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Nondestructive Evaluation of an Existing Concrete Structure using Load Test and Core Test

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Abstract

This research work is focused on nondestructive evaluation of a five storied concrete frame structure of which construction was halted seven years ago. Before further construction could be started again it was imperative to assess the existing condition. For this purpose, load tests and core tests were performed on four floors from basement to first floor. It took more than one year to finish the experimental work. Test results showed that the structure has adequate strength for future use although it was unprotected against severe environmental conditions for several years. Study further confirms the findings of previous researchers that a combination of tests, instead of performing just one type of test, provide more suitable results to confidently accept or reject the structure as a whole or its component for future use.

Key Words: *Nondestructive Testing, NDT, Load Test, Core Test*

1. Introduction

Assessment of the existing properties of reinforced concrete (RC) structures is crucial to evaluate their performance[1]. Therefore, nondestructive evaluation (NDT) has seen significant developments in the last three decades[2]. However, NDT has not yet been incorporated in the syllabi of most of the engineering schools. For instance in United States only 1 in 12 civil engineering programs teach NDT as a part of their concrete laboratories[3]. Bray (1993)[4] emphasized that NDT should be taught as an integral part of civil engineering education.

Most of the times when modifications in the existing structures are proposed the process begins with the performance of NDT. NDT has its application in all types of structures including buildings, bridges, dams, foundations and pavements. NDT is primarily carried out for quality control, identification of problems, assessment of existing condition for retrofitting and quality assurance or concrete repair[5]. Most common methods used to access in-place strength and quality of concrete include: rebound hammer test (RHT); ultrasonic pulse velocity test (USPVT); core test (CT); load test (LT); pullout test (PT); and penetration test (PnT). ACI 228.1R-03[5] provides comprehensive guidelines for applying the NDT methods. Some researchers have recommended that a combination of two or more testing methods may provide better prediction of the strength and quality of concrete[6-8]. For instance SonReb, which is a combination of USPVT and RHT, is beneficial because USPVT provides inner properties of concrete whereas RHT gives idea about the surface strength[1]. Another reason of using a combination of testing methods is that each test has it own limitations and its results may be affected due to several factors including: environmental exposure; age of structure; process of measurement; type of constituent materials and curing conditions etc. Based on this information, a combination of two testing methods (LT and CT) was used for the current project.

This research work is focused on establishing the adequacy of an existing RC building structure. The building had five existing stories (including two basements) with seven still to be constructed (Figure 1). Its construction was started almost 8 years ago and was brought to halt after 1 year due to some disputes between contractor and the client. During these seven years concrete had been exposed to severe cold and hot temperatures, humidity and rains, without any protection. After this long time the construction work was planned to begin once again. It was then imperative to perform NDT to find out the existing condition of concrete because the decision of constructing seven more floors had to be based on the existing strength and the condition of concrete. The panels that were tested had an average size of 25 ft. x 20 ft. with 8 to 9 in. thickness. All of them were two-way flat slabs without drop panels at the columns.

Fig. 1: View of Partially Constructed Building

2. Review of Testing Methods

CT is carried out by following the standard procedure according to ASTM C42[9] for testing specimens to determine compressive strength of in-place hardened concrete. Cores are extracted from the existing structure using a specially design core cutting machine and then after following the procedure recommended by ASTM C42 are tested in similar way as the standard concrete cylinders.

Load test has been commonly used in civil engineering industry to verify the adequacy of structures[10]. Generally, water, sand or bricks are used to reproduce the uniformly distributed loads, however, some researchers have recommended hydraulic jacks for rapid loading[10-12]. Deflections and crack widths are monitored at various intervals both during loading and unloading phases. ACI 318[13] chapter 20 provides detailed testing procedure and criteria of acceptance and rejection. Several researchers[10, 14-17] have recommended methods for applying loads and investigating structural response for the load tests.

3. Experimental Work and Discussion

Primary objective of the experimental work was to conduct detailed evaluation of the building and to provide recommendations for future construction. Details of the experimental works and the analysis of results are discussed in the following sub-sections.

3.1 Load Test

Load tests were performed based on the guidelines of ACI 318-05. Initially, it was very challenging to make arrangements and gather resources for the performance of tests because the building remained abandoned for several years and not even had power. It took more than four month to perform the first test on the basement slab panel and altogether it took more than one year to finish the testing. In all, eight slab panels were tested, two on each floor excluding the top floor. The number and arrangement of spans or panels to be tested were selected to maximize the deflection and stresses in the critical regions of the structural elements. Presence of hairline cracks in a couple of slab panels was also considered as factor while selecting the test panels. More than one test load arrangements were used if a single arrangement was not resulting in maximum values of the effects necessary to demonstrate the adequacy of the structure. As per ACI 318 the test load (including dead and already in place load) should not be less than $0.85(1.4DL + 1.7LL)$. As per the recommendations of American Society of Civil Engineers[18], live load of 60 psf for shops and apartments, and 100 psf for assembly areas and corridors was used to calculate the test load. In case a panel is partially used as an assembly area and partly for the ordinary use, an average live load of 80 psf was used. The test load was applied in five equal increments compared with the minimum figure of four, as recommended by the ACI. Sand bags of 110 lbs were used for loading the basement and lower ground floor slabs. However, the bags were found to have tearing problems and were found to be of significantly lesser weight after their transportation and few loading and unloading cycles. It was then decided to use loose sand contained within the wooden shuttering on the panel centerlines for the panels on ground floor and 1st floor. Figures 2 to 4 show the arrangement and actual placement of deflection gauges, and loading arrangement by using loose sand.

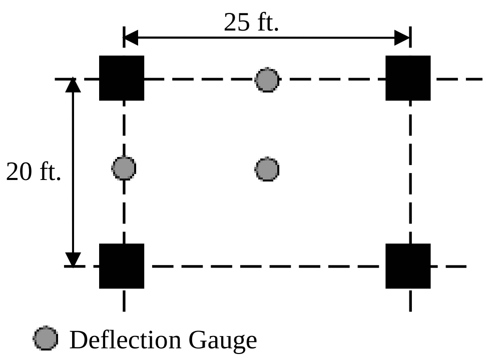

Fig.2 Typical Arrangement of Deflection Gauges on Slab Panels

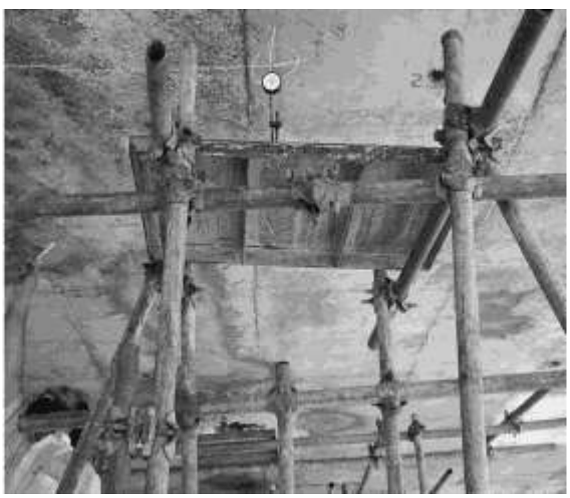

Fig. 3 Deflection Gauge Installed at the Center of Panel

Fig. 4 Load Application with Loose Sand within Wooden Shuttering.

All the selected panels of basement, lower-ground and ground floors behaved well during the load test and could be considered adequate for service. Already present hairline cracks were carefully observed during the loading phase. It was observed that these cracks did not widen during and after testing. Hence, these cracks may be considered as non-structural and may be repaired during finishing phase.

3.1.1 *Acceptance Criteria*

ACI 318 suggests that concrete in loaded panels should not show any sign of failure including spalling and crushing. The measured deflections should satisfy one of the following conditions:

$$\Delta_1 \leq \frac{l_t^2}{20,000\,h} \tag{1}$$

$$\Delta_r \leq \frac{\Delta_1}{4} \tag{2}$$

where l_t, h, Δ_1 and Δ_r are the shorter span of slab panel, slab thickness, maximum and residual deflections respectively. The remaining details can be found in article 20.5.2 of ACI 318.

Table 1 presents the summary of all the load tests. For all cases the maximum deflection (Δ_1) was found to happen at the mid-span. All the panels except panel 2 on first floor qualified the ACI criteria. Although Panel 1 on first floor passed the criteria however it could not be accepted as suitable for use because the signs of failure, both spalling and cracking, were visible. It was observed during the test that the cracks of larger width were appearing and spreading all over these panels. Further, the concrete at most parts of these panels started falling down. On closer observation, it was found that the concrete at the lower surface consisted of very low quality concrete (Figure 5). The aggregate particles could easily be removed from the surface without using any instrument. It was concluded that these panels with such a poor quality of concrete cannot be strengthened. Even if these are strengthened, particles of aggregates may fall later on by any impact on the roof or by driving of any nail on the ceiling surface. The only solution left was to remove all above mentioned panels and fresh construction was recommended.

Table 1: Summary of Load Test Results

Panel	Δ1	lt2/(20,000h)	Result	Δr	Δ1/4	Result	Final Result
Basement Panel 1	0.182	0.32	OK	0.022	0.045	OK	Adequate
Basement Panel 2	0.196	0.31	OK	0.040	0.049	OK	Adequate
Lower Ground Floor Panel 1	0.198	0.32	OK	0.046	0.050	OK	Adequate
Lower Ground Floor Panel 2	0.294	0.34	OK	0.062	0.074	OK	Adequate
Ground Floor Panel 1	0.130	0.31	OK	0.014	0.033	OK	Adequate
Ground Floor Panel 2	0.174	0.23	OK	0.000	0.044	OK	Adequate
First Floor Panel 1	0.400	0.07	Not OK	0.048	0.100	OK	Adequate
First Floor Panel 2	0.773	0.45	Not OK	0.500	0.193	Not OK	Not Adequate

Fig. 5 Poor Concrete at the Bottom Face of First Floor Panel

It is worth mentioning that both the panels on the ground floor exhibited best performance among all eight panels. Ground floor panel 1 showed lowest maximum deflection and panel 2 showed lowest residual deflection. Performance of all the panels in load tests will be compared with their compressive strength results in the core test in the next section.

3.2 Core Test

Since it is recommended to perform combination of tests on a particular structure, therefore core tests were performed on all four levels. Altogether ten cores were extracted however one from the first floor got damaged therefore only nine could be tested. ASTM C42 provides standard procedure for testing core to determine compressive strength of in-place hardened concrete. The diameter of core specimens should preferably be at least three times the nominal maximum size of the coarse aggregate used in the concrete, and must be at least twice the maximum size of the coarse aggregate in the core sample. The length of the specimen, when capped, should be nearly twice its diameter. A core having a maximum height of less than 95% of its diameter before capping or a height less than its diameter after capping shall not be tested. It is preferable to test the cores in moist condition. The ASTM standard prescribes the following procedure: "submerge the test specimens in lime-saturated water at 23.0 ± 1.7° C for at least 40 hours immediately prior to making the compression test. Test the specimens promptly after removal from water storage. During the period between removal from water storage and testing, keep the specimens moist by covering with a wet blanket of burlap or other suitable absorbent fabric." If the ratio of the length to diameter of the specimen is less than 1.75 correction factors are required to be applied. The core samples prepared for the tests are shown in Figures 6 and 7. The results for the tested cores are presented in Table 2. One of the cores taken from the first floor was damaged and could not be tested.

Concrete compressive strength of 3000 psi was used at the time of the design of the building and the idea behind testing cores was to check if concrete still had that strength or not. As presented in Table 2, cores from all levels exhibited compressive strength

Table 2: Summary of Core Test Results

Sr. No.	Location	Diameter of Core	Length	Crossectional Area	Failure Load	Compressive strength
		in	in	(in^2)	(kip)	(psi)
1.	Basement, Core 1	3.96	7.88	12.30	56.88	4640
2.	Basement, Core 2	3.91	7.43	12.03	38.80	3190
3.	Lower G. Floor, Core 1	3.91	5.14	12.00	34.61	2755
4.	Lower G. Floor, Core 2	3.84	7.80	11.57	45.19	3915
5.	Lower G. Floor, Core 3	3.91	7.84	12.00	39.68	3335
6.	Ground Floor, Core 1	3.94	4.84	12.22	41.89	3190
7.	Ground Floor, Core 2	3.93	7.87	12.13	41.89	3480
8.	Ground Floor, Core 3	3.93	4.10	12.10	41.22	3045
9.	First Floor, Core 1	3.93	7.31	12.13	40.23	3335
10.	First Floor, Core 2	Damaged during the test				

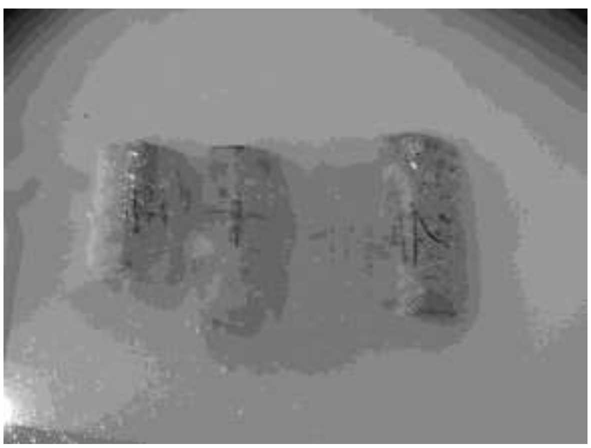

Fig. 6 Core Samples Dipped in Lime Water

Fig. 7 Capped sample before testing

higher than 3000 psi except core 1 of lower ground floor. It is vital to mention that compressive strengths presented in Table 2 are calculated after applying correction factors recommended by ASTM since some of the cores had length to diameter ratios less than 1.75. Figures 8 and 9 present the modes of failure of the tested cores. As visible from the Figures, the failure modes are almost similar to the typical concrete cylinders. As far as the comparison of load and core tests is concerned, both provided similar results in terms of adequacy of concrete strength. The only exception was in the first floor where load test proves the slab as inadequate whereas the core test shows acceptable concrete strength. In such situations, load test should be given preference because load test provides the behavior of the entire slab panel and is more close to the in-service loading conditions whereas core test provides strength of a specific region only. As mentioned earlier, both the ground floor panels exhibited best performance among eight panels, however compressive strength of the core extracted from ground floor did not show extraordinary strength. In case of core tests, basement core 1 showed the maximum compressive strength of 4640 psi. These differences among the load and core tests emphasize the need of performing a combination of tests instead of just one type test.

4. Conclusions

Current project was focused on nondestructive evaluation of a five storied concrete structure of

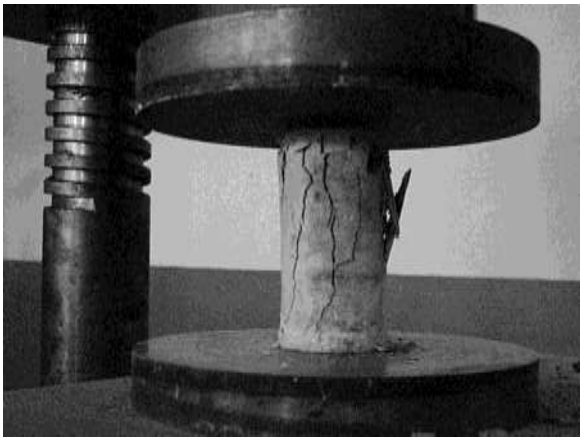

Fig. 8 Core Crushed in Compression Machine

Fig. 9 Samples after Testing

which the construction was ceased seven years ago. Eight load tests on slab panels of four floors were carried out along with ten core tests. In the light of the results it could be concluded that the structure has adequate concrete strength. However, it does not mean that the go-head should be given for 7 more stories to be added. Such a decision would require further structural analysis. Study also confirms the conclusion of previous researchers that a combination of tests, instead of performing just one type of tests, is more suitable to confidently accept or reject the structure or a structural component for future use. This statement is reinforced from the results of load and core tests on first floor where core test showed that concrete of the slab has more strength than the design strength however load test proved that slab panels are inadequate. Based on the results and the experience it could be stated that load test could be more conclusive than core test and should be preferred especially when important decision about future use of structure or change of function has to be made. The fact that even after seven years of unprotected exposure to severe environmental conditions the structure qualified the tests reconfirms that if construction quality is good concrete has the ability to maintain its strength and integrity for a long time.

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