International Journal of Scientific Engineering and Research (IJSER)
ISSN (Online): 2347-3878
Index Copernicus Value (2015): 56.67 | Impact Factor (2017): 5.156

Non-destructive Evaluation of an Existing Concrete Structure using Load Test

Dr. Samuel R. Calisang[1]

Western Mindanao State University, Faculty, Department of Civil Engineering, Zamboanga City, Philippines
Email address: scalisang@yahoo.com
Dionio Compound, Veterans' Avenue Extension, Tumaga
Zamboanga City, 7000
CP# 09062318644
Tel.# (062) 985-0695

Abstract: ***Forensic Engineering involves both curative or remedial and post-failure investigations.The former provides, the needed technical facts on what to do with the structure; while, the latter provides technical data to prevent the recurrence of the same for the policy and decision makers. The research work focused on non-destructive evaluation of a five-story concrete building which was partially burned. Portion of the third and fourth floors slabs and supporting structural members were subjected to intense heat.It was necessary to assess the existing conditions of the building to determine whether or not it is still fit for occupancy. For this purpose, load tests were performed on the identified third floor areas.The test results indicated that the affected areas had adequate but reduced strength for future use or maybe retrofittedto restore the original design load carrying capacity of the structural members affected and the structure as a whole. It is further recommended that other tests be conducted to ensure that management has enough technical data to decide on what to do with the building.***

Keywords: Non-destructive Testing (NDT), Load Test (LT)

1. Introduction

There is a need to assess the existing structural properties of reinforced concrete structures to evaluate their performance[1]. Non-destructive Testing (NDT) evaluation 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 in the Philippines and abroad. 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 begin 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 and investigationof 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, 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 its 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. LT was used for this research work. This research work is focused on establishing the adequacy of an existing RC building structure after it was subjected to intense heat exposure. The building had five (5) existing floors and constructed five(5) years ago. The load tests were conducted only on the areas affected and the other areas not affected were presumed to have been designed and constructed in accordance with sound engineering practice.

The panels that were tested had an average size of 7mx 4.5m and 7mx 3.0m.with 150mm slab thickness (Fig. 1 & 4). One was two-way slab with supporting beams and two one-way slabs with supporting beams.

2. Review of Testing Method

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 chapter 20 provides detailed testing procedure and criteria of acceptance and rejection. Several researchers[9-10,14-17] have recommended methods for applying loads and investigating structural response for the load tests.

3. Experimental Work and Discussion

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

3.1 Load Tests were conducted in accordance with the American Concrete Institute (ACI 318-05):

Six(6) slab panels were tested, all in the third floor. The number and arrangement of spans or panels to be tested were selected to maximize the deflection (midspan) and stresses in the critical regions of the structural elements. Presence of hairline cracks in slab panels and beams were also considered as factor while selecting the test panels. American Concrete Institute (ACI 318), provides that the test load, (including dead and already in place load) should not be less than 0.85(1.4DL + 1.7LL). As recommended by the of American Society of Civil Engineers[18], live load of 60 psf (2.87Kpa) for shops and apartments, and 100 psf (4.75Kpa) 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 should be used. The test load was applied in four equal increments in accordance with the recommendation by the ACI. Sand bags of 20 kgs (44 lb) were used for loading the floor slabs, (see picture 6). Figures 1 & 4show the arrangement and actual placement of deflection lines (also see pictures 1 to 5), and loading arrangement (figure 2.) by using 20 kgs bags loose sand.

Minimum load: (Includes the dead load in-placed)
Load=0.85(1.4DL + 1.7LL)
DL=75 psf (3.60 Kpa)
LL=60 psf 2.87 Kpa)
Load=176psf
Net Load=101psf (4.75 Kpa)
Use only 60% of the allowable net load, 60psf (2.87 Kpa), due to excessive heat exposure.
For 3mx 7m panels use 80 bags @20kgs/bag for each load increment.
For 4.5mx7m panels use115 bags @20kgs/bag for each load increment.

Procedures for Load Test

(ACI 318-05)

1) Record all data available relevant to the slabs and beams under consideration, before applying the loads, like cracks, initial deflections, twisting and discoloration.
   Use TABLE 1 for AREA1 SET1 and TABLE 1A for AREA2 SET2 loadings.
2) Load the first load increment, as indicated in figure 2. Record the deflections and other pertinent data needed in the test.
   Use TABLE 2for AREA1 SET1 and TABLE 2A for AREA2 SET2 loadings.
3) Repeat procedure 2) in loading the second, third and the fourth load increments. Observe three(3) hours interval after each load increment loading.

Use TABLES 3 & 4for AREA1 SET1 and TABLE 3A & 4A for AREA2 SET2 loadings.

4) Remove the loads applied within 24 hours after the application of the first load increment. Record the deflections and the residual deflections 24 hours after the removal of the loads.

Use TABLE 5for AREA1 SET1 and TABLE 5A for AREA2 SET2.

STOP THE TEST ON A PANEL IF ANY OF THE FOLLOWING IS OBSERVED;

1) Spalling of concrete cover
2) Compression crushing of concrete
3) Excessive deflection
4) Widening of crack width
5) Formation of additional cracks

3.1.1 Acceptance/ Rejection Criteria:

The Acceptance/rejection criteria for slabs, as required by ACI318-05, Section 20.5.2, the measured and residual deflections at mid-span should not exceed any of the following values:

a) The measured deflection,
   $D_1=L_S^2/20{,}000h$
b) and the residual deflection,
   $D_r=D_1/4$

Where, L_s: the shorter of the two(2) spans,h: slab thickness.

The Acceptance/rejection criteria for beams, the measured and residual deflections at mid-span should not exceed any of the following values:

a) The measured deflection;
   $D_1=L/420$
b) and the residual deflection;
   $D_r=D_1/4$

Where, L: beam span.

LOADING DETAILS AREA1, SET1:

Table 1: (Initial reading, before loading))

Element	deflection	Remarks
Slab1	482mm	Line below slab center
Slab2	273mm	-do-
Slab3	219mm	-do-
Beam1	7mm	Line below beam center
Beam2	0mm	Line exactly on beam center
Beam3	0mm	-d0-
Beam4	16mm	Line below beam center

3:00pm, loading, (6:00pm, reading)

Table 2: (First load increment)

Element	deflection	Remarks
Slab1	482mm	
Slab2	273mm	
Slab3	218mm	
Beam1	7mm	
Beam2	2mm	
Beam3	2mm	
Beam4	15mm	

6:20pm, loading, (9:00pm, reading)

Table 3: (Second load increment)

Element	deflection	Remarks
Slab1	482mm	
Slab2	272mm	
Slab3	216mm	
Beam1	7mm	
Beam2	4mm	
Beam3	4mm	
Beam4	14mm	beam cracks widen/ appearance of shear crack

9:20pm, loading, (1:00am, reading)

Table 4: (Third load increment)

Element	deflection	Remarks
Slab1	481mm	
Slab2	271mm	
Slab3	214mm	
Beam1	6mm	
Beam2	5mm	
Beam3	5mm	
Beam4	14mm	

Residual deflections taken after full removal of loads.
Loads were removed at 10:00am, the following day.
Summary of Residual deflections after 24 hours of removal of loads.

Table 5: (No fourth load increment)

Element	Deflection (measured)	deflection (actual)	Allowable D_1	Remarks	Residual D_r	$D_1/4$	Remarks
Slab1	481mm	1.0mm	2.286mm*	ok	0mm	0.572mm	ok
Slab2	271mm	2.0mm	2.286mm*	ok	0mm	0.572mm	ok
Slab3	214mm	5.0mm	4.478mm*	Not ok	1mm	1.119mm	ok
Beam1	6mm	1.0mm	12.50mm*	ok	0mm	3.125mm	ok
Beam2	5mm	5.0mm	12.50mm*	ok	1mm	3.125mm	ok
Beam3	5mm	5.0mm	12.50mm*	ok	1mm	3.125mm	ok
Beam4	14mm	2.0mm	12.50mm*	ok	0mm	3.125mm	ok

*Only 0.75 of the Code Allowable was used.

LOADING DETAILS AREA2, SET2:

Table 1A: (Initial, before loading)

Element	deflection	Remarks
Slab1A	485mm	Line below slab center
Slab2A	295mm	-do-
Slab3A	213mm	-do-
Beam1A	14mm	Line below beam center
Beam2A	12mm	Line above beam center
Beam3A	18mm	-do-
Beam4A	8mm	-do-

8:20 am, loading, (11:00 am, reading)

Table 2A: (First load increment)

Element	deflection	Remarks
Slab1A	485mm	
Slab2A	295mm	
Slab3A	213mm	
Beam1A	14mm	
Beam2A	13mm	
Beam3A	19mm	
Beam4A	8mm	

11:20 am, loading, (2:00 pm, reading)

Table 3A: (Second load increment)

Element	deflection	Remarks
Slab1A	484mm	
Slab2A	294mm	
Slab3A	212mm	
Beam1A	14mm	
Beam2A	14mm	
Beam3A	20mm	
Beam4A	9mm	

2:30 pm, loading, (5:00 pm, reading)

Table 4A: (Third load increment)

Element	deflection	Remarks
Slab1A	484mm	
Slab2A	294mm	
Slab3A	211mm	
Beam1A	14mm	
Beam2A	15mm	
Beam3A	21mm	
Beam4A	9mm	

Residual deflections taken after full removal of loads.
Loads were removed at 7:00am, the following day.

Summary of Residual deflections after 24 hours of removal of loads.

Table 5A: (no fourth load increment)

Element	Deflection (measured)	deflection (actual)	Allowable D_1	Remarks	Residual D_r	$D_1/4$	Remarks
Slab1A	484mm	1.0mm	2.286mm*	Ok	0mm	0.572mm	ok
Slab2A	294mm	1.0mm	2.286mm*	Ok	0mm	0.572mm	ok
Slab3A	211mm	2.0mm	4.478mm*	Ok	1mm	1.119mm	ok
Beam1A	14mm	0.0mm	12.50mm*	Ok	0mm	3.125mm	ok
Beam2A	15mm	3.0mm	12.50mm*	Ok	0mm	3.125mm	ok
Beam3A	21mm	3.0mm	12.50mm*	Ok	1mm	3.125mm	ok
Beam4A	9mm	1.0mm	12.50mm*	Ok	0mm	3.125mm	ok

*Only 0.75 of the Code Allowable was used.

4. Summary of Load Test Results

Discussion

AREA 1:

Covers Slabs S1, S2 and S3 / Beams B1, B2 and B3: (See figure 4)

The table shows the deflections of the last load increment and their corresponding residual deflections 24 hours after the removal of the loads.

It compares the actual and residual deflections to the code allowable deflections (ACI 318M-05, Chapter 20). For details, please see above tabulated load test results AREA1, SET 1.

Table 5: Summary of results for AREA1, SET1 loadings

Element	Deflection (mm)	Loading	Allowable D_1 (mm)	Remarks	Residual D_r(mm)	$D_1/4$ (mm)	Remarks
Slab1	1.0	3rd increment	2.286*	ok	0.00	0.572	ok
Slab2	2.0	3rd increment	2.286*	ok	0.00	0.572	ok
Slab3	5.0	3nd increment	4.478*	Not ok	1.00	1.119	ok
Beam1	1.0	-do-	12.05*	ok	0.00	3.125	ok
Beam2	5.0	-do-	12.50*	ok	1.00	3.125	ok
Beam3	5.0	-do-	12.50*	ok	1.00	3.125	ok
Beam4	2.0	-do-	12.50*	ok	0.00	3.125	ok

*Only 0.75 of the Code Allowable was used.

AREA 2:

Covers Slabs S1A, S2A and S3A / Beams B1A, B2A and B3A: (See figure 4)

The table shows the deflections of the last load increment and their corresponding residual deflections 24 hours after the removal of the loads.

It compares the actual and residual deflections to the Code Allowable deflections (ACI 318M-05, Chapter 20). For details, please see above tabulated load test results AREA2, SET 2.

Table 5A: Summary of results for AREA2, SET2 loadings

Element	Deflection (mm)	Loading	Allowable D_1(mm)	Remarks	Residual D_r(mm)	$D_1/4$ (mm)	Remarks
Slab1A	1.0	3rd increment	2.286*	Ok	0.00	0.762	ok
Slab2A	1.0	3rd increment	2.286*	Ok	0.00	0.762	ok
Slab3A	2.0	3nd increment	4.478*	Ok	1.00	1.119	ok
Beam1A	0.0	-do-	12.50*	Ok	0.00	3.125	ok
Beam2A	3.0	-do-	12.50*	Ok	0.00	3.125	ok
Beam3A	3.0	-do-	12.50*	Ok	1.00	3.125	ok
Beam4A	1.0	-do-	12.50*	Ok	0.00	3.125	ok

*Only 0.75 of the Code Allowable was used.

Findings:

1) The deflections recorded on slabs S1, S1A, S2, S2A, and S3A are within the allowable Limits. S3 exceeded the allowable limit.
2) The Residual deflections recorded on slabs S1, S1A, S2, S2A, S3 AND S3A are within the allowable Limits.
3) The deflections recorded on Beams B1, B1A, B2, B2A, B3 and B3A are within the allowable Limits.
4) The Residual deflections recorded on Beams B1, B1A, B2, B2A, B3, and B3A are within the allowable Limits.

5. Recommendations

1) The SLABS and BEAMS identified for AREAS 1 & 2 can still be used provided the load occupancy will be reduced to 40psf (1.9Kpa) from 60psf(2.85Kpa). The occupancy recommended can support OFFICE SPACES and similar spaces only; OR
2) The SLABS and BEAMS identified for AREAS 1 & 2 may be retrofitted, in accordance with sound Engineering Practice, to restore the original design load carrying capacity of the structural elements identified.
3) It is further recommended, either 1) or 2), to construct a 1.0mx 0.15m poured concrete wall stiffeners, as shown in Figure 4, to stiffen COLUMNS C1, C2 and C3 against lateral forces like, wind loads and Earthquake loads. The stiffeners should extend from ground to the last floor of the building.
4) To request theCommission of Higher Education (CHED), to incorporate forensic engineering subjects in the 5th year level of the Civil Engineering curriculum.

Acknowledgements

The Author is pleased to acknowledge the contribution of Dr. Roberto M. Sala, the Dean of the College of Engineering & Technology, Engr. Raul T. Alburo, faculty member of the Department of Civil Engineering and College Secretary, Dr. Milabel E. Ho, Western Mindanao State University President, the owner of the building and support staff in the performance of the researchwork.

References

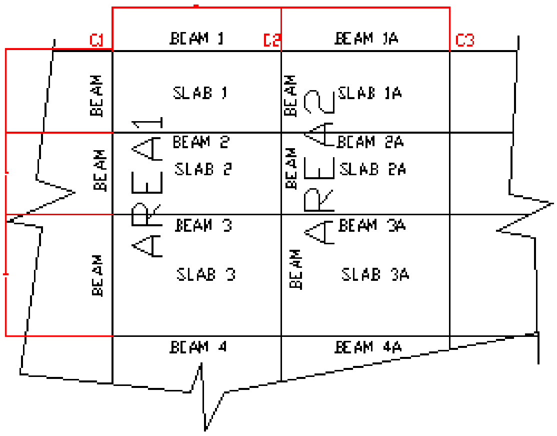
[1] Huang, Q., Gardoni, P. and Hurlebaus, S., 2011, “Predicting Concrete Compressive Strength Using Ultrasonic Pulse Velocity and Rebound Number”, ACI Material Journal, V. 108, No. 4, pp. 403-412

[2] Hertlein, B.H., 1992, “Role of Nondestructive Testing in Assessing the Infrastructure Crisis,”, Proceedings, Materials Engineering Congress on Performance and Prevention of Deficiencies and Failures, ASCE, pp. 80–91.

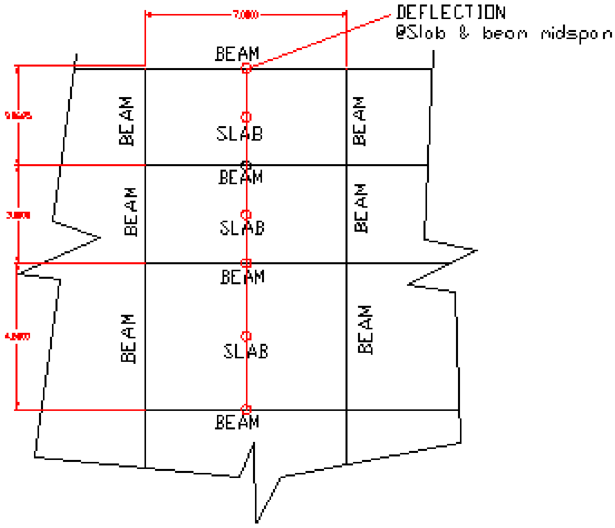
[3] Mirmiran, A., 2001, “Integration of NonDestructive Testing In Concrete Education”, Journal of Engineering Education, V. 90, No. 2, pp. 219-222.

[4] Bray, D.E., 1993, “The Role of NDE in Engineering Education,” Materials Evaluation, vol. 51, no. 6, pp. 651–652.

[5] ACI Committee 228, 2003, “In-Place Methods to Estimate Concrete Strength (ACI 228.1R03),” American Concrete Institute, Farmington Hills, MI.
[6] Samarin, A., and Meynink, P., 1981, “Use of Combined Ultrasonic and Rebound Hammer Method for Determining Strength of Concrete Structural Members,” Concrete International, V. 3, No. 3, pp. 25-29.
[7] Miretti, R., Carrasco, M. F., Grether, R. O. and Passerino, C. R., 2004, “Combined NonDestructive Methods Applied to Normal-Weight and Lightweight Concrete,” Insight, V. 46, No. 12, pp. 748-753.
[8] Hola, J., and Schabowicz, K., 2005, “New Technique of Nondestructive Assessment of Concrete Strength Using Artificial Intelligence,” NDT&E International, V. 38, pp. 251-259.
[9] M. A. Saleem, Z. A. Siddiqi, M. A. Javed and M. Aziz , “Nondestructive Evaluation of an Existing Concrete Structure using Load Test and Core Test” , Department of Civil Engineering, University of Engineering and Technology, Lahore, Pak. J. Engg. & Appl. Sci. Vol. 11, July, 2012 (p. 66-72)
[10] Nanni, A. and M. Mettemeyer, 2001, "Diagnostic Load Testing of a Two-Way Postensioned Concrete Slab," ASCE Practice Periodical on Structural Design and Construction, V. 6, No. 2, pp. 73-82.
[11] Mettemeyer, M., 1999, “In Situ Rapid Load Testing of Concrete Structures”, Masters Thesis, University of Missouri – Rolla, Rolla, Missouri, pp. 113.
[12] Mettemeyer, M. and Nanni, A., 1999, “Guidelines for Rapid Load Testing of Concrete Structural Members”, CIES 99-5, Report, University of Missouri – Rolla, Rolla, Missouri.
[13] ACI Committee 318, 2008, “Building Code Requirements for Structural Concrete (ACI 31808).”American Concrete Institute, Farmington Hills, MI.
[14] Hall, W. B., and Tsai, M. (1989). “Load testing, structural reliability and test evaluation.” Structural safety, Elsevier Science, New York, Vol. 6, 285–302.
[15] Bungey, J. H., 1989, “The Testing of Concrete in Structures, 2nd Ed., Chapman and Hall, New York.
[16] Fling, R. S., McCrate, T. E., and Doncaster, C. W., 1989, “Load test compared to earlier structure failure”, Concrete International, American Concrete Institute, V. 18, No. 11, pp. 22–27.
[17] Casadei, P., Parretti, R., Nanni, A. and Heinze, T., 2005, “In Situ Load Testing of Parking Garage Reinforced Concrete Slabs: Comparison between 24 h and Cyclic Load Testing”, Practice Periodical on Structural Design and Construction, V. 10, No. 1, pp. 40-48.
[18] "Minimum Design Loads for Buildings and Other Structures (7-05)," American Society of Civil Engineers, Reston, VA., USA., 2006.



Slabs and Beams Floor Plans: (Figures 1 & 4)



Incremental load patterns: Figure 2

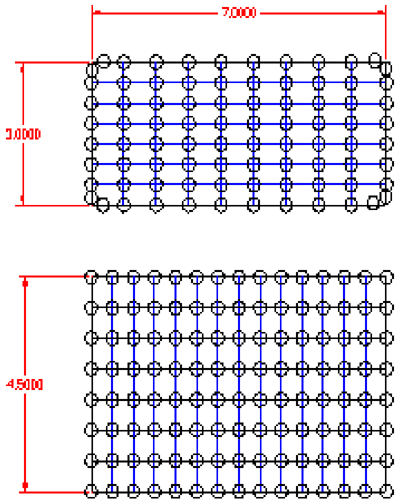


Figure 2

Pictures of the third floor slabs and beams which were burned.

Setting of horizontal and vertical controls for deflection measurements (Pictures 1 to 6).
Picture 1.

Picture 2

Picture 3

Picture 4

Picture 5

Picture 6. LOADS applied to the SLABS AND BEAMS