cracks

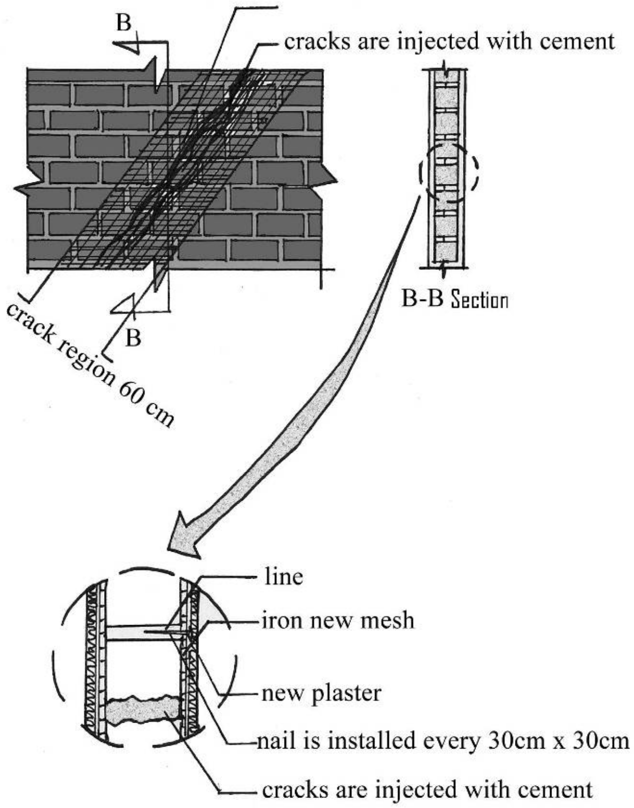


Figure 45 Cracks Injection

Figure 46 Retrofitted Structure

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Save the Children

Safe and Child-Friendly School Initiative

Disaster Risk Reduction Through Retrofitting of Vulnerable School Buildings

Unsafe School Building and Consequences

Retrofitting of Existing Structure - Flow Chart

Vulnerablity Assessment

Physical Assessment

School Retrofitted

Partially Destructive and Non-Destructive Test

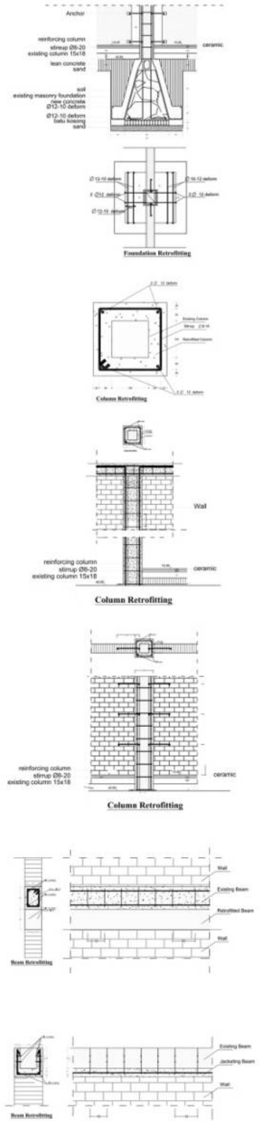
Core Drilling

UTM Testing

Schmidz Hammer Test

Soil Test

Performa Meter Test



Retrofitting Technique & Process

Foundation

Wall

Column

Connection - Column & Beam

Beam

Lateral Wall & Practice Column

Save the Children is the leading independent organization creating real and lasting change for children in need ind the U.S and arround the world. More than 90 percent of expanded resources go to program activities to help children