J Inno Sci Eng, 2024, 9(1):118-133

DOI:https://doi.org/ 10.38088/jise.1617193

Research Article

Damage Assessment of Urban Interface Masonry Buildings after a Severe Wildfire along with a Comparison of NRC-2018

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ARTICLE INFO

Received Date: 14/01/2025
Accepted Date: 18/02/2025

Cite this paper as:
Soyer, A. and Ghatte, H.F. (2025). *Damage Assessment of Urban Interface Masonry Buildings after a Severe Wildfire along with a Comparison of NRC-2018.* Journal of Innovative Science and Engineering. 9(1): 118-133

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Keywords:
Buildings
Damage
Failure mechanism
Masonry
Wildfire

ABSTRACT

The wildland-urban interface (WUI) has emerged as a focal point of wildfire management and community resilience efforts worldwide. The WUI, defined as areas where settlement reaches natural landscapes, presents a unique set of challenges for wildfire mitigation. On the other hand, the performance of the buildings throughout the fire and the provision of proper fire safety measures for structural members is one of the essential aspects of the design of buildings and infrastructures. This study attempts to emphasize the seriousness of the wildfire effects on the WUI in the Mediterranean neighborhood, especially in Turkey. For this purpose, the efficiency of the extreme heat throughout the wildfire on masonry buildings in Manavgat, Turkey (July-August 2021) was investigated in terms of performance and structural damages. Failure mechanisms and the damages that occurred during the wildfire are reported for masonry buildings as the main structural system in this neighborhood. Commonly used technical documents of a national guide for WUI fires presented by the National Research Council Of Canada (NRC- 2018) were employed to compare the condition of the buildings. Turkish standards do not cover wildfire conditions in terms of the WUI buildings. The influences of the materials, the type of cladding, and various types of roofs were investigated in masonry buildings. For this purpose, 121 masonry buildings in Manavgat, Turkey were examined in terms of performance and damage. Furthermore, a comparison of the data with WUI-NRC (2018) is represented to investigate some serviceable recommendations based on the investigation to reduce damages in buildings subjected to wildfire. Finally, an introduction to have detailed written local WUI regulations for masonry buildings to have enough safety in terms of life and economy.

1. Introduction

During the dry seasons, worldwide is subjected to combustible vegetation which can destroy everything. Minimizing the risk to human lives as well as improving the engineering measures of resistance of buildings to the effects of intense radiant heat, burning embers, and flame contact is a vital topic. The outcomes are reducing future property repair, reconstruction costs, and other costs of residential displacement. Furthermore, improving public health, especially those related to deaths, non-fatal injuries, and posttraumatic stress disorder, fewer job losses, and some job creation. Generally, the measures that are recommended to improve the wildfire resistance of buildings typically focus on the materials, design features, and fuel sources close to the building. A series of factors influence wildfire that it is not easy to keep under control, such as weather conditions (wind in terms of speed and direction; humidity; temperature) [1]. Wildfires can destroy the buildings and infrastructure of a subject community. On the other hand, several factors can influence building through wildfires, including its location, the material's flammability, and the design and building materials [2].

In the wildland areas, fire protection of the buildings is one of the main issues. So many design codes consider the safety of the buildings in case of fire, however, the current design codes and investigations in the field of construction and structural systems are mainly based on dead load, live load, wind, and snow as well as seismic actions to improve their performance for these purposes [3-5]. Another main issue is the consideration of fire since the ability of the construction materials to maintain their strength and the structures to preserve their stability throughout the fire have the same importance as well. Not only the investigations related to building damage in wildfires are superficial and extremely limited but also there are no recommendations based on the current design regulations [6]. The main focus in literature in the field of the performance of buildings during a fire is the use of models of buildings as well as the examination of conditions exposed to the fire [7-9]. Improving the performance of structural panel core materials against fire has been investigated by Li et al. [7] and the results showed the use of flame-retardant adhesives can lead to a proper safety level of fire. The effect of geometry and dimensions on the upward fire spread in U-shaped structures has been investigated by Chen et al. [9] and the study provides a guideline for the fire protection design. In another investigation, the performance of a steel structural system has been evaluated by Bailey et al. [10] in terms of structural stability. The tests showed that existing fire codes are not addressing the proper building behavior during a fire and, consequently, are highly conservative. Similarly, an investigation has been conducted by Wald et al. [11] based on the distribution of forces within different structural members of a steel-concrete composite frame construction through the fire test. The results demonstrate the performance of the structures subject to real fires is generally better than that predicted by standard tests. Foster et al. [12] investigate the thermal and structural performance of a full-scale composite building subject to a severe compartment fire. The output of the extended sensitivity studies showed the influence of extra protection on the connection areas of the beams, and the efficiency of different types of supports. As mentioned before the damage assessment of the buildings mainly focused on earthquakes in the literature [13-15]. However, the detailed damage assessment studies provide examples of deficiencies observed in various buildings not only in structural elements but also in nonstructural elements. On the other hand, the countries are updating their codes and standards by introducing performance-based fire safety design provisions. Considering the fire protection and materials as well as the modeling by using different methods, a series of studies have been done to estimate or understand their performance throughout the fire [16- 19]. A group of investigations has been done on the structural performance and behavior of the structural elements tested in terms of flexural and shear responses of prestressed concrete elements under fire conditions, as well as the fire behavior of hollow-core concrete slabs [20 and 21]. As an output of the parametric study, the authors proposed a simplified approach for evaluating the shear capacity of slabs under fire conditions. Furthermore, the numerical and experimental results demonstrate the fire performance of HPLWC hollow core slabs influenced dry curing conditions in reducing the spalling as well as growing the fire resistance capacity [21]. In the case of the high-temperature effects on masonry and stone building materials, Gomez-Heras et.al. [22] tried to show the need for the immediate effects and the long-term management issues of natural stone buildings that have experienced a fire. Similarly, Vasanelli et.al. [23] investigate the efficiency of the high temperature on stone building materials. The outputs were mainly in terms of compromising the aesthetic features of the tested stones, through the color changes.

Considering the density distribution of fire loads, Barnett et.al. [24] conducted a study in school buildings and statistical modeling. The results suggest that fire load selection for design should be better based on local data and a careful review of the unified approach in the international fire engineering guidelines is warranted.

As a result of the increase in urbanization and development in the wildlands, the risk of wildfire and associated hazards will increase as well. Therefore the Wildland-Urban Interface (WUI) regulations and guidelines are indispensable subject matter where developed lands meet or intermingle wildland vegetation. Otherwise, the constructions and structures will be subjected to a higher risk of wildfire and associated hazards. Various regulations have been developed and implemented to mitigate these risks to manage WUI areas. The main objectives of the National WUI guide considering construction are not only to prevent ignition but also to reduce the risk of wildfire in WUI areas by promoting fire-resistant building practices and managing development [25 and 26]. Satisfying the National WUI Guide's recommendations appears to offer benefits that greatly exceed its costs. The benefits come from avoiding future property and life-safety losses. Among the documents for approaching the various aspects of wildfires, one of the common guidelines for the wildland-urban interface areas is presented by the National Research Council Of Canada (NRC) in 2018 [25]. NRC 2018 represented a national guide for WUI fires; a document for use by qualified experts. In addition, standard test methods for resistance to wildfire penetration of door assemblies, and exterior windows are represented [27-30]. The Turkish standard (regulation on fire protection of buildings-2007) presents documents for fire prevention and extinguishing measures to be taken in all kinds of structures, buildings, facilities, and indoor or outdoor establishments in Turkey without any recommendation related to the wildfire condition [31]. Among the effective factors for ignition in Turkey, and all over the world population density, distance from the roads, close to residential areas, elevation, and intensive human activity are the main reasons. Furthermore, the weather conditions and strong winds during the dry seasons are the main reasons for the spreading of wildfires [32 and 33].

In light of the above-mentioned literature review, it is crystal clear that understanding the effect of fire on existing buildings and materials nowadays is one of the most critical topics considering climate change and wildfires all over the world. Furthermore, a deficiency in better understanding and characterizing the effectiveness of different mitigation actions related to individual building features and community layout on the resilience of a WUI community to fire is another issue. In this paper, the results of 121 masonry buildings in Manavgat, Turkey were examined in terms of the performance and building damage conditions exposure to the wildfire. Furthermore, the behavior of different construction materials is investigated based on the deadliest wildfires that occurred in Turkey in July-August 2021. On the other hand, another vital topic after a wildfire is the seismic performance of the existing buildings considering the efficiency of fire on the material and different elements of the buildings. View the fact that the behavior of the building's structural systems will not be the same before and after wildfire if they are subject to seismic actions and the structural systems should carefully control and check after a wildfire. The differences in construction practices between Canada and North America and Turkey reflect different cultural, economic, and historical parameters. Although both regions consider a high priority on building safe and sustainable structures, materials and design codes can vary depending on local conditions and practices. The technical documents of a national guide of WUI were employed in this study to clarify more details of the condition of the buildings. The local recipes had a great impact on relief during the last wildfire in Manavgat, Turkey in terms of general rules and limitations for the access lines and keeping the fire under control. However, the lack of detailed written regulations for WUI buildings and infrastructures in Turkey is a necessity to have enough safety in terms of life and economy. Therefore, it seems establishing a basic guideline for wildfire and protection methods, especially in Turkey will prevent or reduce the efficiency of wildfires on buildings.

2. Buildings and Construction Materials in Fires

Lightning, damaged power cables, and people's activities are the main reasons for a wildfire that can spread uncontrollably, destroying a large residential area. The performance of a building subjected to fire relies on different parameters, including materials, temperature improvement, and the continuance of fire. A nominal fire is represented as a curve of gas temperature with time (e.g., ISO 834-1). A simplified method can be employed for the prediction of the gas temperatures, such as one or two-zone models. Nominative fires are usually used for design purposes. In structural design, fire is treated differently all over the world, where the material is so talented to burn the efficiency is considered higher than in other places where this capacity is not that high. Buildings exposed to fire loads mainly are examined in the ultimate conditions, and it is sufficient to only analyze parts of the building without the need to examine the whole generally without consideration of wildfire. The above-mentioned analysis and the studies related to the analysis of characteristics of the WUI area could help managers to figure out the specific fuel treatment and thinning prescription development [34].

In the case of construction materials, any standards have a summary of the properties, behavior, and strategies represented to improve the resistance of fire for any construction materials composing the structural systems of the buildings. The efficiency of a fire on the performance of materials can also be identified as the effects of fire actions directly and indirectly. In the following section, the behavior of concrete, steel, timber, and masonry materials was discussed mainly in terms of building materials. On the other hand, the main difference between the structural damage caused by normal fires and wildfires is in terms of intensity heat and duration. The wildfire duration, heat, and intensity are generally more than normal fire and mainly can be kept easily under control.

2.1. Concrete and Reinforced Concrete Expose to the Fire

The behavior of concrete is directly related to aggregates, cement, and water. For reinforced concrete, the behavior of rebars will be another issue. The low thermal conductivity caused it to be considered to be non-combustible. Below 500 ◦C the temperature of concrete is not affecting on concrete strength while above 500 ◦C, the compressive strength of concrete begins to reduce based on the direct fire effect. This reduction of strength is higher in the case of high-strength concrete. In terms of modulus of elasticity the same condition is happening and it will reduce with an increase in temperature, mainly at temperatures lower than 200 ◦C. By cooling down the temperatures of concrete, it starts to regain the main part of its strength. Rebars are protected by the cover concrete if it is still in place. The critical consideration is by spalling the cover this efficiency cannot be available anymore. When they are exposed to fire, their yield strength is reduced dramatically above 400 ◦C. When rebars cool down, they regain the main part of their strength [24]. The color of the concrete after exposure to the fire can give a good estimation of the temperature of the surfaces. Although there is no real color change below 300 ◦C, above 300 ◦C, and below 600 ◦C, the color can be almost pink; between 600 and 900 ◦C, the color can change to gray; and above 900 ◦C it is buff-yellow. Smutting of the concrete can appear even below 300 ◦C. By increasing the temperature if thermal expansion is restrained the probability of the large axial forces will increase. Spalling of the cover concrete is the main damage type that can occur in reinforced structures and cause the corrosion of rebars. The pore pressure in the cement paste is the main reason for this phenomenon. Diagonal cracking in continuous beams, sagging of beams and slabs, and cracking of columns are other kinds of damage. It should be noted that by increasing the cover thickness the protection capacity of the rebars increases. Additionally, using fire-resistant materials can increase the capacity and safety of the buildings exposed to fire.

2.2. Masonry Buildings Expose to the Fire

Generally, masonry buildings had better performance than reinforced concrete, steel structures, or timber structures while exposed to fire. This leads to flaking and discoloration of the layers especially the outer layer generally happening in the masonry building exposed to high temperatures. The material that has low porosity experiences more disruption than the material with is porous. Bricks above 400 ◦C experience decreasing strength as well as the modulus of elasticity. The direct fire action is based on both shoot deposition and thermal oxidation of iron-containing minerals [26]. The starting of thermal oxidation can happen at temperatures around 250-300 ◦C. In masonry buildings, various minerals produce different types of colors. Although this kind of action does not destroy the stability of the building, it may change its appearance.

2.3. Timber Structures Expose to the Fire

Although the sustainability of timber building is one of the main reasons for increasing global demands in recent decades due to the combustible capacity of wood, timber structures, and timber materials are vulnerable to fire. When a timber structure is exposed to fire, behaves differently based on the heavy and light conditions of timbers. The large-dimension members (heavy timber structures) have better performance compared to the light ones in fires. When the cross-section of a timber element is big the surfaces start to burn and for a long time, it protects the inner wood from burning. The inner moisture of the wood below evaporates above 100 ◦C and at 200 ◦C, the wood starts to thermally decompose. The estimated charring temperature is considered about 300 ◦C [3]. In the case of direct fire action, the modulus of elasticity and strength of wood in timber structures are reduced by increasing the temperature. For increasing the resistance of smaller-dimension members against fire, protective materials such as gypsum boards and fiber cement panels can be employed. All of the wooden plates have poor performance in a fire if they are not protected properly.

2.4. Steel Structures Expose to the Fire

Generally, steel elements are relatively thin with high thermal conductivity compared to other building materials. The steel members mainly perform poorly if they are subjected to fire. The yield strength and modulus of elasticity of steel drop dramatically at 300 ◦C. In the case of direct fire action, stiffness, as well as strength, decrease almost to half the values. Furthermore, the restriction of thermal expansion causes large deformation and buckling of the steel elements. The mechanical properties like strength and modulus of elasticity return to their initial conditions after cooling down when the temperature does not exceed 700 ◦C. When the steel elements are subjected to temperatures above 700 ◦C for more than 20 min, the process of oxidation will start on the surfaces, as well as loss of the cross-sectional thickness. At temperatures more than 870 ◦C, the features cannot return to the initial conditions. Moreover, the steel elements will have less ductility high strength, and hardness. For aiming the protect steel elements from a fire so many methods are available; the application of certain coatings, encasement with concrete, and enclosure with boards.

3. Wildfire in Manavgat, Turkey

The case study consists of the effects of wildfire in Manavgat-Turkey (July-August 2021) on masonry buildings in terms of structural systems. In the case of the effective factors for ignition in Turkey, as stand before population density, residential areas that were located close to wildlands, elevation, and intensive human activity are the main factors. Additionally, the weather conditions and strong winds during the dry seasons are other main parameters of fire spreading in Turkey.

3.1. Location of the Occurrence of the Wildfire

Manavgat is located in the Antalya region, 75 km away from the city center of Antalya in the southern Mediterranean region (see Figure 1). Manavgat included of 2.283 km² area with a population of 241011 people according to the 2019 datasets. One of the important tourism centers with a 64 km coastline and many ancient and historical places (see Figures 1-3). The wildfire of Manavgat happened in 2021 at four different points on July 28 at 11.30 and spread to some neighborhoods of Akseki, Gundogmus, Ibradi, and Alanya districts. The high temperature (37 centigrade degrees), and low humidity (14%) increased the spreading of the fire immediately. In addition, strong wind blowing (50 km/h) allowed the fire to spread and grow rapidly. The fire spread to 21 different locations just in a day and 59 neighborhoods were severely damaged. After 220 hours of struggling and trying to keep under control it with different methods, it was brought under control at 15.30 on 6 August and the cooling works continued to have a sustainable condition for a few days. Based on the governmental information, 8 aircraft, 2 UAVs, 19 helicopters, 2 management helicopters, 1 unmanned helicopter, 1915 vehicles, and 8,155 personnel took part in the fight against the wildfire. Additionally, a large number of volunteer citizens came to the area to help the people subjected to the wildfire. As a result of the wildfire; 7 people lost their lives, 821 people were affected by smoke, thousands of hectares of forest and agricultural land areas were damaged, as well as many animals lost their lives. Generally, the vegetation cover is Red Pine forests. In low-lying areas (0-800 m) maquis was formed by the destruction of these forests. Maquis is a collection of plants consisting of short stunted trees such as Myrtle, Laurel, Kocayemiş, Olive, Oleander, and Carob that can withstand the summer drought.

Figure 1: Satellite photo of Turkey and the wildfire-affected areas (from Google Maps).

Figure 2: The three-dimensional position of the wildfire-affected areas (from Google Maps)

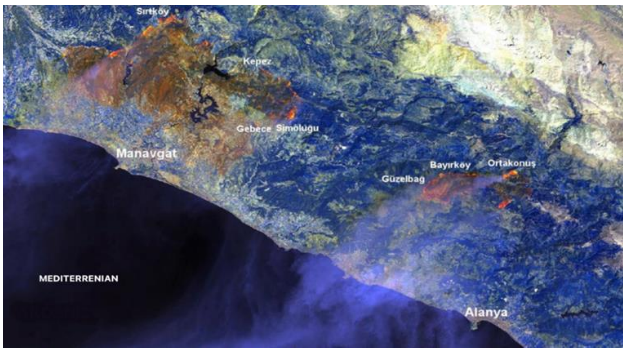

Figure 3: Real-time satellite image of Manavgat wildfire (Landsat-8 OLI satellite, July 31, 2021)

The image processing techniques on Landsat-8 OLI satellite images dated July 31, 2021, served by the US Geological Research Center (USGS) were employed to determine the changes that occurred in Manavgat, where the fire had the greatest impact. As a result of the analysis of the Landsat-8 thermal image, the observations demonstrate that the surface temperature reached 95 °C in the areas where active fires were observed in the region where the fire incident occurred, while the seawater temperature was around 27 °C. Based on the analysis, it was determined that a total of 83 thousand 810 hectares of land were burned, including 56 thousand 663 in Manavgat, 12 thousand 935 in Marmaris, 11 thousand 898 in Bodrum, 1629 in Koycegiz, and 685 in Gundogmus. During the last two decades, the big wildfires in the Antalya regions are Manavgat and Taşağıl region in 2008 with approximately 16 thousand hectares burned area. Considering this data, the 2021 Manavgat wildfire, which caused the burning of approximately 57 thousand hectares, has been recorded as the biggest fire disaster in Turkey [35]. Many strategies and methods have been employed to keep under control the wildfire and one of them was using the roads (Figure 4).

Figure 4: The road separates the forest area to better control fire.

A significant part of Manavgat is covered with red pine trees, which are common in the Mediterranean climate and are highly flammable. Strong winds (between 40 km/h and 60 km/h) carried the fire to the area uncontrollably. The roads separating settlements prevented the fire from spreading in some places, but most could not prevent the fires due to the pine cones blown by the wind.

3.2. The Specifications of the Study

The local buildings in Manavaret are generally masonry and stone structures with wooden beams. During the last three decades, this style has been modernized and changed to the proper buildings like RC frames and steel structures. Building types in terms of structural systems generally are; concrete frames with brick infill walls, masonry with wood/concrete roofs, light steel structural system, and mixed structures.

A total of 57 neighborhoods affected by the “Manavgat wildfire” were combined with a line on Google Maps and the affected areas were represented in Figure 2. To investigate the damage caused by the wildfire in the buildings, 18 neighborhoods in 4 districts (Manavgat, Alanya, Akseki, Gundogmus) were considered affected by the Manavgat wildfire. As stood before, a total, of 121 masonry buildings in various areas heavily damaged in the wildfire were examined in terms of the damage types and failure mechanisms. Most of the masonry buildings affected by the wildfire were 1-2 story buildings based on the situation in forested areas and settlements close to the forest. Near the city center, the number of the story in buildings increased but just two buildings were 3 stories (see Figure 5). Figure 5 shows the distribution of story numbers of the 121 examined buildings. One of the most important points observed during the investigation indicates that the buildings were mostly without any design project and engineering control during the construction process. Furthermore, by the time people have made an addition to the existing buildings based on their needs and possibilities. In the buildings examined in this study, it has been observed that the roof systems have great importance on fire in the buildings. Based on the observations, the fires reached the building mainly from outside, such as forest fires, starting from the most vulnerable part of the building and spreading. The stability of the building and its exposure to fire is closely related to the starting point of the fire in buildings. The observations demonstrate that the fire mostly reached the residential areas through the trees. Therefore, in buildings with wooden roofs, the fire mainly started from the roofs and in buildings without RC slabs under the roof, the fire could penetrate easily enter the building. Consequently, by burning the inside items in the building, the exposure time of the structure system to fire and their efficiency increased. The majority of masonry buildings have timber roofs or RC roofs at the same time which has a great effect on spreading the fire. While RC slab and wooden roof simultaneously could control the spreading better than wooden roof by itself.

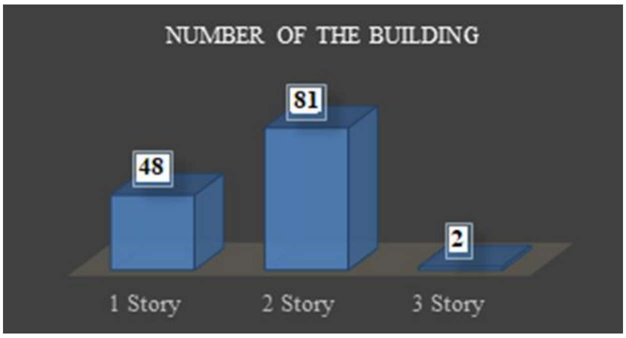

Figure 5: Number of stories and number of buildings.

3.3. Damages and Failure Mechanisms

In the following section, damage mechanisms of buildings in terms of the structural and nonstructural elements with all of the observed details have been investigated in the Manavgat wildfire.

In masonry buildings, fire primarily destroyed roofs, wooden beams, and floors. The burning of the timber structural elements that used to have a balanced condition of the walls mainly caused deformation and several kinds of cracks (see Figure 6). Furthermore, the unbalanced situation causes the disconnection of the joints and local failures. In many cases, reinforced concrete floors lost their capacity and collapsed or had deformation based on the instability conditions of the masonry walls absence of any kind of connections was not considered. Due to the low heat resistance of reinforcing bars, it deforms in fires at high temperatures. Although it was protected because of the cover of concrete, its deformation becomes inevitable as the exposure time increases.

The local structural system of masonry buildings in Manavgat is mainly based on masonry stone walls with wooden beams located inside of the wall (see Figures 7-9). Unfortunately, when the beams were subjected to fire, the stability of the masonry walls dramatically led to different kinds of failures. In some cases, the slabs (reinforced concrete slabs) could control the rate of fire in a safe direction where the wooden roof and beams were quickly subjected to fire and failure.

The observation of the cases showed that the separations and deep cracks in wall-to-wall connections, slab to slab-to-wall joints happened severally in masonry buildings. Furthermore, high temperatures destroy the properties of the mortar and bonding materials causing the separation of the walls, especially in terms of vertical and horizontal separation in wall joints (see Figures 8 and 9). Another observation expressed that the plaster, which was made to obtain a flat surface on walls, was separated from the walls based on the effect of high temperature. It shows that in masonry buildings high temperatures destroyed the cohesion between the wall and plaster not only on the inside of the building but also on the facades. Generally, all of the buildings with different kinds of structural systems are subjected to spalling of plasters in the facade as well as inside of the buildings based on the different temperatures and materials (see Figures 10).

3.4. Evaluation of the Roofs

As a main component of the building during the wildfire, the roof has been investigated separately based on the different types of roofs and their performance throughout the fire action. In buildings without reinforced concrete slabs under the wooden roof, the fire destroyed the roof, and, the elements inside of the roofs filed throughout the buildings and timber slabs. In buildings with reinforced concrete slabs under the wooden roof, it has been observed that although the wooden roof was destroyed, less destruction occurred compared to the buildings that do not have any reinforced concrete slabs under the wooden roofs. In addition, in reinforced concrete slabs with low-quality concrete and low reinforcement ratio collapse and failure happened severally. It has been observed that timber roofs on steel decks were burned and the tiles were collapsed or deformed severally. By increasing the fire exposure time, deformations increase in steel elements with an insufficient cross-sectional area. Generally, as the cross-sectional area decreases in light steel roofs, the resistance to heat decreases and visible deformations occur in the steel bars that are mainly not designed properly based on the updated design codes.

(a)

(b)

Figure 6: The collapse of the reinforced concrete slabs based on the failure in the walls (a and b).

(a)

(b)

Figure 7: Timber beams, slabs, and roofs have been destroyed by fire (a and b)

(a) (b)

Figure 8: The materials lost their qualities (a and b- deep cracks and separations)

Figure 9: Spalling of plasters in the facade

Figure 10: Inside spalling of plaster

(a) (b)

Figure 11: Timber roof without reinforced concrete slab (a and b-totally destroyed).

(a) (b)

Figure 12: Timber roof with RC slab (a and b-less destruction)

Figure 13: Reinforced concrete slab roofs (a and b)

Figure 14: The timber on steel roofs- totally destroyed (a and b)

Figure 15: Light steel roofs-totally destroyed (a and b)

In the mixed system consisting of masonry walls and steel, the plasters on the walls were separated from the steel section and steel elements had big deformation when exposed to the fire. As seen in the photos (Figures 16 and 17), different types of structural materials presented different systems.

Figure 16: Damages in the mixed materials (four types of materials)

Figure 17: Damages in the mixed materials (two types of material)

4. National Guide for Wildland-Urban Interface-NRC

The National Research Council of Canada (NRC) 2018 developed a National Guide for Wildland-Urban Interface (WUI) fires, referred to hereafter as the National WUI Guide [25]. In NRC the wildfire has been defined as an unplanned natural-caused or human-caused fire in live or dead combustible vegetation, as contrasted with prescribed fire. Additionally, the WUI fire is a wildfire that has spread into the wildland-urban interface. This Guide provides guidance not only for the development of a new community but also for the extending the old buildings. Furthermore, the WUI fire is a wildfire that has spread into the wildland-urban interface. This Guide provides guidance not only for the development of a new community but also for the expansion or modification of an existing community (e.g., adding new properties).

A chapter of this guideline represents the construction classes were classified into thirteen categories in terms of existing applicable, structural, and nonstructural elements, liquefied and gas tanks, and access route design for better firefighting capabilities. Since the study deals with the elements of the buildings, the investigation was limited to the construction elements measured in this study. Additionally, the evaluation of the case study of Manavgat, Turkey is represented in any subsection of NRC-2018.

4.1. Exterior Walls and Foundation Walls

The chapter implements all exterior walls, components, and gaps subject to WUI fire exposure. All joints in the exterior wall cladding or related wall components, openings, foundation walls, and penetrations should be covered with no unprotected gaps greater than 3 mm. In the case of the exterior surfaces that are less than 200 mm from the ground or a deck and roof. In this study as mentioned before the exterior plasters which were made to obtain a flat surface on facades were separated from the structural elements when subjected to high temperature. Therefore, high temperature disrupts the continuity between concrete and plaster since the recommendations based on NRC-2018 were not supported accurately.

4.2. Raised or Elevated Buildings

All of the supporting elements for the buildings should be made of non-combustible construction material. The heavy timber construction with a minimum nominal dimension of not less than 150 mm. In this study as already represented in diagrams, just a few buildings were subjected to this condition in NRC-2018 based on the number of stories, and the buildings were not constructed with non-combustible materials properly.

4.3. Roofing Materials

All kinds of roofs that could be exposed to accumulated embers should be non-combustible. Drip edges should be non-combustible, and extend at least 75 mm upslope from the edge of the roof. Roof penetrations, such as pipes, should be non-combustible. Any larger gaps more than 3 mm on the roof, should be sealed with non-combustible material. In this study, as stood before, the roof has been investigated separately as a main component of the building during the wildfire, based on the different types of roofs and their performance throughout the fire action. As pointed out previously, in buildings without reinforced concrete slabs under the wooden roof, the fire destroyed the roof, and, the elements inside of the roofs filled throughout the buildings and timber slabs since the roofs material generally do not support NRC-2018 specifications and material was not non-combustible. Additionally, drip edges mainly were not non-combustible, and did not extend upslope from the edge of the roof and the roof penetrations, such as pipes, were non-combustible considering NRC-2018.

4.4. Doors and Windows

Exterior doors on buildings should be non-combustible and have a fire-protection rating of not less than 20 min when tested using CAN/ULC-S104 [29]. Window glazing and skylights should be tested using SFM Standard 12-7A-2 [30]. The windows should be protected from corrosion, and non-combustible wire meshes with a maximum mesh aperture of 3 mm. The observations demonstrate that, in this study, exterior doors on buildings were not non-combustible with a fire-protection rating based on NRC-2018.

4.5. Decks, Balconies, and Other Building Attachments

All decks, balconies, porches, and similar building elements within 10 m of the main building structure should be prepared using non-combustible materials. Therefore, non-combustible materials should be used for all kinds of decks, balconies, and porches, as well as other similar structural and non-structural elements. Based on the observations in this study, decks, balconies, porches, and other similar building elements as well as graded surfaces were not properly constructed of non-combustible materials based on NRC-2018. As discussed previously, in the case of the buildings with reinforced concrete slabs under the wooden roof although the wooden roof was not non-combustible or appropriately protected and destroyed, less destruction occurred compared to the buildings with any reinforced concrete slabs under the wooden roof. It shows that the reinforced concrete slabs worked as lightly fire-protected elements in this investigation.

4.6. Liquefied Petroleum Gas Tanks and Access Routes

In the case of Liquefied Petroleum Gas (LPG) tanks within 100 m distance of any building should rest upon a non-combustible surface that extends not less than 1.5 m outward in all directions from the perimeter of the tank. The vegetation and combustible components within a zone of not less than 3 m should be removed. Furthermore, all directions from the perimeter of LPG tanks located within 100 m of any building should be removed. The observations in this study, clearly demonstrate that not only most of the items in NRC-2018 covered but also the access routes and primary aid supports were remarkable.

4.7. Comparison of the Current Study Results with Wildland-Urban Interface-NRC 2018

Generally, in the observations, the reinforced concrete slabs under the wooden roof, the wooden roof were destroyed. Furthermore, the percentage of the covered conditions is represented in terms of walls, raised or elevated buildings, roofing materials, gutters and downspouts, service openings and vents, doors and windows decks, balconies tanks, and access routes. Based on the NRC 2018 and observations, just a few items have been covered mainly in terms of the gutters and downspouts fitted with corrosion-resistant, access routes, and primary aid supports. Additionally, the plasters were mainly split up, separating of structural and nonstructural elements occurred, and reinforced concrete floors lost their capacity and collapsed or had deformation. The results of the case study are compared with the NRC 2018 in Table 1 where the covered percentage of the items is represented for all of the structural systems.

As represented in Table 1 the different structural systems such as masonry buildings, RC, steel, and mixed structures could not cover the specifications properly. Therefore, the percentage of the covered conditions is represented in terms of walls, raised or elevated buildings, roofing materials, gutters and downspouts, service openings and vents, doors and windows decks, balconies tanks, and access routes. Based on the NRC 2018 and observations, just a few items have been covered mainly in terms of the gutters and downspouts fitted with corrosion-resistant, access routes, and primary aid supports. The material of the roofs, balconies, porches, and other structural elements of the buildings were not non-combustible regarding NRC-2018.

Table 1: Table 1. The results of masonry buildings and WUI-NRC 2018

NRC 1	NRC 2	NRC 3	NRC 4	NRC 5	NRC 6
Wall s (%)	Raised or Elevated Buildings (%)	Roofing Materials (%)	Doors and Windows (%)	Decks, Balconie s (%)	Tanks and Access Routes (%)
5	0	10	10 <	10	20

As stood before, the seismic performance of the buildings which subjected to a wildfire needs another demand considering the efficiency of fire on the material and structural elements. However, the structural systems will not be the same as before in terms of stiffness and capacity. Therefore, after a wildfire, if they are subject to seismic actions the structural systems will not have the same performance, particularly in terms of ductility and energy dissipation of the structural systems and materials.

5. Conclusions

In light of the observations, the effects of extreme temperatures on masonry buildings and materials were reported during the wildfire in Manavgat, Turkey (July-August 2021). A group of 121 masonry buildings was examined in terms of the performance and building damage mechanisms that occurred in the buildings exposed to the above-mentioned wildfire.

1. The main failure mechanisms in masonry structures; fire primarily destroyed roofs, wooden beams, and floors then disconnection of the joints and local failures, separation at wall-to-wall joints, and structural irregularity the stability of the masonry walls had dramatically led to failure, high temperature destroyed the cohesion between the wall and plaster.

2. In buildings with reinforced concrete slabs under the wooden roof, although the wooden roof was destroyed, less destruction occurred compared to the buildings that had no reinforced concrete slab under the wooden roof.

3. Generally, a main separation of structural and nonstructural elements has been reported.

4. Spalling of plasters in the facade as well as inside of the buildings is observed based on the different temperatures and materials.

5. Based on the NRC 2018 and observations, just a few items have been covered mainly in terms of the gutters and downspouts fitted with corrosion-resistant, access routes, and primary aid supports but the material of the roofs, balconies, porches, and other structural elements were not non-combustible regarding NRC-2018.

6. Because the behavior of the structural systems is not the same before and after wildfires if they are subject to seismic actions. The seismic performance of the existing buildings after a wildfire is another vital topic considering the efficiency of fire on the material and structural elements. Therefore, it seems that presenting a basic guideline and evaluation of the structural systems after a wildfire will prevent or reduce the efficiency of wildfires on buildings

Article Information

Funding

The author (s) has no received any financial support for the research, authorship or publication of this study.

Authors' Contrtibution

Conception or design of the work:
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Hamid Farrokh Ghatte and Aslan Soyer
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Hamid Farrokh Ghatte and Aslan Soyer

The Declaration of Conflict of Interest/Common Interest

No conflict of interest or common interest has been declared by the authors.

The Declaration of Ethics Committee Approval

This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of Journal of Innovative Science and Engineering. in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Journal of Innovative Science and Engineering and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Journal of Innovative Science and Engineering.

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