Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/

(RESEARCH ARTICLE)

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Monitoring of structural health and safety of Flores hall and Valencia hall: Inputs for repair, renovation, and retrofitting phase II

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Global Journal of Engineering and Technology Advances, 2023, 15(02), 073–090

Publication history: Received on 05 April 2023; revised on 15 May 2023; accepted on 18 May 2023

Article DOI: https://doi.org/10.30574/gjeta.2023.15.2.0088

Abstract

The evaluation of structures is imperative as these structures age and exposed to different external and internal stresses and resistances. The strength of any structure inclusive of its structural components, can be determined from its health and safety. This study aimed to evaluate the structural health and safety of Flores Hall and Valencia Hall through the use of Non-Destructive Test specifically the Rebound Hammer Test and consequently propose Preventive Maintenance Management Plan. The researchers conducted non-destructive Rebound Hammer test to the structural components such as beams, bleachers, columns, and slabs of the two Halls. The results of the Rebound Hammer test were automatically produced, tabulated, and analyzed. For Flores Hall, most of the columns in the ground floor have existing condition of structurally sound which means above with the allowable compressive strength while in the second floor some of the columns have existing conditions of moderate, considerable, and major distress which were below the allowable compressive strength; in the beams and slabs, some of the grid lines have existing condition of structurally sound which were above the allowable compressive strength while majority of the grid lines have existing conditions of moderate, considerable, and major distress which were below with the allowable compressive strength. All the grid lines of the bleachers in Valencia Hall when tested by Hammer Rebound equipment yielded compressive strength above the allowable compressive strength of 28 MPa. Also, majority of the columns in Valencia Hall have existing condition of structurally sound which were above the allowable compressive strength but some of the columns have existing condition of moderate, and considerable distress which were below the allowable compressive strength. Furthermore, for the beams tested, all have existing condition of structurally sound which means above the allowable compressive strength. The Non-Destructive Test through the use of Hammer Rebound Test equipment to monitor the structural health and safety of Flores Hall and Valencia Hall yielded data in terms of the existing conditions of the beams, columns, slabs, and bleachers. The results of the Hammer Rebound test revealed the average compressive strength per grid or grid line of the structural components which show if the structural component complied with the allowable compressive strength. The proposed Preventive Maintenance Management Plan may be used to systematically implement the monitoring of structural health and safety of the Flores Hall and Valencia Hall and provide a safe structure where administrative officials, faculty members, students, and other stakeholders can perform their works and transactions.

Keywords: Structural health and safety; Concrete beams; Bleachers; Columns; Slabs; Non-destructive test

1. Introduction

The assessment of structures such as buildings, bridges, dams, tunnels, and other industrial facilities is imperative as these structures age and are exposed to different external and internal stresses and resistances. The strength of any structure, inclusive of its components, can be proven through its health and safety. When there are no usual or sudden changes in resistance, structural assessment should be initiated. The structural deterioration which may happen due to

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time and changes are corrosion, fatigue, structural damage by accident actions, change in loading, and extension of its planning and design working life. Assessing the strength of the structure is required in different conditions, such as the standard of concrete being compromised and not complying with the specifications; change in the use and function of the structure; damage due to man-made or natural ruins; environmental degradation; seismic retrofitting issues (Alwash, 2017).

Phase II of this study will focus on Non-Destructive Tests (NDT). The building inspections on-site or in situ examinations of buildings are difficult to work on and require the use of Non-destructive test techniques. The Non-destructive test method of concrete obtains the compressive strength and other properties of concrete from the existing structures (Tavukcuoglu,2017). It ensures the structure's safety, reliability, and long-lasting integrity (Smith, 2016). The effective NDT method, which has been highly used by professionals in the field of structure inspection, condition assessment, and evaluation, is doing it on-site and visually inspecting the structural and non-structural components.

The Rebound Hammer Test is a non-destructive testing apparatus, where the rebound of the spring-driven mass will be measured after its impact on the concrete surface. The result of the rebound hammer is called the rebound number and is correlated with the surface hardness of concrete. The rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by establishing an appropriate correlation between the rebound index and the compressive strength of concrete. It is useful to test in-situ concrete as well as fresh concrete after the final set; to assess the in-place uniformity of the concrete; to find out the exact location of poor quality and deteriorated concrete; and to estimate in-place strength if a correlation is developed.

Bulacan State University is one of the premier state-operated Higher Education Institutions in Region 3. It has five campuses, the main campus is in the City of Malolos, other campuses are in other municipalities and cities; Bustos, Bulakan, Hagonoy, and the City of San Jose Del Monte. Over the years, several infrastructures were built to accommodate the students, faculty members, and non-teaching personnel. On the main campus, there are more than ten medium-rise buildings which are a combination of old and newly built. Valencia Hall and Flores Hall were built in 1980 and 1988, respectively. The National Structural Code of the Philippines (NSCP) 2015 states that "buildings used for college or adult education with a capacity of 500 or more occupants is one of the structures under special occupancy". The Flores Hall is the Administration Building of Bulacan State University; it is a two-storey building with L-shape. The offices of key officials, registrar, cashier, accounting, budget, human resource management, infirmary, project management, and auditors of the University occupy this building to manage and operate the academic and administrative services of the University. While the Valencia Hall is the University Gymnasium, where all the convocations, sports and academic programs, classes, cultural and technical training, fora, symposia, seminars, and conferences were being held. Considering its years of existence, different internal and external stresses may have been present in these structures. Thus, structural health and safety should always be monitored and assessed. The need to monitor and assess the structural strength of the building is very essential to continue its service to the occupants and users. It is true and necessary that "Prevention is better than cure". The researchers have the measures to prevent the Valencia Hall and Flores Hall from collapsing and assure its structural integrity. There are several reasons why the specific structure should be assessed using the existing and applicable approaches possible like non-destructive tests and rapid visual screening, while not affecting its structure and its purpose. For this study, the very reasons for assessing the Flores Hall and Valencia Hall are to assure the safety of its users or occupants and to identify a cost-benefit application of repairing or renovating, and retrofitting.

1.1. Statement of the Problem

The general problem of this study is "How may the structural health and safety of Flores Hall and Valencia Hall be evaluated through the use of Non-Destructive Test and consequently, the results can be used as inputs in its repair, renovation, and retrofitting?"

Specifically, this study sought answers to the following questions:

- How may the hardness and compressive strength of the reinforced concrete components of Flores Hall and Valencia Hall be monitored through the Non-Destructive Test of the following:
    - Beams;
    - Columns
    - Slabs; and
    - Bleachers?
- Based on the results of the study, what Preventive Maintenance Management Plan may be proposed to improve the health and safety of Flores Hall and Valencia Hall?

2. Material and methods

2.1. Methods and techniques of the study

This study is the second phase of the monitoring of structural health and safety of Flores Hall and Valencia Hall. From the results of the visual inspection report of Flores Hall and Valencia Hall, structural members subject for tests were identified. To determine the health and safety or remaining strength of the main structural concrete components, a Rebound Hammer Testing was used. This equipment can be convenient and can quickly provide compressive strength of hardened structural concrete components not affecting the building strength. The results of the testing were used for recommendation in evaluating or detailed structural assessment of the overall integrity of Flores Hall and Valencia Hall considering the actual strength condition of each main concrete component.

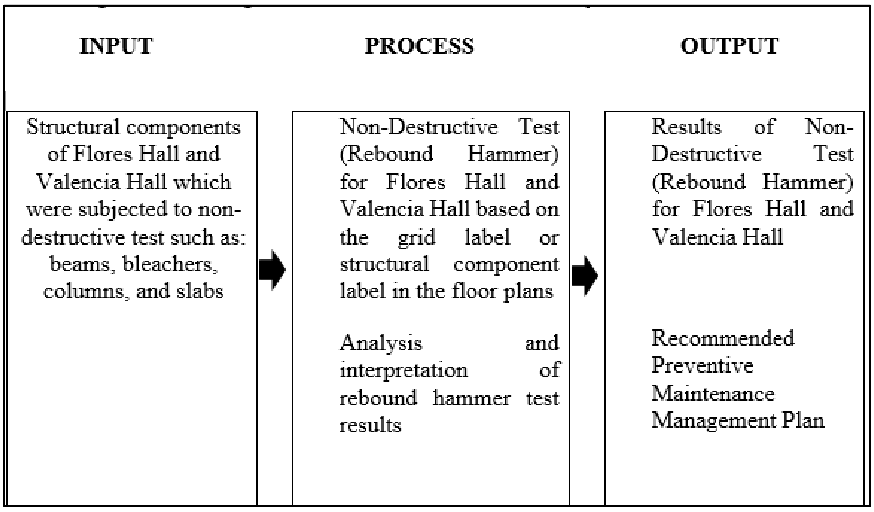

Figure 1 The conceptual paradigm of the study

Figure 1 shows the input-process-output conceptual paradigm of the study. The Input contains the structural components which were subjected to the non-destructive test. Rebound Hammer equipment was used in conducting the non-destructive test. The following structural components were beams, bleachers, columns, and slabs of the Flores Hall and Valencia hall. The Process considered the grid label or structural component label in performing the Non-Destructive Test using the Rebound hammer equipment. After the recording in the equipment and conversion of results in the compressive strength, these data were analyzed and interpreted. The Outputs were composed of the results of the Non-Destructive Test for structural components of Flores Hall and Valencia Hall and the recommended Maintenance Management Plan.

2.2. Research Instruments

This study relies on the results of the visual inspection report of Flores Hall and Valencia Hall considering the checklist used, the building drawing plans, findings, conclusion, and recommendations to identify the desired part of the main concrete components that will undergo a non-destructive rebound hammer test. The researchers assigned grid labels or structural component labels for the beams, bleachers, columns, slabs, and stairs both for Flores Hall and Valencia Hall.

2.3. Data Gathering Procedure

As preliminary preparations, the noted seepage and cracks indicated in the visual report of Flores Hall and Valencia Hall was the priority of the test subject of main concrete components, a hammer tapping was conducted on its perimeter to further identified a potential concrete spalling or dense or hollow, and this served as the critical areas of the building. The researchers initially assigned grid labels or structural component label on the drawing plans for facilitating the continuous flow of Non-Destructive Test.

A rebound hammer non-destructive testing was followed to all structural components of the Flores Hall and Valencia Hall, but there were few structural components which were not accessible due to some blockage. The concrete quality, its uniformity, and especially its actual/present compressive strength was determined by the use of rebound hammer equipment.

2.4. Data Processing and Statistical Tools used in the study

The data obtained from the rebound hammer testing were collated accordingly and tabulated as per structural concrete component. The mean and standard deviation per grid was computed. To evaluate the quality of concrete, an Average Rebound test result was used, and a color-coded analysis report was presented with descriptions, to easily understand even with a non-technical person.

For the color used in presenting the results of the data gathered from the rebound hammer testing, a red mark was interpreted as a major distress on the structural concrete components, an orange mark was a considerable distress, a yellow mark was a moderate distress, while a green mark was structurally sound, all in-terms of its compressive strength.

The four-point Likert scale of concrete quality was used to present the structural soundness or the existing condition of the structural components:

Table 1 The four-point Likert scale of Concrete Quality

Scale	Descriptive equivalent	Color
28.00 MPa and above	Structurally sound	Green
23.00 MPa- 27.99 MPa	Moderate distress	Yellow
18.00 MPa- 22.99 MPa	Considerable distress	Orange
17.99 MPa and below	Major distress	Red

To describe the soundness of its compressive strength, a central tendency statistical tool was employed using the “mean method”. For mean calculations, the rebound hammer sets of values recorded from a single point test was added, and its sum was divided by the total number of that recorded data (Mean = $\sum x / n$), where $\sum x$ is the sum of all recorded data, and n is the total number of the recorded data.

In comparing the predetermined value to the result or computed mean value of a single sample obtained from rebound hammer of Flores Hall and Valencia Hall, the researchers used One Sample T-Test to be able to determine if its difference is significantly greater or lesser. In this study, according to the Department of Public Works and Highways, for public school building standardized plan, the researchers will be using a 28 MPa compressive strength for school buildings as stated.

3. Results and discussion

The chapter deals with the presentation, analysis and interpretation of data gathered by the researchers through non-destructive test using Rebound Hammer Test.

3.1. Part I. Non-Destructive Test Results using Rebound Hammer on Valencia Hall

Table 2 presents the Non-Destructive Test results using the Rebound Hammer equipment on bleachers in Valencia Hall. It was noted from the table that the lowest compressive strength of 30.4 MPa was located along Grid 1 and 2, G to J. While the highest compressive strength of 41.5 MPa was located along Grid 4 and 5, D to F and both are “structurally sound" when referred to the Department of Public Works and Highways (DPWH) standard compressive strength of 28 MPa. All the gridlines of bleachers have compressive strength above the required or standard set by the DPWH.

Table 2 Non-Destructive Test Results using Rebound Hammer on Concrete Bleachers at Valencia Hall

Location	Age	Existing Condition	Rebound Hammer Measurements			Rebound Hammer Conversion ASTM C805			
			Number of Readings	Maximum	Minimum	Maximum (MPa)	Minimum (MPa)	Standard Deviation (MPa)	Average (MPa)
Along Grid 1 and 2									
G to J	42	Str. sound	10	39	29	37.3	23.3	4.7	30.4
K to N	42	Str. sound	10	40	32	38.8	27.3	3.2	34.1
Along Grid 3 and 4									
A to C	42	Str. sound	8	43	32	43.4	27.3	5.7	36.9
D to F	42	Str. sound	10	39	37	37.3	34.4	1.3	35.7
Along Grid 4 and 5									
A to C	42	Str. sound	7	41	36	40.3	32.9	2.4	37.9
D to F	42	Str. sound	9	45	39	46.5	37.3	2.9	41.5
Along Grid 5 and 6									
A to C	42	Str. sound	10	45	34	46.5	30.1	4.4	37.9
D to F	42	Str. sound	9	42	35	41.8	31.5	3.6	36.6
Along Grid 6 and 7									
A to C	42	Str. sound	10	44	35	44.9	31.4	4.1	36.2
D to F	42	Str. sound	10	43	32	43.4	27.3	5.6	35.5

Table 3 Non-Destructive Test Results using Rebound Hammer on Concrete Columns in Valencia Hall

Location	Age	Existing Condition	Rebound Hammer Measurements			Rebound Hammer Conversion ASTM C805			
			Number of Readings	Maximum	Minimum	Maximum (MPa)	Minimum (MPa)	Standard Deviation (MPa)	Average (MPa)
Along Grid 1									
G	42	Str. sound	9	39	31	33.6	22.5	4.1	28.8
H	42	Str. sound	9	40	34	34.9	25.8	2.5	30.4
C	42	Con. distress	10	34	27	26.2	16.8	3.3	22.3
J	42	Mod. distress	10	38	30	32	20.8	3.4	26.9
K	42	Con. distress	10	35	31	27.7	21.3	2.4	23.8
D	42	Str. sound	10	42	32	38	23.5	3.8	30.5
M	42	Str. sound	10	38	31	31.8	21.9	3	28.5

N	42	Mod. distress	10	38	30	32.1	20.6	4	25.2
Along Grid 2									
H	42	Mod. distress	10	35	30	27.6	20.6	2.2	23.5
C	42	Str. Sound	10	41	34	36.3	26	3.5	31.8
J	42	Mod. distress	10	39	30	33.5	20.6	4.6	27.5
K	42	Str. sound	10	39	36	33.5	28.9	1.6	32
D	42	Mod. distress	10	38	31	31.7	21.9	3.2	24.6
M	42	Mod. distress	10	35	30	27.5	20.6	2.4	23.1
Along Grid 3									
G	42	Str. sound	10	38	32	32.1	23.5	2.4	29.4
sB'	42	Str. sound	10	40	34	35	25.9	3.4	32.1
D'	42	Str. sound	9	39	33	33.6	24.8	2.7	31.2
E	42	Str. sound	9	46	34	44.4	26.2	7.9	38.1
N	42	Mod. distress	10	36	30	29	20.6	2.9	23.3
Along Grid 4									
B'	42	Str. sound	8	40	36	35.1	29.2	2.1	33
D'	42	Str. sound	10	39	31	33.4	21.9	3.8	28.5
Along Grid 5									
B'	42	Str. sound	10	40	33	35	24.6	2.9	31.6
D'	42	Str. Sound	9	40	34	35.1	25.5	3.9	31.7
Along Grid 6									
B'	42	Str. sound	10	40	38	34.9	31.7	1.2	33.8
D'	42	Str. sound	10	40	37	35.2	30.4	1.6	33.9
Along Grid 7									
B'	42	Str. sound	10	40	30	35.1	20.6	5.2	28.8
D'	42	Str. sound	10	40	32	34.7	23.1	3.5	31.5
Along Grid 8									
A	42	Str. Sound	10	45	38	42.8	31.6	3.6	38.7
C	42	Mod. distress	8	36	34	29.2	26.1	1.1	27.6
D	42	Str. sound	7	39	33	33.4	24.9	2.6	29
F	42	Str. sound	10	45	39	42.8	33.5	3.1	38.8
Along Grid 9									
C	42	Str. sound	10	42	32	37.6	22.9	4.2	30.6

J	42	Str. sound	6	39	30	33.5	20.8	4.9	28.4
K	42	Con. distress	4	30	28	20.8	18.3	1.4	19.5
D	42	Str. sound	10	43	38	39.7	31.9	2.5	36

As shown on Table 3 are the Non-Destructive test results using Rebound Hammer on the columns in Valencia Hall. It will be noted that the lowest compressive strength was 19.5 MPa which is located along grid line 9 and label K with the existing condition of "considerable distress" while the highest compressive strength was 38.8 located along grid line 8 and label F, and having the existing condition of "structurally sound". Also the lowest compressive strength of 23.1 MPa with an existing condition of "moderate distress" was located in Along Grid 2 Label M. From the 35 columns Rebound Hammer tested, 24 of which have existing condition of structurally sound, 3 were considerable distress, and 8 were moderately distress. Those 11 columns with existing conditions of considerable and moderate distress must be priority in retrofitting to prevent these structural components to be the cause of destruction of this Valencia Hall.

Table 4 Non-Destructive Test Results using Rebound Hammer on Concrete Beams at Valencia Hall

Location	Age	Existing Condition	Rebound Hammer Measurements			Rebound Hammer Conversion ASTM C805			
			Number of Readings	Maximum	Minimum	Maximum (MPa)	Minimum (MPa)	Standard Deviation (MPa)	Average (MPa)
Along Grid 2, 3, D, E									
B1	42	Struc sound	10	44	34	41.0	26.0	4.7	34.6
B2	42	Struc sound	10	43	38	39.5	32.0	2.7	35.6
Along Grid 2, 3, B, C									
B3	42	Struc sound	10	44	39	41.0	33.5	2.5	37.3
B4	42	Struc sound	10	43	30	39.5	20.0	6.2	32.5
Along Grid 7, 9, C, D									
B5	42	Struc sound	10	49	33	48.5	24.5	6.9	40.0
B6	42	Struc sound	10	49	43	48.5	39.5	2.9	43.9

As shown in Table 4 are the non-destructive test results using Rebound Hammer on concrete beams at the Valencia Hall. The existing condition of structurally sound for highest compressive strength of 43.9 MPa while having the same existing condition for the lowest compressive strength of 32.5 MPa. It was noted that all of the grids have existing condition of structurally sound where the beams were tested and have compressive strengths complying with the standard of 28 MPa.

3.2. Part II. Non-Destructive Test Results using Rebound Hammer on Flores Hall

Table 5a presents the Non-Destructive Test results on the first floor columns of Flores Hall. The highest compressive strength of 40.6 MPa which was rated "structurally sound" was located in Grid 1-E; and followed by the compressive strength of 21.7 MPa and rated as "moderately distress, located at Grid 3'-P; also, continuously followed by a compressive strength of 19.7 MPa and was rated as "considerable distress", and located at Grid 8-A; and further the lowest compressive strength of 11.5 MPa and was rated as "major distress", located at Grid 1-H. From the 67 labeled columns, 49 grid labels were structurally sound, 10 grid labels were moderately distress, 2 grid labels were considerable distress, and 6 grid labels were major distress. Although most of the columns were structurally sound, there were still grid label of columns which were distressed.

Table 5a Non-Destructive Test Results using Rebound Hammer on Concrete Columns at the First Floor of Flores Hall

Location	Age	Existing Condition	Rebound Hammer Measurements			Rebound Hammer Conversion ASTM C805			
			Number of Readings	Maximum	Minimum	Maximum (MPa)	Minimum (MPa)	Standard Deviation (MPa)	Average (MPa)
First Floor									
Grid 1-A	34	Struc sound	10	45	33	42.4	24.5	5.7	33.1
Grid 1-B	34	Struc sound	10	45	42	42.7	37.3	2.5	40.2
Grid 1-E	34	Struc sound	9	45	39	43	33.2	3.5	40.6
Grid 1-F	34	major distress	9	29	20	19.1	8	3.5	14.8
Grid 1-G	34	major distress	10	30	25	20.6	13.9	2.5	17.7
Grid 1-H	34	major distress	10	28	21	18.2	8.8	3.4	11.5
Grid 1-J	34	Struc sound	10	45	40	42.6	34.5	3.3	37.7
Grid 1-K	34	Struc sound	10	43	36	39.5	29	3.4	35.9
Grid 1-L	34	Struc sound	4	35	35	38.1	27.5	4.8	33.4
Grid 2-A	34	Struc sound	9	45	39	42.6	33.4	3	39.2
Grid 2-B	34	Struc sound	10	44	38	41.5	31.5	3.9	36.7
Grid 2-E	34	Struc sound	10	44	40	41.1	34.7	2	37.2
Grid 2-F	34	Struc sound	10	45	39	42.5	33.2	3.5	39.7
Grid 2-G	34	Major distress	10	30	23	20.5	11.8	2.8	16.8
Grid 2-H	34	major distress	10	29	20	19.2	8.2	2.9	12.9
Grid 2-J	34	Struc sound	8	39	31	33.5	22.3	3.2	28.9
Grid 2-K	34	Struc sound	10	45	35	42.7	27.2	4.8	33.7
Grid 2-L	34	Struc sound	6	41	30	36.4	20.7	6.3	28.9
Grid 2-M	34	Struc sound	9	41	37	36.4	30.4	2.1	32.1
Grid 2-N	34	Struc sound	5	39	35	33.5	27.6	3	30.9
Grid 3-A	34	Struc sound	10	43	38	39.1	31.6	2.2	35.3
Grid 3-C	34	Struc sound	10	40	36	34.7	28.9	2	32
Grid 3-D	34	Struc sound	10	40	33	34.8	24.1	3.5	31.1
Grid 3-E	34	Struc sound	10	42	35	37.9	27.2	4.1	32.8
Grid 3-F	34	Mod distress	10	38	30	31.6	20.1	3.7	27.8
Grid 3-G	34	Mod distress	10	40	29	34.4	19.1	3.9	26.1
Grid 3-H	34	Struc sound	10	41	38	36.7	32.2	1.3	34.7
Grid 3-J	34	Struc sound	9	45	36	42.3	28.7	5.1	35.8

Grid 3-K	34	Struc sound	8	40	32	34.9	23.2	4	31.1
Grid 3-L	34	Struc sound	8	43	34	39.9	26.2	5.1	32
Grid 3-M	34	Struc sound	10	42	35	38	27.4	3.2	34.2
Grid 3'-K	34	Struc sound	10	43	31	39.5	21.7	5.3	30.2
Grid 3'-L	34	Struc sound	10	39	34	33	25.9	2.4	29.8
Grid 3'-M	34	Struc sound	9	43	35	39.5	27.6	3.7	35.2
Grid 3'-P	34	Mode distress	3	32	30	23.2	20.8	1.3	21.7
Grid 3"-J	34	Struc sound	9	45	42	42.6	37.8	1.6	40
Grid 3"-K	34	Mode distress	10	36	29	29	18.6	3.5	24.6
Grid 3"-M	34	mode distress	3	35	31	27.5	21.9	2.9	25.2
Grid 4-A	34	Struc sound	9	44	39	41.2	33.5	2.3	36.8
Grid 4-C	34	Struc sound	9	45	40	42.9	35	2.5	38.9
Grid 4-D	34	Struc sound	9	43	35	39.7	27.5	3.9	35.5
Grid 4-F	34	Mode distress	10	38	30	32	20.6	3.5	26.2
Grid 4-J	34	Struc sound	9	40	32	34.6	23.3	2.9	29.7
Grid 4-K	34	Struc sound	9	43	37	39.5	30.4	3.3	33.9
Grid 4-L	34	strucsound	10	43	34	39.4	25.5	4.9	32.9
Grid 4-M	34	Mode distress	10	38	28	31.5	17.7	4.4	25.9
Grid 4-P	34	Struc sound	10	45	35	42.8	27.5	4	33.8
Grid 5-A	34	Mode distress	8	39	31	33	21.8	4.2	27.2
Grid 5-C	34	major distress	4	28	17	17.8	4.7	6.1	13.5
Grid 5-D	34	mode distress	10	35	30	27.5	20.6	2.6	24.3
Grid 5-F	34	consider distress	9	33	26	24.9	15.3	3.6	19.9
Grid 5-J	34	Struc sound	10	44	37	41.4	30.7	3.1	37
Grid 5-K	34	Struc sound	10	43	36	39	28.6	3.8	34.2
Grid 5-L	34	Struc sound	10	40	32	34.9	23.1	4	29.5
Grid 5-M	34	Struc sound	10	44	40	41.2	34.9	1.8	38.4
Grid 5-P	34	Struc sound	10	41	36	36.6	28.6	2.8	31.5
Grid 6-A	34	Struc sound	10	45	37	43	30.6	4.6	37.9
Grid 6-C	34	mode distress	10	36	27	28.6	16.6	3.3	22.3
Grid 6-D	34	Struc sound	10	38	34	31.9	25.8	2.1	28.5

Grid 6-F	34	Struc sound	10	41	35	36.3	27.1	2.8	32
Grid 7-A	34	Struc sound	10	41	30	36.5	20.8	6.2	28.6
Grid 7-D	34	Struc sound	9	39	35	33.3	27.6	2.3	31.3
Grid 7-F	34	Struc sound	9	43	39	39.5	32.9	2.4	36.1
Grid 8-A	34	Cons distress	3	33	26	24.6	15.4	4.6	19.7
Grid 8-C	34	Struc sound	10	45	41	42.7	36.3	1.9	39.3
Grid 8-D	34	Struc sound	10	38	33	31.9	24.6	2.3	28
Grid 8-E'	34	Struc sound	10	39	32	33.5	23.4	2.8	28

Table 5b Non-Destructive Test Results using Rebound Hammer on Concrete Columns at the Second Floor of Flores Hall

Location	**Age**	**Existing Condition**	**Rebound Hammer Measurements**			**Rebound Hammer Conversion ASTM C805**			
			Number of Readings	**Maximum**	**Minimum**	**Maximum (MPa)**	**Minimum (MPa)**	**Standard Deviation (MPa)**	**Average (MPa)**
Second Floor									
Grid 1-A	34	Struc sound	7	40	33	35	24.7	3.4	31.9
Grid 1-B	34	struc sound	10	42	32	38.1	23.4	4.6	29.8
Grid 1-E	34	struc sound	10	44	34	40.6	26	5.4	32.9
Grid 1-F	34	Maj distress	10	28	22	17.8	10.6	2.2	15
Grid 1-J	34	Cons distress	7	34	26	25.9	15	3.9	21.3
Grid 1-K	34	struc sound	10	41	32	36.4	23.4	4	30.4
Grid 1-L	34	mode distress	10	36	29	28.6	18.8	2.8	23.4
Grid 2-A	34	struc sound	4	43	42	39.5	38	0.9	38.7
Grid 2-B	34	cons distress	9	33	26	24.3	14.6	3.6	19.5
Grid 2-E	34	mode distress	9	39	29	33.1	19.6	4.7	27.5
Grid 2-F	34	struc sound	9	45	37	42.6	30.4	3.5	38.6
Grid 2-G	34	cons distress	9	33	27	24.6	16.4	2.6	18.9

Grid 2-H	34	cons distress	9	33	24	24.3	13.6	3.5	18.1
Grid 2-J	34	mode distress	10	37	29	30.1	19.2	3.2	25.3
Grid 2-K	34	mode distress	10	37	28	30.4	17.5	4.1	25.5
Grid 2-L	34	mode distress	10	36	30	28.8	20.1	2.6	23.3
Grid 3-A	34	struc sound	10	40	36	34	28.2	2	30.2
Grid 3-C	34	mode distress	10	38	33	31.9	24.4	2.5	27.2
Grid 3-D	34	maj distress	10	32	23	23.3	12	3.1	16.1
Grid 3-E	34	struc sound	8	45	39	43	33.6	2.8	37.5
Grid 3-F	34	struc sound	10	45	37	42.4	30	3.6	37.1
Grid 3-G	34	struc sound	10	40	33	34.9	24.8	2.8	29
Grid 3-H	34	mode distress	10	38	33	32.1	24.2	2.4	27
Grid 3-J	34	mode distress	9	40	31	35.2	22.2	4.7	27.5
Grid 3-K	34	maj distress	6	31	22	22	10.3	4.7	15.8
Grid 3-L	34	mode distress	10	38	31	32	22.1	3	26.5
Grid 3-M	34	struc sound	10	39	33	33.3	24.7	2.4	28.9
Grid 3'-J	34	mode distress	10	38	32	31.9	23.2	3.2	27.3
Grid 3'-K	34	struc sound	9	40	35	35.2	27.2	2.8	30.4
Grid 3'-L	34	mode distress	5	37	28	30.5	18.1	5.4	24.9
Grid 3'-M	34	struc sound	10	40	34	35	26	2.4	30.9
Grid 3'-P	34	mode distress	9	37	27	30.8	16.3	4.9	24.3
Grid 4-A	34	mode distress	9	40	30	34.7	20.2	5	27.9

Grid 4-C	34	mode distress	9	37	29	30.5	19.2	4.6	24.3
Grid 4-D	34	mode distress	10	38	29	31.8	19	4.2	25.5
Grid 4-J	34	mode distress	10	36	27	29.2	16.5	4.2	23.1
Grid 4-K	34	cons distress	10	33	26	24.1	15.3	3	21.3
Grid 4-L	34	mode distress	3	36	28	29.4	17.9	6.3	25
Grid 4-M	34	struc sound	9	42	35	38.2	27.5	4.2	31.9
Grid 4-P	34	struc sound	10	42	37	38	30.6	2.1	33.1
Grid 5-A	34	mode distress	9	39	30	33.4	19.8	4.1	27.5
Grid 5-C	34	cons distress	9	33	27	24.7	16.6	2.4	19.7
Grid 5-D	34	cons distress	9	38	34	31.8	26.2	1.8	29.3
Grid 5-J	34	mode distress	10	35	32	27.4	22.9	1.6	25.1
Grid 5-K	34	mode distress	9	34	29	26	19.2	2.3	23.6
Grid 5-L	34	mode distress	8	38	28	32.1	18.4	5.4	26.9
Grid 5-M	34	mode distress	9	36	30	28.4	20.3	2.5	25.7
Grid 5-P	34	struc sound	9	43	34	39.6	26.1	3.9	33.6
Grid 6-A	34	struc sound	7	39	28	33.2	17.7	5.9	28
Grid 6-C	34	maj distress	9	28	17	17.6	4.9	4.2	10
Grid 6-D	34	struc sound	10	38	31	32.2	22.1	3.2	29.3
Grid 7-C	34	struc sound	10	40	37	34.8	30.1	1.6	32
Grid 7-D	34	struc sound	7	42	33	38.1	24.8	5.1	33.2
Grid 7-F	34	struc sound	10	45	36	43	28.8	4.1	36.3

As presented in Table 5b, the Non-Destructive results of columns on the second floor of Flores Hall. The highest compressive strength was 38.7 MPa with the existing condition of “structurally sound” located in Grid 2-A; while for the lowest compressive strength of 23.1 MPa with the existing condition of “moderate distress” located in Grid 4-J; followed by the lowest compressive strength of 18.1 MPa with existing condition of “considerable distress” located in Grid 2-H; and the lowest compressive strength of 10MPa with existing condition of “major distress” located in Grid 6-C. It may be noted that all the compressive strengths colored yellow, orange, and red with corresponding existing conditions of moderate, considerable, and major distress are far beyond the tolerable or acceptable compressive strength while the colored green with existing condition of structurally sound were less than half of the total number of columns.

Table 6 The Non-Destructive Test Results using Hammer Rebound on Concrete Slabs at the Flores Hall

Location	**Age**	**Existing Condition**	**Rebound Hammer Measurements**			**Rebound Hammer Conversion ASTM C805**			
			Number of Readings	**Maximum**	**Minimum**	**Maximum (MPa)**	**Minimum (MPa)**	**Standard Deviation (MPa)**	**Average (MPa)**
2nd Floor Slabs									
Grid 3-4/C-D	34	Cons distress	9	36	29	23.0	13.2	3.8	18.4
Grid 4-5/C-D	34	Maj distress	10	31	25	15.9	8.1	3.0	12.2
Grid 3-4/J-K	34	Cons distress	10	38	33	26.0	18.7	2.8	22.7
Grid 4-5/J-K	34	Maj distress	10	35	29	21.6	13.3	2.5	16.5
Grid 3-4/K-L	34	Cons distress	10	36	31	23.2	15.9	2.3	20.9
Grid 4-5/K-L	34	Mode distress	10	42	36	32.4	23.0	2.6	26.5
Grid 2-3/L-M	34	Struc sound	10	48	39	42.3	27.5	5.4	34.0
Grid 4-5/L-M	34	Mode distress	10	38	35	26.1	21.6	1.4	24.1
Grid 3-4/M-P	34	Mode distress	8	38	34	26.0	20.1	2.1	24.5
Grid 4-5/M-P	34	Struc sound	9	46	39	38.8	27.5	4.1	32.6

The Non-Destructive test results using Hammer Rebound on concrete slabs on the second floor of Flores Hall was shown on table 6. As can be gleaned from the table, the highest compressive strength was 34 MPa with existing condition of “structurally sound” and located in Grid 2-3/ L-M; while the lowest compressive strength of 24.1 MPa with existing condition of “moderate distress” and located at Grid 4-5/ L-M; similarly, the lowest compressive strength of 18.4 MPa with existing condition of “considerable distress” was located at Grid 3-4/ C-D; and lastly the lowest compressive strength of 12.2 MPa with existing condition of “major distress” was located in Grid 4-5/C-D. It can be opined from the results that only 2 grids out of 10 grids of slab have existing condition of “structurally sound”; also, 3grids out of 10 grids of slab have existing condition of “moderate distress”; moreover, 3 grids out of 10 grids of slab have existing condition of “considerable distress”; and fourthly, 2 grids out of 10 grids of slab have existing condition of “major distress”. Eighty percent of the grids of slab have existing condition below the allowable compressive strength.

Table 7 presented the Non-Destructive test results using the Hammer Rebound on concrete beams of Flores Hall. It may be observed from the table that the highest compressive strength of 36.3 MPa with existing condition of “structurally sound” and located at Grid 3/ J-K; while the lowest compressive strength of 23.5 MPa with existing condition of “moderate distress” and located at Grid L/ 4-5; followed by the lowest compressive strength of 18.1 MPa with existing condition of “considerable distress” was located at Grid J/ 3-4; and finally, the lowest compressive strength of 13.2 MPa with existing condition of “major distress” was located at Grid D/ 4-5. There were 29 non- destructive test results and 7 grids out of 29 grids have existing condition of “structurally sound”; secondly, 7 grids out of 29 grids have existing condition of “moderate stress”; thirdly, 5 grids out of 29 grids have existing condition of “considerable distress”; and 10 grids out of 29 grids have existing condition of “major distress”. This implies that more than three fourths of the beams are not complying with the allowable compressive strength of 28 MPa. This may be alarming since the concrete beams carry the transverse loads.

Table 7 Non-Destructive Test Results using Rebound Hammer on Concrete Beams in Flores Hall

Location	Age	Existing Condition	Rebound Hammer Measurements			Rebound Hammer Conversion ASTM C805			
			Number of Readings	Maximum	Minimum	Maximum (MPa)	Minimum (MPa)	Standard Deviation (MPa)	Average (MPa)
2nd Floor Beams									
Grid 2/F-J	34	Mode distress	10	40	32	29.1	17.3	3.8	23.6
Grid 3/C-D	34	Maj distress	10	31	24	22.0	12.8	3.2	16.6
Grid 3/J-K	34	Struc sound	10	47	40	40.5	29.1	3.5	36.3
Grid 3/K-L	34	Struc sound	9	47	37	40.5	24.5	5.8	32.4
Grid 3/L-M	34	Mode distress	10	42	35	32.2	21.5	3.8	26.5
Grid 3'/M-P	34	Maj distress	10	35	27	21.6	10.6	3.4	15.7
Grid 4/C-D	34	Maj distress	10	34	28	20.1	11.9	2.6	15.4
Grid 4/J-K	34	Struc sound	10	42	35	37.7	27.4	3.3	34.1
Grid 4/K-L	34	Struc sound	10	41	32	36.6	23.5	4.2	28.8
Grid 4/M-P	34	Cons distess	5	38	34	26.0	20.2	2.5	21.9
Grid 5/C-D	34	Mode distress	10	39	36	27.5	23.1	1.3	25.3
Grid 5/J-K	34	Cons distress	10	40	29	29.1	13.2	5.6	20.4
Grid 5/K-L	34	Mode distress	9	43	32	33.8	17.3	5.5	26.0
Grid 5/L-M	34	Struc sound	10	46	37	38.9	24.5	4.1	29.9
Grid 5/M-P	34	Struc sound	10	43	37	33.9	24.5	3.0	29.3
Grid D/3-4	34	Maj distress	8	28	23	17.4	11.6	2.4	14.8
Grid D/4-5	34	Maj distress	10	29	22	19.2	9.6	3.2	13.2
Grid F/2-3	34	Maj distress	10	34	24	20.1	6.8	3.4	13.6
Grid J/2-3	34	Struc sound	10	42	37	32.2	24.5	2.7	28.1
Grid J/3-4	34	Cons distress	10	37	27	24.5	10.6	4.0	18.1
Grid J/4-5	34	Maj distress	10	36	27	23.0	10.6	3.4	15.9
Grid K/3-4	34	Mode distress	10	40	32	29.1	17.3	3.3	25.0
Grid K/4-5	34	Cons distress	10	38	29	26.0	13.2	4.4	19.1
Grid L/2-3	34	Mode distress	7	41	34	30.7	20.1	3.6	26.0
Grid L/4-5	34	Mode distress	10	41	32	30.7	17.3	4.7	23.5
Grid M/2-3	34	Maj distress	10	35	26	21.5	9.3	3.6	13.7
Grid M/4-5	34	Maj distress	10	34	26	20.2	9.4	3.5	13.3
Grid P/3-4	34	Cons distress	10	35	32	21.7	17.3	1.7	19.7

Table 8 Results of One Sample Test of Means of Compressive Strength of Flores Hall

Structure	Mean	Standard Deviation	Count	Standard Error of Mean	Degrees of Freedom	t-value	p-value	Remarks
First Floor								
Columns	30.48	7.115	67	0.869	66	2.856	0.003	Above the standard
2nd Floor								
Columns	26.91	6.081	54	0.828	53	1.320	0.096	Below the standard
Beams	22.19	6.766	29	1.256	28	4.625	0.000	Above the standard
Slabs	23.24	6.773	10	2.142	9	2.222	0.027	Above the standard

Hypothesized Mean = 28 MPa; Level of Significance = 0.05

Table 8 presents the results of one sample test of means of compressive strength of Flores Hall. For the first floor columns, the mean is 30.48, standard deviation of 7.115, frequency count of 67, standard error of mean of 0.869, degrees of freedom of 66, t-value of 2.856, and p-value of 0.003 which yielded “Above the standard” remarks. In the second floor columns, the mean is 26.91, standard deviation of 6.081, frequency count of 54, standard error of mean of 0.828, degrees of freedom of 53, t-value of 1.320, p-value of 0.096 which resulted to “Below the standard” remarks. For the beams, the mean is22.19, standard deviation of 6.766, frequency count of 29, standard error of mean of 1.256, degrees of freedom of 28, t-value of 4.625, and p-value of 0.000 and got the remarks of “Above the standard”. In the slabs, the mean of 23.24, standard deviation of 6.773, frequency count of 10, standard error of mean of 2.142, degrees of freedom of 9, t-value of 2.222, and p-value of 0.027, which resulted to remarks of “Above the standard”. It may be surmised that from the statistical tool results of one sample test of means of compressive strength of columns in the first floor, beams, and slabs complied and “Above the standard” while the columns on the second floor were “below the standard”.

Table 9 Results of One Sample Test of Means of Compressive Strength of Valencia Hall

Structure	Mean	Standard Deviation	Count	Standard Error of Mean	Degrees of Freedom	t-value	p-value	Remarks
Columns	29.55	4.652	35	0.786	34	1.977	0.028	Above the standard
Beams	37.28	4.096	6	1.672	5	5.546	0.001	Above the standard
Bleacher	36.27	2.853	10	0.902	9	9.166	0.000	Above the standard

Hypothesized Mean = 28 MPa; Level of Significance = 0.05

The results of one sample test of means of compressive strength of Valencia Hall were presented in Table 9. For the columns, the mean is 29.55, the standard deviation of 4.652, the frequency count of 35, the standard error of the mean of 0.786, the degrees of freedom of 34, a t-value of 1.977, and the p-value of 0.028, which resulted to remarks of “Above the standard”. In the beams, the mean of 37.28, the standard deviation of 4.096, the frequency count of 6, the standard error of the mean of 1.672, the degrees of freedom of 5, t-value of 5.546, and p-value of 0.001 and resulted in remarks of “Above the standard”. And for the bleacher, the mean of 36.27, a standard deviation of 2.853, a frequency count of 10, standard error of mean of 0.902, degrees of freedom of 9, t-value of 9.166, and p-value of 0.000, which yielded remarks of “Above the standard”. It may be noted that the results of one sample test of means of compressive strength of columns, beams, and bleachers of Valencia Hall have complied and all “Above the standard”.

3.3. Part III. Proposed Preventive Maintenance Management Plan

- The Flores Hall and Valencia Hall where high safety, performance, and service life are very important because these were being used by administrators, faculty members, visitors, and other stakeholders of the Higher Education Institution, regular condition assessment or monitoring of structural health and safety should be don
- The Rapid Visual Screening or actual ocular inspection may be considered to determine the current condition of the structural and non-structural components of the Flores Hall and Valencia Hall.

- Hammer Rebound Test and another non-destructive test may be used to regularly monitor the structural health and safety of Flores Hall and Valencia Hall.
- Each Hall should have a digitized data bank where all the records of the Hall should be put, like the complete designs and plans, a program of works, preventive maintenance such as repair, renovation, and retrofitting was made, materials used with specifications, legal documents about the Halls, earthquake or other disasters experienced by the Halls.
- Establish procedures and guidelines on how Flores Hall and Valencia Hall will be monitored for health and safety. If the two Halls will be repaired, renovated, and retrofitted, there must be a repair, renovation, and retrofitting process flow. The R/R/R items to be considered are the following: drafting of the R/R/R Plan, Ocular Inspection of the two Halls, checking of the performance of the two Halls, selection of methods to be used for R/R/R, implement the R/R/R method, and once the R/R/R is completed, use the Halls and maintain the strength and durability of the Halls.
- The Flores Hall and Valencia Hall are both reinforced concrete buildings. The materials used are cement, sand, gravel, and reinforcing steel bars. If the steel bars will be exposed due to cracks in the structural component, there is a chance for the steel to corrode. This situation should be monitored, and apply the appropriate solution not weaken that material and structural component.
- The office in charge of Preventive Maintenance should keep all the records and documents of Flores Hall and Valencia Hall and coordinate with the technical professional like the Structural consultant and be ready to propose solutions or remedies for specific damage/s which may occur in the two Halls.
- The structural components like beams, columns, and slabs of the Flores Hall and Valencia Hall with the existing condition of moderate distress, considerable distress, and major distress should be continuously monitored using other Non-Destructive Tests and software like MIDAS which may provide another analysis of the structural components. Also, consider other external forces and stresses, including age which may affect its strength and durability. Refer to the results of the monitoring with a structural consultant who will recommend solutions on retrofitting the structural components.

4. Summary of Findings

The following were the findings of the study:

- All the grid lines of the bleachers in Valencia Hall, when tested by Hammer Rebound equipment, yielded compressive strength above the allowable compressive strength of 28 MPa. The majority of the columns in Valencia Hall have the existing condition of structurally sound, which was above the allowable compressive strength, but some of the columns have the existing condition of moderate; and considerable distress, which was below the allowable compressive strength. Furthermore, for the beams tested, all have existing condition of structurally sound, which means above the allowable compressive strength.
- Most of the column grid lines tested by Hammer Rebound on the first floor of Flores Hall have existing conditions of structurally sound, which implies above the compressive strength, while some of the existing conditions were moderate, considerable, and major distress, which means below the allowable compressive strength. While in the second-floor column grid lines, less than one-half have existing conditions of structurally sound, which connotes above the allowable compressive strength, and more than one-half of the column grid lines have existing conditions of moderate, considerable, and major distress, which means below the allowable compressive strength.
- Few of the concrete slab grids tested by Hammer Rebound in the Flores Hall have the existing condition of structurally sound and comply with the allowable compressive strength, and most of the concrete slab grids have existing conditions of moderate, considerable, and major distress, which means below the allowable compressive strength of 28 MPa.
- Few of the concrete beams grids tested by Hammer Rebound in Flores Hall have the existing condition of structurally sound, which complied with the allowable compressive strength, and the majority of the concrete beams grids have existing conditions of moderate, considerable, and major distress, which means did not comply with the allowable compressive strength.
- The Proposed Preventive Maintenance Plan will aid the Office in Charge of the maintenance of Flores Hall and Valencia Hall, specifically focusing on regular condition monitoring, the conduct of Rapid Visual Screening, utilization of Non-Destructive Tests, document keeping such as digitized data bank, establishing Repair, Renovation, and Retrofitting process flow, quick action when the reinforcing steel bars are exposed to cracks, and coordination with the structural consultant to remedy the current condition of the Flores Hall and Valencia Hall. The structural components with existing conditions of moderate distress, considerable distress, and major

distress should be continuously monitored using Non-Destructive Tests and MIDAS software and refer to a structural consultant for a solution to retrofit the structural components.

5. Conclusion

The following conclusions were based on the findings of the study:

- The Non-Destructive Test through the Hammer Rebound Test equipment to monitor the structural health and safety of Flores Hall and Valencia Hall yielded data in terms of the existing conditions of the beams, columns, slabs, and bleachers. The results of the Hammer Rebound test revealed the average compressive strength per grid or grid line of the structural components, which shows if the structural component complied with the allowable compressive strength.
- The proposed Preventive Management Plan may be used to systematically implement the monitoring of structural health and safety of the Flores Hall and Valencia Hall and provide a safe structure where administrative officials, faculty members, students, and other stakeholders can perform their work and transactions.

Recommendations

The following recommendations were drawn based on the conclusions:

- The results yielded by the Hammer Rebound Test to all structural components of Flores Hall and Valencia Hall may be used as inputs to determine the appropriate retrofitting solution to increase its compressive strength. Other Non-Destructive Tests may be used to monitor the structural health and safety of Flores Hall and Valencia Hall, and other concrete structures in the Higher Education Institution.
- The proposed Preventive Maintenance Plan may be used as a reference for other concrete structures in the Higher Education Institution.

Compliance with ethical standards

Acknowledgments

This is to acknowledge the support of the Vice President for Administration and Finance for allowing the researchers to conduct the Hammer Rebound test for Flores Hall and Valencia Hall, the Project Management Office in providing plans for the two halls, the staff; and students who assisted the researchers in the conduct of the test.

Disclosure of conflict of interest

The researchers hereby disclose their interest in the publication of this paper.

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