
ASSESSMENT OF THE MATERIAL PROPERTIES OF A FIRE DAMAGED BUILDING

Oladipupo OLOMO¹, Olufikayo ADERINLEWO², Moses TANIMOLA³, Silvana CROOPE⁴

^{1,2,3}*Department of Civil Engineering, Federal University of Technology Akure, E-mail: faderin2010@yahoo.com*

⁴*Delaware Department of Transportation, Delaware, USA, E-mail: silcroope@gmail.com*

ABSTRACT

This study identifies a process for assessing the material properties of a fire damaged building so as to determine whether the remains can be utilized in construction or be demolished. Physical and chemical analysis were carried out on concrete and steel samples taken from various elements of the building after thorough visual inspection of the entire building had been conducted. The physical (non-destructive) tests included the Schmidt hammer and ultrasonic pulse velocity tests on the concrete samples, tensile strength test on the steel samples and chemical tests involving the assessment of the quantities of cement, sulphates and chloride concentrations in the samples. A redesign of the building elements was also carried out and the results were compared with the existing design. The non-destructive test results indicated compressive strengths as low as 9.9 N/mm², the tensile strength test indicated a maximum strength of 397.48 N/mm² and the chemical test indicated chloride contents as high as 0.534 g per gramme of concrete. These properties deviated significantly from standard requirements. Based on these results, it was concluded that the remains of the building should be demolished.

Keywords: ultrasonic pulse velocity; tensile strength; compressive strength; non-destructive tests

REZUMAT

Studiul de față identifică un proces de evaluare a proprietăților materialelor unei clădiri avariate de cutremur, astfel încât să se determine dacă părțile rămase pot fi utilizate în construcție sau dacă trebuie realizată demolarea. Au fost realizate analize fizice și chimice asupra unor probe de beton și oțel prelevate din diferite elemente ale clădirii, după o atentă inspecție vizuală a întregii clădiri. Încercările fizice (ne-distructive) au inclus încercarea cu sclerometrul Schmidt și cu metoda ultrasonică de impuls pe probe de beton, încercarea de rezistență la întindere pe probe de oțel, ca și probe chimice, implicând evaluarea cantităților de ciment, sulfați și a concentrațiilor de cloruri din probe. De asemenea, a fost efectuată o reproiectare a elementelor de construcție, iar rezultatele au fost comparate cu proiectul inițial. Rezultatele testelor nedistructive au indicat rezistențe la compresiune scăzute până la 9.9 N/mm², încercarea de rezistență la întindere a indicat o rezistență maximă de 397.48 N/mm², iar testul chimic a indicat un conținut de cloruri de până la 0.534 g pe gram de beton. Aceste proprietăți deviază semnificativ de la cerințele standardelor. Pe baza acestor rezultate, s-a tras concluzia că părțile de clădire rămase ar trebui demolate.

Cuvinte cheie: viteza pulsului ultrasonic, rezistență la întindere, rezistență la compresiune, încercări nedistructive

1. 1. INTRODUCTION

A building is essentially a space protected from the natural environment and which is constructed for a specific purpose. The structural elements are parts of the building that cannot be conceived in isolation but are part of the whole design.

A structural element (such as a beam, column, slab) carries the load on it by a system of bending moments, shear forces and axial forces acting in one, two or three directions

depending on the nature of the structural elements. These elements fail due to several reasons such as inadequate design, poor workmanship, overloading and fire occurrence.

The failure of the building elements usually occurs over a certain period of time called the design life and this may not be noticed if adequately maintained but when a fire disaster occurs there is an outright change. The fire hastens the reactions by exposing the structural elements to environmental

conditions that affect their properties. Thereafter, the deterioration can be observed in the changes of the concrete properties such as shrinkage, creep, fatigue and thermal expansion.

In this study, the material properties of a fire damaged single storey building located at No. 2 Gbogi Street, Akure, Ondo State are assessed through physical, mechanical and chemical analysis of both concrete and steel samples collected from the remains. A sizeable proportion of the building collapsed during the fire incidence. The building had been in existence for six years up till the time of the fire which lasted for over three hours (based on information gathered from surrounding residents).

Based on investigation of the building's construction records obtained from the Ministry of Works and Housing, Ondo State, Nigeria, Ordinary Portland cement was used in preparing the concrete used in the building with a mix ratio of 1:2:4.

The underlying objectives of this study are to identify by visual inspection, the level of damage by the fire on the building, carry out non-destructive (physical) tests and chemical tests on concrete samples from different structural elements in the building as well as tensile strength test on steel samples from the reinforcements, redesign the building based on re-constructed design drawings of the building and determine if the remains of the building can be repaired/rehabilitated or if it should be demolished.

2. BACKGROUND LITERATURE

Loss of life and property by fire most commonly occurs because of ignorance about the nature of fire and its behavior. Fire can be viewed as the active principal operative in combustion which is the oxidation of organic material with the development of heat and light. Uncontrolled fire can be very destructive to both the environment and life. The occurrence of fire in a building can be due to various reasons such as incorrect electrical wiring of the building or equipment in a room. This can cause severe overheating of a cable

and combustion of the surrounding materials resulting in flames and ignition of the immediate adjoining fabric.

Concrete is incombustible and also capable of retaining some strength for a reasonable time at high temperatures of up to 500°C. Thereafter, it degrades at a rate depending on the maximum temperature, the concrete constituents and the size of the structural element. There are three main contributions to concrete degradation during the occurrence of a fire namely evaporation of water within the concrete which starts at 100°C, cracking and breakdown of the hydrates in the hardened cement paste and differential expansion between the hardened cement paste and aggregate resulting in thermal stresses.

Concrete attacked by fire experiences negative effects such as creep, fatigue and shrinkage. These can lead to other defects such as cracking, spalling and corrosion of the exposed reinforcement. Cracking in reinforced concrete can be classified into two major categories namely those caused by external loads on the structure such as flexural and unlined shear cracks and those which occur independently of the applied load such as cracking due to concrete shrinkage and temperature change which reduces the strength of the reinforcement (Leonhardt, 1988).

Fire resistance for concrete members has been attained by specifying adequate cover to the reinforcement. BS8110 (Part 2, 1985) allows three methods to be used to calculate fire resistance requirements namely cover and member size data, fire test performance and fire engineering calculations. According to BS8110 (Part 1, 1997), the actual cover should never be less than the nominal cover minus 5mm. The nominal cover protects the steel reinforcement against fire and corrosion and its thickness depends on the exposure conditions.

3. MATERIALS AND METHODS

The properties of concrete are its strength and durability. Other properties are resistance to deformation and shrinkage. These properties

can be measured to assess the structural behavior of the concrete. In this study, the concrete is considered to have reached standard strength after 28 days and the tests are limited to non-destructive tests namely the Schmidt hammer, ultrasonic pulse velocity and the tensometer tests.



Fig. 1. Building section showing collapsed column, slab and beam



Fig. 2. Damaged floor slab with exposed reinforcement

Chemical tests, namely chloride, sulphate and cement content tests are carried out according to BS1881 (Part 124, 1988) on three samples collected from each of the elements namely beam, column and slab.



Fig. 3. Crack in the wall close to a column

3.1. Schmidt (rebound) hammer test

The instrument used for this test is the Schmidt hammer or sclerometer which measures the magnitude of rebound of a steel mass from the concrete surface. The test was carried out according to BS1881 (Part 202, 1986) on the basis that the strength of hardened concrete is proportional to its hardness. Empirical relationships between the rebound number and concrete strength have been established which show that the higher the rebound number, the greater is the concrete strength.

3.2. Ultrasonic pulse velocity test

This test uses the ultrasonic velocity passing through the concrete to assess its strength based on standards specified in BS1881 (Part 203, 1986). The instrument used for the test is a portable Pundit ultrasonic pulse machine. It consists of a gauge for measuring the pulse, a transducer and a receiver. The machine generates an ultrasonic pulse in the transmitting transducer and measures the transmission time taken by the pulse to reach the receiving transducer. The pulse velocity is then calculated by dividing the length of the path travelled through the concrete by the transmission time.

3.3. Tensometer test

The test on the steel reinforcement is required because it provides the tensile strength required by the concrete since it is an engineering fact that concrete is weak in tension. Therefore, there cannot be tensile failure in concrete if the reinforcement does not first fail. This test is carried out according to the standards specified in ASTM E8M-01 (2001). The instrument used for this test on the steel reinforcement is the Monsanto Hounsfield tensometer which generates a stress-strain or force-extension curve as it strains the steel test piece.

3.4. Chloride Content determination

The presence of chloride in reinforced concrete can cause severe corrosion of the reinforcement. This may have been introduced into the concrete during mixing by using water contaminated with salt water or by the use of chloride based admixtures. BS 1881 (Part 124, 1988) limits the chloride content expressed as a percentage of chloride ion by weight of cement to 0.4% for every 1g of concrete containing embedded metal.

The experiment involved crushing the concrete samples into fine powder using a pulverizing machine, extracting the chloride (from 5g of the sample powder) with hot dilute nitric acid, precipitating out any chloride present in the sample by adding Silver Nitrate, titrating Ammonium thiocyanate solution against the remaining Silver Nitrate and deriving the amount of chloride present by finding the difference between the added Silver Nitrate and the remaining after precipitating the chloride.

3.5. Sulphate content determination

The consequences of sulphate attack on concrete include not only disruptive expansion and cracking but also loss of strength due to loss of cohesion in the hydrated cement paste and of adhesion between it and the aggregate particles. BS 1881 (Part 124, 1988) limits the total water-soluble sulphate content in any 5g of the concrete mix to 4% by weight of cement content.

The test involved crushing the samples into fine dust using a pulverizing machine, acid extracting and precipitating (from 5g of the sample powder) the sulphate as Barium Sulphate using Barium Chloride and determining the Sulphate content gravimetrically by filtering and weighing the resulting Barium Sulphate.

3.6. Cement content determination

The cement content in the samples tested was used to determine if the amounts of sulphates and chlorides in the concrete are acceptable. It is a fundamental of good quality concrete that it contains adequate cement or a sufficiently low water/cement ratio so as to provide adequate durability for the intended exposure conditions.

This test involved also crushing the samples into fine dust using a pulverizing machine, thoroughly mixing 6g of anhydrous Sodium Carbonate with 1g of the powder and covering it with a little amount of Sodium Carbonate. This was followed by mixing the mixture gradually on a Bunsen burner for about 20 minutes to melt, removing it from the heat to cool and disintegrating the contents by warming it on a water bath. Thereafter, 25ml of concentrated Hydrochloric acid was introduced slowly to the mixture in a crucible with a pipette and warmed in the water bath until the evolution of Carbon dioxide ceased. The sample was then allowed to dry and cool before weighing. The total weight minus that of the crucible represented the amount of silica present in the sample which also indicated the cement content.

4. ANALYSIS AND INTERPRETATION OF RESULTS

4.1. Chemical analysis results

4.1.1. Sulphate content determination test

- Column sample

Average weight of sulphate in the three column samples = 2.33g

Weight of sulphate in 1g of the sample powder = $\left(\frac{2.33}{5}\right) = 0.466g$

- Beam sample

Average weight of sulphate in the three beam samples = 2.67g

Weight of sulphate in 1g of the sample powder = $\left(\frac{2.67}{5}\right) = 0.534g$

- Slab sample

Average weight of sulphate in the three slab samples = 4g

Weight of sulphate in 1g of the sample powder = $\left(\frac{4}{5}\right) = 0.80g$

4.1.2. Chloride content determination test

- Column sample

Average weight of chloride in the three column samples = 2.67g

Weight of chloride in 1g of the sample powder = $\left(\frac{2.67}{5}\right) = 0.534g$

- Beam sample

Average weight of chloride in the three beam samples = 1.83g

Weight of chloride in 1g of the sample powder = $\left(\frac{1.83}{5}\right) = 0.367g$

- Slab sample

Average weight of chloride in the three slab samples = 0.21g

Weight of chloride in 1g of the sample powder = $\left(\frac{0.21}{5}\right) = 0.043g$

4.1.3. Cement content determination test

Molar mass of Silicate (SiO_2):

Silicon = 28g

Oxygen = 32g

Therefore, mass of Silicate (SiO_2): 60g

- Column sample

Average weight of cement in the three column samples (i.e 1g of sample powder) = 0.12g

- Beam sample

Average weight of cement in the three beam samples = 0.14g

- Slab sample

Average weight of cement in the three slab samples = 0.05g

Based on the results of cement content, the acceptable levels of chloride and sulphates in the sample powder are as follows:

- Chlorides:

Column: $0.14 \times 0.4\% = 0.056g$

Beam: $0.12 \times 0.4\% = 0.048g$

Slab = $0.05 \times 0.4\% = 0.02g$

- Sulphates:

Column: $0.14 \times \frac{4}{5}\% = 0.112g$

Beam: $0.12 \times \frac{4}{5}\% = 0.096g$

Slab = $0.05 \times \frac{4}{5}\% = 0.04g$

4.2. Non-destructive test on concrete

4.2.1. Schmidt hammer test

Table 1 shows the results of the Schmidt hammer test conducted on the building elements. Twelve readings were taken from each element and the average values are also shown.

4.2.2. Ultrasonic pulse velocity test

Tables 2, 3 and 4 show the ultrasonic pulse velocity test results for the slab, beam and column elements.

4.2.3. Tensile strength test on the steel reinforcement

Table 5 shows the readings from the tensometer test carried out on samples of steel reinforcements from the building elements which were loaded to failure. The tensile strength for the steel samples is calculated by using equation (1).

$$\text{Tensile strength} = \frac{\text{Maximum load applied}}{\text{Original cross-sectional area}} \quad (1)$$

Table 1. Schmidt hammer test results (in N/mm^2)

Readings	1	2	3	4	5	6	7	8	9	10	11	12	Total	Mean
Beam	20	16	27	20	26	21	18	20	20	15	18	14	235	20
Slab	26	24	20	11	26	21	27	22	27	30	26	27	287	24
Column	24	17	15	22	20	21	17	18	11	20	20	21	225	19

Table 2. Ultrasonic pulse velocity test results for slab

Path length through element (mm)	Transit time (μ s)	Pulse velocity (km/sec)	Compressive strength (N/mm ²)
140	43.7	3.21	14.1
140	47.6	2.94	13.5
140	52.6	2.66	10
Mean			12.5

Table 3. Ultrasonic pulse velocity test results for beam

Path length through element (mm)	Transit time (μ s)	Pulse velocity (km/sec)	Compressive strength (N/mm ²)
300	92.9	3.22	14.1
300	110.8	2.70	10.5
300	121.3	2.47	9.5
Mean			11.3

Table 4. Ultrasonic pulse velocity test results for column

Path length through element (mm)	Transit time (μ s)	Pulse velocity (km/sec)	Compressive strength (N/mm ²)
270	108.6	2.48	9.5
270	104.5	2.58	9.8
270	100.1	2.69	10.4
Mean			9.9

Table 5. Readings from Tensometer test

Steel Sample	Initial length, L _o (mm)	Initial diameter, D _o (mm)	Final length, L _f (mm)	Final diameter, D _f (mm)	Initial Cross-sectional area (mm ²)	Final cross-sectional area (mm ²)	Maximum applied load (N)	Tensile strength, (N/mm ²)
Slab (Distribution reinforcement)	26.7	9.8	36.8	7.7	75.43	46.57	12,000	159.09
Slab (Main reinforcement)	28.0	11.9	34.0	9.8	111.22	75.43	35,000	314.69
Beam	24.6	11.7	31.3	10.5	107.51	86.59	40,000	372.06
Column	25.2	15.5	32.4	13.9	188.69	151.75	75,000	397.48

4.3. Design calculations

Some of the building elements were redesigned based on the existing dimensions. A comparison of the sizes of reinforcements required based on the redesign with those existing in the building indicate that the existing design was adequate (with regards to size/dimensions only). The redesign calculations for member sizes (both the reinforcements and building elements) were similar to the sizes existing on site.

The distribution reinforcement is made of plain round hot-rolled mild steel bars (10mm in diameter) while the main reinforcement is made of deformed hot-rolled high yield bars (16mm in diameter for columns and 12mm for slabs and beams).

4.4. Interpretation of results

The chemical analysis results indicate that the amount of chlorides and sulphates in the concrete samples from the building far exceed the acceptable levels as recommended by BS

1881 (Part 124, 1988). This could have contributed significantly towards the failure of the building during the fire incidence based on the fact that the reinforcement might have been weakened by these chemicals. This is also corroborated by the presence of considerable amount of rust on the surface of the reinforcements.

The non-destructive test results reveal that the compressive strengths of the concrete as revealed by the tests on the different building elements had been greatly affected by the fire. In comparison with the standard compressive strength of concrete cubes with mix ratio 1:2:4 after 28 days given as 25N/mm^2 (Reynolds and Steedman, 1999), the minimum and maximum compressive strengths obtained through the Schmidt hammer test are 19N/mm^2 (from column element) and 24N/mm^2 (from slab element) respectively. The ultrasonic pulse velocity test results indicated much lower minimum and maximum compressive strengths of 9.9N/mm^2 (from column element) and 12.5N/mm^2 (from slab element) respectively.

Also, the tensometer test indicated low values of tensile strength for the slab, column and beam steel reinforcements compared with the requirements of BS8110 which specifies the characteristic strength of distribution reinforcement (mild steel bars) as 250N/mm^2 , main reinforcement (hot-rolled high yield steel bars) as 460N/mm^2 for diameters not greater than 16mm (Reynolds and Steedman, 1999).

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Based on subjective assessment of the building and what can be inferred from figures 1, 2 and 3, the building has undergone severe damage indicated by the collapse of columns, beams and slabs which has resulted in failure of the internal concrete fabric and the reinforcements.

In addition, the chloride and sulphate contents of samples tested were higher than the acceptable requirements for concrete as

specified by BS1881 (Part 124, 1988). This may have been due to use of salt water in mixing the concrete used for initial construction of the building. It seems that these chemicals may have been responsible for corrosion and subsequent reduction in strength of the reinforcements prior to the fire attack.

The tensile strengths of the reinforcements also seem to have been greatly affected by the fire which continued for 3 hours which was 2 hours more than the duration concrete cover offers protection to reinforcement. This may have led to gradual failure and subsequent collapse of the building.

The Schmidt hammer and ultrasonic pulse velocity test results showed that the resistance of the concrete to cracking had also reduced to levels below the acceptable standards by BS1881 (Parts 202 and 203, 1986). This is indicated by the low compressive strength values especially in the case of the ultrasonic pulse velocity test.

5.2. Recommendations

Based on the results of all the analysis carried out in this study, it is recommended that the building should be totally demolished. The building is beyond repairs because all the properties fall below standard requirements.

The procedure followed in this study for assessing the properties of a fire damaged building can be used for any other similar cases.

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