International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

A Decision-Making Framework for Fire Damaged Reinforced Concrete Buildings Based on Post Fire Detailed Damage Assessment

Prateek Raj Pandit[1], Lekshmy Meenakumari Jayakumar[2]

[1]Postgraduate Student, Department of Civil Engineering, NMIT, Karnataka, India
[2]Principal Engineer, Department of Civil Engineering, VA TECH WABAG, Chennai, Tamil Nadu 600117, India

Abstract
After a building fire the owner has to be told one of three things: repair it, strengthen it, or take it down. The literature on fire damaged concrete is concerned largely with what can be measured. It does not settle the separate question of what to do with the measurement, and the standards in common use do not state the order in which evidence should be gathered, the point at which it is sufficient, or the rule that converts it into a recommendation. This paper sets out a procedure that does, and reports its application to seven fire damaged reinforced concrete buildings in Kathmandu following the fires of September 2025. The procedure classifies every fire affected element into five damage classes, triggers non-destructive testing at a damage class of two or above, expresses residual capacity against a reference capacity taken from the original structural and construction records, and reads that capacity against fixed bands that return a specific action for each member. Damage was concentrated rather than distributed in all seven buildings, and within individual buildings the difference between the weakest and the strongest tested member reached fifty-three percentage points, so a single verdict for a whole building would have described none of the members it was meant to represent. The non-destructive estimate was found to be unusable in two of the five buildings in which it was computed, returning residual capacities above one hundred percent in one and about one megapascal for load-carrying members in the other. Destructive testing was recommended in all seven buildings as the confirming step but could be carried out in only one, the constraint being cost, and the recommendations in the remaining six were issued on the non-destructive evidence read together with the visual classification and the structural parameters of the final step. Those six recommendations are therefore reported as provisional, and the knowledge factor of IS 15988:2013 is proposed as the mechanism by which the resulting loss of confidence is carried into the capacity evaluation. The outcomes were two repairs, three strengthening decisions, one global retrofit with partial reconstruction and one demolition.

Keywords: Post Fire Assessment, Residual Capacity, Damage Classification, Destructive Testing, Structural Decision-Making

1. Introduction

Fire can take away a large part of a building's strength without taking away its appearance of soundness. A reinforced concrete frame may stand, carry its load and look serviceable while its concrete has lost half of its compressive strength. The reverse is equally common. A room left black with soot and stripped of its finishes often contains a frame that was barely heated. Appearance misleads in both directions, and the engineer is asked for a verdict at exactly the moment when the least reliable evidence is the most readily available.

The problem becomes sharper when the buildings are public. In September 2025 a number of government office buildings in Kathmandu were damaged by fire. In most of them the fire burned for more than twenty-four hours, occupancy was suspended, and the owner agencies needed an early and defensible answer on whether the buildings could be used again. Being wrong is costly in both directions. A building cleared for occupancy when it should not have been puts its users at risk, and a building condemned when it could have been saved wastes public money and takes a public service out of operation for years.

1.1 Previous Work

The behaviour of concrete at elevated temperature is well characterised. Kodur reviews the temperature dependence of compressive strength, elastic modulus and thermal properties, and the mechanisms by which each degrades [8]. Annerel and Taerwe show that the temperature history of a member can be recovered after the event from microscopic and colour analysis, which gives access to the depth of thermal penetration that surface inspection cannot reach [9]. Colombo and Felicetti set out non-destructive techniques developed specifically for fire damaged concrete, including drilling resistance profiling, which read the through-depth gradient rather than the surface condition [10]. Deep and co-authors review the available techniques and conclude that no single method is sufficient and that non-destructive and laboratory methods must be used together [11].

Two things follow for the present work. First, methods for reading the depth of damage in concrete exist that are not part of the procedure described here, so the statements made later in this paper about the limits of non-destructive evidence apply to the two methods actually used and not to non-destructive testing in general. Second, this body of work is concerned with what can be measured. It does not settle what should be done with the measurement, and it is the second question that governs whether a building is repaired or demolished.

1.2 Scope of This Paper

Guidance for the technical part of the problem is available and was used. Concrete Society Technical Report No. 68 gives the treatment of fire damaged concrete on which the damage classification is based [1]. The American Concrete Institute code for existing concrete structures states the governing requirement, which is that a repaired member must be shown to carry the required factored loads [2]. Eurocode 2 Part 1 to 2 describes the reduction of material properties with temperature [3]. The Indian Standards prescribe the field procedures for rebound hammer testing, ultrasonic pulse velocity testing, core sampling and carbonation depth measurement [4, 5, 6, 7].

What none of these documents provides is a decision procedure. They explain what each test means, but not which test to carry out first, what result should trigger the next test, when the evidence is sufficient to stop, or how the numbers become a recommendation. In the absence of such a procedure the gap is filled by individual judgement, and the basis of a decision is often not recoverable from the report that issues it. This paper sets out a procedure that closes that gap and reports what happened when it was applied. Section 2 presents the procedure and explains how each step is carried out and what each step triggers. Section 3 describes its application to seven fire damaged buildings and states the constraints under which those assessments were made. Section 4 reports the evidence they produced. Section 5 sets out what the field application supports and what it does not. The claim made for the procedure is a limited one: not that it

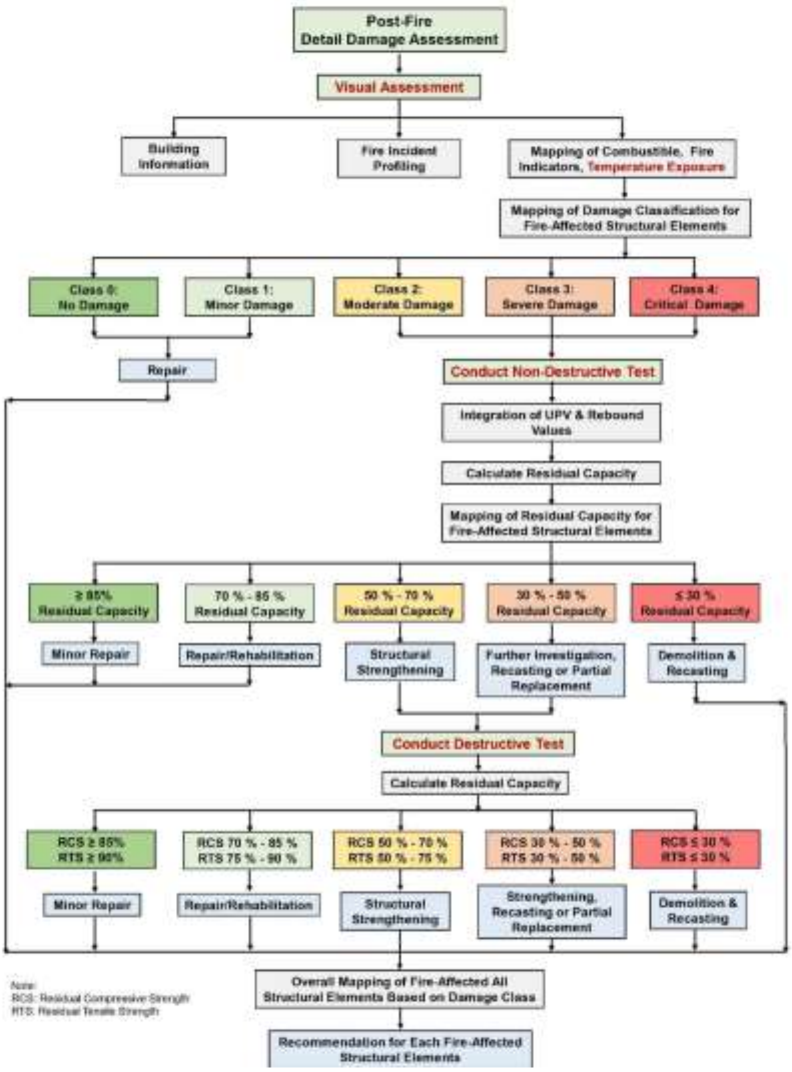
International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

removes disagreement between assessors, which is not tested here, but that it makes the basis of each recommendation explicit, so that a disagreement can be located in the evidence rather than in unstated judgement.

2. The Assessment and Decision-Making Procedure

The procedure is shown in Figure 1. It is built on three working rules. Fire damage varies from member to member, so every fire affected element is assessed on its own rather than as part of a building wide verdict. No single test is sufficient, because a surface method, a wave-based method and a direct strength measurement each interrogate a different part of the material. Testing effort is finite, so the work escalates from rapid methods to intrusive ones only where the preceding result requires it. The steps below follow the flowchart from top to bottom.

Figure 1: Flowchart of the Post Fire Detailed Damage Assessment and Decision-Making Procedure



2.1 Step 1, Visual Assessment

The first step produces the evidence base on which everything later depends, and it has three parallel parts.

Building information is compiled: age, storey count, footprint area, structural typology, phased construction and any earlier retrofitting. The original structural design report and the construction records are collected at this stage, since they are needed later to establish the reference capacity. Fire incident profiling records the date and time of ignition, the estimated duration of burning, the observed intensity, the probable source and the method of extinguishment or cooling. Duration matters as much as intensity, because residual strength depends on how long a temperature was held and not only on how high it reached.

The third part is the mapping of combustibles, fire indicators and temperature exposure onto verified floor plans, or onto measured sketches where drawings are unavailable. Materials change state at known temperatures, so what is left of a fitting or a finish bounds the temperature reached beside it. Melted aluminium indicates roughly 600 °C, glass softened with rounded edges indicates 500 to 600 °C, and charred timber indicates about 240 °C. Concrete carries the clearest record through its own colour, turning pink or red near 300 °C, whitish grey near 500 to 600 °C and buff above that. The marker values are taken from Technical Report No. 68 [1]. They are not measurements and are not used as such. Their purpose is to show where the fire was severe, so that the testing effort in the following steps can be placed there rather than spread evenly.

Observations are recorded on the plan using a fixed code so that the record is legible to a second reader. Fire indicators are coded for soot and char level, concrete colour change, glass damage, metal deformation, wood and cellulose, and plastics. Combustibles are coded by category, covering wood, masonry with plaster finish, furniture and upholstery, plastics and polymers, electrical appliances, paper and documents, fuel or chemicals, and textiles. Each room carries the codes observed in it together with a severity qualifier, so that a reader can see from the drawing alone which rooms were heavily involved and which were reached only by smoke.

2.2 Step 2, Damage Classification and the First Decision Point

Every element within the extent of the fire is assigned a damage class from Class 0 to Class 4, on the basis of surface appearance, the condition of the main reinforcement, cracking and distortion. The classification scheme follows Technical Report No. 68 [1].

This is the first decision point in the procedure, and it is what makes the rest of the work proportionate. Class 0 and Class 1 elements leave the flowchart immediately and go to repair; no testing is carried out on them. Class 2, Class 3 and Class 4 elements cannot receive any recommendation until they have been tested. Table 1 states the classes and what each one triggers.

Table 1: Damage Classes and the Action Each One Triggers

Damage Class	What Is Seen on Site	Reinforcement	What the Class Triggers
0, no damage	Unaffected, or beyond the extent of the fire	None exposed	Leaves the procedure. Redecoration if required
1, minor	Some peeling of finish, normal grey concrete, slight crazing, minor spalling	None exposed, or very minor exposure	Leaves the procedure. Superficial repair
2, moderate	Substantial loss of finish, pink or red concrete, moderate crazing, spalling at corners or in patches	Up to 25 percent exposed, none buckled	Non-destructive testing required before any recommendation

Damage Class	What Is Seen on Site	Reinforcement	What the Class Triggers
3, severe	Total loss of finish, pink to whitish grey concrete, extensive crazing, considerable spalling to corners, surfaces and soffits	Up to 50 percent exposed, not more than one bar buckled	Non-destructive testing required, and reinforcement sampling if testing is escalated
4, critical	Finish destroyed, whitish grey concrete, surface lost, almost all surfaces spalled, visible distortion	Over 50 percent exposed, more than one bar buckled	Non-destructive testing required, and reinforcement sampling if testing is escalated

2.3 Step 3, Non-Destructive Testing

Two methods are applied to every element of Class 2 or above. The Schmidt rebound hammer measures surface hardness, with at least ten readings at each grid point, orientation correction applied, and readings more than twenty percent from the mean discarded [4]. The ultrasonic pulse velocity method measures the transit time of a pulse through a known path length, with direct transmission preferred and at least three readings averaged at each point [5].

Both are needed because they look at different things. The rebound number reports the outermost few millimetres of a member, while the pulse velocity reports the continuity of the whole section. Surfaces are prepared by removing soot, plaster, loose material and any carbonated layer until sound concrete is exposed, and testing is kept at least twenty-five millimetres clear of edges, corners and reinforcement. At least one member outside the extent of the fire is tested alongside the affected members, for the reasons given in Section 2.4.

The two data sets are combined through the SONREB approach, in which compressive strength is expressed as a power law in pulse velocity and rebound number, as in equation (1) [13].

$$f_c = a \times V^b \times R^c \qquad (1)$$

Here f_c is the estimated compressive strength in megapascals, V is the pulse velocity in metres per second and R is the average rebound number.

Two conditions must be satisfied before equation (1) can be relied upon, and both are part of the procedure rather than optional refinements. First, the instruments must be calibrated. The rebound hammer is verified against a standard test anvil on each testing day and the pulse velocity equipment against its calibration rod, and both verifications are recorded in the field log. An uncalibrated instrument produces a number, not a measurement. Second, the coefficients a, b and c are not universal constants. They depend on the aggregate type, the mix, the age of the concrete and the instruments used, and they are obtained by multiple linear regression of the logarithmically linearised form of equation (1) against core results taken from the same structure. Where coefficients are adopted from the literature instead, the output of equation (1) should be read as a comparative index between members of the same building and not as an in-situ strength.

2.4 Step 4, The Reference Capacity and the Estimate of Residual Capacity

Residual capacity is the ratio of the capacity of a fire affected member to the capacity of the same member before the fire, as in equation (2).

$$RC\ (\%) = (f_{c,\ fire} \div f_{c,\ original}) \times 100 \quad (2)$$

The numerator is the strength of the fire affected member, estimated at this step from equation (1) and measured at Step 6 from cores. The denominator is the capacity of the member before the fire, and it is established from three sources used together. The original structural design report gives the specified concrete grade, the section dimensions and the design assumptions. The construction records, including the cube test results from the original quality control, give the strength actually achieved. Testing of members of the same structure lying outside the extent of the fire gives the in-situ condition of comparable concrete at the time of assessment.

The confidence attaching to that value is expressed through the knowledge factor K, which is taken from Table 1 of IS 15988:2013 and applied to the material property used in the capacity evaluation [14]. The factor reflects the completeness of the original documentation together with the extent of testing carried out on the existing structure, and in every documentation condition it is testing that raises it. Section 5.1 returns to this point, because it provides the mechanism by which an assessment made without testing can still be reported honestly.

2.5 Step 5, Reading the Bands and the Second Decision Point

The estimated residual capacity of each tested member is mapped across the affected floors and read against the bands of Table 2. This is the second decision point, and it determines both the action and whether further testing is required. Members at 70 percent and above leave the procedure with a repair recommendation. Members at 30 percent and below leave it with a demolition and recasting recommendation. Members between 30 and 70 percent are escalated to destructive testing, on the reasoning that this is the range in which the answer lies close enough to the boundary between saving and replacing a member for the cost of being wrong to be high.

Table 2: Residual Capacity Bands, the Action Returned and the Escalation Triggered

Residual Capacity from Non-Destructive Testing	Action Returned	After Destructive Testing, Action Returned for the Measured Values	Escalation
85 percent and above	Minor repair	Minor repair, where core strength is 85 percent or above and reinforcement tensile strength is 90 percent or above	None
70 to 85 percent	Repair and rehabilitation	Repair and rehabilitation, where core strength is 70 to 85 percent and reinforcement tensile strength is 75 to 90 percent	None
50 to 70 percent	Structural strengthening	Structural strengthening, where core strength is 50 to 70 percent and reinforcement tensile strength is 50 to 75 percent	Destructive test required

Residual Capacity from Non-Destructive Testing	Action Returned	After Destructive Testing, Action Returned for the Measured Values	Escalation
30 to 50 percent	Further investigation, recasting or partial replacement	Strengthening, recasting or partial replacement, where core strength and reinforcement tensile strength are 30 to 50 percent	Destructive test required
30 percent and below	Demolition and recasting	Demolition and recasting, where core strength and reinforcement tensile strength are 30 percent or below	None

The provenance of the band boundaries should be stated, since they carry the whole mechanism of the framework. They are those of the assessment framework applied here [12], which sets them from the intervention categories of Technical Report No. 68 and the relationship given there between peak temperature, duration of exposure and retained compressive strength. They are threshold criteria expressed in damage states, not the output of a calibrated statistical model, and they are used here as such. No sensitivity analysis of the boundaries is offered in this paper, and the effect of moving them is not examined.

One asymmetry in the bands should also be noted. The escalation is triggered between 30 and 70 percent only, so the procedure as drawn permits a member to be recommended for demolition on non-destructive evidence alone. The reasoning offered is that the action indicated at 30 percent and below is a conservative one that further testing could only confirm or relax, and that a member in that band is removed in any case. The asymmetry is nonetheless a weakness, because a wrongly low estimate leads to unnecessary demolition and Section 4.3 shows that wrongly low estimates occur. In the assessments reported here no member was recommended for demolition on the estimate alone, and the single demolition decision rested on the aggregate of the parameters described in Step 7.

2.6 Step 6, Destructive Testing

Destructive testing is the part of the procedure that measures the property being decided upon rather than inferring it from correlated quantities. Three measurements are made.

2.6.1 Concrete Core Testing

Cores of 100 mm-75 mm preferred diameter and a length to diameter ratio of two are extracted under continuous water cooling, with a minimum of three cores and at least one control core from an unaffected zone [6]. Each core is examined for colour zoning through its depth before it is tested, because the depth of the pink or whitish band reads directly as the depth to which the heat penetrated, which the surface cannot show. The measured strength is corrected for length to diameter ratio, diameter, embedded reinforcement, casting direction and age before conversion to an equivalent cube strength, and this corrected value becomes the numerator of equation (2).

Carbonation depth is measured on a freshly split core face using a one percent phenolphthalein indicator and is compared with the cover thickness [7]. Where the carbonation front has reached the reinforcement, the passive protection of the steel has been lost and corrosion will continue after the fire, so the result affects the durability of any repair as well as the present capacity.

2.6.2 Reinforcement Tensile and Yield Testing

Concrete condition does not predict reinforcement condition, and a member may have acceptable concrete and unacceptable steel. Reinforcement is therefore tested in its own right wherever the escalation is triggered in a Class 3 or Class 4 member.

Samples are taken from bars showing scaling, oxidation, discoloration, or visible distortion and buckling, with a minimum of three samples from each critically affected member and at least one control sample from an unaffected or protected zone. Lengths of three hundred to five hundred millimetres are removed using cold cutting tools only. Flame cutting is prohibited, since it alters the microstructure of the specimen and destroys the property being measured. Before testing, each sample is recorded for surface colour, which indicates the approximate temperature reached, for the thickness of scaling or oxidation, for rib height and deformation pattern, and for any bending or buckling that would signify yielding during the fire.

Testing is carried out in a calibrated universal testing machine under a controlled strain rate [15]. The cross-sectional area used in the calculation is derived from the mass of the specimen rather than from its nominal diameter, since section loss through scaling makes the nominal diameter unrepresentative. Yield strength, ultimate tensile strength, elongation at fracture, the stress and strain curve and the failure mode are recorded. Where the visual evidence indicates exposure above about 600 °C, metallurgical examination for microstructural change, grain growth and decarburisation depth is also carried out.

Residual tensile capacity is expressed as the ratio of the measured strength to that of the control sample, or to the minimum property specified for the grade of steel concerned [16], and is read against the reinforcement column of Table 2. A member whose concrete falls in an acceptable band but whose reinforcement does not is governed by the reinforcement.

2.7 Step 7, Overall Mapping and the Zone-Wise Recommendation

The member results are aggregated into a floor by floor map of all fire affected elements, and a recommendation is issued for each element and for each zone. The building level statement follows from that map rather than replacing it: how many primary elements are affected, whether they are concentrated in one zone or spread through the structure, and whether the load path remains continuous.

The output of this step is a drawing rather than a paragraph, and this matters for how the recommendation is used. Figures 2 and 3 show an example for the basement and ground floor of one building, and illustrate what the procedure delivers to an owner. Each room carries the fire indicator and combustible codes recorded at Step 1, the measured or estimated strengths are annotated at the tested points, and each zone is shaded by the intervention it requires.

Four zones are used. A green zone requires no structural action. A blue zone requires cosmetic repair only, comprising re-plastering, recasting of finishes and repainting. An orange or yellow zone requires the plaster to be chipped off over the marked area, a bonding chemical applied to the chipped surface of the column, wall or beam, the section restored by shotcrete of grade M25 with aggregate ten millimetres down, curing for seven days and re-plastering. A red zone requires the marked area to be demolished and recast in M25 concrete with the defective reinforcement replaced by Fe 500 bars. Presenting the result this way converts a set of member wise percentages into an instruction that a contractor can price and execute, and it keeps the evidence and the action on the same sheet.

Figure 2: Example of the Mapped Output at Basement Level, Showing Fire Indicator Coding, Combustibles Burned and the Zone-Wise Intervention Required

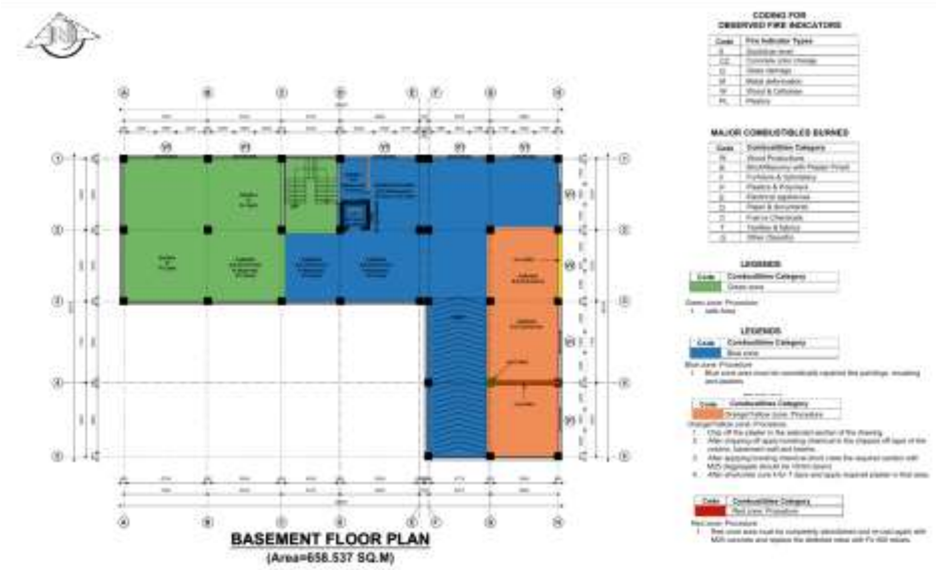
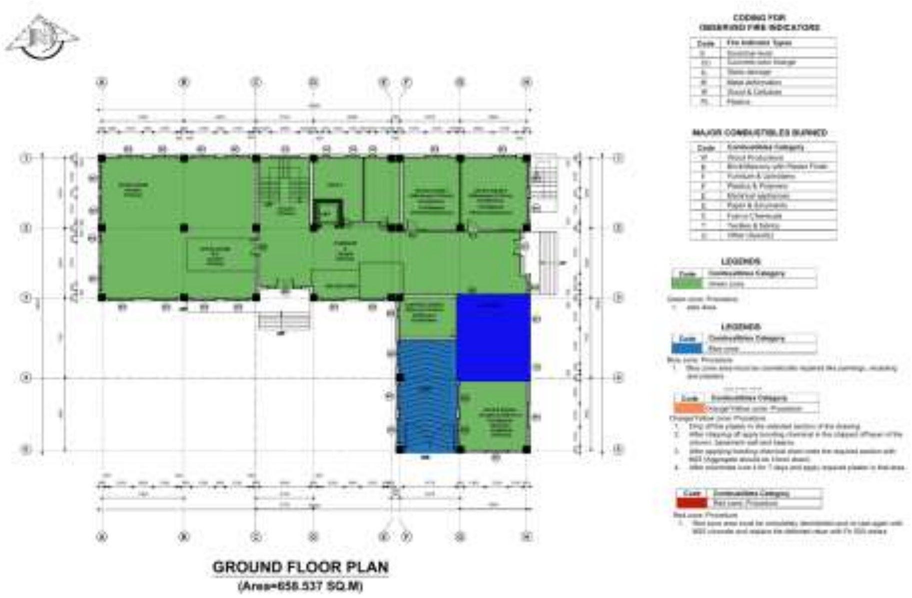


Figure 3: Example of the Mapped Output at Ground Floor Level for the Same Building



The procedure is explicit that this last step is not arithmetic. The role of a member in the structure, the continuity of the load path, the age and history of the building and the cost of intervention are weighed alongside the bands. A single severely weakened column supporting a large tributary area is not equivalent to three weakened secondary beams, even where the residual capacities are the same.

3. Application to Seven Fire Damaged Buildings

The procedure was applied to seven fire damaged reinforced concrete buildings in Kathmandu valley. All were government owned, all were in service when the fire occurred, and all the fires were of arson origin. The assessments were carried out between October 2025 and January 2026, that is between roughly one and four months after the incidents. The buildings are identified here as Case A to Case G and are profiled in Table 3.

Table 3: Profile of the Assessed Buildings and the Reported Fire Exposure

Case	Structural Typology	Storeys	Age at Fire (years)	Fire Duration (hours)	Observed Intensity	Primary Affected Zone
A	Reinforced concrete frame, previously retrofitted	G plus 2	About 37	12 to 24	Moderate	Ground floor and seminar hall
B	Reinforced concrete frame	1	About 3	Above 24	Moderate to severe	Part of the ground floor
C	Reinforced concrete frame with brick masonry infill	5	About 3	Above 24	Moderate	Basement
D	Reinforced concrete frame with brick masonry infill	3	About 10	Above 24	Moderate	Northern zone of the first floor
E	Mixed reinforced concrete frame and brick masonry	2	About 29	Above 24	Moderate	First floor
F	Reinforced concrete frame	3.5	About 36	Above 24	High	Ground and first floors
G	Reinforced concrete frame	Basement plus G plus 3	About 2	Above 24	High	Ground floor record and library rooms

One constraint has to be stated before the results, because it governs how they should be read. Destructive testing was recommended in every one of the seven buildings as the confirming step. It was carried out in one building only. In the remaining six it could not be undertaken within the cost and the time available to the assessing authority, and the recommendations in those buildings were therefore issued on the non-destructive evidence read together with the visual classification and the structural parameters of Step 7. Those six recommendations are provisional in the sense set out in Section 5.1, and are reported as such.

Table 4 sets out, for each building, which elements were tested, which non-destructive methods were applied, the residual capacity obtained, the status of destructive testing, and the evidence that finally governed the recommendation.

Table 4: Elements Tested, Test Methods Applied, Residual Capacity Obtained and Destructive Testing Status for Each Building

Case	Elements Tested	Non-Destructive Test Applied	Residual Capacity Obtained	Destructive Testing	Governing Evidence
A	Columns, beams and slab	Rebound hammer and ultrasonic pulse velocity	45 to 68 percent, with one member at about 45 percent	Recommended; not carried out owing to cost	Estimate read with the damage class
B	Columns, beams and slab	Rebound hammer and ultrasonic pulse velocity	30 to 90 percent, reported as bands; combined estimate not adopted and pulse velocity governed	Recommended; not carried out owing to cost	Pulse velocity read with the damage class
C	Columns, beam, slab and wall	Rebound hammer and ultrasonic pulse velocity	52 to 100 percent	Recommended; not carried out owing to cost	Estimate read with the damage class
D	Columns, with beams and slabs classified visually	Rebound hammer only	65 to 91 percent	Recommended; not carried out owing to cost	Rebound value read with the damage class
E	Columns, beam and slab	Rebound hammer and ultrasonic pulse velocity	14 to 67 percent	Recommended; not carried out owing to cost	Estimate read with the damage class and the Step 7 parameters
F	Columns, beams and slabs on the two lower floors	Rebound hammer and ultrasonic pulse velocity	Estimate rejected as unusable; residual capacity not established	Recommended; not carried out owing to cost	Damage class supported by rebound values
G	Columns	Rebound hammer and ultrasonic pulse velocity, then concrete cores	Estimate rejected as unusable; cores gave about 70 percent to above 90 percent	Carried out: concrete cores, reinforcement tensile test and carbonation depth test	Core compressive strength

4. Evidence from the Assessments

4.1 Damage Was Concentrated, So Member Wise Assessment Was Necessary

In all seven buildings the damage was localised. Every one contained elements of Class 0 or Class 1 in the same structure as elements of Class 3 or Class 4. In Case D the northern rooms of two floors were Class 3 while the southern portion of the same floors was Class 0 to Class 1. In Case G the ground floor record and library rooms showed heavy spalling with exposed reinforcement, while the second and third floors showed only soot carried up through service ducts. In Case F the two lower floors ranged from Class 1 to Class 4 while the third floor was structurally unaffected. Figures 2 and 3 show the same pattern in mapped form, with an unaffected green zone, a cosmetically damaged blue zone and a zone requiring section restoration all present on one floor plate.

Two mechanisms account for this. The fire stayed largely within the rooms holding the fuel, which in these buildings meant stored paper records, timber furniture and joinery, and electrical services. Heat and smoke then moved upward through slabs, ducts and shafts, so the slab soffit of a burning room and the floor finish of the room directly above it were badly damaged while the rest of that upper storey was not. The consequence is that a single verdict for a whole building would have been wrong in all seven cases. Working element by element placed the intervention where it was needed, and in Case D it allowed the less affected part of the building to be returned to use while repair went on elsewhere.

4.2 The Variation Between Fire Affected and Original Capacity

Taken across the set, the residual capacity of tested members ranged from 14 percent to 100 percent. That range on its own says little, because it spans buildings of different age, typology and fire exposure. The more useful observation concerns the spread inside each building.

In Case C the tested members ranged from 52 to 100 percent, in Case E from 14 to 67 percent, in Case A from 45 to 68 percent, and in Case D from 65 to 91 percent. In each of these the difference between the weakest and the strongest tested member of the same structure was between twenty-three and fifty-three percentage points. That internal spread is frequently wider than the difference between the average condition of one building and another, and it is the quantitative form of the observation made in Section 4.1. A building level residual capacity, had one been reported, would have described none of the members it was meant to represent.

A second observation follows from the bands of Table 2. In six of the seven buildings at least one tested element fell at or below 70 percent, which is the threshold at which the procedure requires destructive testing, and in the seventh the estimate could not be used at all. Every building in the set therefore met a condition under which the procedure calls for confirmation by direct measurement. That confirmation was obtained in one building.

4.3 Where the Estimate of Residual Capacity Could Not Be Used

The estimate was computed in five cases and failed in two of them, in opposite directions, and both failures are visible in the result rather than in the raw instrument data.

In Case G the estimate returned residual capacities of approximately 122, 127, 140, 152 and 192 percent for five fire affected columns. A ratio above unity states that the fire affected member is stronger than the reference, which is not a property that a fire can confer. The reference member selected in that building was itself of lower quality than the members being assessed, so the denominator of equation (2) was wrong. In Case F the estimate returned a compressive strength of about one megapascal, and returned comparable values for fire affected and unaffected members alike. A slab carrying its design load does not have concrete of one megapascal. In neither case had the coefficients of equation (1) been obtained by regression against cores from the structure being assessed, which is the condition set out in Section 2.3.

Two further cases show the same limitation in milder form. In Case B the two measurements that feed the estimate disagreed with each other in the same members, the surface-based measurement indicating sound concrete and the wave-based measurement indicating a severely degraded interior; the combined estimate was not adopted and the wave-based result governed. In Case D only the surface-based measurement was available, so no combined estimate could be formed at all, and the assessment recorded that its findings rested on that method alone and that final decisions should follow further testing.

The common point is that the estimate is an inference drawn from two indirect measurements through an equation whose coefficients were not calibrated to the structure. It orders members within a building reliably, and it identifies which of them need attention. It is not a measurement of capacity, and where it is reported as one the error can be large and can run in either direction.

4.4 What the Estimate Settles and What It Does Not

Case G is the only building in which the confirming step was completed, and the comparison with the rest of the set has to be read with that in mind. Cores were taken from the critical members, supported by tensile testing of reinforcement and phenolphthalein testing for carbonation. The core results were described as realistic and as showing marked variation between locations. Two of the three tested zones returned residual capacities above ninety percent and were classified as needing only minor repair. The third returned about seventy percent and was classified as moderately affected. In that building the estimate had been unusable and the cores produced the value the recommendation was issued on.

This is a single instance and it is presented as such. It does not establish a general rate at which core results diverge from estimates, and no such rate can be inferred from one building. What it does establish, taken with Section 4.3, is that the estimate can fail in ways the bands of Table 2 do not detect, and that direct measurement is what resolves the failure when it occurs.

The position for reinforcement is stronger, because it does not depend on the case at all. Neither of the two non-destructive methods used in this procedure reports the residual yield or tensile strength of a bar. A bar heated above about 600 °C may leave no trace on the surface of the member containing it, and the cover that would have carried the visual evidence is often the part that has spalled away. Within the methods applied here, extraction and tensile testing are the only route to the residual strength of reinforcement. Techniques for reading the depth of thermal damage in concrete do exist beyond those used here, including microscopic and colour analysis and drilling resistance profiling [9, 10], and the claim is confined accordingly.

A practical qualification follows, and it is the one that governed this programme. Destructive testing was recommended in all seven buildings and could be afforded in one. Where cost prevents confirmation, the decision still has to be issued, and the honest course is to issue it on the convergence of the evidence that is available and to record what remains unmeasured. Section 5.1 sets out how the knowledge factor of IS 15988:2013 allows that to be done within the capacity evaluation rather than as a caveat in the covering letter.

4.5 The Basis of Each Decision

Because the estimate was the principal quantitative evidence in six of the seven buildings, it matters how much weight it actually carried. In none of the seven was a recommendation issued on the estimate alone. Each decision rested on the convergence of the damage class, the estimate, and the structural parameters of Step 7, and where those disagreed the decision followed the more conservative reading.

Cases B and E show this most clearly, because their measured evidence was similar and their outcomes were not. Both were assessed as severely damaged and both contained members well below the strengthening threshold. Case E was recommended for demolition of the entire building. Case B was recommended for rehabilitation, and its assessment stated explicitly that the building could be saved and that a targeted approach was economically superior to demolition.

Four factors account for the divergence, and none of them is the estimate. The first is the extent of the damage relative to the structure: in Case E the affected members were two columns and the slab of the upper of only two storeys, so a large share of the primary system was involved, while in Case B the severe damage was confined to a single room of a single storey structure. The second is age and accumulated history; Case E was about twenty-nine years old and had been through earlier seismic events, and its assessment cited the combined effect of fire, age and past seismic exposure, while Case B was about three years old. The third is continuity of the load path: in Case B a separation of construction joints was found in the ground floor columns, attributed to restrained thermal expansion against a stiff slab diaphragm, and was met with a specific intervention, namely reinforced concrete jacketing anchored into the foundation and into the slab above. The fourth is pre-existing construction defects; in Case F the assessment recorded honeycombing in beams, inadequate detailing and stiffness incompatibility between damaged and undamaged portions, and concluded that repairing individual elements selectively was not appropriate and that global retrofitting was required.

The demolition recommendation in Case E should be read in that light. It was not issued because two columns returned low estimates. It was issued because a large proportion of the primary system of a two storey building was affected, because the load path through the upper storey was compromised, because the structure was twenty-nine years old with prior seismic exposure, and because the estimated capacities were consistent with that picture rather than in conflict with it. The estimate corroborated a conclusion that the other parameters already supported. Had it been the only evidence, the case for demolition would not have been made out, and Section 5.2 records this as a limitation rather than a strength.

One further finding is worth stating separately. The choice between local repair and global retrofitting was not settled by the severity of the fire damage in any of these buildings, but by whether a selective intervention would leave an unacceptable discontinuity of stiffness in the structural system.

4.6 The Decisions Produced

Table 5 gives the governing condition and the decision reported for each building, and Table 6 summarises the distribution.

Table 5: Governing Condition and Reported Decision for Each Assessed Building

Case	Governing Condition Reported	Reported Decision
A	Severe localised damage in the seminar hall and outer cantilever zones, several members between 45 and 68 percent and one member at about 45 percent classified as critical, no immediate risk of global collapse	Repairable, subject to semi-destructive testing of critical members, targeted strengthening and rehabilitation, and strict engineering supervision
B	Severe but localised damage, separation of construction joints in the columns of one room, severely degraded interior in the same room, remainder of the building viable	Rehabilitation by reinforced concrete jacketing of the affected columns and fibre reinforced polymer wrapping of moderately affected members, with core testing to confirm; demolition of the whole building not required

Case	Governing Condition Reported	Reported Decision
C	One basement beam at 52 percent, basement wall at 68 percent, ground floor slab at 82 percent, tested column unaffected	Section restoration and strengthening of the beam and wall using shotcrete, patch repair of the slab, and cosmetic maintenance of the column
D	Damage concentrated in the northern zone of the ground and first floors with Class 3 members, southern zone and upper floors lightly affected	Repair and rehabilitation of the affected portion with continued use of the less affected portion, and further non-destructive, core and carbonation testing before final decisions
E	Two first floor columns at about 14 and 30 percent and the first floor slab at about 41 percent, a large share of the primary system of a two storey building affected, compromised load path, 29 year old structure with prior seismic exposure	Immediate restriction of access and demolition of the entire building
F	Class 1 to Class 4 damage across the two lower floors with extensive infill wall damage, pre-existing construction defects, 36 year old structure, residual capacity estimate unusable	Restriction of access and temporary shoring, further core and carbonation testing, structural analysis and vulnerability evaluation, followed by a combined strategy of structural repair, partial reconstruction of severely damaged components and global retrofitting
G	Damage localised to the ground floor record and library rooms, core strengths satisfactory in two of three tested zones, structure about two years old	Repair and rehabilitation of affected members and reconstruction of damaged non structural elements; neither retrofitting nor demolition required

Table 6: Distribution of the Reported Decision Outcomes

Decision Category	Number of Buildings	Cases
Repair and rehabilitation of affected members	2	D, G
Strengthening of affected members in addition to repair	3	A, B, C
Global retrofitting with partial reconstruction	1	F
Demolition of the entire building	1	E

Six of the seven buildings were found to be salvageable and one was recommended for demolition. All seven had burned for twelve hours or more and five had interiors with exposed and oxidised reinforcement. Had the decisions been taken on appearance, the number of demolitions would have been higher.

5. What the Assessments Justify, and What They Do Not

5.1 What the Field Application Supports

Four features of the procedure are supported by what happened in the field.

The first decision point earns its place. Every building contained a majority of elements that required no testing at all, and confining the testing effort to Class 2 and above is what made seven assessments possible in the time available. The second is the requirement for two non-destructive methods rather than one. In Case B the surface-based result alone would have supported re-occupancy of a room whose interior was severely degraded, and in Case D, where only the surface-based method was available, the assessment itself had to record that its findings could not be relied upon without further testing. The third is the mapped, zone-wise output of Step 7. Presenting the result as a shaded drawing with the intervention stated for each zone, as in Figures 2 and 3, converts member wise percentages into something an owner can act on and a contractor can price, and it keeps the evidence and the instruction on the same sheet.

The fourth is the one the constraints of this programme brought out most clearly. Destructive testing was recommended in every building and could be carried out in one. That is a common condition rather than an exceptional one, and a procedure that has no answer for it is of little use. The framework already contains the answer in the knowledge factor of IS 15988:2013. An assessment carried out without materials testing cannot be evaluated at a knowledge factor of 1.00; depending on the completeness of the original documentation it sits at 0.90 or lower, and where the documentation is incomplete and no testing has been done the factor falls further. The capacity that may be relied upon falls with it. This is the mechanism by which an untested assessment can be reported honestly: the recommendation is issued, the reduced factor is applied, and the recommendation is recorded as provisional pending the testing that was recommended. The six untested recommendations in this programme are provisional in exactly that sense.

5.2 Limitations

Five limitations are recorded, in the order in which they weaken the paper.

First, the confirming step was completed in one building of seven. The comparison between estimated and measured capacity therefore rests on a single case, and no rate or systematic direction of divergence can be inferred from it. The statements made in Section 4.4 about what direct measurement settles are arguments from the structure of the evidence, supported by one instance, and should be read as such rather than as a quantified result.

Second, the procedure permits demolition to be recommended on non-destructive evidence alone, since the escalation is not triggered below 30 percent. In this programme no member was condemned on the estimate alone and the one demolition decision rested on the aggregate of the Step 7 parameters, but the asymmetry remains available to a future user of the procedure and should be closed.

Third, the band boundaries of Table 2 are threshold criteria in damage states and are not calibrated against a strength distribution. Their sensitivity is not examined here, and a member falling near a boundary may receive a different recommendation from a small change in the estimate.

Fourth, no comparison between independent assessors was carried out. The claim made for the procedure is that it makes the basis of a recommendation explicit and auditable, which the reports themselves demonstrate. Whether it reduces the variation between two teams assessing the same building is a separate question that this work does not answer.

Fifth, the surveys were carried out between one and four months after the fires, and carbonation and corrosion of exposed reinforcement advance over such a period, so measured condition does not necessarily represent condition immediately after the fire. Related to this, the procedure addresses structural elements and does not evaluate the residual seismic performance of the system, which in a region of high seismic hazard is a material omission. It was recognised in Cases B and F, both of which referred the matter to structural analysis and to established evaluation and strengthening guidelines [14, 17].

6. Conclusion

A procedure for deciding between repair, strengthening and demolition of fire damaged reinforced concrete buildings has been set out and applied to seven such buildings. The existing literature and standards supply the material behaviour, the classification and the test methods, but not the decision path, and the contribution here is that path: visual classification of every element, escalation to non-destructive testing at Class 2, a residual capacity expressed against a reference taken from the original structural and construction records and qualified by the knowledge factor of IS 15988:2013, escalation to destructive testing below 70 percent, and a zone-wise mapped output that states the intervention required for each part of each floor.

Fire damage was concentrated rather than distributed in every building assessed. Residual capacities ranged from 14 to 100 percent across the set, and within individual buildings the difference between the weakest and the strongest tested member reached fifty-three percentage points, so a building level figure would have described none of the members it was meant to represent. Member wise assessment was necessary in every case rather than in difficult ones only.

The non-destructive estimate of residual capacity was unusable in two of the five cases in which it was computed, exceeding one hundred percent in one because the reference member was itself of lower quality than the members being assessed, and returning about one megapascal for load-carrying members in the other. In neither case had the coefficients of the correlation been obtained by regression against cores from the structure concerned. The estimate orders members within a building and directs the testing effort. It is not a measurement of capacity and should not be reported as one.

Destructive testing was recommended in all seven buildings and could be carried out in one, the constraint being cost. This is the ordinary condition of public sector post-fire assessment rather than a failure peculiar to this programme, and the conclusion drawn is correspondingly practical. Where confirmation by direct measurement cannot be afforded, the recommendation should still be issued, but on the convergence of the damage class, the estimate and the structural parameters rather than on the estimate alone; the reduced knowledge factor should be applied to the material properties carried into any subsequent capacity evaluation; and the recommendation should be recorded as provisional pending the testing recommended. Six of the seven recommendations reported here are provisional in that sense, and are so stated.

The decisions produced were two repairs, three strengthening outcomes, one global retrofit with partial reconstruction, and one demolition. None was set by the bands alone. The extent of damage relative to the structural system, the age and prior seismic history of the building, the continuity of the load path and the presence of pre-existing construction defects each changed the outcome for buildings with comparable measured damage, which is why the final step of the procedure is a reading of the whole map rather than a calculation.

7. Acknowledgement

The authors thank the field assessment teams whose reports form the basis of the evidence presented here, and the academic institutions and professional societies that contributed to the development of the procedure.

8. References

1. Concrete Society, Technical Report No. 68, Assessment and Repair of Fire Damaged Concrete Structures, The Concrete Society, Camberley, 2008.
2. American Concrete Institute, ACI 562-21, Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures and Commentary, American Concrete Institute, Farmington Hills, 2021.
3. European Committee for Standardization, EN 1992-1-2, Eurocode 2, Design of Concrete Structures, Part 1-2, General Rules, Structural Fire Design, Brussels, 2004.
4. Bureau of Indian Standards, IS 13311 Part 2: 1992, Non-Destructive Testing of Concrete, Methods of Test, Part 2, Rebound Hammer, New Delhi, 1992.
5. Bureau of Indian Standards, IS 13311 Part 1: 1992, Non-Destructive Testing of Concrete, Methods of Test, Part 1, Ultrasonic Pulse Velocity, New Delhi, 1992.
6. Bureau of Indian Standards, IS 516 Part 4: 2018, Hardened Concrete, Methods of Test, Part 4, Sampling, Preparing and Testing of Concrete Cores, New Delhi, 2018.
7. Bureau of Indian Standards, IS 516 Part 5 Section 3: 2021, Hardened Concrete, Methods of Test, Part 5, Non-Destructive Testing of Concrete, Section 3, Carbonation Depth Test, New Delhi, 2021.
8. V. Kodur, Properties of Concrete at Elevated Temperatures, ISRN Civil Engineering, 2014, Article ID 468510.
9. E. Annerel, L. Taerwe, Revealing the Temperature History in Concrete after Fire Exposure by Microscopic Analysis, Cement and Concrete Research, 2009, 39, 1239-1249.
10. M. Colombo, R. Felicetti, New NDT Techniques for the Assessment of Fire-Damaged Concrete Structures, Fire Safety Journal, 2007, 42 (6-7), 461-472.
11. A. Deep, S. Tomar, K.S. Kulkarni, S. Singh, Comprehensive Review of Techniques for Assessing Fire-Exposed Concrete, Principles, Applications, and Integration Strategies, Iranian Journal of Science and Technology, Transactions of Civil Engineering, 2025, 49 (3).
12. Post Fire Detailed Damage Assessment Field Manual and Technical Guideline, Kathmandu, 2025.
13. RILEM Technical Committee 43-CND, Draft Recommendation for In Situ Concrete Strength Determination by Combined Non Destructive Methods, Materials and Structures, 1993, 26 (1), 43-49.
14. Bureau of Indian Standards, IS 15988: 2013, Seismic Evaluation and Strengthening of Existing Reinforced Concrete Buildings, Guidelines, New Delhi, 2013.
15. Bureau of Indian Standards, IS 1608 Part 1: 2018, Metallic Materials, Tensile Testing, Part 1, Method of Test at Room Temperature, New Delhi, 2018.
16. Bureau of Indian Standards, IS 1786: 2008, High Strength Deformed Steel Bars and Wires for Concrete Reinforcement, Specification, New Delhi, 2008.
17. Federal Emergency Management Agency, FEMA 306, Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings, Basic Procedures Manual, Washington, 1998.