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Collapse of the 16-Story Plasco Building in Tehran due to Fire

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Abstract. On January 19, 2017 an accidental fire, which started by an electric shorting, resulted in the complete collapse of the 16-storey Plasco Building in Tehran. Twenty-two people including sixteen firefighters were killed in that incident. This paper reports the study carried out to investigate the most likely causes of the events and collapse of the structure. The information presented in this study was collected through gathering the limited amount of available information on the structure, generating as-built structural drawings, reviewing construction photographs, interviewing fire-fighters and other witnesses, frame-by-frame analysis of a number of available videotapes showing the structure during the fire as well as during the final stage of collapse. Based on these information and some engineering judgments, the paper summarizes the sequence of events from the start of the fire to final collapse, almost 3.5 h later, and the inferred scenario explaining how the structure collapsed completely. Recommendations are provided based on the lessons learned from that incident.

Keywords: Fire effects, Collapse scenario, Tall building, Progressive collapse

1. Introduction

The 16-storey Plasco building located in Tehran, the capital city of Iran, was known as the tallest steel building of the region, when its construction finished in 1962 (see Fig. 1). This building consisted of several retail shops, clothing workshops, and some restaurants.

As shown in Fig. 2, the building comprised of two parts, a 16 storey tower on the south side and a 5 storey building located on the north side of the complex. The two parts of the building were structurally separated. The Plasco tower had 15 storeys above the ground and one storey below the ground. Its total height above the foundation was approximately 60 m. It had a steel structure composed

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Figure 1. Plasco building in 1962.

of built-up members. The plan dimensions of the building were 29.4 m and 31.9 m.

On January 19, 2017 a few minutes before 8:00 a.m., the fire began accidentally in the 10th storey of the building due to a short circuit. Despite the efforts of fire-fighting squads, the fire spread to other storeys very quickly. After about 3.5 h, the building collapsed completely. As a result of the structural collapse, 16 members of the firefighting squad and 6 civilians lost their lives.

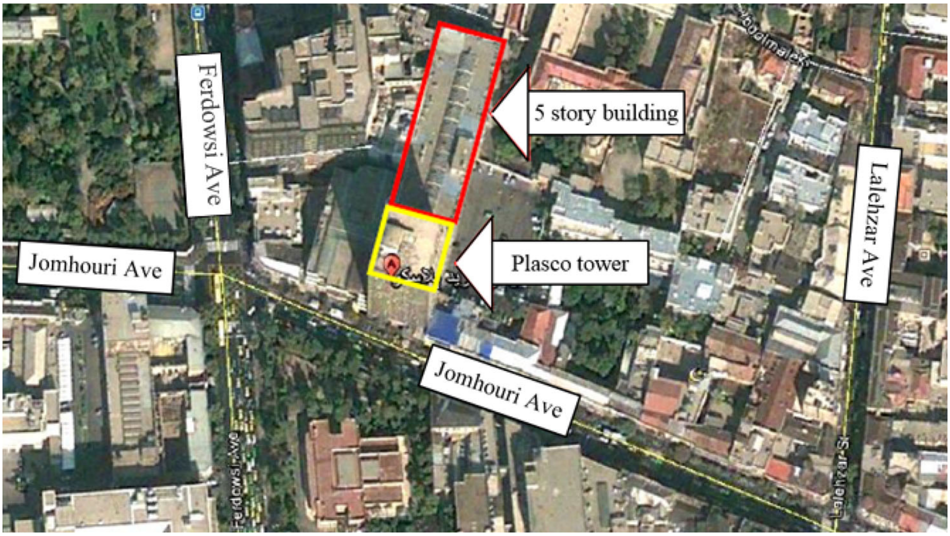


Figure 2. Location of the Plasco building.

After that incident, a national committee was assigned to investigate the incident and all relevant rules, regulations, procedures and actions or lack of actions by the authorities in charge, which led to this unfortunate incident. This committee formed several sub-committees to study the incident from different technical, legal and socio-economic aspects.

One of the sub-committees was assigned to investigate the reasons for building collapse from the structural engineering point of view. This work started by gathering the limited amount of information on the structure and generating as-built structural drawings. These included visiting the building site and the site in which the structural debris were kept after the incident. During site visits, any sign and evidence regarding damages to the structural elements such as the columns, trusses, joists, beams, and welds were investigated. This was followed by studying construction photographs and taking samples from the remaining of different elements of the structure found in debris. In order to establish the sequence of events during the fire, fire-fighters and other witnesses were interviewed. Also a number of available videotapes, showing the structure during the fire as well as during the final stage of collapse, were analyzed frame-by-frame.

This paper presents parts of the global investigation done by the above-mentioned structure sub-committee. The objective of the study presented here, is to establish the most likely sequence of the events, which led to final collapse of the structure. The architectural, structural and fire safety specifications of the building are described and then the most plausible collapse scenario is presented. It should be noted that due to the conditions of the building, as explained later, the analysis presented in this paper are based on engineering judgments and thus there may be some uncertainties involved. Nevertheless this study is of interest for structural engineers, since it helps to carry out the detailed structural analysis, which explain the exact mechanism of structural collapse of the building. In the last sections of the paper, some lessons learned from this incident are also discussed, mostly from a structural point of view.

2. Partial or Total Collapse of High Rise Buildings due to Fire: Literature Review

During past several decades, there have been many cases of fire incidents leading to partial collapse, and a few resulting in total collapse of tall buildings. In this section it is tried to briefly review some of the most important incidents, but those addressed here are not the only ones which happened to-date and they are not the exhaustive list of fires that led to collapse.

Fire incident in Triangle Shirtwaist Factory in Manhattan is considered as the deadliest industrial fire, which occurred in New York City on March 25, 1911. A fire broke out on the seventh and eighth floors of a 10-storey building. It started by a match or a cigarette, but tossed into a scrap bin. The fire spread rapidly, lasting only thirty minutes totally. The building survived the fire and was refurbished [1–3]. After that incident, wide-ranging legislation was passed to require improved factory safety standards.

The most catastrophic hotel fire in the history of the United States occurred in the early morning of December 7, 1946, in the 15-storey building of Winecoff Hotel located in Atlanta, Georgia. The fire point of origin was on the third floor. It was extinguished after 6 h. The fire in that hotel caused significant changes in North American building codes [4–6].

In 1974, a short-circuit in a faulty air-conditioner on the 11th floor of the 25 storey Joelma Building ignited a fire at 8:50 a.m., which reached the building only stairwell and travelled as high as 15th floor. It did not reach any higher floors, due to the lack of flammables in the stairwell. However, the fire rapidly spread in the lower storeys due to the existence of large amount of combustible materials, including paper, plastics, electrical equipment and wooden walls and furniture. By 10:30 a.m., the fire subsided. Two hours later, it had engulfed all flammables and burned itself out [7–9].

The Dupont Plaza Hotel Fire was the second most deadly hotel fire, which occurred in San Juan, Puerto Rico on new year's eve, December 31, 1986. The fire started in ballroom of 17-storey building of the hotel, ignited new furniture wrapping, furniture, combustible ballroom interior and partition, then flashed over ballrooms 9 min after ignition. This fire led to legislation requiring sprinklers in U.S. motels and hotels [10, 11].

The First Interstate Tower (a 62-storey structural steel office building) located in Los Angeles, California was on fire in 1988. Five floors (7th to 12th) were completely destroyed but the building did not completely collapse. The fire origin has been attributed to overloading of the building electrical system by reactive distortion of lighting circuit currents. About 4 h after beginning, the fire was under control [12–15].

The worst building fire in Hong Kong during peacetime occurred in 1996 in the 16-storey Garley commercial building. Welding was revealed to be the source of fire. At the time of fire, the Garley Building was undergoing internal renovation. The fire started in the second floor but after a few hours it reached up to the 15th floor. The building was in fire for about 20 h. The fire damaged the lower two floors and the top three floors of building [16, 17].

In 1999, a fire incident occurred on the 22nd floor of a 38-storey high-rise office building in Philadelphia, One Meridian Plaza. Due to the fire that lasted over nineteen hours, eight floors (22nd to 30th) were completely destroyed [18–20]. One Meridian Plaza building was completely demolished later.

The twin towers of the World Trade Center in New York City were hit by jet airliners hijacked by terrorists on September 11, 2001. Both towers collapsed due to the damage and fire caused by this impact. In that incident WT7 building, a nearby 47 storey tower, was also damaged by the impact of debris from the collapse of WTC1 and caught fire. After almost seven hours, the building completely collapsed [21–24].

An electrical fault was found to be the source of a huge fire in the Windsor Tower, an office building in the financial center of Madrid, Spain in 2005. The Windsor Tower was 106 m high and had 32 floors. The Windsor Tower was known as the eighth tallest building in Madrid and 23rd in Spain. The fire led to

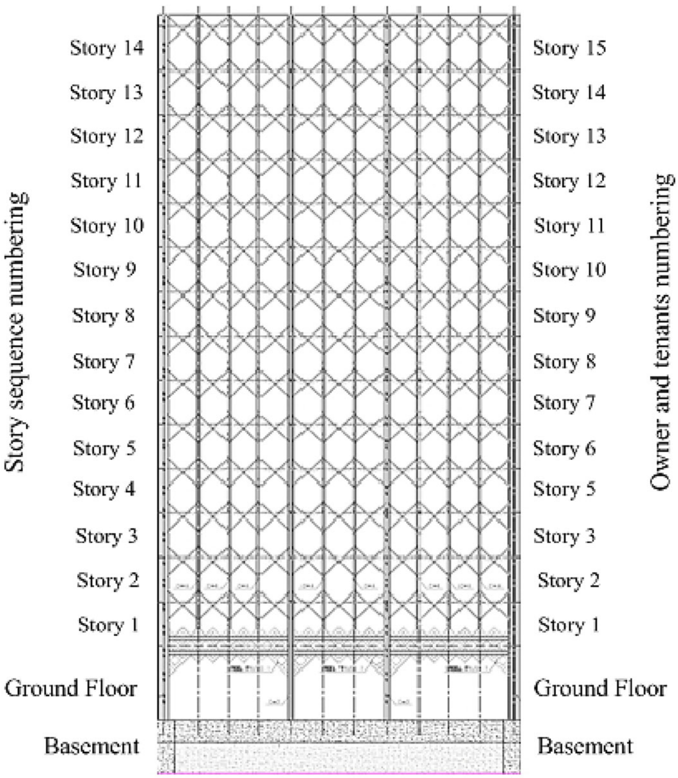


Figure 3. Storey numbering in Plasco building.

the complete collapse of the outermost of the steel structure. The building was totally demolished in 2005 [25, 26].

The 28-storey high-rise apartment building in Shanghai was destroyed in November 2010 due to fire. The fire began at 2:15 p.m. local time in the tenth floor. The building was being renovated at the time of fire. Sparks of welding work was identified as the source of blazing. The fire was contained at about 6:30 p.m. local time, more than four hours after it had begun [27].

3. Description of the Plasco Building

3.1. Architectural Aspects of the Building

The Plasco tower consisted of 16 storeys including an underground floor, a ground floor, and fourteen storeys above the ground. Figure 3 shows the elevation view of the building. On the left side of the figure, floors are labeled based on their sequence. However, the owner and tenants used a different numbering to designate the floors, as shown on the right side of this figure. In this numbering the basement, ground floor, and three storeys above it had the same number, but

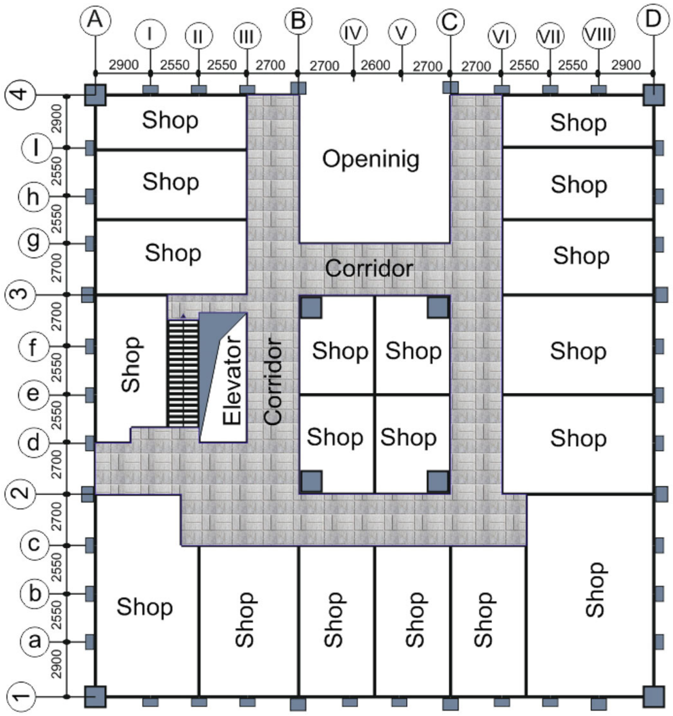


Figure 4. Artichectural plan of the second storey (unit: mm).

due to the existence of some units on the roof of the building located in the north of tower, the fourth storey of the tower was called Storey No. 5. Since all the reports published in media refer to the latter numbering, when the fire events are described, this numbering is used in this paper.

The building had a fairly simple architectural plan. Figures 4 and 5 show the plans of second and sixth storeys as the typical lower and upper floors, respectively. In the lower floors, which were used as shops, there was an opening in the center and continuous corridors existed around that opening for access to the shops. But in the fifth storey and all storeys above, which were used mainly as clothing workshops, there was no opening except for the staircase and lift shaft. Access to the storeys was provided by a stair and lifts located at the western part of the main tower. As it can be seen in the Figs. 4 and 5, the stair was a one-way ramp and its width was 1.6 m.

The exterior sides of the building were covered by steel structure facades in northern and southern sides and cement facade in western and eastern sides. The steel structure facade contained heavy steel members in various dimensions. The southern facade is shown in Fig. 6.

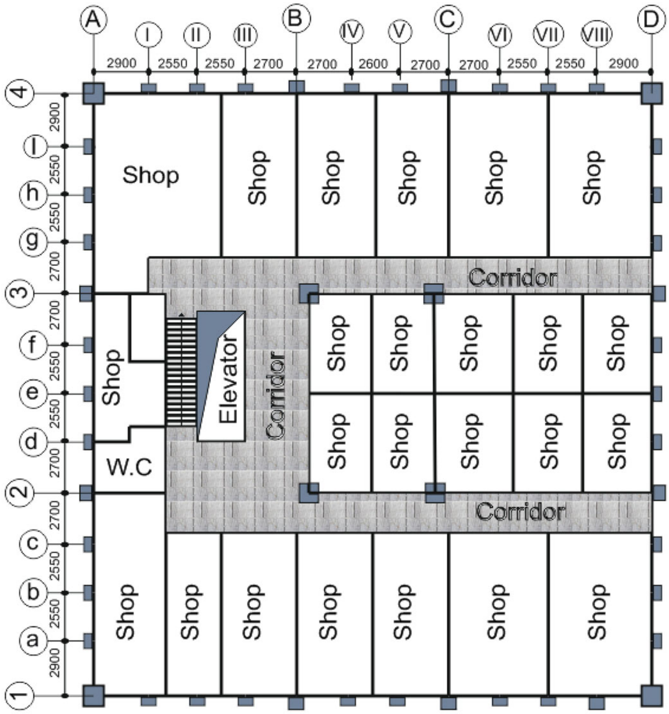


Figure 5. Artichectural plan of the sixth storey (unit: mm).

(a) Overall view **(b)** Facade members built up with heavy steel sections

Figure 6. Steel structure facade in south face of the building.

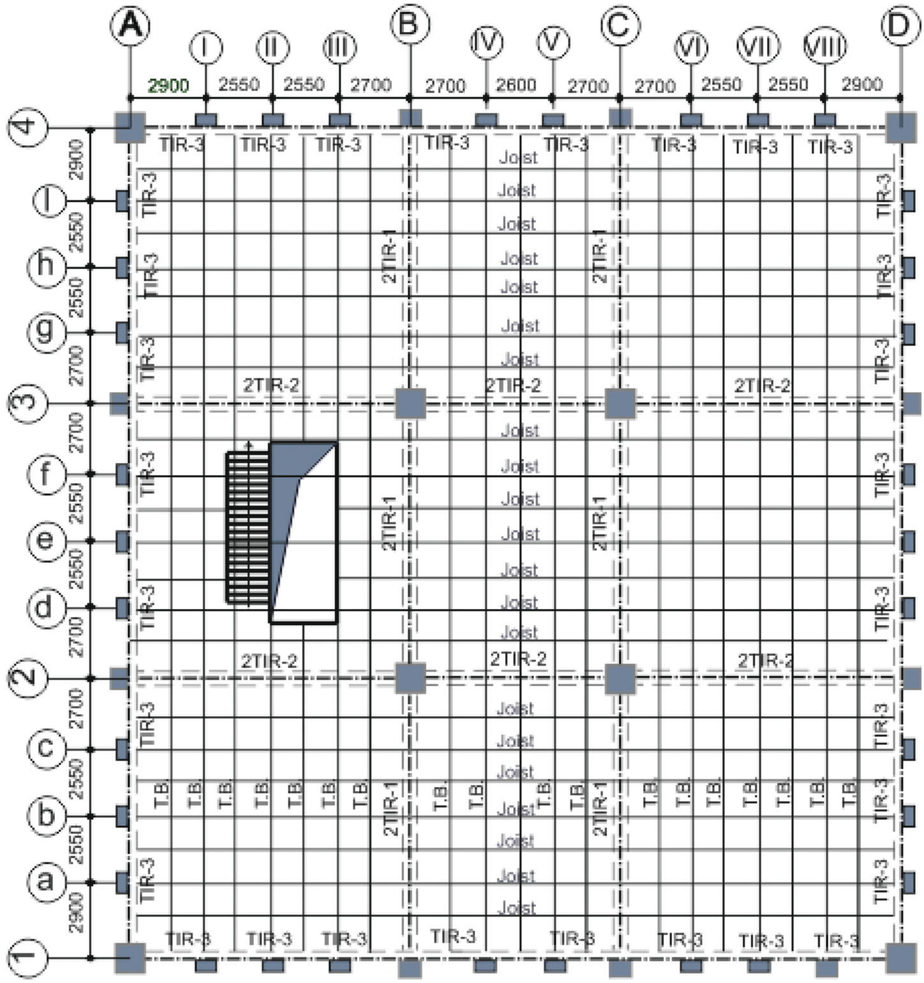


Figure 7. Typical plan of the structure (unit: mm).

3.2. Structural Aspects of the Building

Figure 7 shows a typical plan of the building. The framing of structure consisted of concrete members in the basement and steel members at all storeys above the ground. Concrete columns and beams in the basement had square and rectangular cross-section respectively reinforced with plain bars. Built-up sections were used in all steel members of the structure. Each corner column section consisted of four double channel sections. Steel box members were used to connect double channel sections of the corner column. The perimeter columns, which were located on the main axes of the building, consisted of two double channel sections, whereas other perimeter columns consisted of one double channel section only. The sections of the interior columns also composed of four double channel sections with a differ-

(a) corner column (b) interior column (c) perimeter column

Figure 8. Column setions.

(a) Joist (b) Girder

Figure 9. Floor joists and girders.

ent configuration compared to corner columns. The section of the diagonal braces also consisted of double channel sections. The photographs of the corner, perimeter, and interior column sections are presented in Fig. 8.

The floors contained a 13-cm thick concrete slab. The slabs were supported by open web joists and tie beams, which transferred the gravity loads to the truss type main girders. The global structural system was a semi framed-tube system consisting of only 4 interior columns and a number of closely spaced columns (see Fig. 6) with diagonal braces on the exterior face of the structure. The column spacing in the exterior tube ranged from 2.5 m to 2.9 m. In total, there were 46 perimeter and corner columns in the structure. Figure 9 shows photographs of typical joists and girders used in Plasco building. Both chords of the joists consisted of double angle sections. The joists also contained diagonal double bars, and vertical plates as the web. In the main girders, which were generally similar to the joists, the diagonal double bars and the double angle sections in bottom chord were replaced by diagonal plates and double channel sections, respectively.

Design documents of the building were not available for detailed investigation. However, the structure had surely be designed for gravity loads as well as some lateral loads pertinent to wind and seismic loads. But considering the age of the building and conventional design practice, while one could not be sure, most probably the structure was not designed for fire load.

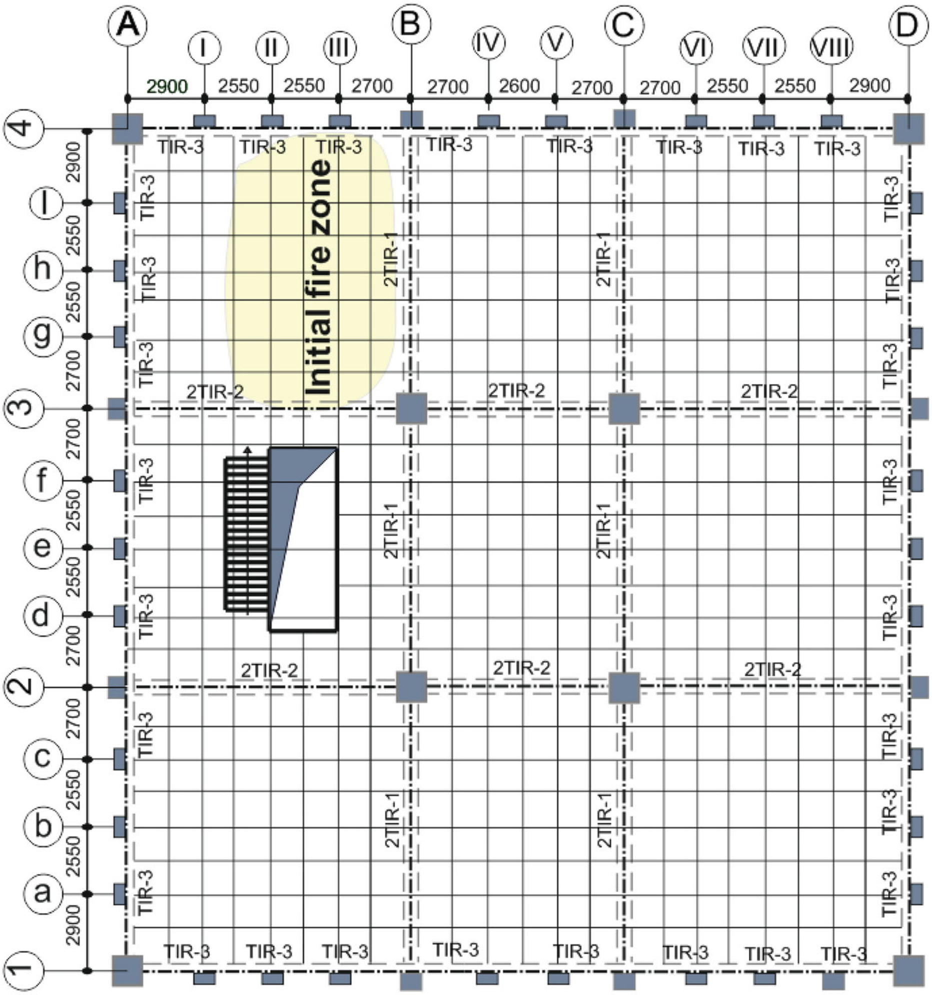


Figure 10. Fire initiation zone in the tenth storey (unit: mm).

3.3. Fire Engineering Aspects of the Building

As Plasco was an old building, unfortunately modern fire engineering standards were observed neither during construction nor during operations. As such the walls or doors in the building were not fire resistant. The main elements of the structure had no fire protection coating. Columns of the building were covered only by architectural coating consisting of gypsum boards and light concrete. Suspended ceilings were present in all floors. Light concrete slabs of the false ceiling were supported by bottom chords of the floors joists and girders, but there was no partitioning in the space between false and main ceilings. Also the building did not have any emergency fire escape stairs and only one main staircase adjacent to the elevators connected the storeys to each other (see Figs. 4, 5). This staircase

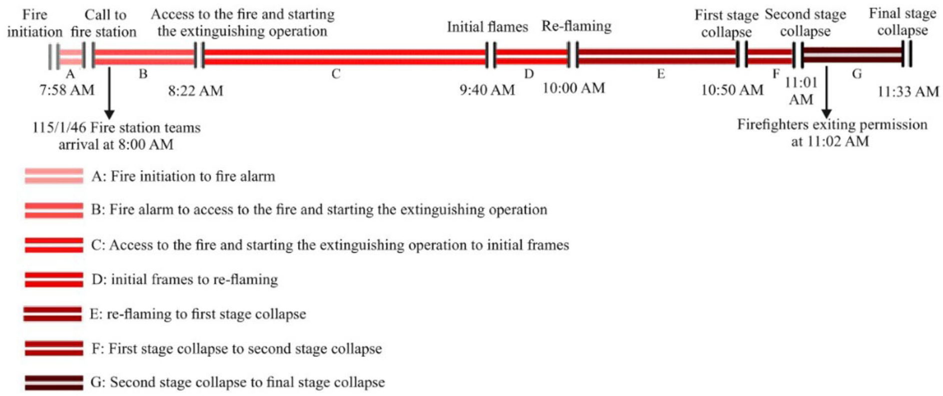


Figure 11. Timeline of the incident.

was open without a fire-resistant peripheral walls. There was no fire detection/alarm or sprinkler system in the building. Although there was a water hosing system for firefighting purpose in each floor, the firefighting squads stated that in the initial stages of firefighting operation, they faced malfunctioning of the system in the floor, where the fire had started.

In addition to normal architectural elements, there were large volumes of textiles and fabrics in the building due to existence of shops and workshops. They were much more than what is normally expected in the shops of a multi-storey building, hence the building contained significant fire fuel load [28].

4. Initiation and Progression of Fire

The fire started in north-western part of the tenth storey as shown in Fig. 10 [29]. The most likely cause of fire initiation has been said to be non-standard electrical wiring and short-circuit in a shop [28]. It appears that the workers in that shop initially tried to extinguish the fire, but as it got out of control, they called the fire station with some delay. As the main focus of this paper is investigating the structural collapse of the building, details of firefighting operations are out of scope of this presentation. However, the infographic presented in Fig. 11 briefly shows the events between fire initiation and final collapse [29]. This figure was produced using the statements of the firefighters, fire department records, available videos and photographs. As seen, the first group of firefighters arrived in site after about 2 min from first contact with the fire department. It should be noted that the nearest fire station was located only about 350 meters from the building. However, for some reasons, such as the fire location at upper storeys, one-way stair case, problems with proper fitting of fire hoses and etc., firefighting operations began 22 min after the arrival of the first team. The firefighters' statements show that at that time the fire had spread in north and western parts of the 10th storey and the whole floor was full of the smoke, so the fire could not be extinguished by the existing firefighting equipment. Also, firefighters stated that at the same time, fire was flowing through the lift shaft to the eleventh and possibly the twelfth storeys. This statement has been verified by the findings reported by fire engineering sub-committee of the National Committee [28]. Although it has not been possible to document the fire travelling events since then, their study indicates that the fire initially started to spread up to the fifteenth storey through the stair shaft without significant horizontal expansion. Also it has been said that simultaneously, fire extended to higher storeys through the windows of the north face of the building. Finally, a combination of many important factors, such as malfunctioning of the equipment, deficiencies in operations, lack of partitioning in false and main ceiling of the building, lead to fire travelling vertically and horizontally in the north and western parts of the storeys above 10th floor [28]. It has been reported that around 9:40 a.m. (about an hour and 40 min after the arrival of firefighters), the fire in the 10th and 11th storeys had been relatively controlled. But, at 10:00 a.m. fire re-flamed in those storeys, so despite the firefighters' efforts the fire got out of control and the first failure in the building occurred at 10:53 a.m. The progressive collapse of the building since then, is discussed in Sect. 5 in details. At 11:02 a.m., the firefighters were ordered to evacuate the building and firefighting operations were continued from the outside. However, as noted in the previous section, there were no escape stairs in the building, and some parts of the only existing staircase were lost in local collapse. Therefore, despite the order to evacuate the building, a number of firefighters were locked inside the building and unfortunately lost their lives during final total collapse.

5. Collapse of the Building

As indicated in Fig. 11, the building collapsed in three stages. This section tries to present an interpretation of these stages. Different steps described in this section are based on the evidences and engineering judgment. However unfortunately there is no evidence of what happened inside the building during the final stage of the collapse.

The surviving firefighters stated that in the first stage of the collapse, north-western part of the floor 11 (see Fig. 12) collapsed on the floor 10. Due to persistence of fire in this area for about three hours, this collapse must have been caused by the effects of rising temperature on the structural elements of the flooring system. As explained in Sect. 3.2, the slabs were supported by open web joists and tie beams, which transferred the gravity loads to the truss type main girders. Photos of these joists and girders were presented in Fig. 9. The webs and bottom chords of these truss type members were directly exposed to fire in the space between the main slab and false ceiling without any fire protection. According to firefighters those slabs had visible deformations before collapse. From the structural point of view the final collapse of the floor in that part must have been due to failure of the connections of main girders to the columns [30].

In the second stage, about ten minutes later, same part of the floors 12 and 13 also collapsed on floor 10. Obviously the floor structure could not support so much additional load and this caused partial collapse of the all lower floors

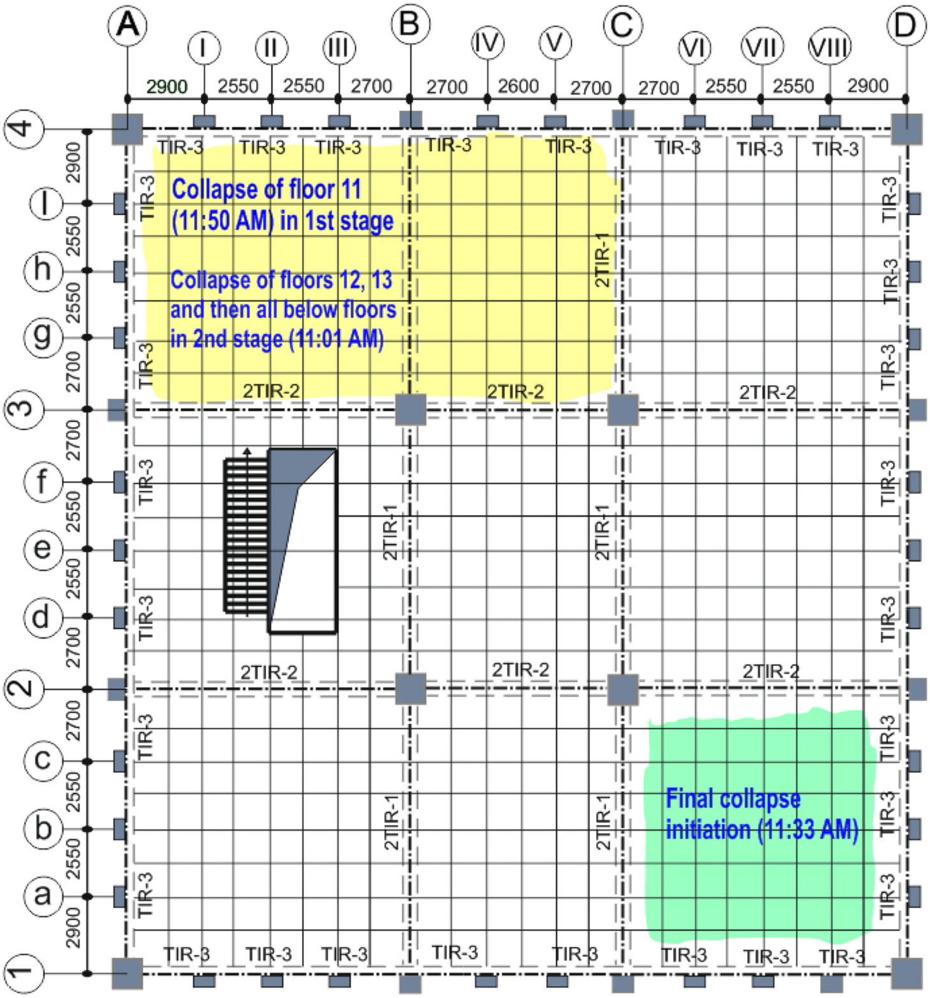


Figure 12. The collapsed area of floor 11 in the first stage (unit: mm).

(Fig. 13). Consequently, the area between the axes A-B-C and 4-3 were completely destroyed below the floor 13 and so a vertical void was created in that part of the building. Figure 14 shows the western view of the building after the second collapse stage showing the failure in the northern panels. As seen in Figs. 13 and 14, the collapse of mentioned floors has made the sky behind the building visible from the windows of the western elevation. This is while the sky is not visible at upper storeys and fire and smoke coming out of the windows indicate that floors of these storeys did not collapse.

After the second stage of the collapse, the building was still stable for about 30 min before final collapse. In order to determine the most plausible collapse sce-

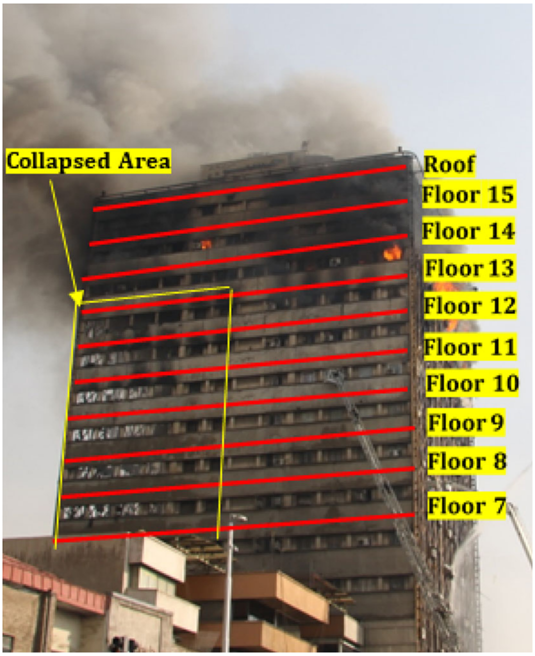


Figure 13. West elevation of the building showing the floors collapsed partially in second stage.

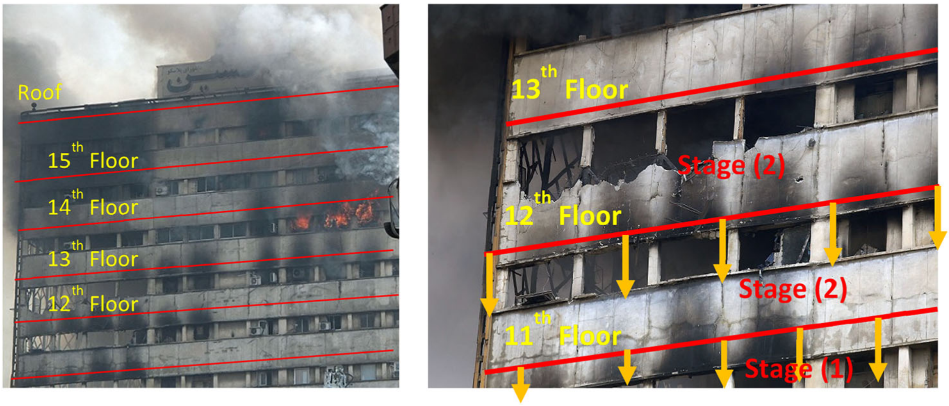
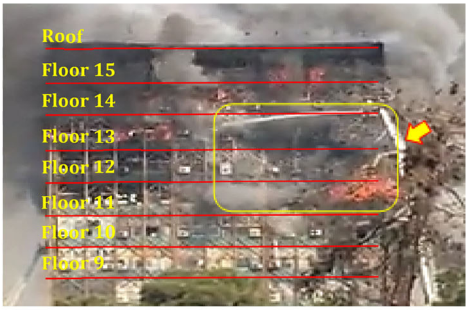


Figure 14. Closer view of west elevation of the building after first and second stage of collapse.

nario, after careful examination of all available videos and photos, three videos from three views (eastern, southern and south-western) were selected and studied frame-by-frame.

Figure 15. Appearance of the first fire bubble in the 11th storey.

(a) Collapse of the floor 12 (first bubble)

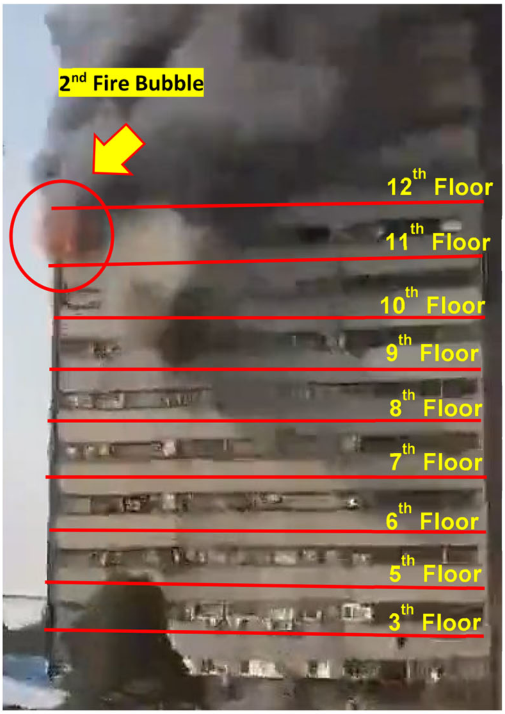


(b) Collapse of the floor 13 (second bubble)

Figure 16. Appearance of the first and second fire bubbles in the 11th storey in south view.

The observations revealed that a few seconds before the final collapse, two fire bubbles appeared with a time interval of three seconds in south-eastern part of floor 11. Figure 15 shows that the first fire bubble burst out in this area together with dust and smoke. It seems that this phenomenon has been due to collapse of the floor 12 on floor 11 in this part of the building. After about three seconds from the appearance of the first fire bubble, the second fire bubble appeared in the same area implying that the same area of floor 13 also collapsed on floor 11 (Fig. 16).

(a) S1



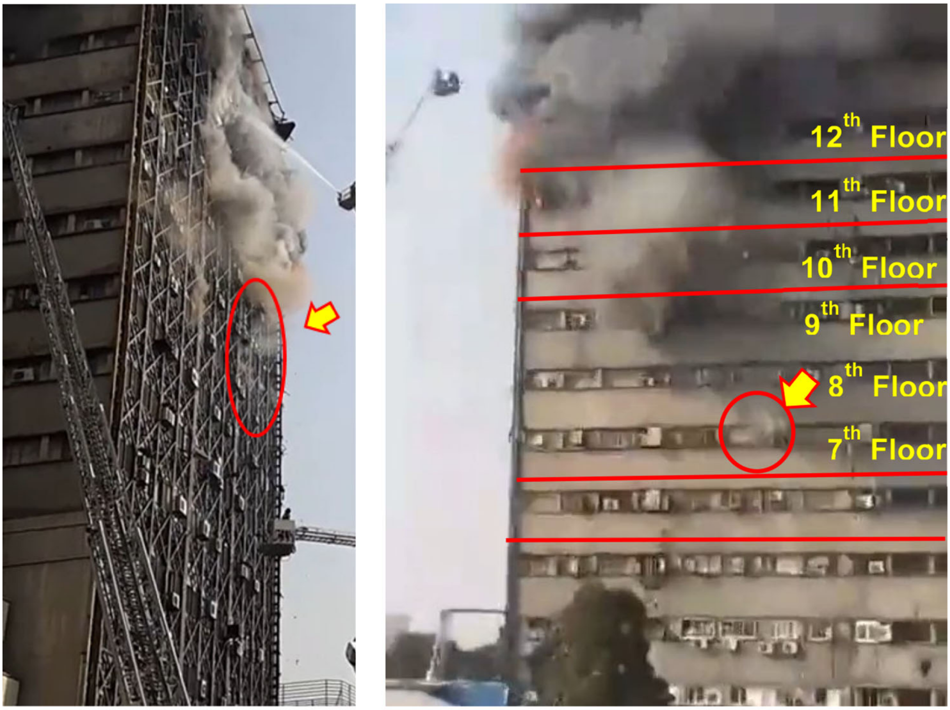
(b) E1

Figure 17. South and east views of the building; at the moment of the second bubble appearance.

After the local collapse in south-eastern part of floors 11 to 13, the progressive collapse of the building floors was initiated. Figure 17 presents the south and east views of the building, named E1 and S1, respectively, exactly at the time that the second fire bubble appeared.

Figures 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27 present the east and south views of the building at different stage of the collapse. Picture E2 in Fig. 18 shows smoke coming out of the window in floor 7, whereas no smoke or dust is observed in E1. This is related to the collapse of the floor 8th in C-D-2-3 area. It should be noted, what is seen in Fig. 17 (E1) is the smoke that has already got out of upper floors and has reached around floor 7, so it is not the dust coming out of windows of floor 7. Comparing the dusts in pictures S2 and E2, it can be understood that the collapse of the floors have likely progressed in the area between the axes C-D-2-3 and B-C-1-2. But it is unlikely that at this time, the floors have collapsed in the area between the axes C-D-1-2 in the south-eastern corner of the building.

Figure 19 shows that at about 0.83 s, there was no new collapse, compared to 0.42 s.



(a) S2 (b) E2

Figure 18. South and east views of the building; about 0.42 s after the second bubble appearance.

The picture E4 in Fig. 20 indicates that the collapse of the side panel of the building, (C-D-1-2), occurred in floor 8 at about 1.25 s. Simultaneously, the picture S4 shows the smoke coming out of floor 3 in the panel of A-B-1-2 but considering the conditions of the windows of west part, an absolute judgment cannot be made about the collapse of the floors in that area.

Figure 21-E5, from the east part, shows that the collapse in the middle panel, C-D-2-3, has progressed to the floor 6 and similar events have also occurred in the panel of C-D-1-2 of the floor 8. In simultaneous images of the south part, picture S5 shows the collapse in panel of A-B-1-2 on the floor 3.

As seen in picture E6 of Fig. 22, the collapse on the east part of the building in panel C-D-2-3 has progressed to floor 4, but in the panel C-D-1-2, collapse has continued to floor 5 and the progression of collapse is still with a delay in this area. The same collapse as presented in previous photographs can be observed with greater intensity in picture S6 of Fig. 22 and no sign of a new collapse is identified.

The next stage of the collapse, at about 2.50 s after the second bubble appearance is presented in pictures E7 and S7 of Fig. 23. The collapse in panel C-D-2-3 on the east side progressed to the ground floor and in panel C-D-1-2, the floors

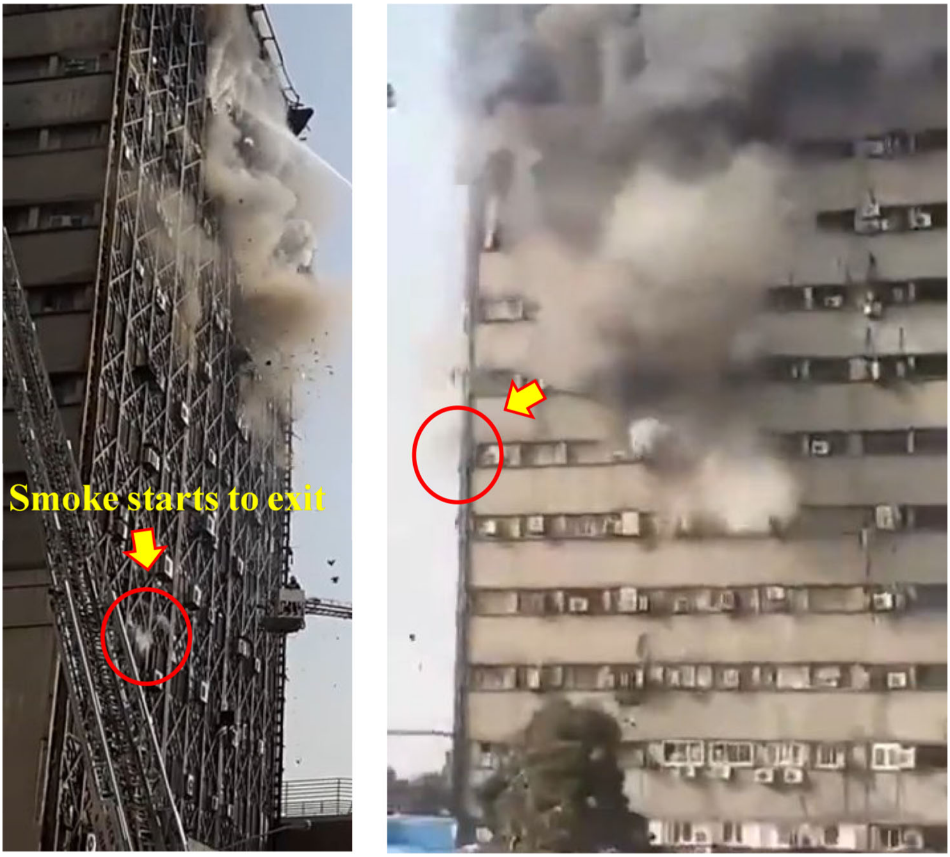
(a) S3 (b) E3

Figure 19. South and east views of the building; about 0.83 s after the second bubble appearance.

collapsed down to floor 4. These observations confirm that the collapse of the panel C-D-1-2 occurred with the same pattern as that occurred in panel C-D-2-3 but with a delay of two floors. In the south part of the building, collapse progressed down to floor 3 at this time.

After above mentioned observations, up to about 3.33 s after the second fire bubble, no new important event was observed but at this moment, a non-uniform deformation began to form in the eastern view of the building, as shown in picture E8 of Fig. 24. This deformation implies the start of instability of the southern part of the structure. At the same time, an out-of-plane movement of the building facade occurred in the upper parts of the south side of the building, noting that the collapse had not progressed to lower floors in the south side (see picture S8 of Fig. 24). Figure 25 shows non-uniform deformation of the east elevation a few moments before the final collapse and Fig. 26 shows the final collapse of the building.

Based on above, the first and second collapse stages occurred in the north-western part of the building and the third and final stages of collapse started in the south-eastern part of the building and then propagated to the whole building. The probable mechanism of the final collapse of the building can be explained using a video file showing the moments of the final collapse from the south view of the building. Figure 27a shows the south view of the building just after the appearance of the second fire bubble, while Fig. 27b shows the same view after a few moments.



(a) S4 (b) E4

Figure 20. South and east view of the building; about 1.25 s after the second bubble appearance.

Comparing the two pictures of Fig. 27 shows that, a significant deformation has occurred in the structure just in less than three seconds. In Fig. 27b, in addition to overall deformation of the structure, a considerable deformation can be seen in column C1. Figure 28a shows the location and schematic section of this column. As seen, column C1 was a built up section composed of two welded boxes. A close look at the final progressive collapse reveals the separation and buckling of these two individual components (see Fig. 28b). In other words, the column C1 is divided into two segments with a single box section and each section has buckled instantly after the separation. These breakdowns could have occurred for several reasons. In fact, the girder of axis C-1-2 was composed of two adjacent truss beams, each of which was connected to one of the column boxes and as can be seen in Fig. 28a, these trusses have different tributary areas. As the temperature increased, simultaneous with the strength deterioration of the welds of the stitches

(a) S5 (b) E5

Figure 21. South and east views of the building; about 1.67 s after the second bubble appearance.

between the column segments, there was a significant increase in the beams deflection due to the reduction of the Young's modulus of steel materials. The excessive deflection has caused the catenary action in the truss girders. Catenary action refers to the ability of girders to resist vertical loads through formation of a catenary-like mechanism, which is associated with development of large deformations in girder so that vertical loads are mainly resisted by the vertical component of axial force developed in the girder [31]. These phenomena, along with the impacts due to the falling of the floors 12 and 13 on the floor 11, ultimately have led the truss beams to pull the column C1 inwards.

The difference in the amount of these tensile forces due to different beams tributary areas, could have created a severe shear demand in the weakened welds of the stitches. All of these events eventually led to the failure of the mentioned welds and so, the separation of the column into two individual components. It should be noted that at this time these segments have already lost their lateral bracing in the direction normal to axis 1, because of the collapse of floors 12 and 13 without losing them in plane of this axis. Dividing the column into two parts, increasing the slenderness ratio of these parts, the reduction of the mechanical properties of the materials simultaneous with the applied forces caused by the

(a) S6 (b) E6

Figure 22. South and east views of the building; about 2.08 s after the second bubble appearance.

catenary action resulted in the buckling of each segment of the column C1 about axis 1. Consequently, the overall instability of the structure began with this column. It should be kept in mind, since the buckling of the column C1 has occurred around axis 1 (out-of-plane the axis 1), the bending deformation of this column is less visible in the southern view shown in Fig. 28b.

Figure 29 presents the damage to the perimeter columns and the collapse of the floors from the south view of the building. Examinations of the available videos showed that in the final stage of the collapse, although the floors and side walls of the building were fully destroyed, the main four middle columns of the building remained stable for few moments and then overturned one by one. Those four middle columns, namely columns C2, C3, B2, and B3, apparently did not suffer major damage till the last moments of global collapse. Figures 30, 31 and 32 show the falling sequence of the middle columns. A top view of the collapsed structure including the locations of the collapsed central columns is shown in Fig. 33.

As noted previously, the loss of lateral bracing of the perimeter columns due to the collapse of floors 12 and 13 simultaneous with the catenary action of the truss girders of floor 11 are likely to be the major sources of the buckling of the

(a) S7 **(b)** E7

Figure 23. South and east views of the building; about 2.50 s after the second bubble appearance.

perimeter columns. The buckling and collapse of the perimeter columns finally led to the general instability and collapse of the whole structure.

6. Lessons Learned and Recommendations

This paper presented a reconnaissance/forensic report of the Plasco collapse incident and as such in this section it is tried to discuss some lessons learned from this incident and some recommendations that can be made qualitatively. The incident once again revealed that many old buildings, in which regulations regarding fire safety is not observed, are prone to major damage and disaster may occur if a fire gets out of control. Third chapter of the Iran National Building Regulations is devoted to fire safety standards in design and construction of new buildings [32]. This is an up-to-date standard prepared with due consideration of international documents [33–38]. But even its first revision, came to effect only seventeen years ago. Also twenty-second chapter of Iran National Building Regulations [39] is devoted to the maintenance of existing buildings, in which some sections specify minimum requirements regarding fire safety standards. However, as explained in previous sections of this paper, in this building none of above standards were strictly followed.

(a) S8 **(b)** E8

Figure 24. South and east views of the building; about 3.33 s after the second bubble appearance.

Figure 25. Non-uniform out-of-plane deformation a few moments before final collapse.

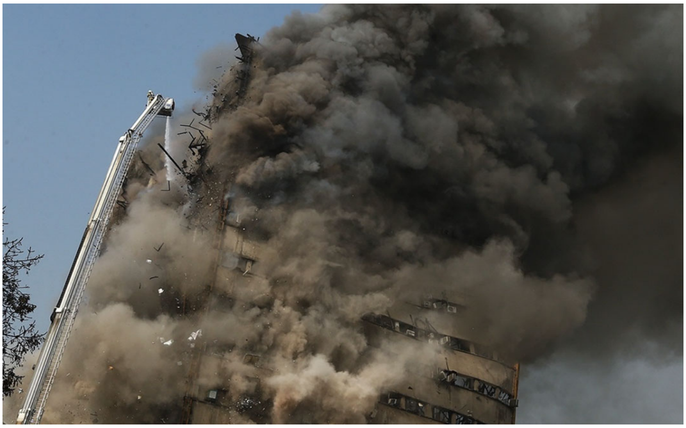


Figure 26. Final collapse of the entire building.

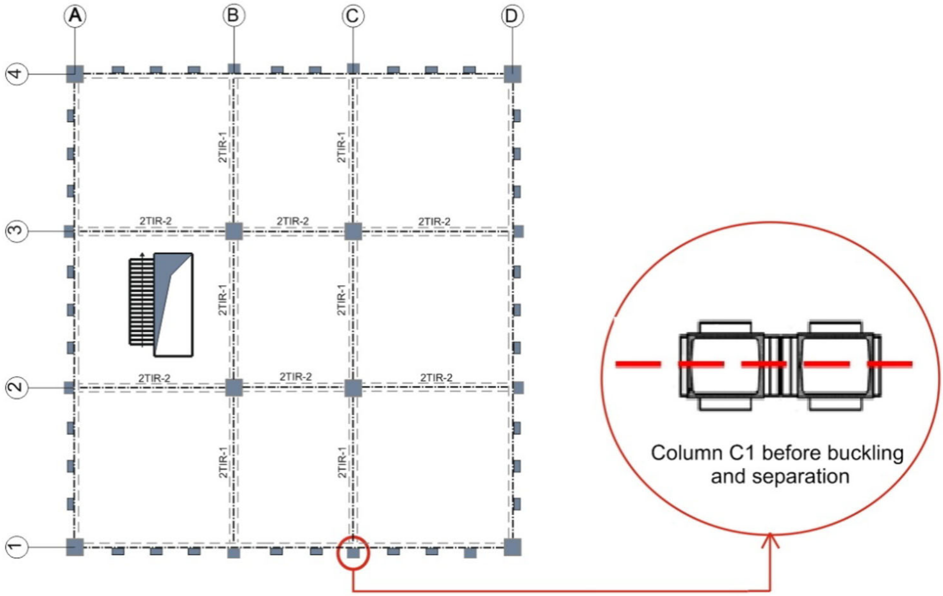
(a) After the appearance of the second fire bubble

(b) Decoupling of the two parts of column C1

Figure 27. Southern view of the building a few moments before final collapse.

Therefore combination of significant fire load, lack of sprinkler system, malfunctioning of the firefighting water supply, and non-compartmentation of different parts of the building were the main causes of spreading of fire to other sections and storeys [28]. Existence of only one stairway and absence of an escape one, resulted in limited access to higher floors and hampered firefighting activities. In addition, it caused the trapping and loss of the lives of a number of firefighters, which highlights the need for second stairway in buildings.

Structural specifications of the building, as explained in Sect. 3.2, and lack of fire proof coating on structural elements resulted in main elements of flooring system to be easily exposed to fire. As they were not designed for rising temperature and its effects on mechanical properties of steel, initially the flooring system and subsequently the global structural system showed a fairly short endurance time to



(a) Column C1 before collapse

(b) Column C1 after collapse

Figure 28. Damage to column C1.

Figure 29. Progressive collapse of the south view of the building.

fire conditions. The three-stage collapse of the building lasted about 40 min. It should be noted that considering the architectural specifications of this building, if the incident had happened at a time that more residents had been in the building, fatalities would have been much more severe.

The incident indicated that similar buildings, i.e. the old existing buildings, need to be surveyed urgently and minimum fire safety regulations must be enforced in them as a matter of urgency. With regard to structural aspects, vulnerability of this type of buildings to local and progressive collapse should be assessed. Based on this assessment, the level of retrofit activities on architectural, structural, electrical, and mechanical systems should be determined.

Apart from existing buildings, there are some lessons to be learned from this incident with regard to new buildings. The need for strict compliance with new regulations regarding architectural aspects and fire protection of building is well confirmed in this incident.

Another point, which is highlighted in this incident, is the need for high degree of redundancy in high rise buildings as well as their high resistance against progressive collapse. Therefore for this type of building it may be preferred to design the structure for fire conditions by advanced methods of analysis instead of simple methods (Appendix 4 of AISC 360-16 [40]). A performance based design, in which

Figure 30. Appearance of the columns B2, C2, C3 and the collapse of the perimeter columns.

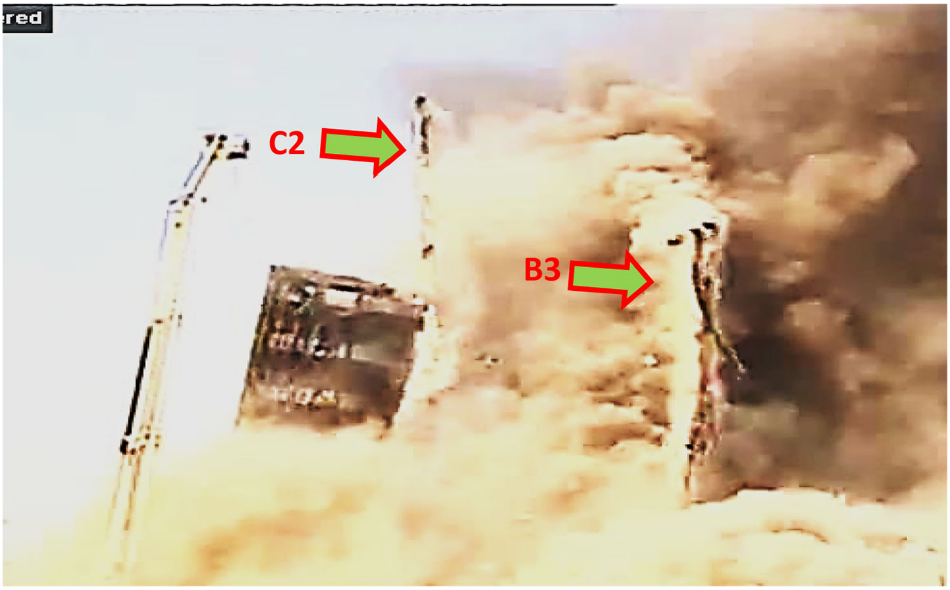


Figure 31. Overturning of column B3 to east direction while column C2 is still remained.

Figure 32. Overturning of column C2.

the structure is checked for intended performance objectives based on probable event scenarios may be very beneficial [41].

Finally the need for education about fire safety may be stressed here. General public education would have helped awareness of the building inhabitants about the vulnerability of the building and possibly taking action to promote its safety. Also more detailed and specific education in the field of fire engineering and effects of fire on structure would have helped the officials in the local municipality and firefighting organization to better assess the fire hazards in this building and to take action in stopping building occupancy.

7. Summary and Conclusions

In this paper, the fire incident in Plasco building located in Tehran was described. Different aspects of the specifications of the building were reviewed. Shortcomings of architectural, structural, and fire safety details were briefly discussed.

Detailed review of the events indicated that the building collapsed in three stages over a short period of time less than an hour. The structural failure was initiated in the flooring system and girder-to-column connections and followed by an overall instability of the structure and total collapse of the building.

Lessons learned from this incident are multidisciplinary. Promoting safety engineering education, updating design, construction and maintenance standards, improving operation procedures are among those lessons. There are also some lessons from structural engineering point of view, which have been highlighted in this paper. These lessons should be used in assessment and retrofit of existing buildings and design of new ones in future.

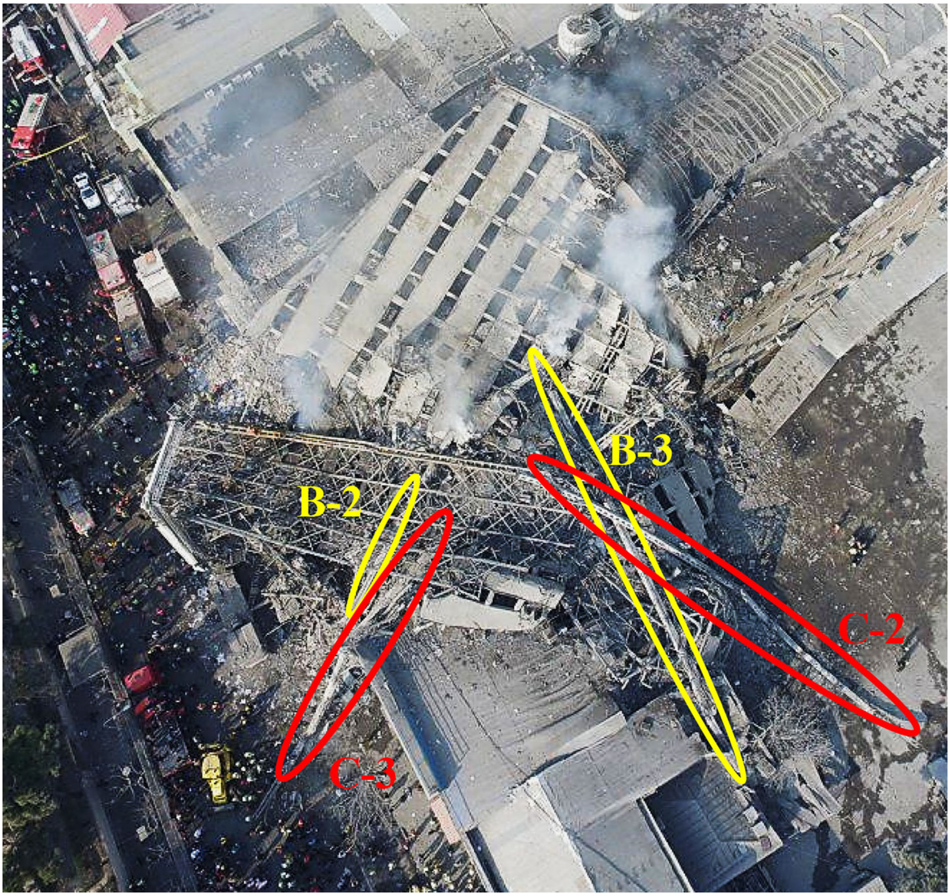


Figure 33. Top view of the collapsed building with the locations of the four middle failed columns.

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