SITE AND RETAINING WALL HAZARD MITIGATION IN POST-DISASTER SITUATIONS:

A PRIMER

DRAFT

January 2014

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ACRONYMS

A&E	Architecture and Engineering
AGS	Australian Geomechanics Society
CBO	Community-based organizations
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
FIDIC	Fédération Internationale des Ingénieurs-Conseils (International Federation of Consulting Engineers)
FS	Factor of safety
GIS	Geographic Information Systems
GPS	Global Positioning System
GSHAP	Global Seismic Hazard Assessment Program
LiDAR	Light Detection and Ranging
NGO	Non-governmental organization
QA/QC	Quality assurance/quality control
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 site hazard mitigation 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 construction of site hazard mitigation measures properly in a post-disaster situation. It provides a road map for developing a project through planning, design, and implementation.

The Primer addresses various phases of the planning, design, and implementation process and the various deliverables and milestones usually included as part of the process.

The Primer is part of a series of three Primers intended to support post-disaster housing reconstruction in developing nations. The other two primers are "Building Back Housing in Post Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer," and "Seismic Retrofit of Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer."[1]

These three Primers address several objectives:

- Greatly reduce deaths, injuries, and economic losses caused by housing collapses due to natural disasters in developing countries
- Permanently change the role of risk management in post disaster settings by educating government officials, aid organizations, community leaders, and homeowners on the need for site hazard assessments and their associated mitigation measures
- Build local capacity through training of builders, homeowners, engineers, and government officials
- Change construction practice permanently by building local skills and stimulating local demand

[1] USAID Primers cited in this text 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 mitigation of site hazards for 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 carry out homeowner-driven site hazard mitigation properly in a post-disaster situation. It provides a road map for developing a project through planning, design and implementation and is considered a parallel document to two other primers, "Building Back Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer," and "Seismic Retrofit of Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer."

SITE HAZARDS: VULNERABILITY AND RISK

Damaging impacts to communities and individual homeowners from site hazards are often the effect of a mismanagement of risk. Risk, in these terms, is associated with the occurrence of intense natural hazards and the conditions of vulnerability, caused by human activities and local customs or cultural practices.

Site hazards are derived from the damaging potential of, or a combination of, the following natural hazards:

- **Internal Geodynamics** – Includes those hazards associated with seismicity and volcanism.
- **External Geodynamic Processes** – Includes those hazards associated with slope movements, landslide movements, erosion, and debris flows.
- **Hydrological and Meteorological Processes** – Includes those hazards associated with intense rainfall, drought, hurricanes, typhoons, and tornadoes.

Population growth around the world has directly increased the vulnerability of people to natural hazards. Most of this population increase has led to migration to already exposed areas on coastal, urban, and marginal lands. Low income families migrating to urban areas often only have the resources to settle on marginal lands or hazard-prone areas. Coastal and urban areas have the highest opportunities for employment and economic viability, inducing migration, poverty, marginality, and further vulnerability.

Urban areas in developing countries are generally vulnerable to natural hazards because of the poor quality of housing, inadequate urban planning, and insufficient investments in infrastructure.

Marginal populations are likely to have an inadequate perception of risk and are usually less likely to be informed about potential site hazards due to their low income and education levels, as well as reduced access to modern information technologies and financial protection instruments. Resettlement or insurance coverage may be too costly given the reduced savings capacities of these low income groups. As most of their income is allocated to immediate survival, and since the risk of intense hazards has a low frequency, the perceived benefits of prevention are rarely sufficient to warrant a change in behavior.

SITE HAZARDS: PROACTIVE RISK MANAGEMENT

Existing development- and risk management-related policies associated with disasters stemming from natural hazards have largely focused on emergency preparedness and response, leading to underinvestment in natural hazard determination, prevention, and mitigation. Financial resources in post-disaster environments are used primarily for emergency response, rehabilitation, and reconstruction. In many developing countries, risk management is seen as a cost and not an investment.

> "The risk associated with natural hazards is increasing more rapidly than the efforts to reduce this risk."

With a more proactive approach to risk management, loss of lives and material damage associated with natural hazards could be significantly reduced. In many developing nations, there is a need for greater risk management efforts because the risk associated with natural hazards is increasing more rapidly than the efforts to reduce this risk.

Disaster Risk Reduction (DRR) is a systematic approach to identifying, assessing, and reducing the risks associated with disasters. DRR falls within the bounds of risk management, as described below. DRR programs are being implemented in many post-disaster settings in developing nations. Due to implementation lag, however, the benefits of these programs have not yet been fully realized. For example, in post-earthquake Haiti, a DRR program was initiated almost a full two years after the earthquake. Many families had already rebuilt their homes using their own resources or with the assistance of aid organizations before the DRR program was initiated, only to find out later that their homes fell within a zone designated as hazardous.

Hazard and risk assessment, as well as mitigation, are key principles of proactive risk management and DRR. Without knowledge of the characteristics of specific hazards and their associated risks, proper planning and implementation of mitigation measures cannot be completed in an economically feasible or sustainable manner.

Proactive risk management and DRR programs implemented on a national level with the backing of government ministries, zoning laws, and building codes are critical for the development of sustainable and safe communities. In many developing countries, however, the conditions for proper implementation of these programs are not in place or are fragmented and cannot be relied upon. Therefore, in many post-disaster settings, risk management of natural hazards at the national level is not practical. Risk management programs are more easily implemented on a micro-, community-, or site-level basis with the proper understanding and support from community leaders or groups.

PRINCIPLES AND STRATEGIES

> "Post-disaster site hazard mitigation presents an opportunity not only to rebuild safe communities for the affected population but also to change construction practice permanently so that local builders, engineers, and homeowners build safe hazard mitigation structures in the future."

Post-disaster site hazard mitigation presents an opportunity not only to rebuild safe communities for the affected population but also to change construction practice permanently so that local builders, engineers, and homeowners build safe hazard mitigation structures in the future. In addition, site hazard mitigation can produce a groundswell of support on a national level for integrated preventive risk management programs by educating homeowners and community leaders. These objectives are addressed here by applying the following principles and strategies:

- **Local Solutions** – Use detailed construction subsector studies, conducted mainly in the housing industry, to determine the most cost-effective ways of building site hazard mitigation measures 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 hazard mitigation efforts while sticking to a carefully compiled list of criteria for local sustainability and acceptance.

- **Equality** – Empower the homeowners to manage their own construction, with technical assistance, by providing a range of mitigation measures appropriate for a variety of site hazards.
- **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 site hazard mitigation measures 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 site hazard mitigation programs so that the many other agencies involved in these efforts build better communities and leave in place more sustainable local impacts.

In many developing countries, **retaining walls** serve as an effective site hazard mitigation method, and in many cases, are able to capture all the above principles and strategies.

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 site hazard mitigation, which is a focus of this primer.

I. IMPLEMENTING PARTNERS AND STAKEHOLDERS

Key roles must be filled in order to execute a homeowner-driven site hazard mitigation 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 Architecture and Engineering (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 partners for design and construction should be different from the implementing partner for homeowner selection and fund distribution. Separating these roles preserves the consultant relationship between the homeowner and technical consultant; the technical consultant is seen as a trusted advisor rather than a source of funding, which facilitates a better dialogue 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 site hazard mitigation and 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 SITE HAZARD MITIGATION

There are a number of stakeholders involved in post-disaster site hazard mitigation. 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:

- 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 construction of site hazard mitigation works):

- 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, 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

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

- Clear debris

- Resolve land tenure issues
- Implement infrastructure projects
- Do civil works such as building retaining walls that apply to more than one house
- 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 project, and in the case of homeowner-driven site hazard mitigation, it contracts directly with engineering and construction companies as a technical assistance provider and implementing partner to distribute funds to homeowners.

2. SITE HAZARD MITIGATION PRE-DESIGN ACTIVITIES

In the wake of a disaster, several activities must take place before reconstruction or retrofitting of permanent housing can begin. Many of these activities are detailed in "Building Back Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer," and "Seismic Retrofit of Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer."

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

Many of these pre-design activities are associated with assessing the immediate safety of individual buildings, understanding the cause of building damage and/or collapse, and assessing associated site hazards. The results of these basic site assessments are used by decision-makers to determine how retrofit and reconstruction programs should proceed, if at all. There may be cases where individual buildings or portions of a community are at risk from future hazards and the risk costs dictate relocation or other potentially drastic measures instead of programming retrofit or reconstruction funds for these buildings.

On a larger scale, the results of these initial assessments can provide a sense of the appropriate level of mitigation required to reduce the risk imposed from observed site hazards. Aid organizations should certainly be aware of these mitigation costs before undertaking a building retrofit or reconstruction program. It is preferable if the results of these assessments are incorporated into a community infrastructure planning effort, where infrastructure improvements and risk reduction measures can be made on a community-wide level.

There are several documented procedures for performing assessments of building safety and forensic studies of building damage, but little exists on performing site hazard assessments. This chapter provides a summary of the steps necessary to perform site hazard assessments.

Detailed site hazard assessments or assessments of complex sites should be completed by a trained geologist or geotechnical engineer; however, basic and routine site hazard assessments can be completed by trained engineers or engineering technicians using the following procedures.

2.1. SITE HAZARD MITIGATION STEPS

Initial site assessments and visual investigations provide critical information during the preliminary stages of a retrofit or reconstruction program. Figure 1 details the steps included in completing a site hazard mitigation program.

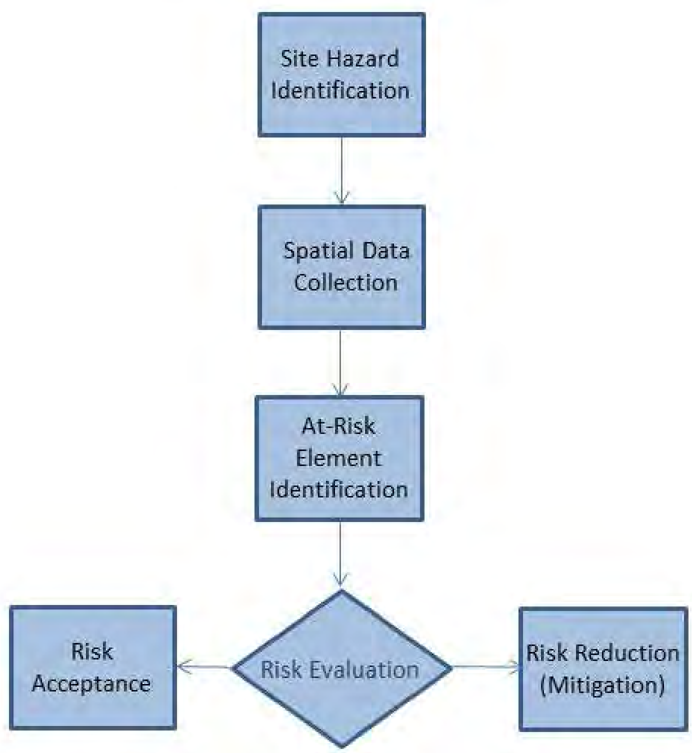


Figure 1. Site Hazard Mitigation Flowchart

2.1.1. NATURAL HAZARD ASSESSMENT

There are several natural hazards which may cause damaging consequences to a site or community. These natural hazards, or triggering events, are loosely grouped into the following categories:

- Volcanism – lava flows, pyroclastic flows, ash fall
- Seismicity – fault rupture, tsunamis, ground shaking
- Meteorological Extremes – wind storms, rainfall extremes

These triggering events often precipitate other damaging events, such as ground shaking resulting from an earthquake or a landslide caused by ground shaking or extreme rainfall. Having a basic understanding of the triggering natural hazard and potential direct effects of that hazard can certainly help shape the site hazard mitigation assessment and focus the site investigation efforts.

The International Disaster Database[2] provides detailed information on the impacts of natural disasters in countries around the world. For many countries the database has a history of natural disaster impacts dating back to the early 1900s.

In addition to understanding the triggering events, it is vital that data on these events are captured. Critical data for respective triggering events include:

- Rainfall amounts
- Wind speeds
- Wave heights
- Seismic ground accelerations

In many cases, monitoring systems (weather stations, tidal buoys, a network of strong ground motion sensors) have been established to collect these data through direct measurements. The data from these monitoring systems can be used to determine the recurrence interval of the event and design criteria can be established to resist future events of similar magnitude.

In some developing nations, these monitoring systems may not exist. If this is the case, anecdotal information gathered from community members can still provide a sense of the magnitude of the event and can assist in developing design criteria. There is often a significant quantity of undocumented local knowledge on disaster occurrences. Much of the information needed for site hazard evaluations and development of associated mitigation measures can be obtained from community members who observed and know what the situation is, but don't have the skills for understanding and organizing what they know. Integrating available data from monitoring systems with local community knowledge relevant to hazards is a useful component in the

[2] www.emdat.be

development of site hazard assessments and associated mitigation measures.

2.1.2. SPATIAL DATA COLLECTION

The collection of spatial data is critical to the effectiveness of site hazard and risk assessments. The availability of certain types of spatial data can be one of the main limitations for completing specific types of analysis. In many developed countries much of this information can be gathered from hazard inventory databases, Geographic Information Systems (GIS)-based platforms, or published maps; however, this information is generally not available in developing countries or at the resolution required for the completion of site hazard assessments. With these limitations in mind, a brief research study should be conducted to determine if any useful data are available, though it is generally understood that much of the required spatial data has to be collected from site reconnaissance efforts or in discussions with community members.

The following spatial data are necessary for the site hazard assessment:

- **Topography:** Topography is one of the major elements in a site hazard assessment. Generation of a Digital Elevation Model (DEM) is an integral tool for visually documenting topographic information. DEMs can be generated through a variety of sources, including digitizing contours from existing topographic maps, electronic distance measurements, Global Positioning System (GPS) measurements, and Light Detection and Ranging (LiDAR) measurements. Data source selection depends on a variety of factors, including availability of method, cost, and applicability. In many cases, simple elevation models can be generated from existing topographic maps coupled with ground measurements using handheld instruments.

- **Geology:** Geologic maps are the primary source of geologic information for a site hazard assessment. Geologic maps of various scales are available for most countries of the world. The lithological information contained in geologic maps provides necessary information in assessing site hazards and developing mitigation strategies to reduce the associated risk.

- **Soil Information:** While geologic maps provide general data on the physical characteristics of the rock and soil found over a large area, soil information collected at a site is used to provide specific engineering properties of encountered soils. For some parts of the world, databases and maps exist which relate soil information and its associated properties. While this information is useful, it is often presented at a large scale, which makes determinations at a site level difficult. In lieu of using databases and maps, useful soil information can be gathered through the performance of test pits at various locations within the site. These test pits can determine the presence of potentially hazardous soils (soft, organic, liquefiable, or highly susceptible to erosion). Various laboratory tests can be completed on soil samples collected from test pits to determine specific engineering properties. Simplified soil tests can also be performed in the field and provide useful correlations to engineering properties of soil. Useful soil information can also be gathered from existing or ongoing construction practices within a community, including slope excavations, building foundation excavation, latrine excavations, slope failure scars, and stream cutbanks.

- **Hydrologic Data:** Gathering pertinent hydrologic data is critical to the analysis of several natural hazards. Determining peak flow rates within a stream or river is necessary to design mitigation measures to protect against future heavy flow and flooding events. Correlating these flow rates to measured precipitation levels yields a useful tool for predicting future flow rates. Determining the water table depth and soil moisture levels from completed test pits or observations from adjacent construction activities are useful in performing analyses associated with landslide or liquefaction failures.

- **Land Use:** Observations of land use and land cover, and specifically their impact on noted hazards or failure areas, are useful in completing site hazard assessments. Changes in land use or land cover as a result of human activities, such as deforestation, construction activity, fire, or agricultural activities, can have a significant effect on hazard impacts.

2.1.3. AT-RISK ELEMENT IDENTIFICATION

After the site hazards have been identified and sufficiently studied, evaluation of at-risk elements is required. Studies to identify at-risk elements can be carried out at different levels, but for purposes of the site hazard assessments, these studies are completed at a community level. Much of the following at-risk element identification occurs during initial housing subsector studies or homeowner preferences surveys, as described in "Building Back Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer."

- **Population:** Collecting census data at a household level provides pertinent information on the most important at-risk elements: people. Census data includes the number of people per household, including their gender, age, education level, and employment status. Similar information with an economic emphasis is also collected for businesses in the community.
- **Buildings:** Information on buildings, including size, height, type, construction methods, quality, and age are necessary to determine the behavior of a building in a hazard event, which may determine the severity of injuries or loss of life of building occupants. Forensic studies also provide critical information on the performance of buildings during a hazard event.
- **Public Facilities:** An inventory of established networks of public facilities, including transportation, water, wastewater, and utilities provides a sense of how these facilities might be impacted during a hazard event.

2.1.4. QUALITATIVE HAZARD RISK ASSESSMENT APPROACH

Simple maps can be used to document visually potentially hazardous areas (landslide prone, soft soils, steep slopes, near rivers or ravines, etc.) based on spatial data collection. Identified at-risk element information can be overlaid on hazard maps, giving a clear indication of risk areas. While these maps and models provide a visual representation of risk areas, they do not provide a sense of the severity of risk or the need for mitigation measures to reduce risk. For that, qualitative risk assessment methods are needed.

Qualitative risk assessment methods are useful as an initial screening process to identify risks and hazards and, specifically, when quantitative variables are not available or they need to be generalized. The simplest form of qualitative risk assessment is to combine hazard data with at risk element data using a simple risk matrix in which measures are defined qualitatively. A qualitative risk analysis matrix can be viewed at www.buildchange.org/USAIDPrimers.html, as adapted from the Australian Geomechanics Society (AGS), 2007[3].

[3] Australian Geomechanics Society, "Practice Note Guidelines for Landslide Risk Management 2007," Journal and News of the Australian Geomechanics Society, Volume 42, No. 1, March, 2007.

The level of risk associated with site hazards, as a product of the qualitative risk analysis matrix, provides general guidance on mitigation required to reduce the associated risk. While the risk analysis matrix does not discuss specific mitigation measures, it does provide a sense of the feasibility of mitigation to reduce the hazard risk at a particular site. At a minimum, the level of risk can initiate discussions with decision makers, as well as engineering studies, to determine the necessary mitigation measures to reduce risk to acceptable levels.

2.2. MITIGATION MEASURE IDENTIFICATION

Experience in various developing countries and in post disaster settings reveals that the poorest people build on the most dangerous sites. For many, the opportunity to build a home means that they move to available land, often in marginal or hazardous locations. While these communities pose a challenge to housing reconstruction programs, they also house some of the most vulnerable populations. Reducing the risks associated with site hazards in these communities should be considered a priority.

The mitigation measures presented in this Primer focus on site hazards associated with seismic geologic phenomena, namely ground shaking, fault rupture, liquefaction, and minor landslides. Mitigation measures for geologic hazards associated with meteorological events are not specifically discussed, other than best practices aimed at creating zoning laws to prevent marginal populations from building in identified flood zones or other at-risk locations. Mitigation measures associated with significant geologic hazards, including major landslides and flooding events, should be evaluated on a case-by-case basis by trained professionals, as design procedures for these hazards are complicated by the number of site and design variables present.

"Retaining walls have proven to be versatile structures that work well in a variety of settings and, when design properly, can be used to mitigate a number of site hazards."

There are a number of potential mitigation measures available to reduce risks associated with seismic geologic site hazards, depending on the characteristics of the specific hazard. However, when consideration is given to local solutions in developing countries, including construction materials, equipment, and skills available through the local private sector, the number of locally sustainable and accepted mitigation measures shrinks considerably.

Retaining walls have proven to be versatile structures that work well in a variety of settings and, when designed properly, can be used to mitigate a number of site hazards.

Retaining walls have been constructed by civilizations for thousands of years using locally available materials and skills and can be found throughout the world. In most cases, these walls are not engineered to modern standards or design codes, but there is a standard of construction, likely based on trial and error, that has been passed on for generations. This standard of construction, while functional during normal conditions, is usually not able to withstand extreme event conditions, namely the forces imposed by various natural hazards.

In the steep, hillside topography of marginal lands, retaining walls are included as a critical element in building construction. To mitigate potential site hazards and protect the structural seismic retrofit and/or reconstruction investment of damaged or condemned buildings on these steep slopes, a streamlined retaining wall assessment and retrofit program is needed. If adequate design time and money are spent retrofitting a building, then proper attention should be paid to the retaining wall supporting or adjacent to that same building as well.

> "If adequate design time and money are spent retrofitting a building, then proper attention should be paid to the retaining wall supporting or adjacent to that same building as well."

FORENSIC ANALYSIS OF RETAINING WALLS

One of the guiding principles of forensic studies is to "Learn First." Engineers and technical practitioners need to understand how natural hazards can affect the existing stock of retaining walls. Initially, a simple but thorough field inspection is required to determine the type and nature of the existing retaining walls. Furthermore, a technical evaluation of the various retaining wall types is needed to understand the particular risks and vulnerabilities of the in-place walls. Once these data are gathered, compiled, analyzed, and understood, more accurate and detailed decisions can be made on possible retaining wall hazard mitigation methods.

A detailed evaluation of observed retaining wall types is a critical component of a forensic study. Component materials used in the construction of retaining walls should be well understood, as well as predominant construction practices. Retaining wall settings (foundation walls, retaining walls, structural walls, parapet walls) should be analyzed as part of the forensic studies. The range of retaining wall geometries should also be investigated as a critical component of the technical evaluation. Retaining wall thickness and embedment often are not readily visible, but can be gathered with simple investigative techniques (i.e. excavating in front of a wall to determine embedment).

Forensic studies of retaining wall failures in post-disaster settings typically reveal that they were not designed to withstand the extreme forces imposed on them by natural disasters. The ability of a retaining

> "The ability of a retaining wall to withstand…extreme forces relies almost solely on the techniques, workmanship, and care of the contractor during construction."

wall to withstand these extreme forces relies almost solely on the techniques, workmanship, and care of the contractor during construction. For example, several hundred retaining walls were evaluated in Haiti, most of which had a base width of 0.4 to 0.5 meters, regardless of wall height or imposed loads. This common wall width has been used for years and is based on the width of a foundation wall necessary to support the wall of a concrete masonry building. This wall width was then transferred to other retaining wall structures, where it is woefully undersized to support the loads imposed on it, especially seismic event loading.

As mentioned previously, forensic studies are also used to identify the various retaining wall types that support or are adjacent to many of the housing structures built on steep slopes in marginal areas. Properly identifying the retaining wall type is a critical component of the assessment program, as the various retaining wall types all behave somewhat differently in extreme event loading conditions.

Data compiled from field inspection aids in the completion of a technical design evaluation, which helps understand how the existing stock of retaining walls perform in static and seismic loading conditions. The technical evaluation provides an indication of existing factors of safety associated with requisite design criteria, based on assumptions related to loading and soil properties.

3. SITE HAZARD MITIGATION DESIGN ACTIVITIES

The design phase entails the compilation of design criteria, engineering analysis of the identified retaining wall types, and development of design rules for application to a variety of wall heights and settings. This phase also includes the preparation of component drawings, bills of quantity, construction specifications, estimated labor needs, and a construction schedule for each type of retaining wall to be retrofit or constructed.

The objective of the design phase in a homeowner-driven site hazard mitigation technical assistance program is to develop a set of guidelines that could apply to a variety of wall types, heights, and imposed loading conditions. The first step is to complete a detailed geotechnical analysis of the commonly observed wall types. General design rules are extrapolated from this process in order to enable a flexible design process that can be easily transferred and applied to the site hazard assessment program.

3.1. CODES AND STANDARDS

Codes and standards used in retaining wall design should include relevant local codes and guidelines, if available, supplemented with international standards where needed. Sources of design codes and standards may include simple guidelines or handbooks from the project country or for similar structural systems used around the world.

3.2. LOADING AND STRUCTURAL DESIGN CRITERIA

Similarly, loads for design should be selected from relevant local codes and supplemented with international standards. The following loads should be specified for the retaining wall technical evaluation cases (if relevant):

- Gravity
- Dead

- Live
- Lateral Earth Pressure
- Lateral Surcharge Loads
- Seismic
- Inertia

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

Once the general geometries of existing wall systems are understood through forensic studies, a parametric analysis should be conducted. Failure modes investigated during the analysis include: sliding, overturning, and bearing capacity. Minimum factors of safety (FS) used to complete the analysis are presented in Table 1. A significant variable in retaining wall design is the nature and properties of retained soils. Retained soils behind a wall provide the primary lateral loads which a wall must be designed to resist. Due to the variable soil conditions in many areas, various combinations of soil properties are used in the analysis.

Table 1. Retaining Wall Analysis, Minimum Factors of Safety

Failure Mode	Min. FS
Static Sliding	1.5
Static Overturning	1.5
Static Bearing Capacity	3.0
Seismic Sliding	1.1
Seismic Overturning	1.1

Parametric analysis results provide an indication of critical wall height, above which retaining walls are only marginally stable under static loading conditions and unstable under seismic loading conditions. This criterion is used for wall acceptance within the framework of the assessment program, as wall heights below this height criterion are considered stable and do not require further assessment or mitigation.

Retaining walls are most easily and universally designed as mass gravity structures and evaluated against overturning, sliding, bearing capacity failure, and global stability. Final, site-specific design of retaining walls is completed in the field and is covered in Section 5.3 of this Primer.

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

3.3. 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, maximum percent slope should be specified, allowable soil bearing capacity estimated, and soil type specified.

> "It is vital that materials used in construction of retaining walls are readily available locally and that construction techniques are well established within the community of contractors."

3.4. BUILDING MATERIALS PROPERTIES

Stone masonry is a traditional form of construction that has been practiced for centuries in regions where stone is locally available. Stone masonry construction can be found in many earthquake-prone regions and countries including Mediterranean Europe, North Africa, the Middle East, and Southeast Asia[5]. To ensure the success of a site hazard mitigation program, it is vital that materials used in construction of retaining walls are readily available locally and that construction techniques are already well established within the community of contractors. Building materials include:

- 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 rubble stone masonry construction
- Masonry units, such as stone: specify allowable size deviations

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

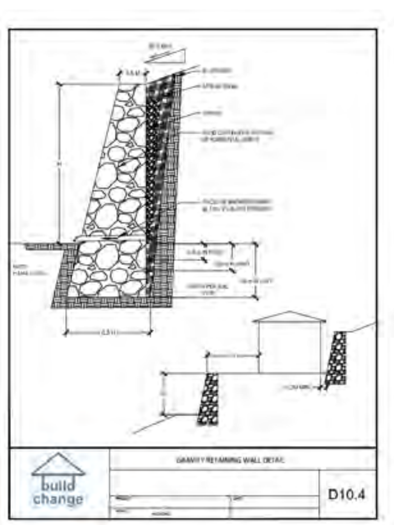
- Tools and equipment
- Scaffolding and shoring: determine minimum specifications and availability
- Mechanical equipment, such as mortar and concrete mixers

[5] Lutman, Marjana. *Stone Masonry Construction.* World Housing Encyclopedia. www.world-housing.net/major-construction-types/stone-introduction.

4. SITE HAZARD MITIGATION: STANDARD DETAILS

Critical to the implementation of a site hazard mitigation program is the development of standard mitigation details for the repair and/or retrofit of damaged, distressed, or under-designed walls. The mitigation details should be developed using a phased approach, as follows:

1. Completion of a study on local construction knowledge and practice (as previously discussed)
2. Development of a mitigation decision tree with associated details
3. Confirmation of mitigation details through a construction pilot program



One of the more significant outcomes of the study on local construction knowledge and practice is a thorough understanding of the possible failure and distress mechanisms for studied retaining walls. A suite of mitigation details is prepared to repair, retrofit, or reconstruct damaged or under-designed retaining walls.

The standard details should be developed using locally available construction practices and materials. Mitigation measures should be developed primarily to provide additional resistance to the governing failure mode(s), as determined by the study on local construction knowledge and practice and back-analysis. Mitigation measures should only be designed once a thorough understanding of the soil conditions and seismic setting is established, as these variables become critical design components.

RETAINING WALL HAZARD MITIGATION DECISION TREE

Once the suite of mitigation tools or details is designed, a decision tree should be developed as a field tool to steer the user towards the correct mitigation detail. The decision tree is formulated to allow engineers and technicians to specify mitigation measures without having to do a detailed analysis, with supporting calculations, for each retaining wall.

The decision tree guides the user through the various mitigation details based on wall type. Please visit www.buildchange.org/USAIDPrimers.html for a retaining wall hazard mitigation decision tree used in Haiti.

The mitigation measures and associated decision tree should be suitable for a majority of the retaining walls that will be encountered in the field. However, there will be situations in which the mitigation details need to be modified slightly to fit conditions in the field. The use of sound engineering judgment is critical when modifying the established details. The significant modification of these details is not recommended without consultation with the geotechnical engineer(s) responsible for creating the details.

5. SITE HAZARD MITIGATION FIELD ACTIVITIES

Assessment teams should undertake a systematic process of inventorying and assessing wall conditions per the specific guidelines presented earlier in this manual. Ideally, teams are comprised of two individuals, both being knowledgeable in the specific processes and procedures of the site hazard assessment program.

More specifically, teams are responsible for the following:

- Accurately locate the wall (unique identifier for each wall usually determined by the implementing partner; include appropriate zone or phase description)
- Accurately measure and describe wall geometry
- Assess the conditions of the wall and its key elements
- Acquire descriptive photos
- Determine the appropriate mitigation strategy, if required

> "The team, as a whole, is responsible for producing a complete, accurate assessment of each retaining wall…. Teams should not leave a retaining wall site until the assessment is completed to the satisfaction of both team members."

Team members do not work independently from one another. The team, as a whole, is responsible for producing a complete, accurate assessment of each retaining wall. This will likely require that team members discuss and reach consensus on the condition of the wall, as well as proposed mitigation strategies. Teams should not leave a retaining wall site until the assessment is completed to the satisfaction of both team members.

Field forms should be completed in their entirety in the field. At no time should teams forgo completion of the field forms or simply copy information from previous forms on similar wall types. This practice can lead to errors and diminishes the overall value of the assessment program.

To optimize overall assessment efficiency and the quality of individual wall assessments, teams should implement the following quality assurance/quality control (QA/QC) practices during each assessment program:

- **Assessment Practice:** Prior to initiating full-scale assessment programs, teams should assess several different wall types/scenarios as a group to ensure wall assessment methods are well understood and can be consistently applied. This effort is critical when multiple teams are completing assessments within the same program neighborhood.
- **Daily Progress Reporting:** Teams should meet together at the end of each day to report progress, discuss wall findings and issues, and refine future assessment plans.

It is intended that retaining wall assessments be completed in parallel with structural assessments of buildings. This parallel process ensures assessments are completed holistically, with consideration given to the entire structure, including its fundamental elements. Decisions on mitigation measures can be made considering both the structure and retaining wall, which will create more cost effective solutions and streamline the construction process by reducing the likelihood of conflicts between various employed mitigation solutions.

5.1. PRE-FIELD TRAINING

The majority of pre-field activities are associated with completing site hazard mitigation training for the technical consultant's local staff. The implementation of an assessment and retrofit program at a sufficient scale to make an impact requires a large staff of well-trained engineers. A thorough understanding of the retaining wall assessment system will greatly enhance the effectiveness and efficiency with which the assessments can be completed. This training can take a week or more of classroom experience, followed by weeks of supervised practical experience in a pilot phase, involving the first walls to be retrofit in the program. The pilot phase includes the completion of wall assessments in the field, including recommendations on appropriate mitigation measures, as well as construction supervision of said mitigation measures. Classroom and field training of local engineers should be completed by geotechnical engineers thoroughly experienced in site hazard evaluation, soils engineering concepts, and retaining wall design and construction. Instructors should also be intimately familiar with the adopted guidelines of the assessment and retrofit program, as well as the various design details and field instruments that have been developed. Site hazard training for local staff should include the following topics:

- Fundamentals of geologic hazard identification and seismicity
- Field classification of soils and associated engineering properties

- Fundamentals of lateral earth pressure theory
- Fundamentals of retaining wall design, including seismic loading and analysis
- Common retaining wall types found in the project area and their common deficiencies and failure modes
- Common building materials used in the project area: quality, suitability, and testing procedures
- Retrofit procedure for the project: evaluation, analysis, design, cost estimation, and methodology for construction quality assurance/quality control

The basics of soils engineering and retaining wall design are covered as a review. In some cases, a review of more basic engineering analysis tools may also be required. Classes should be well designed, include classroom participation for students, and provide feedback for instructors in the form of brief, daily quizzes.

Site hazard mitigation and retaining wall assessments are usually carried out by teams of two individuals who are knowledgeable in the various retaining wall types and individual wall components, and can readily identify distress and pertinent failure modes. The primary goal of the assessment team is to identify and consistently document site hazards and the factors that contribute to a wall's condition and overall performance, and then to determine the appropriate mitigation strategy.

During the field training portion of the pilot program, engineers should assess, recommend mitigation measures, and supervise the construction of retaining wall hazard mitigation measures themselves, under the supervision of instructors. The field training should also allow individual assessment teams the opportunity to share lessons learned at each stage with the larger group.

5.2. PRE-FIELD PROCESSES AND PROCEDURES

Once a site has been selected for production-level assessments, a half day of "refresher" field training will greatly expedite field work and will contribute to complete, consistent wall assessments from the onset. Refresher training should also be included as part of every field inventory, with multiple teams working together during the first day of the inventory to ensure data collection and reporting consistency.

Team members should also familiarize themselves with the location of potential site hazard assessment sites. Maps and photos are generally available from partner organizations or other engineers who have worked in the area. In many cases, GPS coordinates will be available from partner organizations, which will greatly expedite locating structures and their associated retaining walls.

Prior to beginning field activities, team members should have the appropriate field forms and review the equipment inventory checklist. Please visit http://www.buildchange.org/USAIDPrimers.html for an example of a retaining wall assessment form and an equipment inventory checklist.

5.3. FIELD DATA COLLECTION GUIDELINES

The purpose of the site hazard assessment program is to define, quantify, and assess retaining walls associated with homeowner driven retrofit and reconstruction programs in terms of their location, geometry, condition assessment, failure consequence, and cost of maintenance, repair, or replacement. Various wall attributes and elements are measured, calculated, or assessed within the following four data categories, as included on the field form:

- **Wall Acceptance Criteria**: Initial measurements of observed retaining wall geometry – mainly wall height – coupled with established criteria allow a determination to be made on inclusion of specific walls in the site hazard assessment program.

- **Wall Location Data**: Walls are located by their unique identifier, as well as the neighborhood or village, and phase or zone within the neighborhood, if used.

- **Wall Description Data**: Walls are described by their function (foundation, integral, or site). Measurements are recorded pertaining to wall length, wall height, wall thickness, and embedment depth.

- **Wall Condition Assessment**: Wall element conditions are described relative to the extent, severity, and urgency of observable distress. The overall performance of the wall system is included in this assessment.

- **Wall Action Assessment**: Objective consideration is given primarily to the wall condition assessment and secondarily to the wall description data to determine a recommended action. Actions include no action or implementation of one or more of the mitigation alternatives that have been developed for this effort. Details on selecting appropriate mitigation measures are provided in Chapter 4.

By following the data collection and documentation standards presented in this section, each assessment team will be able to produce high quality retaining wall assessments. The field form is a critical tool in completing wall assessments. Details on completing the field form are provided in the following subsections.

5.3.1. WALL ACCEPTANCE CRITERIA

For efficiency and practicality, not all retaining walls encountered in the field need to be included in the retaining wall assessment program. Therefore, the first step in the Data Collection phase is making a determination on whether or not the wall qualifies for inclusion into the program, based on the following criteria:

- **Critical wall height:** Analysis of commonly encountered and constructed retaining walls will provide an indication as to their relative stability. This analysis can also yield a critical wall height, in which retaining walls under this height are considered stable and do not require further assessment or mitigation.

- **Wall elements in poor condition:** Wall elements that are found to be in poor condition and require further strengthening and stabilization measures are included in the assessment program, regardless of wall height. Conditions that may require inclusion into the assessment program include weak, weathered, or missing mortar and/or stone.

- **Poor overall wall performance:** Retaining walls that are found to demonstrate poor performance characteristics are included in the assessment program, regardless of wall height. Examples of demonstrated poor wall performance include:
  - Walls that have rotated and are no longer plumb;
  - Wall that have settled and demonstrate significant cracking of the mortar and stones.

5.3.2. WALL LOCATION DATA

The second step in the assessment program is to locate the wall relative to its associated structure. In most cases, GPS coordinates, provided by the partner organization, will assist in locating retaining walls in the field.

- **Code:** A unique identifier code is critical for referencing the wall to the adjacent structure. The code will generally be developed by the partner organization and provided to the technical consultant.

- **Address:** The general address of the retaining wall location is required for tracking purposes. The name of the village or neighborhood and appropriate zone or phase are entered. Again, the zones and phases of neighborhoods are usually established by the partner organization and provided on various maps or in established databases.

- **Engineer:** The Engineer responsible for filling out the field form for a given wall lists their name on the field form. This person must be properly trained in completing retaining wall assessments.

- **Date:** This date refers to the date the inspection is completed.

5.3.3. WALL DESCRIPTION DATA

Once the retaining wall has been located with respect to its unique identifier and the phase/zone of the neighborhood or village, the next step is to describe and measure respective wall attributes. Wall description data includes wall type; wall measurements include length, maximum height, thickness, and embedment depth.

- **Wall Type:** Wall type refers to the purpose and intended function of the retaining wall.

- **Wall Length:** The wall length is defined as the actual measured maximum earth retaining length of the wall, measured to the nearest 10 cm.

- **Wall Height:** The wall height is defined as the maximum observable and/or verifiable height of the wall, measured to the nearest 10 cm. Estimated embedment and/or parapet heights are not included in the measurement of wall height. The maximum height measurement extends from the groundline at the wall toe to the top of wall groundline, or to the estimated top of wall groundline in cases where retained materials have been removed from behind the wall.

- **Wall Thickness:** The wall thickness is defined as the observable and/or verifiable thickness of the wall. In many cases this measurement will not be possible if access cannot be gained to the top or ends of the wall. While this measurement can provide useful information in completing a more detailed back analysis of the wall it is not critical to the wall assessment and retrofit program. Therefore, probing or destructive methods to obtain this measurement are not required. If the measurement cannot be easily obtained, simply do not include a wall thickness on the field form.

- **Wall Embedment Depth:** The wall embedment depth is defined as the observable and/or verifiable embedment depth of the wall below existing grade. In most cases, this information will have to be provided by the homeowner, assuming the homeowner was responsible for the wall construction. Excavation or probing of the toe of the wall is not required to obtain this measurement. If the measurement cannot be easily obtained, simply do not include a wall embedment depth on the field form.

5.3.4. WALL CONDITION ASSESSMENT

At this point in the field inspection, the retaining wall has been located and wall attributes have been classified, measured, and photographed. The next step in the field inspection is to assess the condition of wall elements (stone, mortar) relative to their extent, severity, and urgency of observable distresses. In addition to the elemental assessment, the overall performance of the wall is evaluated.

The retaining wall assessment field form requires input on a variety of questions, which detail the condition of wall elements, as well as the overall performance of the wall. The field form is broken down into sections depending on the type of wall being assessed.

For all wall types, the field form requires input on the overall performance of the wall, as well as the condition of specific wall elements, namely rock and mortar.

Upon completion of the field form, the engineer should have a general understanding of the condition and performance of the wall, which will assist in completing recommendations on mitigation strategies.

5.3.5. WALL ACTION ASSESSMENT

Upon completion of the evaluation of the overall wall performance, as well as the performance of individual wall elements, a determination of the appropriate actions relative to maintenance, repair, or reconstruction of the wall is made using the decision tree. Input on the field form simply requires a "no action" or "action" determination. If action is required, the appropriate mitigation detail(s) is noted on the field form.

5.3.6. NEW WALL CONSTRUCTION

Field forms can also be used to capture the site-specific geometry required for construction of new retaining walls associated with construction of new buildings.

5.4. POST-FIELD ACTIVITIES AND PROCEDURES

Post-field activities are generally focused on the preparation of retaining wall design packages for retrofit or new construction applications. These packages are very similar in structure and content to structural retrofit or new construction packages. The design packages include the following documents:

- **Design Package Cover Sheet**: The design package cover sheet conveys the unique structure identification code, the location of the retaining wall, including appropriate phase and zone, and the name of the beneficiary.

- **Acknowledgement of Receipt**: The acknowledgment of receipt by the homeowner lists the name of the beneficiary, the structure identification code, and location of the retaining wall. The document is signed by the beneficiary and serves as a tracking mechanism, ensuring the appropriate number of copies have been delivered to initiate the processing and funding mechanisms of the design package process.

- **Assessment Field Form**: The retaining wall assessment field form is to be completed in the field during the actual retaining wall assessment. The form provides location information (unique structure identification code, phase/zone), as well as the name of assessing engineers. The form also includes salient information on the type and geometry of the wall. The form also provides information on the condition and performance of the wall. The form concludes with the selection of appropriate mitigation method(s), if required.

- **Labeled and Dimensioned Site Plan**: The preparation of a site plan is critical to conveying the location of a retaining wall in relation to the structure. The site plan also provides information on the geometry of the wall. The site plan should be labeled with reference to required mitigation details.

- **Mitigation Details**: A suite of mitigation details are designed for the retaining wall retrofit program. These details are consistent with commonly applied techniques for masonry construction and use equipment and materials that are readily available.

- **Scope of Work Checklist**: The scope of work checklist is used as an internal tool for tracking the mitigation details included in individual design packages.

- **Bill of Quantities**: A bill of quantities data entry spreadsheet is developed for the retaining wall retrofit program. The calculations within the spreadsheet are automated, including development of the final bill of quantities cost estimate. The engineer is only required to enter geometry data (wall height and length) for the required mitigation method. The Data Entry worksheet and Bill of Quantities worksheet are included in the final design package.

- **Grant Application Forms**: Depending on the partner or client organization, various grant application forms may be included as part of the retaining wall design package. These forms provide information on the retaining wall retrofit program for the beneficiaries and detail the application process. These forms are filled out by the beneficiary and submitted to the partner organization.

Examples of the various documents that form a retaining wall design package, as well as a completed design package, can be found at www.buildchange.org/USAIDPrimers.html.

> "All of the decision making processes are completed in the field…. Therefore, the preparation of the design package requires little effort."

All of the decision making processes are completed in the field, including determination of retaining wall meeting acceptability criteria, as well as a decision on the appropriate mitigation solution. Therefore, the preparation of the design package requires little effort.

Once the design package is complete, the entire package should be submitted to the supervising engineer for review and approval. Copies of the final, approved retaining wall design package are then made for the technical consultant, USAID, homeowner, and community committee. The design packages are delivered to the beneficiary for signature, at which time the application process is started.

Once the design package has been delivered to and signed by the beneficiary, a copy of the design package should be archived per established process and procedures. At a minimum, final design packages should be scanned and archived for future reference.

Photographs taken during the field assessment are to be archived for future reference. The final version of the bill of quantities should also be archived.

6. HOMEOWNER-DRIVEN DESIGN

This phase of a homeowner-driven site hazard mitigation project extends the design phase to the individual design of each potentially unstable retaining wall with the homeowner. This phase is also best completed in conjunction with housing reconstruction or retrofit efforts, as detailed in "Building Back Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer." At this point in the process, the steps for site hazard mitigation and housing reconstruction or retrofit projects are very similar and do not need to be duplicated, and can be combined or completed in parallel.

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

Initially, the project team should introduce the retaining wall hazard mitigation 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, with specific attention being paid to existing or damaged retaining walls, including assessments of the need for new retaining walls to be constructed on the site. These assessments are best completed with a simple field form, ensuring that collected retaining wall data is consistent and thorough. 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, including the location of existing or new retaining walls, for homeowner review and input.

For further information on the required steps for homeowner qualification, design and cost estimation, homeowner training, and review and paperwork flow for homeowner-driven design in site and retaining wall hazard mitigation projects, please see Sections 3.4-3.8 in "Building Back Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer," which can be found at www.buildchange.org/USAIDPrimers.html. The same principles discussed there for homeowner-driven housing reconstruction and retrofit may be equally applied to homeowner-driven site hazard mitigation and retaining wall construction and retrofit.

7. BUILDER/CONTRACTOR SELECTION

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

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

> "Providing incentives to promote construction in compliance with standards, such as the possibility of winning additional contracts in the future, has proven successful."

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.

For further information on builder or contractor identification, construction contracts, pre-construction training or certification, and the project schedule for homeowner-driven design in site and retaining wall hazard mitigation projects, please see Chapter 4 in "Building Back Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer," which can be found at www.buildchange.org/USAIDPrimers.html. The same principles discussed there for homeowner-driven housing reconstruction and retrofit may be equally applied to homeowner-driven site hazard mitigation and retaining wall construction and retrofit.

8. CONSTRUCTION SUPERVISION

> "Proper inspection by engineers provides a level of quality control and assurance to construction activities. Inspection, at a minimum, should occur daily and at critical milestones in the construction process."

Inspection of activities associated with construction of retaining wall repair or hazard mitigation methods is a critical final step in the process. Proper inspection by engineers provides a level of quality control and assurance to construction activities. Inspection, at a minimum, should occur daily and at critical milestones in the construction process.

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

The level of construction supervision can vary from a cursory review to a full-time site presence, depending on the complexity of the construction and the skills of the builders. Construction supervision is best provided by in-country professionals and technicians, who usually require training but have been shown to 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. Photographs of critical elements in the construction process should be taken as part of checklist completion and archived for future reference. Following is a short list of contents in a checklist used for a typical site hazard mitigation project in a post-disaster environment.

Table 2. Contents of a Construction Checklist Used for a Typical Site Hazard Mitigation Project 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 is not liquefiable sand or expansive clay
MATERIALS QUALITY
Quality of materials, such as sand, gravel, stone, water, cement, masonry units, steel reinforcement, 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 meets 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
MORTAR
Mortar mix proportion as specified
Wall plumb and level

Construction checklists used in Haiti for various retaining wall hazard mitigation strategies can be found at www.buildchange.org/USAIDPrimers.html. These checklists should be completed by engineers in the field to ensure that proper materials and construction practices are employed. Engineers should become comfortable using the checklists and become knowledgeable of the various mitigation details with their supporting construction techniques.

9. FUND DISTRIBUTION

"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 practice."

Fund distribution takes place at the start of and during the construction phase. Funds should be distributed in installments, once phases of construction are complete and deemed to be in compliance with design specifications and construction quality standards. 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 reconstruction will not produce safe, complete structures for all if homeowners do not have sufficient access to financial resources.

For further information on fund distribution options for homeowner-driven design in site and retaining wall hazard mitigation projects – including cash grants to small groups of homeowners, cash grants to each homeowner, and vouchers for building materials – please see Chapter 9 in "Building Back Housing in Post-Disaster Situations – Basic Engineering Principles for Development Professionals: A Primer," which can be found at www.buildchange.org/USAIDPrimers.html.

10. APPENDICES

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

APPENDIX 1: QUALITATIVE RISK ANALYSIS

This Appendix contains supporting documents for completing a qualitative risk analysis:

- Qualitative Measures of Likelihood of Hazard Recurrence Table
- Qualitative Measures of Consequences to Property Table
- Qualitative Risk Analysis Matrix
- Risk Level Implications Table

APPENDIX 2: CASE STUDY: HAITI

This Appendix contains processes and procedures used to develop a site and retaining wall hazard mitigation program in Haiti following the January 2010 earthquake.

APPENDIX 3: FIELD DOCUMENTS AND FORMS

This Appendix contains supporting documents for field activities:

- Retaining Wall Assessment Form
- Equipment Inventory Checklist

APPENDIX 4: DESIGN PACKAGE DOCUMENTS

This Appendix contains the following documents that comprise a retaining wall design package:

- Design Package Cover Sheet
- Acknowledgment of Receipt
- Retaining Wall Assessment Field Form

- Labeled and Dimensioned Site Plan
- Mitigation Details
- Scope of Work Checklist
- Bill of Quantities Data Entry Worksheet
- Bill of Quantities Cost Estimate

APPENDIX 5: CONSTRUCTION QC CHECKLISTS

This Appendix presents the construction checklists for the various retaining wall mitigation strategies:

- Void Fill
- Surface Bond Overlay
- Reinforced Overlay
- New Retaining Wall and Buttress
- Gabion Erosion Protection

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