LESSONS LEARNED FROM YOGYA AND ACEH RECOVERY PROGRAM

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ABSTRACT:
Structural design and construction assessment has been performed as part of quality control for housing construction funded by an international NGO for Aceh and Yogya (Indonesia) earthquake victims. Both design and construction assessments identify vulnerabilities that require significant improvement in the design and construction technology. Although Aceh and Yogya are not close geographically, house construction technology and vurnerabilities observed in in Aceh and Yogya are very similar. In this paper, we present the design and construction assessment results for several housing types in Aceh and Yogya. A new design implementing what have been learned from the assessment of the constructed houses is also presented. The new design has been implemented in the second stage of the house reconstruction project in Yogya.

KEYWORDS: Earthquake resistant, House, Masonry, Infilled frame, Structural detail

1. INTRODUCTION

Two defastating earthquakes hit Indonesian regions within a short space time. The great Aceh earthquake on 26 December 2004 followed by Yogyakarta earthquake on 27 May 2006. The Aceh earthquake claims more than 157,577 human lives with at least 110,229 people were killed by tsunami and earthquake in Aceh region. The Yogya earthquake claims more than 5,100 precious human lives. A lot more victims were injured and/or displaced and rendered temporarily or permanently homeless. An international NGO has funded and organized construction of hundreds of houses for Aceh and Yogya earthquakes victims. As part of quality control and quality assurance we have been requested to perform assessment on the design and construction quality of the houses constructed for both Aceh and Yogya earthquakes victims.

The design assessment was performed by reviewing design drawings and by performing independent analysis using finite element method (FEM). The finite element model includes a macro model for brick wall, besides the standard concrete element model. Three dimensional modal analyses method is used in the analysis.

From the design assessment several design vulnerability have been identified. Site visit of the constructed houses has been made to identify the consistency of the design and the constructed houses. Some deviations from the design in the constructed houses as well as incorrect field decisions and executions due to incomplete design have been identified. It is considered that some of the constructed houses do not satisfy applicable buildings standards and guidelines.

A new improved house design as well as improvements in construction method and materials has been proposed based on results of design assessment and site visit. The proposed improvements have been implemented in the second stage of the reconstruction project.

2. ORIGINAL DESIGN

The original design for Aceh has been developed by an international consultan, while the design for Yogya has been developed by local consultant. The design involved only architects without involvement of civil engineer. Total area for one house for Aceh is about 45 m^2 and for Yogya is about 33.5 m^2. One typical house design for Yogya and six house designs for Aceh were used. The schematic drawing of the original housing design for

Yogya are presented in Figure 1. The exterior wall of the houses is masonry wall constructed from red clay bricks, confined by concrete frame consisting of columns, tie beams, roof ring beams and rafters. The roof material is clay tile for Yogya and corrugated metal for Aceh, supported by timber beams and timber truss or masonry gable. Foundation is continuous stone masonry with depth of 80 cm for Yogya and concrete footing for Aceh.

The material properties are assumed as follows:

- Concrete: Size (cm^2): columns 15x15, beams 15x15, tie beams (15x20). cylinder strength (f_c') = 10 MPa and the Modulus of Elasticity E_c = 25000 MPa.
- Concrete Reinforcement: yield strength, f_y = 240 MPa. The rebar is plain (non deformed type). For longitudinal reinforcement use ϕ = 12 mm, stirrup use ϕ = 8 mm.
- Timber: Timber class II Indonesian Standard with allowable stress = 8.5 MPa
- Masonry Wall: Finished thickness = 15 cm, compressive strength f_w = 2.5 MPa and modulus of elasticity E = 3000 MPa.

Vertical loading is specified according to PPI(1983), “Indonesian Guidelines to the loading design for house and Building”, while seismic load is determined from SNI 03–1726(2002), “Indonesian Earthquake Loading Code” for Aceh and Yogya.

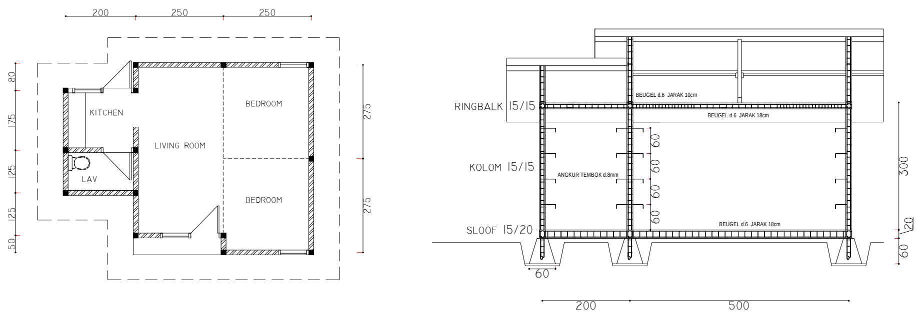


Figure 1. Plan view and section of the original housing design

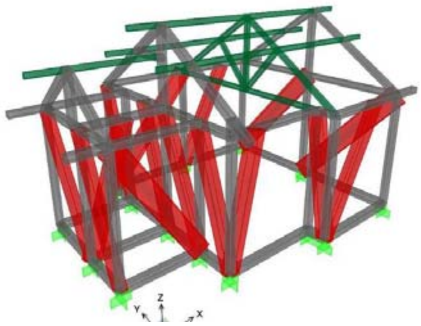
3. DESIGN ASSESSMENT

Structural engineering analysis using a FEM computer program was conducted to assess the structural integrity under gravity and earthquake loads. Dynamic analysis by response spectrum method wads used to analysis the earthquake load effects to the structure. The design was checked by Load and Resistance Factor (LRFD) method according to SNI-03-2847(2002), The Indonesian Concrete Code. The analysis was performed based on assumption that bond between reinforcement and concrete is perfect and properly anchored. This assumption in most cases is not correct since the reinforcement used is non-deformed type with poor anchorage detail.

3.1 *Analysis Model*

Ring beams, columns and foundation tie beams are modeled as concrete frame elements with rigid joints. Roof truss members are modeled as truss elements with pin connection. Anchorage to concrete frame assumed to be installed properly, therefore timber to concrete connection are modeled as pin connections.

Brick walls are modeled as diagonal struts. A pair of diagonal struts, connecting the opposite corners of a wall panel, subjected to compression and tension forces alternately. In actual structure, the struts resist only compression, so only one strut of each pair is resisting forces at any time. The width of a strut is approximately equal to a quarter of its length and the thickness equal to the actual thickness of the brick wall. The masonry model has been proposed and implemented by others (Tomazevic(1999), Asteris(2003), Mostafaei *et al.* (2004), Oliveira *et al.*(2004)). Figure 2 show a sample of analysis model representing houses built in Yogya.



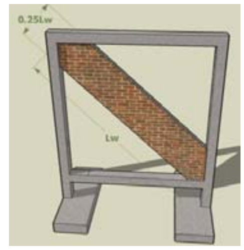


Figure 2. 3D analysis model and detail of masonry wall model

The foundations are modeled as pin support in the horizontal directions. In the vertical directions, the foundations are modeled as line spring with stiffness equivalent to soil stiffness under the footing area.

3.2 *Design Assessment Results*

Design assessment based on review of the design drawings and strength check by FEM found structural vulnerabilities as presented in the followings.

3.2.1 Layout

- Horizontal Layout: horizontal layout is irregular and non-symmetric with vulnerable reentrant corners and torsional vibration modes.
- Vertical Layout: vertical frame for the small gable is not inline with its supporting column, but is attached to the beam. This will induce torsion to the beam (Yogya design).

3.2.2 Reinforcement

- Reinforcement type: reinforcement type specified is non-deformed type. This type is not is not acceptable according to modern concrete code including Indonesian Concrete Code (ACI 318M(2005), SNI-03-2847(2002)) due to its unreliable bond to concrete.
- Stirrup: in many cases the stirrups clearance are too wide without seismic detail for hook and spacing.

3.2.3 Timber Frame

- Roof truss is not provided with adequate lateral support. The designer probably assumes that the ridge beam and rafters will provide the lateral support by transferring the lateral load to the concrete gable frames.

3.2.4 Masonry

- Openings such as doors and windows are not protected by reinforced lintel beams. This practice considered acceptable provided the door or window frames made from timber with acceptable quality and dimension

3.2.5 Structural Detailing

- Reinforcement detail: reinforcement details such as hook detail, required embedment length, reinforcement splice, beam-column joint, etc. are not provided. Probably with assumption that field engineer or mason have the knowledge and will provide the correct details.

3.2.6 Strength Check

The analysis by FEM program for two house type in Aceh and one in Yogya showed the following vulnerabilities and strength deficiencies:

- Torsional vibration modes induce high stress to members around the reentrant corners. Some beams and columns shown to be overstressed due to design earthquake load.
- Overstressed structural members due to incomplete foundation system in some of Aceh house designs.

- Due to assumption that the internal walls will be constructed in the future, the current configuration has wide wall and frame system that has out of plane support system too far apart (6 to 7 meters). The analysis shows that the wide wall and frame system has inadequate strength in the out of plane direction.
- Gable frames are not properly supported in the out of plane direction (by perpendicular concrete beam at the top or bracing system). The concrete frame dimensions for the gable are not specified, so sometimes smaller concrete members (10x10 cm^2) are used. The analysis shows gable frames strength are inadequate.

4. CONSTRUCTION QUALITY ASSESSMENT

Construction assessment based site visits to the partially completed houses in the first stage of the construction project fount structural vulnerabilities as presented in the followings.

4.1 *Layout Variations*

- The lands owned by aid recipients are not always suitable for the generic house design for Yogya. Some site improvisation and radical layout adjustment has been performed on site.
- Vertical member layouts are not always follow the design drawing. This may be results of mason's attempt to simplify the rather complicated layout.

4.2 *Floor Slab*

- The design drawing for Aceh show unreinforced concrete slab with thickness 15 cm for the floor with extra thickness to 25 cm under walls where explicit tie beam is not provided. This type of floor construction is considered too luxurious for a simple house, therefore the floor slab were not constructed. This creates problems to provide support for some walls and to complete tie beams system.

4.3 *Reinforcement*

- Reinforcement type, size and distribution that we observe, in most cases, has been installed according to design drawing (see Design Assessment for required improvement)
- For Aceh, the large number of houses to be built and variations in structural element sizes could create logistic problem. Some concrete member found constructed with stirrup shape and size intended for smaller members resulted in very close longitudinal reinforcement spacing. The mistakes were camouflaged by concreting with correct column sizes (Figure 4).
- Often the reinforcement was found visible, with inadequate concrete cover and rusty. In many cases this is the result of concrete formwork made by laminated wood directly pressed to unfinished brick, so the concrete thickness become equal to brick thickness and in most cases no spacers are used in formwork. The reinforcement bond to concrete becomes unreliable and such reinforcement is also exposed to corrosion.

4.4 *Concrete Quality*

- The quality of raw material for concrete as well as mixture proportion is not always properly controlled. The concrete was mixed manually (by shovel, not in machine mixer).
- The pouring of concrete into formwork is mostly performed by bucket, free fall allowed especially in the column formwork, no vibrators to allow compaction in the formwork. Honey combs and voids in concrete are common for most structures, create weak locations in structure by reducing compressive strength, disable common acting of concrete and reinforcement steel and allow corrosion.
- Inconsistent concrete member sizes and out of plumb is common.
- Some houses without concrete frame for the masonry gable; some provided with incomplete or reduced size concrete elements.

- Concrete curing is completely omitted.
- In most cases, the concrete frames are completed before brick walls construction. The problem is that concrete surfaces very often too smooth and not treated for a good bond between concrete and brick wall.

4.5 *Structural detailing*

Figure 3. Column reinforcement hooked to the timber ridge and rafter

- In most cases, beam and column reinforcements are terminated without hook and therefore installed with inadequate embedment length. In many cases column reinforcements are not terminated inside the concrete but extended as if function to tie the roof timber frames. This results in two very serious problems, namely ineffective reinforcement hook and timber frames without adequate anchorage to the concrete. See Figure 3.
- Reinforcement hooks, if provided, often with incorrect form (Figure 54)
- Reinforcement splice often located in the highly stressed region and without adequate stirrup (stirrup clearance 18 cm).
- In some cases timber frame joints are not properly bolted or not tied with steel belt where required by design. Almost all without adequate anchor to concrete frames.

Figure 4. Incorrect stirrup dimension and joint details

4.6 *Masonry*

Masonry is not provided by donor, so the recipient use local labor, sometimes unskilled, to construct the masonry after the concrete frames finished. Low quality results often observed, such as:

- Thick mortar is very common, sometime as thick as the brick.
- Vertical inter-brick not always filled by mortar.
- Sometimes brick attached directly to concrete frame (column or beam) without mortar for bonding the two materials.
- There are cases where brick used as substitute for stone as shown in Figure 6.

Figure 5. Missing foundation under column and brick detail

Figure 6. Brick for foundation, as concrete aggregate and for retaining wall

5. IMPROVED DESIGN

We were assigned to perform the assessment close to the conclusion of the first stage of the house construction project and during the preparation of the second stage. We see this as a good opportunity to educate the engineers and masons involved in the project. They can have the maximum benefit in improving their skill and knowledge by learning what need to be improved from their completed works and by immediately implementing our recommendations in the second stage of the project. In the followings we present our main recommendations that have been implemented in the second stage of the project.

5.1 *Regular and Symmetric Layout is Better*

Based on established knowledge and also confirmed by the analysis, regular and symmetric structural layout both horizontally and vertically will perform better compared to irregular and non-symmetric structure. Therefore, we recommend to the architect to redesign the layout to get symmetric building. During the discussion it is also recognized that culturally, for hygienic reason, a house in the village usually has bathroom and kitchen separated from the main house. By separating the kitchen and the bathroom, it is much easier to arrange the rooms to get two symmetric building units. This arrangement also facilitates house construction on various land sizes and shapes by adjusting the relative position and orientation of the bathroom-kitchen unit with respect to the main unit. The main unit layout in the improved design is shown in Figure 7.

Design check using the same method as presented for the original design has been performed for the improved design. With structural member sizes the same as for the original design, the analysis shows the improved design conforms the design criteria.

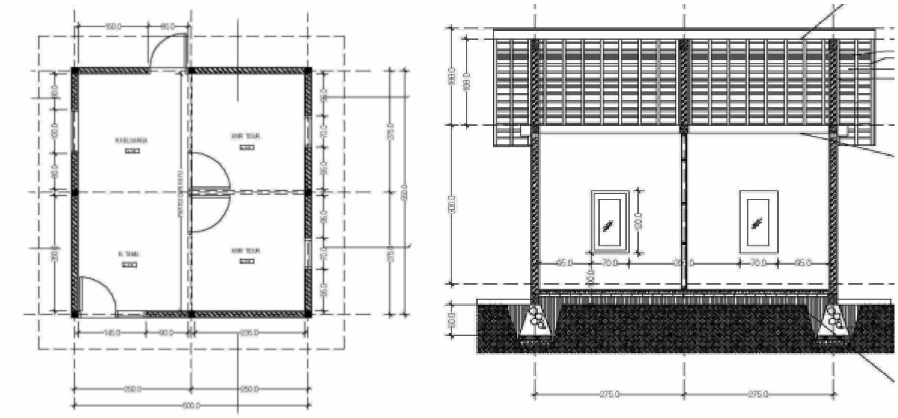


Figure 7. Plan view and section of the main unit in the improved design

5.2 *Use Deformed Reinforcement Bar*

Most modern concrete codes including Indonesian Concrete Code (ACI 318M(2005), SNI-03-2847(2002)) require deformed reinforcement bar. It is shown by experimental work that the bond strength of reinforcement bar is much better compared to plain bar (Imran *et al*. (1998)). Therefore we recommend to use deformed bar. To minimize budget inflation due to higher price per unit weight of deformed bars, we recommend to use diameter 10 mm deformed bar as main (longitudinal) reinforcement to replace diameter 12 mm plain bar. The strength and the price per unit length these bars are comparable.

5.3 *Adequate Reinforcement Anchorage in Beam Column Joint*

In the original design, detail for beam column joint and reinforcement anchorage are not provided, resulted in incorrect construction as presented above. For small houses, (150x150 mm^2) columns and beams with four diameter 10 mm deformed reinforcement bars are shown to be adequate by the analysis. However the beam and column width do not provide adequate space for hooked embedment length, therefore we propose to extend the column and beam to the opposite side of the joint to provide the required space for embedment length as shown in Figure 8.

5.4 *Timber Anchorage*

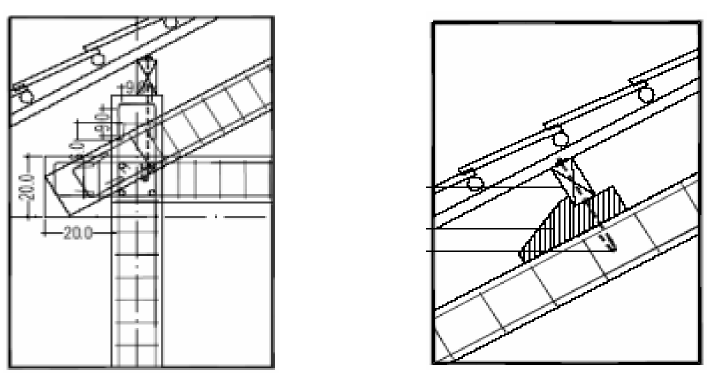


Figure 8. Beam column joint and timber to concrete anchorage details

In the original design, the detail for timber frame attachment to concrete is not provided. In the construction, in some cases the timber frame are tied, incorrectly, by extended and exposed column reinforcement, in some cases the frame are not tied at all. We propose to use anchor bolt embedded in concrete to tie the timber elements as shown in Figure 8. Since we propose to use concrete for the roof main frame, only ridge beams and rafters are constructed from timber.

5.5 *Concrete Gable Frame*

From site visit, it is found that timber qualities used in the construction are not always good. Timber from young coconut trees, sometimes with visible defect often used. We also observed that skilled wood worker is not always available. Therefore we recommend using concrete for all of the roof main frames.

6. SUMMARY AND LESSONS LEARNED

From design and construction assessment we conclude that the design for both Aceh and Yogya Reconstruction Project does not conforms the current design standard and lack of important structural details that are very important for seismic performance of the structure. This can be attributed to the design teams that in most cases do not involve structural enginneer. Usually the design architects do not aware of the latest development in the earthquake resistant design. The field engineers and the masons implement local technologies (common practice) for the missing details. Unfortunately, the local technologies contain many flaws. Among others, the most detrimental problems are:

- Use of plain (non deformed) reinforcement bar
- Incorrect reinforcement details (reinforcement anchorage, lap length, stirrup detail and spacing, roof truss anchorage and connection)
- Incorrect anchorage and incomplete lateral support for roof trusses.
- Irregular vertical and horizontal building layout.
- Inadequate lateral support for walls.

To address the problems we recommend some improvements and working with the local consultant we develop a new house design. The new design has been implemented for the second stage of Yogya Reconstruction Project.

The problems related to structural details observed in Yogya and Aceh are very common and the incorrect details implemented are repeated in many other house constructions throughout Indonesia. The reasons that the incorrect details become the "accepted standard" are as follows:

- Contractors that seek maximum profit tend to choose structural details that require minimum material and simplest detail for faster construction time.
- Lack of strict supervision or supervision by engineer with limited or incorrect knowledges gives opportunity to the incorrect details to evolve into "accepted standard".
- Engineers and masons with minimum knowledge on earthquake resistant design learned the "false standard" from their previous projects. They distribute the incorrect standard and persistently guarded them as if it is the correct standard details.

The implications of the observations are:

- Experienced engineer and masons are not always reliable for earthquake resistant construction; they may learned the "false standard" and persistently implement the incorrect details since the correct details are usually more complicated and more expensive.
- The false standards are widely used so that it is not easy to enforce the correct standard. Creative education and training strategies need to be applied for successful dissemination of earthquake resistant design and construction standard.

The construction of the improved design and standard details in the second stage of Yogya Reconstruction Project has been performed smoothly. The proposed details can be performed by local masons without dificulties. This show that skill and material availability are not the source of the problem. Some masons appreciate the joint details that reduce reinforcement congestion in the beam-column joints. Local material suppliers also ready to supply the proposed deformed reinforcement bar type. However, recent visit to the Yogya construction site show that the example given by the improved design does not change the local construction practice significantly. Houses constructed in the neighborhood of the project were built using the incorrect "standard". This show how deeply the incorrect "standard" has been accepted and practiced by the local masons. It requires a persistent and continues education, training and examples to promote the correct earthquake resistant standard.

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