Pakistan Earthquake Reconstruction and Recovery Structural Engineering Considerations

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SUMMARY:
The Pakistan Earthquake Reconstruction and Recovery Program (PERRP) was established after the devastating October 2005 earthquake in northern Pakistan/Azad-Kashmir. The authors worked in lead roles as structural engineering consultants on the team headed by CDM Constructors, Inc. The project is part of the post-earthquake recovery assistance efforts of the United States Agency for International Development (USAID). Hands-on guidance, assistance, oversight and training were provided to local engineers in order to properly rebuild numerous education and healthcare facilities in the affected area. The PERRP team's efforts ranged from accurately assessing the area's seismic hazard to modernizing the pre-event approaches utilized locally for structural design/construction. The main objective was to achieve essential conformance with the Uniform Building Code (1997 UBC), taking into account local factors. Scores of school and healthcare facilities were successfully completed across this magnificent and challenging mountainous region of the Karakoram and Himalayan Ranges.

Keywords: Reconstruction, Pakistan, Earthquake-Resistant, UBC, Schools

1. INTRODUCTION

On October 8, 2005 at 8:50 a.m. local time, a magnitude Mw=7.6 earthquake struck the western Himalayan (Karakoram) region of northern Pakistan and Kashmir. The earthquake caused widespread death and destruction in the region with notably pronounced losses in public schools and healthcare facilities (Figure 1.1.). The Pakistan government launched a reconstruction and recovery program through the Earthquake Reconstruction & Rehabilitation Authority (ERRA). This reconstruction program is funded by multiple private and public donor organizations including a number of international donors. One such program is funded by the United States Agency for International Development (USAID - a division of the US State Department) and managed by CDM Constructors, Inc. The authors served as specialized structural engineering consultants on the team with the aim of achieving internationally acceptable standards of earthquake resistant design and construction for the buildings that were proposed to be built under the program. The consultant team began this project with the assumption that all design work would be performed by local A/E firms. Due to various factors, including the limited number of qualified local engineers and an inconsistent level of knowledge and proficiency in earthquake resistant design, it soon became clear that a small design office led by American design professionals located in CDM's Islamabad office was needed in order to oversee the work of local A/E firms and in-house technical staff. Local engineers had proposed the use of the same conventional structural system for the new buildings, i.e. masonry infilled reinforced concrete frames (MICF). A number of the common deficiencies found in such systems were clearly evident in the numerous structural failures of old and newer structures in the Kashmir Earthquake. It was decided that the prudent approach for the PERRP project would be to utilize essentially code conforming structural systems properly designed and detailed for a satisfactory level of earthquake resistance aimed at a "Life-Safety" performance objective in a major earthquake.

Figure 1.1. Chowki Girls School Completely Destroyed in the Earthquake (Hussain, 2007)

The Uniform Building Code (1997 UBC) was selected as the main basis document for the project and design guidelines were created along with construction quality assurance provisions, also drawing on the International Building Code (IBC 2006) that were to be followed/enforced by the project team from concept through construction of each of the projects. The first order of business was to establish a proper assessment of the true seismic hazard in the project area (El Nashai, 2006). It is often mistakenly assumed that systematic, well planned and effectively implemented improvements in design and construction will end up substantially increasing the cost of building construction in these regions. The PERRP experience has shown that with very modest increases in total construction costs resulting from the adoption of the measures explained above, a significant enhancement can be obtained in the expected seismic performance of structures, thus saving precious lives and reducing damage in future earthquakes.

2. DEFICIENT STRUCTURAL SYSTEMS

The CDM design oversight office based in Islamabad, Pakistan started work around May, 2007. At that time a local A/E firm was attempting to finish their design on two high school buildings. The structural system proposed by the local firms for these two buildings was the same system typically used in building construction in Pakistan, i.e. masonry infilled concrete frames (MICF). A number of the common deficiencies found in such typical systems were evident in early versions of the structural drawings for these projects, such as frame members not properly detailed for ductile behavior, masonry infill walls not reinforced for out-of-plane loading, infill walls not isolated from the adjoining concrete frames, roof/floor diaphragms not properly connected to the lateral system, inadequate layout of footings etc. Furthermore the design was based on inappropriate and un-conservative seismic design criteria. The design oversight office called for a comprehensive structural redesign of these projects based on a proper and rational structural design approach as outlined below, in accordance with the formulated basic seismic design criteria and approach mentioned above. It is important to note that this type of flawed structural system (MICF) is quite common not just in this part of the world but also in quite a few other countries around the globe (Figure 2.1.). The performance of MICF buildings has been extensively studied by engineers and researchers all over the world. One such group of leading earthquake design experts, supported by the Earthquake Engineering Research Institute (EERI, Oakland, CA) is World Housing Encyclopedia (WHE).

According to WHE (www.world-housing.net), there are more than 37 countries containing high seismic regions across the globe, where reinforced concrete along with masonry is the material of choice for housing and other building construction.

Reinforced concrete frames with infill masonry are extensively used for construction in many regions of high seismic risk, such as Latin America, southern Europe, North Africa, Middle East and south-east Asia. Recent earthquakes across the world, including the 1999 earthquake in Turkey, 2001 earthquakes in India and Taiwan, 2003 earthquake in Algeria and more recently the 2005 earthquake in Pakistan have revealed major deficiencies in these buildings, some of which led to catastrophic collapses causing death tolls measured in the tens of thousands. Information coming out from Sichuan province in China which suffered the M=7.9 earthquake in May of 2008 appears to also corroborate this point.


3.

Figure 2.1. Urban Area Home Collapsed in the Earthquake (Hussain, 2005)

3. IMPROVING STRUCTURAL DESIGN AND CONSTRUCTION DETAILING FOR EARTHQUAKE RESISTANCE

As mentioned above, following extensive consultations between the authors, CDM and USAID it was decided that the prudent approach for the PERRP project would be to utilize code conforming structural systems properly designed and detailed for a satisfactory level of earthquake resistance. The objective was set at an essential “Life-Safety” performance level in a major earthquake of the type experienced in Kashmir in October 2005. The Uniform Building Code (1997 UBC) was selected as the basis document for the project based on the following reasoning. The UBC is very well known across the world including in Pakistan where many provisions of this code are routinely, albeit sometimes inappropriately, used by local engineers to design buildings. The concrete design provisions of the UBC which are essentially the same as the ACI code are the most commonly used concrete structural design provisions in Pakistan. Given the numerous problems with typical MICF construction in Pakistan and after a study of various alternatives it was decided that reinforced concrete shear walls would be used as the primary lateral-force-resisting system for the PERRP buildings. This made eminent sense since these buildings already had numerous partition or exterior

walls called for in the architectural design. Therefore a selected few of these walls could easily be used as shear walls and other designated nonstructural walls would be properly designed and detailed to perform satisfactorily in large earthquakes. Reinforced concrete slab-beam-column construction was used to resist gravity loading and reinforced masonry block walls were used as nonstructural partitions. The decision to use reinforced concrete and masonry blocks for wall construction was based on a number of factors like abundance of ingredient materials in the region, low cost of construction, easy availability of trained workforce, low maintenance costs and the inherent durability of concrete.
Similar to most building projects in high seismic areas of the United States, structural engineers sometimes face challenges as they work with architects to ensure adequate lengths of shear walls along the perimeter/exterior of the building. Openings for windows, doors, breezeways etc. have to be contended with to obtain contiguous shear walls piers that run from roof to foundation. The demand for large windows is greater in this region of the world because classrooms rely primarily on daylight for adequate visibility. The design group, working closely with the local architectural consultants, managed to obtain adequate lengths of walls along the perimeter of the PERRP buildings.

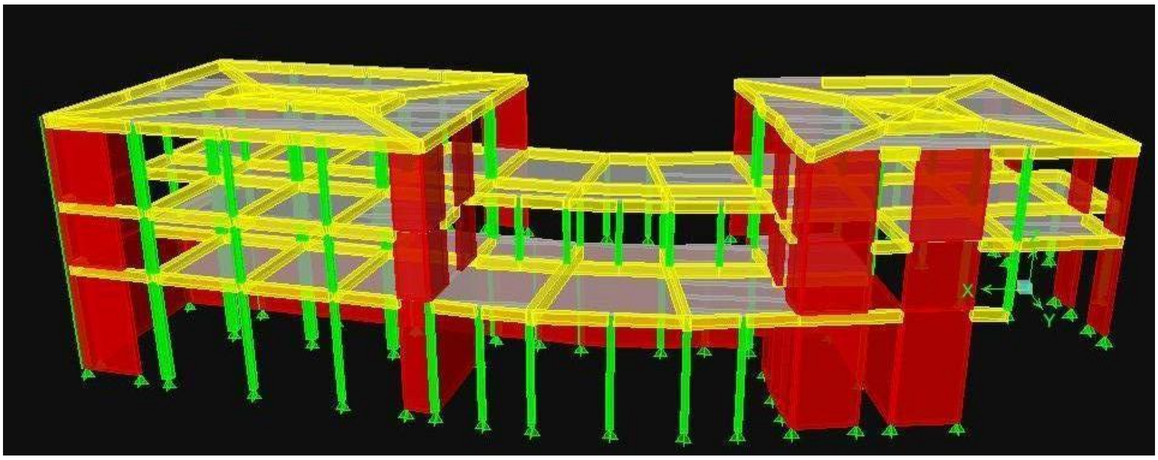

Figure 3.1. 3-D ETABS computer structural model of New Chowki Girls High school

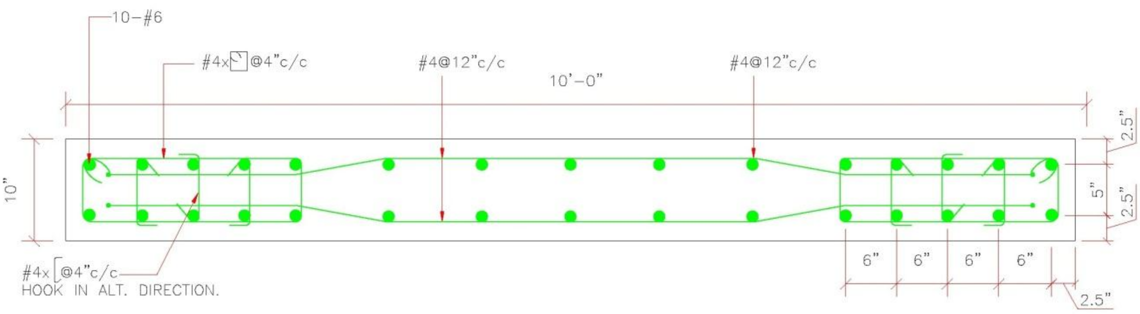

Figure 3.2. Plan view of shear wall rebar layout

One such example of shear wall layout is shown as a computer model in Figure 3.1. This is a 17,000 SF Girl's high school building located in a small town named CHOWKI in the BAGH district of AZAD JAMMU KASHMIR (AJK), the Pakistani controlled region of Kashmir. This building uses the appropriate Importance Factor as per UBC-97 (UBC, 1997) table 16-K. The site is located close to an active earthquake fault Type A which is in an area classified as seismic zone 4, therefore near source factors Na=1.5 & Nv=2.0 have been used. An R value of 4.5 as per table 16-N, Sd type soil profile with seismic coefficients Cv=0.64Nv and Ca=0.44Na are used as seismic design parameters. A three dimensional computer model of the building was produced and analyzed on the ETABS (ETABS, 2007) computer program. The shear wall web and boundaries are properly reinforced for ductility as per UBC-97 section 1921.5.2 as shown in Figure 3.2.

Billet steel A615 reinforcement as per UBC section 1921.2.5.2 is specified in the boundary zones, which is locally manufactured and easily available in the market. Concrete beam-column members are used to support the concrete floor and roof slabs for tributary gravity loading only. These “frames” are not part of the lateral-force-resisting system. The columns are detailed as shown in Figures 3.3. and 3.4. as per UBC-97 section 1921.7 to maintain support of gravity loading when subjected to the expected inelastic deformation caused by the earthquake forces.

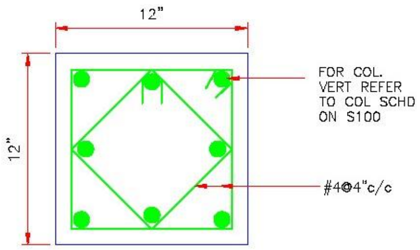

Figure 3.3. Column rebar layout detail

Figure 3.4. Column rebar cage construction photo

When the building frame is subjected to inelastic level deformation, a hinge is typically formed at the top of the column and providing extra ties in the column as per section 1921.4.4 keeps the column intact and prevents total or partial building collapse which is the minimum life-safety and serviceability requirement of the building code. The Code requirements for column rebar confinement result in a fairly large number of ties in the columns which most local contractors are typically not used to seeing. Concrete floor and roof slabs and beams are designed for tributary dead and live loading, which is a fairly routine design procedure for local consultants. In fact their design of these components for gravity loading is quite efficient and cost effective. Material use is minimized through design optimization. However diaphragm action and the need for proper diaphragm design of these elements is commonly not well understood by the local consultants. The concept of story shear, drag, collector and chord forces in the diaphragms had to be explained and illustrated to the local consultants. This eventually led to the proper design of these seismic force resisting elements and to their inclusion in the design drawings.

Concrete Masonry Unit (CMU) block walls have been used for partitions and exterior walls for these projects. These blocks are locally manufactured as per ASTM C90 and are readily available in the market. The block walls are isolated at the top to allow for the in-plane movement of the diaphragm but anchored and properly reinforced for out-of-plane loading as per section 1633.2.8 as shown in Figure 3.5., so the walls do not collapse and injure or kill the occupants or pedestrians during an earthquake.

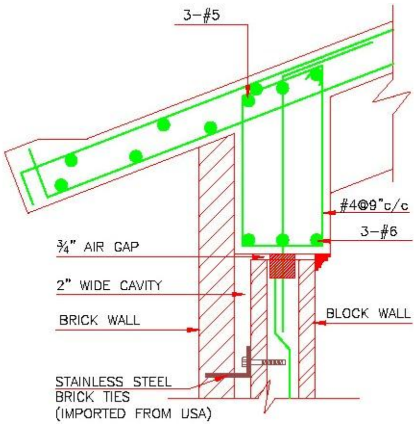

Figure 3.5. CMU/Brick veneer connection detail

4. CONSTRUCTION CONSIDERATIONS

The structural performance of buildings in large earthquakes, where ductility is of greater importance than simply the elastic strength and stiffness of structures, depends heavily not only on proper structural design and detailing but more importantly on proper quality control during construction. This aspect of delivering earthquake-resistant building structures for this project was particularly emphasized by the CDM team. A concerted effort was made to develop proper observation and inspection requirements duly noted in the specifications, training the inspectors and keeping close tabs on the construction of seismic system elements on-site. As part of this process, regional inspection offices in the vicinity of actual construction sites were set up. These inspection offices are staffed with experienced inspectors and resident engineers who are further trained on the UBC-97 Chapter 17 inspection program as well recent construction quality provisions of the 2006 IBC. A detailed construction inspection program which outlines the various types of inspections, different stages for these inspections and inspection frequency has been developed as shown in Fig.4.2.

5. SUMMARY AND CONCLUSIONS

The PERRP Program funded by USAID aims to build numerous adequately earthquake-resistant schools and healthcare facilities in northern Pakistan following the devastating Kashmir Earthquake of October 2005. Though there are a number of well educated and knowledgeable structural engineers practicing in Pakistan, CDM’s experience has shown that the overall practice of earthquake resistant structural design and construction, particularly outside the major urban centers, often does not meet the standards that should be expected in high seismic regions. The PERRP experience has shown that the public safety and performance benefits obtained by introducing well thought out, locally appropriate and rigorously applied basic standards in seismic-structural design and construction are by no means cost-prohibitive. With very modest increases in total construction costs resulting from the adoption of the measures explained above, significant improvements can be expected in the seismic performance of newly built structures (Fig. 5.1.), thus saving lives and reducing damage in sure-to-come future earthquakes in the region.

CONSTRUCTION INSPECTION PROGRAM

TYPES OF WORK	CONTINUOUS	PERIODIC	COMMENTS
SOILS			
FOOTING'S BASE SOIL			GEOTECH ENGINEER INSPECTION & APPROVAL REQUIRED
GRADING, EXCAVATION & FILL			REF. PROJECT SPECIFICATION
CONCRETE			
PLACEMENT OF REINFORCING STEEL			
WELDING OF A706 REINFORCING STEEL FOR EMBEDS LARGER THAN #5			
-#5 & SMALLER			
BOLTS CAST IN CONCRETE			
PLACING OF REINFORCED CONCRETE			
TAKING OFF TEST SPECIMENS			
STRUCTURAL WELDING			
SINGLE PASS FILLET WELDS NOT EXCEEDING 5/16"			
FILLET WELDS EXCEEDING 5/16"			
GROOVE WELDS (FULL OR PARTIAL PEN)			
WELDED STUDS			
STRUCTURAL MASONRY			
PRISM PREPARATION / TEST SPECIMENS			
UNIT PLACEMENT			
PLACEMENT OF REINFORCING STEEL			
GROUT SPACE			
GROUT PLACEMENT			
OTHER			
REINFORCING STEEL MECHANICAL SPLICES			PER ICC/ICBO EVALUATION REPORT
ADHESIVE ANCHOR INSTALLATION			PER ICC/ICBO EVALUATION REPORT
EXPANSION BOLT INSTALLATION			PER ICC/ICBO EVALUATION REPORT
MASONRY VENEER ANCHORS			

CONSTRUCTION INSPECTION PROGRAM FOOTNOTES:

1. PROVIDE CONSTRUCTION INSPECTION, CONSTRUCTION TESTING, REPORTING AND COMPLIANCE PROCEDURES ACCORDING TO CHAPTER 17 OF THE UBC-97 BUILDING CODE.
2. PRIOR TO THE BEGINNING OF CONSTRUCTION, REVIEW THE CONSTRUCTION INSPECTION REQUIREMENTS WITH THE ARCHITECT, ENGINEER, BUILDING OFFICIAL, GENERAL CONTRACTOR AND CONSTRUCTION INSPECTORS.
3. DUTIES OF THE CONSTRUCTION INSPECTOR INCLUDE, BUT ARE NOT LIMITED TO:
   A. OBSERVE THE WORK FOR CONFORMANCE WITH THE APPROVED DRAWINGS AND SPECIFICATIONS. BRING DISCREPANCIES TO THE IMMEDIATE ATTENTION OF THE GENERAL CONTRACTOR FOR CORRECTION, THEN, IF UNCORRECTED, TO THE ENGINEER AND TO THE BUILDING OFFICIAL.
   B. FURNISH INSPECTION REPORTS FOR EACH INSPECTION TO THE BUILDING OFFICIAL, ARCHITECT,STRUCTURAL ENGINEER, GENERAL CONTRACTOR AND OWNER IN A TIMELY MANNER.
   C. SUBMIT A FINAL REPORT STATING WHETHER THE WORK REQUIRING CONSTRUCTION INSPECTION WAS INSPECTED, AND WHETHER THE WORKS IN CONFORMANCE WITH THE APPROVED DRAWINGS AND SPECIFICATIONS.
5. DUTIES TO THE GENERAL CONTRACTOR INCLUDE, BUT ARE NOT LIMITED TO:
   A. NOTIFY CONSTRUCTION INSPECTOR THAT WORK IS READY FOR INSPECTION AT LEAST 24 HOURS BEFORE INSPECTION IS REQUIRED.
   B. MAINTAIN ACCESS TO WORK REQUIRING INSPECTION UNTIL IT HAS BEEN OBSERVED AND INDICATED TO BE IN CONFORMANCE BY THE CONSTRUCTION INSPECTOR AND APPROVED.
   C. PROVIDE THE CONSTRUCTION INSPECTOR WITH ACCESS TO APPROVED DRAWINGS AND SPECIFICATIONS AT THE JOB SITE.
   D. MAINTAIN JOB-SITE COPIES OF ALL REPORTS SUBMITTED BY THE CONSTRUCTION INSPECTOR.
6. DEFINITIONS:
   A. CONTINUOUS INSPECTION: THE SPECIAL INSPECTOR IS OBSERVING THE WORK REQUIRING SPECIAL INSPECTION AT ALL TIMES.
   B. PERIODIC INSPECTION: THE SPECIAL INSPECTOR IS ON SITE AS REQUIRED TO CONFIRM THAT THE WORK REQUIRING SPECIAL INSPECTION IS IN CONFORMANCE.

SPECIAL TESTING REQUIREMENTS

1. STRUCTURAL FILL OR BACK-FILL:
   VERIFY COMPACTION WITH RANDOM FIELD DENSITY TESTS.
2. STRUCTURAL CONCRETE:
   SAMPLE AND TEST ACCORDING TO STRUCTURAL NOTES, DRILL CORES AND TEST AS REQUIRED BY STRUCTURAL ENGINEER.
3. STRUCTURAL MASONRY:
   SAMPLE AND TEST ACCORDING TO STRUCTURAL NOTES.

STRUCTURAL OBSERVATION

STRUCTURAL OBSERVATION, IN ACCORDANCE WITH SECTION 1702 OF THE UBC-97 BUILDING CODE, SHALL BE PERFORMED BY CDM STRUCTURAL GROUP, ISLAMABAD OFFICE. IN THE FOLLOWING SEQUENCE. THE GENERAL CONTRACTOR SHALL CONTACT THE STRUCTURAL ENGINEER FIVE (5) WORKING DAYS PRIOR TO COMPLETION OF THE STAGE INDICATED BELOW TO COORDINATE THE DATE OF OBSERVATION:

1.	FOUNDATIONS:	PRIOR TO CONCRETE POUR. FOLLOWING PLACEMENT OF REINFORCING.
2.	CONCRETE CONSTRUCTION:	PRIOR TO CLOSING FIRST LEVEL COLUMN OR WALL FORMS. DURING PLACEMENT OF SLAB/BEAM REINFORCEMENT.
3.	MASONRY CONSTRUCTION:	DURING LAY UP OF THE FIRST SECTION OF WALL WITH SPECIAL REINFORCEMENT REQUIREMENTS. PRIOR TO GROUTING OF FIRST LIFT.

Figure 4.1. Construction Inspection Program

Figure 5.1. Completed New Chowki Girls School Building

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