# Building Pakistan's Capacity for Instruction, Research, and Practice in Earthquake Engineering and Retrofit

**Final Report**

**for**

**Grant No. PGA-7251-07-012**

Jointly submitted by:


**Dr. Sahibzada Farooq A Rafeeqi**
Professor and Dean
Faculty of Civil Engineering and Architecture
NED University of Engineering and Technology
Karachi, Sindh, Pakistan

**Dr. Brian E. Tucker**
President
GeoHazards International
Palo Alto, California, USA


to

Kelly Robbins, Senior Program Officer

The National Academies

Policy and Global Affairs, 500 Fifth Street NW, Room 542, Washington, DC 20001

**May 2012**

## Executive Summary

Moderate to high levels of seismic hazard are present throughout Pakistan. The numerous building collapse incidents caused by the 2005 Kashmir earthquake verified the seismic vulnerability of existing building types in the country. The lack of capacity of the Pakistani academic, public, and private sectors to assess seismic vulnerability, to identify potential seismic mitigation measures, and to strengthen vulnerable essential buildings became evident. It was realized that without significant increase in capacity in these areas, Pakistan's policymakers will have very limited access to valuable, economically attractive options for reducing earthquake risk. As a result, nationwide efforts in risk reduction will be significantly impeded.

A project funded by Higher Education Commission (HEC) and United States Agency for International Development (USAID) was undertaken to improve Pakistan's capacity for reducing earthquake risk by building the capacity of universities to teach earthquake engineering, and to conduct research in this area and transfer the knowledge needed to seismically retrofit buildings to both new graduates and engineering practitioners.

The completed project has resulted in the following major accomplishments,

1) Pakistan-specific checklist for building vulnerability assessment was developed. Capacity building efforts were carried out using 10 case study buildings with documented assessments, computer analyses and retrofit designs (if required). A practical guide to nonlinear static analysis for engineers and practical courses on building vulnerability assessment and retrofit were produced. Modules for use in academic courses were developed.

2) Understanding of building seismic behavior was greatly enhanced. Consideration of the effects of masonry infill walls in the Pakistani buildings lead to better-design of new buildings on part of the professional as engineers.

3) Nearly 400 professionals including those from universities, structural engineers, architects, engineers from civic agencies and construction contracting firms were trained in seismic vulnerability assessment. The sessions included training on developing retrofit solutions.

4) Hands on experience and intensive mentoring for a group of early and mid-career Pakistani faculty members in applying advanced earthquake engineering techniques to existing buildings was provided.

5) New and innovative applications of retrofit methods to common urban buildings in Pakistan were carried out. An International research-practice collaborative network entitled Framed Infill Network was formed in order to make concrete buildings with masonry infill safe through innovative designs that make beneficial use of infill walls.

6) The relationships between academia and professional engineers and between researchers in Pakistan and the US were strengthened.

**Contents**

## Introduction

On October 8, 2005, a magnitude 7.6 earthquake affected Pakistan, India, and Afghanistan with the epicenter located near Muzaffarabad, which is approximately 86 miles (138 km) northeast of Islamabad. The earthquake killed more than 73,000 people, injured more than 128,000, and rendered millions homeless throughout a mountainous region in northern Pakistan. Because it struck during school hours, schools and children were particularly affected where at least 8,000 schools collapsed or were damaged beyond repair in the Northwest Frontier Province and another 2,000 in the less-populous Kashmir region, resulting in the death of at least 17,000 children, and the serious injury of thousands more.

In response to this disaster, Pakistan-US Cooperative Program in Earthquake-Related Research funded a project. The NED University of Engineering and Technology (NED), Pakistan, and GeoHazards International (GHI), a California based non-profit organization collaborated in this project. The project was aimed at improving Pakistan's earthquake engineering education capacity. On the US side the project was managed by the National Academies with funds provided by the US Agency for International Development (USAID); funds on the Pakistani side are provided by Pakistan Higher Education Commission. In January 2007, a three-year collaborative grant was awarded to GeoHazards International (GHI) and NED University of Engineering and Technology, Karachi.

The focus of the project was to improve Pakistan's capacity for reducing earthquake risk by building the capacity of its universities to teach and conduct research in earthquake engineering and transfer the knowledge needed to seismically retrofit essential structures to both new graduates and practitioners. The employed approach integrated formal instruction in theory with practice by using case studies of existing buildings typical of the local building stock in Pakistan. Building sustainable academic interest in earthquake engineering research by encouraging cooperative research and professional relationships with American researchers through academic exchange and study tours, consultation on research topics that directly impact seismic safety in Pakistan, and creation of an earthquake engineering research agenda for Pakistan were also the objective of this project. The Pacific Earthquake Engineering Research (PEER) center, as one of the collaborating institutions, contributed to the project by facilitating academic exchange and encouraging cooperation between the US and Pakistan.

## Project Participants

The project team comprised of the following members

*a) Pakistan Side*

| Name | Affiliation | Status |
|---|---|---|
| Prof. Dr. Shaibzada Farooq Ahmad Rafeeqi | Pro Vice Chancellor II | PI |
| Prof. Sarosh H. Lodi | Dean, Faculty of Engineering and Architecture | Co-PI |
| Prof. Muhammad Masood Rafi | Department of Earthquake Engineering | Member |
| Prof. Rashid A. Khan | Department of Earthquake Engineering | Member |
| Prof. Abdul Jabbar Sangi | Department of Civil Engineering | Member |

| Name | Affiliation | Status |
|---|---|---|
| Mr. Aslam Faqeer | Department of Civil Engineering | Member |
| Ms. Tehmina Ayub | Department of Civil Engineering | Member |
| Ms. Najmus Sahar Zafar | Department of Civil Engineering | Member |

*b) US Side*

| Name | Affiliation | Status |
|---|---|---|
| Dr. Brian Tucker | GeoHazards International (GHI) | PI |
| Prof. Gregory G. Deierlein | Stanford University | Member |
| Prof. Khalid M. Mosalam | University of California, Berkeley | Member |
| Mr. David Mar | Tipping & Mar Associates | Member |
| Dr. Janise Rodgers | GeoHazards International | Member |
| Mr. L. Thomas Tobin | GeoHazards International | Member |
| Dr. Selim Gunay | University of California, Berkeley | Member |

A complete list of project participants is attached as Appendix A.

**Project Objectives and Implementation Plan**

A consolidated summary of the status of activities planned for the project are given in Table 1. Details of the activities is given in the forthcoming sections.

Table 1. Status of activities planned for the project

| **Tasks** | **Originally Proposed Schedule** | **Status as of 03/31/2012** |
|---|---|---|
| 1. Project organization | | |
| 1a. Evaluate the social and policy context and curriculum needs for capacity building. | Year 1 Q1 | Completed |
| 1b. Review and revise work plan | Year 1 Q1 | Completed |
| 2. Case study development | | |
| 2a. Select case study teams | Year 1 Q1 | Completed |
| 2b. Select case study buildings | Year 1 Q1-Q2 | Completed |
| 2c. Gather information and conduct initial assessments | Year 1 Q1-Q4 | Completed |
| 2d. Model buildings and perform structural analyses | Year 1 Q4-Year 2 Q1 | Completed |
| 2e. Design potential retrofit schemes for case study buildings | Year 2 Q2-Q3 | Completed |
| 2f. Discuss retrofit options with building decision-makers | Year 2 Q3 | Completed |
| 3. Instruction and training | | |

| **Tasks** | **Originally Proposed Schedule** | **Status as of 03/31/2012** |
|---|---|---|
| 3a. Initial building vulnerability assessment | Year 1 Q1 | Completed |
| 3b. Background topics such as structural behavior, nonlinear structural analysis | Year 1 Q3 | Completed |
| 3c. Advanced topics such as strength and deformation capacity of reinforced concrete components and masonry walls | Year 1 Q4 | Completed |
| 3d. Seismic retrofit techniques | Year 2 Q1 | Completed |
| 3e. Research topics such as probabilistic collapse assessment techniques | Year 2 Q2 | Completed |
| 3f. Software training (ETABS, SAP2000, PERFORM) | Year 1 Q4 | Completed |
| 3g. Research software training | Year 1 Q4 | Completed |
| 4. Curriculum development and academic course preparation | | |
| 4a. Assess current curriculum | Year 1 Q1 | Completed |
| 4b. Develop national minimum standards for curricula | Not originally proposed | Completed |
| 4c. Propose new courses | Year 1-Year 2 Q2 | Completed |
| 4d. Complete development of new academic courses | Year 2 Q3 | Completed |
| 4e. Teach new courses to students | Year 2 Q4-Year 3 | Completed |
| 4f. Assess and revise courses | Year 3 | Completed |
| 5. Practical course preparation | | |
| 5a. Develop practical course content outlines | Year 2 | Not needed |
| 5b. Develop course material, incorporate completed case studies | Year 2 Q3-Q4 | Completed |
| 5c. Pilot course at workshop for practitioners | Year 2 Q4 | Completed |
| 5d. Assess and revise course | Year 2 Q4-Year 3 Q1 | Completed |
| 6. Dissemination | | |
| 6a. Hold workshops to teach practical courses | Year 3 Q2-Q4 | Completed |
| 6b. Hold capacity building workshops | Year 3 Q2-Q4 | Completed |
| 7. Academic exchange programs/visits | | |
| 7a. Study visit to California | Year 2 Q1 | Completed |
| 7b. Exchange visits | Years 1-3 | Completed |
| 7b. Establish contacts | During visits | Completed |
| 7c. Develop student exchange | Years 2 & 3 | Could not be achieved |
| 7d. Explore research collaboration | Years 2 & 3 | Completed |
| 8. Program review and evaluation | Year 3 Q3-Q4 | Completed |

## Project Impact and Out Reach

### 1) Exchange Visits

Exchange visits were organized from both the Pakistan and US sides. The details of these visits is given as under

*a) Visit # 1 – US team visit to Pakistan, 20-28 July 2007*

The visiting US team stayed in Pakistan from 20-28 July 2007. The team comprised of the following members: (1) Prof. Gregory Deierlein; (2) Prof. Khalid Mosalam; (3) Mr. David Mar; (4) Dr. Janise Rodgers; and (5) Mr Thomas Tobin (Figure 1). The team members traveled with their Pakistani counterparts to Islamabad and the area affected by the 2005 Kashmir earthquake (Figure 2). Discussions were held with academia, industry and Higher Education Commission (HEC) during this visit. The team also visited Earthquake Reconstruction and Rehabilitation Authority (ERRA) and briefing was arranged by the ERRA regarding their work in the earthquake affected areas. ERRA also arranged for an aerial site visit using helicopter to provide details of reconstruction work in Rawalakot, Bagh, Chakothi, and Muzafferabad. The team members were able to write articles in American Concrete Institute (ACI) and Pacific Earthquake Engineering Research Center (PEER) based on the observations collected during the visit. A comprehensive list of publications from this project is given later in the report.

*b) Visit # 2- Pakistan team visit to US*

A two member team from NED University comprising of Prof Sahibzada Rafeeqi and Prof Sarosh Lodi visited the US on 15-19 October 2007. The agenda of the meeting is given in Table 2. This visit was aimed at discussing curriculum development with a wider US group including academics and professional engineers (Figure 3). In addition, observation of different retrofitting methods was also included in the agenda of the meeting.

Figure 1. Research team for US together with the vice chancellor and administrative staff members of NED University.


Figure 2. Research team during their visit to earthquake damaged sites in Rawalakot, Bagh, Chakothi and Muzaffarabad.

Table 2. Agenda for NED University Visit October 2007

| Day | Monday Oct. 15 | | Tuesday Oct. 16 | | Wednesday Oct. 17 | | Thursday Oct. 18 | | Friday Oct. 19 |
|---|---|---|---|---|---|---|---|---|---|
| | | 8:30<br>9:00 | Depart Faculty Club<br>Presentation on PEER in RFS Bldg. 451 conference room (Yousef Bozorgnia) | 9:30 | Tour of Davis Hall laboratory (Khalid Mosalam) | 9:00 | Presentation on Stanford campus retrofits in Blume Center (Evan Reis) | 9:00 | Depart Palo Alto |
| | | 9:30 | Tour of Richmond Field Station laboratories | 10:30 | Presentation on UCB campus retrofits in PEER conf. room (Craig Comartin) | | Presentation on Stanford campus risk assessment (??) | 10:00 | Rutherford and Chekene office visit and presentation on retrofits (Bill Holmes) |
| | | 11:00 | Computers & Structures Inc. office visit | 11:30 | Walking tour of UC Berkeley campus retrofits (Craig Comartin) | 11:30 | Walking tour of Stanford campus retrofits (Evan Reis) | 12:00 | Walk to lunch looking at retrofits along the way |
| | | 12:00 | Lunch with Ashraf Habillulah | 1:00 | Lunch in 4th Street area | 12:00 | Lunch at Stanford Faculty Club | 1:00 | Lunch near Ferry Building |
| | | 1:30 | Tipping Mar office visit (David Mar) | 2:00 | Visit bridge retrofits (Univ. Ave. viaduct) | 1:30 | Tour of Stanford laboratory and student presentations | | Free time in SF? |
| 2:45 | Arrive SFO on UA 011 | 3:00 | Construction site visit (David | 3:00 | Meet with Anil Chopra | 3:00 | Team meeting (GHI offices) | | |

| Day | Monday Oct. 15 | | Tuesday Oct. 16 | | Wednesday Oct. 17 | | Thursday Oct. 18 | | Friday Oct. 19 |
|---|---|---|---|---|---|---|---|---|---|
| | from JFK | | Mar) | | (Davis Hall) | | | | |
| 4:00 | Depart for Berkeley (GHI to transport) | 4:30 | Coffee with Mark Ketchum to discuss bridges (Berkeley Espresso) | 3:30 5:30 | Team meeting (PEER conf. room) | 5:00 7:00 | GHI Pakistan reception | | |
| 5:30 | Dinner in Berkeley | | Dinner | 6:30 | Dinner | 7:30 | Team Dinner | | Dinner |
| | | | | 7:30 | Depart for Palo Alto | | | | |
| Hotel | UC Berkeley Faculty Club | | UC Berkeley Faculty Club | | Stanford Guest House | | Stanford Guest House | | Stanford Guest House |

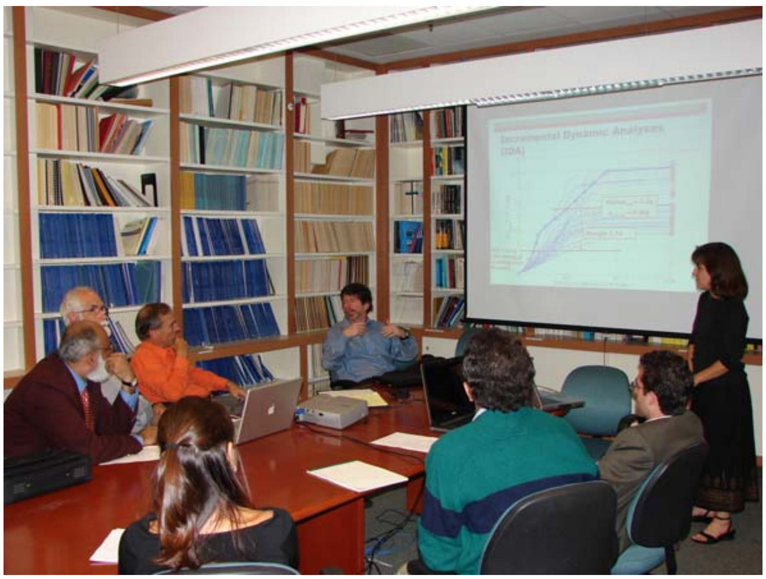


Figure 3. Team members during a workshop at Stanford University.

*c) Visit # 3- Pakistan team visit to US, 25 October - 1 November 2008*

A group of fifteen project participants from Pakistan visited the San Francisco Bay area during 25 October and 1 November 2008. The team consisted of the following members.

1) Prof. Dr. S. F. A. Rafeeqi, Pro Vice Chancellor II, NED University of Engineering and Technology
2) Prof. Sarosh H. Lodi, Dean, Faculty of Civil Engineering & Architecture, NED University of Engineering and Technology
3) Prof. Muhammad Masood Rafi, Chairman, Department of Earthquake Engineering, NED University of Engineering and Technology
4) Prof. Rashid Ahmad Khan, Department of Earthquake Engineering, NED University of Engineering and Technology

5) Mr. Aftab Ahmed Farooqi, Associate Professor, Department of Civil Engineering, NED University of Engineering and Technology
6) Ms. Tehmina Ayub, Assistant Professor, Department of Civil Engineering, NED University of Engineering and Technology
7) Ms. Najmus Sahar Zafar, Lecturer, Department of Civil Engineering, NED University of Engineering and Technology
8) Prof. Dr. M. Asif Khan, Director-National Centre of Excellence in Geology, University of Peshawar
9) Brig. Khaliq ur Rashid Khayani, Professor-National Univ. of Science and Tech. (NUST)
10) Mr. M. Moinuddin Khan, Associate Partner-Professionals Empowered Group
11) Mr. Muhammed Anis, Structural Engineer-Mushtaq & Bilal Associates
12) Mr. M. Tahir Banuri, Director Architecture-Capital Development Authority
13) Mr. Shaukat Qadeer, Professional Engineer-NESPAK
14) Ms. Nighat Fatima, Structural Engineer-NESPAK
15) Mr. Nadeem Manzoor Hassan, Partner-Times Construction

The schedule of the team meetings and visits is summarized in Table 3.

The team started the work with the visit of the Stanford University campus and observed ongoing seismic retrofit programs on the campus. Presentations were made by the visiting team on their case-study buildings (Figure 4). A two-day course on nonlinear analysis and modeling was delivered by Prof Greg Deierlein and Prof Khalid Mosalam (Figure 5). Using a sample building of Karachi, Mr. David Mar and Mr. Mike Korolyk demonstrated modeling and analysis techniques (Figure 6). The representatives form building authorities and contractors in the visiting team visited the state building department which responsible for earthquake-resistant school construction.

The visiting team visited several places including seismically retrofitted buildings in Berkeley and San Francisco, UC Berkeley's structural engineering laboratory facilities, a retrofit construction site, and the Golden Gate Bridge (which is in the midst of a multi-phase seismic retrofit) (Figure 7). At UC Berkeley, Prof. Youssef Bozorgnia, Associate Director, presented an introduction of Pacific Earthquake Engineering Research Center to the participants and were given a of retrofitted buildings on the UC Berkeley campus (Figure 8).

Table 3. Agenda of Pakistani team visit to US

| Time | Sunday Oct. 26 | Monday Oct. 27 | Tuesday Oct. 28 | Wednesday Oct. 29 | Thursday Oct. 30 | Friday Oct. 31 |
|---|---|---|---|---|---|---|
| 8:00 | | Depart Cardinal Hotel | Depart Cardinal Hotel | Breakfast in Palo Alto | Breakfast at Buttercup | Depart hotel 7:45 Take 8:10 ferry to San Francisco; breakfast on ferry |
| 8:30 | | Breakfast and introduction to week – Room 299 Y2E2 Bldg., Stanford University | Breakfast - Room 266 Y2E2 Bldg. Stanford University | Transit from Stanford to Berkeley (8:30 to 9:30 AM); Check into Inn at Jack London Square | Depart hotel | |
| 9:00 | | Presentation by engineer Evan | Nonlinear Analysis | | Introduction to PEER (Youssef | Presentation on retrofit projects |
| 9:30 | | | | | | |

| Time | Sunday Oct. 26 | Monday Oct. 27 | Tuesday Oct. 28 | Wednesday Oct. 29 | Thursday Oct. 30 | Friday Oct. 31 |
|---|---|---|---|---|---|---|
| 10:00 | | Reis on Stanford retrofits followed by tour of retrofitted buildings – Rm. 299 Y2E2 Bldg. | Fundamentals Introduction 9:00 Overview of Assessment Methodology (Greg Deierlein) 9:15 Tea/coffee break 10:45 Theory and Application of NL Analysis (Khalid Mosalam) 11:00 Room 266Y2E2 Bldg. | Modeling and Analysis of the Karachi Archetype Building (David Mar and Mike Korolyk) | Bozorgnia) Introduction to UCB's seismic retrofit program (Christine Shaff) | (Bill Holmes) at Rutherford & Chekene's San Francisco office and walking tour of retrofits |
| 10:30 | | | | | | |
| 11:00 | | Presentations by case study teams (1 hr per team) and discussion Rm. 299 Y2E2 Bldg. | | Tipping+Mar offices<br><br>Visit to Division of the State Architect for building official and contractor | PEER Conference Room, Davis Hall<br><br>Berkeley campus tour of retrofitted buildings | Visit to 800 Market retrofit construction site (Holmes Culley Engineers to host) |
| 11:30 | | | | | | |
| 12:00 | | | | | | |
| 12:30 | | Lunch catered by Kan Zaman in Rm. 299 | Lunch at Stanford Faculty Club | Lunch (Pizza) at Tipping+ Mar | Lunch at Berkeley Faculty Club | |
| 1:00 | | | | | | Lunch (location TBD) |
| 1:30 | | Presentations by case study teams (1 hr per team) and discussion Rm. 299 Y2E2 Bldg.<br><br>Tea/coffee break included | | Practical retrofit design and detailing considerations (David Mar) Tipping+Mar offices<br><br>Curriculum meeting (curriculum team) | Tour of base-isolated Berkeley City Hall | |
| 2:00 | | | Behavior and Modeling of RC Moment Frames (Greg Deierlein) 2:00 Tea/coffee break 3:30 Behavior and Modeling of Masonry (Khalid Mosalam) 3:45 Room 266 Y2E2 Bldg. | | | Golden Gate Bridge and Muir Woods |
| 2:30 | | | | | | |
| 3:00 | Project team meeting at GHI offices | | | | Visit to UC Berkeley Laboratories at Richmond Field Station (RFS) | |
| 3:30 | | | | | | |
| 4:00 | | | | | | |
| 4:30 | | | | | | |
| 5:00 | | Free time for shopping at Stanford bookstore | | | Team discussion (Janise's house) | |
| 5:30 | | | | | | |

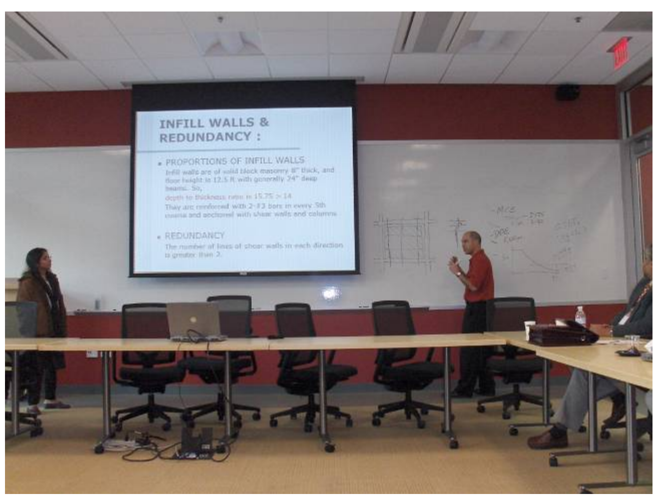



Figure 4. Ms. Nighat Fatima and Mr. David Mar discussing case study building.

Figure 5. Prof. Greg Deierlein during the course on nonlinear analysis.

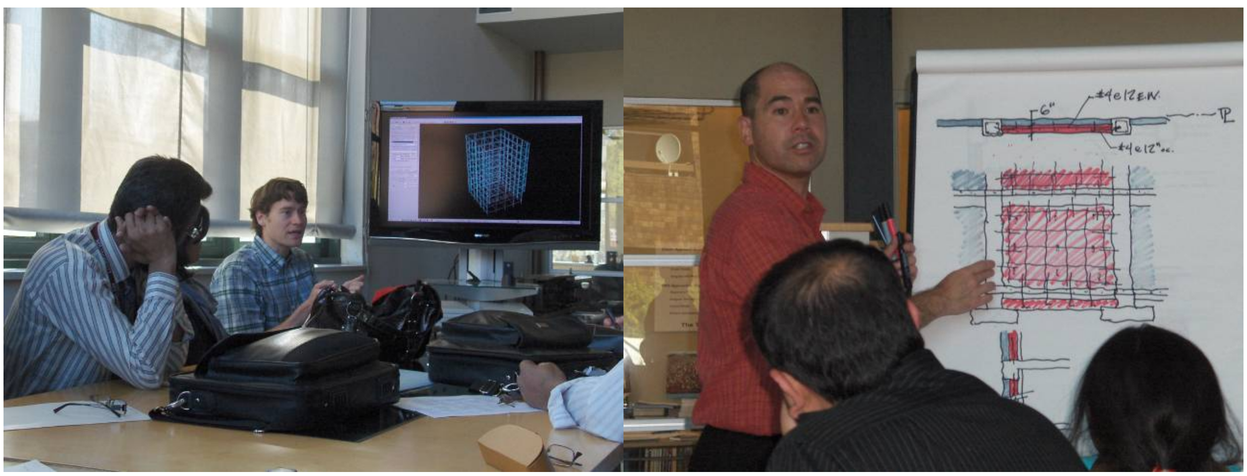


Figure 6. Mr. Mike Korolyk (top) and Mr. David Mar (bottom) demonstrates retrofitting scheme for buildings with masonry infill walls.

Figure 7. A view of participants at the base isolation system underneath Berkeley Civic Center.

Figure 8. Walking tour of seismically retrofitted buildings on the University of California, Berkeley campus.

A tour of the laboratory facilities at UC Berkeley's Richmond Field Station was also arranged by the host US team. The tour included newly reconfigurable reaction wall facility which is part of the George E. Brown Network for Earthquake Engineering Simulation (NEES), shake table facility, and a microNEES lab for small scale experiments. Prof. Stephen A. Mahin, Director, Pacific Earthquake Engineering Research Center, gave the participants tour of his research projects (Figure 9).

On the final day, the participants visited the offices of Rutherford & Chekene, a leading structural engineering firm in San Francisco. William Holmes, one of the firm's principals, gave a presentation on the history of seismic retrofit in California and on the design of some interesting retrofit projects. The participants took a walking tour of seismically retrofitted buildings near their office (Figure 10). A visit to retrofitting construction project was also made. The building was a concrete frame building being seismically retrofitted with stiff moment frames (Figure 11). These tours were of great interest to participants.

Figure 9. Prof. Stephen Mahin explains shake table experiment (left); Dr. Shakhzod Takhirov presents the capabilities of UC Berkeley's laboratory (right).


Figure 10. Bill Holmes points out a seismic retrofit measures on a building south of Market in San Francisco.

Figure 11. Tour a retrofit construction site with Holmes Culley Engineers.

*d) Visit # 4- Meeting in Kathmandu, Nepal, 10-14 July 2010*

A Project meeting was organized in Kathmandu, Nepal on 10-14 July 2010, as the US team was not allowed to travel to Pakistan by the US government. The objective of this meeting was to consider different options for non-linear analysis and seismic retrofit design of case study buildings, and to discuss the steps needed to make concrete buildings with infill walls safer in earthquakes. The meeting was attended by the following team members

*Pakistan Side*

| Name | Affiliation |
|---|---|
| Prof. Dr. Shaibzada Farooq Ahmad Rafeeqi | Pro Vice Chancellor II |
| Prof. Sarosh H. Lodi | Dean, Faculty of Engineering and Architecture |
| Prof. Muhammad Masood Rafi | Department of Earthquake Engineering |
| Mr. Aslam Faqeer | Department of Civil Engineering |
| Ms. Tehmina Ayub | Department of Civil Engineering |

| Name | Affiliation |
|---|---|
| Ms. Najmus Sahar Zafar | Department of Civil Engineering |

*US Side*

| Name | Affiliation |
|---|---|
| Prof. Gregory G. Deierlein | Stanford University |
| Prof. Khalid M. Mosalam | University of California, Berkeley |
| Mr. David Mar | Tipping & Mar Associates |
| Dr. Janise Rodgers | GeoHazards International |
| Mr. L. Thomas Tobin | GeoHazards International |
| Mr. Hari Kumar | GeoHazards International |

The first two days (10-11 July 2010) were allocated for the non-linear finite element (FE) analysis of case study buildings. The participants refined the analytical models by conducted numerical FE analyses during various sessions in these two days (Figure 12). Based on the quantified weaknesses, which were identified by the analysis, different retrofit solutions were tried. This exercise helped in understanding the use nonlinear structural analysis as a design tool and modeling seismic retrofit measures to improve the building's seismic performance.

Figure 12. Participants discussing computer analysis results during a working session

Researchers and engineers from Nepal and the team from the US and Pakistan and met in Kathmandu on 12-14 July 2010 in a workshop related to the performance of infill masonry in RC buildings (Figure 13). The workshop was organized by National Society for Earthquake Technology, Nepal (NSET). The discussion focused on developing means to harness the positive aspects of this very popular structural system to improve global earthquake safety. Participants postulated that with appropriate guidance, engineers and builders could make relatively modest changes to their current practices to create what they termed framed infill buildings: new or retrofitted buildings that intentionally make beneficial use of infill walls to achieve earthquake safety benefits. Through a series of intensive, focused discussions, participants identified specific products and dissemination mechanisms that would have a direct, positive impact on infill buildings' earthquake safety, as well as a comprehensive set of research activities needed to generate those products. NSET also arranged a site tour to study the building construction methods in Nepal (Figure 14).

**2) Trainings**

During the visit of US team to Pakistan training sessions were arranged for professional engineers, contractors, and academics. More than 50 participants attended these sessions. Prof. Deierlien, Mr. Mar, Prof. Mosalam, and Mr. Tobin presented recent advances in earthquake engineering in a technical seminar entitled "Performance- Based Earthquake Engineering and Applications to the Evaluation and Retrofit of Existing Buildings". The seminar was organized on 21 July 2007 at the NED University campus (Figure 15).

Figure 13. Dr. Janise Rodgers facilitates a session during the workshop

Figure 14. Site visit of under construction framed infill building in suburban Kathmandu.


Figure 15. Prof. Gregory G. Deierlein (top left), Prof. Kalid M. Mosalam (top right), Mr. David Mar (bottom left) and Mr. Thomas Tobin (bottom right) presenting the seminar.

Further, Mr. Mar, Dr. Rodgers, and Mr. Tobin led a training session on rapid assessment of existing buildings for younger faculty members and practicing engineers. This was aimed at sensitizing the participants on the methods of assessing seismic vulnerabilities in the building in Karachi. Discussions during this training session provided the starting point for an adaptation of the American Society for Civil Engineers (ASCE) seismic vulnerability screening guidelines for Pakistani conditions (Appendix B). Case study teams were trained on the use of the revised guidelines by Mr. Mar and Dr. Rodgers via videoconference sessions.

Table 4. Summary of trainings in different cities

| S. No | City | Date | No. of Participants | |
|---|---|---|---|---|
| | | | Male | Female |
| 1. | Karachi | 26 February 2008 | 46 | 7 |
| 2. | Karachi | 12-13 August 2009 | 22 | 2 |
| 3. | Nathiagali | 12-13 October 2009 | 21 | 2 |
| 4. | Islamabad | 8-12 March 2010 | 52 | 2 |
| 5. | Islamabad/Murree | 27-30 July 2010 | 45 | - |
| 6. | Karachi | 280May 2011 | 55 | 5 |
| 7. | Muzzafarabad | 6-8 July 2011 | 30 | - |
| 8. | Gawadar | 16-17 November 2011 | 28 | - |
| 9. | Gilgit | 23-24 November 2011 | 24 | 1 |
| | | **Total** | 323 | 19 |

A number of similar trainings were arranged in different cities of Pakistan in order to train the master trainers in using these guidelines. A summary of trainings is given in Table 4. Complete details of these are provided in Appendix C.

**3) Curriculum Development**

The curriculum development efforts were led by a team consisting of Prof. Rafeeqi and Prof. Lodi (Pakistan side), and Prof. Deierlein and Prof. Mosalam (US side). The work started with a review of the existing civil engineering curriculum at the NED University and universities in Pakistan. The team met in Karachi during the visit of US team and discussed modus operandi of revising the existing curriculum so as to include earthquake engineering topics. The team developed a draft curriculum revision plan, for both graduate and undergraduate students, which was discussed with a wider group of faculty members at the NED University. The revision plan includes the addition of earthquake engineering topic modules to existing courses as well as the creation of several new courses. The curriculum was later finalized during the USA visit of Pakistani team (Appendix D). The recommendations consist of the minimum basic earthquake engineering topics to be included in the civil engineering and architecture curricula.

**4) Case Studies**

The selection of case study buildings was carried out based on the following criteria: (a) buildings would be representative of important types of existing construction in the cities where they are located; (b) buildings would have seismic vulnerabilities typical of existing construction; (c) buildings would be representative of important types of occupancy, use, and ownership; and (d) case study teams would have access to the buildings and information about their design and construction.

Mr. David Mar and Dr Janise Rodgers lead the efforts to adapt the American Society of Civil Engineers (ASCE) Tier 1 assessment procedure to Pakistan conditions. Case study teams were trained in these procedures. Ten buildings were chosen in different cities of Pakistan and were analyzed using the adapted procedures to assess the seismic vulnerability of buildings. Summary of the work carried out for each building is included as Appendix E.

Based on the experience gained during case study exercises a document entitled “a guide to nonlinear static pushover analysis” was developed to provide guidance to the practicing structural engineers (Figure 16). In addition, a document entitled “Seismic Hazard, Risk Assessment and Retrofit of Buildings in Pakistan (in Urdu)” was developed for National Institute of Disaster Management, Pakistan and UNDP, Pakistan.

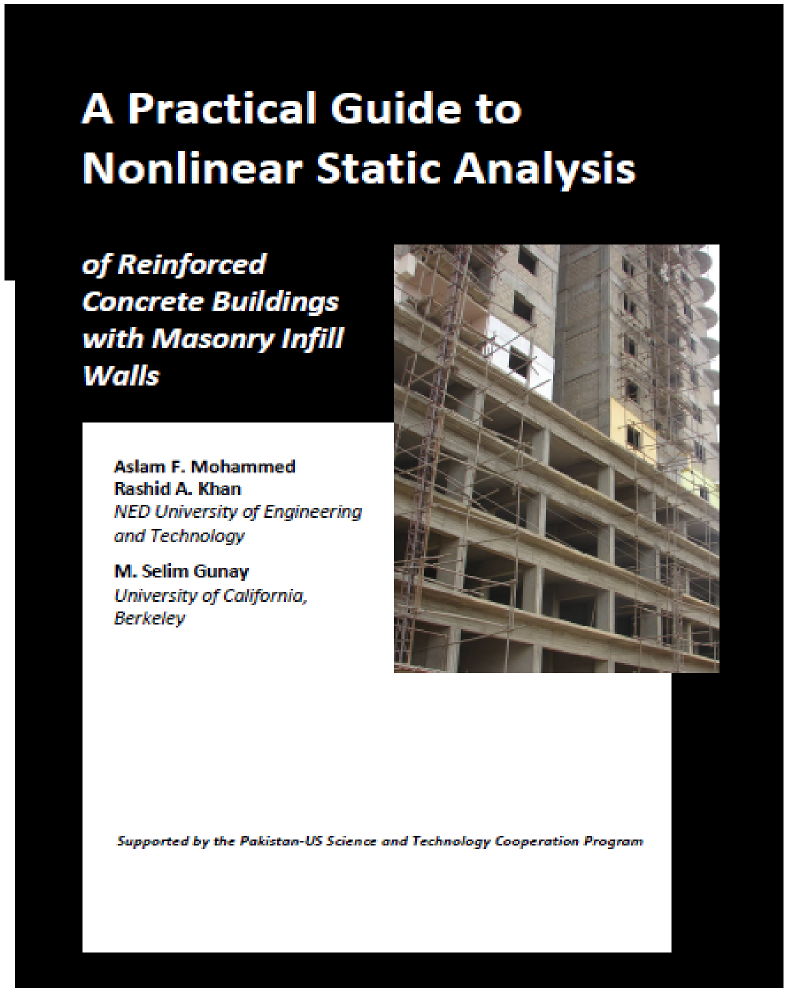



Figure 16. Front cover for practical guide to nonlinear static analysis.

**5) The Framed Infill Network**

The Framed Infill Network is another outcome of the collaboration between project participants on both Pakistan and US sides. The Network, which was formed during a research planning meeting held in July 2010 in Kathmandu, Nepal, is funded by the US National Science Foundation. It is an internet-enabled international collaboration initiative to make reinforced concrete buildings with masonry infill walls (a very common and very vulnerable building type in Pakistan) safer during earthquakes. The Earthquake Engineering Research Institute awarded GeoHazards International a grant to conduct a set of initial activities, which include an online technical literature survey, e-document and development of a draft engineering guidance. These activities are progressing well, and the network's new website at www.framedinfill.org provides an additional dissemination mechanism for the project's case study reports and pushover analysis guide, which are likely to be useful for engineers in the many other countries where concrete buildings with masonry infill walls exist (Figure 17).


Figure 17. A view of Framed Infill Network website.

**6) Development of Research Infrastructure**

A seismic simulator laboratory was established which consists of a 3M × 3M seismic simulation table (Figure 18). This facility can be used to test structures and structural elements under different ground acceleration scenarios. In addition, Advanced Material Testing Laboratory was built. This laboratory is equipped with state-of-the-art testing equipment and is one of its kinds in the region (Figure 19). It has a 1 m thick reaction floor and 1.3 m thick reaction wall which can be used for testing of structures subjected to vertical and lateral loads. The equipments include a portal frame designed to work with the 5000 kN pseudo dynamic test system, actuators of different capacities, hydraulic power supply, hydraulic service manifold, digitally supervised analog servo controls, pseudo dynamic application software and a 300 channel data acquisition system.

Figure 18. A view of seismic simulation table.

Figure 19. A view of reaction frame in Advanced Material Testing Lab.

**7) Establishment of Department of Earthquake Engineering**

The activities in the area of earthquake engineering and the establishment of aforementioned laboratory facilities engineering provided a strong basis for the establishment of Department of Earthquake Engineering. This Department was established at NED University of Engineering and Technology in 2011. The purpose of the Department is to develop highly skilled professionals and researchers who are trained in various aspects of earthquake mitigation so that they are able to serve the society through better planning and preparation. The Department has started its MEngg program and the courses offered in this program are listed in Appendix F.

**8) Miscellaneous**

The project helped in developing international linkages with various agencies in earthquake engineering such as Earthquake Engineering Research Institute (EERI), UN Habitat, etc.

Figure 20. School at Abbottabad before retrofitting.

Figure 21. School at Abbottabad after retrofitting.

The activities in the project enabled the Department of Civil Engineering at NED University to develop expertise in earthquake engineering and seismic retrofitting. As a result, the Department was able to seismically retrofit a stone masonry school building in Abbottabad and Muree (Figures 20 - 22). A patent for the retrofit scheme was submitted to the related agency. Further, the Department strengthened its relations with the agencies, such as National Disaster Management Authority (NDMA) and UN Habitat, which are involved in creating seismically safe built environment.

Prof. Rafeeqi and Prof. Lodi participated in the committee formed to prepare seismic design code of Pakistan.

The Department of Civil Engineering is participating in the projects entitled Earthquake Model for Middle East (EMME) and Global Earthquake Model (GEM).

Figure 22. School at Muree during retrofitting work.

To diversify the efforts in related areas, several workshops were arranged related to hazard of tsunami in coastal areas of Pakistan.

Four undergraduate student groups consisting of twenty two students completed their senior projects related to the project theme.

One masters' student completed a research project to develop a tool for the vulnerability assessment of buildings subjected to earthquakes.

One post-doctoral researcher from the University of California, Berkeley and one junior engineer from Tipping & Mar participated in the project. The post-doctoral researcher provided important guidance on structural analysis and participated in most of the project e-meetings and discussions. The engineer also provided structural analysis guidance.

In order to ensure sustainability and continuity of the work two project proposals were submitted to different agencies for funding.

A design competition for seismically retrofit a building was announced. It was titled as Competition of retrofitting Seismically Essential Structures (CORSET). Teams comprising of professional engineers participated in the competition and submitted their proposals (Figure 23) (Appendix G). The certificate and prize distribution ceremony for the competition was held on 12 May 2012 (Figure 24).

Figure 24. CORSET teams at the initial workshop discussing competition rules and principles

Figure 24. A view of certificate and prize distribution ceremony of CORSET

**9) Project Outcome**
Salient features of the project outcome are as under

Effective capacity building was carried out of more than 300 professionals from different stake holders such as universities, engineering consulting firms, architecture firms, civic agencies and construction contracting firms. These professionals were trained in seismic vulnerability assessment and/or developing retrofit solutions.

Hands on experience and intensive mentoring for a group of early and mid-career Pakistani faculty members in applying advanced earthquake engineering techniques to existing buildings.
Greatly enhanced understanding of building seismic behavior and the effects of masonry infill walls within the Pakistani engineering community, which will lead to better-designed new buildings as engineers consider the contribution of infill walls during structural design.
Results and products to enrich future capacity building efforts, including 10 case study buildings with documented assessments, computer analyses and retrofit designs (if retrofit was needed); a Pakistan-specific checklist for building vulnerability assessment; a practical guide to nonlinear static analysis for engineers; practical courses on building vulnerability assessment and retrofit; and modules for use in academic courses.
New and innovative applications of retrofit methods to common urban buildings in Pakistan, and the formation of an international research-practice collaborative network called the Framed Infill Network to make concrete buildings with masonry infills safer through innovative designs that make beneficial use of infill walls.
Significantly strengthened relationships between academia and professional engineers in Karachi, and between researchers in Pakistan and the US.

**10) Publications**

A list of papers which were published based on the work carried out in the project is given in the following. More details are included in Appendix H.

i) Gunay, M.S., Korolyk, M., Mar, D., Mosalam, K.M., Rodgers, J.E. (2009). Infill walls as a spine to enhance the seismic performance of non-ductile reinforced concrete frames, *Proceedings, ATC-SEI Conference on Improving the Seismic Safety of Existing Buildings and Other Structures*, San Francisco, California, December 9-11, 2009.

ii) Haroon M., Rafeeqi S.F.A and Lodi S.H. (2009). Adaptive conceptual framework for seismic vulnerability assessment of reinforced concrete buildings in Pakistan, *Proceedings,2nd International conference on Computational Methods in Structural Dynamics and Earthquake Engineering, COMPDYN 2009,* Rhodes Island, Greece, June 22-24, 2009.

iii) Mosalam, K.M. and S. Günay (2009). Seismic Retrofit of Non-Ductile Reinforced Concrete Frames Using Infill Walls as a Rocking Spine. *Proceedings, Advances of Performance-Based Earthquake Engineering (ACES Workshop)*, M.N. Fardis, Editor, 4-7 July 2009, Corfu, Greece.

iv) Gunay, M.S., Korolyk, M., Mar, D., Mosalam, K.M., Rodgers, J.E. (2009). Infill walls as a spine to enhance the seismic performance of non-ductile reinforced concrete frames, *Proceedings, ATC-SEI Conference on Improving the Seismic Safety of Existing Buildings and Other Structures*, San Francisco, California, December 9-11, 2009.

v) Haroon M., Rafeeqi S.F.A and Lodi S.H. (2009). Adaptive conceptual framework for seismic vulnerability assessment of reinforced concrete buildings in Pakistan, *Proceedings,2nd International conference on Computational Methods in Structural Dynamics and Earthquake Engineering, COMPDYN 2009,* Rhodes Island, Greece, June 22-24, 2009

vi) Mosalam, K.M. and S. Günay (2009). Seismic Retrofit of Non-Ductile Reinforced Concrete Frames Using Infill Walls as a Rocking Spine. *Proceedings, Advances of* Performance-Based Earthquake Engineering (ACES Workshop), M.N. Fardis, Editor, 4-7 July 2009, Corfu, Greece.

vii) Rodgers, J.E., Cedillos, V., Tobin, L.T., Tucker, B.E., and Kumar, H. (2010). Diffusing seismic safety. *Proceedings, Ninth U.S National Conference and Tenth Canadian Conference on Earthquake Engineering*, Toronto, Canada, July 25-29, 2010.

viii) Mohammad, A.F., Ayub, T., and Zafar, N.S. (2010). Performance based evaluation of non ductile reinforced concrete frames with and without infill. *Proceedings, The 3rd Asia Conference on Earthquake Engineering*, Bangkok, Thailand, December 01-03, 2010.

ix) Rafi, M.M., Lodi, S.H., Rafeeqi, S.F.A (2010). Contribution of NED University in earthquake disaster management and related capacity building. *Proceedings of Third International Symposium on Infrastructure Engineering in Developing Countries (IEDC-2010) and 1st International Conference on Sustainable Transportation and Traffic Management*, Pakistan, July 01-03, 2010.

x) Rafi, M.M., Lodi, S.H., Rafeeqi, S.F.A (2010). An Indigenous Model of Seismic Retrofit of Stone Masonry Structures, *Proceedings, International Conference – Urban Habitat Construction Under Catastrophic Events – COST ACTION – C26*, University of Naples, Italy, 16 – 18 September 2010.

xi) Haroon. M. (2011). Diagnostic tool for assessing seismic vulnerability of buildings, M.Engg Thesis, Department of Civil Engineering at NED University of Engineering and Technology, Pakistan.

# Appendix A

## List of project partners and participating institutions

**Major partners in Pakistan**
NED University of Engineering and Technology, Karachi
National Centre of Excellence in Geology, University of Peshawar
Balochistan University of Engineering and Technology, Khuzdar
National Engineering Services Pakistan (Pvt) Ltd (NESPAK)
Mushtaq & Bilal Consultants, Karachi
Engineering Associates, Karachi
Times Construction, Karachi
Pakistan Engineering Council
Provincial Disaster Management Authority, Sindh
National Disaster Management Authority

**Other Partners in Pakistan**
Arif & Associates, Karachi (Consultant)
SMK Consultants, Karachi
Alliance Consultants Pvt. Ltd., Karachi
Meinhardt Pakistan, (Consultant), Karachi
Council for Works and Housing, Government Department, Karachi
A.A. Associates, Consultants and Planners, Karachi
SBCA, Sindh Building Control Authority, Karachi
KBCA, Karachi Building Control Authority
Pakistan Red Crescent Society
Earthquake Reconstruction & Rehabilitation Authority
Pakistan Council for Architects & Town Planners
Institute of Architects, Pakistan
Association of Consulting Engineers, Pakistan

**In the United States**
GeoHazards International
John A. Blume Earthquake Engineering Center, Stanford University
Pacific Earthquake Engineering Research Center, University of California, Berkeley
Tipping Mar + Associates
Computers and Structures, Inc.

**Appendix B**

**Basic Structural Checklist for Reinforced Concrete Moment Frames with Masonry infill Shear Walls with Flexible and/or Stiff Diaphragms**

**Screening Phase (Tier 1)**

**(ASCE 31-03 Checklist Modified for Pakistan)**

This Basic Structural Checklist shall be completed where Vulnerability Assessment of Reinforced Concrete Moment Frames with Masonry infill Shear Walls is required.

Each of the evaluation statements on this checklist shall be marked Compliant (C), Non-compliant (NC), or Not Applicable (N/A) for a Tier I Evaluation. Compliant statements identify issues that .in acceptable according to the criteria of this standard, while non-compliant statements identify issues that require further investigation. Certain statements may not apply to the buildings being evaluated. For non-compliant evaluation statements, the design professional may choose to conduct further investigation using the corresponding Tier 2 Evaluation procedure.

## Building System

C NC N/A LOAD PATH:

The structure shall contain a minimum of one complete load path for Life Safety and Immediate Occupancy for seismic force effects from any horizontal direction that serve-, in transfer the inertial forces from the mass to the foundation.

C NC N/A ADJACENT BUILDINGS:

The clear distance between the building beings evaluated and any adjacent building shall be greater than 4 percent of the height of the shorter building for life safety and immediate occupancy.

C NC N/A MEZZANINES:

Interior mezzanine levels shall be braced independently from the main structure or shall be anchored to the lateral-force-resisting elements of the main structure.

C NC N/A WEAK STORY:

The strength of the lateral-force-resisting system in any story shall not be less than 80 percent of the strength in an adjacent story, above or below, for Life Safety and Immediate Occupancy.

C NC N/A SOFT STORY:

The stiffness of the lateral-force-resisting system in any story 'shall not be less tli.m70 percent of the lateral-torce-resisting system stiffness in an adjacent story above or below, or Ic.i than 80 percent of the rven.ge lateral-force-resisting system stiffness of the three stories above m below for Life Safety and Immediate Occupancy. (Tier 2: Sec. 4.3.2.2)

C NC N/A GEOMETRY:

There shall be no changes in horizontal dimension of the lateral-force-resisting system of more than 30 percent in a story relative to adjacent stories for Life Safety and Immediate Occupancy, excluding one-story penthouses and mezzanines.

C NC N/A VFRTICAI D1SCONTINUITY:

All vertical elements in the lateral-force-resisting system shall be continuous to the foundation

C NC N/A MASS:

There shall be no change in effective mass more than 50 percent from one story to the next for Life Safety and Immediate Occupancy. Light roots. Penthouses, and mezzanines need not he considered.

C NC N/A TORSION:

The estimated distances between the story center of mass and the story center of rigidity shall be less than 20 percent of the building width in either plan dimension for Life Safety and Immediate Occupancy. *This check need not to be performed in case of flexible diaphragms*

C NC N/A DETERIORATION OF CONCRETE:

There shall be no visible deterioration of concrete or reinforcing steel in any of the vertical-or lateral-forces-resisting elements in the building.

C NC N/A POST TENSIONING ANCHORS:

There shall be no evidence of corrosion or spelling in the vicinity of post-tensioning or end fittings. Coil anchors shall not have been used.

C NC N/A MASONRY UNITS:

There shall be no visible deterioration of masonry units.

C NC N/A MASONRY JOINTS:

The mortar shall not be easily scraped away from the joints by hand with a metal tool, and there shall be no areas of eroded mortar

C NC N/A CRACKS IN INFILL WALLS:

There shall be no existing diagonal cracks in the in filled walls that extend through a panel greater than 1/8 inch for Life Safety and 1/16 inch for immediate Occupancy, or out-of-plane offsets in the bed joint greater than 1/8 inch for Life Safety and 1/16 inch for Immediate Occupancy.

C NC N/A CRACKS IN BOUNDRY COLUMNS:

There shall be no existing diagonal cracks wider than 1/8 inch for Life Safety and 1/16 inch for immediate Occupancy in concrete columns that encase masonry infills.

### Additional Check for Flexible Diaphragms

C NC N/A DETERIORATION OF WOOD:

There shall be no signs of decay, shrinkage, splitting, fire damage, or sagging in any of the wood members, and none of the metal connection hardware shall he deteriorated, broken, or loose.

## Lateral-Force-Resisting System

C NC N/A REDUNDANCY:

The number of lines of moment frames/shear walls in each principal direction shall be greater than equal to 2 for life safety and Immediate Occupancy. And the number of bays of moment frames in each line shall be grater than or equal to 2 for life safety and 3 for Immediate Occupancy.

C NC N/A **WALL CONNECTIONS:**
Masonry shall be in full contact with frame for life safety and immediate occupancy.

**SHEAR STRESS CHECK:**

C NC N/A The shear stress in the concrete column, calculated using the quick check procedure shall be less than the greater of 100 psi or $2\sqrt{f'c}$ for life safety and

Immediate Occupancy.

C NC N/A The Shear Stress in the unreinforced masonry shear wall calculated using the Quick Checks shall be less than 70psi for life safety and Immediate Occupancy.

C NC N/A The Shear Stress in the reinforced masonry shear wall calculated using the Quick Checks shall be less than 30psi for clay and 70psi for concrete units for life safety and Immediate Occupancy.

C NC N/A **AXIAL STRESS CHECK:**
The axial stress due to gravity loads in columns subjected to overturning forces shall be less then 0.10fc for life safety and immediate Occupancy. Alternatively, the axial stresses due to overturning forces alone, calculated using the quick check shall be less then 0.30.fc for life safety and Immediate Occupancy.

C NC N/A **FLAT SLAB FRAMES:**
The lateral-force-resisting system shall not be a frames consisting of columns and a flat slab/plate without beams.

C NC N/A **PRESTRESSED FRAMES:**
The lateral-forces-resisting frames shall not include any pre-stressed or post-tensioned elements where the average pre stressed exceeds the lesser of 700 psi or $6\sqrt{f'_c}$ at potential hinge locations. The average pre-stressed shall be calculated in accordance with the quick check procedure of section 3.5.3.8.

C NC N/A **CAPTIVE COLUMN:**
There shall be no columns at a level with height/depth ratios less than 50 percent of the nominal height/depth ratio of the typical columns at that level for life safety and 75 percent for Immediate Occupancy.

C NC N/A **NO SHEAR FAILURES:**
The shear capacity of frame members shall be able to develop the moment capacity at ends of the members.

C NC N/A **STRONG COLUMN/ WEAK BEAM:**
The sum of moment capacity of the columns shall be 20 percent greater than that of the beams at frame joints.

C NC N/A **BEAM BARS:**
At least two longitudinal top and two longitudinal bottom bars shall extend continuously throughout the length of each frame beam. At least 25 percent of the longitudinal bars provided at the joints for either positive or negative moment shall be continuous throughout the length of the members for Life Safety and Immediate Occupancy.

C NC N/A **COLUMN-BAR SPLICES:**
All column bar lap splice lengths shall be greater than $35d_b$ for Life Safety and $50d_b$ for Immediate Occupancy, and shall be enclosed by ties spaced at or less than $8d_b$ for Life Safety and Immediate Occupancy. Alternative, column bars shall be spliced with mechanical couplers with a capacity of at least 1.25 times the nominal yield strength of the spliced bar.

C NC N/A **BEAM-BAR SPLICES:**
The lap splices or mechanical couplers for longitudinal beam reinforcing shall not be located within $l_b$/4of the joints and shall not be located in the vicinity of potential plastic hinge locations.

C NC N/A **COLUMN-TIE SPACING:**
Frame columns shall have ties spaced at or less than d\4 for Life Safety and Immediate Occupancy throughout their length and at or less than $8d_b$ for Life Safety and Immediate Occupancy at all potential plastic hinge locations.

C NC N/A **STIRRUP SPACING:**
All beams shall have stirrups spaced at or less than d/2 for life Safety and Immediate Occupancy throughout their length. At potential plastic hinge locations, stirrups shall be spaced at or less than the minimum of $8d_b$ or d/4 for life Safety and Immediate Occupancy.

C NC N/A **JOINT REINFORCING:**
Beam-column joints shall have ties spaced at or less than $8d_b$ for Life Safety and Immediate Occupancy.

C NC N/A **JOINT ECCENTRICITY:**
There shall be no eccentricities larger than 20 percent of the smallest column plan dimension between girder and column centerlines. This statement shall apply to the Immediate Occupancy Performance level only.

C NC N/A **STIRRUP AND TIE HOOKS:**
The beam stirrups and column ties shall be anchored into the member cores with Hooks of 135 or more. This Statement shall apply to the Immediate Occupancy Performance level only.

C NC N/A **DEFLECTION COMPATIBILITY:**
Secondary components shall have the shear capacity to develop the flexural strength of the components for life. *This check need not to be performed in case of flexible diaphragms*

C NC N/A **FLAT SLAB:**
Flat Slabs/plates not part of lateral force resisting systems shall have continuous bottom steel through the column joints for life Safety and Immediate Occupancy. *This check need not to be performed in case of flexible diaphragms*

C NC N/A **REINFORCING AT OPENINGS:**
All wall openings that interrupt rebar shall have trim reinforcing on all sides. This statement shall apply to the Immediate Occupancy performance level only.

C NC N/A **PROPORTIONS:**
The height-to-thickness ratio of the infill walls at each story shall be less than 9 for Life

Safety in level of high seismicity, 13 for Immediate Occupancy in levels of moderate seismicity and 8 for immediate occupancy in levels of high seismicity.

C NC N/A SOLID WALLS:
The infill walls shall have not be of cavity construction.

C NC N/A INFILL WALLS:
The infill walls shall be continuous to the soffits of the frame beams and columns to either side.

## Connections

C NC N/A CONCRETE COLUMNS:
All concreted columns shall be doweled into the foundation for life Safety, and the dowels shall be able to develop the tensile capacity of reinforcement in column of lateral-force-resisting system for Immediate Occupancy.

C NC N/A UPLIFT AT PILE CAPS:
Pile caps shall have top reinforcement and piles shall be anchored to the pile caps for life safety, and the pile cap reinforcement and pile anchorage shall be able to develop the tensile capacity of the piles for Immediate Occupancy.

C NC N/A TRANSFER TO SHEAR WALLS:
Diaphragms shall be connected for transfer of loads to the shear walls for Life Safety and the connections shall be able to develop the lesser of the shear strength of the walls or diaphragms for Immediate Occupancy.

### Additional Checks for Flexible Diaphragms

C NC N/A STIFFNESS OF WALL ANCHORS:
Anchors of concrete or masonry walls to wood structural elements shall be installed taut and shall be stiff enough to limit the relative movement between the wall and the diaphragm to no greater than 1/8 inch prior to engagement of the anchors.

## Diaphragms

C NC N/A DIAPHRAGM CONTINUITY:
The diaphragms shall not be composed of split- level floor and shall not have expansion joints.

C NC N/A PLAN IRREGULARITIES:
There shall be tensile capacity to develop the strength of the diaphragm at re-entrant corners or other locations of plan irregularities. This statement shall apply to the Immediate Occupancy Performance Level only.

C NC N/A DIAPHRAGM REINFORCEMENT AT OPENINGS:
There shall be reinforcing around all diaphragm openings larger than 50 percent of the building width in either major plan dimension. This statement shall apply to the Immediate Occupancy Performance Level only.

C NC N/A OPENINGS AT SHEAR WALLS:
Diaphragm openings immediately adjacent to the shear walk shall be less than 25 percent

of the wall length for Life Safety and 15 percent of the wall length lot immediate occupancy.

C NC N/A OPENINGS AT EXTERIOR MASONRY SHEAR WALLS:
Diaphragm openings immediately adjacent to exterior masonry shear walls shall not be greater than 8 feet long for Life Safety and 4 feet long for Immediate Occupancy.

Additional Checks for Flexible Diaphragms

C NC N/A CROSS TIES:
There shall be continuous cross ties between diaphragm chords

C NC N/A STRAIGHT SHEATHING:
All straight sheathed diaphragms shall have aspect ratios less than 2-to-1 for Life Safety and 1-to-l for Immediate Occupancy in the direction being considered.

C NC N/A SPANS:
All wood diaphragms with spans greater than 24 feet for Life Safety and 12 feet for Immediate Occupancy shall consist of wood structural panels or diagonal sheathing.

C NC N/A UNBLOCKED DIAPHRAGMS:
All diagonally sheathed or unblocked wood structural panel diaphragms shall have horizontal spans less than 40 feet for Life Safety and 30 feet for Immediate Occupancy and shall have aspect ratios less than or equal to 4-to-l for Life Safety and 3-to-1 for Immediate Occupancy.

C NC N/A NON-CONCRETE F1LLFD DIAPHRAGMS:
Unstopped metal deck diaphragms or metal deck diaphragm with fill other than concrete shall consist of horizontal spans of less than 40 feet and shall have span/depth ratios less than 4-to-I. This statement shall apply to the Immediate Occupancy Performance Level only.

C NC N/A OTHER DIAPHRAGMS:
The diaphragm shall not consist of a system other than wood. metal deck, concrete, or horizontal bracing.

## Geologic Site Hazard and Foundation Checklist for Reinforced Concrete Moment Frames with Masonry infill Shear Walls with Flexible and/or Stiff Diaphragms

### Geologic Site Hazard

C NC N/A LIQUEFACTION:
Liquefaction-susceptible, saturated, loose granular soils that could jeopardize the building's seismic performance shall not exist in the foundation soils at depths within 50 feet under the building for life Safety and Immediate Occupancy.

C NC N/A SLOPE FAILURE:
The building site shall be sufficiently remote from potential earthquake induced slope failures or rock falls to be unaffected by such failures or shall be capable of accommodating any predicted movements without failure.

C NC N/A SURFACE FAULT RUPTURE:

Surface fault rupture and surface displacement at the building site is not anticipated

## Condition of Foundations

C NC N/A FOUNDATION PERFORMANCE:
There shall be no evidence of excessive foundation movement such as settlement or heave that would affect the integrity or strength of the structure.

C NC N/A DETERIORATION:
There shall be no evidence that foundation elements have deteriorated due to corrosion, sulfate attack, material breakdown, or other reasons in a manner that would affect the integrity or strength of the structure.

## Capacity of Foundations

C NC N/A POLE FOUNDATION:
Pole foundations shall have a minimum embedment depth of 4 feet for Life Safety and Immediate Occupancy.

C NC N/A OVERTURNING:
The ratio of the horizontal dimension of the lateral-force-resisting system at the foundation level to the building height (base/height) shall be greater than $0.6S_a$.

C NC N/A TIES BETWEEN FOUNDATION ELEMENTS:
The foundation shall have ties adequate to resist seismic forces where footings, piles and piers are not restrained by beams, slabs or soils classified as Class A, B, or C

C NC N/A DEEP FOUNDATION:
Piles and piers shall be capable of transferring the lateral forces between the structure and the soil. This statement shall apply to the Immediate Occupancy Performance Level only.

C NC N/A SLOPING SITES:
The difference in foundation embedment depth from one side of the building to another shall not exceed one story in height. This statement shall apply to the Immediate Occupancy Performance Level only.

**Basic Nonstructural Component Checklist for Reinforced Concrete Moment Frames with Masonry infill Shear Walls with Flexible and/or Stiff Diaphragms**

## Partitions

C NC N/A UNREINFORCED MASONRY:
Unreinforced masonry or hollow clay tile partitions shall be braced at spacing equal to or less than 10 feet in levels of low or moderate seismicity and 6 feet in levels of high seismicity.

C NC N/A DRIFT:

Rigid cementititous partitions shall be detailed to accommodate a drift ratio of 0.02 in steel moment frame, concrete moment frame, and wood frame buildings. Rigid cementititous partitions shall be detailed to accommodate a drift ratio of 0.005 in other buildings

C NC N/A STRUCTURAL SEPARATIONS:
Partitions at structural separations shall have seismic or control joints.

C NC N/A TOPS:
The tops of framed or panelized partition that only extend to the ceiling line shall have lateral bracing to the building structure at a spacing equal to or less than 6 feet. .

## Ceiling Systems

C NC N/A SUPPORT:
The integrated suspended ceiling system shall not be used to laterally support the tops of gypsum board, masonry, hollow clay tile partitions. Gypsums boards need not to be evaluated for the Life safety performance criteria in low and moderate zones.

C NC N/A LAY-IN TILES:
Lay-in tiles used in ceiling panels located at exits and Corridors shall be secured with clips.

C NC N/A INTEGRATED CEILINGS:
Integrated suspended ceilings at exits and corridors or weighing more than 2 pounds per square foot shall be laterally restrained with a minimum of four diagonal wires or rigid members attached to the structure above at spacing equal to or less than 12 feet.

C NC N/A SUSPENDED LATH AND PLASTER:
Ceilings consisting of suspended lath and plaster or gypsum board shall be attached to resist seismic forces for every 12 square feet of area.

C NC N/A EDGES:
The edges of integrated suspended ceilings shall be separated from enclosing walls by a minimum of 1/2 inch.

C NC N/A SEISMIC JOINT:
The ceiling system shall not extend continuously across any seismic joint.

## Light Fixtures

C NC N/A EMERGENCY LIGHTING:
Emergency lighting shall be anchored or braced to prevent falling during an earthquake.

C NC N/A INDEPENDENT SUPPORT:
Light fixtures in suspended grid ceilings shall he supported independently of the ceiling suspension system by a minimum of two wires at diagonally opposite corners of the fixtures.

C NC N/A PENDENT SUPPORT:

Light fixtures on pendant supports shall be attached at spacing equal to or less than 6 feet and if rigidly supported, shall be free to move with the structure to which they are attached without damaging adjoining materials.

C NC N/A LENS COVERS:

Lens covers or light fixtures shall be attached or supplied with safety devices.

## Cladding and Glazing

C NC N/A CLADDING ANCHORS:

Cladding components weighing more than 10 psf shall be mechanically anchored to the exterior wall framing at spacing equal to or less than 4 feet. A spacing of up to 6ft is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A DETERIORATION:

There shall be no evidence of deterioration, damage or corrosion in any of the connection elements.

C NC N/A CLADDING ISOLATION:

For moment frame building of the steel or concrete, panel connections shall be detailed to accommodate a story drift ratio of 0.02. Panel connection detailing for a story drift of .01 is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A MULTI-STORY PANELS:

For multistory panels attached at each floor level, panel connections shall be detailed to accommodate a story drift ratio of .02. Panel connection detailing for a story drift of .01 is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A BEARING CONNECTIONS:

Where bearing connections are required, there shall be a minimum of two bearing connections for each wall panel.

C NC N/A INSERTS:

Where inserts are used in concrete connections, the inserts shall be anchored to reinforcing steel or other positive anchorage.

C NC N/A PANEL CONNECTIONS:

Exterior cladding panels shall be anchorage out-of-plane with a minimum of 4 connections for each wall panel. Two connections per wall panel are permitted for for the Life safety performance criteria in low and moderate zones.

C NC N/A GLAZING:

Glazing in curtain walls and individual panels over 16 square feet in area, located up to a height of 10 feet above an exterior walking surface, shall have safety glazing. All exterior glazing shall be laminated annealed or laminated heat-strengthened safety glass or other glazing system that will remain in the frame when glass is cracked.

## Masonry Veneer

C NC N/A SHELF ANGLES:

Masonry veneer shall be supported by shelf angles or other elements at each floor 30 feet or more above ground for Life Safety and at each floor above the first floor for Immediate Occupancy.

C NC N/A TIES:

Masonry Veneer shall be connected to the back-up with corrosion-resistance ties. The Ties shall have spacing equal to or less than 24 inches with a minimum of one tie for every 2-2/3 square feet. A Spacing of up to 36 inches is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A WEAKENED PLANES:

Masonry Veneer shall be anchored to the back-up adjacent to weakened planes, such as at the locations of flashing

C NC N/A DETERIORATION:

There shall be no evidence of deterioration, damage or corrosion in any of the connection elements.

C NC N/A MORTAR:

The mortar in masonry veneer shall not be easily scraped away from the joints by hand with a metal tool, and there shall not be significant areas f eroded mortar.

C NC N/A WEEP HOLES:

In veneer graced by stud walls, functioning weep holes and base flashing shall be Present.

C NC N/A STONE CRACKS:

There shall be no visible cracks or signs of visible distortion in the stone.

## **<u>Parapets, Cornices, Ornaments and Appendages</u>**

C NC N/A URM PARAPETS:

There shall be no laterally unsupported unreinforced masonry parapets or cornices with height-to-thickness ratios greater than 1.5. A height-to-thickness ratio of up to 2.5 is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A CANOPIES:

Canopies located at building exits shall be anchored to the structural framing at a spacing of 6ft or less. An anchorage spacing of up to 10 feet is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A CONCRETE PARAPETS:

Concrete parapets with height-to-thickness ratios greater than 2.5 shall have vertical reinforcement.

C NC N/A APPENDAGES:

Cornices, parapets, signs, and other appendages that extend above the highest point of anchorage to the structure or cantilever from exterior wall faces and other exterior wall ornamentation shall be reinforced and anchored to the structural system at a spacing equal to or less than 10 feet for Life Safety and 6 feet for Immediate Occupancy.

## Masonry Chimneys

C NC N/A URM CHIMNEYS:
No unreinforced masonry chimneys shall extend above the roof surface more than twice the least dimension of the chimney. A height above the roof surface of up to three times the least dimension of the chimney is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A ANCHORAGE:
Masonry Chimneys shall be anchorage at each floor level and the roof.

## Stairs

C NC N/A URM WALLS:
Wall around stair enclosures shall not consist of unbraced hollow clay tile or unreinforced masonry with a height-to-thickness ratio of up to 15-to-1 is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A STAIRS DETAILS:
In moment frame structures, the connection between stairs and the structure shall not rely on shallow anchors in concrete. Alternatively, the stair details shall be capable of accommodating the drift calculated using the Quick Check procedures.

## Metal Stud Back-Up System

C NC N/A STUD TRACKS:
Stud tracks shall be fastened to structural framing at a spacing equal to or less than 24 inches on center.

C NC N/A OPENINGS:
Steel studs shall frame window and door openings.

## Concrete Block and Masonry Back-up Systems

C NC N/A ANCHORAGE:
Back-up shall have a positive anchorage to the structural framing at spacing equal to or less than 4 feet along the floors and roof.

C NC N/A URM BACK-UP:
There shall be no unreinforced masonry back-up.

## Building Contents and Furnishing

C NC N/A TALL NARROW CONTENTS:
Contents over 4 feet in height with a height-to-depth or height-to width ratio greater than 3-to-1 shall be anchored to the floor slab or adjacent structural walls. A height-to-depth or height-to-width ratio of up to 4-to-1 is permitted for the Life safety performance criteria in low and moderate zones.

C NC N/A FILE CABINETS:
File cabinets arranged in groups shall be attached to one another..

C NC N/A CABINET DOORS AND DRAWERS:
Cabinet doors and drawers shall have latches to keep them closed during an earthquake.

C NC N/A ACCESS FLOORS:
Access floors over 9 inches in height shall be braced.

C NC N/A EQUIPMENT ON ACCESS FLOORS:
Equipment and computers supported in access floor systems shall be either attached to the structure or fastened to a laterally braced floor system.

## Mechanical and Electrical Equipment

C NC N/A EMERGENCY POWER:
Equipment used as part of an emergency power system shall be mounted to maintain continued operation after an earthquake

.
C NC N/A HAZARDOUS MATERIAL EQUIPMENT:
HVAC or other equipment containing hazardous material shall not have damaged supply lines or unbraced isolation supports.

C NC N/A DETERIORATION:
There shall be no evidence of deterioration, damage, or corrosion in any of the anchorage or supports of mechanical or electrical equipment.

C NC N/A ATTACHED EQUIPMENT:
Equipments weighing over 20 lbs that is attached to ceilings, walls, or other supports 4 feet above the floor level shall be braced.

C NC N/A VIBRATION ISOLATORS:
Equipment mounted on vibration isolators shall be equipped with restraints of snubbers.

C NC N/A HEAVY EQUIPMENT:
Equipment weighing over 100 pounds shall be anchored to the structure or foundation.

C NC N/A ELECTRICAL EQUIPMENT:
Electrical equipment and associated wiring shall be laterally braced to the structural system.

C NC N/A DOORS:
Mechanically operated doors shall be detailed to operate at a story drift ratio of 0.01.

## Piping

C NC N/A FIRE SUPRESSION PIPING:
Fire suppression piping shall be anchored and braced in accordance with NFPA-13(NFPA 1996)

C NC N/A FLEXIBLE COUPLINGS:
Fluids, gas and fire suppression piping shall have flexible coupling

C NC N/A FLUID AND GAS PIPING:

Fluids and gas piping shall be anchored and braced to the structure to prevent breakage in piping.

C NC N/A SHUT-OFF VALVES:
Shut-off dc\ices shall he present at building utility interfaces to shut off the flow of gas and high-temperature energy in the event of earthquake-induced failure. .

C NC N/A C-CLAMPS:
One sided C-clamps that support piping greater than 2.5 inches in diameter shall be restrained.

## Ducts

C NC N/A STAIR AND SMOKE DUCTS:
Stair pressurization and smoke control ducts shall be braced and shall have flexible connections at seismic joints.

C NC N/A DUCT BRACINGS:
Rectangular ductwork exceeding 6 square feet in cross-sectional area, and round ducts exceeding 28 inches in diameter, shall he braced. Maximum spacing of transverse bracing shall not exceed 30 feet. Maximum spacing of longitudinal bracing shall not exceed 60 feet. Intermediate supports shall not be considered part of the lateral-force-resisting system

C NC N/A DUCT SUPPORT:
Ducts shall not be supported by piping or electrical conduit.

## Hazardous Material Storage and Distribution

C NC N/A TOXIC SUBSTANCES:
Toxic and hazardous substances stored in breakable containers shall be restrained from falling by latched doors, shelf lips, wires or other methods.

C NC N/A GAS CYLINDERS:
Compressed gas cylinders shall be restrained.

C NC N/A HAZARDOUS MATERIALS:
Piping containing hazardous materials shall have shut-off valves or other devices to prevent major spill or leaks

## Elevators

C NC N/A SUPPORT SYSTEM:
All elements of the elevator system shall be anchored.

C NC N/A SEISMIC SWITCHES:
All elevators shall he equipped with seismic switches that will terminate operations when the ground motion exceeds 0.1g.

C NC N/A SHAFT WALLS:

All elevator shaft walls shall be anchored and reinforced to prevent toppling into the shaft during strong shaking.

.

C NC N/A RETAINER GUARDS:

Cable retainer guards on sheaves and drums shall be present to inhibit the displacement of cables.

C NC N/A RETAINER PLATE:

A retainer plate shall be present at the top and bottom of both car and counterweight.

C NC N/A COUNTERWEIGHT RAILS:

All counterweight rails and divider beams shall be sized in accordance with ASME A17.1.

C NC N/A BRACKETS:

The brackets that tie the car rails and the counterweight rail to be building structure shall be sized in accordance with ASME A17.1.

C NC N/A SPREADER BRACKET:

Spreader brackets shall not be used to resist seismic forces.

C NC N/A GO-SLOW ELEVATORS:

The building shall have a go-slow elevator system.

## Appendix C
## Workshops Held During the Project

***Karachi Workshop on 12-13 August 2009***

NED University of Engineering and Technology hosted a workshop on "Vulnerability Assessment of Buildings subjected to Earthquake” (VABE) on 12 -13 August 2009 in the Video Conference room, Department of Civil Engineering, NEDUET, Karachi. About 24 professionals including consulting engineers, builders, civic agency officials, academics, owners and architects participated.

Figure C1: Participants during workshop

Figure C2: Participants visiting seismic simulators in the Department of Civil Engineering

The purpose of the workshop was to disseminate to a larger number of participants the hands-on knowledge the core group of participants had gained on assessing the vulnerability of existing essential buildings and developing the process for identification of vulnerable buildings to the participants. The workshop’s target audience was practicing building professionals who understand earthquake performance and retrofit of existing buildings. Attendance at the workshop was good, and the southern part of the country was well-covered, despite the workshop being arranged on short notice due to security reasons.

The morning session of the first day included remarks by Dr. S.F.A. Rafeeqi, Mr. Shaikh Muhammad Ali (HRD, HEC) and Dr. Shamsul Haq after which a tour to the dynamics and material labs of the department was made. After the tea, in the second session, the first technical presentation was given by Dr. S.H. Lodi on Level of Earthquake Risk. The presentation covered earthquake basics, historical earthquakes and the seismicity of the Sindh.  Afterward, a presentation on the National Disaster Risk Management System was given by Mr. Jiwan Das from National Disaster Management Authority. A detailed presentation about the Vulnerabilities and Deficiencies– Assessment and Mitigation was then presented by Dr. S.F.A.Rafeeqi, which was last presentation before lunch.  Dr. Rafeeqi explained the whole procedure of the assessment process. The session after lunch included presentations by the case study teams about the evaluation of the four different case study buildings which were presented by Anis Bilal (Mustaq & Bilal), Nighat Fatima (NESPAK), Tehmina Ayub and Najmus Sahar.

Figure C3: Participants during Sample building visit

Figure C4: Participants along with the trainers at the end of workshop

The second day consisted of an exercise during which participants evaluated a sample building. The day began with a tour of the sample building. Working in groups of four each group completed the evaluation and presented it. Each group had one resource person and one coordinator to instruct and guide them during the whole process.

***Nathiagali Workshop on 12-13 October 2009***

The Pakistan-based project team members held a second workshop on 12-13 October 2009, at Hotel Green Retreat, Nathiagali. This was the sequel to the Karachi workshop described above. The theme and the majority of the content of the second workshop were the same as the first one, but the audience consisted of participants from the northern part of the country. Twenty one participants from related professions such as consulting engineers, builders, officials of civic agencies, academics, owners and architects participated. The idea behind organizing a workshop in Nathiagali was to train and guide participants both from Punjab and NWFP province in a single workshop. The venue was also selected keeping in mind the financial restrictions as well as the travel distances from both the provinces.

The morning session of the first day was an inaugural session comprising speeches by P.I. of the project Dr. S.F.A.Rafeeqi (Professor & Dean CEA, NEDUET) and Dr. Sarosh Hashmat Lodi (Professor & Chairman, Department of Civil Engineering, NEDUET), introducing the project.

After the tea, in the second session, the first technical presentation was a review of seismic hazard in Pakistan given by Dr. M. Asif Khan[T.I.] (Professor & Director, National Centre of Excellence in Geology, University of Peshawar). The presentation provided the overview of causes and effects of earthquakes, historical earthquakes and the seismicity of northern Pakistan. Thereafter, Dr. S.H.Lodi gave a presentation on National Disaster Risk Management System, in which the National, Provincial and District level disaster risk management systems were discussed in detail. A detailed presentation about the Vulnerabilities and Deficiencies–Assessment and Mitigation was then presented by Dr. S.F.A.Rafeeqi, which was the last presentation before lunch. Dr. Rafeeqi explained the complete assessment procedure and process. The session after lunch covered the evaluation of the four different case study buildings, which were presented by Tehmina Ayub (NEDUET) and Najmus Sahar (NEDUET).


Figure C5: Participants during Q/A session  Figure C6: Participants during a presentation

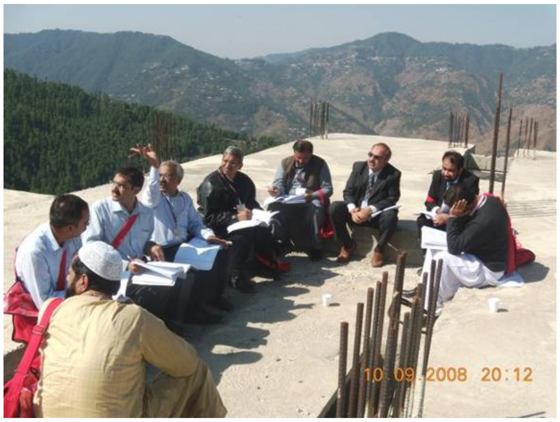




Figure C7: Participants on roof of sample building

Figure C8: Participants during the evaluation of building

Figure C9: Participants group photo along with trainers - Nathiagali workshop

The participants, along with faculty, undertook a visit to the building selected for evaluation, which was located in Bhurban. The participants took notes regarding the building features and various aspects related to its vulnerability and then continued on to the Pakistan Academy of Sciences building in Islamabad to complete the exercise. The participants were divided in groups of 6 and assigned to complete the evaluation process and present the result for discussion. Each group was provided one resource person to help and guide the team during the whole process.

***NIDM Training Course on Earthquake Mitigation, Islamabad, 8-12 March 2010***

Pakistan's National Disaster Management Authority (NDMA) organized a 5-day training course on "Integration of Earthquake Disaster Risk Management into Development Sector and Policies" at the National Institute of Disaster Management (NIDM), Islamabad from 8th -12th March, 2010. Prof. S.F.A. Rafeeqi and Prof. Sarosh Lodi of NED were among the instructors NDMA invited to train the participants from all across the country. The objective of the course was to build the capacity of the officers of the District Government and Civil Society Organizations for effective integration of earthquake disaster risk management into the development programs and policies.

Key experts from academia, government and INGOs, having sound academic background in their field, talked about (1) Earthquake Disaster Risk Situation in Pakistan, (2) Earthquake Risk Assessment, and (3) Earthquake Mitigation Measures.

The Earthquake Mitigation course aimed to promote the sharing of information on preparedness and mitigation measures in Pakistan. Organizers intended that course participants would incorporate their newly learned techniques into their development programmes, as well as effectively mitigate seismic risk to help prevent future earthquake disasters in Pakistan. On the first day of the training, the trainers discussed the nature and causes of earthquake hazard and associated secondary hazards (such as landslides and tsunamis) in Pakistan. The second day consisted of discussions on the impact of earthquakes on different types of buildings in Pakistan, and hazard assessment techniques for such buildings. The workshop also included earthquake vulnerability assessment of the built environment, techniques for earthquake hazard zonation, and risk mapping.

The third day focused on planning techniques to reduce earthquake risk. Participants discussed planning for earthquake vulnerability reduction, city-level action planning for seismic safety, and planning for seismic safety at the community and household level. There were also presentations regarding earthquake mitigation measures, seismic design of buildings, land-use planning, and community-based earthquake mitigation measures. On the fourth day of the training, participants and trainers made a field visit to Muzaffarabad, so that the participants could learn about some hazard risk assessment and the mitigation techniques firsthand. On last day of the course, the closing note emphasized that public awareness, as well as the training and capacity building of masons, engineers, and planners was necessary to improve earthquake safety.


Figure C10: Prof. Rafeeqi and Prof. Lodi during the training


Figure C11: NED University trainers and course participants

***Training on Structural and Non-Structural Vulnerability Assessment of Critical Buildings and Infrastructure, Islamabad/Murree, 27-30 July 2010***

NED University of Engineering and Technology provided the technical support for a four-day training program on “Structural and Non-Structural Vulnerability Assessment of Critical Buildings and Infrastructure”, which was arranged by National Disaster Management Authority (NDMA), in collaboration with United Nations Development Programme (UNDP). Dr. S.F.A. Rafeeqi. Dr. Sarosh H. Lodi, Dr. Masood Rafi, Ms. Tehmina Ayub, Mr. Aslam Mohammed, and Ms. N. Sahar Zafar attended and delivered the lectures during this training. The workshop was held July 27th -30th, 2010, in Islamabad, with a field visit to Murree. About 45 professionals including consulting engineers, builders, officials from civic agencies, academics, owners and architects participated. The training materials that the NED team used were developed during the project.

The first two days of the course included opening speeches, discussions on the level of earthquake risk in Pakistan, and presentations on earthquake basics, historical earthquakes and the seismicity of the Pakistan, and vulnerability and deficiency assessment and mitigation for both the structural and non-structural elements (furnishings, utility systems, architectural finishes, etc.) of the buildings. The third day consisted of a tour to three sample buildings located in Murree. During the visits, the participants practiced collecting information to evaluate each sample building using the techniques they had learned. They noted all the essential features of the building and also completed the checklists provided by the trainers for the initial evaluation of the building.

The fourth day began with the trainers discussing how to complete the evaluation procedure, now that the trainees had visited the buildings and collected information. The trainers outlined the evaluation procedure as specified in American Society of Civil Engineers Standard 31 (ASCE 31), *Seismic Evaluation of Existing Buildings*. The participants were then divided in several groups and instructed to complete the evaluation. Each group had one resource person and one coordinator to instruct and guide them during the whole process. The participants were also asked to present their evaluation. In the training course evaluations, participants identified the training as different from others, and thought it was worthwhile.

Figure C12: Prof. Rafeeqi and Prof. Lodi along with the chief guest during the closing session

Figure C13: Participants during the sessions

Figure C14: Participants evaluate sample buildings with the help of trainers from NED University

***Training on Strengthening & Seismic Retrofitting of Building Structures, Karachi, 28 May 2011***

NED University hosted and organized the one day workshop *"Strengthening and Seismic Retrofitting of Building Structures"* at its main campus for structural engineers working in various organizations in Karachi. Prof. S.F.A. Rafeeqi and Prof. Sarosh Lodi of NED were among the instructors. The workshop built the capacity engineers in rehabilitation and seismic retrofitting of buildings.

The workshop provided the 40 participants with the opportunity to better understand the process of seismic retrofitting through conventional as well as emerging methods to achieve various seismic performance objectives such as increasing the load, deformation, and/or energy dissipation capacity of the building. The workshop utilized the project's case studies as examples.


Figure C15: Group photo of the participants and speakers.

Figure C16: Participants working in groups during the training.

***Training on Vulnerability Assessment of Buildings Subjected to Earthquake, Muzaffarabad, 6-8 July 2011***

NED University of Engineering and Technology arranged and provided the technical support for a three-day training workshop on *"Vulnerability Assessment of Buildings Subjected to Earthquake"* from 6-8 July 2011 in Muzaffarabad**.**

Dr. S.F.A. Rafeeqi. Dr. Sarosh H. Lodi, Dr. Masood Rafi, Dr. Rashid A. Khan, Mr. Aslam Mohammed, and Ms. N. Sahar Zafar attended and delivered the lectures during the workshop. Around 60 professionals including consulting engineers, builders, and officials from civic agencies participated in the workshop.

The topics included were on the level of earthquake risk in Pakistan, earthquake basics, historical earthquakes and the seismicity of Pakistan, and vulnerability assessment and mitigation for both the structural and non-structural elements of the buildings. The participants also took part in a seismic vulnerability assessment exercise of the building in which the workshop took place.

Figure C17: Group photo of the participants speakers with the chief guest.

Figure C18: A group of participants works and together during the training.

Figure C19: Front view of the workshop building, which is also a case study building.

**Appendix D**
**Earthquake Engineering Curriculum**

**The proposed changes in the curriculum have been marked in red**

**Undergraduate Courses of Study and Marks Distribution**

**First Year (F.E.) Civil Engineering**

**Spring Semester**

| S. No. | Course Code | Course Title | Credit Hours | | |
|---|---|---|---|---|---|
| | | | Theory | Practical | Total |
| 1 | CE-101 | Engineering Drawing-I | 2 | 1 | 3 |
| 2 | CE-102 | Statics and Dynamics | 2 | 1 | 3 |
| 3 | EE-102 | Electrical Engineering | 2 | 1 | 3 |
| 4 | CY-105 | Applied Chemistry | 2 | 1 | 3 |
| 5 | MT-111 | Calculus | 2 | 1 | 3 |
| 6 | HS-105 | Pakistan Studies OR | 3 | 0 | 3 |
| 7 | HS-127 | Pakistan Studies (for Foreigners) | 3 | 0 | 3 |

**Fall Semester**

| S. No. | Course Code | Course Title | Credit Hours | | |
|---|---|---|---|---|---|
| | | | Theory | Practical | Total |
| 1 | CE-103 | Engineering Surveying-I | 2 | 2 | 4 |
| 2 | CE-104 | Engineering Materials | 2 | 1 | 3 |
| 3 | ME-105 | Applied Thermodynamics | 2 | 1 | 3 |
| 4 | PH-121 | Applied Physics | 2 | 1 | 3 |
| 5 | HS-101 | English | 3 | 0 | 3 |

**No change in curriculum in First Year**

*Second Year (S.E.) Civil Engineering*

**Spring Semester**

| S. No. | Course Code | Course Title | Credit Hours | | |
|---|---|---|---|---|---|
| | | | **Theory** | **Practical** | **Total** |
| 1 | CE-201 | Engineering Surveying-II | 2 | 1 | 3 |
| 2 | CE-202 | Introduction to Computing | 2 | 2 | 4 |
| 3 | CE-203 | Engineering Drawing-II | 2 | 2 | 4 |
| 4 | CE-205 | Mechanics of Solids-I | 2 | 1 | 3 |
| 5 | HS-205 | Islamic Studies OR | 3 | 0 | 3 |
| 6 | HS-206 | Ethical Behavior | | | |

**Fall Semester**

| S. No. | Course Code | Course Title | Credit Hours | | |
|---|---|---|---|---|---|
| | | | **Theory** | **Practical** | **Total** |
| 1 | CE-204 | Fluid Mechanics-I | 2 | 1 | 3 |
| 2 | CE-206 | Geology for Engineers | 2 | 1 | 3 |
| 3 | CE-209 | Structural Analysis-I | 2 | 1 | 3 |
| 4 | MT-330 | Applied Probability & Statistics | 2 | 1 | 3 |
| 5 | MT-221 | Linear Algebra & Ordinary Differential Equations | 3 | 0 | 3 |
| 6 | AR-309 | Architecture and Town Planning | 3 | 0 | 3 |

**CE- 201** **ENGINEERING SURVEYING – II**

***No change***

**CE-202** **INTRODUCTION TO COMPUTING**

***No change***

**CE-203** **ENGINEERING DRAWING – II**

***No change***

**CE- 204** **FLUID MECHANICS – I**

***No change***

**CE-205** **MECHANICS OF SOLIDS – I**

***No change***

**CE-206** **GEOLOGY FOR ENGINEERS**

**General Geology Definition and Scope:** The earth as planet, Process of external origin, weathering, erosion, transportation and deposition, of rock material by geological agents, Processes of internal origin volcanism, earthquakes, intrusion, metamorphism and the rock cycle, diastrophism and isostasy.

**Elements of Structural Geology:** Folds and faults, joints, fractures and cleavages, unconformities, primary and secondary structural features of rock, Expression of these features on geological field maps and construction of cross sections and geological mapping.

**Elements of Crystallography:** Crystallographic system, Important rock and soil forming minerals, and their identification Igneous Sedimentary and metamorphic rocks, fossils, Basic principles of stratigraphy, Geologic time scale, Brief introduction of local geology from bore logs.

**Applied Geology:** Application of geology to planning and design of dams, reservoirs, bridges and tunnels, Application of geology to building materials and soils.

**Rock Classification:** Litho logical classification, Classification by field measurements and strength tests by rock testing, Physical and mechanical property of rocks.

**Earthquakes:** Theory of plate- tectonics, seismic waves, Basic understanding of the seismology of Pakistan that builds on fundamental knowledge of geology and earth sciences; Causes and mechanisms of earthquakes; Nature and propagation of seismic waves in the earth; Mapping of tectonic plate boundaries and major fault regions in Pakistan; Appreciation for damage to Pakistan and its neighbors in past earthquakes and likelihood of future earthquakes in the region, Ground subsidence and landslides.

**CE - 209 STRUCTURAL ANALYSIS - I**

***No change***

**MT-330 APPLIED PROBABILITY & STATISTICS**

***No change***

**MT-221 LINEAR ALGEBRA AND ORDINARY DIFFERENTIAL EQUATIONS**

***No change***

**HS-205 ISLAMIC STUDIES**

***No change***

**HS-206 ETHICAL BEHAVIOUR**

***No change***

**AR-309 ARCHITECTURE & TOWN PLANNING**

***No change***

**Third Year (T.E.) Civil Engineering**

## Spring Semester

| S. No. | Course Code | Course Title | Credit Hours | | |
|---|---|---|---|---|---|
| | | | Theory | Practical | Total |
| 1 | CE-303 | Engineering Construction | 2 | 1 | 3 |
| 2 | CE-304 | Reinforced Concrete Design-I | 2 | 1 | 3 |
| 3 | CE-310 | Fluid Mechanics-II | 2 | 1 | 3 |
| 4 | CE-314 | Structural Analysis-II | 3 | 0 | 3 |
| 5 | EN-301 | Environmental Engineering-I | 2 | 1 | 3 |
| 6 | HS-304 | Business Communication & Ethics | 3 | 0 | 3 |

## Fall Semester

| S. No. | Course Code | Course Title | Credit Hours | | |
|---|---|---|---|---|---|
| | | | Theory | Practical | Total |
| 1 | CE-301 | Mechanics of Solids-II | 2 | 1 | 3 |
| 2 | CE-302 | Transportation Engineering-I | 2 | 1 | 3 |
| 3 | CE-305 | Soil Mechanics-I | 2 | 1 | 3 |
| 4 | CE-307 | Civil Works Quantity and Cost Estimations | 2 | 1 | 3 |
| 5 | MT-443 | Numerical Analysis | 3 | 0 | 3 |

**No change in curriculum in Third Year**

**Final Year (B.E.) Civil Engineering**

## Spring Semester

| S. No. | Course Code | Course Title | Credit Hours | | |
|---|---|---|---|---|---|
| | | | **Theory** | **Practical** | **Total** |
| 1 | CE-402 | Structural Design & Drawing | 2 | 1 | 3 |
| 2 | CE-403 | Soil Mechanics-II | 2 | 1 | 3 |
| 3 | CE-405 | Reinforced Concrete Design-II | 2 | 1 | 3 |
| 4 | CE-407 | Transportation Engineering-II | 2 | 1 | 3 |
| 5 | CF-303 | Applied Economics for Engineers | 3 | 0 | 3 |
| 6 | CE-409 | * Civil Engineering Project | - | - | - |

## Fall Semester

| S. No. | Course Code | Course Title | Credit Hours | | |
|---|---|---|---|---|---|
| | | | **Theory** | **Practical** | **Total** |
| 1 | CE-401 | Design of Steel Structures | 2 | 1 | 3 |
| 2 | CE-406 | Planning and Management for Construction | 2 | 1 | 3 |
| 3 | CE-408 | Irrigation and Water Resources Engineering | 2 | 1 | 3 |
| 4 | EN-401 | Environmental Engineering-II | 2 | 1 | 3 |
| 5 | CE-409 | Civil Engineering Project | 0 | 6 | 6 |

* Duration one academic year: Requires literature survey and preliminary work during this Semester.

## CE-401 DESIGN OF STEEL STRUCTURES

***No change***

## CE-402 STRUCTURAL DESIGN & DRAWING

**Design of Buildings for Wind & earthquake:** Analysis and design of reinforced concrete and steel, industrial and commercial type of buildings including affects of wind and earthquake.

**Tanks & Reservoirs:** Analysis and design of underground, overhead tanks and reservoirs. Analysis and design of cantilever and counter fort retaining walls

**Shell, Plates and Bridges:** Introduction to analysis and design of thin shell, and folded plate structures, steel and RCC bridges.

**Structural Engineering Design Concepts for Earthquakes:** Basic understanding of how earthquake effects are considered in structural design of buildings, bridges and other structures. Capability to apply equivalent lateral load procedures with the aim toward (a) understanding the relationship of equivalent earthquake forces to regional seismicity, soil conditions, building vibration period and structural ductility, (b) importance of lateral load paths in structural systems, and (c) appreciation of the philosophy behind codes and provisions with examples from major seismic codes.

## CE-403 SOIL MECHANICS-11

**Sub Soil Investigation**: Purpose, Preliminary and detailed investigation, Boring methods, spacing and depth of borings, soil sampling, In situ testings, Standard penetration test, static cone penetration test, Presentation of boring information, Preparation of bore logs

**Settlement Analysis:** Settlement by elastic theory, Settlement analysis of a thin stratum of clay from index properties, Thick clay stratum settlement, analysis by strain versus Logarithm of pressure test data, Construction period correction, Secondary consolidation.

**Bearing Capacity:** Stability of soil masses, Rankine's, Terzahgi's and Meyerhof's analysis, Ultimate and safe bearing capacities for shallow foundations, Plate bearing test, Deep foundations bearing capacity, Static and dynamic load carrying capacity analysis of pile, Pile load test, Group action in piles, Raft foundation.

**Lateral Earth Pressure:** Types of lateral soil pressure, Rankine's and Coulomb's theories of lateral earth pressures, Soil pressure analysis of earth retaining structures (including retaining wall, sheet piles and excavation supports).

**Stability of Slopes:** Varieties of failure, Stability analysis of infinite and finite slopes, General method of slices (Swedish Methods), Bishop simplified methods of slices, Friction circle method. Taylor's stability number and stability curves, Effect of pore water and seepage forces on stability

**Introduction to Soil: Dynamics:** Dynamic **l**oading conditions, Fundamental definitions, Vibration theories of Single- Degree-of-Freedom System, Natural frequency of soil-foundation system, Evaluation of various parameters (damping, mass & spring constant) for dynamic analysis, Analysis of machine foundation (vertical mode of vibration only).

**Soil Property Modification:** Mechanical and chemical stabilizations of soil, principles & methods.

**Geotechnical Engineering Design Concepts for Earthquakes:** Basic understanding of how earthquakes can lead to large ground deformations and ground failure, including liquefaction and landslides. Introduction to factors that contribute to ground deformations and failures and approaches to mitigate these effects through (a) locating of facilities at sites with good soil conditions and (b) counteractive measures such as ground modification and/or enhanced foundation design.

**EN-401** **ENVIRONMENTAL ENGINEERING-II**

***No change***

**CE-405** **REINFORCED CONCRETE DESIGN-II**

***No change***

**CE-406** **PLANNING & MANAGEMENT FOR CONSTRUCTION**

***No change***

**CE-407** **TRANSPORTATION ENGINEERING-II**

***No change***

**CE-408** **IRRIGATION AND WATER RESOURCES ENGINEERING**

***No change***

**CF-303** **APPLIED ECONOMICS FOR ENGINEERS**

**CE-409** **CIVIL ENGINEERING PROJECT**

**CE-410** **OVERVIEW OF EARTHQUAKE EFFECTS ON CIVIL INFRASTRUCTURE**

Awareness of ways that earthquakes can damage the built environment and civil infrastructure, including (a) shaking damage to buildings, bridges and other structures, (b) effects of landslides, liquefaction and large ground deformations, and (c) damage to lifeline systems, such as distribution networks that provide power, communication, oil/gas, water, and sewer systems; Appreciation of risk mitigation through pre-event mitigation (design/construction of new structures and assessment/retrofit of existing structures) and post-event response and reconstruction (including pre-planning that anticipates disruption to lifeline systems and reconstruction capabilities); Concepts of performance-based design that relate engineering analysis to metrics of economic loss, functionality, and life-safety that are relevant to risk decision making.

**Detailed Contents of Courses for the M. Engg. Programme in Civil Engineering**

## Structural Engineering

### CE 501 Advanced Structural Analysis

Matrix algebra, solution of equations, review of energy principles, virtual work; degree of redundancy, choice of redundants, flexibility method, kinematic indeterminacy, development of element stiffness matrices, stiffness method of analysis of structures, computer applications and software development, axial force effects and eigenvalue analysis, introduction to finite element method, introduction to structural stability.

### CE 502 Mechanics of Solids

Introduction to Cartesian tensors; stress tensor and tensorial transformation of stress; Mohr's circle for 3-D stress transformation; dyadic and indicial symbols; finite and infinitesimal strain tensors; Mohr's circle for 3-D strain; constitutive equations for anisotropic material; composite laminates; two dimensional theories of yield; Airy's stress function in plane elasticity; generalized Fourier series solution to biharmonic equation; elasticity in polar coordinates; thermoelasticity; numerical methods in elasticity.

### CE 503 Advanced Reinforced Concrete

Constituent materials and their properties. Material behaviour and common models in various loading regimes and application for concrete, steel and reinforced cement concrete. Analysis in flexure; known methods and theories, pre-cracking, post cracking and behaviour at ultimate load, analysis at discrete point on M-ø curve, moment-curvature relationships and ductility, non-linear analysis in flexure, effect of tension in concrete and tension stiffening load-deflection diagram, plastic rotation capacity and curvature ductility, deflection and crack control mechanism, recent researches in cracking and crack width, idealization and idealized models for analysis in flexure, analysis of prismatic non-prismatic sections in flexure. Shear in reinforced concrete; theories regarding diagonal tension problem, shear-flexure interaction, idealization, assumptions, assumptions, prevailing methods, their limitations and scope, ACI adaptation, Torsion as applied to concrete sections, strength of section in torsion for plain and reinforced concrete; review of theories, adaptation by code committee strength of section in combined shear and torsion.

### CE 504 Advanced Engineering Mathematics

Numerical solutions of linear algebraic equations. Solutions of non-linear using first and second order iterative methods. Numerical differentiation and integration. Partial differential equations and finite difference methods. Eigen Value problems such as plates. Laplace equations. Applications of Legendre., Chebyshev, Hankal and Bessel Functions to Structural Problems. Application of Taylor Series, Runge Kutta Method. Calculus of Variation, Euler-Lagrange equations, Raleigh-Ritz & Galerkin techniques.

## CE 505 Prestressed Concrete Design

Basic concepts of prestressed concrete, Systems of prestressing, materials. Partial prestressing, prestress losses. Use of high strength concrete. Structural behaviour of Beams for Elastic and Ultimate ranges for Bending and Shear. Moment curvature relationship, Camber and deflections. Detailed design of simple and continuous beams for Service and Ultimate loads. Design of End Anchorages. Determination of Cable layout. Construction techniques. Precast and in-situ pre-stressed concrete members. Applications to special structures.

## CE 506 Finite Element Method

Basic equations of elasticity; virtual work; stiffness properties of structural elements; variational and weighted residual methods, applications to trusses, beams, plane frames, two-dimensional, axi-symmetric and three-dimensional solids; higher order and isoparametric elements; field and time-dependent problems of fluid and heat flow; computational modelling.

## CE 507 Advanced Concrete Technology

Raw materials, manufacturing, composition physical properties of Ordinary Portland Cement. Effect and implication of variation in composition and various blends of cement. Hydration process and product of hydration, volume changes upon hydration. Structure of the hardened cement paste, its deformational characteristic and mechanisms, strength of hardened cement paste and factors affecting the strength of hardened cement paste. Properties of rock and mineral aggregates used in concrete and its influence on strength and durability of concrete. Properties of fresh and hardened concrete, factors affecting the properties and its correlation with performance, and test and measurement of these properties. Hot and cold weather concrete, fiber concrete, mass concrete, recycled concrete and Ferrocment. Deterioration, causes and mechanism of deterioration of concrete with emphasis on some well known causes.

## CE 508 Nonlinear Structural Analysis

Theoretical background and computer implementation of methods of analysis to account for geometric (large-displacement) and material (inelastic) nonlinear structural behavior; Comparative analyses of alternative methods to idealize nonlinear member and system response by concentrated inelastic springs (hinges) and distributed plasticity (fiber beam-column and continuum) models; Introduction to numerical solution methods as required to understand the linearization of nonlinear problems and practical implications on accuracy and convergence of numerical (computer) solution algorithms; Practical applications to structural stability, seismic “pushover” analyses, and nonlinear response-history analyses.

## CE 509 Theory of Plates and Shells

Equation of equilibrium and deformation. Cylindrical bending of Plates of Rectangular, Circular and other non-standard shapes. Classical methods of solutions. Navier, Levy Galerkin and Raleigh-Ritz methods. Strain Energy methods. Grillage and Orthotropic Plate theory. Applications of Finite difference and Finite Element methods. Large deflection of Plates. Geometric and material non-linearity.

Theory of Shells. Membrane and bending theories. Shells of revolution, Symmetric and non-symmetric loads applied to Cylindrical, Spherical and Conical Shells.

Study of existing experimental results for Shells with complex boundary conditions. Simplified design of Cylindrical shells. Domes and Folded Plates.

**CE 510 Structural Stability**

Introduction to common areas of stability problems in structures, conservative and non-conservative loads, elastic and inelastic buckling of columns; stability of members under combined bending and axial loads; buckling of frames; torsional buckling of open sections; lateral stability of beams and buckling of thin plates and shells; design considerations for stability.

**CE 511 Structural Dynamics**

Single Degree of Freedom Systems: Theoretical formulation of equilibrium equations to assess free and forced (e.g. subjected to ground motion excitations), Response to different types of dynamic loadings and different methods of analysis of nonlinear structural response. Closed form solutions for basic forcing functions and numerical methods for general input, including direct integration, modal response spectrum analysis and modal time history analysis; Modelling of energy dissipation through hysteretic and viscous damping, including mathematical formulations for viscous damping.

Multi Degree of Freedom Systems: Formulation of equation of motion and evaluation of structural property matrix, undamped free vibration, Vibration frequencies; mode shapes, orthogonality conditions, methods of practical vibration analysis and analysis of nonlinear systems, introduction to random vibration, Application of structural dynamics to earthquake engineering and methods of determinstic analysis, soil frame interaction.

**CE 512 Bridge Analysis and Design**

Bridge loadings and bridge systems; types of deck structures and idealization; orthotropic plate theory and its application to multi-girder deck systems; use of finite difference and finite strip methods; composite steel girder-slab bridges, pseudo slab, girder-slab and multi-beam type prestressed concrete bridges, design consideration for substructures; analysis of horizontally curved bridge decks.

**CE 513 Seismic Analysis & Design**

Introduction to wave propagation in solid media, body and surface waves, reflection and refraction. Causes of earthquake, review of the seismicity of earth with special reference to Pakistan; computation of response to lateral forces. Concepts and theory for capacity design approaches for the seismic design of structural systems and their components; Characterization of earthquakes for design; Development of design criteria for elastic and inelastic structural response; Seismic performace of various structural systems; Prediction of nonlinear seismic behaviour; Basis for code design procedures; Preliminary design of reinforced concrete, masonry and steel structures; Evaluation of earthquake vulnerability of existing structures and rehabilitation of seismic deficiencies.

**CE 514 Design of Tall Structures**

Wind loads, Gust factors & Karman Vortices. Design for strength and stability, thermal loads, fatigue and corrosion. Behaviour of tall structures under static and dynamic loads. Design for buckling. Criteria for design of Chimneys, TV towers, Transmission towers and Tubular Scaffolding.

**CE 515 Design of Steel Structures**

Review of elastic-plastic concepts of structural behaviour; plastic design of beams and frames; design of plate girders, compression member with large width-thickness ratio, stiffened plate, composite design and behaviour, behaviour of rigid and semi-rigid connections; design considerations for fracture and fatigue; design of rigid frames; behaviour of multistory frames and second-order analysis.

Advanced topics in steel construction, including inelastic behavior and plastic design of steel members and structures and behavior of plastic hinge in members subjected to bending moment, axial force, shear, and their combinations; Inelastic cyclic behavior of steel components; Introduction to fracture and fatigue of steel components; seismic rehabilitation.

**CE 516 Repair Maintenance and Strengthening of Reinforced Concrete Structures**

Review of engineering properties of conventional and prestressed reinforced concrete materials. Review of design theories and its implications. Review of deterioration and causes of deterioration of concrete structures and its implication on structures. Implication of debonding of reinforcing steel and analytical modelling of sections with unbounded reinforcement. Need of strengthening are re-strengthening. Prevailing strengthening techniques and their comparison. Recent researches in strengthening in flexure and shear, methodologies, analysis, design and execution. Strengthening techniques related to columns and foundations. Case studies of strengthened and re-strengthened structures.

**CE Seismic Hazard Analysis:**

***Basic:*** Background to understand key concepts in seismic hazard analysis as related to establishing seismic hazard maps and the design basis for special facilities. Topical coverage would include: plate tectonics and elastic rebound theory of earthquakes and faults, seismicity, earthquake fault mechanisms and slip models, ground motion characteristics and attenuation functions, probabilistic integration to assess shaking hazard, dynamic lateral earth pressures, and seismic slope stability.

***Advanced:*** Extension beyond basic introduction to provide students with detailed knowledge to develop a probabilistic site-specific hazard spectrum. Topical coverage would include: deterministic and probabilistic seismic hazard analyses, effects of local soil conditions on ground response, liquefaction, near-fault directivity effects, development of design ground motions

**CE Inelastic Design and Behavior of Reinforced concrete Structures:**

Advanced topics in reinforced concrete construction, including inelastic flexural behavior; applications of plastic analysis to reinforced concrete frames for gravity and lateral loads; behavior and design of reinforced concrete frame-wall structures for gravity and lateral loads; behavior in shear and torsion; yield-line analysis of slabs; behavior under cyclic and reversed loading; seismic rehabilitation.

## Geo-technical Engineering

### CE 531 Advanced Soil Mechanics

Physical characteristic of soils and their identification, clay mineralogy, clay-water relations. Numerical, mathematical and sketching solutions for simple steady-state flow problems. Stress in soil mass under applied stresses for two and three dimensional problems, equilibrium equations, stress invariants and octahedral stresses. One dimensional consolidation equation and its mathematical analysis, immediate and consolidation settlement analysis for thin and thick soil layers, plasticity or creep effetcs (Deconday consolidation).

Shearing strength of cohesionless and cohesive soils using Mohr-columb failure criteria. Critical state theory; representation of stress path on the Rendulic Plot, critical state live and equation, Roscor and Hvorseleve surfaces and their equations.

### CE 532 Foundation Engineering

Properties of sub-surface materials for classification, Bore logs information for foundation selection. Selection criteria of foundation resting on various types of soils, foundation on non-uniform soils and rocks. Case studies of actual foundation problems. Development of theoretical bearing capacity equations for shallow and deep foundations under drained and undrained conditions. Design procedures and behaviour of different types of foundation. Introduction to seismic behaviour of subsoil and building foundations. Foundation problems solution by Finite Difference method, Reinforced earth, Beam on elastic foundation and Lateral thrust due to compaction of soil by rollers.

### CE 533 Soil-Foundation Dynamics

Vibration of elementary systems, foundation vibratory theory, foundation design for vibratory loads, foundation isolation, wave propagation theory, response of soils to dynamic loading, dynamic soil properties, field and laboratory methods for evaluation of dynamic soil properties, liquefaction of sands, vibratory compaction of granular materials.

**CE 534 Soil Investigation & Testing**

Purpose, planning of Subsurface exploration, Sub-soil investigation by conventional and geophysical methods. Sampling techniques: Standard static and dynamic laboratory tests for measurement of Soil Properties, In-situ groundwater conditions. Lab work related to the tests covered, report preparation.

**CE 535 Earth Structures**

Failure Mechanisms in Natural and Artificial Slopes. Stability Analysis for slopes in Cohesive, Non-Cohesive and C-phi soils. Use of stability charts. Steady state seepage problems in Earth Structures. Influence of surcharge, submergence and tension crack on Stability. Numerical Integration Analysis by Fellenius Method and Bishop's Simplified Method. Principles of Design and Stability Analysis of Earth and Rock Fill Dams under Drained and Un-drained conditions: stress Distribution and Deformation within the Dam and Foundation Strata. Effect of earthquakes on slope stability.

**CE 536 Soil Stabilization**

Principles and methods of altering engineering properties of soils. Mechanisms of soil stabilization. Mechanical, electrical and thermal stabilization. Specifications, construction and control methods. Types of compaction equipment. Optimum utilization of compaction equipments. Use of geo-textile fabrics for stability of soft & compressible soils.

**CE 537 Rock Mechanics**

Rock as Material, Rock Formation and Structure, Folding, Faulting and Joints. Analysis of Stress and Infinitesimal strain. Friction, Linear Elasticity. Strength of Rock and Cemented granular materials. Crack Phenomena and the Mechanism of Fracture. Fluid Pressure and Flow in Rocks. Brittle and Creep Behaviour, Determination of Static and Dynamic Mechanical properties of Rock in laboratory and field, Mining and other Civil Engineering Applications. Rock Slope Engineering.

**CE 538 Groundwater & Seepage**

Hydromechanics of confined and unconfined flow of water through soils, potential theory, conformal mapping transient flow. Applications to design of earth dams.

**CE 539 Subsurface Hydrology**

*Introduction:* Groundwater and hydrologic cycle, Groundwater as a Resource, Groundwater as geotechnical problem
*Physical Properties and Principles:* Basic principles of fluid flow in saturated and unsaturated materials Hydraulic Head and Fluid Potential, Darcy’s Law, Hydraulic Conductivity and

Permeability, Transmissivity and storativity, Aquifers and Aquitards, Steady State and Transient Flow Equations of Groundwater Flow; Infiltration and Groundwater Recharge.
*Groundwater Resource Evaluation:* Development of Groundwater Resources, Exploration, Evaluation and exploitation, Well, Aquifer and Basin Yields, Exploration for Aquifers; Geological and Geophysical Methods, Drilling, Installation of Wells and Piezometers, Pumping Tests, Groundwater Quality, Well head Protection. Groundwater monitoring, Groundwater models—analytical and numerical models
*Groundwater and Geotechnical Problems/Applications:* Artificial Recharge, Seawater Intrusion, Drainage and Dewatering, Pore Pressure, Land Subsidence, Landslides and Slope Stability.

**CE 540 Earth Retaining Structures**

Pressure on Retaining Walls. Basic Concepts and Earth Pressure Theories. Design criteria and Pressure Analysis of Rigid Walls with and without surcharge Loads. Effect of seepage and Drainage on Walls. Pile-supported Retaining Wall. Behaviour of Flexible Earth-Retaining structures. Design Criteria and Pressure Analysis of Anchored Bulk Heads, Braced Out and Tie-Back Bracing system, Design criteria for cellular cofferdams. Behaviour of Retaining Walls during earthquakes.

**CE 541 Computer Applications in Geo-technical Engineering**

Numerical solutions of partial differential equations, Finite difference Approximation solutions to two-dimensional flow field and one-dimensional consolidation Soil Layer. Finite Element Method application to stress analysis of Linearly elastic systems of Geotechnical Engineering problems. Soil-foundation Dynamics Interaction problems.

**CE Geotechnical Earthquake Engineering**

Seismicity; Influence of soil conditions on site response; Seismic site response analysis; Evaluation and modeling of dynamic soil properties; Analysis of seismic soil-structure interaction; Evaluation and mitigation of soil liquefaction and its consequences; Seismic code provisions and practice; Seismic earth pressures; Seismic slope stability and deformation analysis; Seismic safety of dams and embankments; Seismic performance of pile foundations.

## Appendix E
## Case Study Buildings

Case Study 1: 6-Storey Mixed Use Building in Karachi: A Pilot Case Study of Seismic Assessment and Retrofit Design

Case Study 2: 3-Storey Library Building in Karachi: A Case Study of Seismic Assessment and Retrofit Design

Case Study 3: 8-Storey Mixed Use Building in Karachi: A Case Study of Seismic Assessment and Retrofit Design

Case Study 4: 5-Storey Mixed Use Building in Karachi: A Case Study of Seismic Assessment and Retrofit Design

Case Study 5: 10-Storey Office Building in Karachi: A Case Study of Seismic Assessment and Retrofit Design

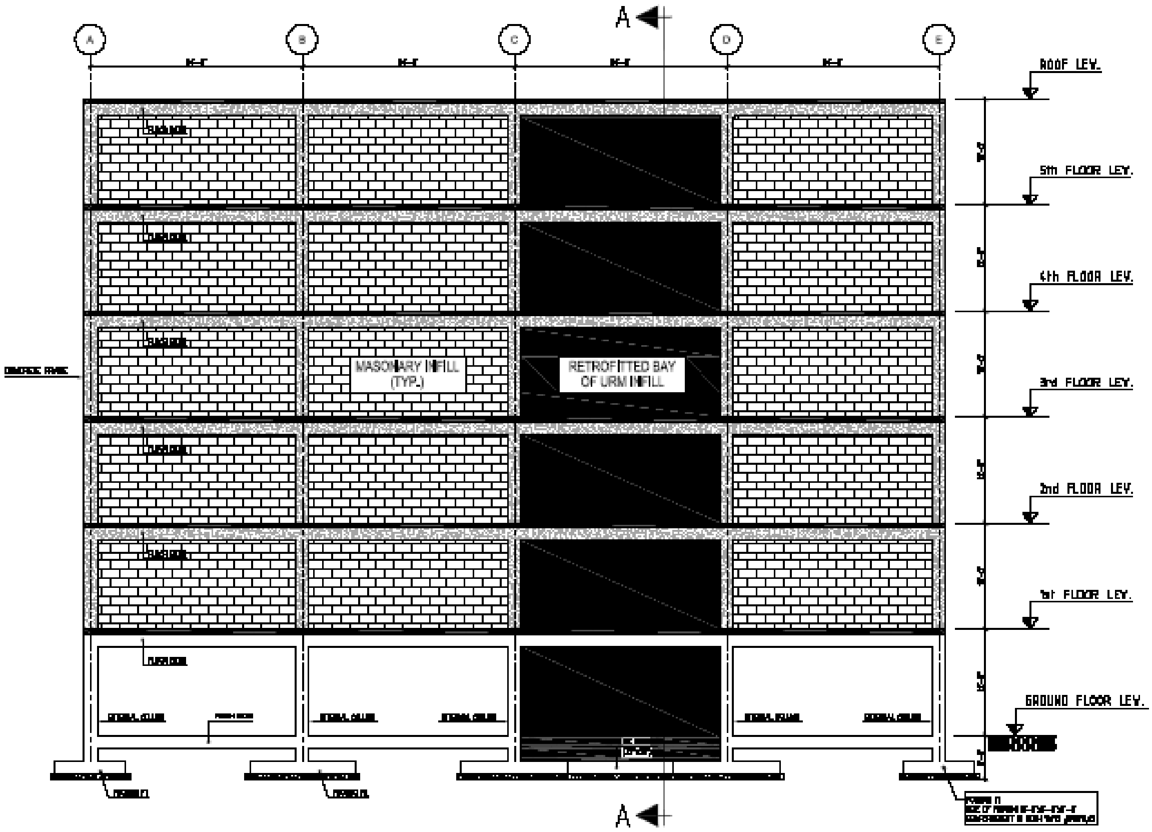
Case Study 6: Stone Masonry School in Abbottabad: A Pilot Case Study of Seismic Assessment and Retrofit Design

Case Study 7: Four Storey Office Building in Muzaffarabad: A Case Study of Seismic Assessment and Retrofit Design

Case Study 8: Four Storey Academic Building in Karachi: A Case Study of Seismic Assessment and Retrofit Design

Case Study 9: 6-Storey Mixed Use Building in Karachi: A Case Study of Seismic Assessment and Retrofit Design

Case Study 10: 5-Storey Residential Apartment Building Near Murree: A Case Study of Seismic Assessment and Retrofit Design




ELEVATION OF RETROFITTED URM INFILLED FRAME

# 6-Storey Mixed Use Building in Karachi

## A Pilot Case Study of Seismic Assessment and Retrofit Design

GeoHazards International
A Nonprofit Working Toward Global Earthquake Safety

Supported by the Pakistan-US Science and Technology Cooperation Program

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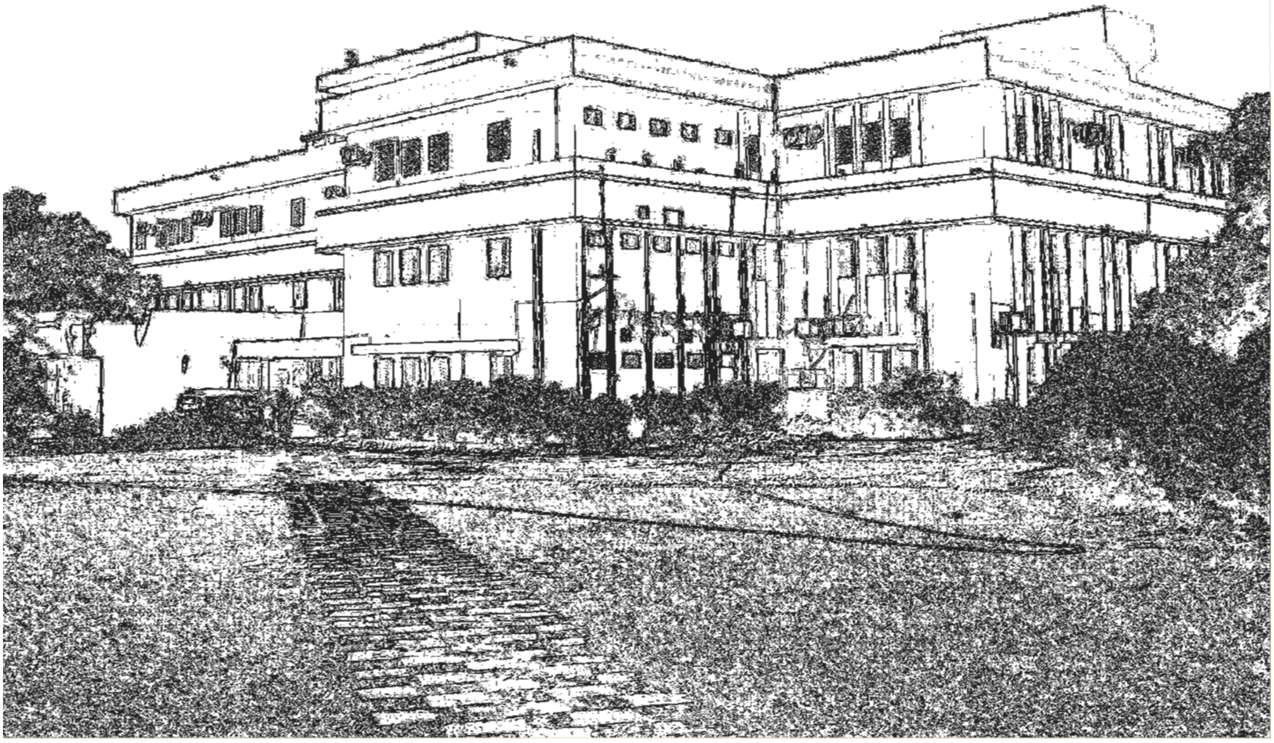
**Summary**
In order to learn how to analyze typical reinforced concrete buildings, understand their seismic behavior and to learn how guidelines such as ASCE 41, ATC-40 and FEMA could apply to buildings in Pakistan, the project team idealized a typical Karachi residential-commercial mixed use building as the pilot case study building. For simplicity, the team investigated the behavior of two-dimensional frame models with and without infill walls, and simplified certain structural details. A separate report describes a study of the three dimensional model of the building.

The building upon which the idealized case study structure is based is located in Gulistan-e-Johar, a densely populated area in Karachi. This building consists of reinforced concrete framed building with five storeys including the ground floor. The building has shops located at the ground floor, while the above floors have residential apartments. The building was constructed before the 2005 Kashmir Earthquake. Project participants selected this building as the pilot case study because it has several seismic vulnerabilities common to mixed-use residential buildings in Karachi: a weak story created by open shop fronts at the ground floor, an eccentrically located reinforced concrete core, and heavy, stiff unreinforced masonry infill walls that were not considered during the structural design of the building.

The case study team assessed the building's potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Prestandard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 and 3 analyses and acceptance and modeling criteria from ASCE 41. The building was found to be inadequate for seismic zone 4 and requires retrofitting to rectify the soft storey at the base and provide lateral stability to the building.

The team examined a number of potential retrofit solutions for both seismic performance and economic considerations. In order to provide a cost-effective and minimally intrusive retrofit, the team selected a rocking spine retrofit solution. A spine of existing infill panels reinforced with shotcrete above a reinforced concrete wall at the open ground storey prevents the building from collapsing. The spine provides stability and strength without extensive foundation work. This retrofit solution promises to be an innovative and cost-effective alternative for buildings in Pakistan.



# 3-Storey Library Building in Karachi

## A Case Study of Seismic Assessment and Retrofit Design

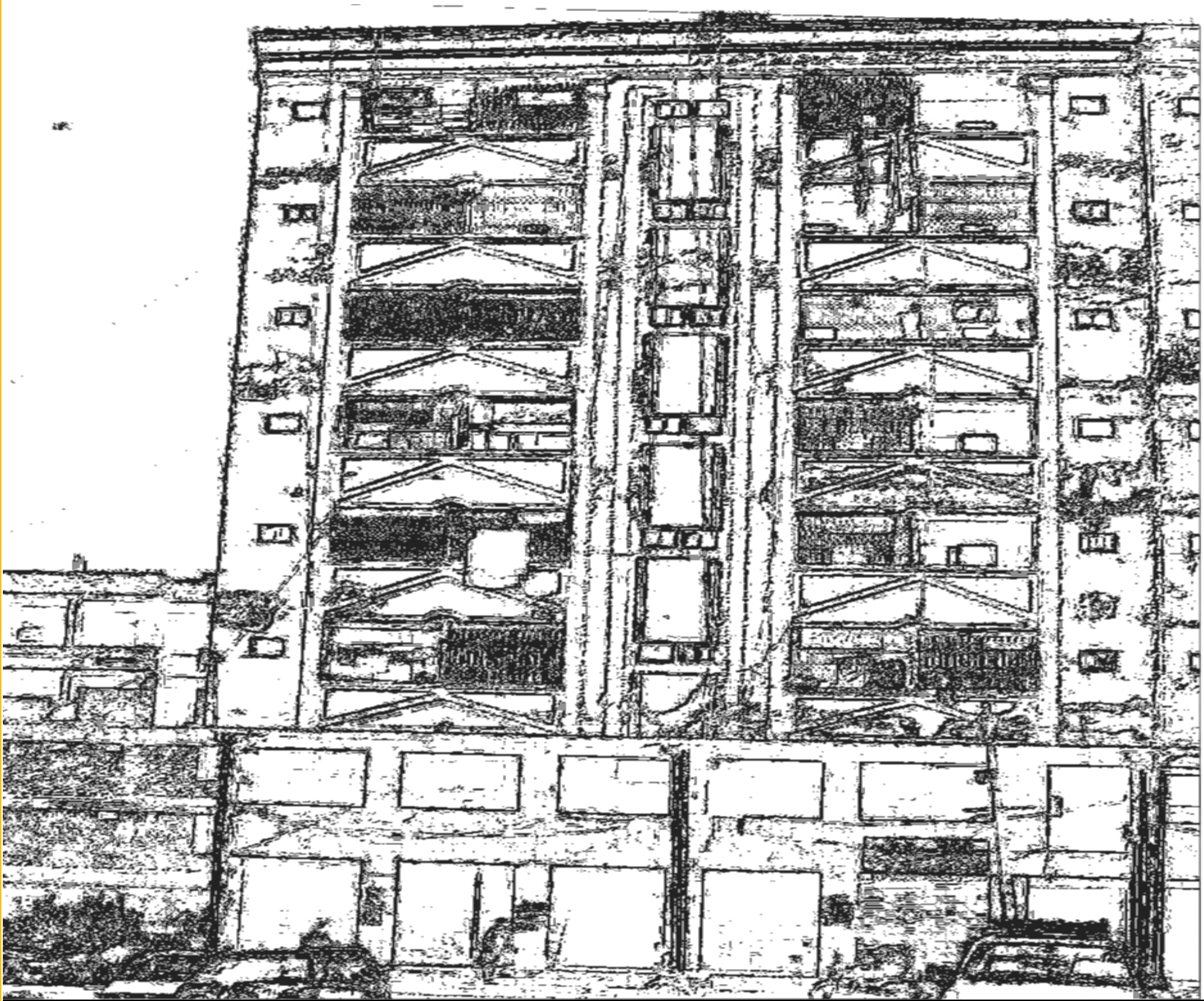
Supported by the Pakistan-US Science and Technology Cooperation Program

**Summary**

This case study building is a library building located on a university campus in Karachi. It is a reinforced concrete framed building initially consisting of two floors with beam-slab framing system. Later on, a small extension was built on the front of the building's ground floor, and separated from original building by expansion joints. Recently, a new floor and a detached external emergency exit stair case at rear of the building have been added. The building was constructed before the 2005 Kashmir Earthquake. Project participants selected this building as a case study because it has several seismic vulnerabilities common to low-rise buildings in Karachi: a weak story created by open working area at the ground floor, an eccentrically located stair case, a heavy rooftop water tank, and heavy, stiff unreinforced masonry infill walls that were not considered during the structural design of the building.

The case study team assessed the building's potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Prestandard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 and 3 analyses and acceptance and modeling criteria from ASCE 41. The building was found to be inadequate for Seismic Zone 4 and requires retrofitting to increase the stiffness and stability of the building.

The team examined several retrofit schemes consisting of combinations of reinforced infill panels and column jacketing, and selected a retrofit solution consisting solely of reinforced infill panels.



# 8-Storey Mixed Use Building in Karachi

## A Case Study of Seismic Assessment and Retrofit Design

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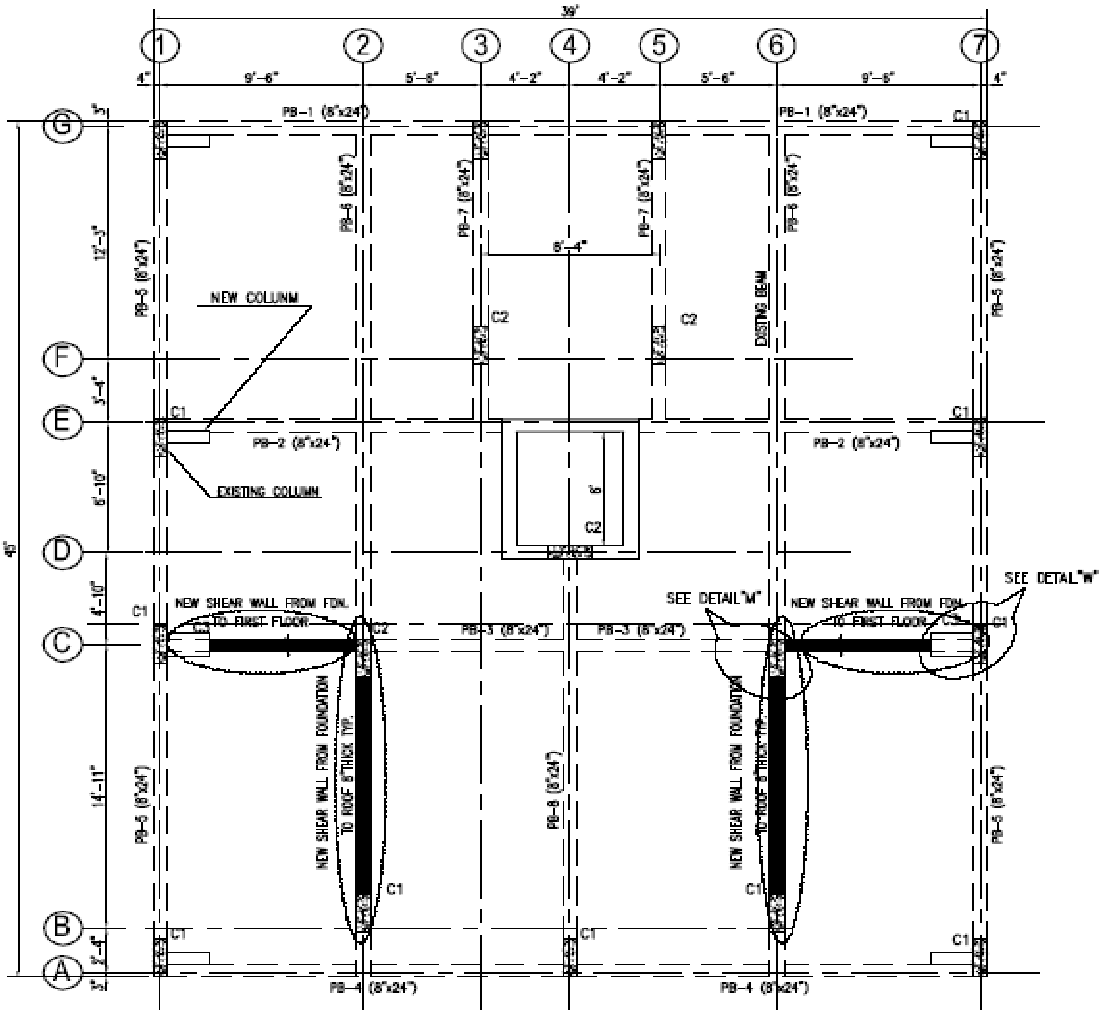
**Summary**

The building is located in Gulistan-e-Johar, a densely populated area in Karachi. It is a reinforced concrete framed building with eight storeys including the ground floor. The building has shops located at the ground floor and the mezzanine floor has offices, while the above floors have residential apartments. The building was constructed after the 2005 Kashmir Earthquake. Project participants selected this building as a case study because it has several seismic vulnerabilities common to mixed-use residential buildings in Karachi: a potential weak story created by open shop fronts at the ground floor, an eccentrically located reinforced concrete core, and heavy, stiff unreinforced masonry infill walls that were not considered during the structural design of the building.

The case study team assessed the building's potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Prestandard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 and 3 analyses and acceptance and modeling criteria from ASCE 41. The Tier 3 nonlinear static pushover analyses showed that the building would be heavily damaged in the maximum considered earthquake (seismic Zone 4), but would be unlikely to collapse. Hand calculations determined that the beam-column joints have insufficient shear strength and are likely to experience significant damage. The case study team advisors considered it unlikely that the joints would deteriorate enough to cause collapse, however.

Because the building is a residential building in which it would be difficult to seismically retrofit the joints (joint retrofit schemes tend to be invasive), and because it is being evaluated for collapse prevention in the maximum considered earthquake, the case study team and advisors determined that the most practical course of action would be to leave the building as it is, and not attempt a retrofit of the beam column joints that would be disruptive to occupants. This case study illustrates the benefit of nonlinear analysis in capturing the existing strength and deformation capacity of a building to reduce, or in this case eliminate, potentially costly and disruptive seismic retrofit measures.




# Five Storey Mixed Use Building in

## A Case Study of Seismic Assessment and Retrofit Design

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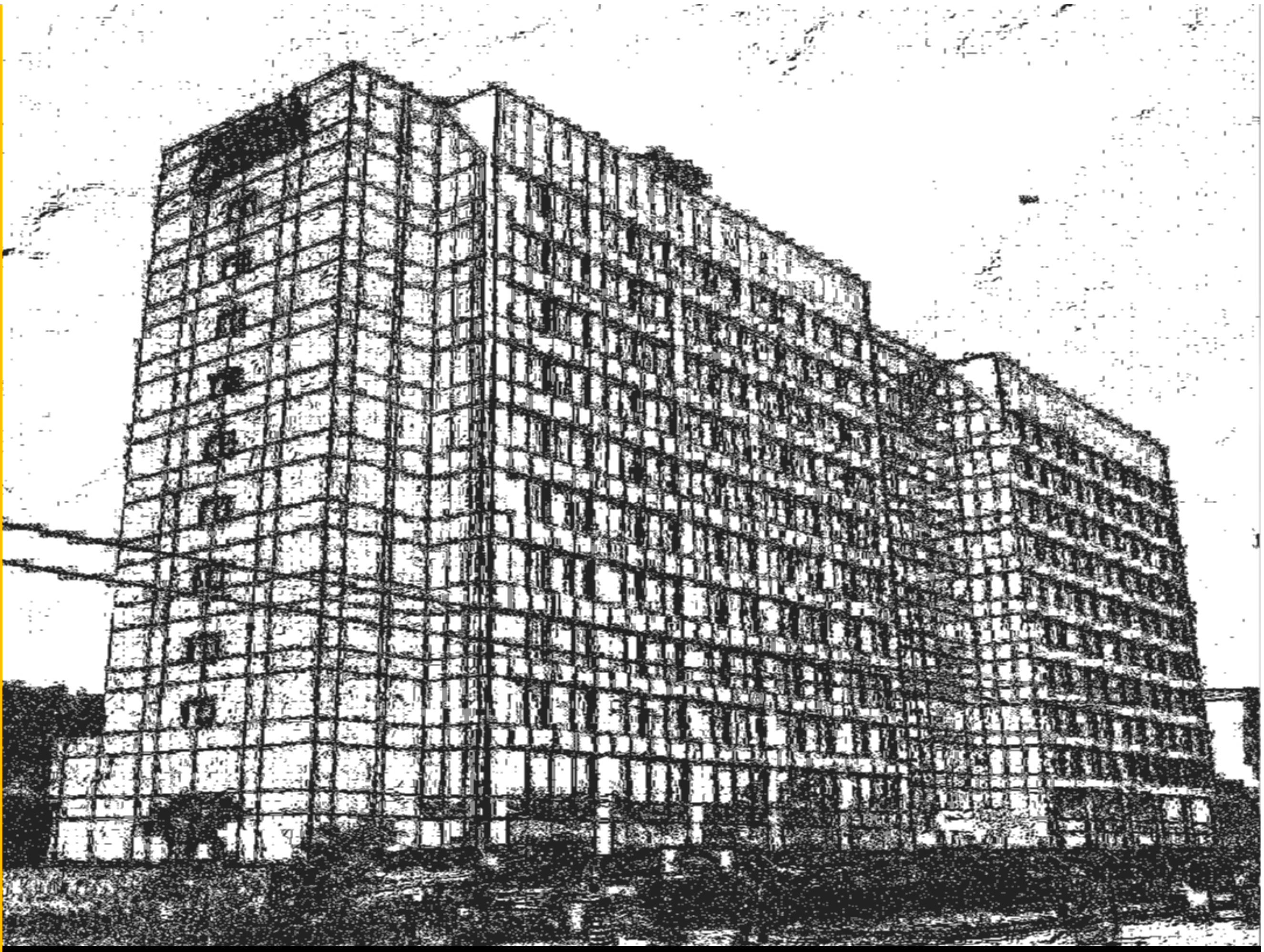
**Summary**

The building is located in Gulistan-e-Johar, a densely populated area in Karachi. The building consists of reinforced concrete framed building with five storeys including the ground floor. The building has shops located at the ground floor, while the above floors have residential apartments. The building was constructed before the 2005 Kashmir Earthquake. Project participants selected this building as a case study because it has several seismic vulnerabilities common to mixed-use residential buildings in Karachi: a weak story created by open shop fronts at the ground floor, an irregular framing pattern and heavy, stiff unreinforced masonry infill walls that were not considered during the building's structural design.

The case study team assessed the building's potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Prestandard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 and 3 analyses and acceptance and modeling criteria from ASCE 41. The building was found to be very weak in one direction, and was inadequate for collapse prevention under the maximum considered earthquake (taken as Zone 4 for Karachi). The team selected a retrofit scheme consisting of a combination of column strengthening by adding column area to create T-columns, beam strengthening near the lift core, and adding new shear walls in the ground storey and above.



# 10-Storey Office Building in Karachi

## A Case Study of Seismic Assessment

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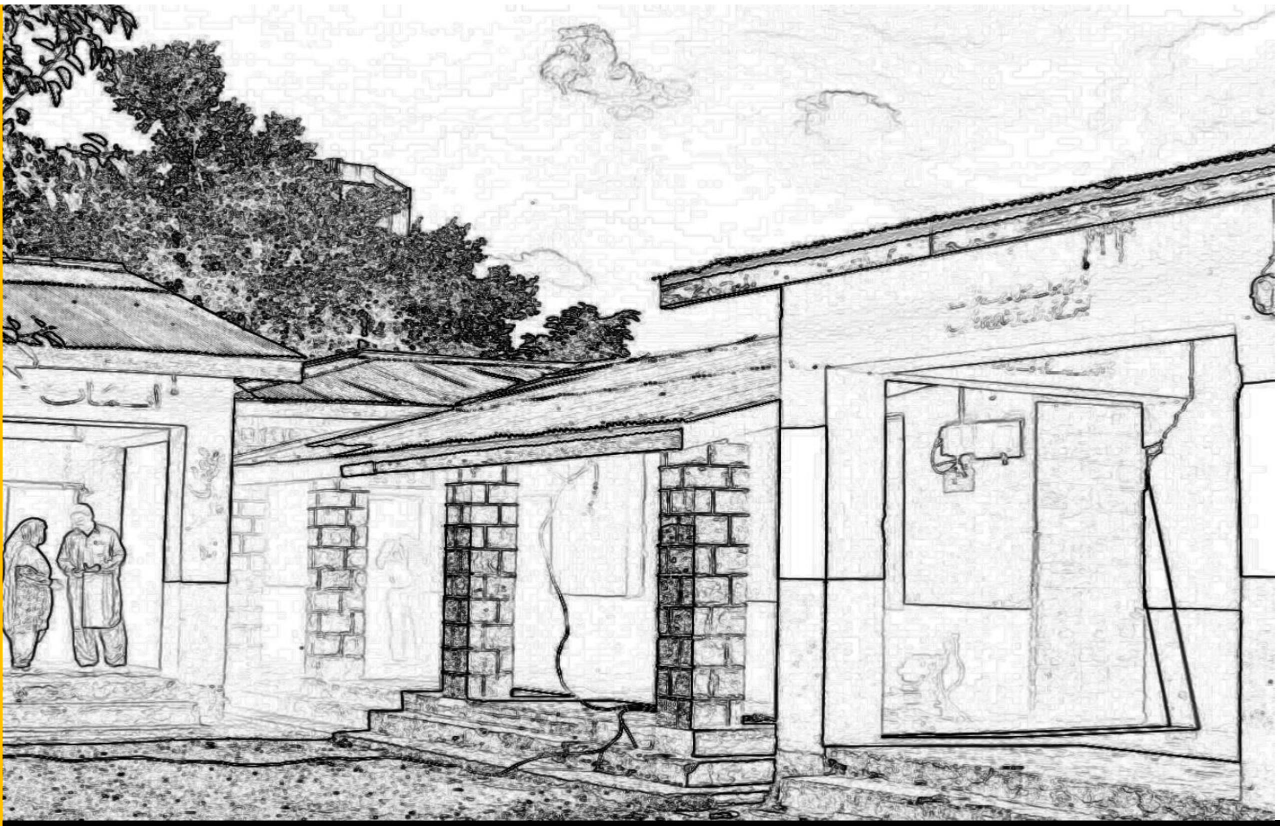
## Summary

The building is located in a densely populated area in Karachi. It is a reinforced concrete framed building with ten storeys above ground and twelve storeys total, including two basements. The building is being used as an office building, therefore it is evaluated for the Life Safety (LS) level of seismic performance, meaning that its occupants should survive the design level earthquake and be able to exit the building safely. The reinforced concrete frame consists of flat slab with drop panel and having outer peripheral beams. The building construction was completed in 2004. Project participants selected this building as a case study because it has several potential seismic vulnerabilities common to high rise buildings in Karachi: a weak story created by open working areas, an eccentrically located reinforced concrete core, and heavy, stiff unreinforced masonry infill walls that were not considered during the structural design of the building.

The case study team assessed the building's potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Prestandard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 and 3 analyses and acceptance and modeling criteria from ASCE 41. The building was found to be adequately designed. Some minor damage, which will not affect the stability of the building, may occur in some columns at the ends of the building. However, the building is expected to meet the Life Safety performance objective, and therefore no seismic retrofit is required.



# Stone Masonry School in Abbottabad

## A Case Study of Seismic Assessment and Retrofit

GeoHazards International
A Nonprofit Working Toward Global Earthquake Safety

Supported by the Pakistan-US Science and Technology Cooperation Program

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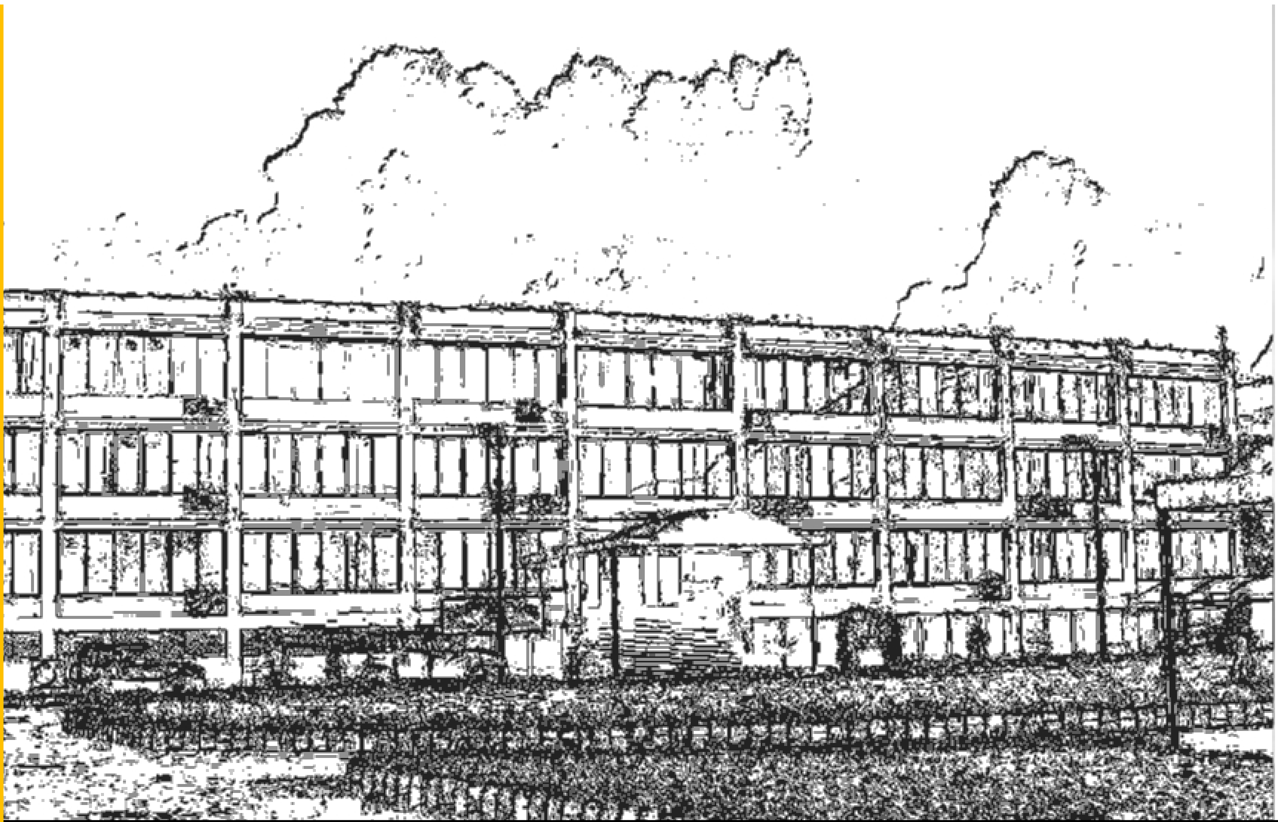
**Summary**

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.



# Four Storey Office Building in Muzaffarabad

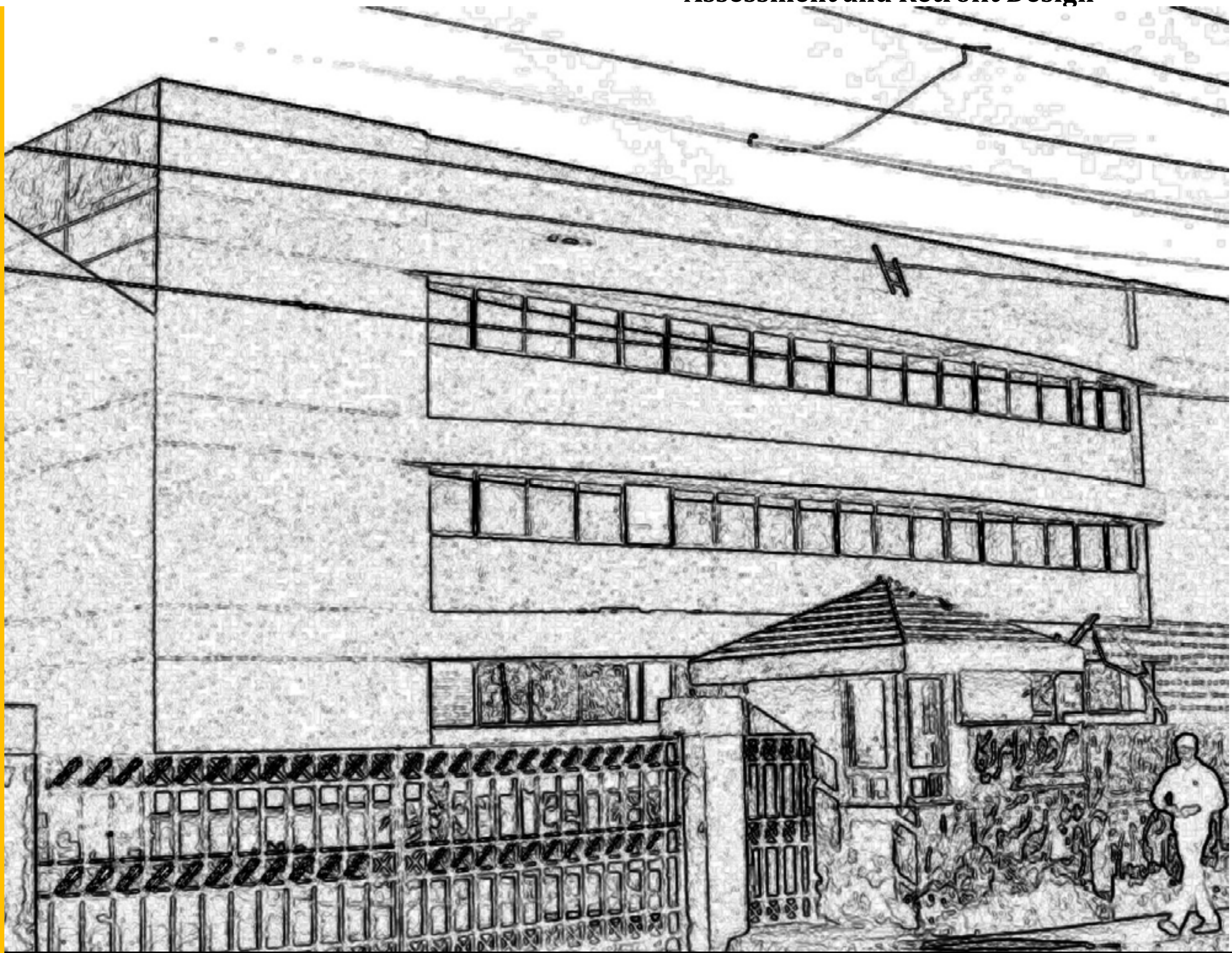
## A Case Study of Seismic Assessment and Retrofit Design

Supported by the Pakistan-US Science and Technology Cooperation Program

**Summary**

The building is located in Muzaffarabad in Azad Jammu and Kashmir (AJK) Province. The building was constructed after the 2005 Kashmir Earthquake. This is a ground plus three storey building. This building has infill framed structure however; infill walls are only present in the shorter plan direction. The framing system used in the building is a beam slab system. Project participants selected this building as a case study in order to check the level of structural design compliance with the design standards, after the 2005 Kashmir Earthquake, in the affected areas.

The case study team assessed the building's potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Pre-standard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 analyses and acceptance and modeling criteria from ASCE 41. The building was found to be adequately designed, but requiring removal of a small number of partial-height infill masonry walls that currently create a captive column condition at the ground storey on one side of the building.



# Four Storey Academic Building in Karachi

## A Case Study of Seismic Assessment and Retrofit Design

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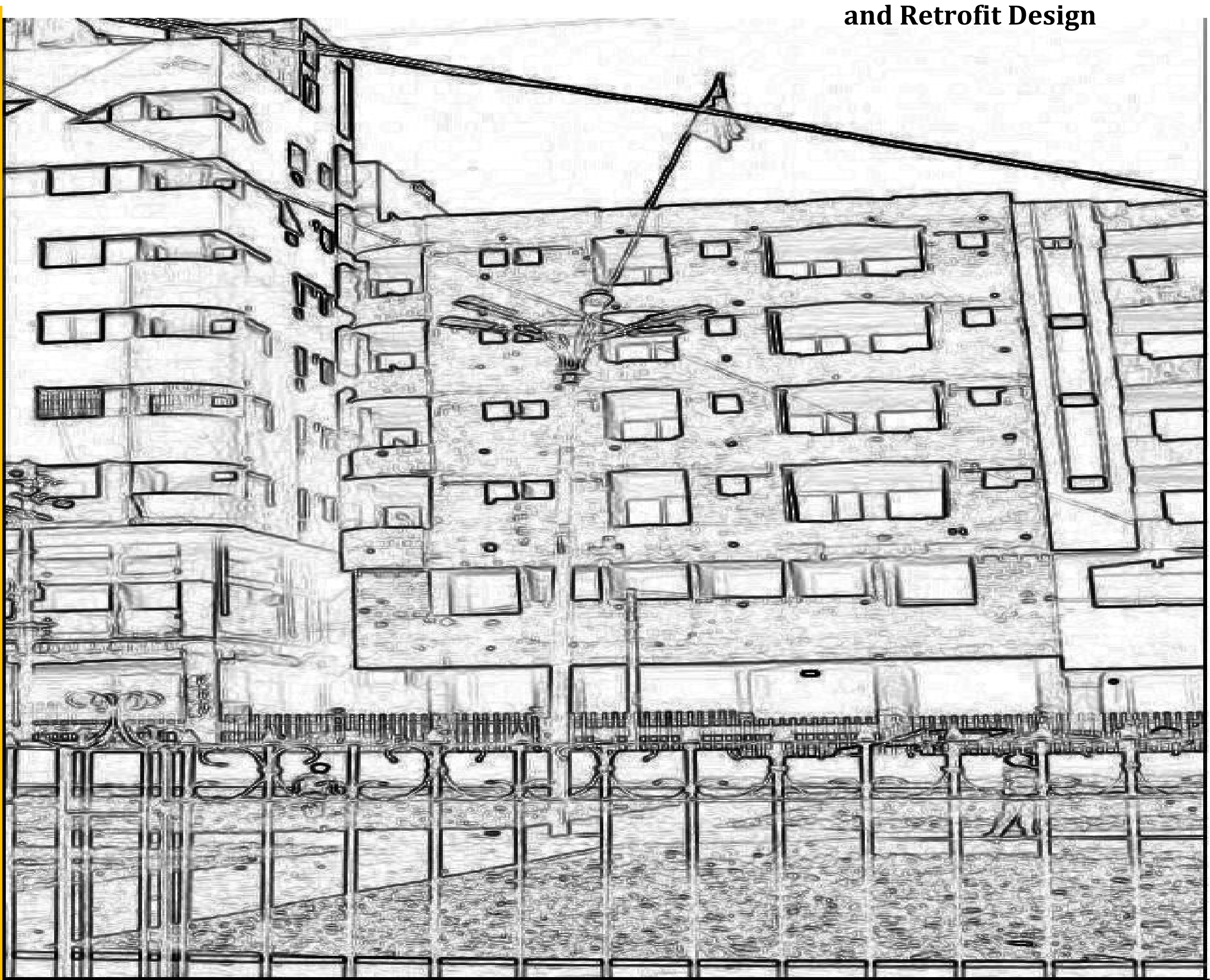
**Summary**

The building is a reinforced concrete framed building with four storeys including the ground floor, which is located in Karachi. It is an academic building with classrooms, computer laboratories and administrative offices. The building was constructed after the 2005 Kashmir Earthquake. Project participants selected this building as a case study because it has several seismic vulnerabilities common to academic buildings: an eccentrically located reinforced concrete core, plan irregularities and heavy, stiff unreinforced masonry infill walls that were not considered during the structural design of the building.

The case study team assessed the building's potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Prestandard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 and 3 analyses and acceptance and modeling criteria from ASCE 41. The building was found to be stable and adequately designed.



# 6-Storey Mixed Use Building in Karachi

## A Case Study of Seismic Assessment and Retrofit Design

GeoHazards International
A Nonprofit Working Toward Global Earthquake Safety

Supported by the Pakistan-US Science and Technology Cooperation Program

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

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**Summary**

The building is located in Gulistan-e-Johar, a densely populated area in Karachi. An idealized two-dimensional frame from this building was studied earlier as the pilot case study. The results from that case study showed that the building needed retrofitting. It was then decided to do a non linear static analysis for the entire building. The building consists of reinforced concrete framed building with six storeys including the ground and mezzanine floors. The building has shops located at the ground and mezzanine floors, while the above floors are residential apartments. The building was constructed before the 2005 Kashmir Earthquake. Project participants selected this building because it has several seismic vulnerabilities common to mixed-use residential buildings in Karachi: a weak story created by open shop fronts at the ground floor, an eccentrically located reinforced concrete core, and heavy, stiff unreinforced masonry infill walls that were not considered during the structural design of the building.

Moreover, the case study team assessed the building's potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Prestandard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 and 3 analyses and acceptance and modeling criteria from ASCE 41. The building was found to be inadequate for seismic zone 4 and requires retrofitting to improve the capacity of the columns and the overall strength and deformation capacity of the structure. The columns were found to be marginal even under gravity loading, so the team decided to jacket a number of them, as well as replacing infill panels with reinforced concrete walls to form rocking spines. It was difficult to find locations to place spines due to the configuration of the building, but the team was able to obtain an acceptable solution by supplementing the base-to-roof spines with an additional shear wall in the weak ground and mezzanine storeys, and by making use of existing infill wall capacity in the upper storeys.

# Five Storey Residential Apartment Building Near Murree

## A Case Study of Seismic Assessment

GeoHazards International
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**Summary**

The case study building is located near Murree, a popular hill station and a summer resort for people, especially for the residents of Rawalpindi/Islamabad. The building is a reinforced concrete framed structure with five storeys including the ground floor. Car parking is located at the ground floor while the above floors have residential apartments. The building was constructed after the 2005 Kashmir Earthquake. This building was selected as a case study because it has several seismic vulnerabilities common to mixed-use residential buildings in northern Pakistan. The building was designed for a lower level of seismic forces than those prescribed in the newest edition of the building code – it was designed for Zone 2B, but with the approval of the Building Code of Pakistan (Seismic Provisions-2007), Murree is now in Zone 3. With the new zoning comes more stringent requirements for the structural detailing of the reinforced concrete frame, so the building must now be considered as an ordinary moment frame rather than an intermediate moment frame, meaning the design forces will be higher. The building also has a weak story created by open space at the ground floor, has an L-shaped plan, and has with stiff unreinforced masonry infill walls that were not considered during the structural design of the building.

The case study building was assessed for potential seismic vulnerabilities using the US Federal Emergency Management Agency (FEMA) Pre-standard 310 Tier 1 Checklist modified for Pakistan conditions, as well as the American Society of Civil Engineers (ASCE) Standard 31 Tier 2 and 3 analyses and acceptance and modeling criteria from ASCE 41. Structural analysis showed that the building is anticipated to protect the lives of its occupants in the design earthquake, and was therefore adequately designed to meet the performance expected of residential buildings.

## Appendix F
## Courses Offered in MEngg Program

### Detailed Contents of Compulsory Courses

### EQ-501 Structural Dynamics

Single Degree of Freedom Systems: Theoretical formulation of equilibrium equations to assess free and forced (e.g. subjected to ground motion excitations), Response to different types of dynamic loadings and different methods of analysis of nonlinear structural response. Closed form solutions for basic forcing functions and numerical methods for general input, including direct integration, modal response spectrum analysis and modal time history analysis; Modelling of energy dissipation through hysteretic and viscous damping, including mathematical formulations for viscous damping.

Multi Degree of Freedom Systems: Formulation of equation of motion and evaluation of structural property matrix, undamped free vibration, Vibration frequencies; mode shapes, orthogonality conditions, methods of practical vibration analysis and analysis of nonlinear systems, introduction to random vibration, Application of structural dynamics to earthquake engineering and methods of determinstic analysis, soil frame interaction.

### EQ-502 Fundamentals of Earthquake Engineering

Plate tectonics and earthquake types, introduction to wave propagation and monitoring, earthquake ground motion measures, influence of source, path and site effects, introduction to ground motion prediction equations (GMPEs) and seismic hazard assessment, inelastic response at section, member and global level, drift and lateral stability, floor diaphragm response, review of structural vibration theory, linear elastic and inelastic seismic response of single degree of freedom (SDF) systems to seismic excitation, development of inelastic response spectrum and its application in force and displacement based seismic design and assessment, inelastic seismic response of multi degree of freedom (MDF) systems, applications and limitations of nonlinear pushover analysis, seismic design and assessment procedures in codes.

### EQ-503 Seismic Design of RC Buildings

Material behaviour of concrete, steel, reinforced concrete and masonry under monotonic and cyclic loading, flexural analysis of sections and members, pre-cracking, post-cracking and behaviour at ultimate load, moment-curvature (M-Φ) curve, moment-curvature relationships and ductility, plastic rotation capacity and curvature ductility relationships, effect of tension in concrete and tension stiffening and load deflection diagram, deflection and crack control mechanism, shear in reinforced concrete, shear-flexure interaction, torsion in reinforced concrete, seismic design limit states and structural properties, essentials of structural systems for seismic resistance, factors influencing seismic response, capacity design philosophy, determination of design forces, principles of member design and aspects of detailing, design of reinforced concrete buildings.

**EQ-504 Advanced Structural Analysis**

Matrix algebra, solution of equations, review of energy principles, virtual work; degree of redundancy, choice of redundants, flexibility method, kinematic indeterminacy, development of element stiffness matrices, stiffness method of analysis of structures, computer applications and software development, axial force effects and eigenvalue analysis, introduction to finite element method, introduction to structural stability.

**EQ-505 Structural Reliability Analysis**

Reliability function, measures of central tendency and dispersion of data, theory of probability, probability distribution, fundamentals of structural reliability theory, first and second-order methods of reliability analysis, structural component and system reliability, reliability sensitivity measures, structural time-invariant and time-variant reliability analysis, dynamic analysis of linear and nonlinear structural systems subjected to stationary and non-stationary random excitations, finite element sensitivity and reliability analysis methods, application of structural reliability analysis in performance based seismic design, probabilistic seismic design codes.

### 3.3 Detailed Contents of Elective Courses

**EQ-521 Displacement Based Seismic Design**

Philosophy and need for displacement based design (DBD), review of conventional force based design (FBD) methods with particular reference to seismic design codes, review for DBD methods, advantages of DBD over FBD with illustrative examples, seismic input for DBD method such as displacement spectrum; concept of hysteretic damping and displacement ductility; influence of displacement and ductility on spectral displacement response; attenuation model for displacement spectrum, fundamental considerations of DBD, design limit states and performance levels, single degree of freedom (SDF) structures, multi-degree of freedom (MDF) structures, p-delta effects, combination of seismic and gravity loadings, considerations for torsional response, capacity design of members, nonlinear analysis tools, force-displacement response for reinforced concrete members, force-displacement response for steel members, analysis related to capacity design philosophy, application of DBD in buildings, bridges and structures with base isolation and added damping.

**EQ-522 Performance Based Seismic Design**

Mechanics of earthquakes and strong ground motion characteristics, response spectra and seismic response of elastic and inelastic systems, mechanical behaviour of structural members under earthquake excitations, seismic design philosophies, philosophy of seismic design for reinforced concrete structures, building code procedures for seismic design, performance based design, advantages of performance-based seismic design, seismic performance levels, measures of seismic performance, seismic hazard, performance objectives, general approaches for estimating deformation capacity of the structures, response spectra, fundamental consideration of direct displacement-based design, analysis tools for direct displacement-based design, framed buildings, dual wall-frame buildings, masonry buildings, structures with isolation and added damping, pushover analysis.

### EQ-523 Seismic Design of Steel and Composite Structures

Elastic and inelastic behaviour of steel subjected to static and dynamic loading, mechanical behaviour of steel beams, types of connection, behaviour of connections, methods of global analysis, seismic design of steel structures using seismic design provisions, concepts of ductility, inter-storey drift; behaviour factors/force reduction factors and damage, capacity design principles, typology of steel structures, effect of global instability, effects of diaphragms, semi-rigid connections and axial forces, seismic design of moment resisting steel frames; braced steel frames and composite structures, introduction to performance and displacement based design, hybrid force and displacement based design and use of advanced methods of analysis.

### EQ-524 Seismic Design and Assessment of Masonry Structures

An introduction to masonry and non-engineered construction, mechanical properties of clay brick, cellular concrete block, autoclave aerated concrete (AAC) block, adobe and stone masonry units, categories of masonry walls for seismic resistance, in-plane and out-of-plane behaviour of masonry assemblages and walls, analytical methods for masonry walls, seismic design of masonry moment resisting wall frames and masonry-infilled frames, assessment of unreinforced masonry structures, design principles and code specifications for masonry construction, repair and strengthening techniques for damaged masonry buildings after earthquakes, displacement based design of masonry structures.

### EQ-525 Loss Estimation and Hazard Mitigation

Modelling parameters, geometric nonlinearity and material inelasticity, concentrated vs. distributed plasticity modelling approach, nonlinear dynamic analysis, selection, scaling and matching of accelerograms, nonlinear static analysis, conventional pushover analysis, multi-modal pushover analysis and adaptive pushover analysis, nonlinear static procedures, capacity spectrum method (CSM), adaptive capacity spectrum method (ACSM), N2 method, modal pushover analysis (MPA) method and displacement based earthquake loss assessment (DBELA) method, seismic vulnerability assessment of single structures using nonlinear static and dynamic procedures with special reference to Federal Emergency Management Agency (FEMA) and Applied Technology Council (ATC) provisions, seismic vulnerability assessment of groups of structures (empirical and analytical methods), hazard, exposure, human/economic losses, remote sensing and global earthquake model (GEM) initiative.

### EQ-600 Independent Study Project

Independent Study Project (ISP) provides an alternative to the credit-bearing taught courses. It allows a student to complete a supervised study in a specific area of interest. It is aimed at increasing the knowledge in a field of study. The student is required to initiate, design and execute the work under the supervision of a faculty member.

**EQ-601 Dissertation**

The dissertation provides an alternative to the credit-bearing taught courses. It must demonstrate a substantial research component and contribution to knowledge with a focus in the specific area of interest. The student should be able to design and execute the work for the dissertation under the supervision of a faculty member. The dissertation should reflect the knowledge and expertise developed by the student in the chosen research area.

**Appendix G**
**Competition on Structural Retrofit of Concrete Buildings Using Infill Masonry (CORSET)**

***Consultation Workshop on 15 January 2011***

The competition was held to transfer and promote improved understanding of the masonry infill behaviour in the analysis and design of reinforced concrete (RC) structures and to develop retrofit solutions appropriate for the Pakistani context**.** CORSET also aimed at strengthening the already existing academic-industry relations by bringing them together on a common platform. The competition was open to individual participation of invited professionals.

Five shortlisted individuals were formally invited to NED University on 5th February 2011 to attend a consultation workshop and to select a case study building through a draw. The competition buildings were selected from a group of real-world buildings. The invited individuals were asked to form their teams and subsequently invited to consultations at NED University.

Each team was required to submit the best retrofit scheme for the building in their professional judgment. Each team submitted a report with a conceptual retrofit design plan with explanatory text and computer models. The retrofit solutions were then evaluated by a jury comprising of members from the NED University and US team members. Successful team was awarded a cash prize of Rs. 100,000/- (equivalent to approximately $1150 US).

Figure F1: Prof. SFA Rafeeqi interacting with retrofit competition participants

## Appendix H
## Publication Details

**Title of the Paper:** *Diffusing Seismic Safety*

**Conference Proceedings:** *Ninth U.S National Conference and Tenth Canadian Conference on Earthquake Engineering*, Toronto, Canada, July 25-29, 2010.

**Authors:** Rodgers, J.E., Cedillos, V., Tobin, L.T., Tucker, B.E., and Kumar, H

# ABSTRACT

Despite the efforts of the earthquake engineering and earth science communities, global earthquake risk continues to grow at a rapid rate. The increase in risk occurs primarily in the rapidly growing cities of the developing world, where engineering issues are often the most easily solved part of the problem. Earthquake resistant methods for building new structures and retrofitting existing ones are available. The challenges are for local people to understand that they are at risk from earthquakes and that risk should and can be managed, and to build the political support for the idea that all elements of society should pay for risk management activities. The theory of the diffusion of innovations, which is widely applied in other professions, provides the techniques to address these challenges. GeoHazards International (GHI) has developed a diffusion-based approach to introduce earthquake safety ideas and practices. The approach applies to both technical ideas and practices, such as performance-based earthquake engineering or specific retrofit methods, and to basic risk reduction measures that empower schoolchildren, their families, teachers, government officials, hospital personnel, and others to make themselves safer now. This paper presents examples from GHI's projects in India, Pakistan, Indonesia and Nepal, and provides suggestions for enhancing the diffusion process in future earthquake safety projects.

**Title of the Paper:** *Performance based evaluation of non ductile reinforced concrete frames with and without infill.*

**Conference Proceedings:** *The 3rd Asia Conference on Earthquake Engineering, Bangkok, Thailand, December 01-03, 2010*.

**Authors:** Mohammad, A.F., Ayub, T., and Zafar, N.S.

# ABSTRACT

Structural deficiencies caused by diverse reasons demand adequate retrofit solutions. In Pakistan, non-engineered non-ductile construction is quite common causing severities to huge stock of existing buildings during an earthquake. This paper focuses on the performance based evaluation of non-ductile two dimensional frame with and without infill, retrofitted by adding struts of variable strengths in two different ways: Retrofitting soft storey and retrofitting only single interior bay gradually converting into a spine for relevant regional seismic hazard, through performance based analysis with indigenous cost effective retrofitting tech showed that the presence of infill significantly alters the collapse mechanism of bare frame as compare to retrofitted infill frame.

**Title of the Paper:** *Contribution of NED University in earthquake disaster management and related capacity building.*

**Conference Proceedings:** *Proceedings of Third International Symposium on Infrastructure Engineering in Developing Countries (IEDC-2010) and 1st International Conference on Sustainable Transportation and Traffic Management, Pakistan, July 01-03, 2010.*

**Authors:** Rafi, M.M., Lodi, S.H., Rafeeqi, S.F.A

# ABSTRACT

Natural hazards and disasters demand a proactive approach in order to mitigate their effects. Historically earthquakes are supposed to be one of the major natural hazards that have caused devastations in terms of high number of human lives, wide spread building and infrastructure failures and sufferings. Many areas of Pakistan lie in seismic risk zones and the January 2001 Bhuj earthquake made it all more important for the Pakistani nation to direct its efforts toward disaster management and mitigation. This outstanding need was further emphasized by the October 2005 Kashmir earthquke. The historical perspective which led to the establishment of Cowasjee Earthquake Study Center NED (CESNED) and the role played by it to combat this natural hazard are highlighted in this write up.

**Title of the Paper:** *An Indigenous Model of Seismic Retrofit of Stone Masonry Structures.*

**Conference Proceedings:** *Proceedings, International Conference – Urban Habitat Construction Under Catastrophic Events – COST ACTION – C26*, University of Naples, Italy, 16 – 18 September 2010.

**Authors:** Rafi, M.M., Lodi, S.H., Rafeeqi, S.F.A

# ABSTRACT

Unreinforced masonry (URM) structures are commonly constructed in different parts of Pakistan. A large number of these buildings consist of schools which are mostly low-rise perimeter bearing wall structures with wooden trusses and corrugated GI sheeting roofs. The bearing walls consist of rubble solid stone masonry units. These school buildings represent typical construction with indigenous factors such as local construction practices, traditions, custom, social values, etc. These URM structures are perhaps the most vulnerable structural type of the existing building stock owing to a lack of resistance against lateral seismic forces. Following the 2005 Kashmir earthquake, the Government of Pakistan and other non-governmental organisations have realised the importance of safety of school buildings. This paper presents the details of an indigenous retrofitting scheme which was employed on a case-study school building in Abbottabad-Pakistan keeping the fabric of aforementioned factors intact. The scheme is based on the basic concepts of strengthening weak areas and links of a structure. A 3-D finite element modelling of the building has been carried out. The performances of the original and retrofitted models were studied using El-Centro ground accelerations. The performance of the retrofitted model was found to be satisfactory and the retrofitting scheme was subsequently implemented on the case-study school building.

**Title of the Paper:** *Infill walls as a spine to enhance the seismic performance of non-ductile reinforced concrete frames.*

**Conference Proceedings:** *Proceedings, ATC-SEI Conference on Improving the Seismic Safety of Existing Buildings and Other Structures*, San Francisco, California, December 9-11, 2009.

**Authors:** Gunay, M.S., Korolyk, M., Mar, D., Mosalam, K.M., Rodgers, J.E.

# ABSTRACT

This paper reports the results of an investigation on the efficacy of using rocking spines of strengthened infill walls as a retrofit measure for non-ductile reinforced concrete (RC) frames with unreinforced masonry (URM) infill walls. The study examines the effects of spines of strengthened URM infill walls on the behavior of the RC frame, with particular emphasis on whether spines could reduce the tendency to form a soft story mechanism. For this purpose, a nine story frame with five bays is selected to represent complex multi-story behavior, where the collapse of stiff infill walls may lead to the formation of a soft story mechanism. The effect of the proposed retrofit is investigated through nonlinear static and dynamic analyses. Fragility relationships are obtained for the frames using pseudo-acceleration corresponding to the first mode as the intensity measure and maximum interstory drift ratio as the response variable. For the analyses, a progressive collapse algorithm, previously developed and implemented into the object-oriented open system for earthquake engineering simulation (OpenSees) is utilized and the interaction between the inplane strength of the infill wall and its out-of-plane strength is taken into consideration. Analyses show that infill retrofit with rocking spines provides significant improvement in the seismic performance of non-ductile RC frames.

**Title of the Paper:** *Adaptive conceptual framework for seismic vulnerability assessment of reinforced concrete buildings in Pakistan.*

**Conference Proceedings:** *Proceedings,2nd International conference on Computational Methods in Structural Dynamics and Earthquake Engineering, COMPDYN 2009, Rhodes Island, Greece, June 22-24, 2009.*

**Authors:** Haroon M., Rafeeqi S.F.A and Lodi S.H.

# ABSTRACT

The devastating Kashmir earthquake of October 2005 identified many shortfalls in the construction practices not only in the rural areas but also the growing urban areas of Pakistan. Seismic activities within and around geographical bounds of Pakistan are now being considered as a potential threat to already existing stock of buildings. In the wake of this awareness, it is the most appropriate time to develop adaptive vulnerability models and suggestive retrofit measures. This paper, therefore, highlights the undertaking in this respect. The paper briefly reviews and discusses the seismic assessment procedure in vogue in various parts of the world and their application according to the local building conditions and seismic hazards, and proposes an Adaptive Conceptual Framework for Vulnerability Assessment of Reinforced Concrete Buildings for the urban stocks of Pakistan. This framework is based on a three tier procedure in which the first level of assessment comprises of Rapid Visual Screening of a building, resulting into categorization of building into four categories and scored according to its seismic vulnerability. The second level of assessment comprises of detailed engineering assessment in which the vulnerability parameters identified from the previous level are further investigated quantitatively, leading to third level of assessment comprising of pushover analysis resulting in identifying the level of needed retrofit and/or techniques for strengthening the assessed structure.

**Title of the Paper:** *Seismic Retrofit of Non-Ductile Reinforced Concrete Frames Using Infill Walls as a Rocking Spine.*

**Conference Proceedings:** *Proceedings, Advances of Performance-Based Earthquake Engineering (ACES Workshop), M.N. Fardis, Editor, 4-7 July 2009, Corfu, Greece.*

**Authors:** *Mosalam, K.M. and S. Günay*

# ABSTRACT

Unreinforced masonry infill walls are prone to early brittle failure and they do not structurally exist after failure. Therefore, they are suitable to be considered in progressive collapse analysis. In this paper, a previously developed infill wall analytical model which considers the interaction between in-plane and out-of- plane responses is implemented into a progressive collapse algorithm. The infill wall model is utilized for investigating the efficacy of a retrofit method which comprises of strengthening the infill walls with mesh reinforcement and a concrete layer taking advantage of the strengthened infill walls as rocking spines.