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Causes, Prevention and Repair of Cracks in Buildings: (A Case Study of Chinua Achebe Lecture Theatre in Michael Okpara University of Agriculture, Umudike)

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Abstract

This study was carried out by employing several observatory and analytical techniques to observe and understand the types and nature of cracks associated with building, the causes of such cracks, what could have been done to prevent these cracks as well as reparative measures that could be employed to remedy the cracks. Reconnaissance study was carried out on the structure to discover the nature and extent of cracks with the aid of traditional laboratory tools that can measures and monitor the cracks. From the overall properties and behaviours of the cracks, their possible causes and reparative measures could be established. The compressive structural strength of the key members of the building (slabs, columns and beams) was determined using the non-destructive Schmidt Hammer test. The minimum required compressive strength of 28day old concrete is 25 N/mm2, this is supposed to have attained a strength of 31 N/mm2 after 1year of the concrete life, and the strength is supposed to marginally increase with time. The shear strength of the foundation soil was determined through the shear box test which yielded the soil cohesion to be, c = 0.0355 kN/m² and angle of internal friction, $\phi = 25.34° = 25°$*. The ultimate bearing capacity of the foundation soil which is 409.86Kpa is satisfactory and was calculated using the Terzaghi's formula, Qu = cNc+γzNq+0.5BNγ. The majority of the cracks observed in the building are non-structural cracks. The main structural cracks observed in the building were caused by differential settlement of soil, faulty design and poor workmanship. Some of these are still actively cracking and hence pose a real threat of future collapse. Hence, they require urgent professional repairs. The appropriate remedy to cracks should be such that its nature and causes should be properly investigated and established before repair. Otherwise, wrongly treated cracks would reappear after some time*

1. Introduction

Buildings have a unique place in the area of construction engineering. Buildings are made to last for decades. Not only because it shares emotional bonds with its residents, other reasons being the construction cost and time taken. With the passing of time, the slow reactions which were continuously working inside the building components (concrete members), start showing their effects in the form of cracks. According to [1]. Concrete structures have being in application since the mid-19thcentury, and because of the low quality of cement at that time, the development of

concrete structure was slow. It was not until the end of the 19th century, that concrete structures began to gain more applications and development with the improvement of production, experimental work, computational theory and improvement of construction technique. Thus it has become one of the most widely used building materials in modern construction.
Cracks are a kind of universal problem of concrete construction as it affects the building artistic. It also destroys the wall integrity by affecting the structural safety which in turn reduce the durability of structure [2]. A crack is a complete or incomplete separation of concrete into two or more parts produced by breaking or fracturing. Cracks in a building are of common occurrence. The first and most common reason of crack development is the stress component exceeding its strength component which can be associated to the externally or internally applied loads (forces) such as dead, live, wind or seismic loads, or foundation settlement or stresses developed internally due to thermal movements, moisture changes and/or chemical action etc. [3].

1.2 Causes of Cracks in Buildings

a. Moisture Movement

Most of the building materials having pores in their structure in the form of intermolecular (example: concrete, mortar, bricks etc) expand on absorbing moisture and shrink on drying. These movements are reversible [3].

b. Thermal Movement

Due to variation in atmospheric temperature, there will be thermal movement in building components. [4]. When there is some restraint to movement of building component, internal stresses are generated resulting in cracks due to tensile or shear stresses[3].

c. Foundation Movement and Settlement of Soil

Shear cracks may occur in the building due to large differential settlement of foundation. It may also occur due to unequal bearing pressure under different parts of the structure, or due to it excessive bearing strength of the soil, or due to minimum factor of safety used in the foundation etc [3].

d. Cracking Due To Vegetation

Existence of vegetation also contributes in building crack formation, for instance, fast growing trees in the vicinity of compound walls can cause cracks in walls due to expansive action of roots growing under the foundation. This type of cracks usually occur in clay soil due to moisture contents of the roots [1].

e. Cracking Due to Corrosion of Reinforcement

When steel reinforcement corrode, it produces iron oxide and iron hydroxide on its surfaces, consequently its volume increases. This increase in volume causes high radial bursting stresses and local radial cracks around reinforcing bars which in turn results in the formation of longitudinal cracks that are parallel to the bar[5]

2. Methodology

2.1 Identification of Cracks

The cracks in the buildings and their causes were identified by

(a) Reconnaissance Survey
(b) Desk Study

(c) Visual Observation
(d) Survey/investigation of the cracks.

- Reconnaissance Survey: An inspection of the buildings was carried out to diagnose the cracks in the buildings, by looking at the whole building from a distance, walking round the building, and observation of each room to locate the cracks, and detail measurement of each crack, and their location in the building.
- Desk Study: The desk study was performed using the architectural design plans to: Check the layout of the building and location of each structural member. It was used to create the identification codes and the detailed observation procedure. The rooms were named as "R", the walls were named as W1 (Wall 1), W2 (Wall 2), etc. The cracks were named as CR 1, CR 2, etc. Other structural elements which are Floor Slabs, Beams, and Columns were coded as SL, BM, and Col respectively. It was used to create design manifest for recording the observation of the cracks and design manifest to record Rebound Hammer Readings.
- Visual Observation: Critical visual observation of key areas of the building such as; the pattern of cracks' defects on load bearing/shear walls, floor slab, beams, columns, examination of floor finishes and walls, the examination of column interface with ground floor slab to establish possible foundation settlement, the study of available relevant architectural plan, in order to affirm the consistency of the design concepts interpreted in detailed drawings and finished construction.
- Survey/Investigation of the cracks was done to investigate on what might have caused the occurrence of each crack in the building. The cracks were grouped based on the findings, which are drying shrinkage, architectural design fault, foundation settlement, and movement due to creep.

2.2 Strength Assessment of the Building's Structural Elements

A Schmidt hammer was used to assess the strength of the structural elements. The strength of each structural element was obtained by taking the average of seven recorded values of Schmidt Hammer Reading. The Non-Destructive Schmidt Hammer Test was conducted on the building under appraisal.

2.3 Assessment of Underlying Soil Bearing Capacity

Some of the major cracks in a building element may be as a result of ground movement. This ground movement may be due to differential settlement, earthquakes or soil failure. While cracks caused by differential settlement can to some extent be corrected post construction, little or nothing can be done to remedy those caused by earthquakes or soil failure except at the design stages.
Soil failure occurs when the pressure imposed on it is greater than its average bearing capacity or when the soil bearing capacity is too low i.e < 100kpa. And this failure could lead to serious structural cracks in the building element.
In order to determine the ultimate soil bearing capacity of the soil underneath the building under investigation, the following tests were employed:

- Direct Shear test
- Bulk Density test

Direct Shear Test
To determine the bearing capacity of the soil using the direct shear apparatus.
Apparatus
Direct shear box apparatus, loading frame (motor attached), Dial gauge, proving ring, Tamper, Straight edge, Balance to weigh up to 200 mg, aluminium container, spatula.
Procedure
1. Check the inner dimension of the soil container.

2. Put the parts of the soil container together.
3. Calculate the volume of the container. Weigh the container.
4. Place the soil in smooth layers (approximately 10 mm thick). If a dense sample is desired tamp the soil.
5. Weigh the soil container, the difference of these two is the weight of the soil. Calculate the density of the soil.
6. Make the surface of the soil plane.
7. Put the upper grating on stone and loading block on top of soil.
8. Measure the thickness of soil specimen.
9. Apply the desired normal load.
10. Remove the shear pin.
11. Attach the dial gauge which measures the change of volume.
12. Record the initial reading of the dial gauge and calibration values.
13. Before proceeding to test check all adjustments to see that there is no connection between two parts except sand/soil.
14. Start the motor. Take the reading of the shear force and record the reading.
15. Take volume change readings till failure.
16. Add 5 kg normal stress 0.5 kg/cm^2 and continue the experiment till failure
17. Record carefully all the readings. Set the dial gauges zero, before starting the experiment
18. Calculation of Cohesion and angle of internal friction by plotting shear stress against normal stress.
19. Calculation of the bearing capacity of the soil using $Q_u = cN_c+\gamma zN_q+0.5BN_\gamma$.

3.0 Results and Discussion

This section presents the results obtained from the observation, measurement and monitoring of the cracks under study; as well as the results obtained from the non-destructive (Schmidt Hammer) test on the structural members of same buildings. It also further discusses the relevance and implications Schmidt Hammer test on the structural members of the buildings as well as the relevance and implications of the data obtained from the measurement and monitoring of the cracks in the respective buildings.
The results of the direct shear tests conducted on different samples of soil around the building is also included in this chapter with a discussion of the implications of these results on the cracks observed in the building.

3.1 Crack Identification and Monitoring Report

The positions of various structural and non-structural cracks identified within this building is illustrated in Figure 1. See appendix for Table A1; the position of cracks are indicated by the X marks. While Table A2 contains the summary of the characteristics of all the cracks observed in the building entailing information such as the view of the cracks, direction of the crack, extent of the crack, type of crack, threat level.
The major structural cracks observed in the building as shown in Figure 1 are cracks 2, 13, 14 and 19. The type of crack observed in crack 2 is a diagonal crack deep into the stair slab around the reinforcement region. It is not too critical to structural stability of structure. This crack seems to be caused by the corrosion of the reinforcement bars due to the penetration of air and water through the thin concrete cover of the slab or by poor quality of concrete. This could have been prevented by using richer concrete mix and/or adding more cover of concrete after the reinforcement bars. This crack could be corrected by filling with a rich concrete mix of ratio cement 1: sand 1: lime 9.

The cracks at the entrance door compartment (cracks 13 and 14), are very serious structural cracks that have evolved into a semi-total failure. Both of these cracks are still very active and propagate at average rate of 1mm/day, thus require immediate remedial action to avoid disastrous failure. The compartment walls (W19 and W20) are rapidly pulling away from their joints to the main wall (W2).

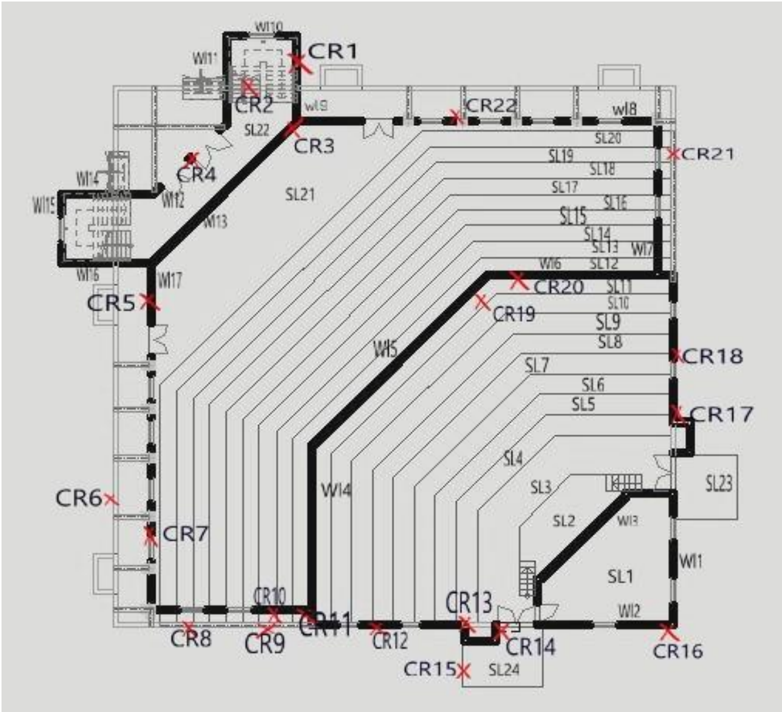

Figure 1: Achebe floor plan showing position of cracks

Having observed the apparent sinking of the base slab (SL24) around the foot of the compartment walls, it is probable that the compartment walls are footed on the slab SL24. Also, judging by the fact that the cracks are wider at the top, they must have been caused by a non-uniform settlement of the soil beneath the base slab (SL24) or failure of the slab (SL24) due to over loading. The latter is supported by the Rebound hammer reading of SL24 which is <20, suggesting that it is poor and deteriorated (refer to Table A4). Poor workmanship also adds to the cause of these cracks as there is not enough interlock (buckling) at the partition joints. This could have been prevented by adequate compaction of the subgrade soil underneath the base slab, and by improved workmanship (providing adequate buckling at partition joints). To repair this crack, the compartment walls as well as SL24 need to be removed and the subsoil should be properly compacted. The walls W19 and W20 should have independent foundation footings other than the slab SL24, or the reinforcement of the slab be increased to satisfactorily carry the load exerted on it by the walls.

For crack 19, it is a horizontal slab crack, involving the separation of slabs of different elevations. This type of crack could be caused by a number of factors: thermal action, ground movement and/or faulty design. This crack could have been prevented by designing the foundation in such a way that there is uniform distribution of pressure to avoid differential soil settlement. This can be corrected by epoxy-injection method. However, crack 11 is another critical crack in the building, although it seems to be dormant. This crack must have been caused by high stress to strength ratio on the affected column. This should be corrected by cementitious grouting as soon as possible, else the crack might become active again with time.

Crack 20 is a vertical crack caused primarily by the effect of CR19. The region of crack was supposed to be joined together (SL11 and SL12), but the separation caused by CR19 led to increased tension on the slab SL11 hence a series of vertical cracks ensued. The correction is to repair CR19 and provide enough support for the slab SL12.Cracks 5, 7, 9, 10, 17, 21, 22 are mere crazing cracks on the surface (plaster deep) caused either by poor work methodology or thermal shrinkage (creep). This should be repaired to improve the look of the building walls where they occur.

From the data above, in general, we could deduce that majority of the cracks in this building are dormant, hence may not require immediate attention, except for the case of few major cracks like cracks 2, 13,14 and 19 which are still actively cracking. Immediate professional attention should be given to these cracks as further cracking could distort the structural balance of the building.

The summary of the results of the Rebound Hammer Test conducted on the structural elements of the building under study are indicated in the appendix Table A3. The minimum compressive strength required in 28 days is $25N/mm^2$. The minimum compressive strength required in one year is $31N/mm^2$. The adequacy of a reinforced concrete structural element to support loads imposed on it, is determined by the compressive strength of concrete, dimension properties, reinforcement constituent and tensile strength of the reinforcement bars. For the building under investigation, Grade 25 concrete with 28day compressive strength of $25N/mm^2$ is considered appropriate and adequate. This is expected to attain $31N/mm^2$ in one year of the concrete age, and then marginally increase over the years. From the non-destructive Schmidt hammer rebound readings obtained for the structural elements, the average strength of the building varies between 46.98, 48.00 and 49.6 N/mm^2 for beam, slab and column respectively. This is within acceptable limit.

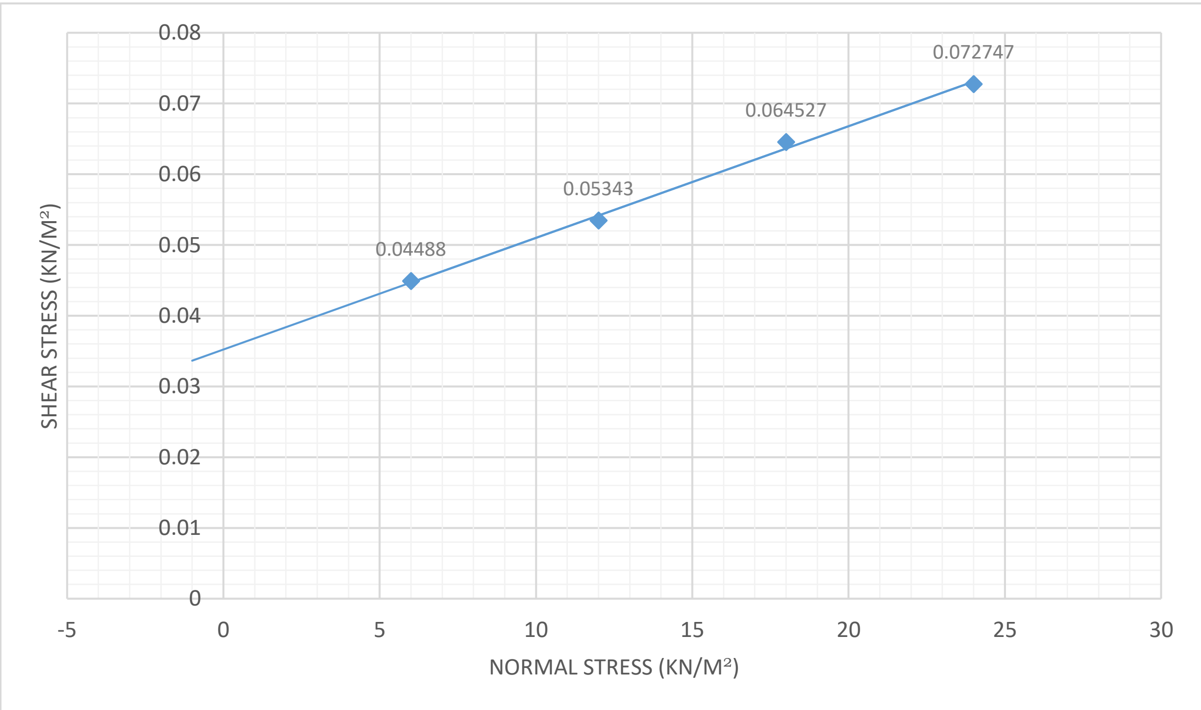

Figure 2: Graph of shear stress against Normal stress

From Figure 2, we obtain the following data

Cohesion, c = 0.0355 kN/m²

Angle of internal friction of soil sample, $\phi = 25.34°$ = 25°.

Ultimate Bearing Capacity of the Soil

$$C = 0.0355\ kN/m^2$$

$$\boldsymbol{\phi} = 25°$$

Using Terzaghi's Formula,
At 25°, $N_c = 25.1$
$N_q = 12.7$
$N_\gamma = 9.7$
Depth of foundation, z = 0.75m
Width of foundation base, B = 1.0m
Bulk density, $\gamma = 2.90g/cm^3$
$= 28.45kN/m^3$
Ultimate bearing capacity,

$$q_u = cN_c + \gamma z N_q + 0.5BN_\gamma$$
$$= 0.0355 \times 25.1 + 28.45 \times 0.75 \times 12.7 + 0.5 \times 28.45 \times 9.7$$
$$= 0.89105 + 270.98625 + 137.9825$$
$$= 409.8598 \approx 409.86kpa. \geq 100kpa. \quad \text{(Satisfactory).}$$

The minimum bearing capacity acceptable for soils is about 100kpa. Any soil with a q_u value less than this value is not safe to build on as it will ultimately shear under tension leading to soil failure, and subsequently structural failure of the building.
From the foregoing analysis, the calculated bearing capacity of the soil under investigation is 409.86kpa. This is satisfactorily above the minimum acceptable limit. Hence, the cracks observed in the building could not have been due to soil shear or failure.

4. Conclusion

After careful observation of the results of the tests and analysis, the following key conclusions have been reached:
The main structural cracks observed in the building were caused by differential settlement of soil, faulty design and poor workmanship. Some of these are still in propagation and hence pose a real threat of future collapse. Hence, they require urgent professional repairs.
The non-destructive Smidcht hammer test conducted on key structural elements of the building shows that the average compressive strength of the building ranges between 48 N/mm^2 and 49.6 N/mm^2 which are well above the one year minimum required value of 31 N/mm^2. The building still possesses high structural strength.
The underlying soil was found to be a cohesionless soil with the value of cohesion, $C = 0.0355\ kN/m^2$, having an angle of internal friction of $\phi = 25°$.
The bulk density of the foundation soil was found to be, $\gamma = 2.90g/cm^3 = 28.45kN/m^3$. Hence, the ultimate bearing capacity of the soil assuming a foundation depth of 750mm and a base width of 1000mm was found to be Qu= 409.86kpa.
The compressive shear strength of the foundation soil was found to be above 100kpa. The cracks could not have occurred as a result of soil shear failure.

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Appendix

Table A1. Crack Monitoring Data of Chinua Achebe Building

Cracks	Week 1				Week 2				Week 3				Week 4				Remarks
	Monday		Friday		Monday		Friday		Monday		Friday		Monday		Friday		
	Width(mm)	depth(mm)	width(mm)	depth(mm)	width(mm)	depth(mm)	width(mm)	depth(mm)	width(mm)	depth(mm)	width(mm)	depth(mm)	width(mm)	depth(mm)	width(mm)	depth(mm)	
CR1	2.0	25.0	2.1	25.0	2.0	25.0	2.0	25.0	2.1	25.0	2.0	25.0	2.0	25.0	2.0	25.0	Dormant
CR2	3.1	150	3.1	151.	3.5	154.	4.0	154.	4.5	155.	4.5	156.	5.5	161.	5.5	161	Active
CR3	1.9	10.0	2.0	10.0	2.0	10.0	1.9	10.0	2.0	10.0	2.0	10.1	2.0	10.0	2.0	10.0	Dormant
CR4	2.5	9.0	2.5	9.0	2.5	9.0	2.5	9.0	2.5	9.0	2.5	9.0	2.5	9.0	2.5	9.0	Dormant
CR5	1.5	5.0	1.5	5.0	1.5	5.0	1.5	5.0	1.5	5.0	1.5	5.0	1.5	5.0	1.5	5.0	Dormant
CR6	2.0	15.0	2.0	15.0	2.0	15.0	2.0	15.0	2.0	15.0	2.0	15.0	2.0	15.0	2.0	15.0	Dormant
CR7	1.0	4.0	1.0	4.0	1.0	4.3	1.0	4.0	1.0	4.0	1.0	4.0	1.0	4.0	1.0	4.0	Dormant
CR8	2.0	12.0	2.0	12.0	2.0	12.0	2.0	12.0	2.0	12.0	2.0	12.0	2.0	12.0	2.0	12.0	Dormant
CR9	1.0	3.0	1.0	3.0	1.0	3.0	1.0	3.0	1.0	3.0	1.0	3.0	1.0	3.0	1.0	3.0	Dormant
CR10	1.0	4.0	1.0	4.0	1.0	4.0	1.0	4.0	1.0	4.0	1.0	4.0	1.0	4.0	1.0	4.0	Dormant
CR11	4.5	50.0	4.5	50.0	4.5	50.0	4.5	50.0	4.5	50.0	4.5	50.0	4.5	50.0	4.5	50.0	Dormant
CR12	1.5	9.0	1.5	9.0	1.5	9.5	1.5	9.5	1.5	9.0	1.5	9.0	1.5	9.0	1.5	9.0	Dormant

CR13	25	300	26	300	30	300	32	300	38	300	40	300	45	300	55	300	Active
CR14	24	300	26	300	31	300	32	300	37	300	41	300	47	300	54	300	Active
CR15	5.0	110	5.0	110	5.0	110	5.0	110	5.0	110	5.0	110	5.0	110	5.0	110	Dormant
CR16	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	1.5	3.0	Dormant
CR17	1.0	5.0	1.0	5.0	1.0	5.0	1.0	5.0	1.0	5.0	1.0	5.0	1.5	5.0	1.5	5.0	Dormant
CR18	2.0	9.0	2.0	9.0	2.0	9.0	2.0	9.0	2.0	9.0	2.0	9.0	2.0	9.0	2.0	9.0	Dormant
CR19	10	150	11	155	14	155	14	158	15	160	16	165	21	171	21	171	Active
CR20	14	55	14	55	14	55	14	55	14	55	14	55	14	55	14	55	Dormant
CR21	1.5	10	1.5	9.5	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	1.5	10	Dormant
CR22	3.0	12	3.0	12	3.0	12	3.0	12	3.0	12	3.0	12	3.0	12	3.0	12	Dormant

Table A2. Characteristics of Cracks Observed in Chinua Achebe Building

Crack	View	Direction	Extent	Type	Threat level
CR1	External	Vertical	Plaster	Non-structural	Mild
CR2	Internal	Diagonal	Slab depth	Structural	Medium
CR3	Internal	Vertical	Plaster	Non-structural	Mild
CR4	Internal	Horizontal	Plaster	Non-structural	Mild
CR5	External	Random	Plaster	Non-structural	Aesthetics
CR6	External	Horizontal	Plaster	Non-structural	Mild
CR7	External	Random	Plaster	Non-structural	Mild
CR8	External	Diagonal	Plaster	Non-structural	Mild
CR9	External	Random	Plaster	Non-structural	Aesthetics
CR10	Internal	Random	Plaster	Non-structural	Aesthetics
CR11	External	Vertical	Column depth	Structural	Critical
CR12	External	Vertical	Plaster	Non-structural	Mild
CR13	Internal	Vertical	Totally cracked	Structural	Critical
CR14	Internal	Vertical	Totally cracked	Structural	Critical
CR15	External	Horizontal	Block region	Structural	Medium
CR16	External	Diagonal	Plaster	Non-structural	Mild
CR17	External	Random	Plaster	Non-structural	Aesthetics
CR18	External	Vertical	Plaster	Non-structural	Mild
CR19	Internal	Horizontal	Slab region	Structural	Critical

CR20	Internal	Vertical	Slab region	Structural	Critical
CR21	Internal	Random	Plaster	Non-structural	Aesthetics
CR22	External	Random	Plaster	Non-structural	Aesthetics

Table A3. Summary of the Compressive strength of the Structural Elements

Element	**Average Compressive strength (*N/mm²*)**	**Remark**
Slab	48.00	Satisfactory
Column	49.60	Satisfactory
Beam	46.98	Satisfactory

Table A4. Direct Shearbox test results

CONDITION OF TEST	UNDRAINED (U) **YES**	SPEEED= **1.5mm**	PROVING RING FACTOR = **0.00411(kN/m²)**
	CONSOLIDATED-UNDRAINED (CU)	BOX SECTION **100mm × 100mm**	LEVER ARM =
	DRAINED (CD)	WEIGHT OF SAMPLE =	

CONSOLIDATION	PRESSURE TIME DIAL BEFORE CONSOLIDATION DIAL AT THE END OF CONSOLIDATION		PRESSURE TIME DIAL BEFORE CONSOLIDATION DIAL AT THE END OF CONSOLIDATION		PRESSURE TIME DIAL BEFORE CONSOLIDATION DIAL AT THE END OF CONSOLIDATION		PRESSURE TIME DIAL BEFORE CONSOLIDATION DIAL AT THE END OF CONSOLIDATION	

6kN/m²		**12kN/m²**		**18kN/m²**		**24kN/m²**	
ELAPSE TIME	DIAL	ELAPSE TIME	DIAL	ELAPSE TIME	DIAL	ELAPSE TIME	DIAL
0.15	20		28		32		38
0.30	59		47		45		49
0.45	65		60		69		55
1.00	71		75		88		59
1.15	78		85		102		65
1.30	84		96		111		115
1.45	90		105		129		119
2.00	96		111		138		135
2.15	101		116		142		141
2.30	104		121		144		150
2.45	106		124		147		157

3.00	108		127		153		161
3.15	108		130		155		175
3.30	107		128		157		177
3.45					150		172

Table A5: Normal Stress-Shearing Gauge Readings

Normal Stress (kN/m^2)	6	12	18	24
Shearing Guage Reading	108	130	157	177

Table A6: Normal stress – Shearing stress

Normal Stress (kN/m^2)	6	12	18	24
Shearing Stress (kN/m^2)	0.04488	0.05343	0.064527	0.072747