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BUILDING BACK HOUSING IN POST-DISASTER SITUATIONS – BASIC ENGINEERING PRINCIPLES FOR DEVELOPMENT PROFESSIONALS:

A PRIMER

January 2012

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Disclaimer

The authors' views expressed in this publication do not necessarily reflect the views of the United States Agency for International Development or the United States Government.

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ACRONYMS

A&E	Architecture and Engineering
CBOs	Community-Based Organizations
EERI	Earthquake Engineering Research Institute
EMMA	Emergency Market Mapping and Analysis
FIDIC	Fédération Internationale des Ingénieurs-Conseils (International Federation of Consulting Engineers)
GSHAP	Global Seismic Hazard Assessment Program
NEHRP	National Earthquake Hazards Reduction Program
NGOs	Non-governmental organizations
USAID	US Agency for International Development

EXECUTIVE SUMMARY

This Primer covers the basic steps in the process of selecting a model for planning and executing post-disaster housing reconstruction projects funded by the US Agency for International Development (USAID). It is intended to provide USAID officers and Host Country officials with the steps, principles, and best practices that need to be taken to properly carry out housing construction and reconstruction in a post-disaster situation. It provides a road map on how to develop a project through planning, design, and implementation and builds on an earlier report, "Basic Engineering and Construction Management: A Primer."

The Primer addresses various phases of the planning, design, and implementation process and the various deliverables and milestones usually included as part of the process. The document also discusses the role and responsibilities of the USAID project manager, including interactions with the affected community(ies), partners, local officials, and other involved organizations.

The Primer addresses several objectives:

- To greatly reduce deaths, injuries, and economic losses caused by housing collapses due to natural disasters in developing countries
- Permanently changing building code enforcement or construction practices so that houses built in the absence of external funding and technical support are substantively more resistant to collapse during and after disaster situations
- Capacity building through training of builders, homeowners, engineers, and government officials
- Permanent change in construction practices by building local skills and stimulating local demand

OVERVIEW

This Primer introduces engineering and development professionals to the basic steps in the process of selecting a model for planning and executing post-disaster homeowner-driven housing reconstruction projects funded by the US Agency for International Development (USAID). It is intended to provide USAID officers and Host Country officials with the steps, principles, and best practices that need to be taken to properly carry out homeowner-driven housing construction and reconstruction in a post-disaster situation. It provides a road map on how to develop a project through planning, design and implementation and builds on an earlier report, "Basic Engineering and Construction Management: A Primer."

PRINCIPLES AND STRATEGIES

Post-disaster housing reconstruction presents an opportunity to not only rebuild safe housing for the affected population, but also to change construction practice permanently so that local builders, engineers, and homeowners build safe houses in the future. These objectives are addressed here by applying the following principles and strategies, which are documented in the text:

- **Local Solutions** – Use detailed housing subsector studies to determine the most cost-effective ways of building disaster-resistant houses using materials and skills that are available through the local private sector.

- **Technical Excellence** – Leverage the knowledge and skills of the best engineers and architects in the world – both in the US and the developing world – to ensure that the very best designs and design thinking are applied to the reconstruction efforts while sticking to a carefully compiled list of criteria for local sustainability and acceptance.

- **Equality** – Empower the homeowners to choose their own layout and materials and manage their own construction with technical assistance, by providing a range of solutions appropriate for different income levels, family size, cultures, and climates.

- **Local Capacity** – Build local capacity by hiring and working with local engineers, architects, builders, universities and governments and training vocational or trade school students.

- **Job Creation** – Work with local masons, carpenters, and homeowners to incorporate disaster-resistant building techniques that are culturally accepted and easy to adopt with limited training and education.

- **Economic Growth** – Kickstart the local economy by purchasing locally available materials and products.

- **Bridging the Gap** – Learn and spread best practices from post-disaster housing reconstruction programs so that the many other agencies involved in these efforts build better houses and leave in place more sustainable local impacts.

A project's success over the longer term requires knowledge, skills, and abilities on the part of those implementing and managing it. However, many professionals in the developing world have not yet internalized the core competencies that those in more advanced economies take for granted. For this reason, USAID incorporates capacity building activities into many of its engineering projects. This is an integral part of homeowner-driven reconstruction.

OPTIONS FOR POST-DISASTER HOUSING

The focus of this Primer is on homeowner-driven housing reconstruction and retrofitting.

Homeowner-Driven Reconstruction. Homeowner-driven reconstruction is a post-disaster housing reconstruction model that is gaining in usage and popularity worldwide. It has been successfully implemented after recent earthquakes in India, Indonesia, China, and Haiti. More specifically, homeowner-driven reconstruction was the reconstruction model of choice by government agencies overseeing the reconstructions following the 2001 Gujarat, India earthquake, 2007 and 2009 West Sumatra, Indonesia earthquakes and the 2008 Sichuan, China earthquake.[1] It can be a lower cost, higher impact model than donor-driven reconstruction and can produce safe homes, satisfied homeowners, and sustainable change in construction practice.

[1] Though the government of Haiti has not yet released a housing reconstruction policy, homeowner-driven approaches are being promoted and used by many agencies.

Homeowners are empowered to make their own choice, which results in greater satisfaction and buy-in, an increased willingness to invest more in earthquake and hurricane safety, and a reduction in dependency. Homeowners drive the process themselves; they choose the structural type, materials, layout, and architecture. They usually do not build the house themselves, but rather hire small scale, local contractors to do the construction. Financing is provided directly to the homeowner or to small groups of homeowners in the form of cash grants and/or materials vouchers.

This approach is most effective when government provides some enforcement, and/or the provision of grant or loan financing is contingent upon meeting minimum standards for good construction quality. In other words, financing should be provided in installments, with checks on construction quality.

Community-Driven Reconstruction. Community-driven reconstruction has also been used in recent earthquakes around the world. It differs from homeowner-driven reconstruction in that homeowners typically choose from a small number of floor plans and structural systems, or the choice of structural floor plans is made by a group of community leaders on behalf of all homeowners. Also, homeowners may not control the funding, and contractors or small groups of community labor may be used to build the house.

Donor-Driven Reconstruction Also referred to as contractor-driven reconstruction, in this model, homeowners are minimally involved in design or construction, if at all. Houses are designed by the donor or its consultant and built by a contractor hired by the donor.

The implementation models are described in more detail in the table below.

Table 1. Comparison of Homeowner-Driven, Community-Driven and Donor-Driven Housing Reconstruction Implementation Models

	Homeowner-Driven	Community-Driven	Donor-Driven
ARCHITECTURE and DESIGN			
Who Chooses Structural System	Homeowner	Donor or government	Donor or government
Who Chooses Floor Plan	Homeowner can choose any layout provided it confirms with disaster-resistant design standards	Donor, community groups or homeowners choose from a limited number of floor plans	Donor, or homeowners choose from a limited number of floor plans
Homeowner Satisfaction with Type and Floor Plan	High	Can be low if floor plan is too small, not appropriate for lifestyle or climate	Can be low if floor plan is too small, not appropriate for lifestyle or climate
CONSTRUCTION			
Who Builds	Small scale, local builders hired by homeowner or small groups of	Local builders or contractors hired by groups of homeowners; in limited	Large scale contractors hired by relief agencies or governments, may not be local

	Homeowner-Driven	Community-Driven	Donor-Driven
	homeowners; in limited cases, homeowners themselves	cases, homeowners themselves	
Resource Consumption	Lowest	High	Highest
Use of Recycled Materials	Highest	Low	Rare
QUALITY AND TIME			
Who Supervises	Homeowner, technical consultant, and/or government	Homeowner, community group, technical consultant, and/or government	Contractor, technical consultant, and/or government
Quality	Varies; can be high and can be very poor; depends on homeowner's budget and desire for a safe house; helps if government enforces building standards	Varies; can be high and can be very poor; depends on competence of implementing agencies and willingness to enforce quality standards	Varies; can be high and can be very poor; depends on competence of implementing agencies or government staff, avoiding corruption, and willingness to enforce quality standards
Homeowner Confidence in Construction Quality	Can be highest (if funding sufficient)	Varies	Can be low (homeowner not involved)
Potential for Corruption	Low; "owner" is the homeowner	Medium; "owner" is the implementing agency or donor, more peer pressure mechanisms in place	Highest; "owner" is donor or contractor
Speed	Unpredictable, can be accelerated through fast, sufficient disbursement of cash grants	Can be fast or slow	Fast if managed well, slow if not
Photo Op	Genuine but not always finished or pretty	Varies	Good
FINANCIAL			
Who Pays	Homeowner, with grant from government or donor, their own savings and/or loan (if available)	Donors or government pay community groups or contractors directly	Implementing agencies or government act as contractors or hire and pay contractors, contractors purchase materials and hire labor
Who Hires Builder	Homeowner	Community Group or Implementing Agency	Donor or Implementing Agency
Who Buys Materials	Homeowner or Builder	Community Group, Implementing Agency, or Contractor	Donor, Implementing Agency, or Contractor
Level of Homeowner Contribution	Highest	Medium	Lowest
Who Profits	Local builders and materials producers	Community members, local builders and materials producers	Contractors, consultants, larger-scale materials producers, maybe non-local
COST PER HOUSE			
Design	High	Low	Low
Construction Management	Low	Depends	High
Materials and Labor	Lowest	High	Highest
On-the-job training	Highest	Depends	Low
Overall Cost to Donor	Lowest	Varies	Highest
DEVELOPMENT POTENTIAL			
Type of Model	Bottom-up	Top-down with some bottom-up elements	Top-down
Role of	Limited to technical	Limited to technical	More extensive; design-build,

	Homeowner-Driven	Community-Driven	Donor-Driven
Implementing Agencies	assistance only; may provide materials vouchers or cash grants to supplement government grants	assistance, grant disbursement	hire contractors, manage construction
Donor Contribution	Technical assistance, capacity building, cash to build a house	Varies, technical assistance, capacity building, cash, house	House
Potential to Cause Long-Term Change in Practice	Highest	Depends	Low
Potential to Increase Dependency and Cause Social Conflict	Lowest; empowers homeowners to drive process, allows for more equitable treatment	Depends	Highest; houses are given away, homeowners are not empowered; due to high cost, unlikely all will be treated equitably
Where Model Has Been Used For Permanent Housing	2001 Gujarat, India; 2007 and 2009 West Sumatra, Indonesia; 2008 Wenchuan, China; 2010 Haiti; and others	2004 Aceh, Indonesia; 2004 Sri Lanka; 2005 Balakut, Pakistan; 2006 Central Java, Indonesia; and others	1993 Maharashtra, India; 2001 Gujarat, India; 2004 Aceh, Indonesia; and others
Host Country Government Preference	Preferred model in India, Indonesia, China. Indonesia now strongly discourages donor-driven housing.	Varies	High initially due to apparent scale, efficiency, and possibility for kickbacks in some countries; lower as costs rise and social conflicts occur.
Homeowner Satisfaction	Highest, except for homeowners with the most limited funds	Varies; model can result in conflicts between homeowners and communities if quality or size of house varies by agency	Varies; model can result in conflicts between homeowners and communities if quality or size of house varies by agency

ADVANTAGES OF HOMEOWNER-DRIVEN RECONSTRUCTION

Working directly with homeowners to choose the design and hire and oversee builders is a rewarding process that can result in safer houses and satisfied families. Empowering homeowners, builders, construction professionals, and local governments to drive change is a more cost-effective and lasting solution than building houses for people. But these households will not build an earthquake-resistant house unless they can afford to and they need access to technology, materials, and skilled construction professionals. They also need incentives and government ministries able to enforce the building standards. By addressing all three barriers – technology, money, and people – the homeowner-driven development model encourages the growth of an environment in which earthquake-resistant construction becomes the common practice.

Homeowner-driven reconstruction can:

Increase Safety

- Provide a more complete, structurally integrated solution than a core home or partially built home.
- Result in a disaster-resistant building, if sufficient financing and incentives for following standards are provided.
- Increase the technical capacity of the workforce, including engineers, site supervisors, builders, materials producers, and other construction professionals, if coupled with technical assistance.

Increase Homeowner Satisfaction

- Produce a more satisfied, empowered homeowner.

Increase Sustainability.

- Leverage the financial resources of the homeowner. In homeowner-driven reconstruction, homeowners can add in their own financial resources, resulting in a larger and more long-term solution.
- Reuse or recycle materials, reducing the overall cost per house.
- Put resources back into the local economy. Homeowners typically buy local materials and hire local labor.
- Stimulate investment in local businesses, which creates jobs.
- Stretch the donor's dollar further by reducing the donor contribution per house.

DRAWBACKS TO HOMEOWNER-DRIVEN RECONSTRUCTION

Homeowner-driven reconstruction may:

- Take longer. When the homeowner is driving the process, it is difficult to control the pace of the reconstruction. Thus, homeowner-driven reconstruction requires a patient donor.
- Result in some unfinished houses. If the financial subsidy and homeowner's funds are not sufficient to complete the house, the homeowner may not finish it during the grant period.
- Result in some houses that are not disaster-resistant. If the financial subsidy and the homeowner's funds are not sufficient to complete the house in a manner which is disaster-resistant, the homeowner and builder may not produce an disaster-resistant house. In addition, corruption or lack of will may reduce construction quality.

- Produce houses that are less attractive for photographs. Homeowners may not choose to finish the house during the course of the grant – they may not plaster or paint the house until further funding is available. Thus, it is difficult to obtain picture-perfect images of houses for reports and PR materials.

Homeowner-driven reconstruction may not be the best choice for large-scale greenfield, relocation, or multi-unit commercial developments, which may be more efficiently designed by Architecture and Engineering (A&E) firms and built by large-scale developers or contractors. However, implementers of such projects should consider including elements of homeowner-driven reconstruction in these projects, such as enabling the homeowners to choose the structure type and layout, training of local construction professionals, and the universal need to supervise and oversee construction to ensure quality.

COST

The following describes the cost of homeowner-driven reconstruction as compared to alternative approaches for reconstruction programs, by contrasting the reconstruction programs in Aceh and West Sumatra, Indonesia. Findings may be different elsewhere.

Cost of House: The overall cost of the house materials and labor and the donor cost per house can be lower in homeowner-driven reconstruction than donor-driven reconstruction. Consider the following two cases:

- After the 2004 Indian Ocean tsunami hit Aceh, Indonesia, donor and community-driven approaches were used. Cost of house materials and labor including donor/NGO direct and indirect costs were on the order of US$12,000 – US$20,000 for a 36m^2 house. This does not include additional costs incurred by some agencies to retrofit or tear down and rebuild newly built houses which were built to inferior quality standards.

- After the 2007 and 2009 earthquakes in West Sumatra, Indonesia, homeowner-driven approaches were mandated by the Indonesian government; the government provided $1,700 in cash support to homeowners who lost houses. Technical assistance was provided by local universities, government subcontractors and foreign technical assistance providers. Cost of house materials and labor including technical assistance was on the order of US$3,000 – US$8,000.

Reasons for this cost differential:

- **Donor/Implementing Agency Costs**: In a donor-driven model, the donor typically has high direct and indirect costs – vehicles, staff, warehouses, procurement infrastructure, expat salaries, project management, etc. In a homeowner-driven model, though foreign agencies may be involved in providing technical assistance, costs will be limited to personnel, which can be low if local engineers and construction professionals are relied upon.

- **Price Escalation**: Though donors/non-governmental organizations (NGOs)/contractors can sometimes get lower prices because they can buy in bulk, usually in a post-disaster situation in which substantial foreign aid funding is available, unit prices will go up due to the demand and the perceived deep pockets of the foreign aid agencies. These agencies were not present in West Sumatra, demand was lower and spread out over a longer timeframe, thus fluctuations in prices were more likely associated with normal market changes.

- **Reduced Theft And Corruption**: Homeowners are more likely to protect and avoid theft of materials they purchase themselves.

- **Reusing Materials**: In a donor-driven model, all materials are usually purchased new. In homeowner-driven, the homeowner usually uses some salvaged or stockpiled materials, such as old window and door frames, timber, roof sheets, sometimes bricks. This reduces the cost of the building.

- **Finishing**: Donors may provide a completely finished house – plastered and painted. Homeowners may wait to paint their house until they can afford it.

- **Choice of a More Affordable Structure**: In Aceh, homeowners and donors chose more expensive and difficult to build structural systems (confined masonry and reinforced concrete frame with masonry infill) because they could, donors would pay for it; and the environment was such that competition existed between aid agencies. In West Sumatra, an increasing number of homeowners choose to build from timber frame with a masonry skirt wall – a less expensive, easier to build, more earthquake-resistant building.

SUCCESSFUL HOMEOWNER-DRIVEN RECONSTRUCTION

The homeowner-driven reconstruction model is most effective when the essential technical, financial and social components are in place.

Technical: Earthquake-resistant construction will become common only if the right technology is locally available, widely known, and culturally accepted.

- Technology Choice: It is easier and more effective to make improvements to existing building methods, rather than introduce something new. When given the choice, homeowners will choose what they are already familiar with. The opportunity exists to work with the homeowner to build better using locally available materials and techniques.
- Standards: A clear, complete, consensus-based, government produced or endorsed guideline for each common structural system that consists of design rules and component drawings, and can be applied to any floor plan.
- Capacity: Trained builders, engineers, architects, building materials suppliers.

Financial: Homeowners must have access to sufficient funds to rebuild safely and completely.

- Access to Capital: Sufficient funding in the form of grants, loans, or materials vouchers.
- Incentives: Provision of financing must be contingent on applying minimum standards.
- Subsidies: Subsidies or price controls on certain building materials.

Social: Someone has to want the house to be earthquake-resistant.

- Motivation: Demand creation among homeowners, tying financing to compliance with building standards.
- Enforcement: Building standard enforcement by government officials, donors, or a third party.

The following table contrasts homeowner-driven reconstruction programs in three countries in terms of the above criteria.

Table 2. Comparison of Homeowner-Driven Housing Reconstruction Programs in India, Indonesia, and China

	2001 Gujarat, India	2007 and 2009 West Sumatra, Indonesia	2008 Wenchuan, China
TECHNICAL			
Technology Choice	Wide Ranging and Flexible – Government provided prescriptive reinforcement details but allowed many types	Sufficient – Government allowed two most common structural systems – timber frame with masonry skirt and	Sufficient – Government allowed the most common structural system – confined masonry with a reinforced concrete roof – but

	2001 Gujarat, India	2007 and 2009 West Sumatra, Indonesia	2008 Wenchuan, China
	of wall materials (brick, block, stone); also allowed earth-based systems	confined masonry – but initially discouraged the former	discouraged timber roof with clay tiles
Standards	Clear and Comprehensive – prescriptive standards issued by government, except for gable wall reinforcement	Limited – a variety of standards and guidelines available, but not clear and comprehensive standard issued by government	Limited – a variety of standards and codes available from national to local, but applying to typical houses required judgment and interpretation
Capacity	Sufficient; capacity building programs were implemented	Limited capacity building by universities and technical consultants	Sufficient capacity, limited capacity building needed
FINANCIAL			
Access to Capital	Sufficient cash grant provided by government to most homeowners	Insufficient cash grant provided by government, limited donor agency funding following 2009 earthquake	Sufficient cash grant and loan access provided by government to most homeonwers
Incentives	Yes – funding given out in installments,	No – limited to no building standard enforcement by government	Varies – incentives given to builders
Subsidies	Some	None	Some
SOCIAL			
Homeowner Motivation	High – funding contingent upon meeting standards	Homeowner, community group, technical consultant, and/or government	Contractor, technical consultant, and/or government
Building Standard Enforcement	High – government employed a third party quality inspector	None	Varied – depended on contractor, government and presence of external technical consultant
OVERALL SUCCESS			
Completion Rate	High completion rate	Mixed; higher completion rate for timber frame houses than confined masonry houses	High completion rate
Building Standard Compliance Rate	High compliance rate except for gable wall reinforcement or cases in which third party inspector was absent, or not competent	Mixed: higher standard compliance rate for timber frame houses; lower for confined masonry	Varied; higher in areas with external technical consultant

1. IMPLEMENTING PARTNERS AND STAKEHOLDERS

Key roles must be filled in order to execute a homeowner-driven housing reconstruction program: technical consultant(s) for design and construction supervision, and implementing partner(s) for homeowner selection and fund distribution.

It is possible and recommended that the same organization be used as the technical consultant for design and construction. The technical consultant or consultant team could be an A&E firm, a specialized non-profit organization or social enterprise, a team of local experts from the academic and business sector, or any combination of the above.

However, the implementing partners for design and construction should be different from the implementing partner for homeowner selection and fund distribution. Separating these roles preserves the consultant relationship between the homeowner and technical consultant; the technical consultant is seen as a trusted advisor rather than a source of funding, which facilitates a better dialogue about safe construction. Plus, this separation better mirrors the contracting requirements and separation of roles under FIDIC (Fédération Internationale des Ingénieurs-Conseils or International Federation of Consulting Engineers).

Additional partners may be needed for other activities which are necessary prior to housing reconstruction but are outside the scope of this Primer. Those activities include but are not limited to the following:

- Rubble clearing
- Property rights and land titles
- Community mapping and planning, with plot boundaries identified
- Infrastructure planning and implementation

Options for selection of and contracting with the technical consultants and implementing partners are covered in other resources.

THE STAKEHOLDERS IN POST-DISASTER HOUSING RECONSTRUCTION

There are a number of stakeholders involved in post-earthquake housing reconstruction. It is important to clearly define the role of each stakeholder group and leverage their core competency. The major stakeholder groups and their roles are identified in this section.

Donor, in this case, USAID:

- Provide funding for the technical assistance and other work
- Manage disbursement of financial subsidy to homeowner or community group for materials and labor, or oversee the distribution of funding by an implementing partner

Government (Relevant ministries, municipal engineers, and building inspectors):

- Produce consensus-based, clear, easy-to-implement building standards and guidelines
- Provide certification programs for builders, engineers, government officials
- Provide building inspections, drawing reviews, and quality supervision
- Manage disbursement of financial subsidy to homeowner or community group

Homeowners:

- Select the type of structure, layout, materials, and architecture
- Procure the building materials
- Hire the contractor
- Oversee construction
- Pay for building materials and pay the contractor

Community Groups:

- Select homeowners who qualify for the program
- Assist with gathering homeowners for informational meetings and resolving disputes
- Assist in resolution of land rights and property boundary issues

- Identify local builders, building materials suppliers, and other stakeholders

Technical Assistance Providers (Engineers and architects who provide support in developing the building standards and direct technical assistance to homeowners during reconstruction):

- Develop design, construction, siting and materials guidelines, related resources and tools in support of the government and in partnership with all stakeholders

- Provide training and capacity building to homeowners, builders, engineers, and government officials

- Guide the homeowner through the design, builder selection, and construction process

- Supervise construction and provide hands-on training to builders as needed

NGOs/Community-Based Organizations (CBOs): work with community groups and homeowners to:

- Clear debris

- Resolve land tenure issues

- Implement infrastructure projects

- Do civil works such as building retaining walls that apply to more than one house

- Manage disbursement of financial subsidy to homeowner or community group.

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USAID is usually the sponsor of the housing project, and in the case of homeowner-driven housing reconstruction, it contracts directly with engineering and construction companies as technical assistance providers and implementing partners to distribute funds to homeowners.

2. PRE-DESIGN ACTIVITIES

In the wake of a disaster, several activities must take place before reconstruction or retrofitting of permanent housing can begin.

In addition, certain actions, such as conducting an environmental analysis, are required for any USAID project. These mandatory requirements are described in the report "Basic Engineering and Construction Management: A Primer."

1	Assess safety and tag affected buildings
2	Use post-earthquake reconnaissance and forensic engineering to understand causes of collapse
3	Assess other hazards
4	Do housing subsector and market studies
5	Determine which building standards apply
6	Evaluate location options
7	Clarify objectives, performance criteria

2.1. PRE-DESIGN STEPS

Post-disaster housing reconstruction projects require several sets of activities before the project can enter the design phase.

2.1.1. ASSESS SAFETY AND TAG BUILDINGS

Rapid safety assessments will allow for a quick inventory of damaged buildings, and facilitate the quick return of some homeowners to undamaged, safe buildings. An ATC-20 [2] type survey was used successfully following the January 12, 2010 earthquake in Haiti.

2.1.2. UNDERSTAND CAUSES OF COLLAPSE

A post-earthquake environment presents an ideal laboratory in which to learn why buildings collapsed and why they do not. Forensic engineering studies are regularly performed by professional engineers, technical assistance providers, and research institutes such as the Earthquake Engineering Research Institute (EERI) to document lessons learned and make recommendations for safe rebuilding. Identifying causes of collapse can help shape and inform reconstruction guidelines, especially in situations in which building codes or guidelines are not available.

[2] ATC-20 is a rapid method for evaluating the safety of buildings after earthquakes, developed by the Applied Technology Council. Implementation results in placarding or tagging buildings as follows: INSPECTED (apparently safe, green placard), LIMITED ENTRY (yellow placard), or UNSAFE (red placard). More information is available at https://www.atcouncil.org/downloads/atc-20-download.html

See Appendix 1 for a summary of causes of collapse for confined masonry buildings in Indonesia.

2.1.3. ASSESS OTHER HAZARDS

Additional studies may be needed to quantify the likelihood and magnitude of future disasters, including the following:

- Earthquakes
- Tsunamis
- Hurricanes, cyclones or high winds
- Floods
- Landslides
- Climate extremes

2.1.4. DO HOUSING SUBSECTOR STUDIES

It is easier and more sustainable to make minor low or no-cost improvements to existing ways of building, than it is to introduce a completely new technology or reintroduce a traditional building method that is no longer common. Housing subsector studies address the following questions:

- What types of houses do people want to build here, now? For example, will people build from timber, masonry, earth, or some other structural system?
- What size, shape, number of stories and layout are common?
- Where do people cook? Bathe? Use the toilet?
- What are the common architectural, cultural, and climate preferences? Have these preferences changed as a result of the disaster?
- What materials are used, where are they produced, how much do they cost, will the production be able to meet demand? Who buys the materials (homeowners, builders, contractors)?
- What is the skill level of local builders? What tools and techniques do they use? How much do they earn?
- How are houses commonly built – Do homeowners build themselves or hire local builders? Or are housing units built by the government or through the commercial private sector?

- What other issues may arise during reconstruction – security, conflict?

The most effective way of obtaining the above information is through direct interviews and surveying of various stakeholder groups, such as homeowners, builders, building materials producers, and municipal officials. The Emergency Market Mapping and Analysis (EMMA) Toolkit[3] has become a popular method of rapidly assessing the market for reconstruction after a disaster.

2.1.5. DETERMINE WHICH BUILDING STANDARDS APPLY

In the pre-design phase, it is necessary to determine if relevant and adequate building codes and standards exist in the project country. Codes may not exist, or the codes may not be relevant to the most common structural system used for housing. For example, in many developing countries, building codes for multi-story buildings may exist, but applying these codes to a single or two-story single family home may result in overly conservative design and construction guidelines which lack important details on essential techniques to build an earthquake-resistant structure.

The codes and standards used should meet the standards applicable in the country in which the project is located. If such standards are not available, regional or international standards can be used. US standards are typically used on USAID projects; however, these usually exceed local codes and standards.

In the case of incomplete or inapplicable building codes, the best design solution may be a mix of international building codes, existing simple design and construction guidelines, and engineering judgment to arrive at a solution that is sufficiently safe yet affordable, sustainable, and implementable for the local context. Appendix 2 contains a review of standards for confined masonry homes in Indonesia.

2.1.6. EVALUATE LOCATION OPTIONS

Every effort should be made to facilitate reconstruction of homes in their original location; however, government-mandated land reorganization or decentralization or presence of extremely hazardous site conditions may necessitate the need for relocation. The choice to relocate displaced individuals to new settlements should not be made

[3] http://emma-toolkit.org/

without serious consideration of the possible consequences, including but not limited to the following:

- Additional cost of land acquisition
- Additional cost of roads, sewers, utilities, and other infrastructure
- Inability to connect homes to utilities
- Disruption of social network
- Lack of employment opportunities
- Lack of services
- Lack of or additional cost of transportation
- Change in environment and space, such as lack of trees, sources of shade, and communal spaces

Furthermore, unclear or poorly documented property rights have the potential to seriously delay post-disaster housing reconstruction programs. Techniques and case histories for resolving these issues to a donor's expectation are beyond the scope of this Primer.

2.1.7. CLARIFY OBJECTIVES AND PERFORMANCE CRITERIA

At this stage of the studies, the project team, in consultation with project country government officials, must decide on performance objectives and priorities. Some questions to be addressed:

- Should damaged houses be repaired (returned to pre-disaster conditions) or retrofitted (strengthened to resist the next disaster)? To what performance level should houses be rebuilt or retrofitted? A common performance level for housing is life safety, which according to National Earthquake Hazards Reduction Program (NEHRP) means that significant damage to structural elements may occur, but a margin remains against collapse. Occupancy may be prevented until repairs can be implemented.

Some design criteria for consideration are the following:

TECHNOLOGY

- Disaster-resistant in design – compliant with standards and guidelines
- Disaster-resistant in construction – built with quality workmanship

- Durable and permanent
- Built with locally available materials, skills, and tools
- Easily expanded and maintained using locally available materials and skills
- Where possible, reuses materials
- Can be built incrementally, improved from transitional to permanent, and/or expanded horizontally or vertically

MONEY

- Competitive in cost with local, common (but vulnerable) building methods

PEOPLE

- Environmentally neutral – using no illegal materials
- Suitable to the climate
- Culturally appropriate in architecture, space, and features
- Secure from break-ins and pests
- Designed and built with the participation of the people
- Trusted by the inhabitants who believe their house will survive a disaster.

Following are some examples of consequences when a detailed housing subsector study is not completed and/or design criteria are not followed.

1) Poor choice of structural system. Following the 1993 Killari Earthquake in eastern Maharashtra, India, an agency implemented a geodesic dome type building for housing reconstruction. This design choice certainly meets disaster resistance criteria, however, according to the homeowners, the structure is not culturally appropriate in architecture, space and features. The homeowners complained that the interior was too dark, air circulation was poor, and it was not easy to divide the interior space for privacy. Furthermore, the homeowners could not extend the house easily, and used poorly confined masonry to do so. Because the agency implemented a building technology that was not common or culturally appropriate, the opportunity to train local homeowners and builders in common techniques was missed.

2) Poor choice of layout. Following the 2001 earthquake near Bhuj in Gujarat, India, though most homeowners opted for homeowner-driven reconstruction; some homeowners received a house designed for them by a relief agency. In this case, the agency chose to put the toilet inside the house, though the common preference for the toilet in this area is outside the house. As a result, the toilet is unused, space is wasted in a small dwelling, and structural modifications could be made that reduce the disaster resistance of the building.

3) Lack of homeowner involvement in reconstruction. Following the 1993 Killari, India earthquake, a contractor-driven approach was used in which homeowners were minimally involved. Ten years after the earthquake, these homeowners were still sleeping outside their house because they did not trust that the concrete was mixed with enough cement to withstand the next earthquake.

3. DESIGN

The design phase entails the compilation of design criteria, structural engineering analysis for a few typical floor plans, and development of prescriptive design rules for application to a variety of configurations. This phase also includes the preparation of component drawings, bills of quantity, construction specifications, estimated manpower needs, and a construction schedule for each structural system likely to be selected by a homeowner.

The objective of the design phase in a homeowner-driven housing reconstruction technical assistance program is to develop a set of prescriptive guidelines that could apply to a variety of floor plans and horizontal and vertical configurations. The first step is to complete a detailed structural analysis of a few common floor plans. General design rules are extrapolated from this process in order to enable homeowner choice of building materials, layout and other design features while ensuring the house is sufficiently disaster-resistant.

Design Criteria	Codes and standards Loading and structural design criteria Siting and foundation criteria Architectural criteria Building materials properties
Structural Analysis for Typical Floor Plans	Detailed structural engineering analysis Detailed structural, architectural, and construction drawings for typical horizontal and vertical configurations Detailed technical specifications Bill of quantity and cost estimate Construction schedule Installment payment schedule
Design Rules and Standard Documents	Design rules for application to a variety of floor plans Component drawings Quantity and cost estimating form Cost estimate per unit of floor area Contract template

The phases of design are as follows

2.2. DESIGN CRITERIA

2.2.1. CODES AND STANDARDS

The compilation of codes and standards should include local, relevant codes and guidelines, supplemented with international standards where needed. The selection should include structural design codes as well as material design codes. The selection may include relevant simple guidelines or handbooks from the project country or for similar structural systems used around the world.

2.2.2. LOADING AND STRUCTURAL DESIGN CRITERIA

Similarly, load codes and loads for design should be selected based on local relevant codes and supplemented with international standards. The following loads should be specified (if relevant):

- Gravity
- Dead
- Live
- Snow
- Flood
- Wind
- Seismic

Seismic loads should be based on seismic hazard mapping. If detailed studies are not available for the project country, the Global Seismic Hazard Assessment Program (GSHAP) mapping can be used[4].

2.2.3. SITING AND FOUNDATION CRITERIA

Critical factors to consider in evaluating existing and new sites for reconstruction include soil conditions, slope and slope stability, potential for settlement and liquefaction, flood risk, and proximity to known faults. Examining regional, local, and neighboring sites for evidence of hazardous conditions is helpful when it is unlikely that a formal soil investigation will be performed for each building site.

[4] The Global Seismic Hazard Assessment Program (GSHAP) produced global and seismic hazard maps. Please see http://www.seismo.ethz.ch/static/GSHAP/

At a minimum, maximum percent slope should be specified, allowable soil bearing capacity should be estimated, soil type specified, and during the analysis, foundation design should be checked for uplift due to wind and seismic loading.

2.2.4. ARCHITECTURAL DESIGN CRITERIA

Architectural preferences should be gathered from visual inspection of recently built structures, recent publications on architectural preferences, and interviews with stakeholders, particularly homeowners. Preferences will likely vary based on location (urban vs. rural).

Preferences on the following should be collected in the housing subsector study described previously. Design suggestions and parameters should be specified on the following:

- Structural System, such as confined masonry, unreinforced masonry, timber frame with infill, earth-based systems; materials to avoid and use in construction
- Configuration and Layout, including typical number of stories, layout and usage of rooms including kitchen and toilet, size of rooms, presence and design of porch, garage, parapet wall, and other features; specify maximum room size, special considerations for parapet walls, overhangs, and open space on the ground floor of multi-story buildings; consider Sphere project standards
- Floor and Roof Elevations, including floor-to-ceiling heights, specify finished floor elevations and maximum and minimum floor-to-ceiling height
- Future Building Additions, evaluate the likelihood of future building additions for consideration in design; for example, even if a one-story building is anticipated in the funded reconstruction program, the single-story building may require design for a second story if that is likely during the lifetime of the building
- Doors and Windows, including size, materials, typical locations, and security considerations; specify the preferred location, maximum size, and reinforcement alternatives in the event the cultural preference is for a larger than suggested opening; consider requirements for ventilation and light and positioning to minimize intrusion of rain and sun

- Roofs, typical styles and materials for roofs, specify pitch, elevation, waterproofing and drainage, minimum and maximum eave projection, and considerations for rainwater harvesting systems
- Stairs, identify typical locations and materials used for stairs, specify structural and connection details
- Water, Sanitation, and Electrical, determine common placement of utilities and specify the locations to avoid.

2.2.5. BUILDING MATERIALS PROPERTIES

Typical materials properties should be gathered and minimum materials strengths should be suggested. Common building materials include the following:

- Aggregates, such as sand and gravel: specify size, gradation, and acceptability of using rounded gravel
- Cement and Lime, evaluate the prevalence of lime and cement products such as Portland Type 1 cement and blended products with additives, recommend appropriate products for each application, such as foundation, reinforced concrete, and masonry
- Masonry units, such as fired bricks, concrete blocks, earth blocks, stone; specify minimum strength and allowable size deviations
- Steel reinforcement, specify size, strength, and acceptability of using smooth bar and reused steel
- Structural timber, specify grade, treatment
- Structural steel, specify size and grade
- Wall coverings, such as plywood, mineral board, fiber cement board, chain link fencing, bamboo mats, or other products; specify size, treatment, and strength
- Roof coverings, such as clay tiles, thatch, corrugated galvanized iron, corrugated plastic or asbestos sheets; specify size, thickness, and treatment
- Connectors, such as nails, screws, roof tie downs
- Hardware, such as door knobs and hinges and window latches
- Utilities, such as piping, toilets, faucets, electrical boxes and switches.

For all cases, specify materials to avoid. Information should also be provided on:

- Tools and equipment
- Scaffolding and shoring, determine minimum specifications and availability
- Mechanical equipment, such as mortar and concrete mixers; such machinery is not often used in the construction of single family housing in developing countries.

2.3. STRUCTURAL ENGINEERING ANALYSIS FOR TYPICAL FLOOR PLANS

Once the project management team has completed its review of the design criteria, the technical consultant should be given permission to proceed to the structural engineering design phase for one or more typical floor plans for each structural system.

Deliverables for the structural analysis phase include:

- Structural analysis narrative, which explains the assumptions and limitations of the analysis
- Structural, architectural, and construction drawings to an acceptable standard showing in detail the proposed construction
- Technical specifications
- Bill of quantity and cost estimate
- Construction quality checklist
- Construction schedule
- Installment payment schedule

2.4. DESIGN RULES AND STANDARD DOCUMENTS

Once the project management team has completed its review and approval of the structural analysis on a few typical floor plans, the technical consultant should proceed to the development of design rules and associated documents that can apply to a variety of floor plans.

Deliverables for this phase include:

- Design rules

- Standard detail drawings
- Simple cost estimating tool
- Simple construction scheduling tool

To see a set of design rules and standard documents for confined masonry homes for Haiti, please go to: http://www.buildchange.org/HousingPrimer.html

3. HOMEOWNER-DRIVEN DESIGN

This phase of a homeowner-driven housing reconstruction project extends the design phase to the individual design of each house with the homeowner.

It should be noted that this phase may result in refinement and revision of the documents prepared in the previous phase. As such, it is recommended to use the same technical consultant team for the entire design phase.

Initially, the project team should introduce the program to community leaders to gain their endorsement. A community meeting should be held with all homeowners to explain the process, schedule, requirements, and their responsibilities for receiving grant funding.

The next step is to interview each homeowner and to inspect their plot or existing home in the case of retrofitting. It is recommended that local engineers and architects be employed in this process to minimize misunderstandings due to language and cultural differences and to achieve the goal of capacity building and job creation in a post-disaster environment.

During the initial meeting with the homeowner, a trained architect or engineer can develop a simple hand sketch of the floor plan for homeowner review and input. Also, a quick cost estimate can be obtained using a simple estimating tool in order to allow for modification of the plan in the event that the homeowner's aspirations are beyond their budget.

3.1. HOMEOWNER QUALIFICATION

To qualify for homeowner-driven reconstruction technical and financial assistance, homeowners should:

- Apply for it. It should be up to the homeowners to decide to participate in the program. In the initial stages, homeowners should not need to specify if they are applying for retrofit or new construction; this is an informed decision to be made by the homeowner after the retrofit evaluation.

- Document their rights to land to the expectation of the donor
- Declare that they are building residential unit(s), as opposed to a commercial property
- Attend a workshop on disaster-resistant design, construction, and materials standards
- Sign a contract with the donor or implementing partner in which they agree to meet minimum standards for earthquake and hurricane safety (or other relevant disaster-resistant standards), and acknowledge that provision of funding is contingent upon meeting minimum standards
- Review and provide sign-off on the floor plan, structural details, and bill of quantity
- For new housing, clear the property of debris; for retrofitting, prepare the building for retrofitting by removing contents and temporarily relocating if necessary
- Choose builders and building materials suppliers who have been certified by the government, donor, technical assistance provider or others
- Protect materials from theft and damage (store cement out of the rain)
- Assist with supervision of materials and construction quality
- Pay building materials suppliers and builders in a timely and fair manner.

3.2. HOMEOWNER PREFERENCES SURVEY

The engineer or architect employed by the technical consultant will sit down with each homeowner and fill out a homeowner preferences survey. This survey collects much of the same data as in a housing subsector study, but specific to each homeowner. The homeowner preferences survey includes the following:

General Data	Homeowner name, address, ID House address, GPS coordinates Surveyor name and survey date
Homeowner Data	Family structure, number of family members, gender Special needs or mobility issues Current living situation Land tenure status Job and income

Old House Facts	Location, size, layout, materials, earthquake-related damage, other issues such as ventilation, leaky roof, security Location of kitchen and bath, septic and well, electrical hookups
New House Preferences	Preferences for size, layout, materials, locations of windows and doors Priorities (size, durability, safety, comfort, services such as kitchen and bath) Willingness to share walls or live in multi-unit dwellings Intention to expand horizontally or vertically
Homeowner Contribution	**Design** – Does the homeowner want to choose the layout, materials, and architectural features? **Construction** – Does the homeowner want to build himself, choose the contractor, supervise construction, or remain uninvolved? **Materials contribution** – Does the homeowner have stockpiled or salvaged materials for use in rebuilding? What type and how much? **Construction inputs** – Can the homeowner provide water and/or electricity to be used during construction? **Funds contribution** – Can the homeowner contribute funds to build a larger or more disaster-resistant home?

3.3. PLOT SURVEY AND SKETCH

The architect or engineer should inspect the plot to orient the house on the plot, note the presence or absence of utilities, drainage, septic systems, wells, trees, excavations, or other obstacles which may impact the design and construction of the home or access to the property. The architect or engineer should pay special attention to the orientation of the house and sanitation facilities relative to sun, wind, and cultural norms. A plot sketch should be prepared.

3.4. DESIGN AND COST ESTIMATION

The architect or engineer should then prepare a plan, elevation and detailed cost estimate for the home. Depending on schedule and budget, this can be done using hand sketches and calculators, or drafting software and spreadsheets. Once the design documents are completed, the architect or engineer should meet again with the homeowner to gain the homeowner's approval or make the necessary modifications.

For large-scale projects, common floor plans tend to be used by more than one homeowner, offering economies of scale.

3.5. HOMEOWNER TRAINING

Prior to start of construction, groups of homeowners should attend short training courses on safe construction, in order to empower the homeowners to assist with construction supervision. When provided with basic information such as relative proportions of cement, sand, and gravel required to achieve the specified concrete strength, homeowners can play an integral and valuable role in construction supervision. Sharing such knowledge with homeowners can build their confidence that their house will withstand the next earthquake, and contribute to long-term recovery from the traumatic effects of the disaster.

Suggested content for homeowner trainings includes the following:

- Why did your house collapse in the earthquake?
- How likely are more earthquakes in your location?
- How can you make your house resist the next earthquake and other disasters?
- Design features to avoid and why
- Simple methods for evaluating materials quality
- Concrete mix proportions
- Basics for concrete mixing, masonry work, or other relevant construction techniques.

Go to http://www.buildchange.org/HousingPrimer.html for examples of typical instructional materials for homeowners from Indonesia, China, and Haiti.

3.6. REVIEW AND PAPERWORK FLOW

The drawings and cost estimate are presented to the homeowner for review. Once the homeowner agrees with the plan, the complete packet is submitted to the fund distribution implementing partner for first tranche payment. The homeowner is provided with one set of drawings for him/herself and one set of drawings to attach to the contract with the contractor, if used.

All parties involved in the project are responsible for record-keeping:

- The ***design technical consultant*** will keep the design file and submit it to the fund distribution partner when the design is final and ready for construction. The design technical consultant will report on how the number of design packets completed compares to goals.

- The ***construction technical consultant*** will keep construction quality checklists and file for tranche payments. Though construction management is the responsibility of the contractor/builder, he or she will keep a daily record of the work performed, the weather conditions, and other information (for example, safety issues). The construction technical consultant will also note how the work is progressing relative to the schedule. An essential element of the construction technical consultant's files is a library of photographs which documents the construction progress and provides adequate documentation of compliance with construction quality standards.

- The ***fund distribution implementing partner*** should keep records of funds distribution to the homeowners.

- The ***homeowner*** should maintain his or her own records, including the complete design packet with structural, architectural, and detail drawings, contract with the contractor, receipts for building materials purchases and payment to contractors.

- The ***contractor/builder*** will also maintain his or her own records, such as contract with the homeowner, drawing packet, daily work log, reasons for delays, safety issues, receipts for building materials purchases and payments to builders.

- The ***USAID project manager*** must maintain adequate records in order to be able to readily produce reports on the project's status, problems, and successes. He or she will reply primarily on reports from the technical consultant and fund distribution implementing partners. It is important that the project manager make routine site visits and records his/her observations, especially concerning problem areas. Photographs are important and should be part of the project manager's files.

4. CONTRACTOR/BUILDER SELECTION

Contractor or builder selection is usually done by the homeowner with oversight and advice of the technical consultants.

This section covers identification and selection of the contractor or builder and contracting between the homeowner and builder.

4.1. BUILDER OR CONTRACTOR IDENTIFICATION

Homeowners can choose to rebuild the house themselves; however, this choice is usually made only by homeowners who have construction experience or those who have skilled builders in their family. It is more common for homeowners to hire a local builder. This is done individually or as a group; some homeowner-driven reconstruction projects resemble community-driven reconstruction in that small groups of homeowners will join together to hire one larger contractor to build several houses. In this case, the funds may be given to a community group rather than each individual family.

Builders or builder groups can be selected by the homeowner as follows:

- The homeowner him/herself or relatives
- Local builders selected by the homeowner
- Builders recommended by community leaders
- Builders identified through local trade institutions

Because the homeowner is selecting the builder, it is difficult to implement a thorough prequalification process. However, the donor or implementing partner could require some review of the builder's experience and/or require the builder's team to participate in a training or certification program prior to being considered for a housing construction contract. Also, providing incentives to promote construction in compliance with standards, such as the possibility of winning additional contracts in the future, has proven successful.

4.2. CONSTRUCTION CONTRACT

Houses built through the informal construction sector in most project countries rarely have formal contracts in place between the homeowner/owner and the builder. However, the post-disaster reconstruction environment provides an opportunity to take this step forward and implement a simple contract intended to protect the rights of both the builder and the homeowner.

Relevant government officials should be consulted to determine if such a contract already exists in practice in the project country. Simple two page contracts should include the following, as appropriate:

Some Elements of Simple Contracts Between Homeowners and Contractors
Owner name, address and identification number
Contractor name, address and identification number
Commitment to follow governing law
Project name
Project address
Building footprint area, number of stories
Type of contract (typically lump sum paid in installments)
Total price, specify materials and labor, labor only, materials only; price usually includes Contractor's fees, construction management, profit, taxes
Payment schedule, including defects liability period
Construction schedule (start date, end date, number of days)
Force majeure clause, typically requires homeowner to pay for completed parts that meet quality specifications; contractor to cover loss of tools or equipment on site
Homeowner commitment to pay the Contractor per the terms of the contract
Homeowner's rights, such as the right to inspect the site and offer technical inputs
Contractor commitment to complete the construction works to acceptable quality and on schedule per the terms of the contract, and duty to protect workers' safety
Cancellation clause
Signatures of both parties

4.3. PRE-CONSTRUCTION TRAINING OR CERTIFICATION

Expectations for quality should be made clear to the contractor. Quality control is the responsibility of the contractor and the homeowner. For example, the technical consultant could hold short training courses or workshops to groups of contractors prior to construction. Homeowners and local government officials should be invited to join. These trainings should cover both construction quality and construction site safety.

4.4. PROJECT SCHEDULE

The schedule is difficult to control in homeowner-driven reconstruction, as the pace is typically set by the homeowner and contractor. Interruptions related to weather, holidays, cash flow, and work or family obligations for the homeowner can be common. However, interruptions can be minimized if funding is provided promptly as described in the final section of this Primer.

ANNEXES to Simple Contracts Between Homeowners and Contractors
Design specifications
Structural, architectural, and construction drawings, including plan, elevation, relevant sections, standard connection details
Materials specifications

5. CONSTRUCTION SUPERVISION

Construction supervision is necessary to achieve the objective of a disaster-resistant home, and to authorize the release of the next funding installment for reconstruction. Construction supervision also provides an opportunity for on-the-job training of local building professionals.

The level of construction supervision can vary from a cursory review to a detailed review depending on the complexity of the construction and the skills of the builders. Construction supervision is best provided by in-country professionals and technicians, who usually require training but have been shown to evolve into competent supervisors. The assigned field personnel's integrity and attention to detail are very important. Oversight and mentorship by experienced mid- or senior-level professionals is essential.

5.1. CONSTRUCTION CHECKLIST

A simple construction quality checklist should be developed and used in this process. The level of detail expected in the checklist depends on the donor's expectations. Following is a short list of contents in a checklist used for a typical confined masonry building built in a post-disaster environment. For a more detailed checklist, please go to http://www.buildchange.org/HousingPrimer.html.

SAFE SITE and SOIL
Percent slope or slope stability
Setbacks from slopes, riverbeds, drainage, roads, and other buildings
Soil is not liquefiable sand or expansive clay
MATERIALS QUALITY
Quality of materials, such as sand, gravel, stone, cement, masonry units, reinforcement, timber, roof covering, others
FOUNDATION
Excavation in correct location and at proper angles, bottom flat and level, no standing water, loose soil, tree trunks or voids
Soil meets bearing capacity requirements
Foundation base layer meets thickness and strength

requirements
Foundation follows proper masonry or reinforced concrete practices (see next sections)
Superstructure elements are anchored in foundation
REINFORCED CONCRETE
Reinforcement diameter, strength, and condition
Reinforcement assembly as per specification
Concrete formwork installed correctly and using spacers to maintain cover of concrete over steel
Concrete mix proportion as specified
Concrete poured, compacted and cured per specification
MASONRY WALL
Mortar mix proportion as specified
Masonry units laid with proper bonding, staggered joints, joints completely filled with mortar
Masonry wall cured per specification
Wall is plumb and level
Electrical and plumbing installed properly
Wall plastered and painted per specification
ROOF
Roof tied down to walls
If timber, connections reinforced, roof cover installed to prevent leakage
If reinforced concrete, follows reinforcement detail specification and concrete mixing specification
Waterproofing adequate

6. FUND DISTRIBUTION

Fund distribution takes place at the start of and during the construction phase. Funds should be distributed in installments, once phases of construction are complete and deemed to be in compliance with design specifications and construction quality standards.

Providing funds in installments, contingent upon compliance with standards, is one of the best ways to increase quality and leverage reconstruction funding to promote change in construction practices.

Giving funding out in installments at appropriate junctures in construction is an important mechanism for compelling compliance with building standards: homeowners should not be provided with the next installment until compliance has been documented on previous construction steps. This will help to assure that the work is completed in accordance with the host country's understanding and USAID's regulations and policies. Fund distribution runs concurrently with the construction phase.

Homeowner-driven housing reconstruction will not produce safe, complete homes for all if the homeowners do not have sufficient access to financial resources.

6.1. FUND DISTRIBUTION OPTIONS

Homeowner-driven reconstruction is most effective when the financing is provided in installments, and contingent upon meeting minimum standards for design, materials, and construction quality. Some options for fund distribution include the following:

Provide cash grants to small groups of homeowners

Pros:

- More efficient distribution of cash; fewer transactions and bank accounts involved
- More economies of scale for labor and building materials: larger scale contractors could build or retrofit several housing units at once for small groups of homeowners
- Can use peer pressure to solve problems

Cons:

- May result in inequitable distribution of funds and/or fees charged by facilitators
- May result in less individual choice by each homeowner

Provide cash grants *to each homeowner*

Pros:

- May eliminate "fees" with a facilitator or community group
- Empowers each homeowner to make their own decisions

Cons:

- More administrative requirements, as requires setting up a bank account for each homeowner
- May be more difficult to solve problems

Provide *vouchers* for building materials

Pros:

- Higher likelihood that funds are used to purchase building materials
- Allows some control over quality and vendor choice

Cons:

- May encourage nepotism or corruption in the process for selection as a preferred vendor
- May discourage using small vendors
- Limits choices and provides less empowerment to homeowners.

6.2. FUND DISTRIBUTION SCHEDULE

There are several options, here is one scenario if the donor is providing all of the funds needed to build a typical confined masonry house:

- **Installment 1: Prior to construction.** Includes funds needed to procure sand, gravel, stone, cement, steel, and formwork; and labor to build the foundation, erect steel for columns and foundation beam, and pour concrete for the foundation beam.

- **Installment 2: After completion of foundation.** Includes funds needed to procure masonry units or other wall material, build the wall and cast the concrete for columns.
- **Installment 3: After completion of wall.** Includes funds needed to procure materials for the ring beam and roof and labor to cast the ring beam and build the roof.
- **Installment 4: Finishing bonus, after roof and all structural elements are completed.** Includes funds needed to procure doors, windows, door and window hardware, flooring, plastering, and finishing.

If the donor is providing only a portion of the funds needed to build the house, the homeowner should provide the first installment of funds. This will help to ensure a complete house is built. Remaining installments should be proportioned out as above.

APPENDIX 1: UNDERSTANDING CAUSES OF COLLAPSE CONFINED MASONRY HOUSES IN INDONESIA

Since the 2004 Indian Ocean tsunami, there have been at least seven earthquakes of significant strength to cause housing collapses, deaths, and injuries in other parts of Indonesia: Central Java, M6.3 on May 27, 2006; West Sumatra, M6.4 and 6.3 on March 6, 2007; Bengkulu and the Mentawai Islands, M8.5, 7.9 and 7.0 on September 12 and 13, 2007, and Padang, West Sumatra M7.6 on September 30, 2009. Strong ground motion recordings are not available for any of the events. The Central Java event was the most deadly (killing 5,782 people), had the most devastating effect on housing stock, damaging or destroying 135,000 houses, and yielded compelling examples of good performance of confined masonry houses in villages where 70-90% of the other buildings were destroyed or heavily damaged.

Many newly built confined masonry houses with reinforced concrete tie columns and bond beams at the plinth and roof levels performed well in these earthquakes while confined masonry homes that did not follow minimum design and construction standards were damaged. See Figures 1 and 2 for a well-built confined masonry house with no evidence of damage, on the edge of heavily damaged Pleret (2006 Central Java earthquake). In typical confined masonry practice, the tie columns are cast after the masonry wall was built, flush with the wall, and thus the same width as a brick or block (10 or 11 cm). Smooth reinforcing steel is common in both Central Java and West Sumatra, typically 6 or 8mm in diameter with stirrups ranging from 3 to 6mm in diameter. Stirrups were often spaced at 15 to 25 cm intervals.

Figure 1. Well designed and built confined brick masonry house, edge of heavily damaged Pleret (Bantul), S7.83686° E110.41552°, IMG_6636

Figure 2. Well-built confined masonry wall, house on edge of heavily damaged Pleret (Bantul), S7.83686° E110.41552°, IMG_6640

In contrast, the house shown in Figure 3 illustrates many of the shortcomings common to poorly designed and built confined masonry houses in Indonesia – tall slender wall with tendency to overturn, insufficient connections between confining elements, no reinforcement in the wall especially above openings. These flaws, and how the flaws can be addressed in design, are described in the following sections. The problems and solutions are grouped according to the three C's – configuration, connections, and construction quality.

Fig. 3. Confined masonry house under construction, insufficient connections, Pleret (Bantul). S7.87574°, E110.40703°, IMG_6575

THE FIRST C: CONFIGURATION

(1) MASONRY GABLE WALLS

Problem: Masonry gables are notoriously poor performers in earthquakes (see Figures 4 and 5) and should be avoided. Damage and failure to masonry gable walls was widespread throughout all three earthquake-affected regions, and plagued both new and older houses with and without reinforced concrete ring beams. In most cases, gable masonry was neither properly confined nor properly connected to the roof. Cross-bracing between gables was not common.

Figure 4. Masonry gable wall overturning in 27 May 2006 Central Java Earthquake, Keputren, Pleret (Bantul) S7.86905° E110.40272°, IMG_6721

Figure 5. Masonry gable wall overturning in 27 May 2006 Central Java Earthquake, (Bantul) S7.89468°, E110.37341°, IMG_6542

Solution: REMOVE THE MASONRY ABOVE THE RING BEAM: Shift the truss over to rest on the wall and use a timber or other lightweight cover (Figure 6). Alternatively, use a hipped roof (Figure 7) which is the lowest cost alternative, and also performs better in high winds.

Figure 6. Papan Gable (Maimunah's house designed and built by Build Change, Keunue ue, Peukan Bada, Aceh Besar)

Figure 7. Rabung Empat Roof (Rusdi Razali's house designed and built by Build Change, Keunue ue, Peukan Bada, Aceh Besar

Other Options: In theory, it should be possible to properly detail and build a masonry gable wall. However, there are so many construction challenges, including but not limited to: locating the gable beam reinforcing correctly, bending the reinforcing at the ends at the proper angle, and embedding the gable beam reinforcement into the columns or ring beams below. Most builders have difficulty constructing these elements correctly. In Aceh, cases were observed in which the steel cage is assembled, laid to rest on the wall for show, and just prior to pouring concrete, it is removed and used for the next house. This results in dangerously insufficient construction.

(2) LARGE OPENINGS

Problem: Large openings at the front of the house are common. There are many examples from all earthquakes in which the front of the house has collapsed, while the back of the house remained intact (see Figures 8 and 9). The problem associated with this lack of stiffness in the in-plane direction of walls with large openings and lack of confining elements to restrain masonry panels from failing outwards is exacerbated by the heavy mass of the masonry gable wall.

Figure 8.Collapse of front wall in confined masonry house , Padang Panjang, IMG_8831

Figure 9. Partially collapsed brick masonry house with RC tie columns and timber bond beams, note partial collapse of masonry gable wall, and lack of in-plane stiffness in front wall, Kec. Lais (North Bengkulu) S3.53217° E102.03771

Figure 10. Rabung Empat Roof (Rusdi Razali's house designed and built by Build Change, Keunue ue, Peukan Bada, Aceh Besar)

Solution (Figure 10):

(1) Reduce the weight above the openings by following the previous recommendation about gable walls,

(2) Reduce the number and area of windows, and consolidate them to provide longer, continuous shear walls,

(3) Add vertical confining elements to all openings with area greater than $2.5m^2$. To reduce cost, shift openings from the middle of the panel to the corner, and

(4) Add horizontal reinforcement to the wall every seven courses and above and below openings.

Other Options: Instead of the horizontal reinforcement every seven courses, consider using a lintel beam and sill beam.

(3) TALL WALLS and LONG WALLS

Problem: Walls upwards of 4m in height and longer than 6m without crosswalls and bracing are common and prone to out-of-plane failure, as illustrated in Figure 11 for a tall wall and Figure 12 for a long wall.

Figure 11. Confined masonry building with overturning failure of tall, unsupported wall, Kec. Airnapal (North Bengkulu)

Figure 12. Confined masonry warehouse with overturning failure of long walls without cross-bracing, , IMG 8891

Solution: Reduce the wall height to a maximum of 3m, and add crosswalls or bracing at the ring-beam level for spans longer than 4m. Tie the walls into the columns using horizontal reinforcement.

(4) COVERED TERRACES

Problem: Covered terraces are en vogue in Indonesia. These open frame elements often have heavy, unreinforced and unconfined masonry gable walls above them. The frame elements are poorly detailed and connected to each other and to the main walls of the house. See Figures 13 and 14.

Figure 13. Subdivision of confined masonry houses, damage to covered terrace, Bengkulu. S3.83218° E102.29287

Figure 14.Subdivision of confined masonry houses, damage to covered terrace, Bengkulu. S3.83218° E102.29287

Solution: (1) Avoid the covered terrace by using a simple extended overhang, as shown in Figure 10. Note that this requires good quality timber, or bracketing to support the overhang. Or, (2) Reduce the mass above the open frame by replacing the masonry, and ensure the connections are detailed properly (Figure 15).

Figure 15. Covered terrace with lightweight wall, Build Change designed house for Catholic Relief Services (Aceh Besar)

THE SECOND C: CONNECTIONS

(5) BETWEEN CONFINING ELEMENTS

Insufficient connections between reinforced concrete tie columns and bond beams in confined masonry structures contributed to a majority of failures in all three events. The common practice of terminating the bond beam and tie column bars in the joint, while providing a small hook at the end, does not provide sufficient development or confinement. This problem was widespread in all earthquakes, and a dominant cause of failure for newly-built confined masonry houses in which both tie columns and bond beams were present. In Indonesia, insufficient connections are a problem that plagues both confined masonry and RC frame construction. See Figures 16 through 18 for examples.

Solution: Bend the column reinforcement into the beams and overlap by 50 times the diameter of the bar. Similarly, bend the plinth and ring beam reinforcing around corners. Tie with double binding wire.

Figure 16. Zoom-in view of ring beam column connection. IMG_6577

Figure 17. Confined masonry house with failure in masonry walls and connections between tie columns and bond beams, Kec. Airnapal (North Bengkulu)

Figure 18.Connection failure, RC frame building, Central Java

(6) BETWEEN MASONRY WALL and TIE COLUMN

Problem: Critical to good performance of confined masonry buildings is the connection between the wall and tie columns. Separation between wall and confining elements occurred in many houses in all earthquakes. See Figures 19 and 20.

Figure 19. Insufficient connection between wall and tie column and between tie column and bond beam, Pleret (Bantul) S7.88174° E100.40869°, IMG_6746

Figure 20. Insufficient connection between wall and tie column and between tie column and bond beam, Segoroyoso, Pleret (Bantul) S7.88174° E100.40869°, IMG_6749

Solution: Toothing, which is recommended for confined masonry buildings, is not commonly practiced in Indonesia. Homeowners and builders are unwilling to spend the extra money and time (respectively) on additional formwork required to accommodate a toothed wall. Further, our experience has been that it is difficult to get the concrete to flow completely into the toothed area. Instead, truss-type horizontal steel reinforcement can be used in the bed joint of the masonry, every seven courses and above and below openings, and tied into the columns and beams.

(7) BETWEEN RING BEAM and TRUSS

Roof trusses are typically connected to the walls by simply and wrapping the bars from the columns around the truss chord. Improving this connection can provide some bracing against out-of-plane failure.

Solution: Strengthen this connection by using a U-shaped steel plate with bolts.

THE THIRD C: CONSTRUCTION QUALITY

(8) MASONRY WALL QUALITY AND USE OF PLASTER

The first line of defense in a confined masonry structure in earthquake strong shaking is a well-built masonry wall. Typical single story confined masonry houses in Indonesia have been shown to perform well in earthquakes, even when the tie columns are small in section and use smooth bars of small diameter, provided the masonry wall is well constructed, with adequate bonding between bricks and mortar. See Figures 21 and 22 for examples of wall collapses with columns and roof intact. Weak bonding is clearly a contributor to failure (Figure 23); bricks were not soaked in water before building wall, and/or the mortar mix was too dry.

Figure 21. Subdivision of confined masonry houses, collapse of masonry wall exacerbated by insufficient connections, Bengkulu. S3.83218° E102.29287

Figure 22. Confined masonry house with failure in masonry walls and connections between tie columns and bond beams, Kec. Airnapal (North Bengkulu)

Plaster is often ignored in structural engineering analysis; however, for a simple confined masonry building with a relatively weak wall, high quality cement-based plaster can add significant strength. The house in Figure 21 is the only house in which wall collapse occurred in a subdivision of similar houses affected by the 2007 earthquakes near Bengkulu. It is the only house that hadn't been plastered yet.

Solution: Insist on good construction quality, and finish the wall with cement-based plaster. above it.

Figure 23. Close up view of collapsed ring beam and wall, same as Fig. 20. Failure plane between top of mortar bed and bottom of brick above it.

Figure 24. Homeowner standing in front of her collapsed wall, note quality of concrete, Padang Panjang, IMG_8840.

(9) CONCRETE QUALITY

Problem: Poor quality concrete also contributed to failures. See Figure 24. Same solutions apply: ensure good quality materials and workmanship are used.

(10) FOUNDATION, SOIL and DRAINAGE

Very little earthquake-induced damage to confined masonry houses in Indonesia in recent earthquakes can be attributed to a soil or foundation problem. In the Central Java event, one example of sliding along the wall-foundation interface was found; in this case, there was no foundation beam. Effects of liquefaction were observed in one village in the Bengkulu event (Figure 26).

Figure 25. Displacement alongwall/foundation interface, Tegal Kebong Agung, Imogir (Bantul) S7.93434° E110.36667°, CIMG1769

Figure 26. Cracks in foundation and walls associated with settlement and tilt on liquefiable soils, Lempuing (Bengkulu), S3.82799° E102.28473

APPENDIX 2: HOUSING SUBSECTOR STUDY AND DESIGN CONFINED MASONRY HOUSES IN INDONESIA

HOUSING SUBSECTOR STUDY

In March 2005 we began work in Aceh with a detailed housing subsector study, including a survey of

- Common structural systems
- Locally available building materials, including quality and cost
- Skill level of local builders, and commonly used tools
- Architectural and cultural preferences
- Climate considerations and other hazards, such as high winds and flooding.

We identified four common structural types (confined masonry, reinforced concrete block masonry, timber frame on stilts, and timber frame with a masonry skirt), established design criteria, and using teams of volunteer structural engineers from San Francisco Bay Area design firms, performed preliminary cost estimating and design analysis on the four systems.[1] Funding to build 11 houses in a pilot project was obtained from Mercy Corps, an international relief and development agency active in the reconstruction since shortly after the tsunami. We asked each of the 11 homeowners which structural system they preferred. All chose confined masonry.

The pro bono structural engineers then performed more detailed analysis of a confined masonry house. At the same time, we hired Acehnese engineers and an architect who created bills of quantity, detailed drawings, and a suite of floor plans and roofing alternatives that were appropriate to family size, plot size and local culture.

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[1] See Hart, T.M. (2006) “Indonesia Tsunami Housing Reconstruction” SEAONC Newsletter, May 2006.

SEISMIC HAZARD and ANALYSIS METHOD

Building designs were checked for seismic forces in both principal directions using equivalent static analysis methods. Calculations were performed for a spectral design acceleration of 0.4g.This assumption is based on

1. Indonesian Seismic Standard (SNI 03-1726-2002) – for Zone 6 on soft soils (0.38g), which is the highest standard currently applicable in Indonesia. Although the pilot project houses are located in Zone 5 on medium soil (0.32g), the intent was to design a structural system that could be built anywhere in Aceh or Nias and assuming the worst case soil condition.

2. International Building Code (IBC) 0.4g is the design seismic force prescribed in the International Building Code (IBC) for a building on standard soil and within 2 km of an active seismic fault that has the potential to generate earthquakes with magnitudes of 5.0 and larger. The seismic zonation in the most recent version of the Indonesian Seismic Standard (SNI 03-1726-2002) does not recognize the seismic hazard imposed by the Sumatra fault. Current research (see Peterson et al.[2]) indicates that this fault, which lies within a few km of the pilot project houses, is active and has the potential to produce earthquakes of magnitude 5.0 and higher.

APPLICABLE CODES AND GUIDELINES

A building code for confined masonry does not yet exist in Indonesia. The Indonesian Seismic Standard (SNI 03-1726-2002), which is based on UBC 1997, applies to reinforced concrete frame construction. Infill walls are assumed non-structural and are therefore not addressed in buildings designed according to the Indonesia Seismic Code. Indonesia has a concrete code, but does not have a masonry code.

The Badan Rehabilitasi dan Rekonstruksi (BRR), the Indonesian governmental agency charged with overseeing the Aceh recovery program, produced a building guideline for houses in mid-2005.

Given that this guideline was based on the SNI, it was interpreted as applicable to RC frame construction. The guideline was prescriptive in terms of size of frame elements, diameter of reinforcing bars, spacing of stirrups and ties, and so on, but it omitted important details such as connections and anchoring.

During the design process, we reviewed several other codes and guidelines, such as a series of posters produced by Teddy Boen[3], guidance associated with Eurocode 8[4], Marcial Blondet's construction guideline,[5] and the IAEE Manual.[6] All guidelines were very useful but none was sufficient and

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[2] Peterson, M.D., Dewey, J. Hartzell, S., Mueller, C., Harmsen, S., Frankel, A.D. and Rukstales, K. "Probablistic seismic hazard analysis for Sumatra, Indonesia and across the Southern Malaysian Peninsula", Tectonophysics 390 (2004) 141-158.

[3] Boen, Teddy & REKAN (2005). "Syarat-Syarat Minimum Bangunan Tembokan Bata / Batako Tahan Gempa Dengan Perkuatan Beton Bertulang"

[4] City University of London http://www.staff.city.ac.uk/earthquakes/MasonryBrick/ConfinedBrickMasonry.htm

[5] Blondet, Marcial (editor). Construction and Maintenance of Masonry Houses: For Masons and

completely appropriate for the structural and architectural system common in Aceh.Most codes and guidelines assume a two or more story structure with rigid diaphragm at the floor level and thicker wall.

In addition to producing our own detailed set of design drawings, bar bending schedules, bills of quality, we drafted a design and construction guideline for earthquake-resistant confined masonry houses[7] which was shared with BRR and other organizations working in housing at a seminar in May

2006 and through personal communication and meetings with partner organizations. The guideline is now available on the Build Change website. A simple step-by-step construction guideline for homeowners and builders is in press.

BRR hired a consultant to check drawings for completeness starting in 2006. Even though we had already completed building our pilot project houses, we submitted our drawings for approval in order to gain additional validation and support for promoting confined masonry with partner organizations. Approval was granted in late 2006.

Our design for Aceh received a 2006 Excellence in Structural Engineering Award from the Structural Engineers Association of Northern California and a Certificate of Merit in the statewide competition. An independent review of one of our designs was done by a structural engineering company in Jakarta. With the exception of recommending deeper anchorage between the foundation and the foundation beam, the design was endorsed by the structural engineering firm. Our house design was called "best in Aceh" in 2006 by a team of Indonesian seismic experts. ARUP, an international design engineering firm, commented in a review of one of our client's projects, that the Build Change "design…combines seismic resilience with a high degree of buildability."

Figure 1. Build Change Pilot Project House, Hipped Roof (Owner: Rusdi Razali).

ARCHITECTURAL, CULTURAL and CLIMATE CONSIDERATIONS

Single Story. All houses designed and built by Build Change were single story. Typical two or more story construction in Indonesia is a hybrid system between RC frame with masonry infill and confined masonry.

Tall, Slender Wall. Because of the hot climate, there is a preference for a tall wall, up to 3m in height from floor to ceiling. Masonry is built using running bond, in which the bricks are laid end to end, resulting in a half-brick wide wall.

This tall, slender wall has an aspect ratio that is higher than what is typically recommended for confined masonry buildings.

Construction Technicians, PUCP

[6] IAEE (revised edition, 2004). Guidelines for Earthquake Resistant Non-Engineered Construction.

[7] Build Change (2006) "Earthquake-Resistant Design and Construction Guideline for Single Story Reinforced Concrete Confined Masonry Houses Built in the Aceh Permanent Housing Reconstruction Program"

Large Openings. Similarly, there is a preference for tall doors and windows with vents above over the doors and windows, especially at the front of the house.

Lightweight, Timber Truss Roof. Pitched or hipped roofs are preferred because of the significant amount of rainfall.

Other Criteria. The BRR building guideline included additional architectural criteria which we followed, such as minimum 36m2 in plan, at least two bedrooms, at least two entrances and exits, orientation appropriate for sun, wind, and Islamic culture, and toilet, septic tank, soakaway.

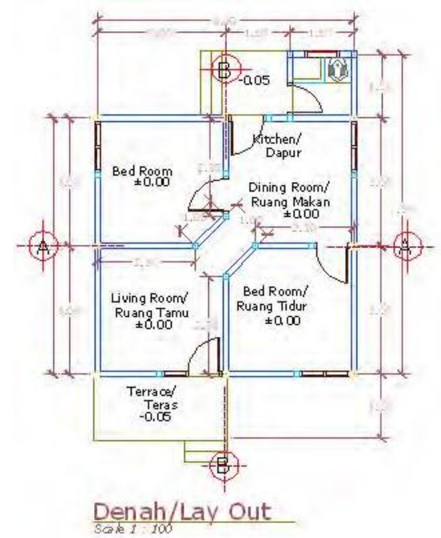

Figure 2. Build Change Pilot Project House, 2 bedroom, 2 living room, toilet outside.

DESIGN DETAILS

Foundation and Floor: Trapezoidal-shaped stone masonry strip footing. S-shaped, 50 cm steel anchors were used every 1m, as recommended by the BRR Guideline. These anchors are intended to prevent uplift and to function as shear keys between the stone masonry foundation and the plinth beam. The floor was unreinforced concrete on compacted fill, with finished floor height at least 60 cm above ground surface.

Reinforced Concrete Confining Elements: Reinforced concrete bond beams at the foundation/plinth and roof level, and reinforced concrete major tie columns at all corners, and wall intersections, minor tie columns at changes in contour and adjacent to all openings except the small bathroom vent window. See table 1 for details.

Table 1. Confining Element Section and Bar Details (dimensions in cm)

	BRR Guideline	Build Change Design
PLINTH BEAM		
--Section	15 x 20	18 x 25
--Longitudinal Bars	4-12mm dia smooth	4-10mm dia ribbed
--Stirrups	8mm dia at 15 cm	6mm at 15 cm
MAJOR COLUMNS		
--Section	15 x 15	15 x 15
--Longitudinal Bars	4-12mm dia smooth	4-10mm dia ribbed
--Ties	8mm dia at 15 cm	6mm at 7.5 cm for the first 7 ties at top and bottom, elsewhere 15
MINOR COLUMNS		
--Section	11 x 11	11 x 11
--Longitudinal Bars	4-12mm dia smooth	4-8mm dia ribbed
--Ties	8mm dia at 15 cm	6mm at 7.5 cm for the first 7 ties at top and bottom, elsewhere 15 cm
RING BEAM		
--Section	15 x 20	15 x 20
--Longitudinal Bars	4-12mm dia smooth	4-10mm dia ribbed

We started building our first house with the bar detailing and section size specified by BRR, however, quickly encountered construction challenges. We pulled our first foundation beam out and rebuilt it. How and why we deviated from the BRR Guideline:

Figure 3. Bond Beam-Tie Column Connection Model. Note it has been suggested that to strengthen the interior corner, the interior long bars should pass through the joint and tie to the external long bars.

- Increased the section size of the plinth beam: To increase the strength of the foundation beam in light of variable soil conditions, and to make it easier to connect beams with columns. With a 15 x 20 foundation (plinth) beam and a 15 x 15 column, it is very difficult to fit column steel inside beam steel, maintain sufficient cover over the concrete in the plinth beam, while also maintaining sufficient space between the long bars in the column, so as to be able to bend a stirrup that is square, not round.
- Reduced longitudinal bar diameter and used ribbed instead of smooth: 12mm long bars and 8mm bars for stirrups and ties were too difficult for builders to cut and bend properly.

- Reduced the stirrup and tie bar diameter and reduced the spacing of stirrups at the top and bottom of the columns: again for workability reasons, and to provide increased strength in shear at the top and bottoms of the columns.

- Considered increasing the spacing of stirrups in the bond beams, all of which were resting on a masonry wall or foundation. Our design calculations indicated that greater stirrup spacing was allowed.

- Specified hook length, hook rotation, and joint detailing on the drawings. It was not common practice to call out these details on engineering drawings used in Aceh. See Figs. 3 and 4.

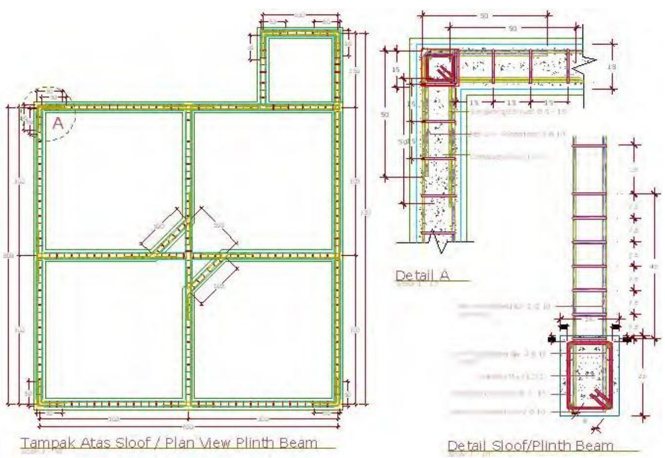

Figure 4. Bond Beam Layout and Connection Detailing

Walls: Fired clay brick masonry walls built prior to casting the columns, with Durowall-type steel reinforcement placed in the bed joint every seven courses of masonry, above and below openings, and tied into the columns.

Out of plane failure of the tall, slender wall was a primary concern in the design process. Several alternatives were considered in order to mitigate against out-of-plane failure:

(1) increase the number and length of shear walls in both directions, and addcross walls or bracing. All floor plans had cross walls every 4m or less,

(2) increase the wall thickness by changing the masonry bond to English or Flemish bond, as is common for confined masonry structures in other countries, such as India, Peru, and Iran. To use full-brick wide bonding, the length of the brick must be twice as long as it's width plus the thickness of a head joint. Most of the bricks in Aceh are the wrong proportion for this bonding (too wide and short). Plus, this type of bond adds cost and requires a higher skill level from the masons, therefore this was not a feasible option,

(3) reinforce or restrain the wall by using additional confining elements such as extra tie columns, a lintel beam, or reinforcement in the wall. We considered wrapping wire mesh around the wall, tied into the foundation and ring beams, but we thought this might be difficult to build, and although the mesh would be covered in plaster, we had concerns that the mesh would delaminate over time.[8] A lintel beam would add little value at high cost because the top of the frames were already so close to the top of the wall.

[8] Inspired by Prof. Ken Elwood, UBC

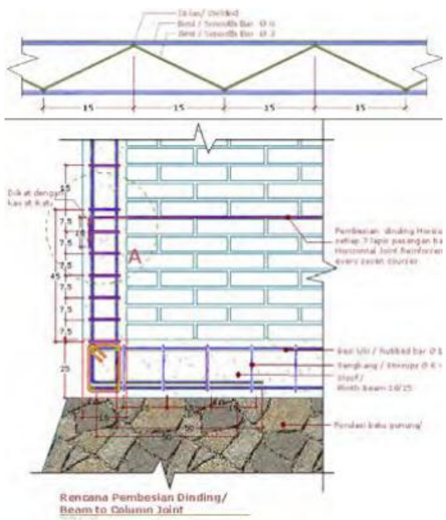

Figure 5.Horizontal Wall Reinforcement.

We opted for the combined solution of additional vertical confining elements adjacent to all large openings, and horizontal steel reinforcement in the wall. The reinforcement detail (Figure 5 and 6) was also assumed to increase the in-plane strength of the wall. We shifted the openings to the corners to and locations of major columns so that only one additional tie column would be needed (rather than two, if the openings remain centered). All walls were finished with cement-based plaster and painted.


Figure 6. Wall with Horizontal Reinforcement.

Roof. Roof was made of timber trusses covered by corrugated galvanized sheeting. Both hipped (Figure 1) and pitched (Figure 7) roofs covers with CGI sheets were already common. Timber gables were used for pitched roofs. Trusses were tied down with U-shaped steel plates. The tie downs were needed to prevent uplift in strong winds, and intended as an alternative the common practice of wrapping the tie column bars around the trusses, leaving them exposed to corrosion.

Although not considered in the analysis, it is likely that this connection between the roof truss and ring beam provides some bracing against out of plane failure. The

benefits of having lower mass (and thus lower inertia force) at the roof level by using an already common and appropriate timber truss roof were considered to outweigh the lack of rigidity at the ring

beam level. Replacing the roof system with a more rigid system, such as a reinforced concrete slab,

was not considered because such a system is ill-suited to the climate and can be very dangerous if constructed poorly.


Figure 7.Build Change Pilot Project House, Pitched Roof. Owner: Ruslan AB.

BUILDING MATERIALS AND PROPERTIES

Bricks. Fired clay bricks are widely available in Sumatra.

Soil is mixed by buffalo, machine, or by hand; bricks are hand-molded and fired in open kilns using wood or rice husks as fuel. Brick quality (strength, consistency of size and shape) was variable. We did a quick review of the brick manufacturing process at several kilns to determine which vendors to purchase from. The type of clay and the firing process had the biggest impact on brick quality. Many brick producers had access only to a source of clay that was prone to warping and shrinking during firing. The length of burn, fuel used in burning, and the location of the brick in the kiln also strongly influenced its properties. Bricks at the top of the kiln were rarely completely fired, and would erode or crumble in the rain. We used simple three-point bending tests[9] (see Figure 8) and the following checks to evaluate brick strength in the field.

- No cracks or chips
- No visible unmixed portions or divits
- Brick is square, not warped or curved
- Dimensions are consistent among a sample of 10-20 bricks; they do not vary by more than 1 cm in the long direction and 5 mm in width and height
- When two bricks are hit together, the sound is a metallic clink, not a dull thud
- When left out in the rain or soaked in water for 24 hours, bricks do not crumble.

Figure 8. Three point bending test for brick strength, use average size Indonesian male, no bouncing

Cement. Two types of cement are common in Sumatra: Type 1 Portland Cement (SNI 15-2049-2004 or ASTM C-150) and Portland Pozzolan Cement, PPC (SNI 15-0302-2004 or ASTM C-595 M95). We used Type 1 for the concrete, foundation and floor, and PPC for the masonry wall and plaster, because of the increased workability and lower price. We have not found lime in local shops in Indonesia.

Rebar. Both ribbed and smooth bar is available in Aceh. Ribbed bar is more expensive. We used ribbed bars for longitudinal bars and smooth for stirrups and ties. SCL performed pro bono tensile tests on 22 random samples of steel reinforcement obtained from local shops, including both ribbed and smooth steel in diameter between 4 and 13mm. Yield strength was in the range of 57 to 81 ksi for bars in 7 to 13mm diameter range, and 40 ksi was assumed in design.

Figure 9. Horizontal reinforcement fabricated on-site with binding wire (top) and prefabricated at welding shop (bottom).

Durowall-Type Reinforcement. This truss type reinforcement was initially assembled on-site by the builders using two 6mm diameter bars tied together with binding wire in a truss pattern (Figure 9, top). This process was time consuming, and consistent separation between the long bars was difficult to maintain due to flexibility of the binding wire. We switched to a welding school to prefabricate the reinforcement using 3mm bars as the diagonals (Figure 9 bottom). When the welding school could not meet our demand, we used private sector local welding shops.

Figure 10. U-Plate for ring beam-truss

U-Shaped Steel Plates. The U-shaped steel plates for the ring beam – truss connection were manufactured by local shops (Figure 10). The 4mm thick, 4cm wide plates were embedded in the ring beam and bolted to trusses.

Stone. Angular mountain stone for the stone masonry strip footing was available in yellow, red, and black varieties. The least expensive yellow stone was a weak, weathered clayey sandstone. We used red, which is also sandstone, but stronger

connection.

Gravel. Crushed gravel was expensive and not easily found in Aceh. As such, we used rounded gravel with diameter up to 3 cm. Quality of gravel varied in that depending on the source, some gravel was coated with fine clay and required rinsing prior to use.

Sand. Like gravel, depending on the source, the sand was often mixed with fine clay particles. To evaluate sand in the field, we put a handful of sand in a plastic cup or bottle, filled it with water, and shook it up. If the water was clear, the sand was accepted. If it was cloudy, it was rejected.

Timber. Timber was loosely divided into three classes. Class 1 is tropical hardwood, which was largely unavailable. Type 2 is a less dense, tropical softwood that is strong enough for structural timber. We used Class 2 for structural roofing elements and window and door frames. Class 3 includes other softwoods of lower quality and appropriate only for batterboard and formwork. It was very difficult to reuse formwork made with such soft, easily warped timber. In later projects, we fabricated formwork out of plywood that could be used two to three times.

Lightweight Steel. All new houses designed and/or built by Build Change following the 11 pilot project houses used lightweight steel channels for the roof trusses. This shift away from timber was made due to the increasing cost and difficulty in obtaining good quality structural timber, and concerns over legality of the timber source. Although all timber purchased in the pilot project came with documentation certifying legality, we had concerns about the authenticity of these certificates.

CONSTRUCTION PROCESS

Soils: The pilot project houses were built on coastal alluvium. We screened for soil hazards by

1. inspecting other nearby masonry houses to check for cracks associated with differential settlement,
2. digging the pits for the septic tanks first so we could take a look at the soil profile and screen for liquefaction hazards and soft, expansive clays or peats. Although the water table was within 2-4m of the ground surface, the soil was clayey, so liquefaction was not considered a hazard. Expansive clay was a bigger concern. Expansive clays were identified by touch and shrinkage tests. When it was encountered, we dug it out and replaced it with compacted fill.
3. (testing the soil strength every 1m along the length of the foundation excavation by pushing a 12mm diameter steel rod into the ground. If the rod could be pushed more than 20cm into the ground, we kept digging.

Figure 11. Poorly built stone masonry strip footing. Note gaps between stones, stones standing on end.

Stone Masonry Strip Footing Construction: At the base of the excavation, we used a weak screed layer instead of the more common layer of loose cobbles. The challenge with the stone masonry strip footing was to ensure the builders filled all the gaps between the stones with mortar, laid the stones down rather than standing them up, and used long stones at corners and t-junctions. See Figure11 for an example of a poorly built strip footing.

Bar Bending and Assembly: In addition to detailed design drawings, we produced bar bending schedules that showed the cut length of each bar so as to facilitate the overlaps as detailed in the drawings and reduce waste.

Concrete Mixing and Pouring: Concrete was mixed at 1:2:3 by volume on the ground or on a paved surface. Builders had a tendency to add too much water to the mix, especially when using a mechanical mixer on one of our later projects. We used different methods to illustrate the importance of too much water, from slump tests, and simply picking up a handful of mixed concrete and if the water (and cement) ran out through one's fingers, it was too wet.

Concrete spacers were used to separate the steel from the formwork. Concrete spacers were known about but not common; if the builders used spacers, they used small stones rather than squares of concrete with binding wire we used in our projects. Formwork was wetted prior to pouring concrete. In the pilot project, we rammed the concrete with a rod and tapped the formwork with a hammer in order to compact the concrete. In a later project, we used vibrators, however, the builders had a tendency to overvibrate and liquefy the concrete. We required builders to cast the entire bond beam all in one day. Concrete was cured by sprinkling water on it for five to seven days.

During the pilot project, a team of researchers from Institute of Technology – Bandung (ITB) performed handheld concrete hammer testing on a random sample of concrete elements in our houses. Foundation beams and column strengths at 28 days or older were in the range of 175-200 kg/cm2, which meets or exceeds the requirement in the BRR building guideline. According to the researchers, this was significantly higher than they were finding in houses built by other organizations, which were in the range of 60-100kg/cm2 at 28 days. One of our ring beams tested at 7 days was 125 kg/cm2.

Figure 12. Typical Build Change foundation beam, Build Change-designed house for CRS

Figure 13. Typical Build Change ring beam, Build Change-designed house for CRS

Figure 14. Bad practice, connections and concrete quality, other organizations

Bricklaying: Mortar was mixed at 1:3 in the same manner as concrete. A mix of 1:2 was used for the damp proof course and the walls in the bathroom. Because the bricks are so porous, they have a tendency to absorb water from the mortar before the cement has time to hydrate and create a strong bond. We promoted wetting or soaking the bricks prior to building the wall.11 In addition, we stressed uniform joint thickness no greater than 15mm, filling the joints completely with mortar, staggering the vertical joints, and ensuring the wall remained plumb. Some examples of masonry produced by Build Change-trained masons, vs. that produced by other organizations, is shown in Figs. 15 through 20.

Figure 15.Typical wall built by Build Change-trained mason

Figure 16. Typical wall built by Build Change-trained mason

Figure 17. Typical wall built by Build Change-trained mason

Figure 18. Typical wall built by other mason

Figure 19. Typical wall built by other mason

Figure 20. Typical wall built by other mason

Carpentry: Carpentry was the least challenging aspect of the construction process; we found many skilled carpenters, some of whom suggested changes to our truss details that made them simpler to build (Figure 21). The primary challenge with the timber elements was that some of the window and door frames were produced with timber that wasn't totally dry. The frames would look straight and square when we accepted the order from the vendor, but a few days in the tropical sun, and some of them would warp or split.

Figure 21. Builder, homeowner, Build Change architect, and Build Change engineer discuss ring beam-truss

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