Assessment of Strength Evaluation and Structure Stability of Building Destroyed in Fire by Using Techniques of Non-destructive Testing

Inderpreet Kaur, Chander Sheikhar Singla and Amandeep Singh Gill

Abstract The two-storey industrial building with area of 41,000 sq. ft on each floor was framed structure. The machinery in the building was used for the manufacturing of cotton and synthetic fabric. Concrete of M20 grade and steel of Fe 415 grade were used for construction. A fire incident was occurred for 42–50 h after one year of construction. Visual examination of columns, slabs and beams of ground floor showed cracks on the concrete surface. At many places, concrete had fallen off, and reinforcement was exposed. At few places, colour of concrete had also been changed from its natural grey to reddish brown which indicated that the temperature during fire might had crossed 600 °C. In some of the circular columns, the thickness was reduced by about 25 % and fallen off concrete in between circular columns are a resulted in reducing the thickness of the slab by about 40 %. Due to inadequate circumstances for core extraction at some sections, decision of non-destructive testing like ultrasonic pulse velocity (UPV), rebound hammer (RH) were used to evaluate the elements. The quality of concrete was assessed by UPV. In situ strength of R.C.C. members, integrity and homogeneity of concrete help to evolve repair/strengthening/rehabilitation measures. Load test was also conducted to ascertain the actual load-carrying capacity of structural members. It was concluded that due to fire and excessive increase in temperature, the column concrete surface gets hardened, causing increase in value of rebound number. Further, results of concrete core test are more reliable when compared with rebound hammer test.

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S. S. Khangura et al. (eds.), *Proceedings of the International Conference on Research and Innovations in Mechanical Engineering*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1859-3_11, © Springer India 2014

Keywords Concrete core test · Fire damage · Load test · Rebound Hammer test · Strength · Ultrasonic testing

1 Introduction

Non-destructive testing (NDT) is a wide group of analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage (Cartz 1995). The terms non-destructive examination (NDE), non-destructive inspection (NDI) and non-destructive evaluation (NDE) are also commonly used to describe this technology (Reis and Dilek 2012). NDT is commonly used in forensic, mechanical, electrical, civil, aeronautical engineering. As NDT does not permanently alter the article being inspected, it is a highly valuable technique that can save both money and time in product evaluation, troubleshooting and research. NDT is used in a variety of settings that covers a wide range of industrial activity, with new NDT methods and applications, being continuously developed. NDT is divided into various methods of non-destructive testing, each based on a particular scientific principle (http://en.wikipedia.org/wiki/nondestructive_testing) like Acoustic emission testing, Blue Etch Anodic, dye penetrant inspection, liquid penetrant testing, electromagnetic testing, ellipsometry, guided wave testing, hardness testing, impulsive excitation technique, laser testing, low coherence interferometry (Dufour et al. 2005; Losert 2009), metallographic replicas (BS ISO 3057 1998; ASTM 1351 2006), optical microscopy, rebound hammer testing, ultrasonic testing, vibration analysis and visual inspection.

The non-destructive and laboratory testing findings are used in determination of extent of heat damage to concrete and their potential effects. The in situ NDT phase consisted of locating affected areas using ultrasonic pulse velocity (UPV) through concrete members in the vicinity of the fire. Subsequently, cores are removed, and Young's modulus of 25-mm (1 in.)-thick concrete disk is determined by utilizing non-destructive measurement of resonant frequency (Hellier 2003). Determination of Young's modulus at small depth increments permitted assessment of the heat-induced damage front into the concrete. Based on the extent of damage identified, repairs are performed on the affected members.

Fire represents a transfer of energy from a stable condition to a transient condition as combustion occurs; examples are the burning of warehouse contents, office furniture, books, filing cabinet contents or other material (Tide 1998). The heat associated with fires may vaporize trapped concrete pore water. The lack of continuous voids for pressure relief creates internal tensile stresses that are relieved by cracks and spalls extending to the surface (Chiang and Tsai 2003). The spalling may be explosive in higher-strength concretes. Additionally, severe heat may cause chemical changes that lead to micro-cracking (visible only under magnification) and loss of strength and integrity.

All structures subjected to fire should be evaluated in a systematic manner to determine the extent, if any, of required repairs. The intensity and duration of the fire can be estimated by observing the collateral damage: a variety of testing methods and tools are available to evaluate the effects of the fire on both the materials and structural elements. These evaluations, combined with an engineering analysis, allow effective and economical repair details to be developed and installed as needed (Narendra et al. 2008).

2 Case Study

The data were collected from testing and consultancy cell of Guru Nanak Dev Engineering College, Ludhiana.

Industrial building under testing belonged to Jain Uday Hosiery Private Limited, Ludhiana. The main structural system of the fire-affected building was frame work of beams and columns as the main load-carrying elements. It was a two-storey industrial building with an area of 41,000 sq. ft of each floor. In plan, the building was divided into two parts with an expansion joint throughout the length. In plan, the ground floor and first floor were exactly same. The machinery in the building was used for the manufacturing of cotton and synthetic fabric and in the building, concrete of M20 grade and steel of Fe 415 grade were used. The fire incidence had occurred at night about a year after construction, and it continued for about 42 h. In some portions, the fire continued for more than 50 h. A visit to the site by engineers was aimed at deciding the location and types of tests to be conducted to assess the extent of damage caused by the fire. Following this, extensive testing work was carried out to check the strength and structural stability of the building.

2.1 Observations Based on Visual Inspection

2.1.1 Ground Floor

Visual examination of columns, slab and beams of ground floor showed cracks on the concrete surface. At many places, concrete fallen off and reinforcement was exposed. At few places, colour of concrete had also been changed from its natural grey to reddish brown which indicated that the temperature during fire might had crossed 600 °C. The building area was divided into two parts: (a) front portion with square/rectangular columns and (b) back portion with mostly circular columns. The damage during fire was more in the back area than in the front area. In some of the circular columns of the back area, the thickness was reduced by about 25 %. In the circular column area, concrete had fallen off at many places reducing the thickness of the slab by about 40 %. Steel was exposed in large portions of the slab. In some of the circular columns, cracks seem to be penetrating up to a large depth. Deflection in slab and beams was also excessive in the circular column area.

Concrete cores were taken out from some of the columns and slab to know the exact condition of concrete. Visual examination of cores and the places from where cores were taken out indicated the presence of cracks throughout the depth of the concrete members. At some places, it was not possible to take out cores as concrete was so soft that was breaking into small pieces during core extraction. Damage to the front portion of the building was less compared with back portion, although at some locations of the slab, the concrete had fallen off exposing the steel.

2.1.2 First Floor

On the first floor, damage due to fire was more in the front portion than in the back portion with circular columns. A portion of first floor adjoining the stair case and with nine columns was severely damaged during fire. The reason for this could be lesser roof height and storage of highly inflammable polyester material. Thickness of roof slab at certain portions was reduced by more than 50 %, and steel was exposed and had lost its elasticity. Visual examination of columns, slab and beams of first floor showed cracks on the surface. Cracks in the floor slab seemed to be penetrating up to a large depth. At many places on the roof slab, concrete had fallen off and reinforcement was exposed. The colour of concrete was also changed to reddish brown from its natural colour of grey. The back portion of the first floor was relatively less affected during fire. Columns, beams and roof slab of this portion were relatively in good condition compared with front portion. The concrete cores were taken out from some of the columns and slab of second floor to know the exact condition of concrete. Visual examination of cores and at places from where cores were taken out indicated the presence of cracks throughout the depth of the floor slab, while the columns and roof slab were in good condition of back portion. At some places of the floor slab, it was not possible to take out cores as concrete was so soft that was getting broken into small pieces during core extraction.

2.2 Non-destructive Testing of the Building

It is possible to determine various engineering properties of concrete like strength, quality, etc. by using NDT. The assessment of existing structure for damage, its repair, strengthening and rehabilitation areas which extensively postulates use of such test methods. In addition to check the strength and quality of concrete, NDT also gives an idea about the estimate of repairs, urgent and non-urgent repairs, etc. NDT provides invaluable means of both qualitative and quantitative determination of the extent and type of defects in R.C.C. members. It also helps in determining the mechanism of deterioration in the structure.

Purpose of NDT

1. To evaluate integrity and homogeneity of concrete for all accessible R.C.C. members.
2. To identify areas of concrete which were defective and not apparent on visual inspection.
3. To help evolve repair/strengthening/rehabilitation measures.

Types of NDT used in the building

1. Ultrasonic pulse velocity (UPV)
2. Rebound hammer (RH)
3. Concrete core test (partially destructive test method)

In addition to above, limited use of rebar locator was made. Basically, it was used to decide about the correct locations for UPV test points. For ground-floor columns, wherever possible or required, reinforcement was located using rebar locater, and UPV test points were selected such that reinforcement does not lie in or close to the direct path between transducers.

The UPV test was used with the following objectives:

(a) To judge homogeneity of concrete
(b) To judge the quality of concrete
(c) For qualitative comparison of one element of concrete in relation to another.

The RH test was used for:

(a) Assessing the most likely cube compressive strength of concrete.
(b) Qualitative comparison of one element of concrete in relation to another.

Examination of cores extracted from hardened concrete also enables visual inspection of interior regions of the structural member. Thus, core drilling and testing were considered to arrive at more accurate estimation of strength and to visually inspect the interior region of structural member. An attempt was made so that majority of structural elements are covered by any one of the test method, namely UPV, RH and concrete core test. Concrete core test shall give more exact idea about actual in situ condition of concrete, including compressive strength and thereby suggesting overall condition of the structure, due to certain restraints like accessibility, instrument handling, availability of proper surface for testing, time, finance, etc.

2.3 Ultrasonic Pulse Velocity Test

In this test, ultrasonic pulse is generated by electro-acoustical transducer. It undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (compressional), shear (transverse) and surface (rayleigh) waves. The receiving transducer detects the onset of the longitudinal waves, which is the fastest. Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its elastic properties, pulse velocity method is a convenient technique for investigating structural concrete. The underlying principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consequently, lower velocities are obtained. The actual pulse velocity obtained depends primarily upon the materials and mix proportions of concrete. Density and modulus of elasticity of aggregate also significantly affect the pulse velocity.

During testing, the ultrasonic pulse is produced by the transducer, which is held in contact with one surface of the concrete member under test. After traversing a known path length (L) in the concrete, the pulse of vibrations is converted into an electrical signal by the second transducer held in contact with the other surface of the concrete member, and an electronic timing circuit enables the transit time (T) of the pulse to be measured. The pulse velocity (V) is given by:

$$V = \frac{L}{T}. \tag{1}$$

Once the ultrasonic pulse impinges on the surface of the material, the maximum energy is propagated at right angles to the face of the transmitting transducer, and best results are, therefore, obtained when the receiving transducer is placed on the opposite face of the concrete member (direct transmission or cross-probing). The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks and segregation, etc., indicative of the level of workmanship employed, can be assessed using the guidelines give in the Table 1, which have been evolved for characterizing the quality of concrete in structures in terms of the UPV.

UPV test point locations were decided as follows:

For columns: Within middle half of the height such that path length of ultrasonic wave was parallel to shorter dimension of the member. Wherever possible or required, due care was taken for locating reinforcement using rebar locator, and UPV test points were located such that the steel bar did not lie in or close to the direct path of wave propagation.

For beams: Within middle half of the span, such that path length of ultrasonic wave was parallel to width of the beam.

For slabs: All slabs could not be scanned for UPV due to non-accessibility and limiting length of instrument cable. Wherever possible, readings were taken near external boundary of the slab panel.

For all the elements mentioned above, readings were taken by direct method (cross-probing). Due care was taken for aligning transducers for shortest path length. Perfect contact between test surface and transducers was assured by use of grease.

Table 1 Velocity criterion for concrete quality grading (IS: 13311 Part I)

S. no.	Pulse velocity by cross probing (km/s)	Concrete quality grading
1	Above 4.5	Excellent
2	3.5–4.5	Good
3	3.0–3.5	Medium
4	Below 3.0	Doubtful

2.4 Rebound Hammer (RH) Test

The RH consists of a spring-controlled mass that slides on a plunger within a tabular housing. When the plunger of rebound hammer is pressed against the surface of concrete, the spring-controlled mass rebound depends upon the surface hardness of concrete, the surface hardness, and therefore, the rebound is taken to be related to the compressive strength of the concrete. The rebound is read off along a graduated scale and is designated as the rebound number. The rebound hammer method provides a convenient and rapid indication of most likely cube compressive strength of concrete.

For columns and beams, rebound hammer test locations were selected approximately within middle half of member height. Plaster was removed, and original concrete surface was exposed. The surface was rubbed and smoothened by carborundum stone, and readings were taken with horizontal position of hammer. Readings were taken on larger face of the column and beam. Similar procedure was followed for slabs, except that RH position was kept vertically upwards.

2.5 Concrete Core Test

The examination and compressive strength of cores drilled from hardened concrete enable the visual inspection of interior regions of the structural member along with estimation of actual in situ concrete strength. Use of rebar locator was made to decide correct location for drilling and extracting cores such that reinforcement bars were avoided. Columns—being prominent structural element—were selected randomly for this test, so as to represent both, good appearing and fire-affected concrete. Majority of samples were taken from fire-affected area. Cores were extracted from vertical.

2.6 Load Test

Load test is generally carried out to ascertain the actual load-carrying capacity of the structural members like beams and columns to verify the extent of direct or indirect damage caused by fire. There were certain portions of the building, where minor or no cracks were present on the surface, and direct affect of fire was negligible as compared to other parts. Other NDT tests also indicate negligible damage during fire.

Load test was conducted at four places on the slab, three on ground-floor slab and one on first-floor slab. The tests were conducted as specified in IS 456: 2006, in which the slab portion was subjected to a load equal to full dead load plus the 1.25 times the imposed load specified for industrial building for a period of 24 h. Deflection was recorded with full loading. Load was kept in position for 24 h, and deflection was again recorded. After recording the deflection, the imposed load was removed, and recovery in deflection was recorded.

3 Observations and Results

Data of the observations and results of all tests performed on 142 columns, 38 beams and 28 slab panels of Jain Uday Hosiery Private Lt., Ludhiana, are presented in Tables 2, 3, 4, 5, 6, 7, 8.

3.1 Load Test

Load test was conducted on three slab panels of ground-floor roof and one beam span of first-floor roof slab. All the slab panels were loaded with a uniformly distributed load of 12.5 kN/m^2 which was 1.25 times the imposed load specified in IS 456 for industrial buildings. A dial gauge was installed on the underside of the roof slab before applying load on the roof slab. Deflection was measured after the application of full load. Load was applied by putting sand bags on the specified area of the slab. Deflection was also measured after applying load for 24 h. After the removal of the load recovery in deflection was also measured (Table 9).

4 Discussion and Recommendation

1. Almost all possible columns within fire-affected area, and few columns outside this area were tested for both rebound number and UPV evaluation. Out of the 142 columns tested by rebound hammer, about 97 locations suggested strength less than 20 N/mm^2 (28 days cube compressive strength of M20 grade concrete). Evaluation of rebound member is directly related to hardness of concrete surface. Because of fire and great increase in temperature, sometimes the column concrete surface gets hardened, causing increase in value of rebound number. This resulted in conservative estimation of compressive strength of

Table 2 Rebound hammer and ultrasonic pulse velocity test of ground-floor columns (partial data)

Rebound hammer			Ultrasonic pulse velocity			
S. no.	Member	Avg. rebound hammer reading	Equivalent cube comp. strength (N/mm^2)[a]	Method applied	U.P.V. (Km/s)	Concrete quality grading
1	C22	32	26	Direct	4.7	Excellent
2	C71	30	24	Direct	4.2	Good
3	C82	30	24	Direct	4.1	Good
4	C11	30	24	Direct	4.0	Good
5	C65	28	20	Direct	3.4	Medium
6	C61	27	18	Direct	3.3	Medium
7	C47	23	14	Direct	2.3	Doubtful
8	C34	20	8	Direct	2	Doubtful
9	C118	20	8	Direct	1.1	Doubtful

[a] Required minimum 28-day cube strength for M20 grade concrete = 20 N/mm^2 , core diameter (mm) = 50

Table 3 Rebound hammer and ultrasonic pulse velocity test of first-floor columns (partial data)

Rebound hammer				Ultrasonic pulse velocity		
S. no.	Member	Avg. rebound hammer reading	Equivalent cube comp. strength (N/mm^2)[a]	Method applied	U.P.V. (Km/s)	Concrete quality grading
1	C91	29	22	Direct	3.9	Good
2	C72	28	20	Direct	3.5	Medium
3	C96	25	16	Direct	3.4	Medium
4	C88	26	17	Direct	3.2	Medium
5	C51	24	15	Direct	2.6	Doubtful
6	C11	24	15	Direct	2.5	Doubtful
7	C26	22	12	Direct	2.1	Doubtful

[a] Required minimum 28 day cube strength for M20 grade concrete = 20 N/mm^2 , Core diameter (mm) = 50

Table 4 Rebound hammer and ultrasonic pulse velocity test of ground-floor beams (partial data)

Rebound hammer				Ultrasonic pulse velocity		
S. no.	Member	Avg. rebound hammer reading	Equivalent cube comp. strength (N/mm^2)[a]	Method applied	U.P.V. (Km/s)	Concrete quality grading
1	B32-33	30	24	Direct	3.8	Good
2	B21-22	29	22	Direct	3.4	Medium

[a] Required minimum 28-day cube strength for M20 grade concrete = 20 N/mm^2 , core diameter (mm) = 50

Table 5 Rebound hammer and ultrasonic pulse velocity test of first-floor beams (partial data)

Rebound hammer				Ultrasonic pulse velocity		
S. no.	Member	Avg. rebound hammer reading	Equivalent cube comp. strength (N/mm^2)[a]	Method applied	U.P.V. (Km/s)	Concrete quality grading
1	B32-33	30	24	Direct	3.8	Good
2	B45-46	23	14	Direct	2.9	Doubtful

[a] Required minimum 28-day cube strength for M20 grade concrete = 20 N/mm^2 , core diameter (mm) = 50

Table 6 Rebound Hammer and ultrasonic pulse velocity test of ground-floor slab (partial data)

Rebound hammer				Ultrasonic pulse velocity		
S. no.	Member	Avg. rebound hammer reading	Equivalent cube comp. strength (N/mm^2)[a]	Method applied	U.P.V. (Km/s)	Concrete quality grading
1	SP 91-92-102-101	30	24	Direct	3.3	Good
2	SP 53-54-64-63	28	20	Direct	3.2	Medium
3	SP 95-96-106-105	18	05	Direct	1.7	Doubtful

[a] Required minimum 28-day cube strength for M20 grade concrete = 20 N/mm^2 , core diameter (mm) = 50

Table 7 Rebound hammer and ultrasonic pulse velocity test of first-floor slab (partial data)

Rebound hammer				Ultrasonic pulse velocity		
S. no.	Member	Avg. rebound hammer reading	Equivalent cube comp. strength (N/mm^2)[a]	Method applied	U.P.V. (Km/s)	Concrete quality grading
1	SP 75-76-86-87	30	24	Direct	3.3	Good
2	SP 32-33-42-43	21	10	Direct	2.0	Doubtful

[a] Required minimum 28-day cube strength for M20 grade concrete = 20 N/mm^2 , core diameter (mm) = 50

concrete, which was on higher side than the actual in situ strength. Such views are supported by the fact that concrete core test on selected columns gives much lower compressive strength when compared with rebound hammer test. Results of concrete core test are more reliable when compared with rebound hammer test. Analysis of core test results and relevant discussion is given in point No. 5.

2. Majority of columns in fire-affected area and few columns outside this area were tested for UPV test. Out of 142 columns tested, about 79 test locations gave doubtful concrete quality. There was large variation observed in the results, and no specific trend was observed. At few locations, large fluctuation was observed in readings. Such unsteady reading, when test is conducted according to standard procedure suggests cavity, voids, cracks and non-

Table 8 Concrete core test

S. no.	Member	Location	Crushing load (kN)	Equivalent cube strength (N/mm^2)[a]	Minimum required strength (N/mm^2)
1	Column C34	Ground floor	8.5	10	20
2	Column C36	Ground floor	10.0	12	20
3	Column C87	Ground floor	5.0	06	20
4	Column C95	Ground floor	4.20	05	20
5	Column C23	First floor	6.8	08	20
6	Column C46	First floor	7.6	09	20
7	Column C75	First floor	19.5	23	20
8	Slab panel 14-15-25-24	Ground-floor roof slab	8.5	10	20
9	Slab panel 22-23-33-32	Ground-floor roof slab	18.7	22	20
10	Slab panel 45-46-56-55	Ground-floor roof slab	9.3	11	20
11	Slab panel 95-96-106-105	Ground-floor roof slab	7.6	09	20
12	Slab panel 16-17-27-26	First-floor roof slab	12	14	20
13	Slab panel 36-37-47-46	First-floor roof slab	10.0	12	20
14	Slab panel 87-88-98-97	First-floor roof slab	17.0	20	20

[a] Required minimum 28-day cube strength for M20 grade concrete = 20 N/mm^2 , core diameter (mm) = 50

homogeneity within direct path length of the wave. Out of all the readings taken on columns, only 39 readings (27.5 %) showed good or excellent quality concrete.

3. RCC beams were selected randomly to represent the entire area of factory building and tested for RH and UPV tests. Out of 77 locations, 52 locations (67.5 %) had compressive strength evaluated using RH test less than 20 N/mm^2, whereas only seven locations (9.1 %) suggested "good" concrete quality.
4. Slab panels were selected randomly to represent the entire area of the building and tested for RH and UPV tests. Total 28 locations were tested for RH test and UPV test. Due to limitations of instrument handling and accessibility on opposite faces of slab, readings could be taken at about twelve locations. At 18 test points, RH test gave compressive strength that was much less than 20 N/mm^2; while, except for two test location, UPV measurements revealed "good" quality of concrete resulting in conclusion that all test locations did not comply with expected strength and quality criteria.
5. Concrete core test was performed on 14 locations (seven columns and seven slabs). Visual inspection of extracted concrete core invariably revealed the presence of voids on its surface. Few cores also revealed reddish brown colour

Table 9 Load test

S. no.	Slab	Deflection after application of full load (mm)	Deflection after application of full load for 24 h (mm)	Permissible deflection (mm)	Deflection after removal of full load (mm)	Remarks
1	Ground-floor roof slab panel 82-83-93-92	2.1	2.8	26.8	Not required as per IS 456	Deflection within permissible range
2	Ground-floor roof slab panel 22-23-33-32	2.3	3.0	26.8	Not required as per IS 456	Deflection within permissible range
3	Ground-floor roof slab panel 45-46-56-55	12.2	13.2	26.8	5.2	Recovery in deflection does not conform to IS:456
4	First-floor beam panel 73-83	–	–	–	–	Shear cracks start appearing in beam before the application of full load

of concrete. Change in colour of concrete takes place, when it is subjected to very high temperature. Wherever reddish brown colour of concrete was observed, the core disintegrated into finer pieces of basic ingredients, which reflected the effect of fire. The maximum six of coarse aggregate as observed in extracted core was not more than nominal size of 15 mm. At three locations, core was broken during extraction. It is mainly because of the presence of interconnected fractures and not due to mishandling of cores. To summary, seventeen attempts were made to extract cores, three cores got disintegrated while drilling and were broken during extraction, whereas remaining fourteen cores were taken to laboratory and tested for compressive strength strictly in accordance with IS 516 code of practice.

Categorization of area on the basis of intensity of damage: On the basis of intensity of damage, the whole area of two-storey building was divided into following four categories:

Severely damaged area during fire: This was the area where intensity of damage was maximum leading to major cracks penetrating to large depth of structure. Size reduction in columns and large-scale deflection could also be seen in some slabs and beams. Surface concrete had changed its colour to reddish brown and become brittle. In this area, the average compressive strength by rebound hammer was about 12 N/mm^2, while UPV indicated concrete of doubtful quality. Ground-floor area between few columns had concrete of doubtful quality. Steel exposure at many places and large-scale deflection in beams and slabs had also been noted. The intensity and duration must be very high which had turned a large thickness of surface concrete into ash. The area adjoining stair case and at level above first floor had also concrete of doubtful quality. In this area, the slab thickness was reduced by about 50 % due to spalling of concrete.

Keeping in view the severity of damage, it was recommended to dismantle this portion of the building.

Moderately damaged area during fire: In this area, damage caused by fire was not very severe. Minor cracks could be seen on the surface of concrete and plaster. In this area, the average compressive strength by RH test remained between 16 and 20 N/mm^2, while at most places, the UPV indicated concrete of "medium" quality.

Although this area was not so severely damaged to be recommended for dismantling but almost all of this area lied above the area which had been severely damaged by fire. Considering the above-mentioned facts, it was recommended to dismantle this portion of the building.

Area not affected by fire but cracks of adjoining areas penetrating in this area: There was no direct effect of fire on small portion of the ground-floor area due to the presence of partition walls, but cracks and deflection in the adjoining slab had damaged the slab of this area. In this area, the average compressive strength by RH test was more than 20 N/mm^2, while at most places the UPV indicated concrete of "good" quality. Load test was conducted on a portion of slab of this area, which indicated deflection within permissible range as per IS 456.

Although almost all the test results indicated that the direct damage to this portion of the building was negligible suggesting no need of dismantling, this area was of very small width and was situated along the periphery of severely damaged area by fire. Moreover, slab deflection and large-scale temperature variation in the adjoining portion had caused cracks in this area.

It was very difficult to isolate this area from the adjoining area during dismantling. Thus, this portion of the building was also recommended for dismantling due to its doubtful structural stability.

Area unaffected by fire: In this area, only top of slab had slightly been damaged, but its structural efficiency was not affected. Moreover, columns and beams of this area were also intact. The average compressive strength by RH test was more than 20 N/mm^2, while the UPV indicated concrete of "good" quality. Load test also indicated deflection within permissible range as per IS 456.

Although this portion did not require dismantling, it was to be isolated both vertically as well horizontally from the remaining building. Whenever some part of a framed building is required to be isolated from the part to be dismantled, the isolation/cutting is done at the bay line (along the line joining the columns). The isolation process is very laborious and requires skilled workmanship and costly equipments. Whole of the concrete slab, beams and reinforcement are to be cut skillfully along the bay line so that cracks do not penetrate the portion to be kept intact. If proper isolation can be possible, then there is no need to dismantle the unaffected area.

5 Conclusions

Field assessment of fire-damaged concrete members requires a systematic approach to determine their conditions. Visual observation provides the most practical means to assess the potential of damage in fire exposed members. NDT like UPV and RH provides the information regarding the strength and stability of members. Further, area can be categorized on the basis of intensity of damage.

Acknowledgments Authors are grateful to the testing and Consultancy Cell of Guru Nanak Dev Engineering College, Ludhiana, for their cooperation in assessing the data of fire-damaged building for technical support of this article.

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