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Case Study

Condition assessment and strengthening of residential units

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ABSTRACT

About 40, ground plus one (G+1) residential units were designed using a hybrid structural framing system (RC frame and load bearing walls). A few months after the completion of the ground floor of the residential units, cracks appeared at several locations in the structure. Field and Laboratory testing was conducted to ascertain the in situ strength of concrete and steel reinforcement. The results of the experimental work were used in the analytical ETABS model for the structural stability calculations. The results indicated that residential units were marginally safe in the existing condition (completed ground floor), but the anticipated construction of the floor above the ground floor (G+1) could not be carried out as the strength of the structural system was inadequate. To increase the safety of existing ground floor and to provide the option of the construction of one floor above, rehabilitation and strengthening design was performed. The proposed strengthening design made use of welded wire fabric (WWF) and carbon fibre reinforced polymer (CFRP) laminates/sheets for the strengthening of walls, columns and slabs. The residential units will be strengthened in the near future.

1. Introduction

A significant part of the residential units in Pakistan use unreinforced masonry wall load bearing structures, since they offer a relatively economical construction type. About 40, ground plus one (G+1) residential units were designed using a hybrid structural framing system (RC frame and load bearing walls). Part of the load transfer mechanism was through the frame system while part of the load transfer mechanism was through load bearing walls. A few months after the completion of the ground floor of the residential units, cracks started to appear at several locations in the structure. To ascertain the reasons for the cracking and the structural stability, a combined experimental and analytical study was carried out. The experimental study included field testing to ascertain the in situ strength of concrete, extraction of samples of reinforcing steel for laboratory testing and obtaining stress-strain of reinforcing steel. Non Destructive Testing (NDT) was conducted using CAPO Tests at many locations to determine the in situ strength of concrete in structural members. Samples of the reinforcing steel bars (extracted from the members) were tested in the laboratory to obtain the stress-strain relationship. Analytical model using ETABS was developed. The results of the experimental work were used in the analytical ETABS model for the structural stability calculations. Seismic forces were also incorporated in analysis. The analysis results showed that the residential units were marginally safe under existing conditions and construction of (G+1) was not feasible due to

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inadequacy of the structural stability. Two strengthening options were explored. *Option A*, in which the existing units could be rehabilitated for use. *Option B*, in which the residential units could be strengthened for G+1 construction and use.

2. Condition assessment of existing structure

For the condition assessment of the existing residential units, first the structural designs were checked for compliance with ACI Building Code. The units were modelled using ETABS. The results indicated that designs of some members were non-compliant with the Code. The compliance with the construction drawings, some forensic work (including Ferro Scanning) was conducted and the results indicated intermittent non-compliance. For structural stability calculations, in situ strength of concrete and reinforcing steel were obtained for use in the ETABS model.

2.1. Review of structural design and Code conformance

In this study, the structural design calculation (using UBC 97 [UBC, 1997] and ACI Code 318-95 [ACI, 1995]) were performed for typical 4 units (2 adjacent units and front/back units) of 180 sq. yards each. The 2 adjacent units had a common wall connecting the 2 units. The provision of G+1 construction and the seismic conditions (loads) for Zone 2B (Karachi) were included in design. For the structural design, concrete strength-f_c' of 3000 psi (20.7 MPa) and steel re-bar strength-f_y of 60,000 psi (414 MPa) were used. The results are summarized in Table 1.

As can be seen from the Table 1, the structural design for only the wall footings and columns are in compliance with the design as per the UBC 97 and ACI 318-95 Codes, however the structural designs of plinth beams, walls, beams and slabs (as per the structural drawings) are non-compliant as they seem to have less reinforcement than required.

2.2. Forensic study

A forensic study was conducted to ascertain the compliance of the construction with the structural drawings and to ascertain the strength of concrete and re-bar steel reinforcement. For the forensic study, a survey of the residential units constructed was undertaken. On the basis of this survey, some units were identified for detailed study.

For the construction compliance, the survey team inspected the selected units and marked the areas for the Ferro Scanning and CAPO testing work. The Ferro scanning was done to verify the compliance of the placement of the reinforcing steel re-bars with the structural drawings. In some selected location, the steel re-bars were exposed and physical confirmation was also obtained.

2.3. Ferro scanning, CAPO testing and Schmidt hammer testing

Schmidt hammer testing was conducted at number of locations and the results were calibrated with the results CAPO testing for in situ strength of concrete (Fig. 1). Ten (10) CAPO tests were performed.

To obtain the properties of the reinforcing steel re-bars, four samples were taken from the members. The reinforcing steel re-bar samples were tested in the laboratory for strength and deformation capacity. (See Results in Table 2).

Table 1
Summary of the code compliance check for the design of residential units.

Member	Design computations								
	As per structural drawings						Design as per code		
	fc' (psi/MPa)	fy (psi/MPa)	b (in/mm)	h (in/mm)	Main R/F	Secondary R/F	Main R/F	Secondary R/F	Code compliant (yes or no)
Wall footings	3000 (20.7)	60,000 (414)	42″ (1050)	6″ (150)	# 3 @ 8″ (#10@200 mm)	# 3 @ 8″ (#10@200)	# 3 @ 10″ (#10@250)	# 3 @ 10″ (#10@250)	YES
Plinth beams	3000 (20.7)	60,000 (414)	8″ (200)	12″ (300)	2-#3 (Top) 2-#3 (Bottom) (2-#10 T &B)	1/4″@ 6″ (#6@150)	2-#4 (Top) 2-#4 (Bottom) (2-#13 T&B)	#3 @ 6″ (#10@150)	NO
Walls	1500 (10.3)	60,000 (414)	–	8″ (200)	1-#4 @ 10′ (HOR) (1-#13@3m)	1-#3 @ 4′ (VER) (1-#10@1.2m)	#4 @ 12″ (#13@300)	#3 @ 12″ (#10@300)	NO
Columns	3000 (20.7)	60,000 (414)	8″ (200)	8″ (200)	4-#4 (4-#13)	# 3 @ 8″ (#10@200)	4-#4 (4-#13)	# 3 @ 8″ (#10@200)	YES
Beams	3000 (20.7)	60,000 (414)	8″ (200)	12″ (300)	2-#3 (Top) 2-#3 (Bottom) (2-#10 T&B)	1/4″ @ 9″ (#6@225)	3-#4 (Top) 3-#4 (Bottom) (3-#13 T&B)	#3 @ 5″ (#10@125)	NO
Slabs	3000 (20.7)	60,000 (414)	–	5″ (125)	# 3 @ 6″ (#10@150)	# 3 @ 8″ (#10@200)	# 3 @ 4.5″ (#10@112)	# 3 @ 8″ (#10@200)	NO

Note: Values in parenthesis are SI conversion of the original ones.