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STRUCTURAL HEALTH ASSESSMENT OF AN HISTORIC BUILDING THROUGH NON-DESTRUCTIVE TESTING

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ABSTRACT

The existing building of Provincial Assembly of the North-Western Frontier Province of Pakistan was built in 1936 in the centre of the capital city, Peshawar, one of the oldest cities of the South-Asian sub-continent. This single-storey building houses a main hall where sessions of the Provincial Assembly are held and a number of rooms which have been used as offices by the Assembly staff. To overcome the problem of space due to increasing number of Assembly Representatives and secretarial staff, it was decided by the Provincial Government that, in addition to the construction of a new building close to the existing building, construction shall be carried out in the space available over the roof of the existing building to furnish additional rooms. This necessitated the assessment of the structural condition of the building through non-destructive testing and evaluation of the existing building, so that its safety and serviceability for the new occupancy can be explicitly verified. This paper contains information about the building, the testing methodology, and the non-destructive tests carried out including Rebound Number Test, Ultrasonic Pulse Velocity Test, Testing of Concrete Cores, Magnetic rebar Locator Test, and the Physical Load Test of the Structure. In the test, marked degree of consistency was observed for compressive strength of results of concrete obtained from different tests. The orientation, size and spacing of main flexural reinforcement in the slab were also determined. It was concluded that in spite of non-composite construction, the concrete slab-steel beam systems showed enhanced strength and stiffness due to full composite action even at the full test load recommended by the ACI Code.

INTRODUCTION

The existing single story building of Legislative Assembly of North-Western Frontier Province of Pakistan is located in the centre of the capital city, Peshawar, one of the oldest cities of the South-Asian sub-continent. It was built in 1936, eleven years before the partition of Indian Sub-Continent in 1947 into two separate independent countries of Pakistan and India. The sessions of the Provincial Assembly are held in the main hall of the building while the rooms have been used as offices by Assembly staff. The scarcity of rooms in the existing building has been felt over a time due to increase in the number of Assembly Representatives and secretarial staff. In this regard, it was decided by the Provincial Government to add additional story to the existing building. This necessitated the

non-destructive testing and evaluation of the existing building so that its safety and serviceability for the new occupancy can be explicitly verified.

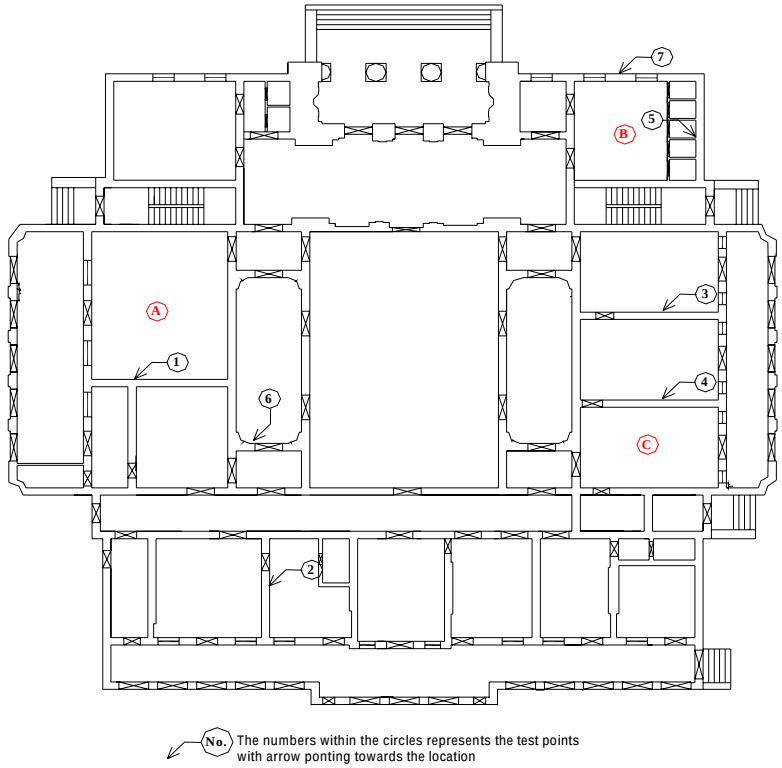

Figure 1. Plan of the building showing locations where concrete cores have been taken

DESCRIPTION OF THE BUILDING

This single-story building houses a main hall and several rooms as shown in Figure 1. The removal of false-ceiling at many locations revealed that reinforced concrete slabs were supported by steel girders and load bearing burnt clay brick masonry walls. The 6-in thick reinforced concrete slab is overlain by several layers of overburden materials comprising brick tiles, mud, plain cement concrete and brick ballast as illustrated in Figure 2. Cross-sectional dimensions of the steel girders were measured and found to be close to S8x18.4 and S15x50. It was concluded from the detailed inside and outside examination of the peripheral walls of the building that no foundation-related problems are there in the building.

TESTING PROGRAMME

The following tests were carried out in the non-destructive testing of this historic building:

1. Rebound Number (Schmidt Hammer) Test
2. Ultrasonic Pulse Velocity Test
3. Cutting and Compression Test of Concrete Cores
4. Magnetic rebar Locator (Profometer) Test
5. Physical Load Test

The first three tests were carried out to determine the in-place strength of concrete, which will subsequently be used in the analytical study of the building. The fourth test was conducted to determine the orientation, size and spacing

of the main flexural reinforcement in the slab to be used in the determination of flexural capacity of the concrete slab at critical locations. The adequacy of the existing building with regards to safety and serviceability for loads corresponding to the new occupancy was verified through Physical Load Test of the Structure. To assess the foundation of the building, concrete core was taken form the foundation of the peripheral wall. Undisturbed soil samples were also taken from the four pits adjacent to the peripheral wall foundation. Brick samples were also taken and tested for compression. The forthcoming paragraphs give detailed information about nature, limitations, procedure, results, discussions and recommendations for each of the tests mentioned previously. All the equipments used in these tests were calibrated before their use in the non-destructive tests of the building.

METHODOLOGY

A detailed site visit was made to ascertain the site conditions so that an efficient methodology can be developed. Due to availability of architectural drawings, details such as foundations, overburden, location of girders etc. were directly mapped from the field. It was decided that existing overburden on the concrete slabs shall remain in place during a physical load test as the removal may cause disruption in the assembly proceedings and testing time may increase manifolds. However, its influence shall be fully accounted for during the load test and numerical modeling.

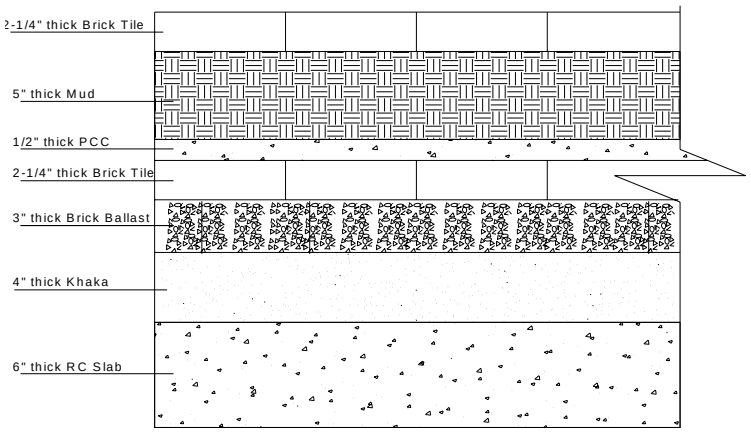

Figure 2. Section of slab showing layers of various materials overlain by concrete slab

For the new occupancy of the building office, a minimum live load of 70 lbs/ft^2 was adopted to suit the local environment, whereas minimum live load recommended by ASCE 7-95 [1] for the same occupancy is 50 lbs/ft^2. Tests were scheduled in such a manner to optimize the performance and avoid conflict with assembly proceedings. The following general methodology was adopted for every test:

- Identification of Resources
  - Logistics
  - Technical Resources
- Staff Assignment
- Field Activities
  - Mobilization
  - Mapping of Details
  - Calibration of Equipments
  - Identification of testing locations with due consultation of Consultants
  - Performing the tests
- Desk/office Work
  - Data entry
  - Compilation of test data
  - Preparation of Evaluation & Recommendation Report

CUTTING AND COMPRESSION TEST OF CONCRETE CORES

Six cores were taken from the reinforced concrete slabs (Figure 1) and tested for compressive strength in the Material Testing laboratory, in accordance with the provisions of ASTM C42-90 [2]. Before cutting core from slab, the overlying material was removed and the slab was scanned for reinforcement location to avoid cutting of rebars in the cores. Core cutting machine with a 4 in. diameter diamond bit was used in the core cutting operation (Figure 3). The core samples collected in field were kept in polythene bags and were subsequently soaked in lime saturated water at 23.0 ± 1.7 °C (73.4 ± 3 °F) for 40 hours prior to the compression test.

Figure 3. Concrete cores taken from the concrete slab and tested for compressive strength

Cores were cut straight, capped and measurements were made to determine the average diameter and height of each core. Compressive strengths of core samples were determined in accordance with ASTM C39 [3]. Because of Length to Diameter (L/D), less than 1.94 for all core samples, the compressive strength of each core sample was reduced with the correction factor taken from ASTM C42-90 (Table 1). Higher strength and increased specific weight of Core No.4 as compared with the strengths and specific weights of other cores may be attributed to the rebar encountered in it and the bond between rebar and concrete.

Table 1. Results of Core Sampling and Testing

No	Location of cores (See Figure 1)	Length / Diameter Ratio	Correction Factor	Compressive Strength (psi)	Remarks
1	Wall of Conference Room	1.26	0.931	**4,400**	5/8” diameter plain steel bar encountered
2	Wall of Retiring Room	1.07	0.887	**2,700**	Normal
3	Wall of PA of Leader of Opposition’s Office	1.25	0.930	**3,000**	Normal
4	Wall of Leader of House Chamber	1.07	0.887	**7,050**	5/8” diameter plain steel bar encountered
5	Southern Wall of Toilet	1.25	0.930	**3,650**	Normal
6	Corner Northern Lobby	1.00	0.870	**3,000**	Normal

REBOUND NUMBER (SCHMIDT HAMMER) TEST

To determine the in-place strength of concrete, Rebound Number (Schmidt Hammer) test was performed on 14 locations on concrete slabs in accordance with ASTM C805-85 [4]. A new Calibration graph was developed using the compressive strengths obtained from core tests and rebound number tests. For this purpose, a Schmidt Hammer

test was performed in the vicinity of those six locations in the slabs where concrete cores have already been obtained. This graph was then utilized to determine the strength of concrete at other locations from where cores have not been taken.

Before performing this test, the existing overburden on the concrete slab was removed and the testing surface was smoothened with abrasion stone wherever required. A circular area of 6 inch diameter was marked with the help of chalk where Schmidt Hammer test had to be performed. Ten readings were taken at each test point with a hammer held normal to the test surface. A minimum distance of 1 inch was maintained between two consecutive readings of the hammer. Having taken the readings, the impression made on the testing surfaces was inspected and the set of readings was discarded where the impact of the hammer crushed the surface. The results of the Schmidt Hammer tests are summarized. From the rebound number test results given in Table 2, the average compressive strength of concrete was found to be 3,300 lbs/in^2.

ULTRASONIC PULSE VELOCITY TEST

This test was performed to determine the compressive strength of slab concrete at 14 locations as per provisions of ASTM C 597-83 [5]. This test was conducted with the help of an instrument called PUNDIT (Portable Ultrasonic Non–Destructive Digital Indicating Tester), which directly gives the time taken by ultrasonic waves to travel through the test specimen with a pulse frequency of 50 kHz. The velocity has a definite relationship with the density, homogeneity and compressive strength of the material through which it passes. Pulse-velocity measurements were made in the vicinity of those six locations where cores have been taken. Before measuring the pulse velocity, the testing surface was smoothened with abrasion stone wherever required. Due to space constraints, tests were performed in an indirect manner in which the Emitting and Receiving Transducers were placed on the same side of the specimen. Slab reinforcements were first located using Magnetic Rebar Locator (Profometer) and marked with chalk at each test point to minimize the effect of reinforcement in the measurement of pulse velocity. Grease as a lubricating medium was applied to the test surface. Receiving Transducer was placed at distances of 4, 8, 12, and 16 inches from the Emitting transducer and pulse velocity was measured corresponding to each position of the Receiving Transducer. A new calibration graph was developed using the compressive strengths obtained from core tests and pulse-velocity tests. This calibration graph was then used to determine the strength of concrete at other 8 locations where concrete cores have not been taken. Table No. 3 gives the test results obtained from the ultrasonic pulse velocity test. The average compressive strength of the slab concrete was determined to be 3,450 lbs/in^2 fairly close to the results of Rebound number test.

Table 2. Results of Schmidt Hammer and Ultrasonic Pulse-Velocity Tests

No	Location	Mean Rebound Number	Mean Velocity (ft/sec)	Strength from the Relationship between Core Strength and	
				Rebound Number	Pulse Velocity
1	Southern Wall of Toilet	24.3	13680	3650	3700
2	Eastern Wall of Toilet	24.6	13643	3750	3650
3	Western Wall of the Lady Members' Room	23.9	11560	3600	4000
4	Northern Wall of the Lady Members' Room	21.3	13318	2900	3300
5	Western corner of northern Lobby	21.6	13050	3000	3000
6	Wall of Conference Room	21.5	13326	2950	3300
7	Wall of Retiring Room with Speaker's Office	27	14350	4400	4400
8	Wall of Speaker's Office	21.8	13425	3050	3400
9	Wall of Retiring Room with Dy. Speaker's Office	20.4	12740	2700	2700
10	Wall of the Dy. Speaker's Office	21.7	13532	3000	3500
11	Wall of PS to Leader of the House's Office	21.7	13747	3000	3750
12	Wall of Leader of House Office	21.6	13050	3000	3000
13	Wall of Staff of Leader of House Office	22.4	13274	3800	3200
14	Wall of PRO of Leader of House	23.7	13256	3550	3200
Average Compressive Strength:				3300	3450

MAGNETIC REBAR LOCATORE (PROFOMETER) TEST

Magnetic Rebar Locator (Profometer) was used to determine orientation, size and spacing of flexural reinforcing bars in concrete slabs of 43 rooms. Profometer consists of an indicator unit and two probes, the spot probe and depth probe. The spot probe can be used up to a maximum concrete cover of 6 centimeters. For concrete covers in excess of 6 cm, the depth probe was used.

The test was performed on the underside of the slabs at various locations of the building. For exact determination of orientation, size and spacing of reinforcing flexural bars, systematic scanning of the test surface was carried out with the help of the two probes. In the scanning process, the spot probe is first brought in full contact with the underside of the slab and moved over the slab surface. The indicator unit showed some deflection as soon as the probe comes closer to a reinforcing bar and gave maximum deflection when it was exactly below a reinforcing bar. Reinforcing bars were located at the centre and near the supporting wall in each panel of the room selected for load testing.

Slab flexural reinforcing bars were determined to be 5/8 inch in diameter plain steel reinforcing bars. Spacing of the flexural reinforcement was found to be in the range from six to nine inches in the main direction and nine to eleven inches in the orthogonal direction.

PHYSICAL LOAD TEST

To explicitly determine safety and serviceability of the building for new occupancy, three rooms of the existing building were subjected to Physical Load Test as per provisions of Chapter 20 of the ACI Code 318–2002 [6]

Live load corresponding to new occupancy as an office was taken as 70 lbs/ft^2 instead of 50 lbs/ft^2 as recommended by ASCE 7-95 and 6 inch of concrete flooring was assumed over the existing reinforced concrete slab. The greater value of the live load was taken to be representative of the local loading conditions.

As per requirements of Chapter 20 of ACI Code, a total test load of 0.85(1.4D+1.7L) was determined for each room to be tested where dead load D and live load L both corresponded to the new occupancy. The dead loads of concrete slab and overburden materials were determined and subtracted from the total test load to obtain the test load to be applied.

The first step in the physical load test was the removal of false-ceiling and erection of a horizontal plate-form supported by a rigid space frame of steel pipes. The plate-form was used to support displacement transducers during the load test. Before the load test, an inventory of the rooms was prepared. Visual inspections were carried out before and after the application of each installment of test load. After the visual inspection, the positions of displacement transducers were marked on the underside of the slab and below the beam. Strain-gage based displacement transducers were installed on rigid steel platform to determine mid-span deflections in concrete slab panels and steel beams after application of every installment of a test load. Displacement transducers were also installed to determine deflections at 1/3rd and 1/4th of the span in concrete slab panels and steel beams. The displacement transducers were connected with the data acquisition system, Kyowa's UCAM-70A Data Logger. Before the application of first installment of the test load, the capacity and rated output for each displacement transducer was entered in the Data Logger and all the transducers were initialized.

The test load was applied to the slab in four equal installments and comprised sand-filled polythene bags, each weighing forty (40) Kg. To eliminate any dynamic effect due to load application, deflections of slab panels and beams were recorded one hour after the application of every installment of a test load. Slab-beam junction in each testing room was inspected for all four installments of the test load to determine the degree of a composite behavior between concrete slab and steel beam. Throughout the load testing, the slab panels were constantly inspected for any sign of distress such as spalling and/or crushing of concrete in compression. Cracks were traced along their lengths and their depths and widths were measured with the help of a crack microscope and 0.3 mm standard blade.

The full test load was maintained for 24 hours and a set of deflections were recorded. The test load was then removed immediately and a final set of deflections was recorded 24 hours after the removal of a test load. After the

completion of a load test, data processing was done to evaluate the response of the building in the light of recommendations made by ACI Code.

As per ACI Code, the measured maximum deflection of slab-beam system shall satisfy one of the following two conditions:

$$\Delta_{max} \leq \frac{l_t^2}{20000h} \qquad \text{Eq. 1}$$

$$\Delta_{r\,max} \leq \frac{\Delta_{max}}{4} \qquad \text{Eq. 2}$$

Where

Δ_{max} = Measured maximum deflection, Δ_{rmax} = Measured residual deflection,
h = overall thickness of slab & l_t = span of member under load test, inches

In the case of a very stiff structure where maximum deflection is less than that given in Eq. 1, recovery requirements are waived off by the ACI Code.

The measured maximum deflections in Room A and Room C were found to be smaller than that permitted by the ACI Code for serviceability limit state. It was concluded from the measured behavior of these two rooms that the existing slab-beam system was very stiff and strong and their performance was found satisfactory for full loads corresponding to new occupancy.

In the case of Room B where wide and deep cracks were already present in the slab, the load test was progressed in a very careful manner so that any mishap can be prevented. The 50% test load was maintained for 12 hours and the system was closely monitored for any sign of distress. The remaining load was then applied in two equal installment and the deflections were recorded. The maximum deflection in the structural system at full test load was far below the value permitted by Chapter 20 of the ACI Code showing that the slab-beam system is also stiff and strong in this room. The measured maximum deflections in this room were found to be greater than those permitted by the ACI Code for serviceability limit state. From these considerations, the live load corresponding to the new occupancy was reduced to a value of 30 psf in addition to 6 inches of concrete flooring over the existing concrete slab. To ensure satisfactory performance regarding serviceability, cracks in slab must be properly treated and controlled. Table 3 gives detailed results of the physical load test performed on the three rooms.

CONCLUSIONS

The conclusions drawn from the non-destructive testing of this historic building are as follows:

- Compressive strength of slab concretes varied from 2,700 to 4,400 lbs/in^2 for different locations of the building. It is worth mentioning that there is marked degree of consistency between compressive strength results of different tests.
- Similarly unit weight of concrete was found to be in the range of 140 to 160 lbs/ft^3 for different core samples taken at different points.
- Maximum measured deflection of various slabs and girders was in the range from 0.27 mm to 1.61 mm. Similarly maximum crack width observed was 2 mm in common toilet only which exceeded the permissible crack width of 0.41 mm for this exposure specified by the ACI Code.
- Bearing capacities of soil samples taken from different foundation locations were found to be in the range from 1.10 to 1.30 tonnes/ft^2.
- Compressive strength of brick specimens taken from the structure and tested in the laboratory were found to be in the range from 1,300 psi to 3,050 psi.
- From the test of concrete core taken from the foundation and tested in the laboratory, the compressive strength of foundation concrete was found to be 3,450 psi.

RECOMMENDATIONS

Since strength and integrity of different structural components of the tested location were found satisfactory, the proposed construction over the tested portions of the existing Assembly building is allowed with the following recommendations:

- All the overburden materials over the existing concrete slab shall be completely removed
- There shall be a maximum of 6 inches of concrete flooring over the existing concrete slab
- Occupancy for the tested portions of the building shall only be office with live load not exceeding 70 lbs/ft^2 for Rooms A and C, and 30 lbs/ft^2 for Room B
- Sources of loads causing vibrating or impact shall be avoided
- No concentrated load either from walls or columns shall be placed on the slab
- Wall coming over the existing walls shall be so proportioned that vertical stress in the existing walls shall not exceed 250 lbs/in^2 and the total load transferred to the foundation shall not exceed allowable bearing capacity of soil
- The complete structural system shall be kept under routine observation by the maintenance staff. Observation shall include but not limited to monitoring of cracks, spalling and crushing of concrete, and deflections etc. In case of any distress, affected structure and/or structural components must be rehabilitated or replaced.
- The existing Room B slab shall preferably be rehabilitated/replaced. In the meantime, the tested portion can be used for light storage such as stationery or equivalent with a live load not exceeding 30 lbs/ft^2.

Table 3. Results of Physical Load Test of the Building

Description of Item	**Room**		
	Room A	**Room B****	**Room C**
Maximum width of cracks, mm	0.2	2.0	0.2
Maximum depth of cracks, mm	---	21	---
Maximum width of cracks allowed by ACI Code for serviceability limit state, mm	0.4	0.4	0.4
Girder section	S15x50	S15x50	S8x18.4
No. of displacement transducers installed	20	16	11
Total test load, psf	280	280	272
Dead load already in place, psf	229	229	225
Test load to be applied, psf	51	51	47
Test load to be applied, No. of 40 kg. bags	719	256	132
Maximum deflection recorded (24 hours after the application of 100% test load), mm	1.61*	0.61*	0.27*
Maximum deflection allowed (Eq. 1), mm	2.43	2.14	1.48
Maximum numerical model deflection at 100% test load, mm	6.57*	4.39*	2.86*
Results of Numerical Analysis of Model	Section un-cracked and stresses elastic	Section cracked and stresses elastic	Section cracked and stresses elastic
Recovery Measurements as per ACI Code	Waived	Waived	Waived
Performance of slab-beam structural system during load test	Satisfactory	Satisfactory	Satisfactory
Appropriateness about new occupancy	Allowed for 70 psf live load	Allowed for light occupancy with maximum live load of 30 psf	Allowed for 70 psf live load
Remarks	None	Cracked slab shall be rehabilitated/replaced	None

* These two values were not recorded at the same place
** 50% of the test load was maintained for 12 hours as a precautionary measure and the structural response of the slab-beam system was closely monitored

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