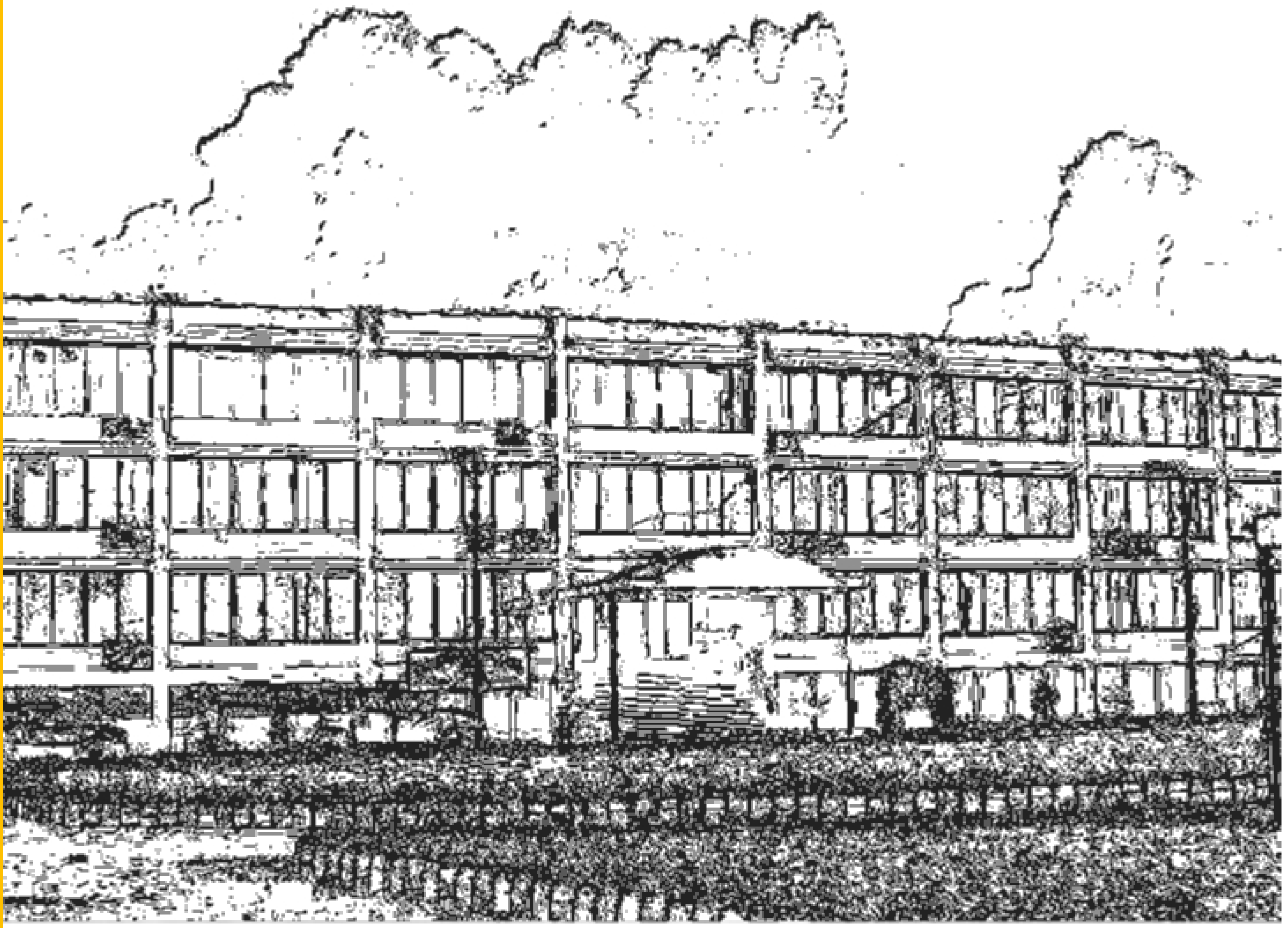

Four Storey Office Building in Muzaffarabad

A Case Study of Seismic Assessment and Retrofit Design

NED University of Engineering & Technology, Karachi

GeoHazards International
A Nonprofit Working Toward Global Earthquake Safety

Supported by the Pakistan-US Science and Technology Cooperation Program

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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.

About the Project

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

Case Study Participants

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

This case study building was investigated by Mr. Aslam Faqeer Mohammad, Assistant Professor, Department of Civil Engineering, NED University of Engineering and Technology, and Ms. Shahida Manzoor and Mr. Naveed Alam, Research Assistants and Master of Engineering students in the Department of Civil Engineering, NED University of Engineering and Technology.

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

Contents

Introduction

The Tier 1 vulnerability assessment exercise carried out by the team members gave them the opportunity to evaluate a real building with all the physical constraints. On the basis of the vulnerabilities found through the Tier 1 assessment and Tier 2 (linear static structural analysis) assessment was carried out to evaluate the vulnerabilities and potential solutions in more detail and the results showed that further Tier 3 analysis was not needed. The Tier 2 analysis provided the members a chance to do hands-on practice on ETABS and understand the ASCE/SEI 31-03 and FEMA documents.

Building Information

The building, shown in Figure 1, is a four storey (ground plus three) office building with a basement. The building's overall dimensions are 176'-3" by 52'-6" and it is approximately 48 feet tall. The building has a reinforced concrete moment frame structural system with 8 inch thick concrete block infill walls, which are present only in the shorter direction. The building has no infill walls in the long direction. The foundation is a reinforced concrete raft foundation. The building is newly constructed and is in reasonably good condition. No condition assessments or repairs have been made.

Figure 1. Front elevation view

The building's architectural and structural drawings are shown in Figure 4 through Figure 10. Typical storey height is 10'-0" having typical column sizes of 18"x18" and typical beam sizes of 18"x17.5". The typical slabs are 5.5" thick. Original design calculations were carried out using ACI-99 and earthquake analysis was carried out using UBC-97.

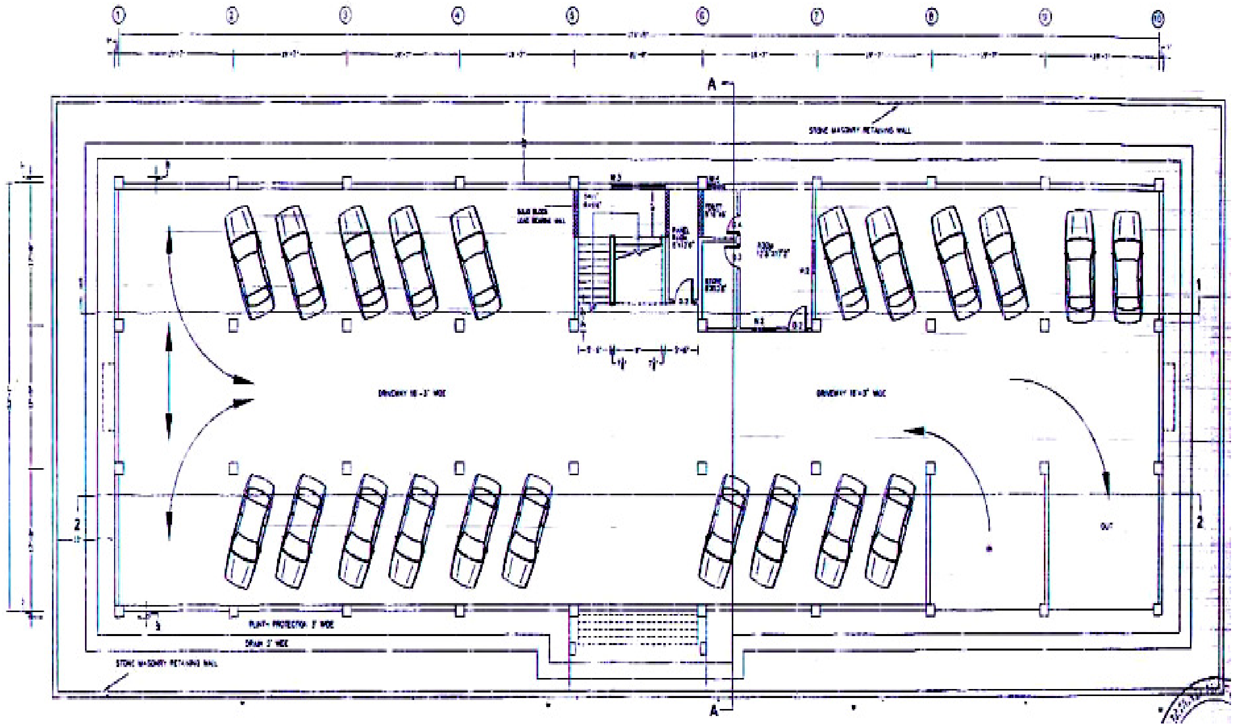


Figure 2. Architectural plans of basement

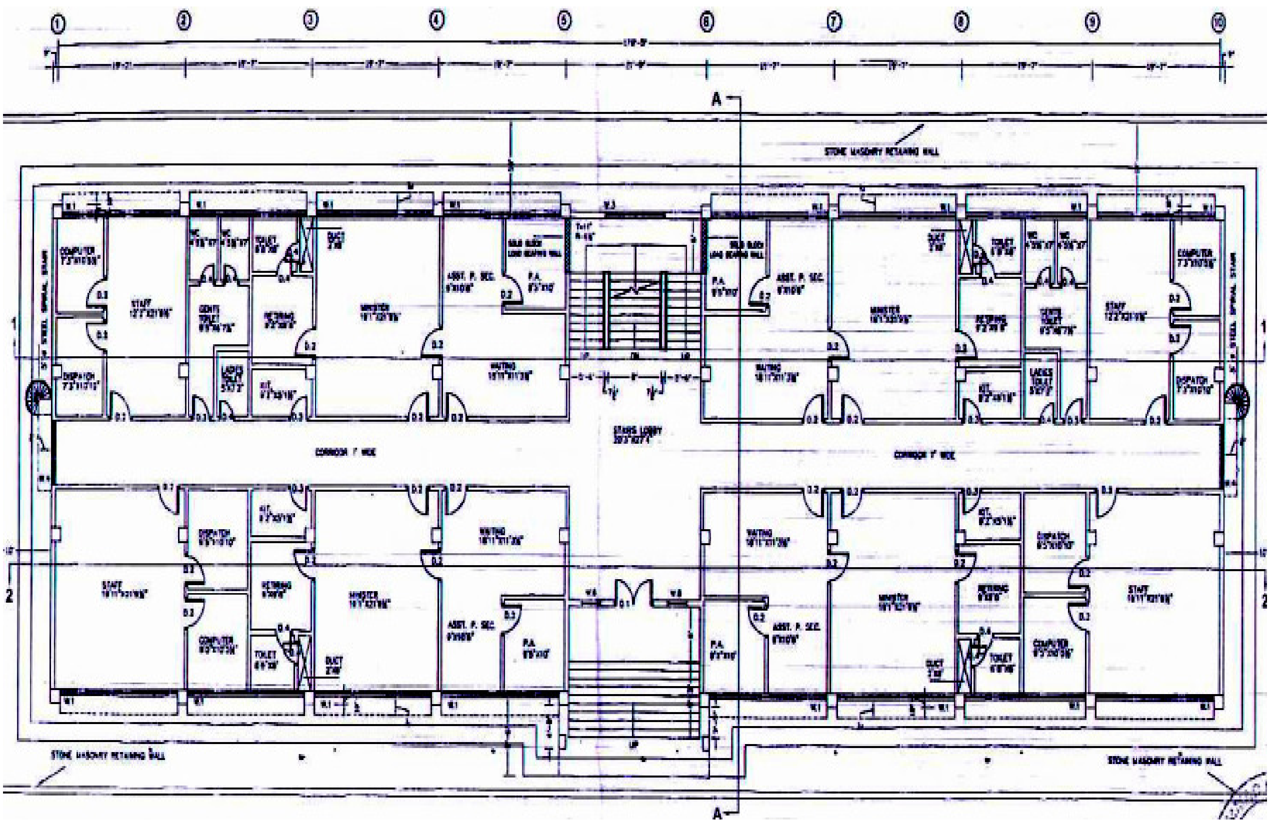


Figure 3. Architectural plans of ground floor

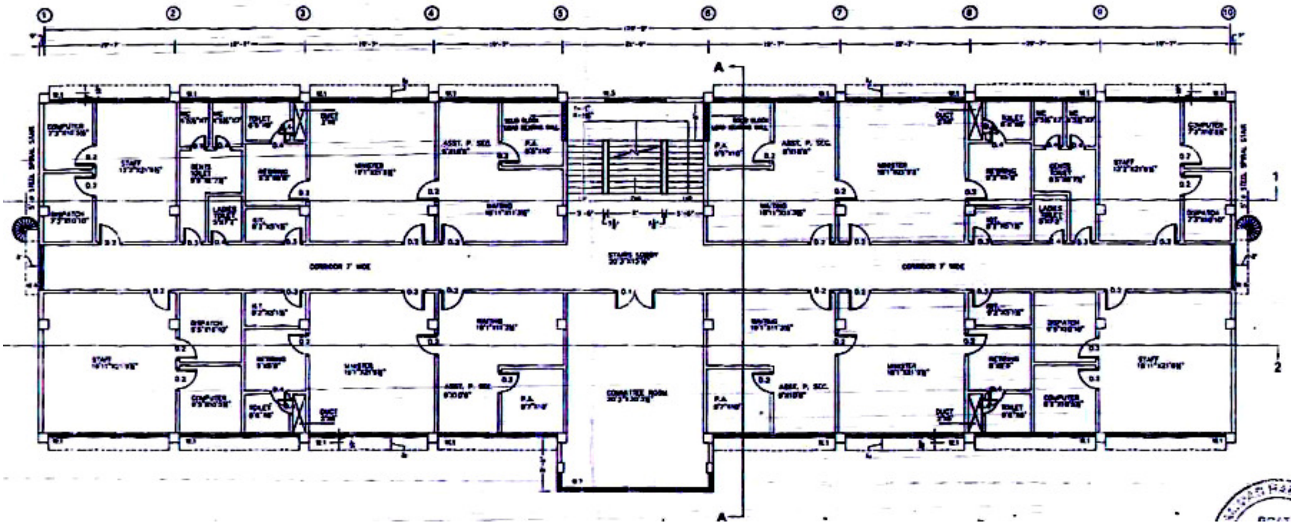


Figure 4. Architectural plans of first and second floor

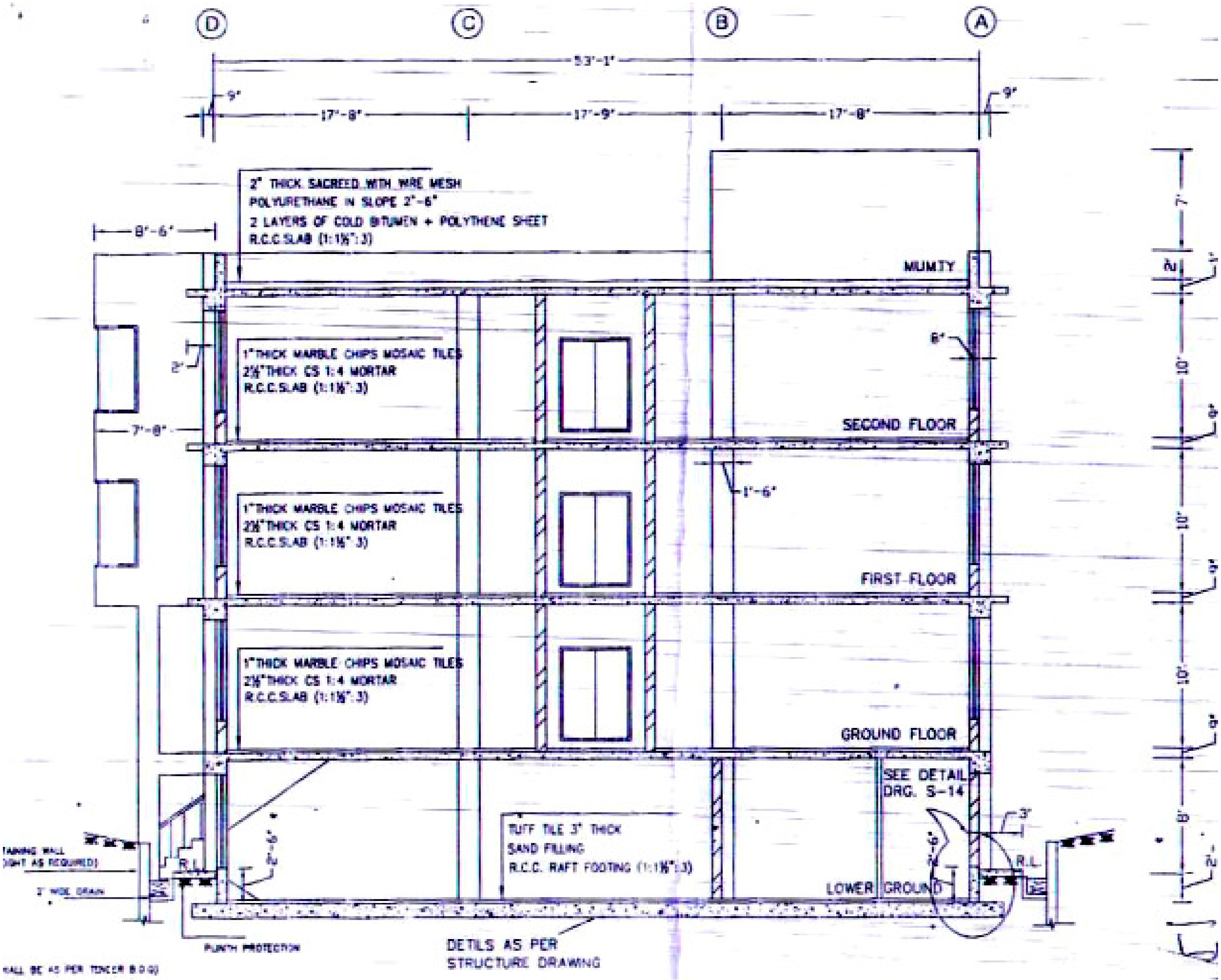


Figure 5. Architectural typical section in elevation

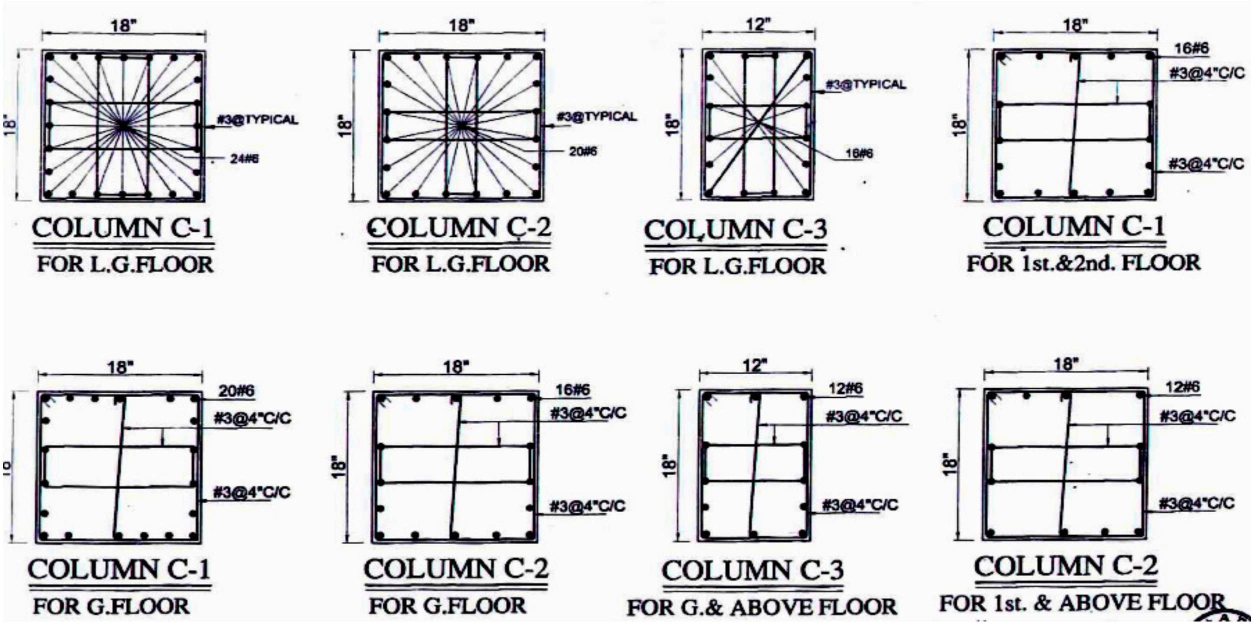


Figure 6. Column sections

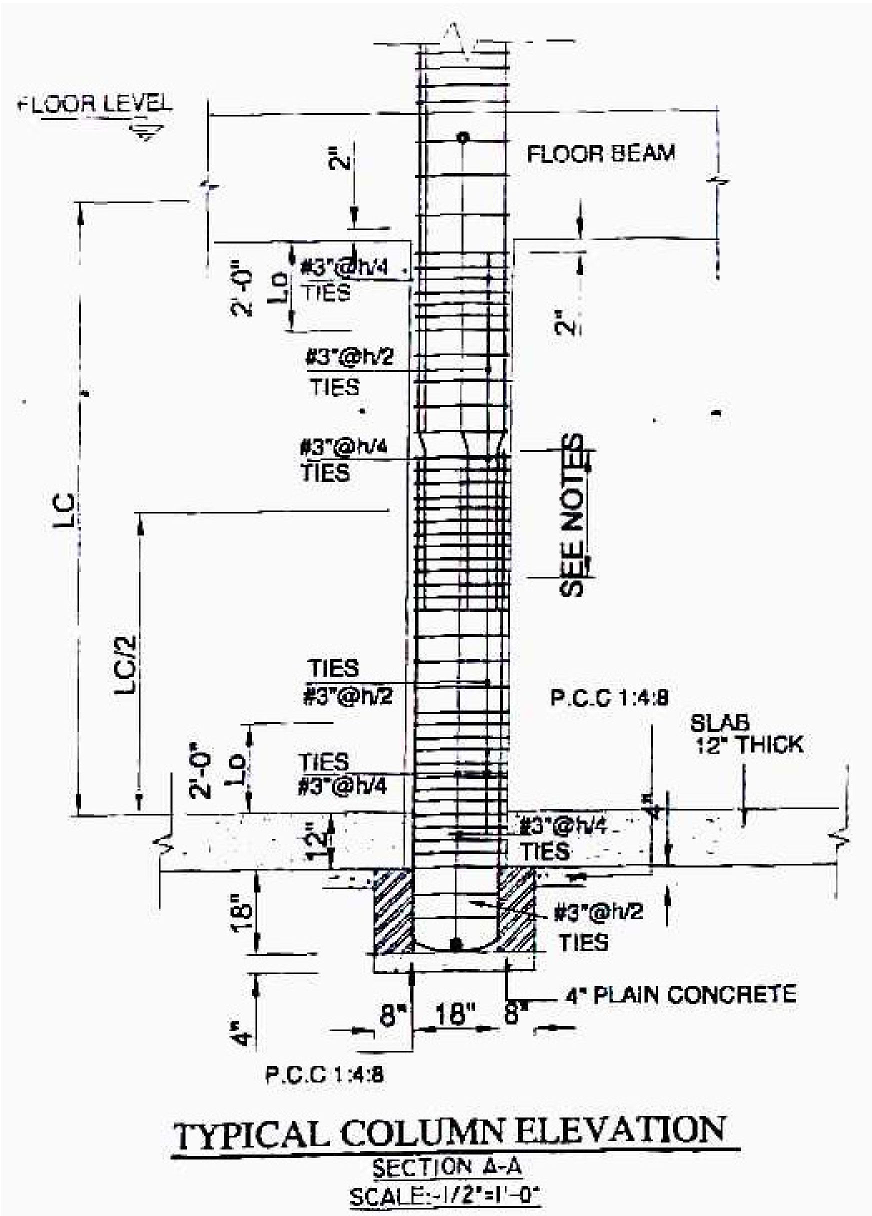


Figure 7. Structural drawings for columns

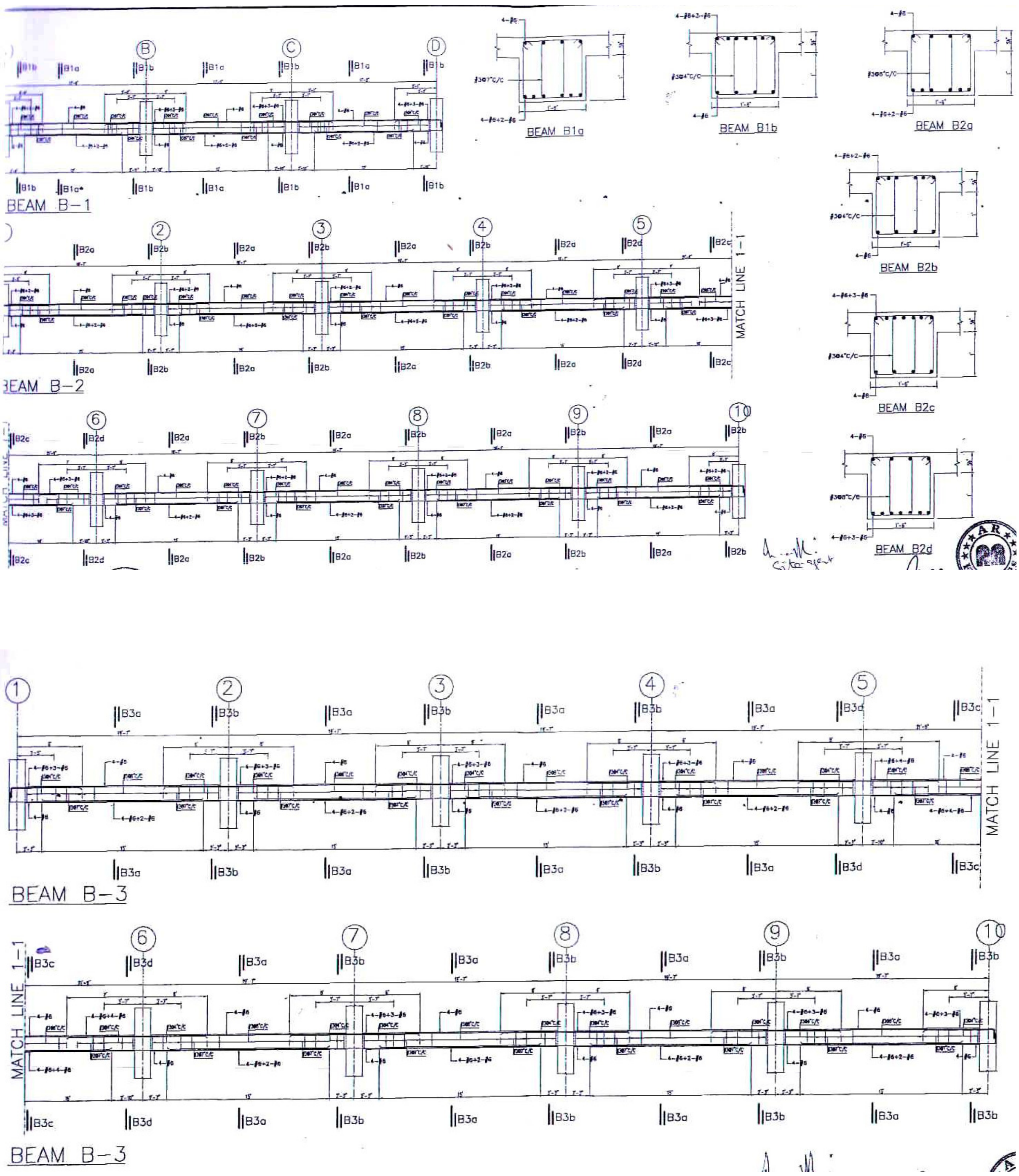


Figure 8. Structural beam elevations

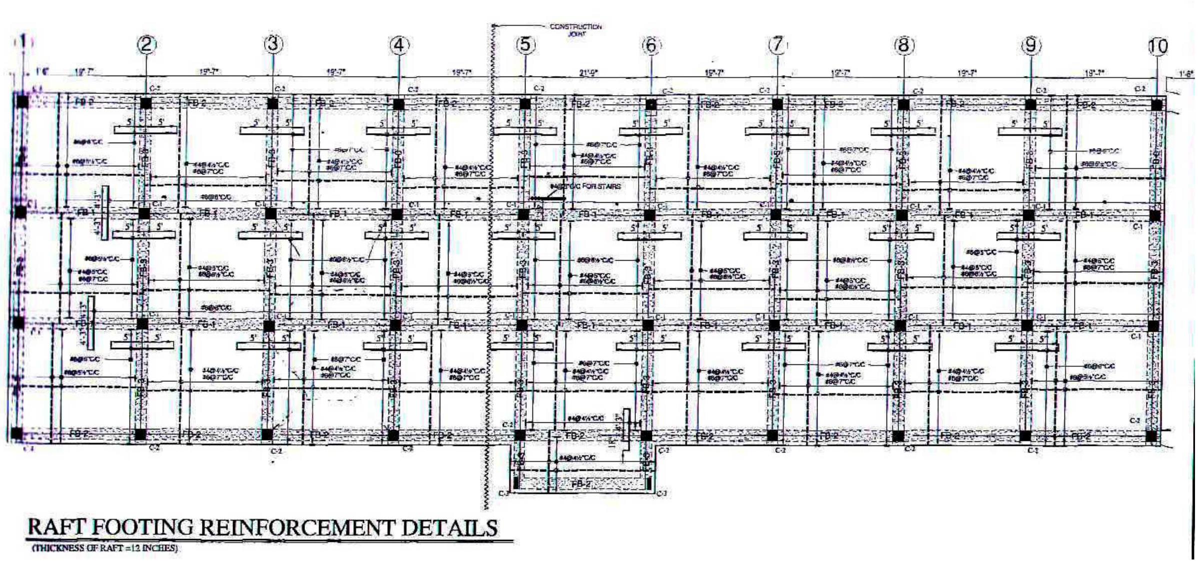


Figure 9. Structural raft foundation

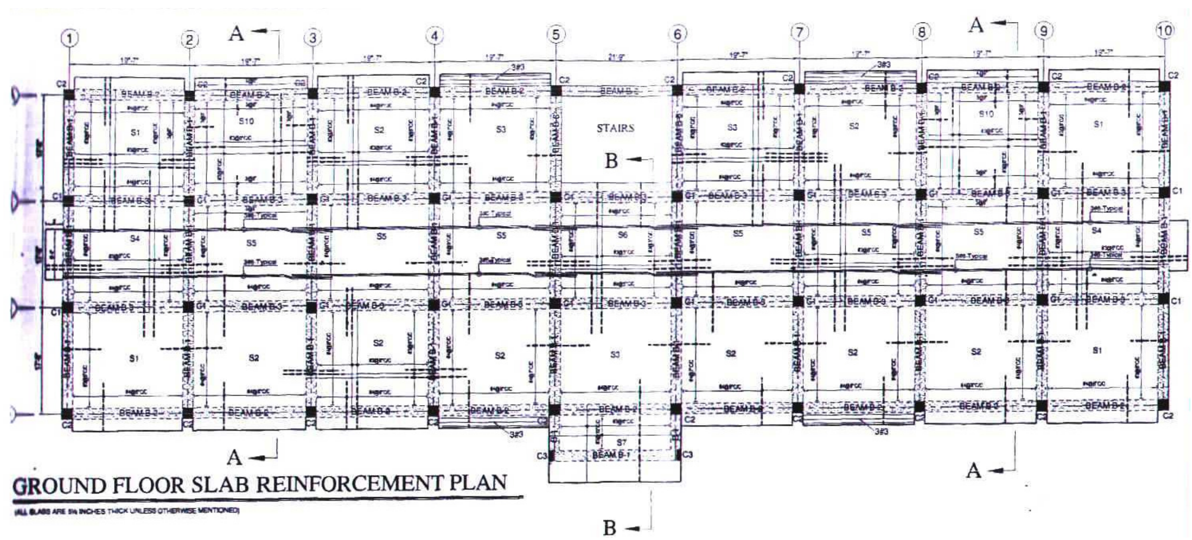


Figure 10. Reinforcement details for floor slabs

Site Information

The building is located in an area with firm soil, where bedrock outcrops are often found close to the surface. No known active faults pass through or near the site. The bearing capacity of the soil is 2.0 tons per square foot (tsf).

Hazard Information

Muzaffarabad-AJK's current seismic zoning under the National Building Code of Pakistan is Zone 4.

Initial and Linear Evaluations of Existing Building

Checklist-based Evaluation

The building was assessed using a version of the FEMA 310 Tier 1 Checklist modified for Pakistan conditions. This Tier 1 assessment indicated a number of non-compliant items (i.e., deficiencies) in the building, which are summarized in Table 1.

Table 1. Tier 1 assessment results

Checklist	Tier 1 Non-compliant Items
Building System	Soft storey Weak storey Mass irregularity Torsion irregularity
Lateral Force-resisting System	Captive column Strong column weak beam
Geologic Hazards and Foundation	None

Linear Evaluation

A 3-D model of the building was developed in ETABS Nonlinear version 9.7.0, using the modeling parameters shown in Table 2. The model is shown in Figure 11. The beams and columns were modeled with linear beam-column elements, and the infill walls were modeled with single linear compression struts. The team then performed a linear static analysis. This analysis shows that there are no columns with demand/capacity ratios (DCRs) greater than one, so the building is not expected to respond in the nonlinear range, except for a small number of captive columns that need retrofit measures to resolve the captive condition. Please see Appendix B for linear analysis results.

Table 2. ETABS modelling parameters

Dead load Live load	Self weight. 6” thick wall load 20 psf partition load 30 psf finishes load 60 psf
Earthquake load Z C_a C_v	 0.4g $0.4N_a$ and N_a =1.0 $0.4N_v$ and N_v =1.0
Soil type	S_B

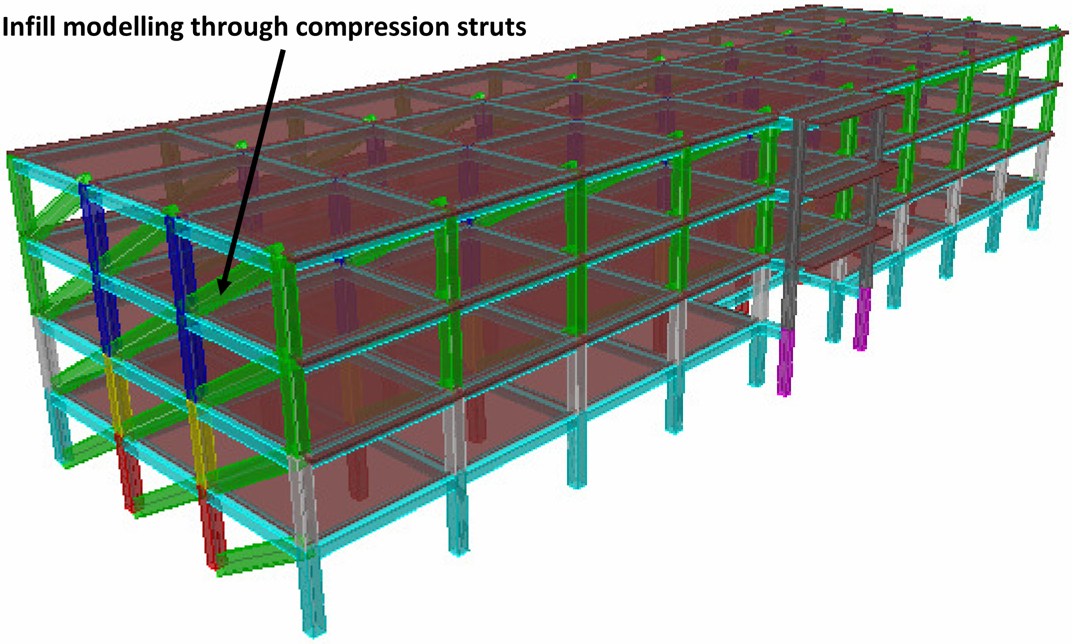


Figure 11. Rendering of linear ETABS model of the building

The team also conducted the other checks mandated in ASCE 31 for Tier 2 analysis based on the Tier 1 Checklist results. Despite using a modified FEMA 310 Tier 1 Checklist there was enough correspondence between items in the ASCE 31 Tier 1 Checklist and the modified FEMA 310 checklist to use ASCE 31's Tier 2 checks directly. For this building, the required Tier 2 checks were for mass irregularity (shown in Table 3), torsion irregularity (shown in Table 4), soft storey (shown in Table 5), and storey drift (shown in Table 6).

Table 3. Mass irregularity check

		% diff in Mass (50% allow)	
		% difference compare to	
Story	MassX	Above storey	Below storey
ROOF	3.9946	---	26
2ND	5.3732	35	0
1ST	5.3732	0	7
GROUND	5.006	7	---

From the above data, no mass irregularity is found in the structure.

Table 4. Torsion irregularity check

Story	Diaphragm	XCM	YCM	XCR	YCR	% diff X (allow 20%)	% diff Y (allow 20%)
ROOF	D1	1070.37	372.236	1070.5	370.614	0.0	0.3
2ND	D1	1070.53	369.543	1070.5	372.737	0.0	0.5
1ST	D1	1070.53	369.543	1070.5	375.477	0.0	0.9
GROUND	D1	1070.22	378.871	1070.5	374.546	0.0	0.7

From the above data, no torsion irregularity was found in the structure.

Table 5. Soft storey check

Story	Load	storey force	Total Displacement	Stiffness	% diff in K (30% allow)	
					% difference compare to	
		kips	inches	kip/in	Above storey	Below storey
ROOF	EX	300	1.9053	157.46	----	17.2
2ND	EX	301	1.5822	190.24	20.8	0.6
1ST	EX	201	1.0502	191.39	0.6	17.0
GROUND	EX	94	0.4078	230.51	20.4	----
Story	Load	storey force	Total Displacement	Stiffness	% diff in K (30% allow)	
					% difference compare to	
		kips	inches	kip/in	Above storey	Below storey
ROOF	EY	448	1.0063	445.20	----	13.5
2ND	EY	453	0.8806	514.42	15.5	12.7
1ST	EY	301	0.6596	456.34	11.3	12.1
GROUND	EY	140	0.344	406.98	10.8	----

From the above data, no Soft storey was found in the structure.

Table 6. Storey drift check

Story	Etab Drift X	Code Modified Drift	Etab Drift Y	Code Modified Drift
	Δ_S	Δ_M	Δ_S	Δ_M
ROOF	0.002711	0.01044	0.001273	0.00490
2ND	0.004468	0.01720	0.002244	0.00864
1ST	0.005391	0.02076	0.003187	0.01227
GROUND	0.003431	0.01321	0.003398	0.01308

From the above data, the first storey drift in the X-direction is slightly higher than allowable limit.

Detailed Evaluations of Existing Building

Through the results of linear static analysis, as shown in Appendix B, the building response is not expected to go into the nonlinear range, furthermore the checks for building system (mass irregularities, torsion etc.) in Tier 1 analysis which were assumed non-compliant through visual inspection, came out to be compliant in Tier 2 analysis i.e. the building has satisfactorily passed the Tier 2 analysis, except for a small number of captive columns that could be dealt with by disconnecting or removing partial-height masonry infill walls. Hence there is no need to perform Tier 3 (nonlinear) analysis.

Retrofit Solution

Conceptual Solutions Considered

As can be seen in Figure 12 , there are captive columns in the bottom left corner of the front elevation of building. This is the only check that remained non-complaint after the Tier 2 analysis. Because the captive columns are created by partial-height masonry infill walls, conceptual solutions include creating a gap between the infill and column, which would be filled with elastomeric material, or replacing the infill walls with the same panels as used on the right side of the building, glazing, or a wire screen.

Figure 12. Captive columns at ground storey

Recommended Retrofit Solution

The case study team recommends that to eliminate the captive columns, the partition walls maybe replaced with a similar configuration used on the right side of the building or having glass windows installed as done in the above floors.

Appendix A: Tier 1 Checklists

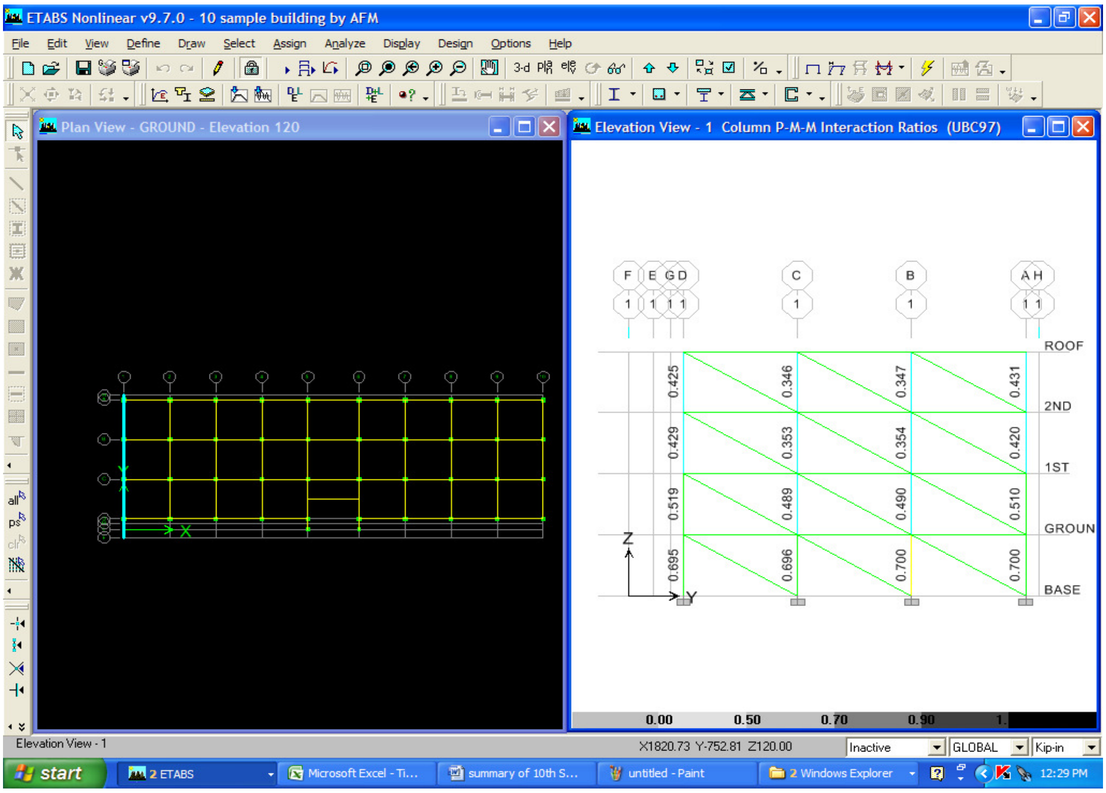
BUILDING SYSTEM	
Load Path	C
Adjacent Building	NA
Mezzanine	NA
Weak Story	NC
Soft Story	NC
Geometry	C
Vertical Discontinuities	C
Mass Irregular	NC
Torsion	NC
Deterioration	C
Post Tensioning Anchors	NA

LATERAL-FORCE RESISTING SYSTEM	
Redundancy	C
Wall Connections	C
Shear Stress Check	C
Axial Stress Check	C
flat Slab Frames	NA
Pre Stressed Frames	NA
Captive Column	NC
No Shear Failure	C
Strong Columns/ Weak Beams	NC
Beam Bars	C
Columns Bar Splices	C

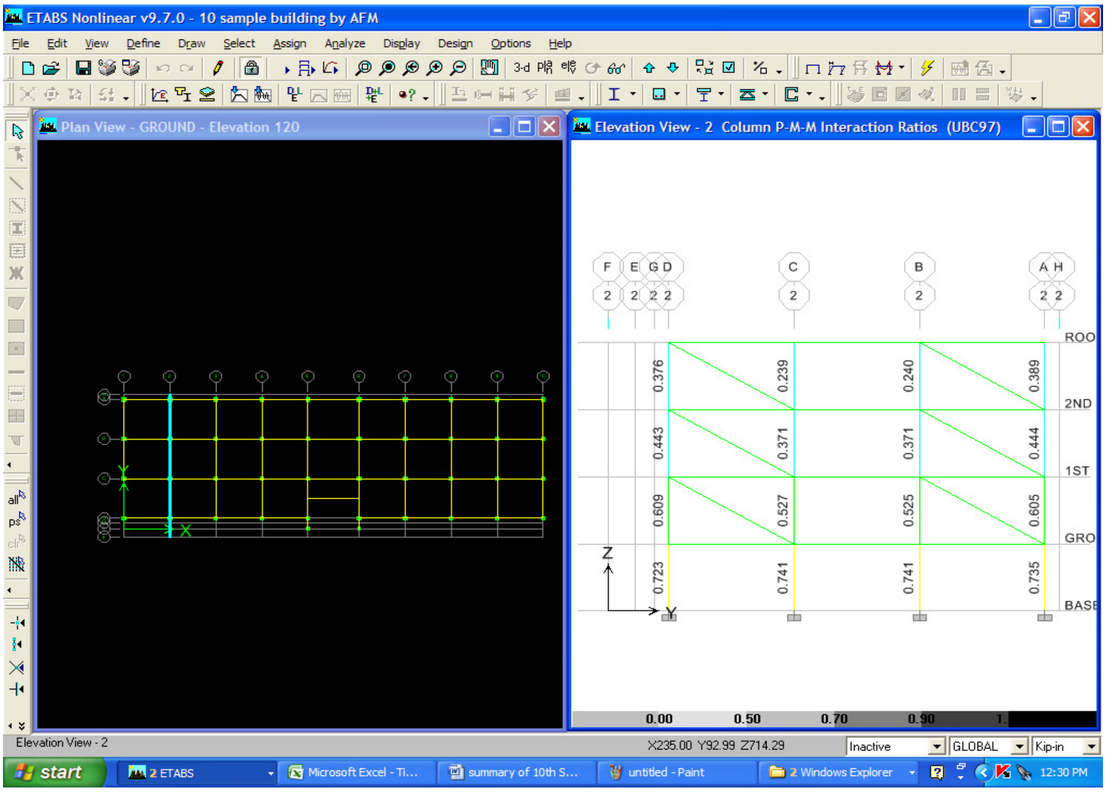
GEOLOGIC SITE HAZARDS AND FOUNDATION CHECKLIST

Liquefaction	NA
Slope Failure	NA
Surface Fault rupture	NA
Foundation Performance	C
Deterioration	C
Pole Foundation	NA
Over turning	C
Ties between Foundation element	NA
Deep foundation	NA
Sloping Sites	NA

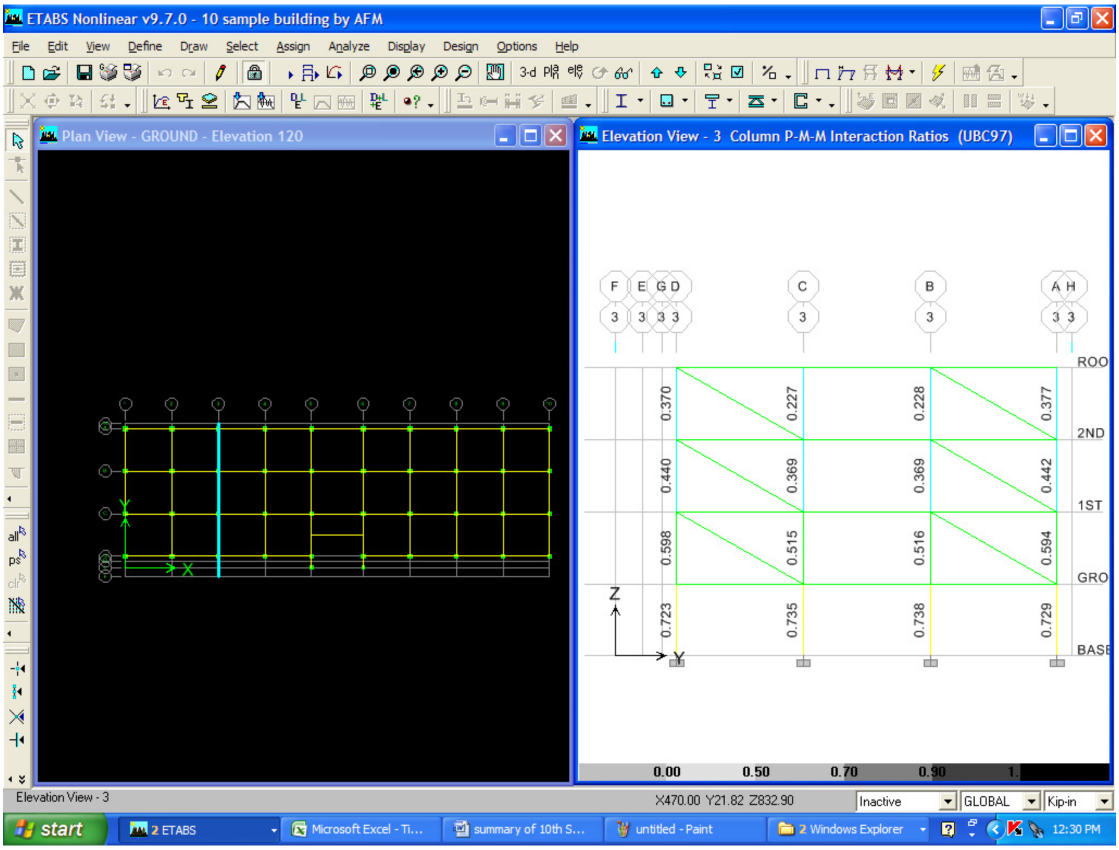
Appendix B: Linear Analysis (Tier 2) Results



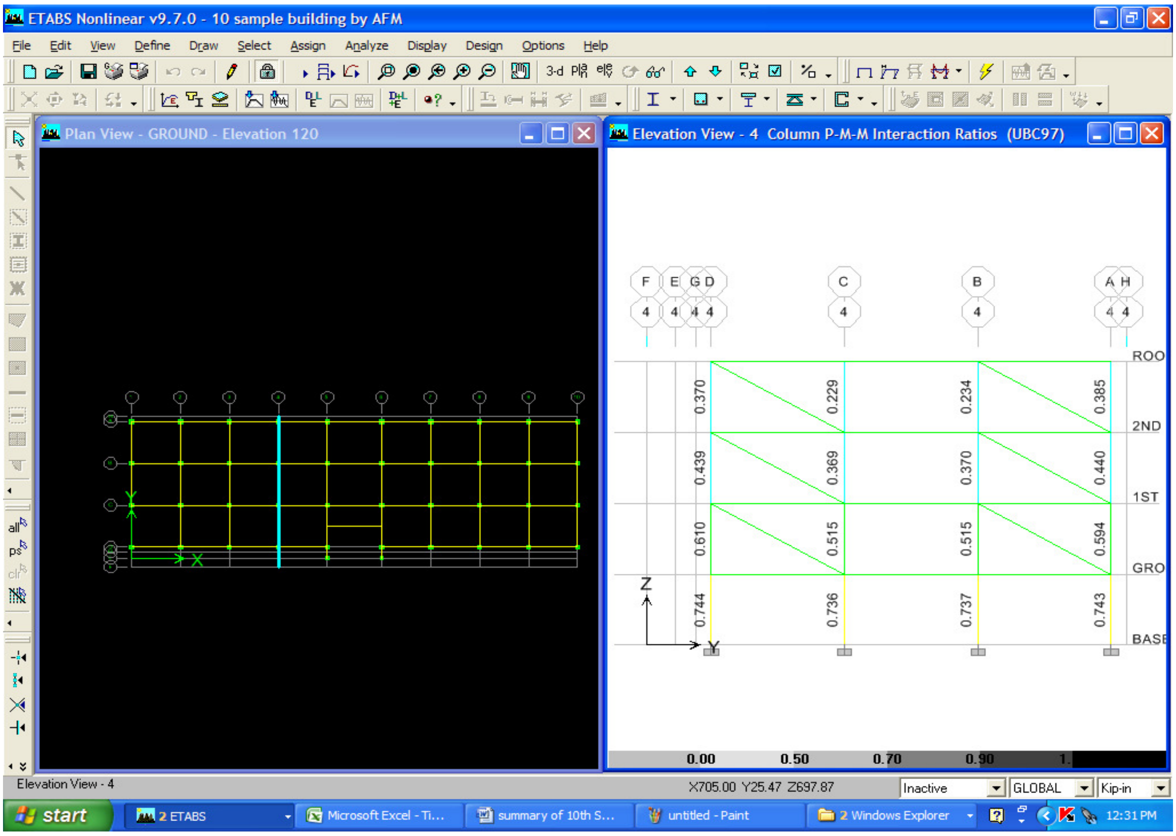
Demand/Capacity Ratios for columns at Grid-1



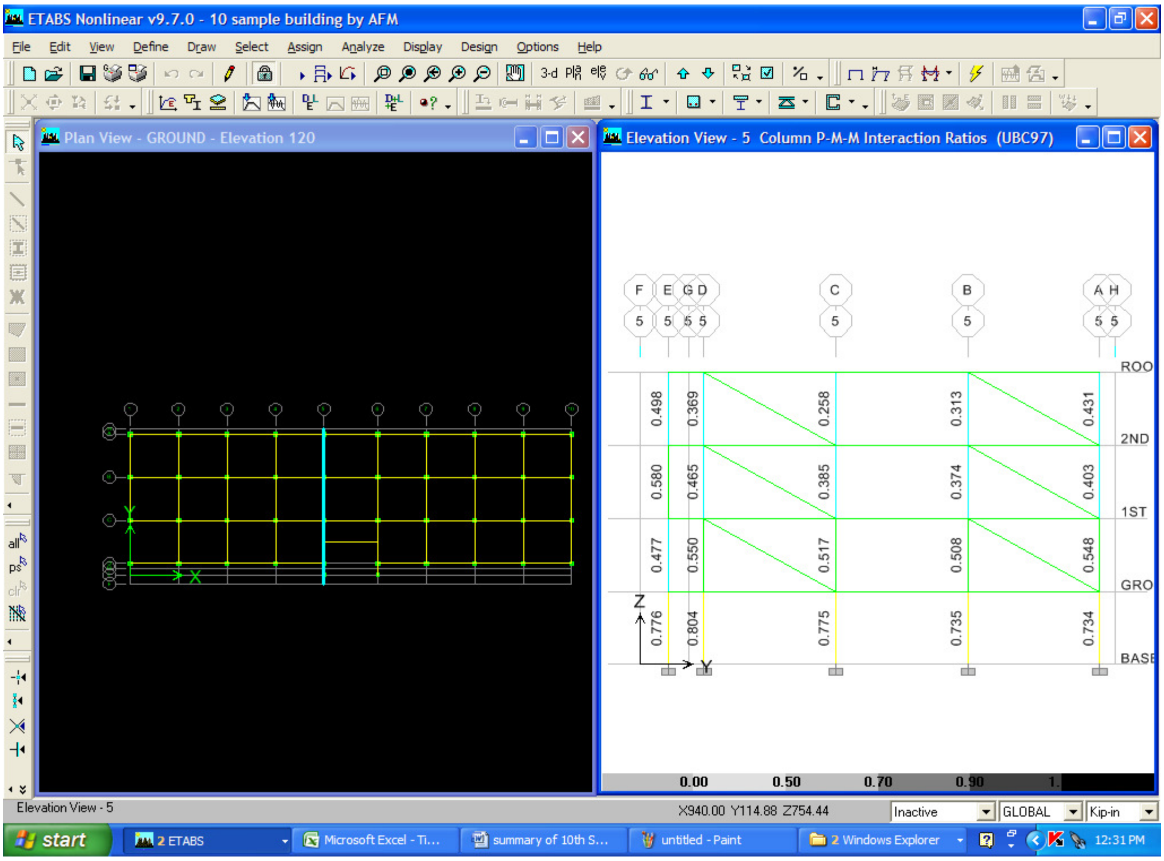
Demand/Capacity Ratios for columns at Grid-2



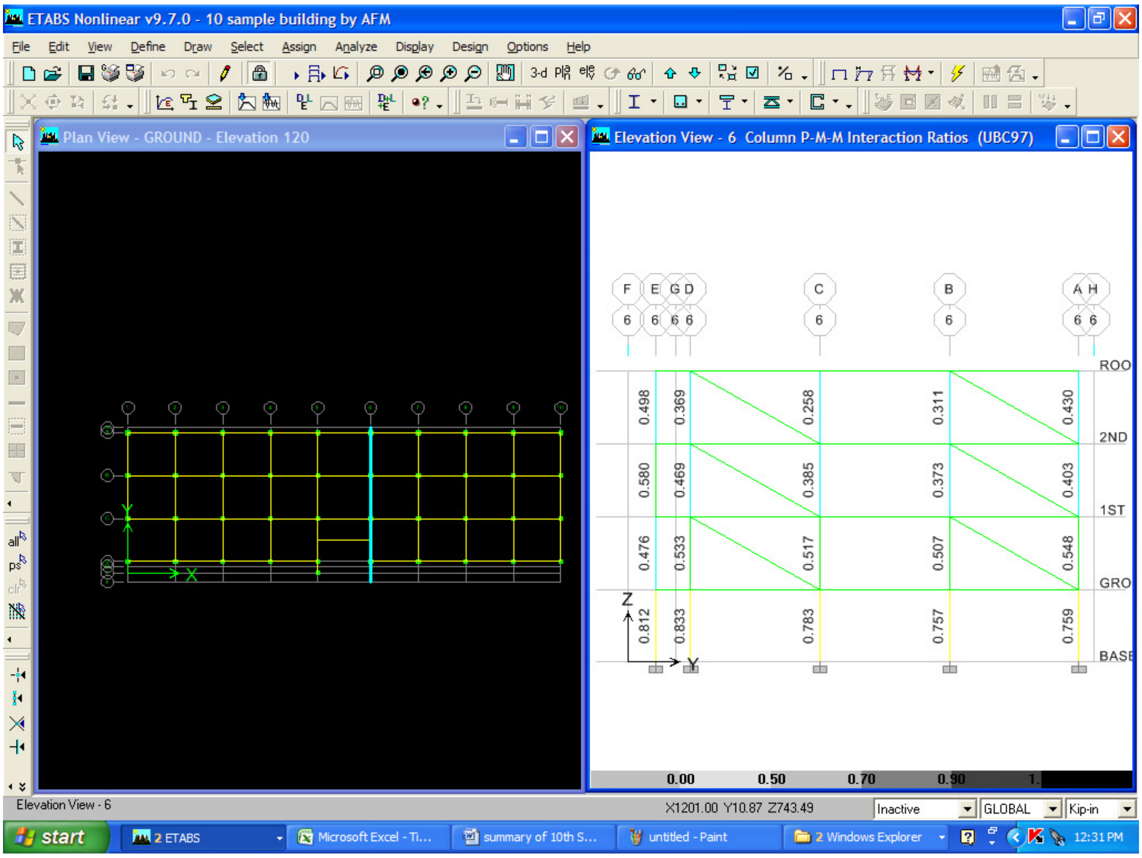
Demand/Capacity Ratios for columns at Grid-3



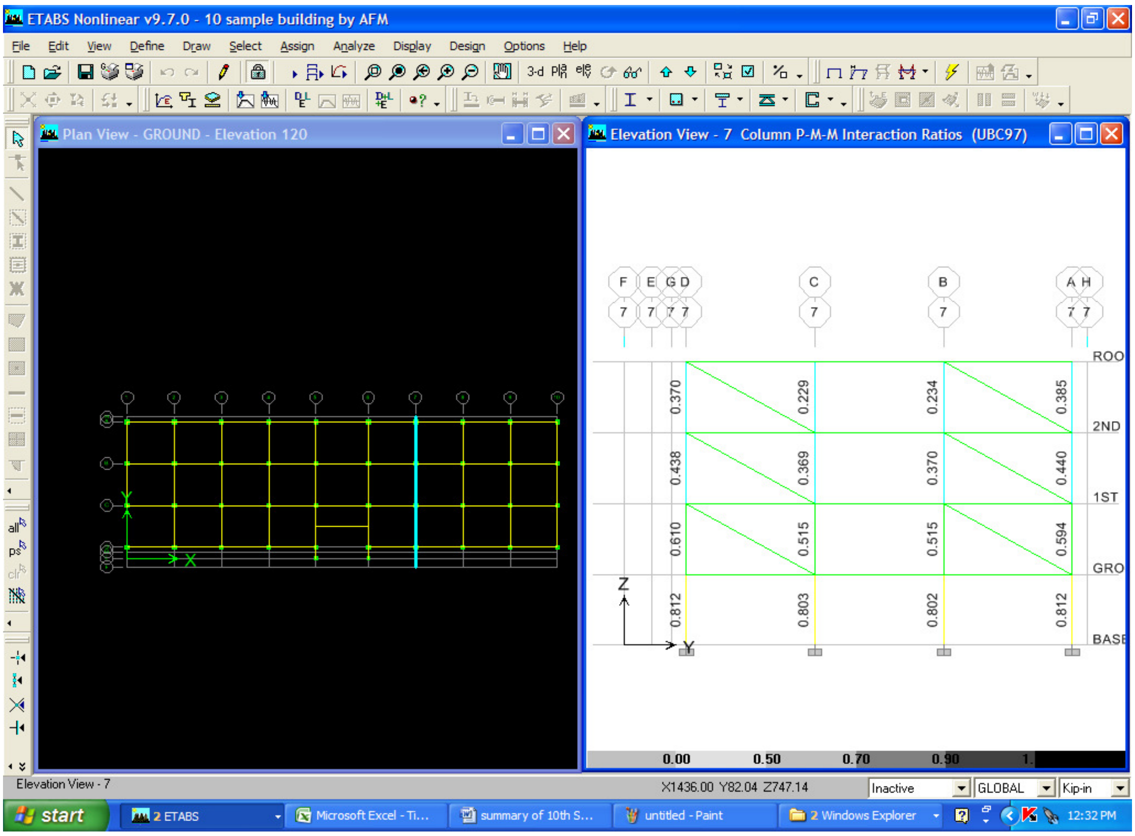
Demand/Capacity Ratios for columns at Grid-4



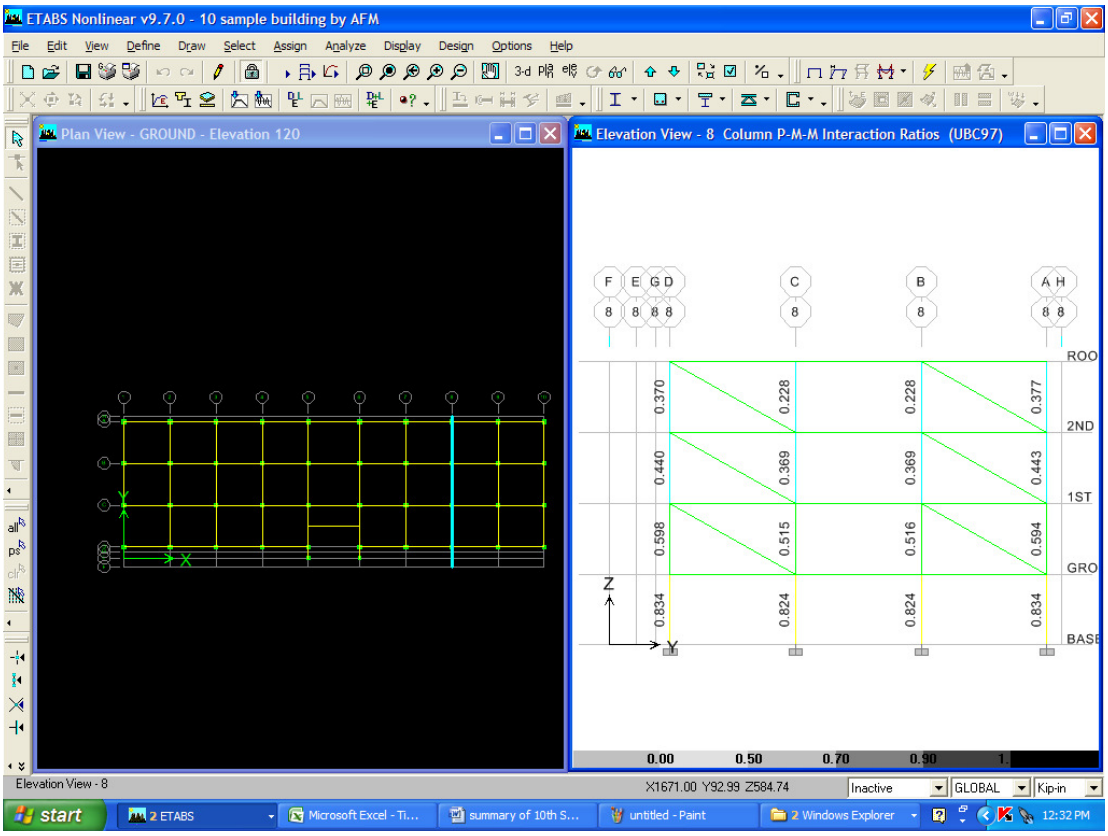
Demand/Capacity Ratios for columns at Grid-5



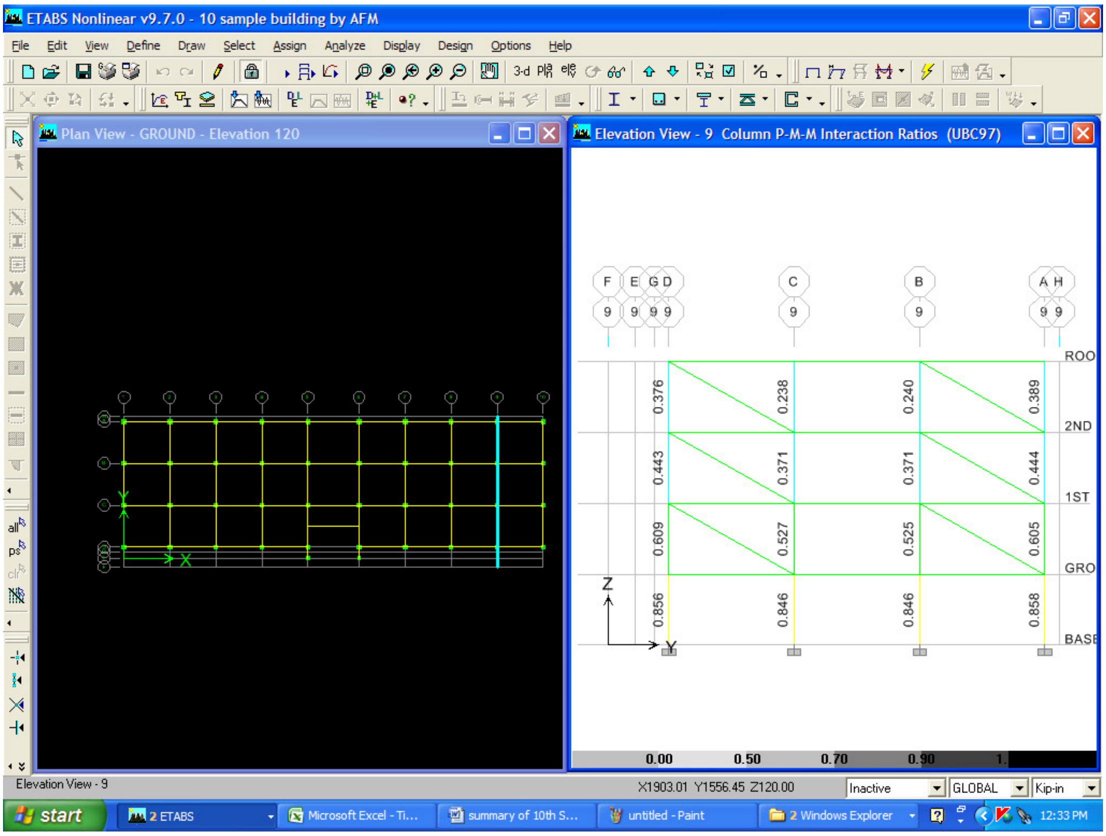
Demand/Capacity Ratios for columns at Grid-6



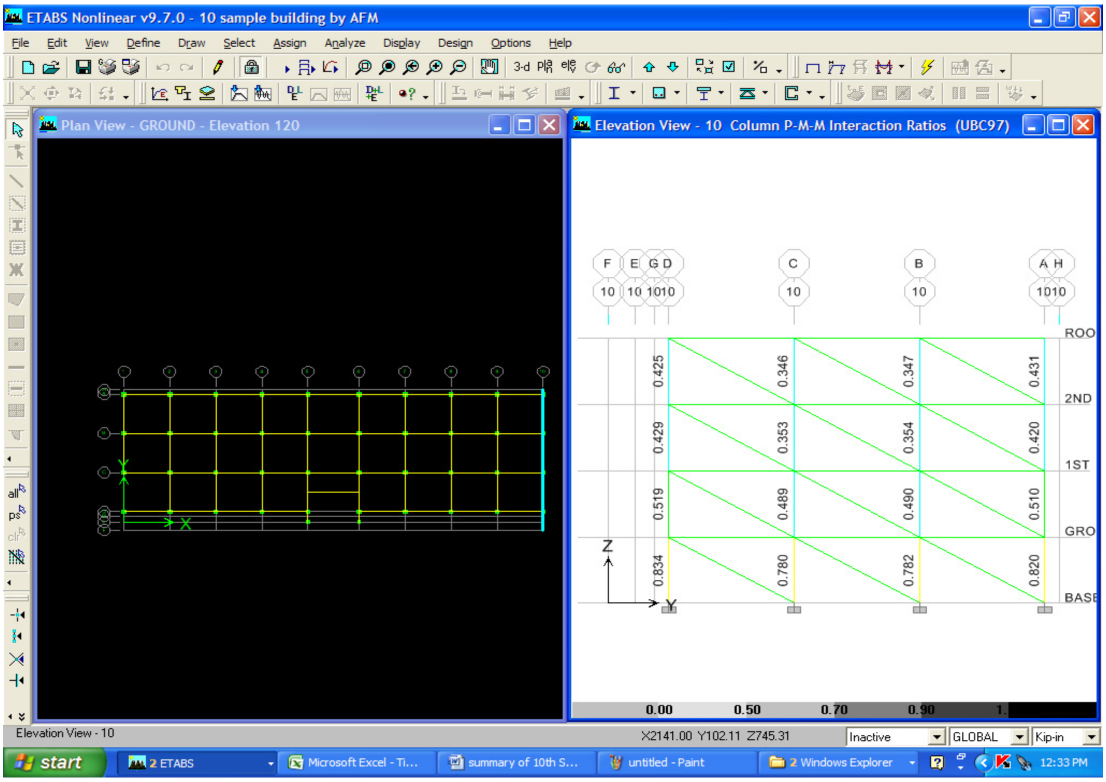
Demand/Capacity Ratios for columns at Grid-7



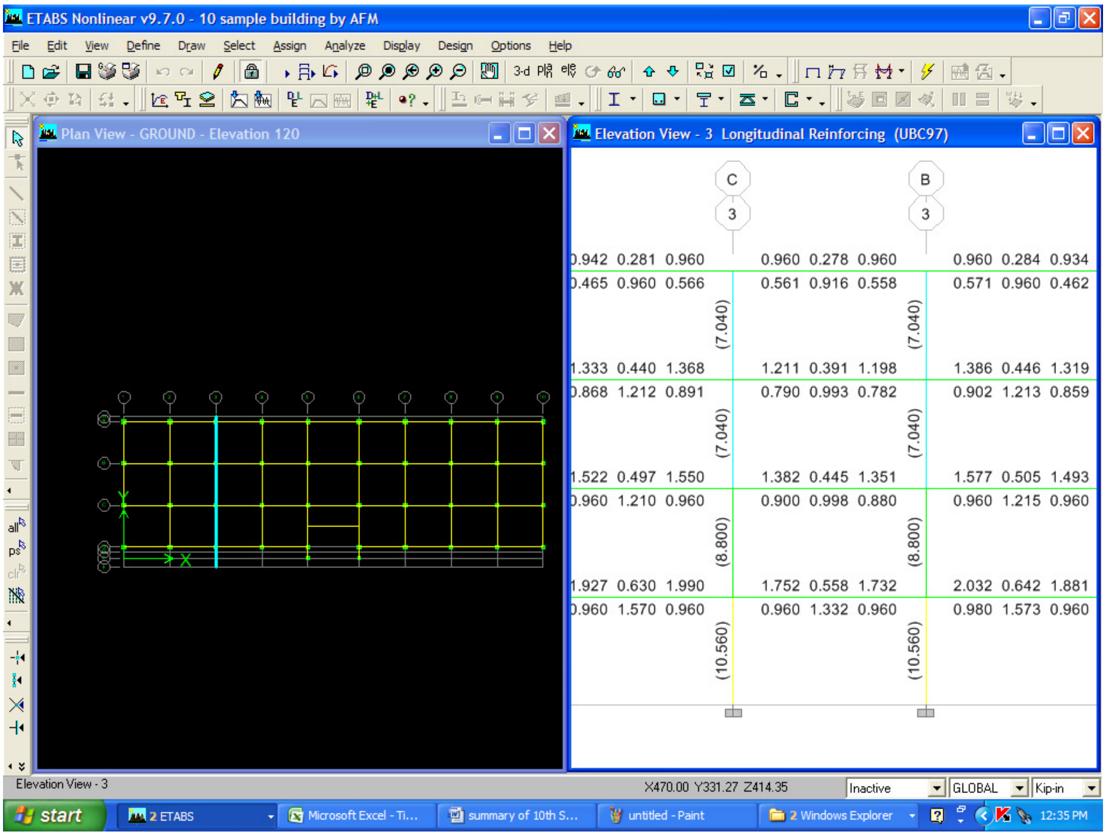
Demand/Capacity Ratios for columns at Grid-8



Demand/Capacity Ratios for Frame at Grid-9



Demand/Capacity Ratios for Frame at Grid-10



Required Reinforcement in Beams

Hand Calculations for Determining Demand Capacity Ratios

Because ETABS does not automatically calculate demand/capacity ratios for beams from required reinforcement (ETABS performs this calcultion for columns), demand/capacity ratios were determined by hand calculations as shown below. Beam demand capacity ratios were less than 1.

At Roof and 2nd Floor

Required reinforcement at mid span = 0.994 in2

Provided reinforcement at mid span = 1.53 in2

Demand/ Capacity = 0.65

Required reinforcement at support = 1.211 in2

Provided reinforcement at support = 1.53 in2

Demand/ Capacity = 0.79

At Ground Floor and 1st Floor

Required reinforcement at mid span = 1.332 in2

Provided reinforcement at mid span = 2.64 in2

Demand/ Capacity = 0.5

Required reinforcement at support = 1.752 in2

Provided reinforcement at support = 3.08 in2

Demand/ Capacity = 0.57