Investigation of Structural Integrity and Stability Evaluation of Fire affected Building by Non-Destructive Testing

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Abstract

The structural integrity evaluation of building is an important concern in any post disastrous situations like earthquakes, fires, and etc. Fire hazard is probably initiated by the small electrical leakages or unnoticed straining in the building premises. However, such situations are controlled by manual or automatic surveillance. In Covid-19 scenario, many industrial buildings were under lock down and the monitoring of fire accidents became difficult. Such an event occurred in a Chennai industrial estate and the fire has caused huge structural and non-structural damages. A detailed visual inspection study is carried out. The structural beams, columns and slabs have been affected with micro to macro cracks and spalling of cover concretes. Reinforcements are exposed fire and some members are severely deformed. The extent of fire has been investigated using neutralisation test, relative geometrical variation measures. The structural integrity of structural elements are assessed using Non Destructive Testing (NDT) and Partial Destructive Testing (PDT). Using cores, the neutralization test and compressive strength tests are carried out. From the visualisation study, it has been observed that about 60 to 70 % of the structure is severely affected by fire. The NDT and PDT results indicated that the surface hardness, strength and integrity of concrete are severely affected due to fire. The neutralisation test indicates that about 50 mm depth of the concrete become acidic nature. The relative dimensional measures agreed with NDT and PDT findings and indicated that, the structural components are excessively deformed and it is not fit to usage without rehabilitation and structural restoration.

Keywords: *NDT; Condition assessment; Structural Stability; PDT*

1 Introduction

In general belief in common is that the concrete is a non-combustible nature and it has an ability to preventing heat and the spreading of fire. Even the engineers and researchers are finding difficulties to clearly understand the nature of fire and its influence of different concrete materials. Based on the preambles of research, the design criteria are arrived and usually recommends adequate concrete cover to the reinforcement [4]. In reality, at a distinct point of heat, it is hard to believe that the concrete is also vulnerable for the safety. The problems appear to be equally severe for concrete columns and beams. When the concrete heated to a prolonged higher temperature undergoes explosive thermal spalling, thermal fracture, and disintegration due to dehydration [12]. The concrete structures are need to be designed with higher precautions on fire incidences.

1.1 Performance of concrete during fire

The reinforced concrete structures are normally good in fire resistance compared to the steel and other metal structures and they are found slightly inferior compared to the solid wooden structures. Due to the lower thermal conductivity and non-flammability, the concrete structures are performing well under fire of up to 300°C. It develops micro cracks on the concrete surface without any major loss to its strength and functionality. When the temperature increases beyond 300°C affects the concrete integrity due to the volumetric expansion of aggregates and, the moisture filled micro and macro voids present in the concrete [5]. The micro cracks affect the surface integrity of concrete and it reduces the compression strength of concrete and it affects the tensile strength of concrete. The incompatibility of thermal strains leads to the straining of the heterogeneous composite system and forms numerous micro and macro cracks in the interfacial transition zone, and result in degradation of the mechanical and physical properties [3,10]. The reduction in mechanical properties are also influenced by the method of cooling or breaking the fire [1,2]. The further increase in temperature fracture the surface cover concrete and heat up the inner concrete portions. During fire, many factors are affects the changes in the strength characteristic of concrete including size, source and position of aggregates, cement, duration and intensity of heating, the mix design and etc. [9]. The functionality of reinforced concrete structural system has been affected when the structure is exposed to temperature between 600°C and 1,400°C. The higher exposure of temperature modifies the chemical characterisation of concrete and weakens the physical properties. The concrete colour changes and the colour variation is depending on the duration and the intensity of heat exposure. For higher exposure conditions, the concrete's normal light grey becomes dark pink or red [11]. The moisture present in the inner pores are heated up and escalates the pore pressure and forms micro cracks on the surface and it allows the fire to directly contact to the inner surfaces of cover concrete and it leads to the further widening of cracks which leads to the falling cover concrete. Irrespective of the concrete mix proportions, the microstructure of normal and high strength concretes exhibits an analogous trend against the contact temperature [3]. The increase it temperature affects the performance of steel. The physical and mechanical characteristic steel is drastically affected during the prolonged temperature greater than 800°C. The steel conducts the heat at a higher rate to the entire portion of structures and it significantly reduces the strength of steel and lead to the failure of entire structure in catastrophically.

2 General Observation on Post Fire Study of Reinforced concrete – A Case Study

2.1 A Visual Observation Study

The structure is primarily constructed and used for the research and development activities on polymerisation process and a development of adhesive components. The structure has been used for storing highly inflammable components. The fire safety systems are installed in the entire building premises ad due to the COVID19, the entire industrial estate have been closed and the fire incident was unnoticed at the initial stage. The post fire analysis is started with investigating the structure with visual observation. In general, visual inspection can partly decide on the quality and integrity of fire affected building for taking a decision on the possibility of further operation of the facility. The typical view of fire affected building is shown in figure.1. The fire affected building is of G+2 story with RCC framed structure and partially loading brick masonry. RCC columns are placed in three rows along the length directions. These columns are spaced at 3.0 m intervals along the longer directions.

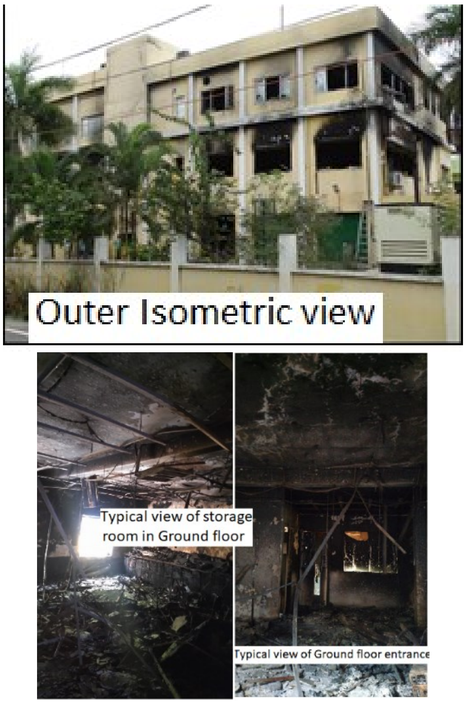

Fig.1 Typical view of fire affected building – Outer and ground floor

In the ground floor area, there rooms for administration, meeting Chamber, Instrumentation & Testing, Main entrance & reception area, Record Storage, Staircase area, Conference Hall, Raw materials Storage, EB room and Materials Processing area. All these areas were visually inspected and documented. The fire is probably started by electrical short-circuiting. The cables, panels and supporting systems are completely burned and it has spread into the adjacent rooms which are meant for conference and for storage of raw materials. The wooden furniture and other ignitable items fuelled the initial spread of fire. The floor partitioned with brick infill has showed minimum damage compared to the floors partitioned with wooden reapers and plywood. The wooden furniture and partition walls have fuelled the fire and made the structure to exposed in high temperature. The brick infills have lost the mortar cover and cracked severely, but the brick infills have protected the beams and columns during fire. Unlike the ground floor, the first floor is seeming to be worst affected by the fire incident as shown in figure.2. This floor doesn't have a partition walls around the interior columns and beams. A full height wooden cabinets as partitions with chairs and wooden tables are provided in this floor. Inflammable chemicals and resigns are stacked in few cabins. The official paper and patent documents, computer CPU's and monitors are kept in the cabins. During fire, the inflammables kept in the first floor is fuelled the fire heavily. The cabinets to carry out different research activities.

Fig.2 Typical view of fire damage in first floor of fire affected Building

In a similar way, the second floor is visually inspected and seen that the concrete has damaged with numerous micro cracks and the cover concrete is removed off partially at few locations. The roof slab is found damped and some seepage of water from the terrace is observed. From the visual observations, the ground floor is very minimally affected and the second floor is moderately affected, and the 1st floor is seeming to be damaged extremely. The stability studies and the non-destructive and partial destructive studies are carried out to understand the actual integrity of concrete and the expediency of structure.

2.2 Non-Destructive Testing (NDT) on fire affected building components

Non-destructive testing (NDT) is carried out to assess the condition of fire affected structures using the Rebound Hammer Method (RHM), Ultrasonic Pulse Velocity (UPV) on some selected members. The surface hardness and integrity of the structural components are measured.

Ultrasonic Pulse Velocity (UPV) Test

Ultrasonic Pulse Velocity test is basically a wave propagation test and consists of transmitting ultrasonic pulses of 50 – 60 kHz frequency through a concrete medium and measuring the travel time of ultrasonic pulses and arrive the velocity and from which the concrete quality is assed indirectly. With reference to Indian Standard code of practice [7], UPV values can suitably interpreted to assess qualitatively the condition of concrete with regard to homogeneity, uniformity, integrity. The presence of cracks, voids, and other imperfections, Changes in the structure of the concrete which occur with time, Quality of the concrete and etc. The beams and columns are tested in direct method to assess the presence of flaws along the sections and the in-direct method is used to measure the integrity along a plane, specifically the cracks. The semi-direct method is used to assess the concrete quality, where there is a minimal access on the side of section as shown in fig.3.

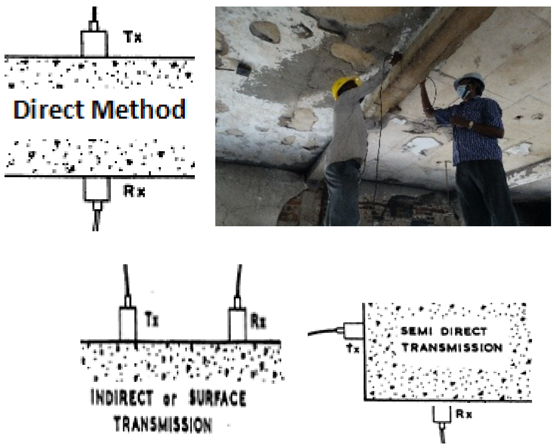

Fig.3 Typical procedures of different methods for measuring UPV values

Rebound Hammer Test

Rebound hammer test is performed to evaluate the surface hardness of concrete as typically shown in figure.4a, by essentially of impacting the concrete surface in a standard manner. The test method consists of a spring controlled mass that slides on a plunger within a tubular housing. The rebound values quantitatively reflect the quality of concrete within a depth of 50 mm from the surface. The rebound hammer method provides a convenient and rapid indication of the compressive strength of concrete by means of establishing a suitable correlation between the rebound index and the compressive strength of concrete [8] is shown in figure.4b.

Fig.4a Typical view of Rebound Hammer Test in ground floor

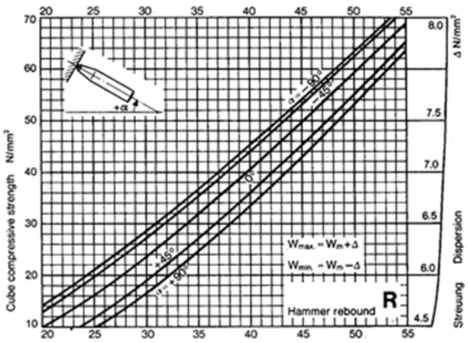

Fig.4b correlation graph between Rebound Hammer Number and Strength

Cover Meter test

The cover meter test is performed to locate the steel reinforcement present inside the reinforced concrete and to measure their concrete cover. From the test, cover thickness and the profile of the re-bar is displayed on the screen and from that the location are chosen for core sampling and powder sampling. The cover meter works on eddy current pulse induction principle and this is a best imaging technology not influenced by concrete composition and humidity. Further. This test essential to understand the bar spacing and their placement in existing structures.

2.2 Partial destructive tests (PDT) – Core sampling ad powder sampling

The rebound Hammer and ultrasonic pulse velocity tests can give indirect evidence of concrete quality. During fire, the raise in temperature alters the original chemical composition of constituent materials. More realistic assessment on concrete can be made by core and powder sampling and testing. The PDT can give a quantitative measurement of actual concrete strength exists in the structure, Carbonation attack, pH and Chloride Level present in the actual site condition. The core samples are used to arrive the compressive strength, chemical analysis, petrography examination etc. the typical view of core sampling in floor slab is shown in figure.5.

Fig.5 Concrete Core Extraction on Slab in Progress

Neutralization Test of Concrete

Concrete is of alkaline in nature and its pH value about 13.0. When the concrete is exposed to fire, the pH value of concrete falls below 7 and it properties changes from alkaline to acidic. The core samples taken out from the structural elements are used to assess it pH condition with respect to depth and from that the depth of concrete affected by fire. For this, phenolphthalein solution is used as an indicator on the affected concrete portions. The Phenolphthalein solution remains colourless in acids/neutral substances, but turns bright reddish/pink in base substances. From that, the present study is inferred the temperature history and depth of heat penetration.

2.3 Deformation measurements and stability checks on Flexural Members

Due to thermal effects, some of the beams and slabs deflected. The extent of deformation was measured typically. Levelling was done with water tube and a rope was tied between two points. The level difference was noted by measuring. Typical measurement of deformation of beam is given in figure.6.

Table.1 Statistical Parameters of UPV Values

Floor	Member ID	No.of	Max.	Min.	Avg.	S.D	C.O.V.	VcK
Ground	B5 ,Column	9	2.20	0.00	0.90	0.90	95.30	-0.50
	B6, Column	9	1.90	0.10	0.60	0.50	89.10	-0.30
	B7, Column	8	4.20	1.10	2.50	1.30	53.10	0.30
	A3-B3, Beam	24	3.00	0.40	1.50	1.00	63.80	-0.10
First	B2, Column	20	3.60	0.30	1.70	1.10	65.40	-0.10
	B3, Column	10	3.80	0.30	1.90	1.40	73.50	-0.40
	B4, Column	20	2.90	0.00	1.20	1.10	92.20	-0.60
	B5, Column	20	3.20	0.50	1.70	0.80	46.20	0.40
	B6, Column	20	1.70	0.40	1.00	0.40	40.70	0.30
	B7, Column	20	0.50	0.00	0.00	0.10	447.20	-0.20
	B8, Column	10	3.20	0.00	1.50	1.00	64.10	-0.10
	B4-C4, Beam	26	3.50	0.00	1.40	1.40	97.80	-0.90
	B3-A3, Beam	30	3.30	0.00	1.10	1.10	95.50	-0.60
	A4,A5 & B4,B5, Slab	12	1.90	0.50	1.00	0.50	43.30	0.30
	A3,A4 & B3,B4, Slab	10	1.70	0.60	1.20	0.30	24.00	0.70
Second	B7, Column	35	3.30	0.10	1.80	0.80	44.90	0.50
	B8, Column	23	2.80	0.40	1.80	0.60	34.20	0.80
	B2-C2, Beam	42	3.50	0.30	1.60	0.90	59.00	0.00
	B5-C5, Beam	14	1.03	0.00	0.26	0.38	142.94	-0.36
	B6-C6, Beam	14	3.20	0.40	2.30	0.80	36.50	0.90
	B5C5-B6C6, Slab	12	3.41	2.08	2.65	0.41	15.64	1.97
	B6C6-B7C7, Slab	55	3.06	0.60	2.16	0.52	23.98	1.30

Fig.6 typical view of levelling and the measurement of sectional deflection

3 RESULTS AND DISCUSSIONS

3.1 Visual Inspection

At the ground floor level, several cracks were noticed in brick infilled walls. Roof false ceiling was completely fallen. Several micro cracks and few macro cracks were observed on beams and the roofs. The infills have protected the ground floor columns. A portion of building is isolated from the region of fire where the Liquid Nitrogen Cylinder, Raw Materials for developing resigns, packing materials, Silicon containers, Epoxy storage tins, Oil Storage tins and other Hazards Waste Storage bins is avoided the major blast during fire. The brick infills covered the columns and beams by acting as a barrier between the heat and the reinforced concrete. concrete beams and columns are seen in block colour due to the deposit of fumes. In most of the columns and beams is in grey colour after swiping with cotton. In very few locations, the concrete colour is observed in pink to red colour, specifically where the reinforced concrete section is exposed to fire, due to lack of brick infill. This colour changes indicates that the temperature load is less than the 600°C and probably between 200°C and 400°C. In contrary, the first floor is visually found to be worst affected during the fire. The reinforced concrete beams and columns are directly contacted with fire and the most of the reinforced concrete sections have lost their cover concrete and the steel has got is exposed to fire. Due to the abnormal fire load, the column, beams and slabs have lost its stiffness and deformed. The exposed steel in few columns are buckled and this is happened due to the loss steel strength during the heat and failed to transfer the compression load. The concrete colour in the columns, beams and slabs are in whitish grey in many locations and few locations are in brown and blockiest Buff colour. This concrete colour change indicates that the entire floor is fire loaded with a temperature between 600°C and 1,400°C [5,11]. The second floor has moderately damaged due to fire. The second floor area covered with brick infills are showing undamaged with natural grey colour and the floor areas with wooden partitions and chemical stacking are affected in fire. Several crack have been seen in the columns, beams and roofs. The concrete colour is in light red colour in many locations and it is in grey colour in few locations. it indicates that the part of floor is fire loaded with a temperature above 600°C. The structural elements are found slightly deformed and it needs to be verified with a deflection checks. In overall, the ground floor concrete is not much affected due to fire and the non-structural damages can be repaired and it can be used for its regular activities. The 1st floor cannot be used and further study is required for rehabilitation and strength and serviceability condition restoration. Further, the usefulness of second floor can be decided after the detailed NDT and stability check investigations.

3.2 Ultrasonic Pulse Velocity (UPV) Test

Ultrasonic Pulse Velocity (UPV) was carried out using with 54 kHz frequency transducers. UPV test has been carried out on selected RC structural members in a systematic way by marking grid points. Measurement of transmit time is made at each grid point and the velocity is calculated by dividing the distance between the transducer and the receiver. The Ultrasonic Pulse Velocity (UPV) data generated from the structure is reported in Annexure-IV and the statistical parameters such as maximum, minimum, average, standard deviation, co-efficient of variation and characteristic values of velocity are reported in table-1, for the affected members of different floors.

The UPV data collected from the identified RCC beams both from affected and un-affected beams. From the results, it is observed that the characteristics UPV values in affected beams was found ranging from 0 and 0.90 km/sec. and the corresponding co-efficient of variation was found to ranging from 59.00 to 36.50. The co-efficient of variation in un-affected members was found to be 3.90 and its corresponding characteristics UPV value found to be 3.70 km/sec. The UPV results shows that the beams the fire affected area are lost its concrete integrity and it is indirectly indicating that the composite action between the steel and concrete lost and it is susceptible for further damage to corrosion and loss of flexural strength. In similar way the UPV data collected from the identified RCC Columns both from affected and un-affected beams and compared. The results indicate that the characteristics values of UPV values in affected columns was found ranging from -0.90 and 0.80 km/sec. and the corresponding co-efficient of variation was found to ranging from 34.20 to 97.80. The co-efficient of variation in un-affected members was found ranging from 2.90 to 9.62 and its corresponding characteristics UPV values found to be 4.30 and 3.51 km/sec. The results clearly show that the structural beams and columns present in the firer affected area are not fit to usage with the present condition. The slab in fire affected area is also showed a similar trend with UPV values are in a ranging from 0.30 and 1.97 km/sec. and the corresponding co-efficient of variation was found to ranging from 43.30 to 15.64. The co-efficient of variation in un-affected member was found to be 2.30 km/sec. and its corresponding characteristics UPV values found to be 20.95. In overall the slab concrete is found to be inferior and not satisfying the design criteria.

3.3 Rebound Hammer Test

Rebound hammer test was carried out in the identified locations where the Ultrasonic test also carried out. The Rebound Hammer Number data generated from the structure and the statistical parameters such as maximum, minimum, average, standard deviation, co-efficient of variation and characteristic values of velocity are assessed and compared. The Rebound Hammer data collected from the RCC Beams are observed that the unaffected members, the co-efficient of variation of affected members was found to be 22.40 and its corresponding characteristics Rck values was found to be 12.00. The results indicate that these beam members become dis-stressed with a very low reserved strength. The columns in the firer affected building regions, co-efficient of variation of affected members was found to be 34.40 and its corresponding characteristics Rck values was found to be 5.40. The results indicate that these columns are in dis=stressed condition and it lost its strength and need to be supported with temporary supports, extended from the firm ground floor and needs to be repaired for carrying out other repair works or installation of other regular activities. The slabs are also showed that the slabs are in dis-stressed condition and needs to be strengthened.

3.4 Deflection measurement and stability Checks

The deformation of beams and slabs were measured on selected portions and the maximum level difference is presented in table.2. The measured deflections are checked for the flexural stability checks as per prescribed in the Indian code of practice [6]. The deflection measured in the beams and slabs are exceeds the limiting deflection at first floor level. In second floor level, the beams and slabs in affected area partly fulfils the design criteria and partly exceeds the design criteria for the stability checks.

Table.2 Maximum deflection measured in selected members

Floor	Location	Member	Maximum deflection, mm
First Floor	B2 – C2	Beam	46
	B3 - C3	Beam	58
	B4 – C4	Beam	57
	B5 – C5	Beam	50
	B7 – C7	Beam,	58
	A7 – B7	Beam	50
	B6 – B7	Beam	54
	A3 – B3	Beam	38
	A2 – B2	Beam	45
	B3,C3 - B4,C4	Slab	54
Second Floor	A3,A4 and B3,B4	Slab	22
	A3 – B3	Beam	40
	B5 – C5	Beam	16

3.5 Neutralization Test

During the test on the structural members and extracted concrete core samples, 1% phenolphthalein solution was first applied to their side surfaces that were affected by the fire without treating the surfaces. As shown in figure.7. the colour did not change in cover region up to 40 mm and with a purple area where the alkaline concrete reacted to the indicator for the sample extracted in fire affected zone. Whereas the test was conducted for the core samples extracted from un-affected area indicates fully change in colour which shows that the concrete is of fully alkaline in nature. Therefore, the concrete cover of 40-50 mm have experienced a maximum temperature of more than 600^{o}C.

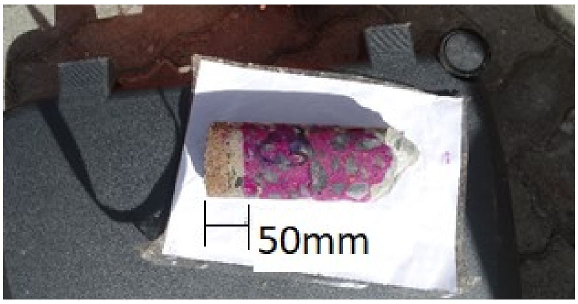

Fig.7 Neutralization Test on Extracted Concrete Core Sample

3.6 Core Sampling and Testing

Concrete core samples of 69 mm dia. were collected from the RCC columns and slabs both from affected and unaffected areas. These samples were extracted from the identified locations and marking was done on the samples for proper identifications as shown in figure.8a. The extracted cores are cleaned and dressing of the core is carried out in the laboratory. The dressed samples are placed under CTM and levelled with capping material, and tested for its actual compressive strength as shown in figure 8b. The compressive strength values were corrected for its h/d ratio and later the equivalent cube strength was obtained. The equivalent cube compressive strength values of core samples are reported in table.3.

Fig.8a Extracted Concrete Samples

Fig.8b Concrete Core under Compressive Load

Table.3 Compression test results of core samples

Core Details	l/d, Ratio	Load, kN	Compressive Strength, MPa		Equivalent Cube Strength, MPa
A1 Column, Ground Floor*	2	80	18.60	18.60	23.25
B5 Column, Ground Floor	2	45	10.46	10.46	13.08
Passage Lintel Beam Between A3-B3, Ground Floor	2	40	9.30	9.30	11.62
First Floor Slab Between B3C3 & B4C4	1.3	50	11.62	10.64	13.30
First Floor Slab Between B2C2 & B3C3	1.2	48	11.16	10.27	12.83
Roof Beam near First Floor to Second Floor Staircase Landing area, A4-B4	2	38	8.83	8.83	11.04
B3 Column, Second Floor	2	36	8.37	8.37	10.46
Second Floor Slab Between B3C3 & B4C4	1.4	48	11.16	10.32	12.90
B6 Column, Second Floor	2	30	6.97	6.97	8.72

* - Core Extracted from un-affected area

The acceptance criteria with respect to cube strength obtained by testing concrete core i.e. individual specimen shall be at least 75% and average strength shall be at least 85% of the concrete strength considered in design. From the test results, it is observed that the concrete strength in unaffected areas was about 23.25 MPa and at the affected areas is ranging from 8.72 MPa to 13.30 MPa, which 60 % reduction lesser strength compared to unaffected areas. The strength of concrete is fails to satisfy the design criteria and needs to restored with appropriate strengthening measures.

4 Conclusions

Based on the visual observations, geometrical stability analysis measurement of the structure, Non Destructive Tests and Partially Destructive Tests are carried out on the fire affected building structure, the following major observations and inferences were arrived.

- From the visual observations and deflection criteria of the RC structural members indicate that 60 to 70 % of the area is severely affected by fire. The fire fightening systems installed in the building has failed due to COVID19 and longer lock down, which lacked the support from the human maintenance around the in-and-around the building premises.
- The floor partitioned with brick infill has showed minimum damage compared to the floors partitioned with wooden reapers and plywood. The wooden furniture and partition walls have fuelled the fire and made the structure to exposed in high temperature.
- The brick infills have lost the mortar cover and cracked severely. The brick infills have protected the beams and columns during fire in the ground floor area.
- In second floor, the portion walls are made-up of wood reapers and ply boards, and many inflammable chemicals and resigns have fuelled the fire. Lack of brick infill, the columns, beams and slabs are directly exposed to fire and its colour changed red and buff. From the colour change, it inferred that the floor is exposed to the temperature about 800 to 1400 degree centigrade.
- Cross-sectional loss in the beams, columns and slabs have been observed due to concrete cracking and spalling.
- The rebound hammer and UPV test results have confirmed the damages observed during the visual observation. The loss of concrete bond, integrity and strength have been inferred from the results. About 60% of loss concrete strength is estimated from the NDT tests.
- The cylinder core samples have confirmed the loss of strength due to the fire.

- The neutralisation test have shown that the concrete section has lost its alkali character and become acidic to a depth 50mm from the concrete surface.
- Due to the loss of cover, bared reinforcement was observed in columns, beams and slab. Due to loss of concrete strength, integrity and softening of steel during fire have resulted in excessive deformation and steel buckling.
- The deformation measures and the stability checks have confirmed the findings of NDT and PDT tests. The NDT and PDT methods have clearly indicated that the structure is not fit for the use with the present condition, requires extensive investigation for rehabilitation and restoration of structural strength and serviceability requirements.

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