Comprehensive condition assessment program on the fire damaged structure – a project case in Singapore

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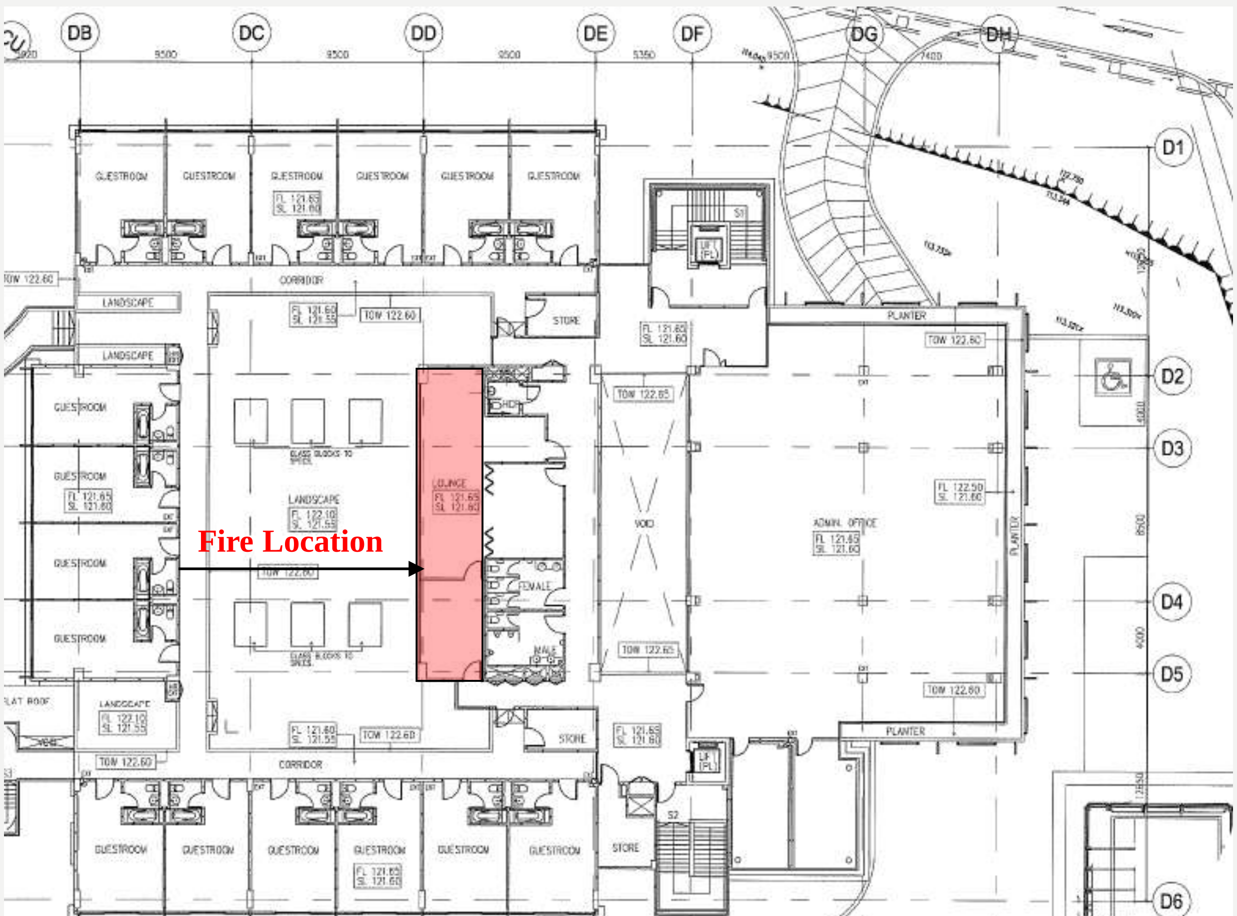
4th International Conference on Rehabilitation and Maintenance in Civil Engineering
Solo Baru, July 11th – 12th 2018

AGENDA

1. General Background
2. Literature Review
3. Condition Assessment
4. Analysis
5. Conclusion

1. GENERAL BACKGROUND

- Fire incident at construction site in the Eastern Part of Singapore



1. GENERAL BACKGROUND

Some concrete spalling exposing corroded steel reinforcements were noted on the roof level post tensioned beam and reinforced concrete slab

1. GENERAL BACKGROUND

- The objective of the works was to **evaluate the condition** of the affected structure and the **residual material mechanical properties**.
- To determine the most effective structural rehabilitation program, which includes structural repair and strengthening works, further to this condition assessment, a complete structural assessment was performed

2. LITERATURE REVIEW

- When exposed to high temperature, such as in the case of a fire, the concrete surface will become porous with lots of void and micro cracks.
- Some portion of the concrete may have shallow delamination, and some may even spall off.
- Porous concrete will reduce its compressive strength and increase the risk of rebar corrosion.

2. LITERATURE REVIEW

- The extent of concrete damage, such as carbonation depth, the existence of void and micro cracks, and estimation of concrete temperature during a fire, can be examined using Petrographic Examination on the concrete core sample [ASTM C856-04]
- Although the concrete surface may look to be in a good condition, with no crack and spalling, some internal separation (delamination) may occur, which is quite dangerous if not properly assessed. Structural repairs are required for this area to prevent concrete spalling in the future. Acoustic impact testing was used to detect the concrete area with shallow delamination [ASTM D4580]
- The residual concrete compressive strength might be the most important thing to be assessed to ensure the affected structures still have the required capacity to take the load. The compressive test was conducted on the extracted core samples [BS 1881: Part 120]

2. LITERATURE REVIEW

- It would be difficult to assess the extent of damage the fire caused to the structure unless a lot of samples are taken. To minimize the number of samples, a material uniformity test is required. This can be done using the Rebound Hammer test on the accessible concrete surface [ASTM C805]. Once the test showed that the readings of the material were not uniform, more samples would be required.

2. LITERATURE REVIEW

- After the fire reached a certain temperature, the steel mechanical properties, including its tensile strength, ductility, and hardness will change. The tensile strength test is required to determine the residual strength of the steel rebar to ensure that it has the required strength as per design requirement. Steel bend test is one method to qualitatively evaluate ductility. Vickers hardness test is used to evaluate the steel rebar hardness

2. LITERATURE REVIEW

Petrographic Examination

- Petrographic Examination was performed in accordance to ASTM C856-04 on a ground section using a stereo microscope and on a thin section with a polarizing and fluorescent microscope (PFM), under transmitted and reflected light.
- Through an examination of the ground section, the assessment was made on the homogeneity of the concrete, compaction and types and distribution of large particles.
- Under transmitted light on the examination of a thin section, various components (type of cement and aggregates), air voids content, compaction pores and damage phenomenon in the sample were identified.
- Under reflected light, the fluorescent microscopy made it possible to study the homogeneity of the mix and the cement paste, capillary porosity, micro cracks and other defects in the sample.

2. LITERATURE REVIEW

Acoustic Impact Testing

- Using the principle of emission of elastic sound waves, the impacted surfaces exhibit either a sharp metallic ring or a dull hollow sound representing “sound” and “unsound” concrete conditions, respectively

2. LITERATURE REVIEW

Steel Bend Test

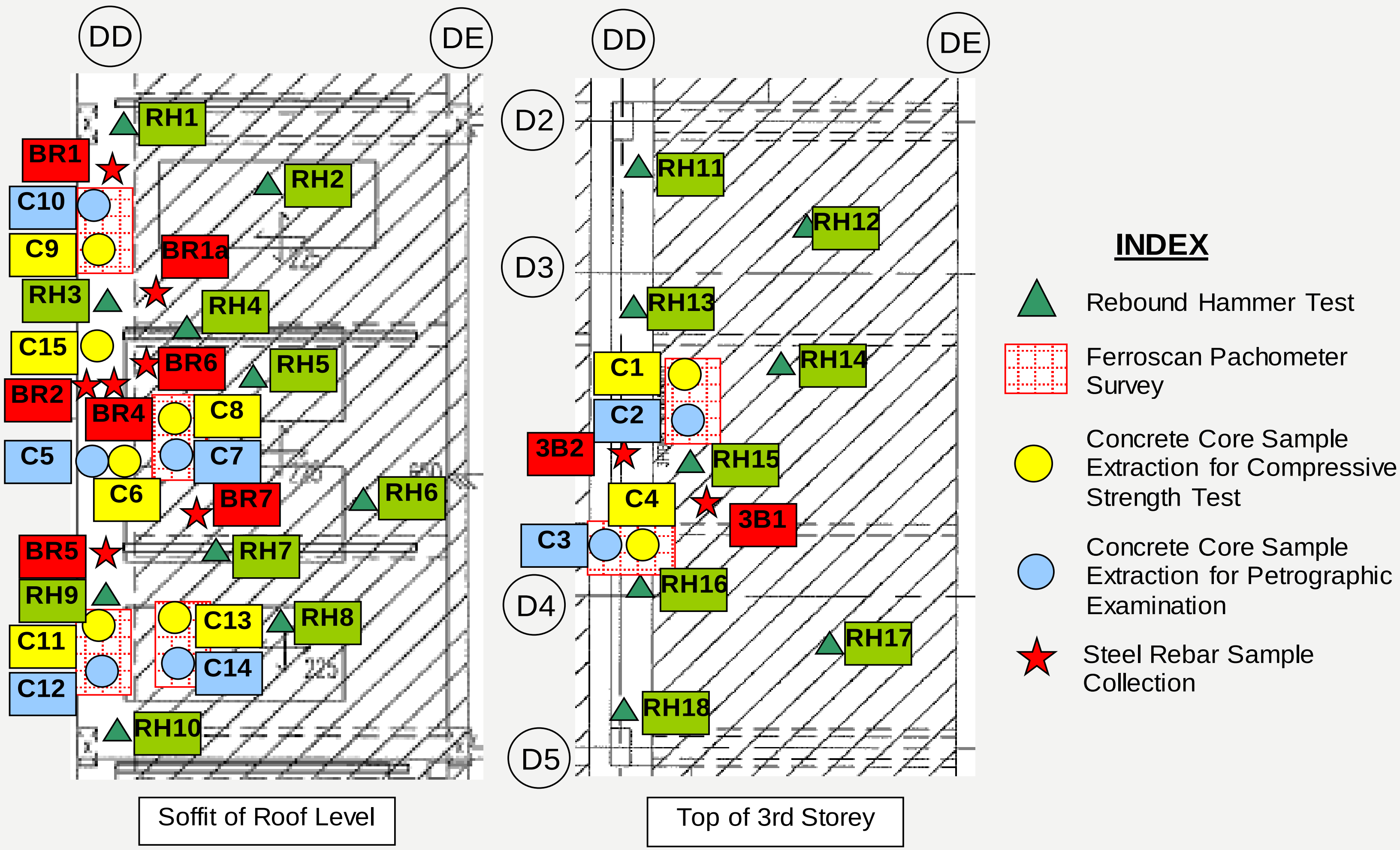
- Steel bend test is one method to qualitatively evaluate ductility. It is done by bending the steel sample to a 45^o angle and then heating it up to 100^oC for at least 30 minutes. After it cools down the specimen is re-straightened to at least a 23^o angle and it should not show any damage.

Steel Hardness Test [Vickers Hardness Test]

- Vickers hardness test is used to evaluate the steel rebar hardness. A constant force of 10kg is often used to obtain the Vickers Hardness Value (VH10), which can be indicatively correlated to give an estimation to its yield strength.

3. CONDITION ASSESSMENT

3.1. FIELD ASSESSMENT



3. CONDITION ASSESSMENT

3.1. FIELD ASSESSMENT

3.1.1. Visual Inspection

- Accessible areas of the concrete structure were visually examined.
- Some concrete spalling exposing corroded steel reinforcements were noted on the roof storey beam and slab soffit.
- No sign of concrete defect was found on the 3rd storey beam and slab where the fire occurred.
- No damage was noted on the PT Tendon ducts, even at the most severely spalled concrete.

3.1.2. Acoustic Impact Testing

- Generally, unsound (i.e., delaminated) areas were in the immediate proximity of cracks in the beams. No concrete delamination was noted outside the spalled concrete area.

3. CONDITION ASSESSMENT

3.1. FIELD ASSESSMENT

3.1.3. Rebound Hammer Testing

- This method is not intended as an alternative for strength determination of concrete, but rather the scale number values provide qualitative comparisons between similar concrete materials.
- Typically, for each location, a series of 10 readings are performed approximately 25mm apart with test results recorded and tabulated.
- Eighteen (18) locations were tested with Rebound Hammer testing.
- Interpolating concrete strengths derived from Rebound Hammer manufacturer Data Charts, revealed a mean interpretative compressive strength of 30 - 50 N/mm^2.

3. CONDITION ASSESSMENT

3.1. FIELD ASSESSMENT

3.1.3. Rebound Hammer Testing

No	Location	Measurement			Interpretive f_{cu} (N/mm^2)
		Low	High	Ave	
1	Roof level beam soffit	39	48	44	40
2	Roof level slab soffit	42	47	45	40
3	Roof level beam soffit	40	47	44	40
4	Roof level secondary beam soffit	39	43	41	40
5	Roof level slab soffit	39	48	44	40
6	Roof level slab soffit	40	49	45	40
7	Roof level secondary beam soffit	38	42	40	40
8	Roof level slab soffit	37	43	40	40
9	Roof level beam soffit	35	45	40	40
10	Roof level beam soffit	36	48	42	40
11	3^{rd} level top beam	28	32	30	30
12	3^{rd} level top slab	32	36	34	40
13	3^{rd} level top beam	36	40	38	40
14	3^{rd} level top slab	32	36	34	40
15	3^{rd} level top slab	31	35	33	30
16	3^{rd} level top beam	30	38	34	40
17	3^{rd} level top slab	32	38	35	40
18	3^{rd} level top beam	38	42	40	50

3. CONDITION ASSESSMENT

3.1. FIELD ASSESSMENT

3.1.4. Ferroscan Pachometer Survey

- The ferroscan pachometer surveys were performed to estimate the core sample locations.
- No scans were performed on the concrete surface with exposed rebars as the core sample location can be visibly determined.

3. CONDITION ASSESSMENT

3.1. FIELD ASSESSMENT

3.1.5. Concrete Core and Steel Rebar Sample Extraction

- Fifteen (15) concrete core specimens were collected using wet rotary diamond core drilling techniques at selected locations. Concrete core samples were visually examined and photographed prior to concrete laboratory testing. Concrete core holes were patched with shrinkage-compensating repair mortar subsequent to sample collection.
- A total of nine (9) steel rebar samples were collected on site. Seven (7) samples were collected from the roof level which is grade 460 rebar, and two (2) samples (3B1 and 3B2) were collected from the 3rd storey level which is A6 BRC. The collected steel samples were sent to the accredited laboratory for further laboratory tests

3. CONDITION ASSESSMENT

3.2. LABORATORY TEST

3.2.1. Concrete Compressive Strength Test

- Eight (8) numbers of extracted core samples were tested to determine the laboratory compressive strength. The core samples were prepared by the laboratory such that it reflected the homogeneity of the sample.
- The concrete compressive strength ranges from 30.00 to 39.00 N/mm^2,

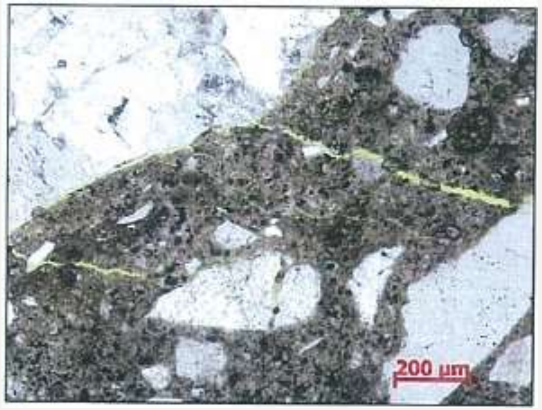
Core sample reference	Location	Estimated in situ cube strength f_{cu} (N/mm^2)
C1	3rd Floor Top Slab	33.00
C4	3rd Floor Top Slab	32.50
C6	Roof Level Beam Soffit	38.50
C8	Roof Level Slab Soffit	30.00
C9	Roof Level Beam Soffit	36.50
C11	Roof Level Beam Soffit	35.50
C13	Roof Level Slab Soffit	39.00
C15	Roof Level Beam Soffit	32.50

3. CONDITION ASSESSMENT

3.2. LABORATORY TEST

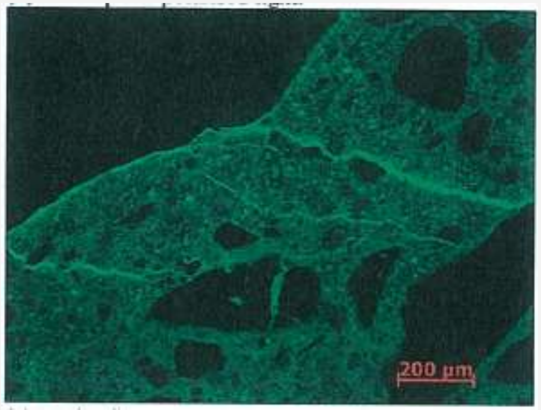
3.2.2. Petrographic Examination

- Petrographic examinations were performed on seven (7) submitted core samples to determine the extent of the concrete damage. All samples were analyzed starting from the sample surface exposed to the fire.
- Carbonation was noted within the 5mm depth.
- Some micro cracks were noted on the cement paste. Some of these were not fire-induced cracks which occurred before the fire.



(a) Under plane polarized light

(b) Under cross polarized light



(c) Under fluorescent light

3. CONDITION ASSESSMENT

3.2. LABORATORY TEST

3.2.2. Petrographic Examination

Core sample reference	Location	Carbonation depth	Cement paste condition	Estimated exposed temperature
C2	3rd Floor Top Slab	4mm	- Very small amount of micro cracks on cement paste were noted. - No Aggregate-cement paste debonding was noted	< 300°C
C3	3rd Floor Top Beam	4mm	- Hardened Crack with aggregate-cement paste debonding was noted at within 3mm from the exposed surface - No fire-induced micro cracks were noted	< 300°C
C5	Roof Level Beam Soffit	0.5mm	- Hardened Crack with aggregate-cement paste debonding was noted at within 4mm from the exposed surface - No fire-induced micro cracks were noted	< 450°C
C7	Roof Level Slab Soffit	2mm	- Hardened Crack with aggregate-cement paste debonding was noted at within 20mm from the exposed surface - No fire-induced micro cracks were noted	< 450°C

3. CONDITION ASSESSMENT

3.2. LABORATORY TEST

3.2.2. Petrographic Examination

Core sample reference	Location	Carbonation depth	Cement paste condition	Estimated exposed temperatu e
C10	Roof Level Beam Soffit	1.5mm	- Hardened Crack with aggregate-cement paste debonding was noted at within 20mm from the exposed surface - No fire-induced micro cracks were noted	< 450ºC
C12	Roof Level Slab Soffit	4mm	- Hardened Crack with aggregate-cement paste debonding was noted at within 1.5mm from the exposed surface - No fire-induced micro cracks were noted	< 450ºC
C14	Roof Level Beam Soffit	3mm	- Hardened Crack with aggregate-cement paste debonding was noted at within 1.5mm from the exposed surface - No fire-induced micro cracks were noted	< 450ºC

3. CONDITION ASSESSMENT

3.2. LABORATORY TEST

3.2.3. Steel Rebar Test

- The tensile test results showed that the yield strength ranged from 573.10 to 670.50 N/mm^2 which was more than the requirement specified in BS 4449:1997 of 460 N/mm^2.
- The bending test showed a satisfactory result for all the rebar samples.
- The Vickers Hardness Test showed an HV10 value range from 175 to 300, which could be correlated to estimate the tensile strength of 590 to 960 N/mm^2.

Sample reference	Location	Yield strength (N/mm^2)	Bending test	HV10
BR1	Roof Level Beam Soffit	635.00	Satisfactory	188 – 230
BR1a	Roof Level Slab Soffit	581.80	Satisfactory	188 – 237
BR2	Roof Level Beam Soffit	623.70	Satisfactory	192 – 237
BR4	Roof Level Beam Soffit	670.50	Satisfactory	192 – 300
BR5	Roof Level Beam Soffit	650.70	Satisfactory	196 – 242
BR6	Roof Level Slab Soffit	608.50	Satisfactory	194 – 219
BR7	Roof Level Slab Soffit	573.10	Satisfactory	175 – 233
3B1	3rd Floor Top Slab	530.70	Satisfactory	208 – 227
3B2	3rd Floor Top Beam	570.70	Satisfactory	215 – 218

3. CONDITION ASSESSMENT

3.2. LABORATORY TEST

3.2.3. Steel Rebar Test

Approximate Hardness Conversion Numbers [ASTM A370]

Rockwell C Scale, 150-kgf Load, Diamond Penetrator	Vickers Hardness Number	Brinell Indentation Diameter, mm	Brinell Hardness, 3000-kgf Load, 10-mm Ball	Knoop Hardness, 500-gf Load and Over	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness			Approximate Tensile Strength, ksi (MPa)
						15N Scale, 15-kgf Load, Diamond Penetrator	30N Scale 30-kgf Load, Diamond Penetrator	45N Scale, 45-kgf Load, Diamond Penetrator	
30	302	3.59	286	311	65.3	75.0	50.4	31.3	138 (950)
29	294	3.64	279	304	64.6	74.5	49.5	30.1	135 (930)
28	286	3.69	271	297	64.3	73.9	48.6	28.9	131 (900)
27	279	3.73	264	290	63.8	73.3	47.7	27.8	128 (880)
26	272	3.77	258	284	63.3	72.8	46.8	26.7	125 (860)
25	266	3.81	253	278	62.8	72.2	45.9	25.5	123 (850)
24	260	3.86	247	272	62.4	71.6	45.0	24.3	119 (820)
23	254	3.89	243	266	62.0	71.0	44.0	23.1	117 (810)
22	248	3.93	237	261	61.5	70.5	43.2	22.0	115 (790)
21	243	3.98	231	256	61.0	69.9	42.3	20.7	112 (770)
20	238	4.02	226	251	60.5	69.4	41.5	19.6	110 (760)

[A] This table gives the approximate interrelationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness-tensile strength relationship from the data presented in this table. The data in this table should not be used for austenitic stainless steels, but have been shown to be applicable for ferritic and martensitic stainless steels. Where more precise conversions are required, they should be developed specially for each steel composition, heat treatment, and part.

4. ANALYSIS

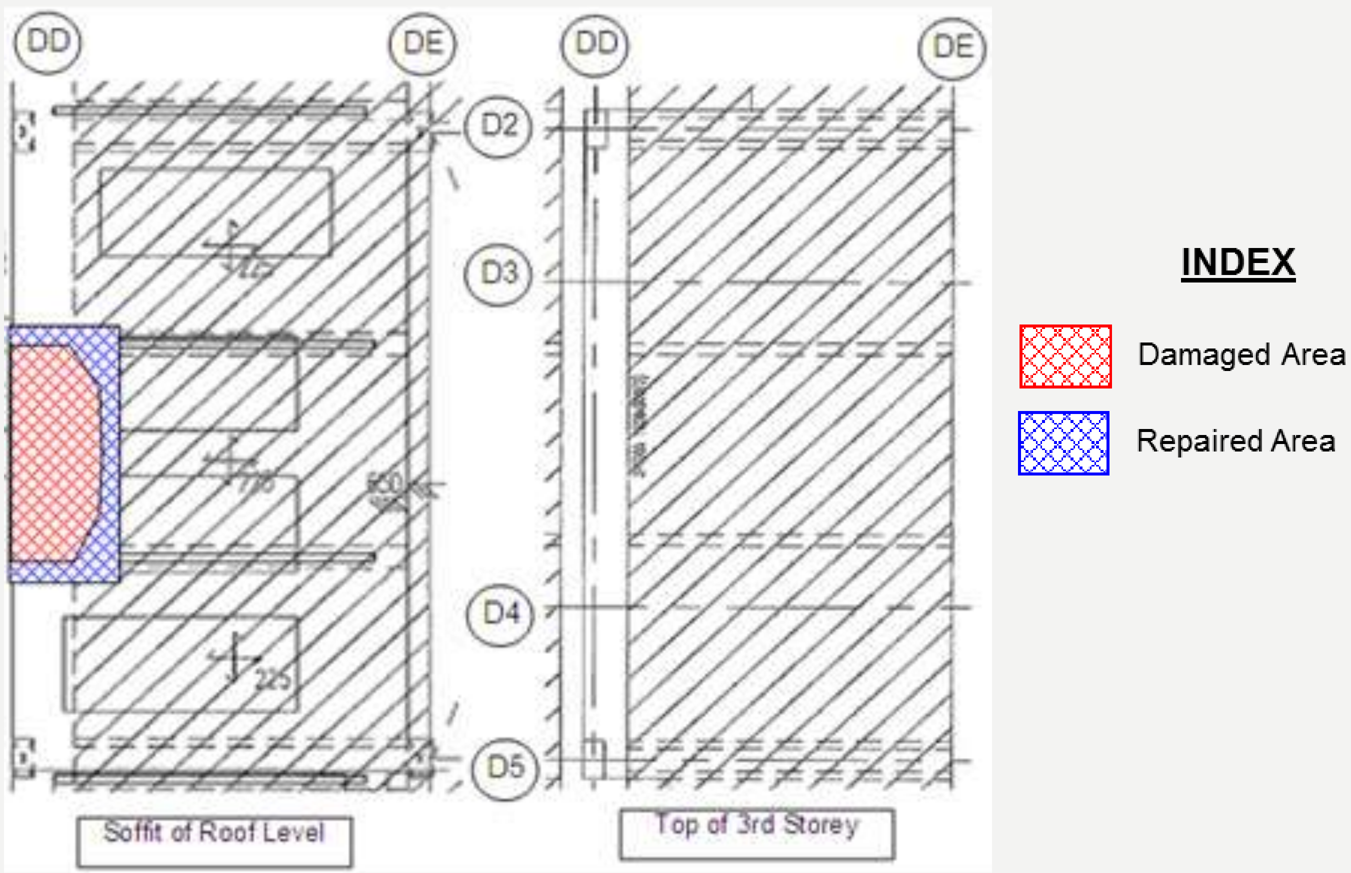
4.1. CONCRETE MATERIAL PROPERTIES

- Compressive strength results indicated that concrete strength ranged from 30.00 to 39.00 N/mm^2. The average laboratory compressive strength tested for eight (8) of the concrete cores extracted was 34.69 N/mm^2. BS1881 Part 120 allows extracted concrete core specimens subjected to laboratory compression testing to represent 95% of the design compressive strength due to the destructive nature of the core extraction process. Thus, the average residual concrete compressive strength on the site shall be 36.51 N/mm^2, which was slightly higher than the original design compressive strength of 35 N/mm^2.
- Rebound Hammer conducted on the concrete structure revealed relatively consistent concrete material properties. Testing data revealed that the concrete could be considered in a general “good” condition.

4. ANALYSIS

4.1. CONCRETE MATERIAL PROPERTIES

- No concrete delamination was noted outside the concrete spalled area as confirmed by the acoustic impact testing.



4. ANALYSIS

4.1. CONCRETE MATERIAL PROPERTIES

- Petrographic examination showed that all tested core samples had some carbonation that occurred at a depth of 5mm below the exposed surface. At the location where concrete spalled exposing steel rebar, the exposed surface was deeper than the steel rebar depth. Hence, concrete material carbonation might be a significant contributor to the steel rebar corrosion in the future. However, in the location where there was no concrete spalling, the 5mm deep carbonation was well within the concrete cover, thus carbonation would not have a significant impact on rebar corrosion.

4. ANALYSIS

4.1. CONCRETE MATERIAL PROPERTIES

- Some micro cracks were noted inside the cement paste within 20mm from the exposed surface. Some of these micro cracks were existing cracks which occurred before the fire whereas some were fire-induced. Some aggregate-cement paste debonding was observed on the existing micro cracks within 20mm from the exposed surface. However, no cracks were observed on the aggregates. The concrete at the depth of more than 20mm was considered to be in good condition as no signs of distress were observed.
- Petrographic examination suggested that the top 5mm of the concrete surface might be exposed to a temperature not more than 450^{o}C. The remaining depth of the concrete was strongly believed to be exposed to a temperature of less than 300^{o}C.

4. ANALYSIS

4.2. STEEL MATERIAL PROPERTIES

- All three tests (tensile, bending, and hardness) on the steel samples showed that the steel rebars were still in good condition with no significant material degradations caused by the fire incident.
- All post tension strands were encased inside fully grouted corrugated steel ducts. In order for the fire to damage the strands, the heat needed to go through the 70mm thick concrete cover, steel duct, and about 30mm-thick grout. After the fire incident, no tendons were exposed even at the most severely spalled concrete. This showed that the strands were still in good condition.
- Thus, it could be concluded that the steel rebars and PT strands were considered to be structurally able to perform as designed.

5. CONCLUSION

- A comprehensive condition assessment is a very important work to determine the extent of structural damage and the residual material mechanical properties.
- The findings of this assessment were used for the structural assessment work to determine the residual structural capacity of the affected structural elements.
- The effective structural rehabilitations, which includes structural repair and strengthening works, were done based on the findings of both condition and structural assessment works, respectively.

THANK YOU