A case study on the structural assessment of fire damaged building

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A case study on the structural assessment of fire damaged building

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Abstract. This paper presents a case study on the structural assessment of building damaged by fire and discussed on the site investigations and test results prior to determine the existing condition of the building. The building was on fire for about one hour before it was extinguished. In order to ascertain the integrity of the building, a visual inspection was conducted for all elements (truss, beam, column and wall), followed by non-destructive, load and material tests. The load test was conducted to determine the ability of truss to resist service load, while the material test to determine the residual strength of the material. At the end of the investigation, a structural analysis was carried out to determine the new factor of safety by considering the residual strength. The highlighted was on the truss element due to steel behaviour that is hardly been predicted. Meanwhile, reinforced concrete elements (beam, column and wall) were found externally affected and caused its strength to be considered as sufficient for further used of building. The new factor of safety is equal to 2, considered as the minimum calculated value for the truss member. Therefore, this fire damaged building was found safe and can be used for further application.

1. Introduction

This paper discussed on the case study of a fire damaged building. The building is made up from reinforced concrete for the beam, column and wall, while have steel trusses as a main structural element. In general, the condition inside the office was affected by the fire (figure 1). There were a lot of things that were affected such as partitions, windows, electrical circuit, electrical sockets and insulations. All the things mentioned were found broken and damaged due to the fire. Effect of fire to the structural components can be seen from the shaded colour of walls, columns and beams, at all over the surfaces. On the other hand, the trusses components were also affected by showing rusted steel appearance all over the surfaces.The structural assessment was aimed to investigate the effect of fire to the elements inside the building, to investigate the condition of the main structural element due to the fire (steel trusses) and to recommend overall condition of the building.

In general, reinforced concrete structure performed well under fire [1-3]. Its behaviour as fire resisting element caused most of fire damaged structure being reused after the fire, provided structural assessment has been carried out. With sufficient information on the level of fire during the event will assist the assessment to investigate the existing condition of a building. Effect of fire level to the

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structural element inside the fire damaged building need to be investigated in order to ascertain the existing capacity and condition.

Several important information in carried out the structural assessment of a fire damaged building are; types of building elements and materials, point of fire initiated, exposure condition, predicted fire temperature, duration of fire and other possible data. As structure itself is made up by different other materials, it made each fire damaged building investigation to become more difficult. In other word, each investigation will be unique between different fire damaged building incidents. Therefore, it is very important for investigator to share their experienced wherever they facing such of fire damaged building investigation.

On the other hand, in reinforced concrete structure, colour changes are normally used to investigate the temperature of the material exposed to [4-7]. Table 1 is used to determine the level of temperature exposed to the building elements. Meanwhile, figure 1 shows the flowchart of current structural assessment of a fire damaged building. The flowchart is determine based on review of important data that need to be collected in order to ascertain the existing condition of the building element after exposed to fire.

Figure 1. Interior view of the building damaged by fire shows most of the elements inside the building were affected.

Table 1. Colour changes in concrete at specified range of temperature, T.

Range of temperature, °C	Colour	Appearance	Condition
$T < 300$	Normal	Normal	Normal
$300 \leq T < 600$	Pink to red	Surface crazing, cracking and aggregates pop outs	Sound but strength may be reduced
$600 \leq T < 950$	Whitish grey	Spalling, exposed of steel reinforcement and powdered existence	Weak
$T \geq 950$	Buff	Extreme spalling	Extreme/severe

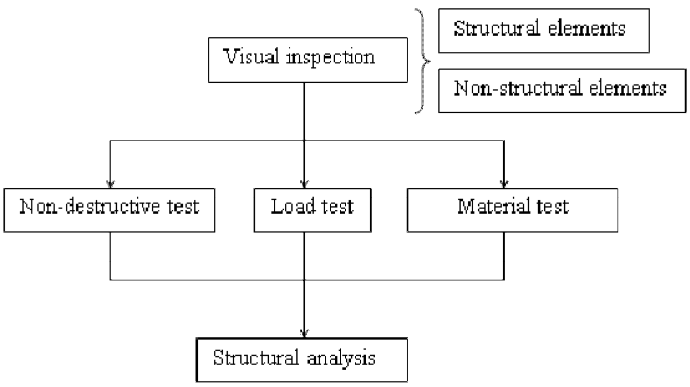

Figure 2. Flowchart of a structural assessment.

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2. Site Investigation

2.1. Visual inspection

Visual inspection has been conducted for all elements inside building (figure 3). Through visual inspection, it was found that there were many damages to the roof due to the fire. There was a few damages found at the metal sheets which made it not fit for roofing system. The same observation were found for the foil insulations. It was found that all of the foil insulations were damaged and was not suitable for use.

The condition of steel purlins was found most affected. These conditions were expected due to the material properties of steel purlin of which have a strength that is lower compared to the steel truss. Therefore, the effect of fire will create so much impact to the steel purlin compared to the steel trusses. General overview on the steel purlins that were corroded on-site was shown in figure 4. Most of the steel purlins were corroded along their lengths. The most affected steel purlin was found for a purlin located above the area of fire initiated. The steel purlin was heavily buckled and twisted along their length.

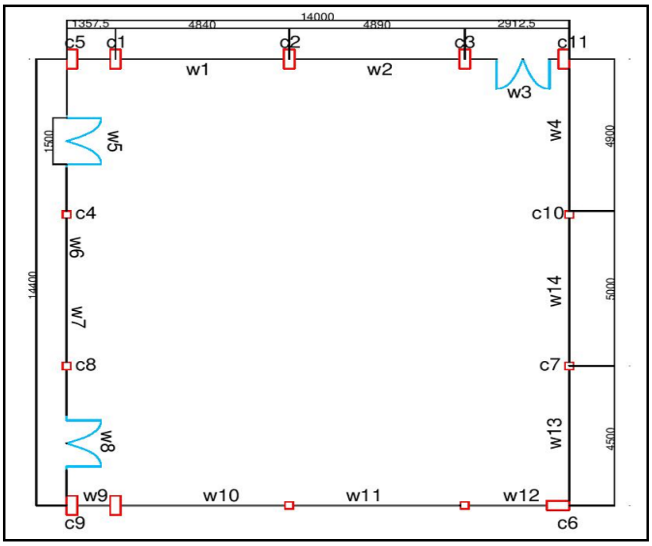


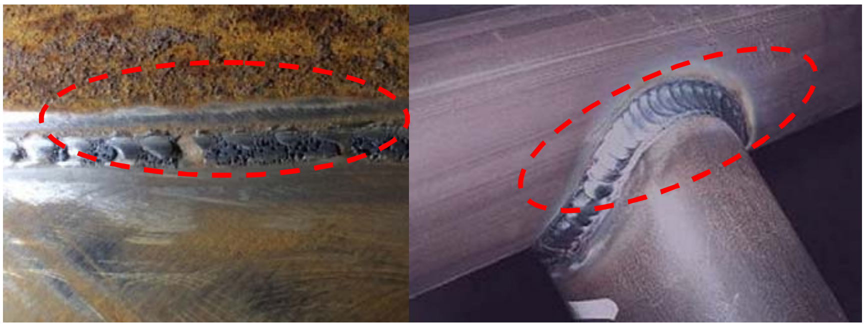
Figure 3. Plan view of a fire damaged building shows ten columns (c1 to c10) and fourteen walls (w1 to w14). Other elements that were not visible inside the plan view are two beams spanning from c5 to c9 and from c11 to c6; and six steel trusses spanning in between the beams.

Figure 4. Observation on steel purlins that were affected by fire.

The steel trusses are the main structural elements on-site, as the members carry the roof loads. Visual inspection shows that all members are affected by the fire. Other than the original colour of black was brownish in color which was found to be colour of corrosion.In determining the state of the corrosion; the corroded part was polished using a sandpaper and stiff wire brush to investigate the extent of the depth of the corrosion. After the process, it was found that the condition of the welding at most of the connections were not satisfactory. An example of the less satisfactory condition that was found on-site is shown in figure 5(a) is considered as poor quality.

On the other hand, the visual inspection shows that there are many spalling of the plaster on the surface of the beam. However, the concrete surface beneath the plaster layer is not affected. The concrete was found not affected due to the appearance and condition that still intact and shows the original grey in their colour (figure 6). The observation is also shown by column and wall elements.

In general, it can be summarized that reinforced concrete elements inside the building were just externally affected by the fire. Although comparison of the elements colour and texture to table 1 shows that the elements were experiencing about 600 to 800 °C temperature, nevertheless, only plastering of the RC elements were affected. In this case, only RC beams were found affected showing by spalling of the plastering. This proved on the capacity of RC elements in resisting fire as per mentioned by previous works [1-3]. Meanwhile, the steel purlins and trusses needs to be investigated in detail due to the confirmation on its behaviour after fire.



(a) Unsatisfactory (b) Satisfactory

Figure 5. Appearance of welding quality at connection.

Figure 6. Physical appearance of the beams

2.2 .Non-Destructive Test

Although the observation from the visual inspection has shown that all RC elements (wall, column and beam) were just externally affected by the fire, a "Schmidt" rebound hammer test is still been carried out to ascertain the existing concrete uniformity of the elements. The test is in accordance to ASTM C805/C805M-13a [8] and was carried out for beam elements on-site due to the occurrence of concrete spalling. A few points on the beams were selected to carry out the test. In general, the test results show that the compressive strength for concrete beams are in between 40 $\pm$ 4 N/mm^2, which is considered as more than adequate.

2.3.Load Test

The objective of load test is to ascertain current capacity of trusses on-site (figure 7). Previously, RC elements have been found externally affected; however, the truss is made up from steel material. Therefore, further test is needed for the truss elements. Two trusses are selected based on its condition as the most (Truss 1) and least (Truss 2) affected truss. Full load test was carried out to determine the truss behaviour due to the loading and unloading process at service load. Loading was applied in 1 kN increment; and up to maximum service load of 14 kN at point D and E (at the middle of the truss span). The results for load-deflection relationship for two LVDTs location is shown in figure 8(a).

In general, the deflection relationship have the same curve pattern at LVDTs position (point D and E) indicating that the loading system and test setup are closely symmetrical and aligned. The same pattern was observed for both trusses, during the loading and unloading process. The recorded deflection at LVDT 1 (point D) and LVDT 2 (point E) was 4.24 mm and 4.79 mm for Truss 1, respectively. Meanwhile, Truss 2 recorded deflection of 4.06 mm and 4.49 mm at LVDT 1 (point D) and LVDT 2 (point E), respectively.

Meanwhile, the sustained load test (for service load at 14 kN) was carried out for 24 hours and at the same time, deflection was recorded at every 30 minutes. Truss 1, the most affected truss was selected to undergo this sustained load test. The deflection relationship at points D and E is shown in figure 8(b). The deflection of the truss at LVDT 1 (point D) ranged between 3.51 mm and 4.24 mm, while LVDT 2 (point E) ranged between 3.96 mm and 4.85 mm. The graph pattern indicates a bit increasing trend as the load remained sustained on the slabs; at early 8 hours. However, the deflection became constant after 8 hours from the start of the sustained load.

The full load test and sustained load test results shows that the trusses are still stable and capable in resisting service load for further used.

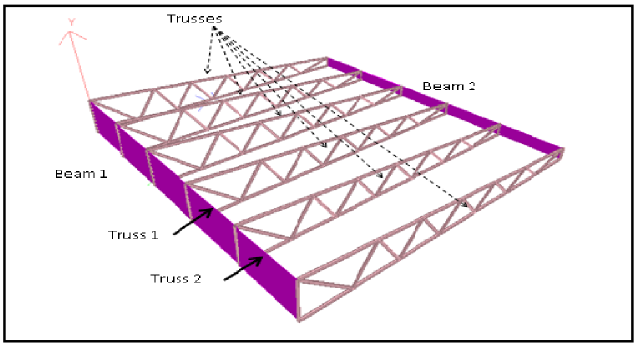
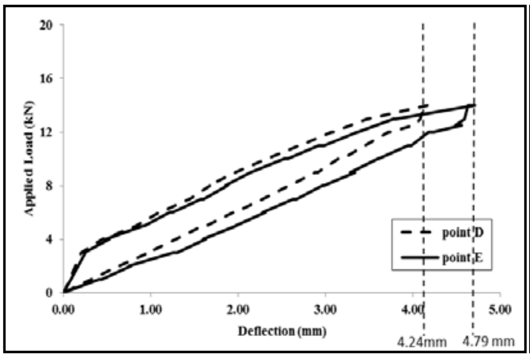
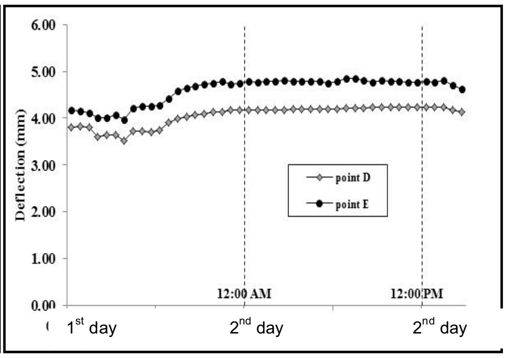


Figure 7. Steel trusses on-site





(a) Full load test results (b) Sustained load test results

Figure 8. Deflection relationship during the test

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2.4Material Test

The coupon tensile test was carried out on the steel purlins [9]. The test is conducted for the steel purlin due the observation during visual inspection which found that steel purlins were the most affected element on-site. This is due to the appearance of the element that was heavily buckled and twisted compared to the steel trusses. A total of 6 samples that consisted of:3 samples from the most affected area and 3 samples from less affected area.The average tensile capacity is 341 N/mm^2 for least affected samples, which is 15% less than the design requirements of 400 N/mm^2. Meanwhile, the average tensile capacity is 324 N/mm^2 for the most affected samples, which is 19% less than the design requirements of 400 N/mm^2. Therefore, the test results show that the steel purlin was severely affected with it yield capacity reduced at maximum of 19% from the actual capacity.

3.Structural Analysis

In predicting the current capacity of the steel truss, a structural analysis has been carried out using STAAD.Pro v8i Analysis Software and in accordance to BS 5950 [10].The values under the design load and un-factored load were gained from the software analysis. Meanwhile, the design capacity was calculated based on the actual capacity of the member. Factor of safety, *FOS* was determined and it was calculated using equations (1) and (2). The reduce capacity was calculated by considering the higher temperature that the steel truss was exposed; in a range of 600 to 800 ºC.

Based on an assumption that was made from the literature and investigation, the exposed temperature caused the capacity of the truss to drop by 30% from the actual. It means that, about 30% of the actual capacity of the truss members were reduced due to the exposure to the fire. This is also similar to the previous work reported [11]. From their findings, the steel with characteristic strength of 400 to 460 N/mm^2 will have a strength loss of about 30% when exposed to a temperature of between 800 to 1000 ºC. Subsequently, the coupon tensile strength test of which the steel purlin was made from the steel with 400 N/mm^2 design strength dropped at about 20% from the strength. Therefore, assumption on 30% of strength dropped for the steel truss was make sense, although the load test has already giving unaffected fire condition of a steel truss .After calculation, the FOS_{new} that was considering the reduced capacity of each truss members lies between a range of 2 and 64. To the best knowledge, this will conclude that the steel trusses have enough residual capacity for reused and further application.

$$FOS = \frac{Design\ capacity}{Design\ load} \tag{1}$$

$$FOS_{new} = \frac{Reduce\ capacity}{Design\ load} \tag{2}$$

4.Conclusion and Recommendation

The findings of the investigation are:

1) There is no appearance of severe damage for reinforced concrete elements, except for spalling of mortar screeding found appeared in certain parts of columns and beams. No crack found on the concrete surface. Strength of concrete beams and columns have been estimated by using Schmidt rebound hammer test. From the results of the test, it indicates that the strength of concrete is still unaffected by the fire. It proves the finding of the physical inspection on the appearance of the concrete surface, i.e. no sign of degradation of strength of concrete in the building structure.

2) From the comparison of colour change on mortar and concrete surface, we can assumed the building experienced temperature in the range of 600℃ to 800℃. This is confirmed with the occurrence of corrosion on steel truss members which is similar to the occurrence of corrosion on steel coupon specimen when exposed to fire. From the full-scale loading test, it was found that the steel trusses are still strong. The maximum deflection of the trusses was very small, i.e in the range of 4 mm, compared to the span of the truss which is 14 m (deflection/span ratio of 1/3500, as compared to the maximum allowable which is 1/200). The small deflection is also an indication that there is no structural degradation of the truss members and connections, and proved that they are over-designed.

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