

Structural Integrity Assessment of an Abandoned Reinforced Concrete Structure

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Abstract. This paper presents details of findings for the structural integrity assessment of an abandoned building located in the southern part of Nigeria. Construction work on the uncompleted building commenced in June 2010 with the foundation laying and progressed up to the first-floor slab before work was abruptly suspended. The investigation was aimed at providing the relevant technical information to enable work on the project to resume safely. The investigation involved excavation to expose selected foundations, visual observations and non-destructive tests to determine the compressive strengths of reinforced concrete elements. The results showed the mean strengths of the existing structural members ranging from 23.47 to 29.93 N/mm².

Keywords-Building, Integrity, Reinforced concrete, Structure, Structural

I. INTRODUCTION

Several non-destructive methods (NDT) are available for evaluating the quality of concrete in existing structures. Some of the common methods include: Schmidt or rebound hammer, visual inspection, ultrasonic pulse velocity, electromechanical methods, tomographic mapping, electrical resistivity, magnetic cover meters, petrographic testing, infrared thermography, radar, etc. The purpose being to assess strength and durability parameters such as: compressive strength, concrete cover, carbonation depth, chloride penetration, etc [1-4]. The choice of methods to be adopted in a given investigation is dependent on the purpose of the investigation and availability of necessary equipment. The use of visual inspection and rebound hammer are common methods to evaluate the quality of concrete structures [5-8], especially in developing countries where sophisticated instruments are not esily available. Mathematical models have been developed to predict compressive strengths of concrete from Rebond Hammer numbers [9].

1.1 Project description and data acquisition

The structure covered a plan area of approximately 422 square metre. The design was for 3 floors (i.e. Ground, First and Second Floors). The ground floor consisted of an auditorium of approximately 190 square metre with a stage and spaces for conveniences. The first floor consisted of 5 halls, a lounge, a foyer, including spaces for archives and conveniences, while the second floor was made up of offices, library and spaces for conveniences.

The building design also incorporated 3 stairs located at the 3 extreme corners.

However, actual construction had terminated at the firstfloor level, with concreting for the slab deck partially completed. Also, concreting for the stairs were only achieved for first flights and landings. Construction work was then abruptly abandoned.

1.1 SCOPE OF WORK:

The scope of work include the following:

- A. Integrity Check:
- a. Supperstructure:
- i. Carry-out integrity check/assessment of structural elements such as cloumns, beams and deck-slab within the ground floor of the supperstructure, to evaluate the present state, quality and serviceablility of the structural members; including non-destructive assessment of reinforcement bar locations, sizes and concrete cover, using "profoscope cover meter" evaluation.
- b. Foundation Footings:
- i. Excavate to expose external foundation footings inorder to perform integrity assessment, to evaluate present state, defects (if any) and structural stability of the foundation footing; using non-destructive investigative approach.

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B. Quality Assessment:

- a. Carry-out insitu non-destructive quality assessement of the foundation footings, columns, beams and deck-slab of the Engineering centre building; using rebound (Schmidt) hammer method, to evaluate the nondestructive strength and density of concrete components of the structual elements.
- **C.** Adopt minimal destructutive approach where necessary, to expose the structural members for purpose of performing items 1 and 2 of this technical proposal.

Collate all observations and findings of the integrity check and quality assessment, analyse, interpret, prepare and submitt detailed report of the investigation to the branch chairman, Nigerian Society of Engineers, Eket Branch.

1.2 Objectives of the structural integrity assessment

The objectives of the structural integrity evaluation were to ascertain the following:

- i. That the construction work relating to structural members were in line with the structural design;
- ii. That the strength of concrete was adequate to sustain both dead and life loads of the building.
- iii. That the foundation was adequate to sustain both dead and life loads of the building, given the findings of geotechnical investigation.

2.0 METHODOLOGY

The investigation involved field work, laboratory work as well as documents study and structural analysis and design.

2.1 Field work

The investigations at the site involved visual observations of the structural members, measurements to ascertain sizes of structural members and measurements of compressive strengths of concrete members using Rebound Hammer – non-destructive tests on structural members selected randomly.

The first-floor concrete slab was gridded at approximately 1 - 2m centers to form nodes for obtaining compressive strength of the concrete using non-destructive rebound hammer. 9 rows were identified and compressive tests were performed with the rebound hammer at approximately 10 times on each row with the average result reported. Other structural members also had 8 to 10 test points.

At the top of the first-floor slab and for all the stairs, steel reinforcement placements and sizes for reinforced concrete slab panels, beams, columns and stairs were observed where concreting were partially completed.

Two numbers pad foundations located externally at structural grid points A3 and T3 were excavated to ascertain the depths and dimensions of the pad foundations, as well as the compressive strengths of the concretes used. An additional internal foundation located at structural grid K2 within the auditorium, which had been excavated after the construction of the oversite concrete, but not covered was also observed.

2.1.1 Non-Destructive Compressive Strength Test

The concrete test hammer is the most frequently used nondestructive test method to determine the compressive strength of normal concrete and for detecting weak spots on concrete elements. The test was performed according to ASTM C805 [10], Standard Test Method for Rebound Number of Harden Concrete. The hammer measuring range was 10 - 70 N/mm² and the weight was 1.5Kg.

The test was performed by first warming-up the test hammer with a few trial tests and proceeding with actual measurements. Each test surface was first cleaned and smoothened using a grindstone. Actual measurements performed with the hammer positioned were perpendicular to the test surface. A total of 174 rebound hammer measurements were made for the various structural elements as shown in Table 2. The rebound values were converted to compressive strengths in N/mm² using the equipment chart in Figure 1. The results were later validated in the laboratory by obtaining compressive strengths from 5 Nos. 150mm concrete cube samples. At least 10 rebound hammer measurements were obtained from 2 perpendicular sides of each cube and the average used to compare with the actual crushing strengths obtained from corresponding cubes, using a compression machine immediately after the rebound test.

Table 2: Number of Rebound Hammer Test Recorded

No.	Element	No. of recorded Measurements
1.	Slab/Beam	71
2.	Foundation/Column	55
3.	Stair 1	25
4.	Stair 2	23
	Total	174

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Figure 1: Chart for determining compressive strength (N/mm^2) [11]

2.1.2 Destructive Compressive Strength Test on Concrete Cubes

A 2000KN capacity motorized compression testing machine was used to crush 5 nos. 150mm concrete cubes to obtain the crushing load (P) in Kilo Newton (KN). The compressive strength (N/mm²) of the concrete cube was calculated by dividing the crushing load (N) by the cross-sectional area (mm²) of the cube. The objective of the destructive compressive strength was to validate the non-destructive field test results.

2.2 Documents study

Design drawings and geotechnical report were studied to relate the provisions of the designs with actual construction.

2.3 Structural design

Although, this was not part of the scope of the present investigation, structural design [12] was carried out using Orion Building Design software version 18, based on the findings of the actual strength of concrete at site, to ascertain if the completed works were structurally adequate to sustain the design loads of the structure.

3.0 FINDINGS OF THE FIELD WORK

3.1 Foundations/Columns

The references in this report for locating structural elements of the existing structure were based the design

structural grids shown in Figure 2 for foundation/column layout.



Figure 2: Foundation/column layout

Dimensions

As shown in Figures 3 and 4, two external pad foundations were excavated in order to determine their dimensions and compressive strength of concrete used.

At grid node A3, the pad foundation was located at a depth of approximately 1.73m below ground level, while the plan area was approximately 1630mm by 1800mm with a thickness of 400mm. The structural design identified the foundation as *Foundation Base Type 7* and showed dimensions as 1900mm by 1900mm with a thickness of 400mm. The actual provision of plan area was therefore less than the design provision.

At grid node T3, identified in the structural design as *Foundation Base Type 3*, the foundation plan size was 2400mm by 2400mm in line with the structural design. However, the actual thickness was approximately 350mm, while the design provided for 450mm.

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Figure 3: Excavated foundations to reveal pad foundations



Figure 4: Excavated foundations showing rebound hammer concrete test in progress.

Internally, it was observed that pad foundations were introduced to the enlarged columns on grid lines 3 and 6, from F to Q, using the grid numbers on the structural foundation layout (Figure 2). Excavated concrete floor to introduce such foundation for grid point K2 was yet to be filled. The side of the enlarged columns were found to be 500mm x 500mm. Similar work at K3 was observed to be the possible cause of cracks found on adjacent wall (See Figure 5).

Most of the other columns were approximately 230mm x 230mm in size. These were mostly sandwiched in sandcrete block walls.



Figure 5: Enlarged columns and excavated pit for foundation and cracks on adjacent wall.

Reinforced Concrete

The summary of average compressive strengths measured for all elements are shown in Table 3. The average compressive strength of the foundation/column concrete was investigated using non-destructive Rebound Hammer test. The foundation/columns concrete mean compressive strength was 25.66N/mm². Generally, the compressive strength results for all the elements were found to meet the design strength of 20.0N/mm² used in the structural design. Figure 6 shows that the mean compressive strengths for all the structural members were greater than the design strength of concrete.

Tensile strength test for steel rebars was not within the scope of the present investigation. Nevertheless, unlike concrete, steel rebars are generally manufactured under more controlled regime and supplied under license by the Standard Organization of Nigeria (SON). Hence, usually should meet the standard requirements. Furthermore, the structural design provided for a conservative design

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strength of 410 N/mm² for high yield steel, which gives good factor of safety.

Table 3: Summary of compressive strengths of concrete

	Compressive strength (N/mm ²)									
Element				Std						
	Minimum	Median	Mean	Dev.						
Slab/beam	20.00	26.40	26.33	1.87						
Foundation/col	22.50	26.00	25.66	2.98						
Stair 1	21.00	24.00	23.47	0.76						
Stair 2	23.00	29.00	29.93	1.85						



Figure 6: Mean compressive strengths for various structural elements

Columns starter bars observed at the top of the first-floor slab are presented in Table 4. The design specifications of T20 were not provided though the T16 bars provided had more than the required area of steel. In other cases, the as built was in line with design specifications.

Table 4: Columns steel observed at site

Column Locatio	Colum n Type	No. of bars	Bar Size (mm)	Bar Typ	Design specificatio
n		provide d	diamete r	e	n
C2	C1	6	16	High yield	4T16
C3	C1	4	16	High vield	Same provided
F3	C3	12	16	High vield	6T16
J3	C4	14	16	High yield	8T20
K3	C4	14	16	High yield	8T20
N3	C4	14	16	High vield	8T20
Q3	C4	14	16	High yield	8T20

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$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	T3	C3	6	16	High	Same
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$					yield	provided
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	F6	C3	8 + 4T12	16	High	6T16
J6 C4 14 16 High 8T20 yield K6 C4 12 16 High 8T20 yield N6 C4 14 16 High 8T20 yield Q6 C4 14 16 High 8T20 yield T6 C3 6 16 High 8T20 yield yield yield 8T20 yield 90 yield T6 C3 6 16 High Same yield yield yield 90 yield 90 yield					vield	
K6C41216High yieldK6C41216High yieldN6C41416High yieldQ6C41416High yieldT6C3616High yieldT6C3616High yield	16	C4	14	16	High	8T20
K6C41216High yield8T20 yieldN6C41416High yield8T20 yieldQ6C41416High yield8T20 yieldT6C3616High yieldSame yield	30	01		10	vield	0120
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N6 C4 14 16 High 8T20 yield Q6 C4 14 16 High 8T20 yield T6 C3 6 16 High Same yield provided	Ko	C4	12	16	High	8120
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Q6 C4 14 16 High 8T20 yield T6 C3 6 16 High Same yield provided					vield	
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T6 C3 6 16 High Same yield provided	X ⁰	0.		10	vield	0120
10 C5 0 10 High Same yield provided	TC	C 2	6	16	JI:-h	C
yield provided	10	03	0	10	High	Same
					yield	provided

3.2 Stairs

They were 3 stairs found which were partially completed. The stairs at grid 2-3/C-G and 6-7/A-F, of the three stairs had concrete cast for first flights and landings only (Figure 7). The third had only steel reinforcement in place. The completed portion of the concrete stairs had as built approximate dimensions are shown below:

One stair had the following details observed:

Risers = 150 -175mm Tread = 280 – 300mm Waist = 150 - 200mm Flight width = 1370mm They were 12 steps to landing.

The second stair had the following:

Risers = 150mm Tread = 300mm Waist = 150 - 200mm Flight width = 1340mm They were 12 steps to landing.

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Figure 7: State of stairs observed during site visit

The range of values in the measurement reveal irregular dimensions of the concrete steps. From the uncast portion of the stairs, the steel reinforcements were found to be approximately 12mm diameters spaced at 150 - 200mm for main bars and spacing of 200 - 250mm centers for distribution bars.

The average compressive strength of concrete for the two stairs were found to be 23.47 ± 0.76 and 29.93 ± 1.85 N/mm² respectively. As shown in Figure 6, these values are greater than the design strength of 20N/mm².

3.3 First floor concrete slab deck

Most slab panels of the first-floor concrete decking were completed leaving only a small section not cast, revealing steel reinforcement bars. Observations were made for the beams.

The concrete solid slab thickness was estimated to range between 150mm to 200mm as measured from exposed sides adjacent to the stairs. The design thickness for slab deck was found to be 150mm.

The slab steel reinforcements were 12mm diameter high yield steel placed at 150mm centers both directions for

bottom bars and spacing of 300 - 350mm for top bars. Concrete cover to steel reinforcement was approximately 25mm.

As indicated in Tables 2 and 3 earlier, compressive strength was obtained from 71 test points spaced approximately 1 - 2m. The average compressive strength of the concrete slab was found to be 26.33 ± 1.87 N/mm². Also, from physical observation the slab deck did not show any noticeable vibrations. The existing conditions of the first-floor slab are shown in Figure 8.



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Figure 8: Completed First floor slab (top/under) and uncompleted portion

3.4 First floor concrete beams

First floor beams were cast monolithically with the firstfloor slab panels. Hence, the same concrete compressive strength holds for beam compressive strength. The beam on grid line 3/A-G (Beam 3) measured 230mm x 750mm. Only the top bars were exposed and was found to be 3 Nos. 16mm diameter bars. Links were 8mm diameter at 250mm centers. The design provided 2T16 top and 3T16 bottom. Hence, the design provision was exceeded for the top bars.

The beam on grid line 2/C-G (Beam 2) was also 230mm x 750mm concrete section. Steel reinforcement, 16mm diameter, having 2 at the top layer and 3 at the bottom. The design provided 2T16 top and 2T16 bottom.

Similarly, beam 26 (gridline T/3-6) was 230mm x 750mm concrete section. As observed from the uncompleted sections of the beam, the steel reinforcements were 6T20+4T12 (bottom) and 5T16 (top). Links were T8 @ 250mm centers. The design provided 2T16 top and 5T20 bottom. Generally, the steel provisions for the beams observed were either similar or above design provisions. Some exposed beam reinforcements are shown in Figure 9.



Figure 9: Exposed beam reinforcement yet to receive concrete cast

3.5 General visual observations

Overall, the completed components of the engineering center appear structurally sound and did not show any visible cracks on the major structural members.

The alignments of the first-floor beams above the auditorium, linking the 500 x 500mm columns appear inconsistent. The 500 x 500mm columns at the auditorium seem to be after thought as there were visible evidences of the introduction after the ground floor concrete slab. The structural design provided for 225 x 450mm columns. The purpose of the enlargement of columns could not be ascertained at the time of site visit.

Some completed beams show exposed steel reinforcements bars and honey combs. Some sections of completed structural members viewed internally from the auditorium are shown in Figure 10.

Figure 11 shows external conditions of the main structure, while Figure 12 shows structural members and their steel reinforcement bars, where concreting was not completed or executed.



Figure 10: Underside of completed 1st floor slab and beams viewed from the auditorium, showing exposed steel bars under threat of corrosion.



Figure 11: Different external views of the state of completed works



Figure 12: Uncompleted concreting of staircases and first floor slab viewed internally

3.6 Ground conditions

Excavation of pits made during the site visit, to locate the positions and dimensions of selected foundation bases, showed wet silty to sandy clay soils. The geotechnical investigation report provided by the client recommended allowable bearing pressure of 163KN/m² at 1.5m depth. Geotechnical investigation was not within the scope of the present structural integrity assessment.

4.0 RELATIONSHIP BETWEEN NON-DESTRUCTIVE COMPRESSION TEST AND LABORATORY DESTRUCTIVE COMPRESSION TEST

The results of concrete rebound hammer tests were compared with those of compression machine in the laboratory using concrete cubes, in order to validate the field tests. Figure 13 shows the tests progress in the

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laboratory, while Figure 14 shows the relationship between compressive strength values obtain from compression testing machine and rebound hammer. A positive correlation coefficient of 0.65 was obtained. The results also show that the rebound hammer slightly overestimates the compressive strength for all the cubes except one. The average difference was approximately 3.0 N/mm² which was used to correct the results obtained from the field.



Figure 13: Laboratory tests on concrete cube samples to establish relationship between compression machine and rebound hammer.



Figure 14: Relationship between compressive strengths of concrete cubes obtained from compression machine and rebound hammer

5.0 FINDINGS OF DOCUMENTS STUDY

The documents provided by the client were design drawings, structural design calculations and report of geotechnical investigation for the project site.

i. The documents were not stamped or endorsed by any Planning Authority, indicating that the project may not have received the local Town Planning Authority approval for construction. Standard practice requires all designs to be approved prior to actual construction.

- The structural design calculations indicated the intended use of the structure to be 'Residential'. This tends to underestimate the live loads that may be encountered in a multi-purpose structure during service, such as an engineering center with conference halls.
- A conservative allowable soil bearing capacity of 150KN/m² was used in the structural design. This is reasonable being below the findings of the geotechnical investigation.
- iv. All the slab panels were designed to be 150mm thick, though physical observations showed that some parts of the slab may be thicker. This will result in increased dead loads than anticipated during the design.

6.0 FINDINGS OF STRUCTURAL DESIGN

The findings of the revised structural design showed that most of the structural elements were consistent with the project structural design. In some cases, such as in the bottom reinforcement for first floor slab, the provisions at site were slightly above the design requirement. This difference may depend on the differences in design parameters adopted in each design.

However, a few elements on the project design did not meet the provisions of the revised design. The foundation bases at grid K3 and K6 provided for 2500 x 2500mm bases which were less than 2700 x 2700mm required by the revised design.

Similarly, foundation base B6 was designed to be 3300 x 1500 x 300mm. However, the revised design required 2180.5 x 1000 x 450mm, raising concern for the depth of concrete pad used in the structure.

The major columns on the auditorium met the requirements of the revised design, though they were enlarged prior to site visit.

7.0 CONCLUSION

7.1 CONCLUSION

The structural integrity of the uncompleted reinforced concrete structure for the engineering center was investigated. Though the results show some inadequacies in foundation sizes, visual observations and compressive strength tests showed that the structure was still sound.

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They were no visual signs of any structural cracks or adverse settlements. The observed cracks on one wall within the auditorium appear to have been induced by vibrations from adjacent breaking of concrete floor slab and piping for electrical work. The completed panels of the first-floor solid slab did not show any noticeable vibrations. A few evidences of poor concreting were observed showing honeycombs. Most of the steel provisions at site were more than design requirements.

7.2 RECOMMENDATIONS

- i. The areas where steel reinforcement bars were still exposed should be covered by completing all outstanding casting of concrete at the first-floor level and staircases, to prevent adverse corrosion of the rebars.
- ii. Foundations may be checked further, though there were no visible signs of uneven settlements.
- iii. Subsequent concrete work should be done using kickers to ensure that the designed concrete covers were maintained. Where steel bars are exposed due to inadequate covers, the steel should be protected using cement mortar plaster or grouts.
- iv. Due to concerns about foundations, it may be reasonable to reduce the number of suspended floors from the two as designed to one.
- v. Where the designed two suspended floors are to be maintained, the alignments of the first-floor columns from ground floor level should be maintained at the same positions to avoid increasing the effects of bending and shear stresses. Also, it may be necessary to revise the design for second floor from solid floor slab to a lightweight slab system and partition walls, to reduce the deadloads on the foundations. Any case, the course of action should be based on a revised structural design, which accounts for actual situations of loadings and the adequacy of structural elements, to safely carry the loads.

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APPENDICES

Appendix 1: Detailed results of non-destructive concrete hammer test

COMPRESSIVE S	TRENGTH	OF IN	I SIT	U CC	ONCI	RETE	ELEN	NEN	TS E	STIN	IATE	D FROM R	EBOUND HA	AMMER			
											Std.	Rebound	Adjusted				
		Rebound No.						Average	Deviation	Compressive	Compressive						
	Test							0.				Rebound	Rebound	strength	strength		
ELEMENT	Rows											No.	No.	(N/mm²)	(N/mm²)		
First Floor Slab		1	2	3	4	5	6	7	8	9	10					Slab	
	1	20	22	25	20	20	19	21	20			20.88	1.89	31	28.00	Min. =	20
	2	19	20	18	19	20	19					19.17	0.75	30.0	27.00	Median =	26.4
	3	20	19	20	17	20	20	21				19.57	1.27	30	27.00	Mean =	26.33
	4	20	20	20	24	20	20	24	24	24	23	21.90	2.02	32	29.00	S.Dev. =	1.87
	5	20	20	21	19	20	19	15	15			18.63	2.33	29.0	26.00		
	6	19	22	19	20	20	19	19	15	20	20	19.30	1.77	30	27.00	71	
	7	16	17	19	15	15	20	15	15	16	19	16.70	1.95	27	24.00		
	8	18	21	19	19	19	19	15				18.57	1.81	29	26.00		
	9	18	19	11	11	11						14.00	4.12	26	23.00		
		Min	•	11	23	Me	dian	19	29					Av.	26.33		
	10	22	47	10	4.4		25	24	45	20	27	22.40	0.02	27.4	24.40	Courselant	
Fdn/Col A3	10	33	1/	16	14	14	35	34	15	26	27	23.10	8.82	27.4	24.40	Foundation	on/Column
	11	33	18	21	20	20	33	30				25.00	0.08	29.2	26.20	IVIIII. =	22.5
Column Ab	12	22	20	24	24	22	20					23.00	2.10	27.3	24.30	Mean -	20
Column 12	15	10	17	17	10	10	20					27.00	4.10	31	28.00	S Dov -	25.00
Column K3	14	25	26	27	21	25	26					25.00	2 10	23	20.00	3.Dev	2.90
Column I6	15	27	20	27	21	25	20	32				25.00	2.10	29	20.00	ς α	
Column K6	17	32	23	32	34	20	25	30				29.86	3.08	33.2	30.20		
cordinii ko	1/	52	20	52	34	20	23	50				25100	5.00	33.2	30.20		
		Min		14	26	Me	dian	25	29					Av.	25.66		
Stair 1 Landing	18	20	12	14	15	15						15.20	2.95	26.8	23.80	Stair 1	
Stair 1 Steps	19	12	15	16	12	14	16	12	14	16	12	13.90	1.79	25.6	22.60	Min. =	21
Ditto	20	17	15	17	15	17	25	15	15	16	14	16.60	3.13	27	24.00	Median =	24
																Mean =	23.47
		Min	•	12	24	Me	dian	15	27					Av.	23.47	S.Dev. =	0.76
																25	l
Stair 2 Landing	21	22	24	20	25	20	20					21.83	2.23	34	31.00	Stair 2	
Stair 2 Steps	22	14	23	18	20	24	16	18	22	24	18	19.70	3.47	30.8	27.80	Min. =	23
Ditto	23	18	21	28	25	28	24	24				24.00	3.61	34	31.00	Median =	29
														•		Mean =	29.93
		Min	•	14	26	Me	dian	22	32					Av.	29.93	S.Dev. =	1.85
																23	4