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

DRAFT

January 2012

Revised January 2014

This report was produced for review by the United States Agency for International Development (USAID). It was prepared by Build Change for International Resources Group (IRG).

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ACRONYMS

A&E	Architecture and Engineering
ATC	Applied Technology Council
CBO	Community-based organization
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
NGO	Non-governmental organization
USAID	United States 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 United States 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 carry out housing construction and reconstruction properly in a post-disaster situation. It provides a road map for developing a project through planning, design, and implementation and builds on two earlier USAID Primers, "Basic Host Country Construction Contracting for Development Professionals: A Primer," and "Basic Engineering and Construction Management: A Primer."[1]

This 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:

- Greatly reduce deaths, injuries, and economic losses caused by housing collapses due to natural disasters in developing countries
- Permanently change building code enforcement and/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
- Build local capacity through training of builders, homeowners, engineers, and government officials
- Change construction practices permanently by building local skills and stimulating local demand

[1] USAID Primers referenced are available at www.buildchange.org/USAIDPrimers.html.

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 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 two earlier USAID Primers, "Basic Host Country Construction Contracting for Development Professionals: a Primer," and “Basic Engineering and Construction Management: A Primer.”

PRINCIPLES AND STRATEGIES

Post-disaster housing reconstruction presents an opportunity not only to 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:

- **Local Solutions** – Use detailed housing subsector studies to determine the most cost-effective ways of rebuilding 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 layouts and materials and manage their own construction, with technical assistance, by providing a range of solutions appropriate for different income levels, family sizes, cultures, and climates.

- **Local Capacity** – Build local capacity by hiring and working with local engineers, architects, builders, universities, and governments, and by 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 chief post-disaster housing reconstruction options are driven either by homeowners, communities, or donors. 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, the 2007 and 2009 West Sumatra, Indonesia earthquakes, and the 2008 Sichuan, China earthquake.[2] It can be a lower cost, higher impact model than

[2] The Government of Haiti's National Housing and Habitat Policy, released in October 2013, promotes the participation of homeowners in the construction process to select housing solutions that meet their needs. Visit http://uclbp.gouv.ht/download/pnlh-resume-executif.pdf for the executive summary. Though there is no official housing

donor-driven reconstruction and can produce safe homes, satisfied homeowners, and sustainable change in construction practice.

Homeowners are empowered to make their own choices, which results in greater satisfaction and buy-in, an increased willingness to invest more in disaster preparedness, 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 houses 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, materials vouchers, and/or small loans.

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 disasters 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. The community-driven approach has been used successfully in places where a strong government or other authority oversaw the reconstruction process, such as in China. In the absence of this authority to keep community groups focused on the priorities of reconstruction there is potential for disagreement, uncooperative behavior, corruption, and theft. Careful consideration of this possibility is warranted in program design in order to ensure that community group decisions both serve and are supported by individual homeowner needs.

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.

These three implementation models are described in more detail in the table below.

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reconstruction policy for Haiti, homeowner-driven approaches to reconstruction are being promoted and used by many agencies there.

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 conforms 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 or not appropriate for lifestyle or climate	Can be low if floor plan is too small or not appropriate for lifestyle or climate
CONSTRUCTION			
Who Builds	Small scale, local builders hired by homeowner or small groups of homeowners; in limited cases, homeowners themselves	Local builders or contractors hired by groups of homeowners; in limited cases, homeowners themselves	Large scale contractors hired by relief agencies or governments (may be non-local)
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, avoidance of 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; project "owner" is the homeowner	Medium; project "owner" is the implementing agency or donor; more peer pressure mechanisms in place	Highest; project "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 Potential	Genuine, but not always finished or pretty	Varies	Good
FINANCIAL			
Who Pays	Homeowner, with grant from government or donor, or 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

	Homeowner-Driven	Community-Driven	Donor-Driven
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 in Addition to Homeowner	Local builders and materials producers	Community members, local builders and materials producers	Contractors, consultants, larger-scale materials producers (may be non-local)
COST PER HOUSE			
Design	High	Low	Low
Construction Management	Low	Varies	High
Materials and Labor	Lowest	High	Highest
On-the-Job Training	Highest	Varies	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 Implementing Agencies	Limited to technical assistance only; may provide materials vouchers or cash grants to supplement government grants	Limited to technical assistance, grant disbursement	More extensive; design-build, 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	Varies	Low
Potential to Increase Dependency and Cause Social Conflict	Lowest; empowers homeowners to drive process, allows for more equitable treatment	Varies	Highest; houses are given away, homeowners are not empowered, unlikely all will be treated equitably due to high cost
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[3]; 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

[3] Though the donor-driven approach was employed in the reconstruction of houses in approximately 50 villages that were most severely damaged by the Maharashtra earthquake, many other damaged houses – approximately 200,000 – were repaired or reconstructed using the homeowner-driven approach, with technical assistance provided by the government.

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 homeowners will not build disaster-resistant houses unless they can afford to and have access to needed technology, materials, and skilled construction professionals. They also need incentives and government ministries able to enforce building standards. By addressing these three critical barriers – technology, money, and people – the homeowner-driven development model encourages the growth of an environment in which disaster-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 a 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 may be 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, 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 by contrasting the reconstruction programs in Aceh (2004) and West Sumatra (2007, 2009), Indonesia. (Findings may be different elsewhere.)

The overall cost of the housing materials and labor and the donor cost per house can be lower in homeowner-driven reconstruction than donor-driven reconstruction. Consider:

- After the 2004 Indian Ocean tsunami hit Aceh, Indonesia, donor and community-driven approaches were used. Cost of house materials and labor including donor/non-governmental organization (NGO) direct and indirect costs was 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 include:

- **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/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, and 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 reconstruction, the homeowner usually uses some salvaged or stockpiled materials, such as old window and door frames, timber, roof sheets, and 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 chose to build from a 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: Disaster-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 evaluation, analysis, and design procedures and solution detail drawings, and can be applied to any floor plan.

- Capacity: Builders, engineers, architects, building materials suppliers, and inspectors must be trained.

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

- Access to Capital: Homeowners must have sufficient funding in the form of grants, loans, or materials vouchers.

- Incentives: Provision of financing must be contingent on applying minimum construction standards. This is best done in stages, so that the homeowner must meet milestones in compliance with the construction documents in order to receive the next stage of funding and continue the work.

- Subsidies: Subsidies or price controls on certain building materials may be required to meet funding goals.

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

- Motivation: Demand for safe housing must be created among homeowners through information campaigns[4] and coupling financing with building standard compliance.

- Acceptance: People from different cultures have their own ideas about what a house should be. They will accept structural requirements if their ideas about layout of interior and exterior spaces, orientation to light/wind/view, privacy, and security are respected.

- 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 of wall materials (brick, block, stone) and earth-based systems	Sufficient; government allowed two most common structural systems – timber frame with masonry skirt and confined masonry – but initially discouraged the former	Sufficient; government allowed the most common structural system – confined masonry with a reinforced concrete roof – but 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 no clear and comprehensive standard issued by government	Limited; a variety of standards and codes available from national to local, but applying them to typical houses required judgment and interpretation
Capacity	Sufficient; capacity building programs were implemented	Limited capacity building by universities and technical consultants	Sufficient capacity in place; limited capacity building needed
FINANCIAL			
Access to Capital	Sufficient cash grant provided	Insufficient cash grant provided	Sufficient cash grant and loan

[4] For examples of outreach posters used in China, Haiti, and Indonesia, please visit www.buildchange.org/USAIDPrimers.html.

	2001 Gujarat, India	2007 and 2009 West Sumatra, Indonesia	2008 Wenchuan, China
	by government to most homeowners	by government, limited donor agency funding following 2009 earthquake	access provided by government to most homeowners
Incentives	Yes; funding given out in installments	No; limited building standard enforcement to no enforcement by government	Varied; incentives given to builders only
Subsidies	Some	None	Some
SOCIAL			
Homeowner Motivation	High; funding contingent upon meeting standards	Moderate; homeowner level of risk-awareness good, but cash incentive insufficient	High; government oversight and enforcement sufficient to prompt compliance
Building Standard Enforcement	High; government employed a third party quality inspector	Limited to 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. In more developed countries there is often a perception that, while improving efficiency and reducing cost, the design-build model suggested here does not provide for independent design error checking in the field. Implementing partners must openly acknowledge that this is a potential avenue for corruption. Periodic independent qualified auditing of the compliance of finished houses should be included in the program.

However, the implementing partner 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 with the homeowner about safe construction. Plus, this separation better mirrors the contracting requirements and separation of roles of the Fédération Internationale des Ingénieurs-Conseils (FIDIC, 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:

- Site cleanup
- Property rights and land titles
- Community mapping and planning, with plot boundaries identified

- Infrastructure planning and implementation
- Banking and access to capital

Options for selection of and contracting with the technical consultants and implementing partners are covered in two earlier USAID Primers: "Basic Host Country Construction Contracting for Development Professionals: A Primer," and "Basic Engineering and Construction Management: A Primer."

THE STAKEHOLDERS IN POST-DISASTER HOUSING RECONSTRUCTION

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

Donor (in this case, USAID):

- Provide funding for 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):

- Adopt consensus-based code guidance for required loadings, including seismic loading, for building construction
- Produce or adopt consensus-based, clear, easy-to-implement building standards and guidelines
- Provide certification programs or licensure regulations for builders, engineers, and government officials
- Provide plan review and permitting services and building inspections to ensure compliance with approved construction documents
- 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 with public awareness outreach campaigns
- 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 evaluation, analysis, design, construction, and siting and materials guidelines and related resources and tools
- Support the government in building code and guideline development, adoption, and enforcement
- Provide training and capacity building to homeowners, builders, engineers, building materials producers, and government officials
- Guide the homeowner through the design, builder selection, and construction process
- Supervise construction and provide on-the-job 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 that apply to more than one house, such as building pathways, roads, and retaining walls

- Approve final list of homeowners who qualify for the program
- Manage disbursement of financial subsidy to homeowner or community group.

United States Agency for International Development:

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 a technical assistance provider and implementing partner to distribute funds to homeowners.

2. PRE-DESIGN STEPS

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 USAID Primer "Basic Engineering and Construction Management: A Primer.")

Table 3. Pre-Design Steps for Post-Disaster Housing Reconstruction

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

2.1. ASSESS SAFETY AND TAG BUILDINGS

Assess safety and tag affected buildings using the methodology of the US Applied Technology Council (ATC) *ATC-20, Post-Earthquake Damage and Safety Evaluation of Buildings*.[5]

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

2.2. UNDERSTAND CAUSES OF COLLAPSE

A post-disaster environment presents an ideal laboratory in which to learn why some buildings collapsed and others did 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

[5] ATC-20 is a rapid method for evaluating building safety for immediate reoccupation after earthquakes, developed by the Applied Technology Council. Implementation results in 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/index.php/component/mijoshop/product/36-procedures-for-postearthquake-safety-evaluation-of-buildings-addendum.

causes of collapse can help shape and inform reconstruction guidelines, especially in situations in which building codes or guidelines are not available.

Please visit www.buildchange.org/USAIDPrimers.html for a summary of causes of collapse for confined masonry buildings in Indonesia.

2.3. ASSESS OTHER HAZARDS

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

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

2.4. PERFORM 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. A reconstruction program should be based upon design solutions that can be understood, learned, and implemented by the local workforce using local materials. 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, of what quality, where are they produced, how much do they cost, and will the production be able to meet

reconstruction demand? Who buys the materials (homeowners, builders, contractors)?

- What is the skill level of local builders? What tools and techniques do they use? What tools and technologies are locally available? What solutions will the local workforce be capable of implementing once trained? How much do they earn?

- How are houses commonly built? What systems and techniques are used? 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[6] has become a popular method of rapidly assessing the market for reconstruction after a disaster.

2.5. 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 exist, but applying these codes to one- or two-story single family homes may result in overly conservative design and construction guidelines which lack important details on essential techniques to build a disaster-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 or are not adequate, regional or international standards can be used. US standards are typically used on USAID projects; these usually exceed the requirements of local codes and standards, which will help ensure that reconstructed houses are safe, but may add to the cost of the project.

[6] More information is available at www.emma-toolkit.org.

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 qualified engineering judgment to arrive at a solution that is sufficiently safe yet affordable, sustainable, and can be implemented in the local context. Please visit www.buildchange.org/USAIDPrimers.html for a review of standards for confined masonry homes in Indonesia.

2.6. 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 the presence of extremely hazardous site conditions, such as a very high water table, liquefiable soils, excessively steep slopes, or a very close-by known seismic fault, may necessitate relocation. The choice to relocate displaced individuals to new settlements should not be made without serious consideration of the possible consequences, including but not limited to:

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

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

2.7. CLARIFY OBJECTIVES AND PERFORMANCE CRITERIA

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

- 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 the 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 again.)

Design criteria for consideration include:

TECHNOLOGY

- Disaster-resistant in design – compliant with standards and guidelines
- Disaster-resistant in construction – built with quality workmanship and materials
- Durable and permanent
- Built with locally available materials, skills, and tools
- Easy to expand and maintain 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 that their house will survive a disaster.

Following are three 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 met disaster resistance criteria, but according to the homeowners, the structure was not culturally appropriate in architecture, space, or 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 anyway. Because the agency implemented a building technology that was not common or culturally appropriate, the opportunity to train local homeowners and builders in useful 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 was outside the house. As a result, the toilet went unused, space was wasted in a small dwelling, and structural modifications that would reduce the disaster resistance of the building could be made.

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 houses 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 labor 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.

Table 4. Design Stages and Steps for Post-Disaster Housing Reconstruction

3.1 Design Criteria	– Codes and standards – Loading and structural design criteria – Siting and foundation criteria – Architectural design criteria – Building materials properties
3.2 Structural Engineering Analysis for Typical Floor Plans	– Detailed structural engineering analysis – Detailed structural, architectural, and construction drawings for typical horizontal and vertical configurations – Detailed materials specifications – Bill of quantity and cost estimate – Construction quality checklist – Construction schedule – Installment payment schedule
3.3 Design Rules and Standard Documents	– Design rules for application to a variety of floor plans – Standard detail component drawings – Simple quantity and cost estimating tool – Simple construction scheduling tool – Cost estimate per unit of floor area – Contract template
3.4 Homeowner-Driven Design	– Homeowner qualification – Homeowner preferences survey
3.5 Plot Survey and Sketch	– Plot inspection – Plot sketch preparation

3.6 Design and Cost Estimation	– Plan, elevation, and detailed cost estimate preparation – Homeowner approval
3.7 Homeowner Training	– Disaster, damage, and safety training – Materials training – Design and construction training
3.8 Review and Paperwork Flow	– Document submission – Record keeping

The stages of design are as follows:

3.1. DESIGN CRITERIA

3.1.1. CODES AND STANDARDS

The compilation of codes and standards should include relevant local 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.

3.1.2. LOADING AND STRUCTURAL DESIGN CRITERIA

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

- Dead Loads
  - Gravity load of structure
  - Gravity load of permanent fixtures
- Live Loads
  - Occupant (including furnishings)
  - Snow
  - Flood
  - Wind
  - Seismic
  - Tsunami

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[7].

3.1.3. 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.

At a minimum, percent slope (maximum) 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.

3.1.4. 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 for the following should be collected in the housing subsector study described previously; design suggestions and parameters should also be specified:

- Structural System, such as confined masonry, reinforced masonry, timber frame with infill, earth-based systems; stipulate materials to use or avoid 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[8]

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

[8] Please see www.sphereproject.org/handbook/

- Disability access, when applicable; if the homeowner has or foresees family members with disabilities needing special access, these considerations should be taken into account
- 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, it may require design for a second story if that is likely during the building's lifetime – in dense urban environments future expansion of the housing stock and rental market is an important consideration)
- 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, including typical styles and materials used for roofs; specify pitch, elevation, waterproofing and drainage, minimum and maximum eave projection, and considerations for rainwater harvesting systems
- Stairs, including 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.

3.1.5. BUILDING MATERIALS PROPERTIES

Typical materials properties should be gathered through previous or new testing 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, and 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 and treatment
- Structural steel: specify size and grade
- Wall coverings, such as plywood, mineral board, fiber cement board, chain link fencing, bamboo mats, and other products: specify size, treatment, and strength
- Roof coverings, such as clay tiles, thatch, corrugated galvanized iron, corrugated plastic and asbestos sheets: specify size, thickness, and treatment
- Connectors, such as nails, screws, and roof tie downs
- Hardware, such as door knobs and hinges and window latches
- Utilities, such as piping, toilets, faucets, and electrical boxes and switches

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

- 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)

3.2. 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 stage for one or more typical floor plans for each structural system.

Deliverables for the structural analysis stage include:

- Detailed structural engineering analysis narrative, which explains the assumptions and limitations of the analysis
- Detailed structural, architectural, and construction drawings to an acceptable standard showing the proposed construction for horizontal and vertical configurations
- Detailed materials specifications
- Bill of quantity and cost estimate
- Construction quality checklist
- Construction schedule
- Installment payment schedule

3.3. DESIGN RULES AND STANDARD DOCUMENTS

Once the project management team has completed its review and approval of the structural analysis for 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 stage include:

- Design rules
- Standard detail component drawings
- Simple quantity and cost estimating tool
- Simple construction scheduling tool
- Cost estimate per unit of floor area
- Contract template

A complete design package with a structural design narrative and set of general design rules for the construction of new housing in confined masonry in Haiti is available at www.buildchange.org/USAIDPrimers.html.

3.4. HOMEOWNER-DRIVEN DESIGN

This stage 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 stage may result in refinement and revision of the documents prepared in the previous stage. For this reason, 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 the 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 if it turns out that the homeowner's aspirations are beyond the budget.

3.4.1. 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 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 its contents and temporarily relocating if necessary
- Choose builders and building materials suppliers who have been certified by the government, donor, technical assistance provider or another trustworthy source
- Protect materials from theft and damage (e.g., 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.

3.4.2. HOMEOWNER PREFERENCES SURVEY

The engineer or architect employed by the technical consultant should 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 is specific to each homeowner.

Table 5. Homeowner Preferences Survey Contents

General Data	– Homeowner name, address, ID – House address, GPS coordinates – Surveyor name, survey date
Homeowner Data	– Willingness to participate in the program – Family structure, number of family members, gender – Special needs, mobility issues – Current living situation – Land tenure status – Job and income
Old House Facts	– Location, size, layout, materials, disaster-related damage, other issues such as ventilation, leaky roof, security – Location of kitchen and bath, septic, 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	– **Design**: Does the homeowner want to choose the layout, materials, and architectural

Contribution	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 for use during construction? – **Funds contribution**: Can the homeowner contribute funds to build a larger or more disaster-resistant home?

3.5. PLOT SURVEY AND SKETCH

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

3.6. 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 necessary modifications.

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

3.7. HOMEOWNER TRAINING

Prior to start of construction, groups of homeowners should attend short training courses on safe construction in order to empower them to assist with construction supervision. Sharing construction knowledge with homeowners can build their confidence that their houses will withstand the next disaster and can contribute to long-term recovery from a disaster's traumatic effects. Providing homeowners with the skills to understand design documents and the work required will allow them to participate in the process and interact meaningfully with both the contractor and the technical consultant's supervising engineer.

Suggested content for homeowner trainings includes:

- Why was your house damaged in the disaster?
- Why were other buildings around yours not damaged in the disaster?
- How likely are more disasters in your location?
- How can you make your house resist the next disaster?
- Design features to avoid and why
- Simple methods for evaluating materials quality
- Basics for concrete mixing, masonry work, and other relevant construction techniques
- Reading construction plans and details

Please visit www.buildchange.org/USAIDPrimers.html for examples of typical instructional materials for homeowners from China, Haiti, and Indonesia.

3.8. REVIEW AND PAPERWORK FLOW

The drawings and cost estimate should be presented to the homeowner for review. Once the homeowner agrees with the plan, the complete design package is submitted to the fund distribution implementing partner for the first installment payment. There is one set of drawings for the homeowner, one set for the contractor, and one set 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 them for installment payment requests. Though construction management is the responsibility of the contractor/builder, the construction technical consultant will keep a daily record of the work performed, the weather conditions, and other relevant 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*** will keep records of funds distributed to the homeowners.
- The ***homeowner*** will maintain homeowner records, including the complete design packet with structural, architectural, and detail drawings, the contract with the contractor, receipts for building materials purchased, and payments to contractors.
- The ***contractor/builder*** will also maintain contractor or builder records, such as the contract with the homeowner, the drawing packet, the daily work log, reasons for delays, safety issues, receipts for building materials purchased, and payments to builders.
- The ***USAID project manager*** will maintain adequate records in order to be able to readily produce reports on the project's status, problems, and successes. The USAID project manager will rely primarily on reports from the technical consultant and fund distribution implementing partners. It is important that the USAID project manager make routine site visits and record observations, especially concerning problem areas. Photographs are important and should be part of the USAID project manager's files.

4. BUILDER/CONTRACTOR SELECTION

Builder or contractor selection is usually done by the homeowner with the oversight and advice of the technical consultant.

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

4.1. BUILDER OR CONTRACTOR IDENTIFICATION

Builder or contractor selection is usually done by the homeowner with the oversight and advice of the technical consultants. Homeowners can choose to rebuild their house themselves; however, this choice is usually made only by homeowners who have construction experience or skilled builders in their families. 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 large contractor to build several houses. In this case, the funds may be given to a community group rather than individual families.

The following types of builders or builder groups can be selected by the homeowner:

- The homeowner him/herself or relatives
- Local builders known to 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 a review of the builder's experience and/or require the builder's team to participate in a training and/or certification program prior to being considered for a housing construction contract. 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 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. Short, simple contracts should include the following, as appropriate:

Table 6. 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 and number of stories
Type of contract (typically lump sum paid in installments)
Total price: specify materials and labor, labor only, or materials only; price usually includes contractor's fees, construction management, profit, and 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 according to 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 according to the terms of the contract, and duty to protect workers' safety
Cancellation clause
Signatures of both parties

Table 7. Annexes to Simple Contracts between Homeowners and Contractors

Design specifications
Structural, architectural, and construction drawings, including plan, elevation, relevant sections, and standard connection details
Materials specifications

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 project schedule is difficult to control in homeowner-driven reconstruction, as the pace is typically set by the homeowner and the contractor's abilities and access to resources. 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.

5. CONSTRUCTION SUPERVISION

Construction supervision is necessary to authorize the release of each funding installment for reconstruction and to achieve the objective of a disaster-resistant home. 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 full-time site presence, depending on the complexity of the construction, the skills of the builders, and the level of government inspection. Construction supervision is best provided by in-country professionals and technicians, who usually require training but have been shown to develop 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.

CONSTRUCTION CHECKLIST

A simple construction quality checklist should be developed and used in the construction process. The level of detail expected in the checklist depends on the donor's expectations and the complexity of minimum requirements to meet the intended safety standard. 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 construction checklist used in China, please visit www.buildchange.org/USAIDPrimers.html.

Table 8. Contents of a Construction Checklist Used for a Typical Confined Masonry Building in a Post-Disaster Environment

SAFE SITE and SOIL
Percent slope or slope stability as specified
Set back from slopes, riverbeds, drainage, roads, and other buildings
Soil not liquefiable sand or expansive clay
MATERIALS QUALITY
Quality of materials, such as sand, gravel, stone, water, cement, masonry units, steel reinforcement, timber, roof covering, and others as per specification
FOUNDATION
Excavation in correct location and at proper angles; bottom flat and

level; no standing water, loose soil, organic matter, or voids
Soil meets bearing capacity requirements
Foundation base layer and/or footings meet thickness and strength requirements
Foundation follows proper masonry or reinforced concrete practices
Superstructure elements anchored in foundation
REINFORCED CONCRETE
Reinforcement diameter, strength, type, and condition as per specification
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 meet specification and laid with proper bonding and staggered joints; joints completely filled with mortar
Masonry wall cured per specification
Wall plumb and level
Electrical and plumbing installed properly
Wall plastered and painted per specification
ROOF
Roof tied down to walls
If timber, connections reinforced and 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 stages of construction are complete and deemed to be in compliance with design specifications and construction quality standards. 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.

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.

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

6.1. FUND DISTRIBUTION OPTIONS

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

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 can 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 homeowners to make their own decisions

Cons:

- More administrative requirements; requires setting up a bank account or other transfer mechanism for each homeowner
- May be more difficult to solve systemic 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 (safeguards should be put in place to ensure that preferred vendors are selected based on objective criteria)
- May discourage using small vendors
- Limits choices and empowers homeowners less

6.2. FUND DISTRIBUTION SCHEDULE

There are several options for the fund distribution schedule. Following 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 the 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 tie element reinforcement, and cast the concrete for columns and ring beam.

- **Installment 3: After completion of walls.** Includes funds needed to procure materials for the roof and labor to build it, along with any finishes required structurally or by the donor.
- **Installment 4: Finishing bonus, after roof and all structural elements are completed.** Includes funds needed to procure doors, windows, door and window hardware, flooring, non-structural 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.

7. APPENDICES

For all of the following Appendices to this Primer and additional resources, please visit www.buildchange.org/USAIDPrimers.html.

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

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

APPENDIX 3: STRUCTURAL DESIGN NARRATIVE FOR CONFINED MASONRY HOUSING IN HAITI

APPENDIX 4: DESIGN AND CONSTRUCTION GUIDELINES FOR CONFINED MASONRY HOUSING IN HAITI

U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov

APPENDIX 1: UNDERSTANDING CAUSES OF COLLAPSE OF 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 out-of-plane failure in 27 May 2006 Central Java Earthquake, Keputren, Pleret (Bantul) S7.86905° E110.40272°, IMG_6721

Figure 5. Masonry gable wall out-of-plane failure 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 reinforced concrete (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 out-of-plane 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 for connection 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 use of smooth rebar and the common practice of terminating the bond beam and tie column bars in the joint with a small hook does not provide sufficient rebar 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: Use deformed bars. Bend the column reinforcement into the beams and overlap by 40 times the diameter of the bar. Similarly, bend the plinth and ring beam reinforcing around corners. Tie with double binding wire to maintain proper placement in the poured RC element.

Figure 16. Zoomed 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 and allowed the walls to fail out-of-plane. 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, or staggering the bricks/blocks at the column interface so that the concrete pours into the wall every other course, is recommended for confined masonry buildings. The practice is not common in Indonesia. Homeowners and builders are unwilling to spend the extra money and time (respectively) on additional formwork required to accommodate a toothed wall or concrete to pour it. 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 of bricks and above and below openings, and tied into the columns and beams.

Other Options: Instead of running ladder reinforcement column-to-column, a single bar can be laid in the bed joint for 50cm and tied into the column every seven courses of bricks. This adds less out-of-plane capacity to the center of the wall panel, but solves the wall panel-to-column problem sufficiently.

(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 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.

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 OF 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 production capacity, 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.

SEISMIC HAZARD and ANALYSIS METHOD

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

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 assuming the worst case soil condition.
2. International Building Code (IBC) -- 0.4g is the design seismic force prescribed in the 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 SNI 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 SNI, which is based on a now-outdated American standard, the 1997 Universal Building Code (UBC), 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 Construction Technicians, PUCP

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

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 walls.

In addition to producing our own detailed set of design drawings, bar bending schedules, and bills of quantity, 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. This guideline has been published as a simple step-by-step construction guideline for homeowners and builders is available on the Build Change website[8].

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.

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"

8 www.buildchange.org/USAIDPrimers.html

Large Openings. Similarly, there is a preference for tall doors and windows with vents above, 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/exits, orientation appropriate for sun, wind, and Islamic culture, and toilet, septic tank, soakaway.

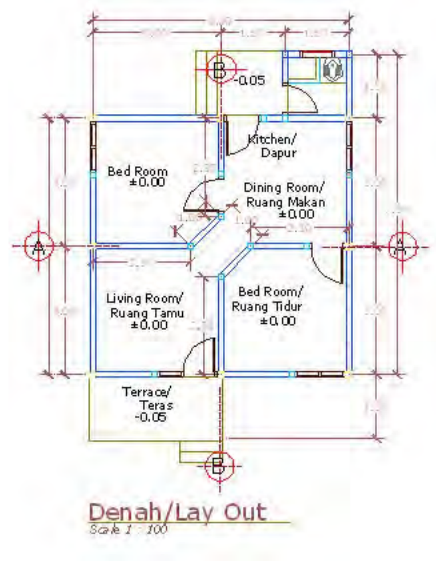

Figure 2. Build Change Pilot Project House, 2 bedroom, living room, dining room, with toilet outside.

DESIGN DETAILS

Foundation and Floor: Trapezoidal-shaped stone masonry foundation wall. 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 unless noted otherwise)

	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 cm
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
--Ties	8mm dia at 15 cm	6mm, at 7.5 cm for the first 7 ties at column intersections, elsewhere 15 cm

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 connections of columns and beams.
- 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.

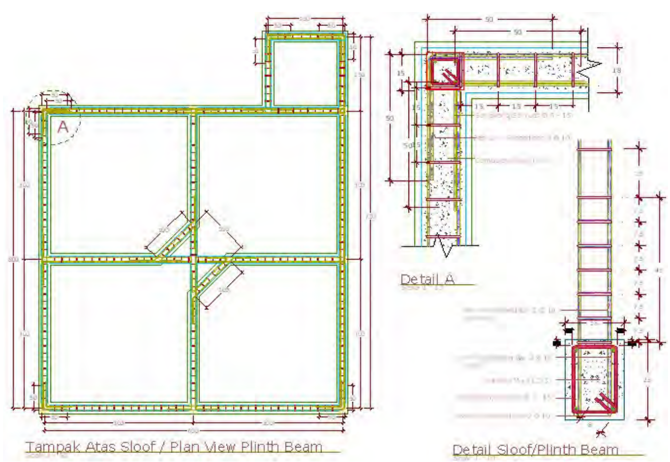

Figure 4. Bond Beam Layout and Connection Detailing

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 overturning and out-of-plane failure:

(1) increase the number and length of shear walls in both directions and cross 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.[9] 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.

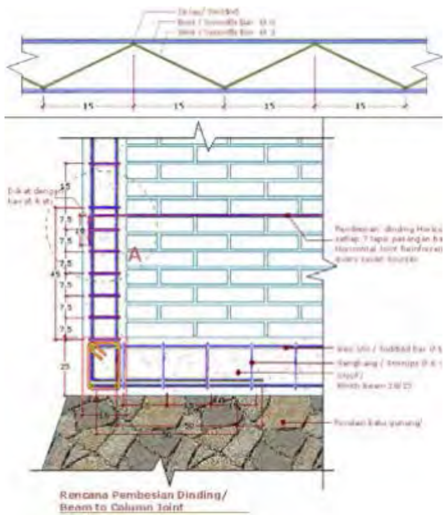

Figure 5.Horizontal Wall Reinforcement.

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

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 embedded in the ring beam and bolted to the trusses. 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.

Figure 6. Wall with Horizontal Reinforcement.

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

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 seismic inertial 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.

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 in forms 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

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

[9] Inspired by Prof. Ken Elwood, University of British Columbia

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

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.

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 connection

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.

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 roof 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 encountered, we dug them out and replaced them 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 foundation. Note gaps between stones, stones standing on end.

Stone Masonry Foundation Wall 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 foundation 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 Figure 11 for an example of a poorly built strip foundation.

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 to reduce waste.

Concrete Mixing and Pouring: Concrete was mixed at 1:2:3 (cement : sand : aggregate) 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 correct water/cement ratio, from slump tests to 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 the 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 consolidate the concrete. On a later project we used mechanical vibrators. However, the builders had a tendency to overvibrate and liquefy the concrete. We required builders to cast the entire bond beam 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/cm^2, 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/cm^2 at 28 days. One of our ring beams tested at 7 days was 125 kg/cm2.

Figure 12. Typical Build Change foundation (plinth) 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 (cement : sand) 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, are 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 detail

APPENDIX 3: STRUCTURAL DESIGN NARRATIVE FOR CONFINED MASONRY HOUSING IN HAITI

CALCULATION REPORT FOR CONFINED MASONRY HOUSING
(narrative only, structural calculations not included[1])

Build Change Post-Earthquake Housing Reconstruction Technical Assistance Program, Haiti

Prepared for

Build Change
Denver CO

31 January 2011

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[1] For the complete document, including appendices of drawings, go to www.buildchange.org/USAIDPrimers.html .

TABLE OF CONTENTS

1.0 INTRODUCTION

The following is a narrative of the structural design calculations that were performed for a variety of single-story and two-story confined masonry house configurations with both lightweight timber-framed and concrete flat slab roofs to arrive at a set of design rules and guidelines for use in the construction of confined masonry permanent housing in Haiti.

This narrative provides a summary of the design of the primary gravity and lateral load carrying systems including the masonry bearing walls, confining elements and their reinforcement and roof systems. Also included is additional information regarding the design of the foundations, porches and stairs.

1.1 General Methodology

Confined masonry is not a recognized engineered structural system in most building codes. Therefore, these designs referenced US-based design standards and specifications for reinforced concrete and masonry while drawing from current and past research and testing results on confined masonry systems. The designs also relied upon the provisions for confined masonry provided in the Mexican Building Code. Existing prescriptive confined masonry guidelines, including those recently developed by the Haitian Ministry of Public Works (MTPTC) were also consulted but not used directly as the basis of the design.

Two general house categories were considered in the calculations and a set of design and construction guidelines was developed for each:

- Single-story house with lightweight timber frame roof
- Single-story house with concrete roof OR two-story house with either a timber frame or concrete roof

For each house category, the structural load demands in elements were checked for numerous floor plan configurations complying with the design guidelines developed for that house category, and the elements were sized for the greatest demands resulting from the most severe configuration. Therefore, all confining elements for the single- story house with lightweight roof have the same reinforcement and detailing requirements, and all confining elements for the single-story house with concrete roof or two-story house have the same reinforcement and detailing requirements. This approach was taken to minimize the complexity of the guidelines and to allow a simple, easy-to-follow and repeatable standard.

Where possible, an effort was also made to unify the guidelines for the single-story house with concrete roof / two-story house with the design guidelines developed for the same system by the MTPTC in order to minimize inconsistency between two design standards. For example, the MTPTC detailing guidelines for ring beams and tie column reinforcement were followed and Grade 60 rather than Grade 40 steel was used for confinement in this system. The guidelines for the single-story house with lightweight roof deviate from the MTPTC guidelines in order to reduce the cost of this type of house to the greatest extent possible.

2.0 DESIGN CRITERIA

This section provides a summary of the codes and references consulted as well as the material properties and loading criteria used in the design of the confined masonry house systems and development of building construction guidelines.

2.1 References

The design of the one- and two-story confined masonry houses references provisions from US-based codes, the Mexican Building Code, the International Building Code, the Association of Caribbean States' Building Code, as well as various recommendations from research on confined masonry structures. The references consulted in the design include the following:

2.1.1 Loads

- Pan American Health Organization (PAHO) Wind Speed Maps for the Caribbean for Application with the Wind Load Provisions of ASCE 7, 2008
- United States Geological Survey (USGS) Documentation for Initial Seismic Hazard Maps for Haiti, 2010
- United States Geological Survey (USGS) Worldwide Seismic "Design Maps" Web Application, Beta version, 2010
- American Society of Civil Engineers' Minimum Design Loads for Buildings and Other Structures, SEI/ASCE 7-05, 2005
- International Code Council's International Building Code (IBC), 2009

2.1.2 Confined Masonry and Masonry Design

- Mexican Building Code's "Complementary Technical Norms for Design and Construction of Masonry Structures"
- American Concrete Institute's Building Code Requirements for Masonry Structures (ACI 530-05)
- The Masonry Society's Building Code Requirements for Masonry Structures (TMS 602-08), 2008
- ASCE/SEI 41-06 Seismic Rehabilitation of Buildings, which includes strut-and-tie provisions for infill walls
- "Out of Plane Resistance of Concrete Masonry Infilled Panels" by Dawe and Seah, 1988
- "Arching of Masonry Infilled Frames: Comparison of Analytical Methods" by Flanagan and Bennett, 1999
- "Behavior of Confined Masonry Shear Walls with Large Openings" by Yanez et al, 2004
- "Seismic Design Guide for Confined Masonry Buildings - Draft" by the Confined Masonry Network, 2010
- "Seismic Design Guide for Masonry Buildings" by Anderson and Brzev, Canadian Concrete Masonry Producers Association, 2009

2.1.3 Concrete Design

- American Concrete Institute's Building Code Requirements for Structural Concrete (ACI 318)

2.1.4 Wood Design

- American Forest and Paper Association Wood Frame Construction Manual for One and Two-Family Dwellings (WFCM-01), 2001
- American Forest and Paper Association National Design Specification for Wood Construction with 2005 Supplement (NDS-05), 2005
- American Forest and Paper Association Special Design Provisions for Wind and Seismic (ANSI/AF&PA SDPWS-08), 2008

2.1.6 Other References Consulted

- Association of Caribbean States' Model Building Code for Wind Loads, 2003
- Association of Caribbean States' Model Building Code for Seismic Loads, 2003
- Caribbean Uniform Building Code (CUBiC), 1985
- European Standard for Earthquake Resistant Design of Structures (Eurocode 8), 2003
- Small Building Code of Trinidad and Tobago 2000
- Organization of Eastern Caribbean States Building Guidelines, 1999
- Minimum Building Standards and Environmental Guidelines for Housing, Safer Housing and Retrofit Program, St Lucia National Research and Development Foundation, 2003
- Architecture for Humanity Rebuilding 101 Manual, 2010
- "Seismic Behavior of Confined Masonry Walls" by Tomazevic and Klemenc, 1997
- "Verification of Seismic Resistance of Confined Masonry Buildings" by Tomazevic and Klemenc, 1997
- "Effect of Vertical and Horizontal Wall Reinforcement on Seismic Behavior of Confined Masonry Walls" by Yoshimura et al, 1996
- "Design of Confined Masonry Walls Under Lateral Loading" by Bariola and Delgado, 1996
- "Simplified Method for Seismic Analysis of Masonry Shear-Wall Buildings" by Tena-Colunga and Cano-Licona, ASCE Journal of Structural Engineering, May 2010
- "Use of Nonlinear Static Analysis for the Displacement-based Assessment of Confined Masonry Buildings" by Teran-Gilmore et al, 2010
- "Simplified Drift-Based Fragility Assessment of Confined Masonry Buildings" by Ruiz-Garcia et al, 2010
- "User's Guide to NZS 4230:2004, Design of Reinforced Concrete Masonry Structures", New Zealand Concrete Masonry Association Inc, 2004
- Various prescriptive confined masonry guidelines including those developed by the following organizations or individuals: City University, Marcial Blondet, Tom Schacher, and Build Change (for programs in Indonesia and China)

2.2 Materials

Material properties for the masonry wall, concrete, reinforcing steel and timber used in the calculations were selected from the US and international codes based on the properties of materials commonly available in Haiti. According to field surveys, the following material types are locally available in Haiti:

2.2.1 Concrete Block

- “Bloc 15” type, dimensions are 40 cm x 20 cm x 15 cm
- “Bloc 20” type, dimensions are 40 cm x 20 cm x 20 cm
- “Bloc 10” type, dimensions are 40 cm x 20 cm x 10 cm
- Density: 2400 kg/m3
- Compressive strengths considered: 4.8 MPa (700 psi), 6.9 MPa (1,000 psi), 11.7 MPa (1700 psi)
- Modulus of elasticity of the masonry/mortar matrix: 2,700 MPa – 6,500 MPa (392,000 psi – 942,300 psi)

2.2.2 Concrete Block Masonry

- Mortar Type M assumed (17 MPa or 2500 psi compressive strength)
- Compressive strength (f’m) (net area): 3.86 MPa (560 psi), 5.52 MPa (800 psi), 9.28 MPa (1,346 psi) for the three block strengths listed above based upon Unit Strength Method (Table 2105.2.2.1.1) of IBC 2009
- Tensile strength: 431 kPa (63 psi) vertical, 862 kPa (125 psi) horizontal based on modulus of rupture strength for Strength Design listed in ACI 530 Table 31.18.2.1

2.2.3 Grout

- Density: 2400 kg/m3
- Compressive strength assumed: 13.8 MPa or 2000 psi (ASTM C476)
- Modulus of elasticity: 17,575 MPa

2.2.4 Plaster

- Density: 2,400 kg/m3
- Compressive strength assumed: 17 MPa or 2500 psi
- Modulus of elasticity: 19,650 MPa

2.2.5 Concrete

- Density: 2,400 kg/m3
- Design compressive strength (f’c) for confining elements and roof: 17 MPa (2,500 psi) although mix proportions specified may provide higher actual strength
- Design compressive strength (f’c) for foundations: 15 MPa or 2,200 psi
- Modulus of elasticity: 19650 MPa

2.2.6 Steel Reinforcement

- Grade 40 bars (fy = 276 MPa or 40 ksi) or Grade 60 bars (fy = 414 MPa or 60 ksi)
- All bars are #4 or smaller
- All reinforcement is ribbed

2.2.7 Timber

- Visually Graded Southern Pine No. 2
- Density: 550 kg/m3 (specific gravity based on weight and volume when oven-dry)
- Design Bending Stress (Fb): 10.3 MPa (1,500 psi)
- Design Tension Stress (Parallel to Grain) (Ft): 5.7MPa (825 psi)
- Design Shear Stress (Parallel to Grain) (Fv): 1.2 MPa (175 psi)
- Design Compression Stress (Perpendicular to Grain) (Fc+): 3.9 MPa (565 psi)
- Design Compression Stress (Parallel to Grain) (Fc): 11.3 MPa (1,650 psi)
- Modulus of Elasticity (E): 4,000 MPa (580,000 psi)

2.3 Loads

2.3.1 Dead Loads

Dead loads include the self weight of building materials including concrete block masonry walls, reinforced concrete confining elements, timber frame roof with CGI panels, and foundations.

These calculations make the following assumptions regarding the dead loads of the structure in order to calculate gravity and seismic loads:

- Confined masonry walls: 2.25 kPa (47.0 psf) estimated, including confining elements, bed joints and grouted cells (additional load due to plaster also considered in cases where plaster is used)
- Concrete flat slab floor/roof with waterproofing: 4.0 kPa (84 psf)
- Timber frame roof with CGI panels: 1.05 kPa (22 psf)

2.3.2 Live Loads

A live load of 1.0 kPa (20 psf) is assumed on timber frame roofs and 2.5 kPa (50 psf) is assumed on flat concrete slab floors/roofs.

2.3.3 Wind Loads

Wind pressures for the main structural system and roof cladding were calculated using the Simplified Procedure (Method 1) of ASCE 7-05 in combination with the Basic Wind Speed of 119 mph provided by the *Pan American Health Organization (PAHO) Wind Speed Maps for the Caribbean for Application with the Wind Load Provisions of ASCE 7, 2008*. Exposure Category C was assumed as well as an Importance Factor of 1.0. The maximum wind pressure calculated for any region of a surface was taken as the governing load.

- Lateral Wind Pressure on Walls: 1.87 kPa (39 psf) maximum
- Wind Pressure (down) on Gable/Hip Roof Structure: 0.14 kPa (3 psf) maximum
- Wind Pressure (up) on Gable/Hip Roof Structure: 1.72 kPa (36 psf) maximum
- Wind Pressure (down) on Roof Cladding: 0.67 kPa (14 psf) maximum
- Wind Pressure (up) on Roof Cladding: 1.91 kPa (40 psf) maximum
- Wind Pressure (up) on Roof Cladding corners: 3.01 kPa (63 psf maximum)

2.3.4 Seismic Loads

The seismic design loads were determined using the short period spectral acceleration (Ss) data provided in the 2010 USGS Worldwide Seismic "Design Maps" Web Application in combination with the equivalent lateral force procedure of ASCE 7-05. The seismic loads correspond to a 2% probability of exceedance in 50 years.

Two sets of seismic criteria were considered in the designs. The first set (Orange Zone), corresponding approximately to a peak ground acceleration of 0.6g, covers Port-au- Prince, where most of the reconstruction is likely to occur. The second set (Red Zone), corresponding approximately to a peak ground acceleration of 1.0g, covers the more severe seismic hazard areas to the north and west of Port-au-Prince, which for the most part are outside of the zones affected by the January 2010 earthquake.

Orange Zone Seismic Criteria

- Mapped MCE Short Period Spectral Response Acceleration (Ss): 1.58g (corresponds approximately to a peak ground acceleration of 0.6g for 2% in 50 years)
- Site Class D (Fa = 1.0)
- Short Period Design Spectral Response Acceleration (Sds): 1.05g

Red Zone Seismic Criteria

- Mapped MCE Short Period Spectral Response Acceleration (Ss): 2.51g (corresponds approximately to a peak ground acceleration of 1.0g for 2% in 50 years)
- Site Class D (Fa = 1.0)
- Short Period Design Spectral Response Acceleration (Sds): 1.67g

The following map shown in Figure 2.1, which was developed using data gathered in 2010 by USGS, indicates regions of Haiti where either the Orange Zone or Red Zone seismic criteria apply. The Red Zone covers all regions of Haiti including those with the highest anticipated ground motions. The Orange Zone covers a majority of Haiti, including most areas in the earthquake-affected zone around Port-au-Prince. The zones shown in yellow on the map have lower expected ground motions. These zones were not a focus of the design because they are not in the earthquake-affected zone.

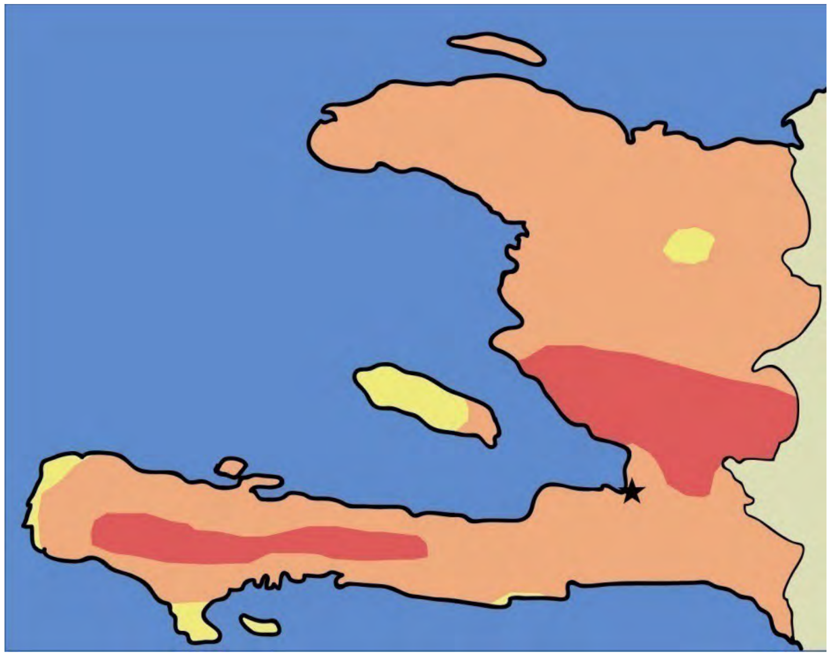

Figure 2.1 Map of Haiti showing severity of seismic demands by region based upon 2010 USGS data (Sds = 0.5g for yellow zones, Sds = 1.05g for orange zones, Sds = 1.67g for red zones)

The Response Modification Coefficient (R Factor) that was used to arrive at seismic demands on the structure varied between 2.5 and 3.0 depending upon the strength of concrete block assumed in the design. Where concrete block strengths were specified ranging from 6.9 MPa (1000 psi) to 11.7 MPa (1700 psi) (ie strengths which are generally consistent with accepted design standards and test data) an R-factor of 3.0 was used, based upon the recommendation of the Confined Masonry Network's "Draft Seismic Design Guide for Confined Masonry Buildings". Where a lower concrete block strength of 4.8MPa (700 psi) was assumed, a more conservative R-factor of 2.5 was selected.

3.0 DESIGN METHODOLOGY

Due to the significant variation in strength of concrete blocks available in Haiti as well as the large range of ground motions expected in Haiti based upon current USGS maps, we approached the design by coupling the use of a specific concrete block strength with an anticipated seismic performance for one set of design and construction guidelines (and house layouts) for the single-story case and one set for the two-story case.

The primary benefit of this approach is that the use of one set of design and construction guidelines should simplify its implementation and reduce misunderstanding, thereby allowing it to be more widespread, understood, and, ideally, replicated. This approach also allows for an understanding of the improvement in the seismic performance that could be achieved if the concrete block manufacturing industry in Haiti is more tightly controlled. The present poor quality of most blocks in Haiti makes it near-impossible to design for the highest anticipated ground motions in Haiti; however, it is reasonable to assume that the quality control standards for the production of these blocks may improve over time, enabling an increased seismic performance for an identical house configuration built with better blocks.

On this basis, the following cases were considered:

Cases Considered for Single Story with Lightweight Roof

CONCRETE BLOCK STRENGTH	SEISMIC DESIGN CRITERIA
4.8 MPa (700 psi) min	Permitted in all zones (Sds = 1.05g to 1.67g)

Cases Considered for Single Story with Concrete Roof/Two Story

CONCRETE BLOCK STRENGTH	SEISMIC DESIGN CRITERIA
4.8 MPa (700 psi)	Not permitted
6.9 MPa (1,000 psi) min	Permitted in orange and yellow zones only (Sds = 1.05g)
11.7 MPa (1,700 psi) min	Permitted in all zones (Sds = 1.67g)

Using the above criteria, one set of design and construction guidelines and proposed house layouts was developed for the single-story house with a lightweight timber frame roof, and a second set of design and construction guidelines and proposed house layouts was developed for the single-story house with concrete roof / two-story house.

The guidelines also include provisions for vertical and horizontal expansion. The additional house layouts in the single-story house with timber frame roof provide examples of options for horizontal expansion. Vertical expansion is permitted only in the single-story house with a concrete roof. The single-story house with a timber frame roof is not designed for the additional load of a second story.

The following sections describe the calculation methodology used to arrive at the set of design and construction guidelines and proposed house layouts. The design of all masonry and concrete elements is based upon strength design principles. The design of timber frame roof and determination of foundation dimensions are based upon allowable stress design principles.

The in-plane shear behavior of the confined masonry walls is the governing factor in the house layouts and design and construction guidelines due to the generally low concrete block masonry compressive strength. Out-of-plane behavior of the confined masonry walls is less of a factor due to the relatively low wall height-to-thickness ratio resulting from the 15cm-wide concrete block.

3.1 In-Plane Shear Design

The in-plane design of the confined masonry walls was based upon the provisions of the Mexican masonry code for in-plane shear capacity of confined masonry systems. For a variety of house layouts coupled with a variety of concrete block strengths and seismic loads, the in-plane seismic shear force demand was calculated for each wall and compared to its capacity. The set of guidelines were developed based upon an evaluation of this data set.

For these calculations, all masonry walls, including those with openings, were considered to be shear-resisting elements and assumed to be designed and detailed according to the design guidelines. In these calculations, the wall lengths were divided into individual 'shear walls' at wall ends, corner, windows or doors. The guidelines for tie column placement and reinforcement requirements around openings were developed to always result in individual 'shear walls' with tie columns at their extreme ends and at most one window opening centered on a wall panel between tie columns. This permitted direct application of the in-plane shear capacity provisions of the Mexican masonry code as well as the recommendations of Yanez et al, which tested only individual confined masonry panels with a single large opening. The following figures demonstrate the subdivision of a longer wall length into individual shear walls for the purposes of the calculation:

Figure 3.1 Examples of subdivision of walls into individual shear walls (each bounded by tie columns with at most one opening) for in-plane shear calculations

3.1.1 In-Plane Shear Demand

The shear force demands on the shear walls were calculated according to the equivalent lateral force procedure in ASCE 7-05. The base shear was calculated using the effective weight of the confined masonry walls and the floor/roof system. No Redundancy Factor was assumed in calculating the seismic shear demands.

For the lightweight roof cases, a flexible diaphragm assumption (ie tributary area) was used to distribute the seismic load of the roof to each wall, in addition to its own seismic load. Seismic load due to orthogonal walls was also distributed to shear walls based on tributary area, assuming they are spanning approximately horizontally between the perpendicular shear walls.

For the concrete roof cases, a rigid diaphragm assumption was used to distribute all seismic loads from walls, floor and roof to the shear walls. For this case, the reduction in wall stiffness due to openings and its influence on shear distribution was accounted for by using finite element models built in SAP2000 for the primary house configurations to determine the rigidity of each wall (the increased relative stiffness of short wall lengths due to the high tie column-to-wall area ratio was neglected). A 5% accidental torsion was also considered per ASCE 7-05.

3.1.2 In-Plane Shear Capacity

The in-plane shear capacities were calculated according to Mexico's "Complementary Technical Norms for Design and Construction of Masonry Structures" using the following equation (where P represents the axial loading on the wall, v_m represents the shear strength of the masonry-mortar matrix based upon gross area, A represents the gross area of the confined masonry wall, and R is a reduction factor):

$$V_{mR} = R_F (0.5\ v_m * A_T + 0.3P) < 1.5\ F_R\ v_m * A_T$$

The value v was calculated from the compressive strength of the masonry-mortar matrix according to 0.25 * sqrt (f'm) [MPa]. The Mexican code places a limit on v of 0.6 MPa.

Using this methodology it was determined that the single-story house with a lightweight timber roof constructed from 700 psi concrete block has sufficient in-plane shear capacity for the most severe seismic criteria of Sds = 1.67g:

Table 3.1 Shear stress demand vs capacity for single-story house

Wall Label	Shear Stress Demand [kPa]	Shear Stress Capacity [kPa]
A	73.66	137.32
B	128.96	139.78
C	104.79	138.83
D	104.79	138.83
E	110.05	137.42
F	68.02	137.42
1	97.91	137.04
2	100.40	138.72
3	107.57	138.91
4	100.40	138.72
5	89.76	137.87
6	74.94	137.73

Using this methodology it was determined that the two-story house constructed from 1000 psi concrete block has sufficient in-plane shear capacity to resist a short period design spectral acceleration of 1.05g. A higher block strength of 1700 psi is required for the more severe seismic criteria of Sds = 1.67g:

Table 3.2 Shear stress demand vs capacity for two-story house with concrete roof

Wall Label	Shear Stress Demand [kPa] With Sds = 1.67g	Shear Stress Capacity [kPa] With 1700 psi blocks
A	206.42	229.08
B	206.42	229.08
C	198.15	229.08
D	179.72	228.41
1	224.93	230.79
2	224.93	230.79
3	214.73	236.16
4	214.73	236.16

5	214.73	236.16
6	214.73	236.16
7	224.93	225.41
8	224.93	225.41

3.1.3 Influence of Openings

As described in Section 3.1.1, the influence of openings on the stiffness of the walls was considered in determining the distribution of shear demands to the walls where required. Additionally, the openings were considered in determining the in-plane shear capacity of the walls. Based upon research by Yanez et al which tested the behavior of individual confined masonry shear walls with large openings, it was assumed that the shear capacity of a wall with window opening is proportional its net transverse area.

Therefore, the full shear capacity of each shear wall was calculated according to the provisions of the Mexican masonry code, and for walls with window openings this capacity was reduced proportionally. According to the same research by Yanez et al, the effect of door openings is not well-represented by this methodology; therefore, these calculations assume that each door opening is confined on either side by a tie column, and each masonry wall on either side of the door is considered to be an independent shear wall.

Two cases were developed for the reinforcement requirements around window openings:

Case A: Where a single window is centered on a confined masonry panel and it is the only opening in the shear wall, it is permitted to be reinforced according to the provisions of Section 5.1.3 of the Mexican masonry code and the recommendations found in the research by Yanez et al. Per the Mexican code, horizontal steel bars anchored in the walls may be used as reinforcement at the lower edge of an opening if the bars are designed to withstand a tension force of 29kN. The horizontal reinforcement below these window openings has been designed for this load. Vertical reinforcing at the edges of these window openings was designed based on testing configurations in Yanez et al's research, which used one 10mm diameter bar in a continuous, fully grouted cell of the masonry block on either side of the window opening.

Case B: When window openings are positioned in series along a single wall, every other window must be reinforced with full tie columns and sill beams in order to ensure that the individual shear wall piers created by the openings are bounded by tie columns at their extremities. The following sketch demonstrates the reason for this requirement:

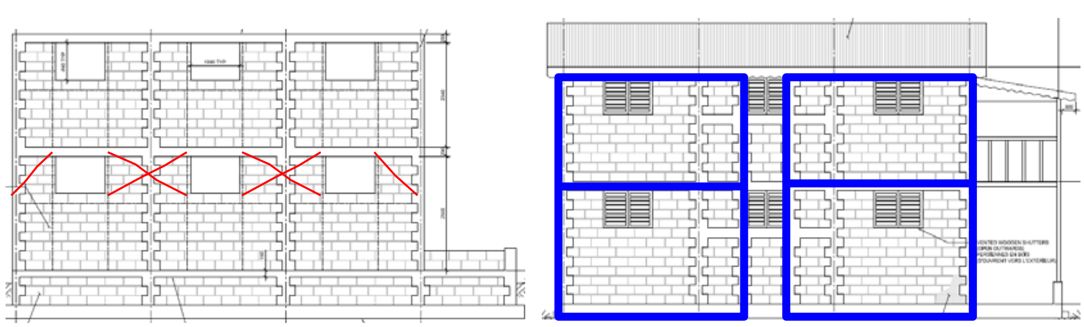

Figure 3.2 Window openings in series without tie columns may result in cracking of the unconfined piers created by the openings. Placing tie columns at every other window in series allows subdivision of walls into individual shear walls (with a maximum of one opening) bounded by confining elements

More details regarding the design of tie columns and wall reinforcement can be found in Section 3.4.

3.1.4 Spacing of Orthogonal Walls

In performing the above in-plane calculations for a variety of configurations for single- story and two-story houses, it was determined that there must be a limit on the spacing of orthogonal walls in order to limit the in-plane shear force distributed to each wall. For the single-story house with a lightweight roof, the maximum spacing of orthogonal walls set at 4m, although the limit in the guidelines was conservatively set at 3.5m. For the single-story house with a concrete roof (or two-story house), the maximum spacing of orthogonal walls cannot be greater than 3.5m.

3.1.5 Influence of Plaster Finish

The influence of adding a 1cm plaster finish to the walls was investigated. The addition of plaster increases the in-plane shear capacity of the walls because the thickness of the wall and therefore A is increased; however, it also increases the seismic demands due to the increased weight. Overall, there is a net benefit to adding plaster (on the order of 5%); however, the guidelines and house layouts were developed conservatively assuming that plaster would not be applied to the walls, although this practice is recommended.

3.2 Axial and In-Plane Wall Flexural Design

The combined axial and in-plane flexural strength of each confined masonry shear wall was calculated according to the confined masonry provisions of the Mexican masonry code and compared to the axial and flexural demands on each wall due to gravity plus seismic loads. This design check was particularly relevant for the two-story house design.

3.2.1 In-Plane Flexural Demands

To determine in-plane flexural demands on each wall, seismic forces were distributed to each wall using the Cv factors of the equivalent lateral force method of ASCE-7. For the lightweight roof case, orthogonal walls were assumed to span horizontally between shear walls; therefore the seismic load from orthogonal walls was assumed to act at the mid-height of the walls in the calculation of Cv factors. For the concrete roof case, the orthogonal walls were assumed to span vertically and horizontally. Therefore the seismic load from orthogonal walls was distributed accordingly in the calculation of Cv factors.

3.2.2 In-Plane Flexural Capacity

The in-plane flexural capacities were calculated according to Mexico's "Complementary Technical Norms for Design and Construction of Masonry Structures" using the following equation:

$M_R = F_R * Mo + 0.3 * Pu * d$ where $0 < Pu < P_R/3$
$= [(1.5 * F_R * Mo) + (0.15 * P_R * d)] * [1 – Pu/P_R]$ where $Pu > P_R / 3$

where Mo = As * fy * d' and d' is the distance between centroids of tie column steel and where P_R, the compressive strength of the wall, is equal to

$F_R * F_E * (f'm + 0.4) * A_T$

The in-plane flexural demands and axial loads on the single story house with lightweight roof were not significant. However, for the two-story case, this equation governed the longitudinal steel requirements of the tie columns.

3.3 Out-of-Plane Design

The seismic surface pressure on the masonry walls was taken as the maximum of 0.4*Sds*Weight of the wall or 0.1*Weight of the wall per ASCE-7 and compared to the design wind pressures on the walls. The seismic pressure governed over the wind pressure and was used to compute out-of-plane bending demands.

The out-of-plane capacity of the confined masonry walls was calculated using the equations provided in Flanagan and Bennett based on research by Dawe and Seah with an assumed strength reduction factor of 0.75. For the lightweight roof case, the following equations were used, assuming a three-side supported wall which is not supported at the roof:

$$q_{ult} = 800 * f'm^{0.75} * t^2 * \alpha / L^{2.5}$$

$$\alpha = 1/H * E * I_c * H^2 < 50$$

where "t" represents the full width of the masonry block walls, "H" is the wall panel height, "L" is the wall panel length, and "I_c" is the tie column moment of inertia.

Using this equation, the out-of-plane capacity of a 4m wide by 2.7m tall wall (which is the maximum wall size permitted by the guidelines due to in-plane shear considerations) is 80 kPa (1,670 psf). This capacity is well above the anticipated out-of-plane demands.

For the concrete roof case, the following equations were used, assuming a four-side supported wall:

$$q_{ult} = 800 * f'm^{0.75} * t^2 * \alpha / ((\alpha / L^{2.5}) + (\beta / H^{2.5}))$$

$$\alpha = 1/H * E * I_c * H^2 \leq 50$$

$$\beta = 1/L * E * I_b * L^2 \leq 50$$

where “t” represents the full width of the masonry block walls, “H” is the wall panel height, “L” is the wall panel length, and “I_c” is the tie column moment of inertia, and “I_b” is the ring beam moment of inertia.

Using this equation, the out-of-plane capacity of a 3 m wide by 2.7 m tall wall (which is the maximum wall size permitted by the guidelines due to in-plane shear considerations) is more than 80 kPa, also well-above the anticipated out-of-plane demands.

3.4 Design of Confining Elements

3.4.1 Tie Columns

The longitudinal reinforcement in the tie columns was designed for the governing flexural or axial demands resulting from the following checks:

1 Tension due to overturning in the wall resulting from the in-plane flexural strength provisions of the Mexican masonry code (see Section 3.2.2)
2 Tension due to strut and tie action (see Section 3.4.1.1)
3 Flexure due to strut and tie action (see Section 3.4.1.1)
4 Flexure in tie column acting as a vertical beam for out-of-plane support of masonry walls (see Section 3.4.1.2)
5 ACI 318 minimum longitudinal steel requirement (1% Ag)

The single-story design was governed by case #3 above. The two-story design was governed by case #1 above.

The transverse reinforcement in the tie columns was designed for the governing shear demands resulting from the following checks:

1 Shear due to strut and tie action (see Section 3.4.1.1)
2 Shear in tie column acting as a vertical beam for out-of-plane support of masonry walls (see Section 3.4.1.2)

Both the single-story and two-story designs were governed by case #1 above. It should be noted that the maximum spacing requirement in ACI 318 of d/2 for shear reinforcement in the confining elements is not satisfied. The small dimension of the confining elements makes application of this requirement impractical.

3.4.1.1 Demands Due to Strut and Tie Action

Although strut-and-tie action was not considered to be the dominant lateral force transfer mechanism for in-plane shear in the confined masonry systems, this behavior was considered in the detailing of reinforcement for the tie columns and ring beams, particularly at their joints.

Although the confined masonry system is not equivalent to an infill frame system, Equation 8-10 of FEMA 306 (or ASCE/SEI 41-06), which defines the shear capacity of an infill wall based on the compressive failure of the diagonal strut, was used to compute the maximum capacity of a diagonal compression strut through each confined masonry wall, and this capacity was used as the maximum demand on the surrounding confining elements. The following equation was used in combination with an assumed strength reduction factor of 0.75 to compute the horizontal component of the compression strut:

$$Vc = a * t_{inf} * f'_{m90} * c\,os\theta$$

where f'm90 per FEMA 306 was assumed to be 50% of f'm. In this equation, "tinf" represents the thickness of the compression strut which was assumed to be two-times the wall side wall thickness of the concrete block (ie 5.4cm) on the basis that these side walls are the only continuous parts of the concrete masonry wall. In this equation, "a" represents the equivalent width of the compression strut which is computed according to FEMA 306 Equation 8-1 (or ASCE/SEI 41-06 Equation 7-7):

$$a = 0.175 * (\lambda_1 * h_{col}))^{-0.4} * r_{inf}$$

where r_{inf} is the diagonal length of the compression strut and λ_1 is defined according toFEMA 306 Equation 8-2 (or ASCE/SEI 41-06 Equation 7-7) as:

$$\lambda_1 = [(E_{me} * t_{inf} * \sin 2\theta)/(4 * E_{fe} * I_{col} * h_{inf})]^{0.25}$$

In this equation, "t_{inf}" is assumed to be the full width of the concrete block rather than the reduced value used above.

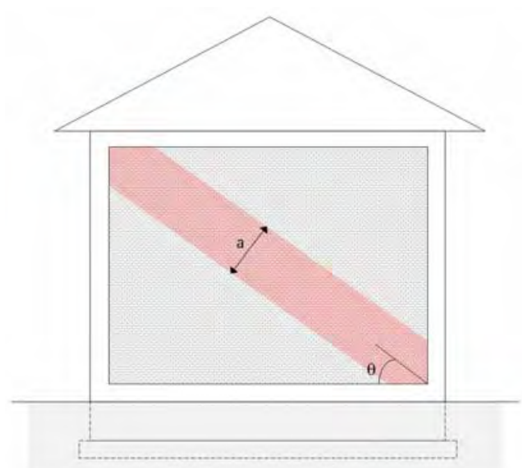

Figure 3.3 Diagonal compression strut in confined masonry wall

Longitudinal reinforcing in the tie column was sized for tension in the tie column resulting from strut-and-tie behavior of the confined masonry shear wall. A minimum of four bars were used to facilitate the placing of the reinforcement. This reinforcing steel was then checked against ACI criteria for minimum longitudinal steel ratio.

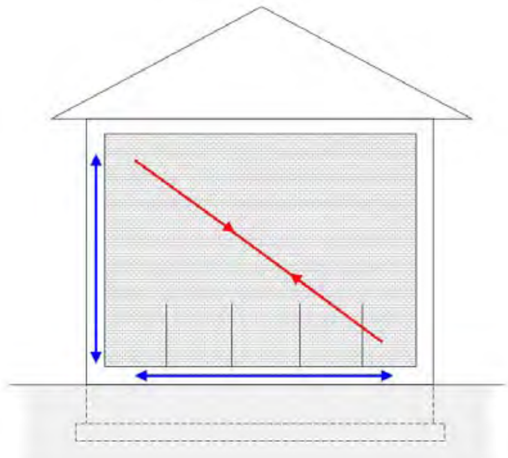

Figure 3.4 Tension in confining elements (blue) resulting from compression strut in masonry wall (red)

Longitudinal reinforcement in the tie column was also checked for the flexural demands resulting from the concentrated loading of the compression strut in the masonry wall near the joints between the tie-columns and ring beams. Figure 3.5 shows the distributed load (ie the total compression strut capacity divided by the length of contact between the strut and confining elements) applied to the tie column to determine the flexural demand. In this calculation, the tie column was assumed to be fixed at both top and bottom. The shear reinforcement in the tie columns near the top and bottom joints was also sized for the shear force demands resulting from this loading condition.

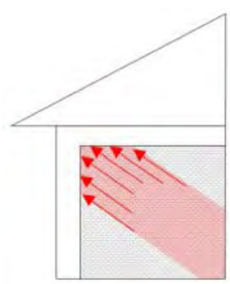

Figure 3.5 Concentrated loading on tie column-ring beam joint from compression strut

3.4.1.2 Demands Due to Out of Plane Action

The flexural and shear reinforcement in the tie columns were also checked for the demands on a tie column resulting from the condition where it is not braced by a masonry wall along both axes and therefore must function as a vertical beam to support one side of a masonry wall panel.

For the single-story house with lightweight roof, in this calculation, the maximum length of wall panel without orthogonal walls bracing both ends was 1.3m and the wall was assumed to span out-of-plane horizontally, resulting in a tributary width of wall of 0.65m loading the tie column.

For the two-story house, in this calculation the maximum length of wall panel without orthogonal walls bracing both ends was 2.6m and the wall was conservatively assumed to span horizontally only, resulting in a tributary width of wall of 1.3m loading the tie column.

In both cases, the tie column was conservatively assumed to be pinned at top and bottom.

3.4.2 Ring Beam

The longitudinal reinforcement in the ring beams was designed for the governing flexural or axial demands resulting from the following checks:

1. Tension due to strut and tie action (see Section 3.4.2.1)
2. Flexure due to strut and tie action (see Section 3.4.2.1)
3. Flexure in ring beam for out-of-plane support of masonry walls for the flexible diaphragm case only (see Section 3.4.2.2)
4. Tension due to diaphragm action of concrete roof (chord and drag forces) (see Section 3.4.2.3)
5. Flexure due to effect of openings (ie load transfer, coupling etc) (see Section 3.4.2.4)

The single-story design was governed by case #2 above. The two-story design was governed by case #2 above.

The transverse reinforcement in the ring beams was designed for the governing shear demands resulting from the following checks:

1. Shear due to strut and tie action (see Section 3.4.2.1)
2. Shear in ring beam acting for out-of-plane support of masonry walls for the flexible diaphragm case only (see Section 3.4.2.2)
3. Shear due to effect of openings (ie load transfer, coupling, etc) (see Section 3.4.2.4)

Both the single-story and two-story designs were governed by case #1 above. It should be noted that the maximum spacing requirement in ACI 318 of d/2 for shear reinforcement in the confining elements is not satisfied. The small dimension of the confining elements makes application of this requirement impractical.

3.4.2.1 Demands Due to Strut and Tie Action

A similar methodology to that used for the tie column detailing was used to determine axial, flexural and shear force demands on the ring beams as a result of strut-and-tie action of the confined masonry system. The ring beam reinforcement was sized for a tension force equal to the horizontal component of the compression strut capacity as well as the flexural and shear forces at the joints resulting from the concentrated loading of the compression strut. In these calculations, the ring beam was assumed to be fixed at both ends.

Refer to Section 3.4.1.1 for additional information regarding this calculation methodology.

3.4.2.2 Demands Due to Out of Plane Action (Flexible Diaphragm Only)

The flexural and shear reinforcement in the ring beams was also checked for the demands resulting from the condition where a wooden roof is used. In this scenario, the flexible roof diaphragm cannot provide continuous bracing to the top of the confined masonry walls for out of plane loading and the ring beam at the top of the wall must act as a horizontal beam to transfer out of plane loads to the orthogonal shear walls.

In this calculation, the ring beam was conservatively assumed to be pinned at both ends. The loading on the beam was based upon a tributary width of wall of 1.35m, assuming conservatively that the 2.7m tall masonry wall spans vertically between the ground and the ring beam.

3.4.2.3 Demands Due to Roof Diaphragm (Rigid Diaphragm Only)

Longitudinal reinforcing was also checked against the demand due to the development of chord forces in the beams perpendicular to the direction of seismic force, which did not govern the sizing of the reinforcing in any configuration.

3.4.2.4 Demands Due to Openings

The longitudinal and shear reinforcement in the ring beams was also checked for the shear and bending forces over door and window openings due to coupling beam behavior and due to the vertical concentrated loading from the timber truss or concrete roof slab. The coupling beam forces were determined using two-dimensional analytical structural models of the shear wall and ring beam with the openings accurately proportioned. These forces were found not to govern the design of the ring beam reinforcement. The reactions due to the roof loading were found with simple hand calculations and were also found not to govern the design of the ring beam.

3.4.3 Plinth Beam

The cast-in-place reinforced concrete plinth beam and longitudinal reinforcement was designed for the tension resulting from the strut-and-tie behavior of the confined masonry shear wall. Again, a minimum of four bars were used to facilitate uniform placement of the longitudinal steel. Due to the anchorage of the tie column in the footing below, there is no interaction between the tie column and the plinth beam and therefore no additional plinth beam reinforcing due to tie column influence was required.

It should be noted that the spacing of shear reinforcement in the plinth beam does not comply with the maximum spacing requirements of ACI 318.

3.4.4 Wall-Column Interface

Strut-and-tie shear wall behavior does not rely on the transfer of shear between the tie column/masonry wall interface. The Mexican masonry code calculations, however, rely on this transfer of force, and therefore the wall/column interfaces were checked for their ability to transfer these loads.

To confirm that no additional shear reinforcement was necessary, the confined masonry shear walls were checked to confirm that no uplift forces resulted at the base of the tie columns that would need to be transferred to the plinth beam through shear. There was found to be no net tension in the tie columns at the plinth beams in any configuration. This was determined by calculating the transfer of load between the tie column and the masonry wall over their interface due to the shear capacity of the unreinforced concrete toothing pattern.

3.5 Reinforcement Detailing

In most reinforced elements, the design of the reinforcing steel was in accordance with the provisions of ACI 318 for ratios, placement, cover, splice lengths, and development lengths. However, in certain instances, ACI recommendations were not met for reasons of economy and practicality. For example, due to the small dimensions of the confining elements, the maximum spacing requirements for transverse reinforcement in confining elements and the reinforcement cover requirements were not always met. A minimum of 25mm (1in) of cover was provided for all reinforced elements, with most non-tie column elements having the full 1.5in of cover.

3.6 Foundation Design

The foundation system was designed as an unreinforced concrete strip footing supporting reinforced concrete columns at the tie column locations and supporting unreinforced concrete block masonry foundation walls between tie columns.

Soil bearing pressures due to axial loads and overturning were checked locally per individual wall as well as globally as if the building had a continuous mat foundation for the worst case configuration permitted by the design guidelines for the one and two story houses. Allowable Stress Design (ASD) load combinations were used for these calculations, and the ground floor was set at 0.8m above the ground level, as the most conservative case. The bearing pressures were checked to ensure no uplift on any portion of the footing for the global check; however, the factor of safety against overturning was found to be less than 1.5. For overturning calculations, the portion of the reduced foundation below the porch area was not considered to participate in overturning resistance.

While the single story house with timber roof footing calculations were based on an allowable bearing capacity of 50 kN/m^2, the calculations for the two-story house assumed an allowable soil bearing capacity of 70kN/m^2 with a 1/3 increase permitted for seismic loads. While the design criteria had specified using an allowable bearing capacity of 50 kN/m^2, it was determined that this assumption would result in a footing width greater than 1m for the two-story house designed for Sds=1.67g. Because the MTPTC guidelines specify a footing width of 70cm for poor soil conditions, we felt that a 1m footing width was sufficiently conservative and the 50kN/m^2 allowable bearing capacity criterion was overly restrictive for the two-story case.

The depth of the unreinforced concrete footings was determined based on shear demand at the critical section. The depth was set such that the shear capacity of the concrete was adequate to resist the shear force without requiring any reinforcement.

The foundation design assumed that in-plane wall shear forces were transferred from the confined masonry superstructure to the foundation system through a combination of shear in the lower portion of the tie columns that extend below the plinth beam into the footing and shear in the unreinforced masonry foundation wall (transferred from the plinth beam through friction) (Figure 3.6). A check was made to ensure that for each wall the shear demand remaining after the shear capacity of the tie columns extending below the plinth beam was subtracted out was less than the shear capacity of the unreinforced masonry foundation wall per ACI 530.

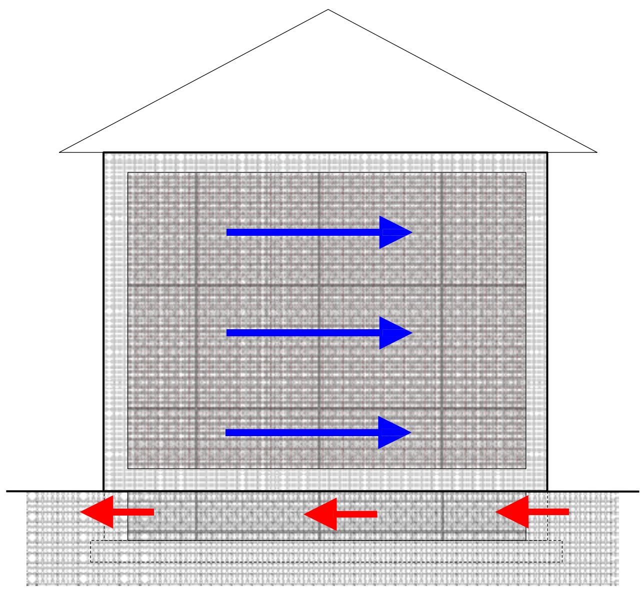

Figure 3.6 Shear transfer from confined masonry walls to foundation (capacity is based upon a combination of shear resistance of reinforced concrete tie columns and shear resistance of unreinforced masonry wall)

Lateral stability of the foundation system was checked to ensure a factor of safety against sliding of 1.5. This calculation was based on assumed coefficients of soil / concrete friction plus passive bearing at the ends of walls parallel to the direction of ground motion being considered. A coefficient of friction between the sand underlying the footing and the footing itself was assumed to be 0.5. Passive pressure was assumed to be 300lb/sqft, or approximately 15kPa. This calculation was used to set the minimum depth below grade required for the foundation system.

Foundation walls, which could extend above grade up to 80cm in flood zones, were also checked for out of plane bending due to active soil pressure. Out-of-plane bending calculations were based on the assumption that the foundation walls perpendicular to the direction of ground motion restrain the slab and retain the interior soil build-up.

Out-of-plane calculations were carried out using the same methodology outlined in Section 3.2. Out-of-plane forces were calculated for the governing case in which the ground level slab is elevated 0.8m above the surrounding grade and found to be lower than the out-of-plane capacity of the foundation walls.

3.7 Roof Design

3.7.1 Timber Frame Roof

The timber frame roofs for one- and two-story options were designed according to the American Forest and Paper Association's National Design Specification for Wood Construction with 2005 Supplement (NDS 2005) using assumed superimposed dead loads and live loads as well as the region-specific wind loads as defined in PAHO's wind speed report which includes the effects of hurricanes. Gable roof frames were designed as simple roof trusses spaced at a maximum of 0.5 meters on centers for spans of 3-3.5m without an intermediate support and a maximum of 1.0m on centers for spans of 3-3.5m with an intermediate support. Roof truss members are 2x4 timbers and have 2x4 roof purlins running perpendicular to their top chord.

Roof truss configuration is determined by span. For the maximum loading condition for up to 3.5 meter spans, trusses with a single vertical member and two interior diagonals can be used. For spans greater than 3.5 m, two additional verticals and two additional diagonals are added to the truss configurations. Roof slope is kept constant at 25 degrees. Light-gauge corrugated metal roof deck spans between purlins and provides a continuous roof surface.

Each truss member was checked per NDS 2005 requirements for axial load, bending, and the interaction of axial and bending. Truss connections, including plywood gusset plates and sheet steel hurricane straps, were designed according to NDS 2005 specifications. Lag screw connections securing the metal roof decking to the 2x4 purlins were designed per the specifications and were typically governed by wind and uplift loads, as was much of the wood truss roof design. Detailed calculations for the wood roof system can be found in Appendix A.

3.7.2 Concrete Roof

The concrete roof and floor slabs are assumed to be two-way ribbed (or coffered) slabs created using void forms of 10 cm thick confined masonry block as is common practice in Haiti. The total depth of the ribbed two-way system is assumed to be 20 cm, consisting of 10 cm deep ribs and 10cm continuous slab above, creating a span to depth ratio that, for the longest wall-to-wall spans of 3.5m, is within ACI's recommendation for minimum slab depths.

Concrete floor and roof slabs were designed as two-way beam systems supporting slabs between beams. Beam reinforcing was designed for shear and bending, and reinforcing was designed to span between adjacent beams. Slab reinforcement was checked for diaphragm action.
For the most part, the design of the reinforcing steel was in accordance with the provisions of ACI 318 for ratios, placement, and splice lengths. However, in certain instances, ACI recommendations were not met for reasons of economy and practicality. For example, due to the small dimensions of the roof joists, the maximum spacing requirements for transverse reinforcement in confining elements and the reinforcement cover requirements were not always met.

3.8 Stair Design

It is recommended that two-story houses be built with either wooden stairs or prefabricated metal spiral stairs located on the exterior of the building. However, properly detailed reinforced concrete stairs are also permitted. Reinforced concrete stairs were designed and detailed for the particular rise and run resulting from the two-story configuration shown in the drawing set. Due to the highly specific nature of stair design, it was not practical to generate a set of guidelines to cover all possible stair geometries.

It should be noted that the reinforced concrete stair design was based upon the specification of a cold joint between the base of the stair and its foundation as well as between the edge of the stair and the adjacent wall. The purpose of this requirement is to limit the seismic load transfer from the building into the stairs, which are typically a stiffer lateral load path and therefore tend to take seismic load. Therefore, the in-plane seismic load calculations described in Section 3.1 for the two-story rigid diaphragm case conservatively assumed that the full seismic load of the stairs is transferred to the shear walls of the building in determining the center of mass of the building but not the center of rigidity.

For reasons of economy and practicality, in certain instances, ACI recommendations for reinforcement detailing were not met in the stair design.

APPENDIX 4: DESIGN AND CONSTRUCTION GUIDELINES FOR CONFINED MASONRY HOUSING IN HAITI

DESIGN AND CONSTUCTION GUIDELINES FOR CONFINED MASONRY HOUSING
(narrative only, design drawings not included[1])

Build Change Post-Earthquake Housing Reconstruction Technical Assistance Program, Haiti

Prepared for

Build Change
Denver CO

31 January 2011

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[1] For the complete document, including appendices of drawings, go to www.buildchange.org/USAIDPrimers.html .

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1.0 DESIGN AND CONSTRUCTION GUIDELINES

The following rules should be followed when designing and building a one- or two-story confined masonry house.

1.1 Material and Construction Quality

1.1.1 Concrete Block

The seismic resistance of the confined masonry house designs depends upon the strength and quality of concrete block used. Therefore, the following table should be used to identify the concrete block strength required to achieve the desired level of seismic resistance, and a testing program (with a sufficient sample size) should be implemented to ensure that the blocks achieve the required compression strength.

Single Story House with Lightweight Roof

CONCRETE BLOCK STRENGTH	SEISMIC DESIGN CRITERIA
4.8 MPa (700 psi) min	Permitted in all zones (Sds = 1.05g to 1.67g)

Single Story House with Concrete Roof

CONCRETE BLOCK STRENGTH	SEISMIC DESIGN CRITERIA
4.8 MPa (700 psi)	Not permitted
6.9 MPa (1,000 psi) min	Permitted in orange and yellow zones only (Sds = 1.05g)
11.7 MPa (1,700 psi) min	Permitted in all zones (Sds = 1.67g)

Two Story House with Concrete or Lightweight Roof

CONCRETE BLOCK STRENGTH	SEISMIC DESIGN CRITERIA
4.8 MPa (700 psi)	Not permitted
6.9 MPa (1,000 psi) min	Permitted in orange and yellow zones only (Sds = 1.05g)
11.7 MPa (1,700 psi) min	Permitted in all zones (Sds = 1.67g)

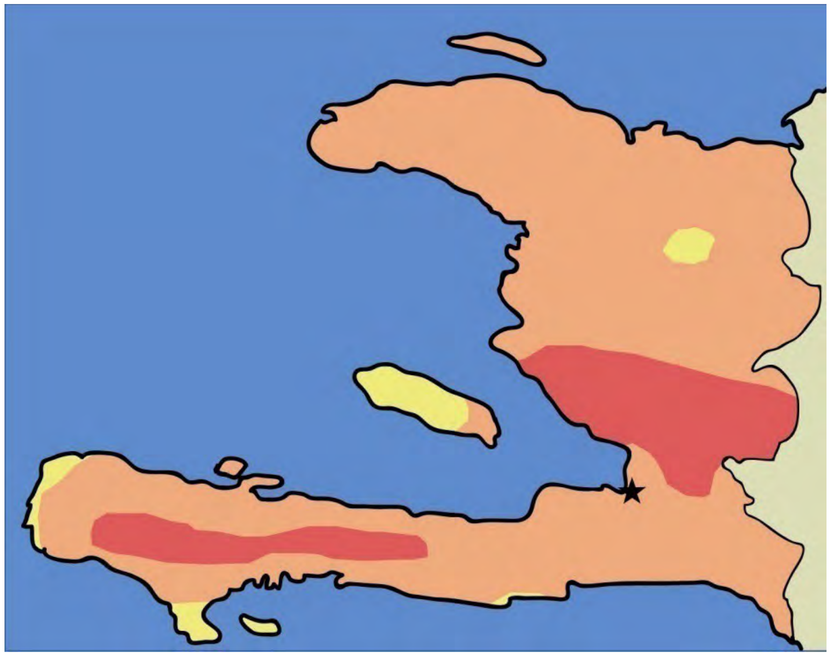

Figure 1.1 Map of Haiti showing severity of seismic demands by region based upon 2010 USGS data (Sds = 0.5g for yellow zones, Sds = 1.05g for orange zones, Sds = 1.67g for red zones)

In addition, the following quality control guidelines are recommended for the fabrication of sound concrete blocks with adequate compressive strength:

- Use a materials, mix proportions, and curing procedures consistent with tested blocks with required compressive strength
- Cement should be Type 1 Portland Cement
- Weigh the cement bags to ensure they contain correct amount of cement
- Only use clean river sand (or a combination of clean river sand and white quarry sand – the required proportion of each to be confirmed through testing)
- Do not use aggregate greater than 1 cm (3/8") in dimension
- Use clean water and only enough water to wet the mix (typically 7-8% max)
- Ram or vibrate block forms to consolidate
- Let blocks cure for at least 7 days prior to use in construction
- Do not allow blocks to cure in the sun. Cover blocks with a tarp and wet them with clean water while curing
- Do not re-use old concrete blocks
- Do not use irregular, chipped or cracked concrete blocks

1.1.2 Mortar

- Use a 1:3 mix ratio (cement : sand) for concrete block wall mortar (add 0.5 parts lime if available) to achieve 17 MPa (2500 psi) minimum compressive strength
- Use a 1:3:3 mix ratio (cement : sand : gravel) for mortar for foundation walls
- Cement should be Type 1 Portland Cement
- Weigh the cement bags to ensure they contain correct amount of cement
- Use only clean river sand in the mortar mix

- Never use white quarry sand or beach sand
- Mix dry components until color is uniform prior to adding water
- Use clean water in mortar mix
- Add only enough water for workability
- Mix mortar for 3 minutes
- Use mortar within 1 hour
- Do not remix mortar

1.1.3 Grout

- For filled grouted cores, use a 1:2:2 mix ratio (cement : sand : pea gravel) to achieve 13.8 MPa (2000 psi) minimum compressive strength
- Cement should be Type I Portland Cement
- Weigh the cement bags to ensure they contain correct amount of cement
- Only use clean river sand and pea gravel in the grout mix
- Pea gravel should be maximum 0.6 cm (1/4") in dimension
- Never use white quarry sand or beach sand
- Use clean water in the grout mix and do not use too much water
- Use a rod to compact the grout within the filled block cavities

1.1.4 Cast-in-Place Concrete

- For beams, columns and roof slabs, use a 1:3:3 mix ratio (cement : sand : gravel) to achieve 21 MPa (3000 psi) minimum compressive strength
- For foundations and slab on grade, use a 1:3:6 mix ratio (cement : sand : gravel) to achieve 15 MPa (2200 psi) minimum compressive strength
- Cement should be Type I Portland Cement
- Weigh the cement bags to ensure they contain correct amount of cement
- Only use clean river sand in the concrete mix
- Never use white quarry sand or beach sand
- Use clean water in the concrete mix and do not use too much water
- Use crushed gravel rather than rounded river stones as the coarse aggregate
- Do not use gravel greater than 2 cm (3/4") in dimension
- Ensure that the concrete mix is consolidated and distributed around reinforcement with no voids (ram with rod or tap formwork with hammer)

1.1.5 Steel Reinforcement

- Verify grade of steel by checking marking on bars (Grade 40 or Grade 60)
- Use ribbed (ie deformed) reinforcement for all reinforcing steel
- Smooth steel is not permitted
- Do not use rusty or corroded reinforcement
- Do not reuse old or bent reinforcement

1.1.6 Timber

- Verify species and grade of timber by checking markings on pieces
- Verify type of plywood by checking markings on sheets
- Do not use lumber with large or frequent knots, holes, splits or checks
- Do not use green lumber or lumber with high moisture content

- Do not use CCA pressure treated lumber. Use naturally decay- and termite-resistant wood or an alternative natural treatment. Paint all wood in addition for weather protection and do not allow wood to come in contact with the ground

1.1.7 Roofing

- Verify panel type (strength and gauge) by checking markings on panels

1.1.8 Connections

- Do not use unprotected mild steel reinforcement to connect timber structure to concrete as it will corrode
- Verify type (grade and gauge) of stainless steel straps for timber-to-concrete and timber-to-timber connections
- Do not reuse old, rusty or bent nails, screws, straps or other connections

1.2 Siting

- Build on flat terrain with strong, stable ground
- Do not build on steep hillsides or next to a steep drop-off
- Do not build below areas that are vulnerable to landslides
- Do not build over riverbeds or in other areas prone to flooding
- Ensure that the concrete block strength used is sufficient to provide a design which provides adequate resistance to the expected ground motion at the site

1.3 Configuration

1.3.1 All House Types

- Limit length of layout to 3 times the width of the layout for single-story houses with lightweight roofs
- For single-story houses with lightweight roofs, strive for a layout that is symmetrical about both axes; the maximum asymmetry permitted is 3.5m in one direction
- A minimum wall area of 5% of the ground floor area is required in each direction on each floor (wall area equals wall thickness x wall length without windows or doors)
- A minimum of two separate lines of walls is required in each direction; an additional line of walls is required for each additional 3.5m of building dimension over 3.5m meters
- The maximum distance permitted between adjacent parallel walls (ie the spacing of orthogonal walls) is 3.5m
- Do not use walls that are angled or rounded in plan; all walls must be parallel or perpendicular to each other
- The maximum story height permitted for the first story is 2.7m from the ground floor slab
- Place tie columns at each corner and wall intersection and on either side of each door opening (and window openings where required)
- Use a continuous plinth beam below the masonry wall
- Use a continuous ring beam above the masonry wall

1.3.2 Additional Single-Story House with Concrete Roof / Two-Story Provisions

- Limit length of layout to approximately 2.5 times the width of the layout for single-story houses with concrete roofs and/or two-story houses
- Single-story houses with concrete roofs and all two-story houses should be square or rectangular with wall layouts that are symmetrical about both axes with walls and openings uniformly distributed
- Limit roof height of two-story houses to approximately 1.7 times the narrowest dimension of the layout
- The maximum story height permitted for the second story is 2.5m
- Vertically align all walls of first and second stories
- Do not build second story walls on eaves of first story concrete roof or over first story porch
- Construct the front porch and porch roofs using only timber
- Only support the concrete slab on masonry walls, not on concrete or timber posts

1.4 Windows and Doors

1.4.1 Window Openings

- Windows without confining elements are permitted only when centered on a wall panel AND when one of the following is satisfied: 1) the window opening is the only window opening located on that side of the building, 2) all openings adjacent to the window opening are surrounded by confining elements
- For windows in series on one side (or wall) of a building, every other window must have confinement
- For single-story houses with lightweight roofs, window openings should be centered on wall panels
- Confined windows do not need to be centered on wall panels if a concrete roof is used
- The top of window openings shall be aligned with the underside of the ring beam
- The maximum window opening height for unconfined windows shall be the minimum of 85cm or 33% of the wall height including the confining elements
- The maximum window opening width shall be the minimum of 1m or 1/3 of the wall width

1.4.2 Door Openings

- Door openings shall be a maximum of 1m wide
- Door openings shall extend the entire height of the masonry wall (the zone above the door may be filled with a perforated plywood panel for ventilation)
- Tie columns shall be located on either side of all door openings
- For single-story houses with lightweight roofs, door openings should be centered on wall panels
- It is not permitted to locate door openings adjacent to orthogonal walls or wall corners for single-story houses with lightweight roofs
- Full-height wall piers created by door openings shall be a minimum of 1m wide

1.4.3 Additional Two-Story Provisions

- Window and door openings shall be vertically aligned with identical widths on first and second stories of a two-story house

- The first story of a two-story house shall have at least as much solid wall area as the second story to prevent a soft story failure

1.5 Foundation

1.5.1 Strip Footings

- Footings shall be continuous below all walls
- The bottom of footings should be at least 75cm below grade (or as deep as necessary to bear on sound, undisturbed soil)
- Slope the sides of foundations trenches approximately 2:1 (rise to run) to maintain stability
- Width of concrete strip footing below all walls shall be at least 50cm for single story houses with lightweight roofs and 100cm for single story houses with concrete roofs or two story houses for soil of intermediate quality
- Width of concrete strip footing below porches and terraces (not supporting walls) shall be approximately 50cm
- Use 20cm wide concrete blocks for masonry foundation wall
- Extend reinforced concrete tie column to concrete footing. Build masonry foundation wall prior to casting concrete tie column extensions
- Use wire chairs or small concrete blocks to lift reinforcement off soil to achieve required 75mm concrete cover where tie column reinforcement is anchored into footing
- Space closed steel ties in tie column extensions at 10cm spacing between plinth beam and concrete footing
- Compact the backfill around foundation wall and footing

1.5.2 Ground Floor Slab

- The ground floor slab shall be raised a minimum of 30cm above grade (80cm in areas prone to flooding, although it is recommended not to build in these areas)
- Do not build ground floor higher than 80cm above grade
- Use 10cm compacted sand fill below concrete ground floor slab (consider use of crushed concrete debris as fill below ground floor slab)
- Use a 5cm unreinforced concrete ground floor slab
- Align top of plinth beam with top of concrete ground floor slab

1.6 Plinth Beam

- Use a continuous reinforced concrete plinth beam above the concrete block masonry foundation wall
- The plinth beam shall be 20cm wide and 15cm deep
- For a single story house with lightweight roof, reinforce the plinth beam with 4 #3 Grade 40 longitudinal steel bars and #2 Grade 40 closed stirrups spaced at 15cm near tie columns and 20cm otherwise
- For a single story house with concrete roof or two story house, reinforce the plinth beam with 4 #3 Grade 60 minimum longitudinal steel bars and #2 Grade 60 closed stirrups
- Maintain a minimum cover of 25mm on all sides, although greater cover will result in order for the longitudinal bars to pass through between the tie column reinforcement

- Provide adequate connection between reinforcement in intersecting and orthogonal plinth beams

1.7 Ring Beam

- Use a continuous reinforced concrete ring beam above the concrete block masonry walls
- The ring beam shall be 15cm wide and 15cm deep except when a concrete roof or floor slab is used. In this case, it shall be 15cm wide by 20cm deep
- For a single story house with lightweight roof, reinforce the ring beam with 4 #3 Grade 40 longitudinal steel bars and #2 Grade 40 closed stirrups spaced at 10cm near tie columns and 20cm otherwise
- For a single story house with concrete roof or two story house, reinforce the ring beam with 4 #3 Grade 60 longitudinal steel bars and #2 Grade 60 closed stirrups spaced at 10cm near tie columns and 20cm otherwise
- Maintain a minimum cover of 25mm on all sides, although greater cover will result in order for the longitudinal bars to pass through between the tie column reinforcement
- Provide adequate connection between reinforcement in intersecting and orthogonal ring beams
- If a concrete roof is used, provide adequate anchorage for the roof slab reinforcement in the ring beam
- If a timber frame roof is used, secure all embedded stainless steel straps for connections to timber structure to ring beam reinforcement prior to casting concrete

1.8 Tie Columns

- Cast reinforced tie columns after the concrete block masonry wall is built
- Place tie columns at each corner and wall intersection and on either side of each door opening and each window opening that requires confinement
- Tie columns shall be 15cm x 15cm in cross section with additional width due to toothing into concrete block masonry wall
- Ensure that concrete has completely filled toothed areas (it is not required for concrete to fill the concrete block cells
- For a single story house with lightweight roof, reinforce tie columns with 4 #4 Grade 40 longitudinal steel bars and #2 Grade 40 closed ties spaced at 10cm near top and bottom joints and 20cm otherwise
- For a single story house with concrete roof or two story house, reinforce tie columns with 4 #4 Grade 60 longitudinal steel bars and #2 Grade 60 closed ties spaced at 10cm near top and bottom joints and 20cm otherwise
- Maintain a minimum cover of 25mm on all sides
- Anchor tie column longitudinal reinforcement into foundation at bottom and ring beam at top
- Splice longitudinal reinforcement extended from foundation above plinth beam if necessary using detail provided
- If it is expected that a second story will be added to a single-story house with a concrete roof, instead of anchoring the tie column's longitudinal reinforcement into the ring beam, extend it above the ring beam by at least 70-90cm and cover it completely with lean concrete (which can be removed to create a splice when the

additional floor is added)

1.9 Masonry Wall

1.9.1 Masonry Wall Detailing

- Build concrete block masonry walls prior to reinforced concrete tie columns and ring beams
- Wet concrete blocks prior to placement
- Use 15cm-wide concrete blocks for all walls above the plinth beam
- Use 1.25cm-thick mortar joints between blocks
- Stagger joints on each course by 1/3 block
- Maintain a staggered edge (by 1/3 block) adjacent to all tie column locations
- Do not use 1/3 blocks to create staggered edge. Use either whole blocks or 2/3 blocks
- Do not use partial blocks unless they have intact cells
- A 1cm plaster finish on both the interior and exterior of masonry walls is recommended

1.9.2 Detailing of Unconfined Window Openings

- Use 1/3 or 2/3 blocks to create vertical edges at unconfined window openings
- Grout the vertical cell on each side of a window opening and reinforce it with one Grade 40 or 60 #4 bar anchored into the plinth beam and ring beam
- Use horizontal bed joint reinforcement in the course below each window opening, anchored into the nearest tie column on each side. Horizontal bed joint reinforcement should be either two Grade 40 #4 bars sufficiently embedded in a 2.5cm bed joint or a prefabricated truss-type system

1.9.3 Detailing of Confined Window and Door Openings

- Cast 15cm x15cm reinforced concrete tie columns on either side of window (see Section 1.8 for reinforcement and detailing)
- Cast 15cm wide reinforced concrete sill beam directly below window opening and extend beam to nearest non-window tie column on either side
- Reinforce sill beam with the same reinforcement as the ring beam

1.10 Roof System

1.10.1 Timber Frame Roof

- Use a gable or hipped timber frame roof (hipped is preferable)
- Use a minimum roof slope of 25 degrees
- Make porch roof independent of primary roof
- Use a maximum eave projection of 30cm
- Use a lightweight plywood gable wall (do not use a masonry gable wall)
- Use 2x4 dimensional lumber to fabricate roof trusses
- For gable roofs, trusses which span 3-3.5m between two supports without an intermediate support shall be spaced at a maximum of 0.5m on center

- For gable roofs, trusses which span over an intermediate support with 3-3.5m on each side may be spaced at up to 1m on center
- Avoid positioning roof trusses over window or door openings in walls
- Truss configuration shall be at least 1 central vertical member and 2 diagonals for spans up to 3.5m
- Purlins to be spaced at a maximum of 50cm orthogonal to gable trusses
- Connect bottom of truss chords with orthogonal 2x4 members on either side of center vertical
- Connect 2x4 truss members using 0.75" thick plywood gusset plates nailed on both sides
- Corrugated metal sheets shall be oriented with ribs perpendicular to purlins
- Connect roof trusses to concrete ring beams using stainless steel straps anchored to ring beam reinforcement
- Provide connections as shown in the drawings to allow for sufficient tie-down due to hurricane-level wind forces

1.10.2 Flat Concrete Roof

- A house designed with a concrete roof must follow the guidelines and block strengths required for two-story houses
- Use 10cm-wide blocks (on their sides) as slab void forms to create a two-way concrete beam system
- Group void forms into approximately 80cm x 80cm zones with approximately 22.5cm to 30cm continuous clear spacing between them to create continuous 22.5cm to 30cm wide roof beams in two directions
- Leave a small amount of space between the concrete blocks within each group to allow bond between concrete and blocks
- Wet blocks prior to placement to increase bond between concrete and blocks
- Use 10cm continuous cast-in-place concrete slab on top of void forms with #3 Grade 40 or 60 bars spaced at 20cm on center in both directions positioned at the center of the continuous slab
- Reinforce the concrete roof beams with 4 #4 longitudinal bars and #2 Grade 40 closed stirrups spaced at 10cm within 1.2m of walls and 20cm otherwise
- Maintain at least 25mm concrete cover over all steel using wire chairs or small concrete blocks
- Anchor all reinforcing steel in the roof slab into the ring beams on all sides
- Provide for adequate drainage of roof to prevent ponding
- Avoid eave projections which may invite discontinuous second story walls

1.11 Stairs

- Use exterior stairs for two-story houses
- Use either reinforced concrete stairs, wooden stairs or prefabricated steel spiral stairs
- Do not connect stairs to confined masonry wall panels
- Support stairs on independent spread footing foundation
- Provide cold joint between bottom of the stair and the footing with no steel reinforcement through the joint
- Reinforced concrete stairs should be a maximum of 1m wide
- See drawings for reinforcement and detailing required for a specific stair configuration

1.12 Future Expansion

- If it is expected that a second story will be added to a single-story house with a concrete roof, instead of anchoring the tie column's longitudinal reinforcement into the ring beam, extend it above the ring beam by at least 70-90cm and cover it completely with lean concrete (which can be removed to create a splice when the additional floor is added)
- If it is expected that a house may grow in footprint, provisions should be made to allow for adequate connection between existing and new confined masonry walls and to maintain a symmetrical layout with well-distributed walls and openings. See suggested details provided for horizontal expansion in drawings.
- The best solution for horizontal expansion is for new structures to be completely separated from existing structures by 3cm (for a single story structure) to 6cm (for a two-story structure)