# Stone Masonry School in Abbottabad

## A Case Study of Seismic Assessment and Retrofit

Supported by the Pakistan-US Science and Technology Cooperation Program

## Summary

Non-engineered construction is very common in many parts of Pakistan. Most such buildings are unreinforced masonry (URM) structures with walls constructed from either stone, brick or concrete block masonry, depending on which material is locally available. These masonry walls are brittle and often cannot resist the lateral forces which are generated during a seismic activity. In the Kashmir 2005 earthquake, an estimated 19,000 children died due to the collapse of masonry school structures.

The case-study school is situated in the seismically active Abbottabad region. The school has been built using a design template which is the same for most of the schools in the area. The school consists of four classrooms which have been divided into 3 blocks. The structural system of the building consists of load bearing walls which have been constructed using double leaf random rubble stone masonry with a cavity in the middle. The roof is constructed of timber trusses topped with corrugated metal sheets.

Following the Kashmir earthquake, concerns arose that the case study school building and a number of similar schools would be demolished due to their seismic vulnerability (they were declared unsafe by a government agency), and that it would be difficult for replacement school buildings to be built in timely manner. NED University provided a solution: retrofit the existing school buildings to improve their earthquake resistance and repair the damage so that the schools could continue to be used and local children would not suffer a damaging gap in their education. The case study team developed an indigenous retrofit solution for stone masonry school buildings that uses the available material and skill in the region. This solution uses steel straps and angles to provide out-of-plane capacity, to reinforce areas near openings, and to connect the walls together to form a box that better resists shaking; as well as a ferrocement overlay to increase stiffness and provide additional containment for the stone walls.

Local builders constructed the retrofit and the school is open and functioning. The community was very appreciative of the retrofit. This case study has been published by investigators in The Proceedings of the Urban Habitat Construction under Catastrophic Events Conference, 2010.

## About the Project

NED University of Engineering (NED) and Technology and GeoHazards International (GHI), a California based non-profit organization that improves global earthquake safety, are working to build capacity in Pakistan's academic, public, and private sectors to assess and reduce the seismic vulnerability of existing buildings, and to construct new buildings better. The project is part of the Pakistan-US Science and Technology Cooperation Program, which is funded by the Pakistan Higher Education Commission (HEC) and the National Academies through a grant from the United States Agency for International Development (USAID). Together, the NED and GHI project teams are assessing and designing seismic retrofits for existing buildings typical of the local building stock, such as the one described in this report, in order to provide case studies for use in teaching students and professionals how to address the earthquake risks posed by existing building. The teams are also improving the earthquake engineering curriculum, providing professional training for Pakistani engineers, and strengthening cooperative research and professional relationships between Pakistani and American researchers.

## Case Study Participants

This report was compiled by Dr. Rashid Khan, Professor, Department of Earthquake Engineering, NED University of Engineering and Technology, and Dr. Janise Rodgers, Project Manager, GeoHazards International.

This building was investigated by a case study team consisting of Prof. Sarosh H. Lodi, Dean, Faculty of Civil Engineering and Architecture, Prof. Muhammad Masood Rafi, Chairman, Department of Earthquake Engineering, and Prof. Dr. S. F. A. Rafeeqi, Pro Vice Chancellor, NED University of Engineering and Technology

The case study team and authors wish to express their gratitude for the technical guidance provided by Dr. Gregory G. Deierlein, Professor, Department of Civil and Environmental Engineering, Stanford University; Dr. S.F.A. Rafeeqi, Pro Vice Chancellor, NED University of Engineering and Technology; Dr. Khalid M. Mosalam, Professor and Vice-Chair, Department of Civil and Environmental Engineering, University of California, Berkeley; Dr. Sarosh H. Lodi, Professor and Dean, Faculty of Engineering and Architecture, NED University Engineering and Technology; Dr. Selim Gunay, Post-doctoral Researcher, Department of Civil and Environmental Engineering, University of California, Berkeley; Mr. David Mar, Principal and Lead Designer, Tipping Mar, and Mr. L. Thomas Tobin, Senior Advisor, GeoHazards International.

# Contents

Summary ........ 2

About the Project ........ 3

Case Study Participants ........ 3

Introduction ........ 5

Building Information ........ 5

Site Information ........ 7

Hazard Information ........ 7

Assessment of Damage Caused by the 2005 Kashmir Earthquake ........ 7

Detailed Evaluations ........ 9

  Analytical Model ........ 9

  Performance Criteria and Material Properties ........ 10

Retrofit Solution ........ 11

  Design Features ........ 12

    Increased out-of-plane bending resistance of walls ........ 12

    Stronger lateral resisting system ........ 12

    Strengthening of weak areas ........ 12

    Tying individual and isolated members ........ 12

    Increased stiffness ........ 13

  Analytical Model of Retrofitted Building ........ 13

  Analysis Results ........ 13

Retrofit Construction ........ 14

Observations and Future Work ........ 15

# Introduction

The school is a government primary school located in Abbottabad built from unreinforced stone masonry. Because many of the unreinforced masonry schools in Kashmir that were shaken more strongly by the earthquake collapsed, killing students and teachers, some government agencies declared unreinforced masonry schools in the area dangerous. The case study school, along with a number of similar schools nearby, was marked for demolition. The community was concerned that once the school was demolished, it would be difficult to get a new school built in a timely manner, and the local children's education would suffer greatly.

A team from NED University visited the case study school and a number of others, and found that terrified students and teachers were still holding classes in the building, for lack of another, safer space. The NED team proposed a solution: retrofit the school to improve its earthquake resistance and repair the earthquake damage. The team developed a retrofit solution using locally available materials and construction skills, and local builders readily constructed the retrofit scheme for all three blocks. The retrofit was completed in 2009, and the school is open and serving the students in the community. The community was very pleased that their school remained open, and that the students no longer have to attend classes in a dangerous building.

# Building Information

The school consists of 4 classrooms which have been divided into 3 blocks. A view of the school before retrofitting is presented in Figure 1. A plan of the school building is shown in Figure 2.

**Figure 1. View of the case-study school building before retrofitting.**

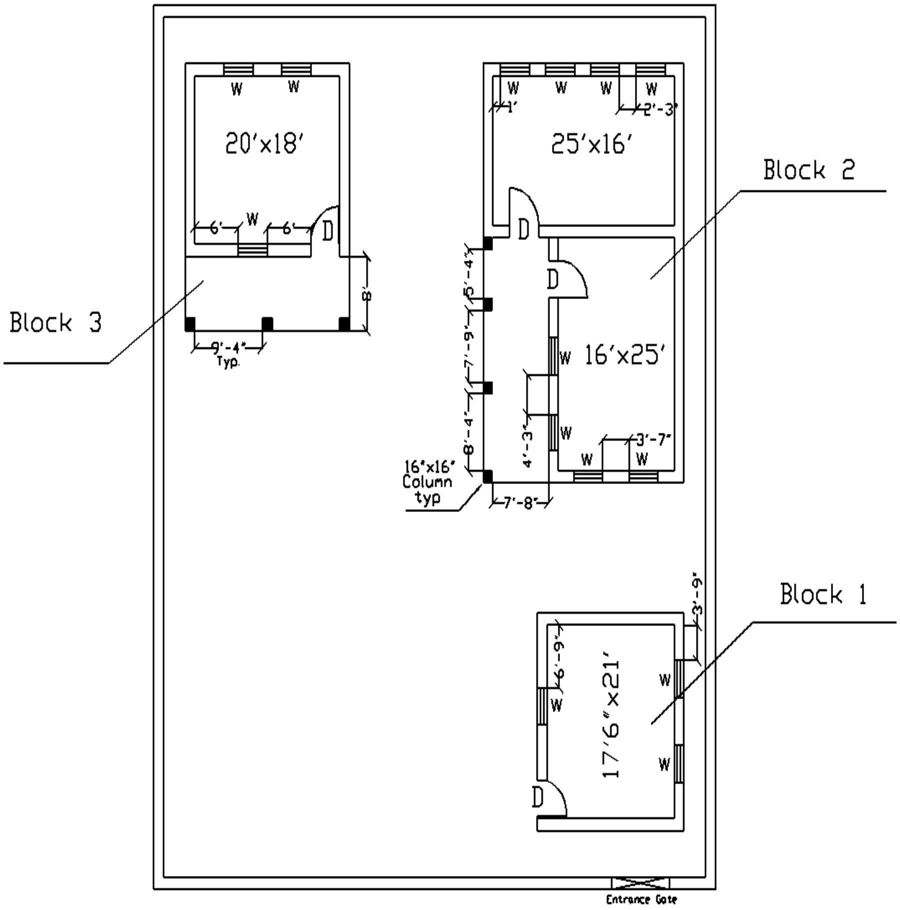

**Figure 2. Plan of the masonry school structure**

The structural system of the building consists of load bearing walls which have been constructed using double leaf random rubble stone masonry with a cavity in the middle. Figure 3 shows a wall of this type under construction. The cavity is filled with rubble stones blended with mortar. This mortar infill provides a connection between the inner and the outer layers of stonework. These walls provide a strong structural system to resist gravity loads but lack resistance to lateral loads as the walls are not well connected together at their ends or to the roof trusses and act as free standing walls. Because there is no reinforcing, the walls have very limited tensile capacity and fail in a brittle manner. As shown in Figure 1, the columns stand alone with no bracing either at roof level or at plinth level leaving them to behave independently of the other parts of the building.

The roof consists of timber trusses and corrugated metal sheets which rest on these walls. Since these trusses do not have any lateral restraint against their movement, they fail to provide diaphragm action and can undergo rigid-body translation when subjected to lateral earthquake forces.

**Figure 3. Typical wall construction**

## Site Information

Very little information is available for the site, but it does not appear to be at risk of ground failure or surface fault rupture.

## Hazard Information

Abbottabad's current seismic zoning under the National Building Code of Pakistan is Zone 3. The site is not located near any known active faults so near-source factors are not applicable.

## Assessment of Damage Caused by the 2005 Kashmir Earthquake

The vulnerability assessment exercise carried out by the team members for the schools in the region showed that no major earthquake damage was apparent in these buildings. The buildings were located some distance from the region of strongest shaking, as Figure 4 shows. However, mortar cracks were visible between stone blocks. Cracks were also visible at the corners of adjacent walls and door and window openings, as Figure 5 shows. These cracks are typical of this type of construction. In addition, the gable wall at a few locations failed out-of-plane near the roof line, as Figure 6 shows. Such failures are common in unreinforced masonry gable walls.

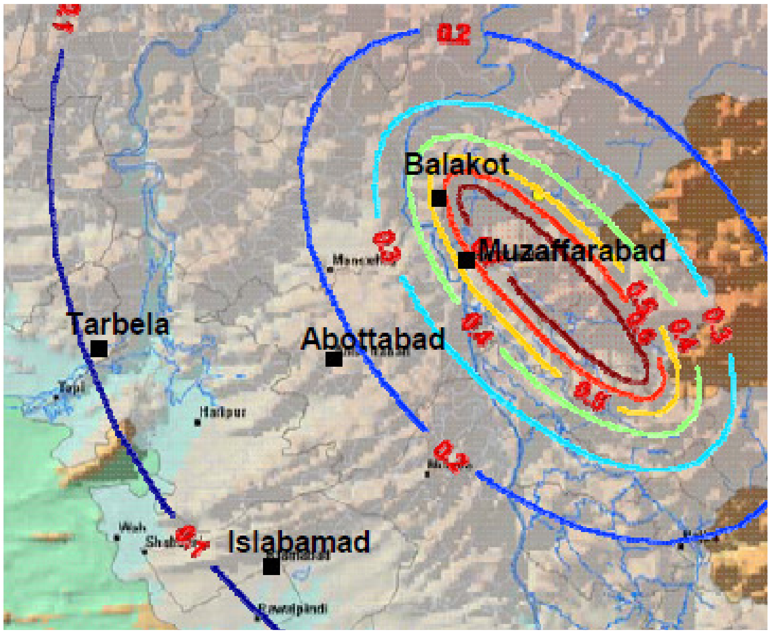

**Figure 4. Peak ground acceleration contours for 2005 Kashmir earthquake showing location of Abbottabad (Durrani et al., Mid-America Earthquake Center, 2005)**

**Figure 5. Typical cracks at openings (left) and wall junctions (right)**

**Figure 6. Out of plane failure of the gable wall in a school building**

## Detailed Evaluations

The case study team performed nonlinear time-history analysis on a three-dimensional finite element model of a typical room in the existing building, as well as on a model with the retrofit solution applied.

## Analytical Model

Two 3-D finite element models of the school were created in SAP2000; the model of the existing building is shown in Figure 7. A brick-by-brick modelling approach was employed and the stone masonry blocks were modelled as three dimensional linear solid brick elements which were connected to each other by the nonlinear spring elements representing the mortar joints as shown in Figure 8. Only a single room was modelled in view of the computation time required to analyse the structure. Roof trusses were excluded in the 3-D model and as a result, no diaphragm action was considered.  However, as mentioned previously the roof trusses and CGI sheets are not well connected to the walls and do not provide diaphragm action.

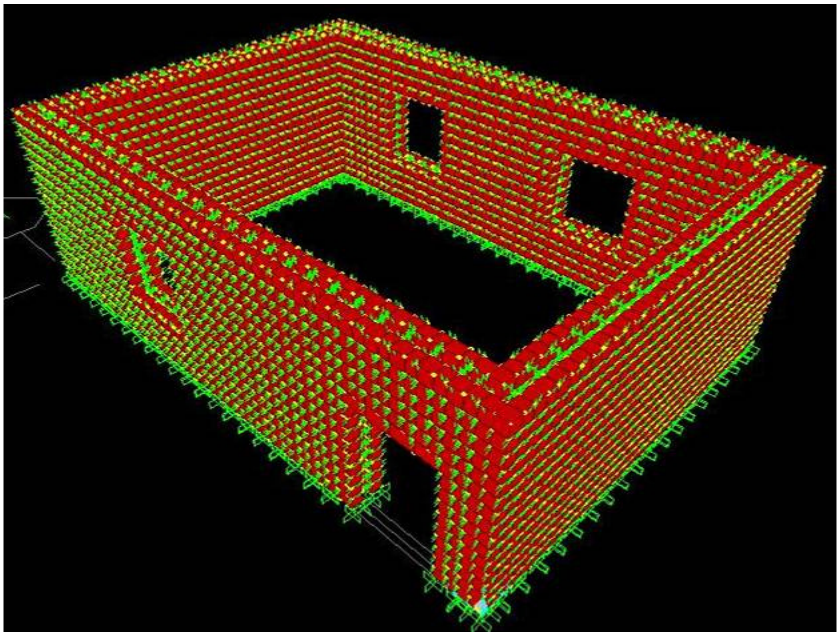

**Figure 7. 3-D model of the masonry school structure**

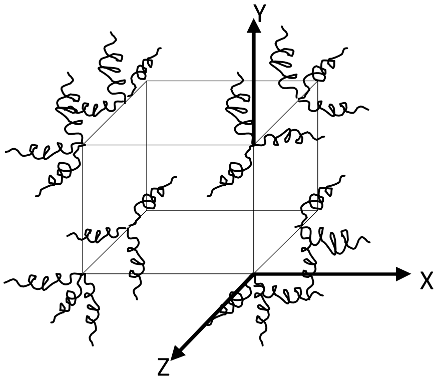

**Figure 8. Idealisation of mortar joints**

## Performance Criteria and Material Properties

A nonlinear time history analysis was conducted for the masonry school structure. The performances of the original and retrofitted models were studied using the 1940 El Centro, California ground acceleration record. Because the building is being used as a school building, therefore it is evaluated for 'Immediate Occupancy' (IO) to determine whether it can be used in post-earthquake relief operations.

| **Material Properties for the 3-D Modelling** | |
|---|---|
| **Stone masonry** | E = 50GPa<br>$\gamma$ = 23 MPa |
| **Mortar** | f'c = 15 MPa<br>Tensile strength = 0.1f'c (Tasuji at el. 1979)<br>Shear Strength = 0.15f'c (Tasuji at el 1979) |

Figure 9 shows the stress-strain relation used to model the mortar joints. The non-linear compressive behaviour of mortar in the direction of principal compressive strain was defined using the Popovics (1973) compression curve. A linear relaxation of normal stress in the direction orthogonal to the crack is adopted with a linear tension-softening diagram.

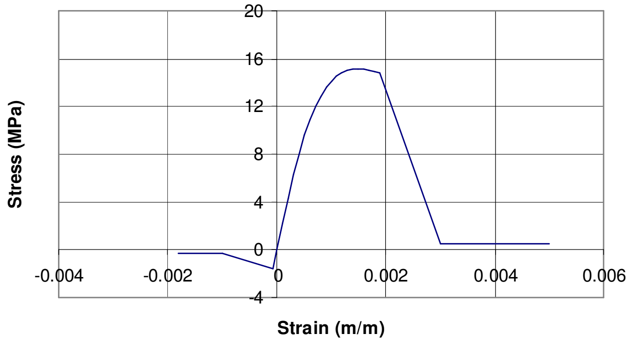

**Figure 9. Mortar behaviour in compression and tension**

A linear stress-strain relation was employed to model the shear behaviour of the mortar and its post peak behaviour was modelled as a brittle material as Figure 10 shows.

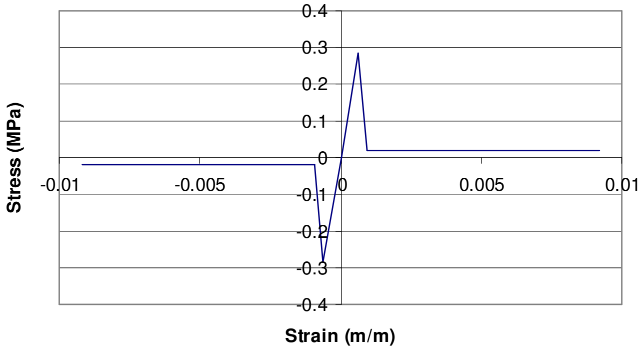

**Figure 10. Mortar behaviour in shear**

Geometric nonlinearities were considered in the analysis with the help of the Total Lagrangian approach.

## Retrofit Solution

The team sought a retrofit solution that gives acceptable seismic performance while being readily constructible with locally available materials. The retrofitting scheme has four objectives:

- To increase lateral load resistance of individual walls against out-of-plane forces locally;
- To form a closed box action between the four walls to enable them to act as monolithic walls to increase their resistance globally;
- To strength weak areas within the walls such as openings for doors and windows; and

- To tie individual and isolated members together such as stone masonry columns in the veranda.

## Design Features

The following innovative features were provided in the seismic retrofitting design in order to increase the seismic capacity of the building.

### Increased out-of-plane bending resistance of walls

Lateral load resistance of individual masonry walls have been increased against out-of-plane bending by providing both horizontal as well as vertical metal strips (50 x 6 mm). These strips have been provided on both the internal and external faces of the walls and well connected with each other using 12 mm diameter pins, as shown in Figure 11.

**Figure 11. Installation of vertical and horizontal metal strips**

### Stronger lateral resisting system

All the four walls have also been connected together at their junctions using steel angles (75 x 75 x 3 mm) from inside as well as outside to enable closed box action and provide a stronger lateral load resisting system.

### Strengthening of weak areas

Weak areas within the walls such as openings for doors and windows were additionally strengthened using metal strips around the openings from both inside and outside, as shown in Figure 11.

### Tying individual and isolated members

Individual and isolated members, such as stone masonry columns, were tied together by tie beams both at plinth and lintel levels as shown in Figure 12.

**Figure 12. Strengthening of stone masonry columns (left) and adding tie beams and slab on grade (right)**

### Increased stiffness

The stiffness of the system has further been increased by casting a Slab-on-Grade well connected to the wall as shown in Figure 12 and applying Ferrocement plaster (1:4 cement: sand plaster overlain on G.I. Expanded metal lathe of 18 Swg) on the walls both internally and externally.

Members of the case study team have applied for a patent of the retrofitting scheme.

## Analytical Model of Retrofitted Building

The retrofitted model was based on the retrofitting design as mentioned above. However, Ferrocement plaster was not modelled in the created 3-D retrofit model shown in Figure 13.

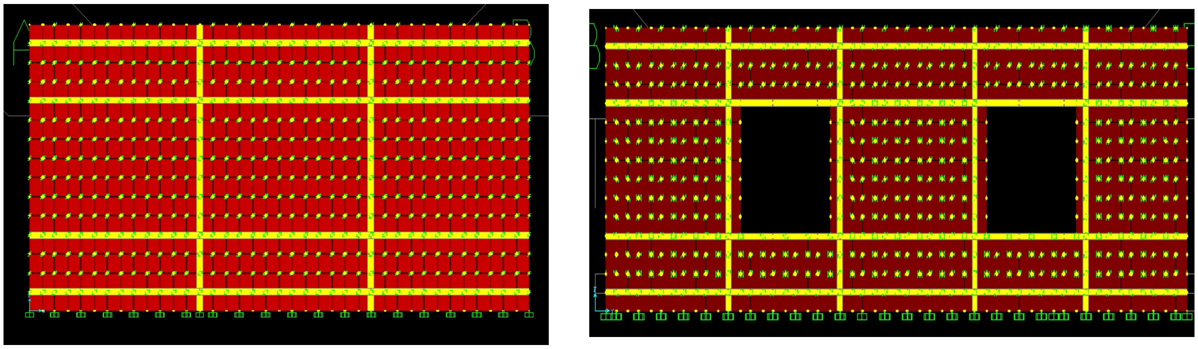

**Figure 13. View of 3-D modelled walls with metal strips – short direction wall (left) long direction wall (right)**

## Analysis Results

Figure 14 shows the out-of-plane (lateral) deflections of the long wall of building, which were determined by using ratio of $\Delta/\Delta_{top}$; where $\Delta_{top}$ is the deflection at the top wall level of the original structure.

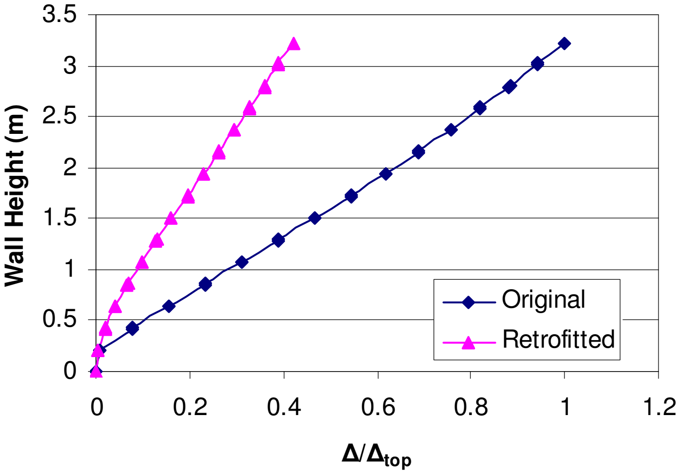

**Figure 14. Normalised deflection of original and retrofitted structure**

It can be seen in Figure 14 that the deflection at the top of retrofitted wall is 58% less than that of the original structure. Although the deflection of the structure after applying Ferrocement was not measured it is clear that this will further reduce deflection.

## Retrofit Construction

Local builders readily learned the techniques required to construct the retrofit, because the retrofit was designed to make use of locally available materials with which the builders were accustomed to working. The retrofit was completed in June 2009, with construction taking less than two months. The school's function was not disrupted because construction occurred during the school break in summer. The retrofit cost approximately Rs. 400 per square foot of floor area (at the prevailing currency conversion rate of 88 Rupees per US dollar, the cost in dollars would be less than $5 per square foot). Construction is shown in Figure 15 through Figure 17.

**Figure 15. Preparation of surface inside school (left); installation of steel straps (right)**

**Figure 16. Placement of the vertical and horizontal steel straps – short wall (left) long wall (right).**

**Figure 17. Retrofit of masonry columns (left); new slab on grad and plinth level tie beams (right)**

## Observations and Future Work

Observations drawn from this case study include the following:

1. The retrofitting scheme which was based on the basic concepts of strengthening weak areas and links of the structure showed significant improvement in load resistance in terms of stiffness and strength.
2. The retrofitting scheme was easily understood by the local construction workers and applied easily through top supervision only.
3. The school, which is now regularly functioning, has immensely boosted the morale of the community. The local people are now confident that they can apply the scheme to other schools in the community and can confidently oppose demolition of their schools. At the time of this writing, no information was available as to whether the community had been able to retrofit additional schools.