Fire Fighting Strategies for Light Steel Structure Buildings (Metal Houses)

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***Abstract*—Light steel structure buildings, also called metal houses in Taiwan, lack durability and fire resistance performance. When such a building is on fire, because of its relatively high internal fire loading, the fire is more severe, the fire resistance level of the steel structural members is quickly exceeded, and the steel materials are rapidly weakened. Because this kind of building when on fire collapses very quickly, it could threaten the life and safety of fire fighters inside. The study reviewed cases of metal house fires and relevant references to examine the causes of fires and the fatal as well as non-fatal casualties. It also analyzed metal house fire hazards and causes of the collapse of metal houses in fires. The objective is to develop metal house firefighting strategies and to provide the government with useful information for amending relevant laws and regulations to prevent metal house fire disasters.**

***Index Terms*—light steel structure, metal houses, fire resistance performance, fire loading, fire fighting strategies**

I. Introduction

Most buildings in Taiwan are either reinforced concrete or steel structure buildings. There are also the so-called metal houses, which are a type of light steel structure building commonly used by furniture factories, chemical factories, warehouses, and hypermarkets. Many of these metal houses are illegal or for temporary purposes. They are very popular in Taiwan because they can be built quickly, have well earthquake resistance, and are cheap [1]. It is stipulated in Article 69 of Taiwan's Building Technical Regulations [2] that the only requirement for the main structural members of buildings with no more than two floors is to use non-flammable materials. In other words, the present laws and regulations can be satisfied as long as a light steel structure or other non-flammable materials are used. There is no instruction on the effective length of fire resistance of the steel structure. In the same article, it is also stipulated that buildings with more than three floors that are used for factories or warehousing have to satisfy fire resistant structure regulations, but buildings with no more than two floors are exempt from such requirements. Similarly, buildings with a total floor area of 1,500m^2 or more that are used for warehousing have to meet fire resistant structural regulations, but again, if they are used for factories, then regardless of the size of the total floor area, they are exempt from these regulations.

As mentioned earlier, most factory and warehousing buildings do not have a fire resistant structure, and the beams, columns, and floor slabs, i.e., the main structural members supporting these buildings are not protected by any fire resistant cover or fire resistant paint. Therefore, when a fire breaks out in this type of building, it will be fierce if many objects are stored inside. When the temperature of the fire inside a building exceeds 600 ℃, the strength of the steel materials is weakened quickly, resulting in significant heat-induced deformation of the steel structural members. In this case, the center of gravity of the entire metal house will shift and the balance will be lost—the metal house will collapse once the joints of the steel structure are broken by uneven force. Therefore, the mentioned building technical regulations should be revised to be more rigorous to protect fire fighters from such dangers. Results from the literature review show that the mechanical properties, such as the yielding strength and the modulus of elasticity, of a steel structure under force at high temperatures is substantially affected; these mechanical properties are weakened by increase in temperature. When steel is heated to 550 ℃, the yielding strength is reduced by 30%, and when the temperature reaches 600 ℃, the yielding strength is halved. Common metal houses take only about five minutes to reach such a temperature in a blaze [3], [4]. Moreover, the mechanical properties of steel materials at high temperatures are also affected by the method of cooling, e.g., air cooling vs. rapid water cooling, and the higher the temperature is, the greater the impacts from cooling are [5]. It is therefore not surprising that the water spraying approach used by fire fighters for reducing temperature would affect the mechanical properties of steel materials at high temperatures. Taken together, this type of building fire threatens the lives and safety of people inside the building and may lead to serious casualties, fatal as well as non-fatal, among fire fighters. The aims of the study are to examine metal

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house fire incidents in Taiwan, explore causes of the fire and level of deaths and injuries, and analyze the level of the risk of metal house fires in order to develop metal house fire rescue strategies. The study results can be used by the government for amending relevant laws and regulations to prevent metal house fire disasters.

II. Statistical Data of Fire Incidents

According to Taiwan's official statistical data between 2010 and 2014, the number of metal house fire incidents accounted for about 10.8% to 11.1% of all fire incidents, the fatality rate of civilians in metal house fire incidents ranged from 8.4% to 18.3% (including 8.4% of 2010, 13.4% of 2011, 18.3% of 2012, 10.9% of 2013, and 13.7% of 2014), and the non-fatal casualty rate of residents in metal house fire incidents ranged from 13.3% to 13.6% [6]. Regionally, New Taipei City, Taichung City, and Taoyuan City had the most severe metal house fire incident casualties; take New Taipei City as an example, there are between 40 and 60 fire incidents at metal houses used by factories each year, and the number accounts for about one-third of all fire incidents that occurred all year [7].

In addition, it can be found from Table I that between 1962 and 2015, there were 23 building fire incidents, and 38 fire fighters in total were killed in these incidents. Among these 23 incidents, five of them were metal house fire incidents, and 12 fighters (about 31.5%) died there. More details are provided below. In June 2003, one volunteer fire fighter was killed in a factory warehouse fire at Rende District, Tainan City. In July 2004, a fire fighter was killed in an electrical and mechanical fire in Sanxia District, New Taipe City. In March 2005, two fire fighters were killed in a furniture factory fire incident on Boai Road, Kaohsiung City. In July 2013, two fire fighters were killed in a factory warehouse fire incident at Taishan District of Taipei City. In January 2015, six fire fighters were killed in a bowling center at Hsinwu District, Taoyuan City. Taken together, metal houses definitely pose a great threat to the life and safety of fire fighters.

TABLE I. Statistics of Fire Fighter Fatalities in Building Fire Incidents in Taiwan

No.	Year/Month /Day	Location	Number of people	Note
1	1962/04/23	Hengyang Road, Taipei City	1	
2	1966/01/19	Xinsheng Theater, Taipei City	1	
3	1966/07/06	A factory in Taipei City	1	
4	1969/09/29	A hardware factory in Tainan City	1	
5	1983/06/25	Zhongying Building, Taichung City	1	
6	1988/07/05	Hezuo Building on Zhongzheng Road, Tainan City	1	
7	1988/10/10	Wenhuacheng Barber House on Jianken Road, Taipei City	1	
8	1989/08/04	Jinre Department Store on Ermei Street, Taipei City	2	
9	1991/12/08	Haibawang Restaurant on Zhongzheng N. Road, Taipei City	1	
10	1992/08/28	Liufu Building on Hankou Road, Taipei City	3	
11	1995/03/15	Hawaii Massage Center, Taichung City	1	
12	1996/10/07	Yongxing Resin Company, Taoyuan City	6	
13	1998/09/25	Ouyi Furniture Company, Changhua County	1	
14	2001/07/13	Dongxin Road, Keeloung Road	1	
15	2003/06/26	Baosheng Factory Warehouse, Rende Township, Tainan County	1	metal house
16	2004/04/26	Jingkou Road, Taoyuan City	1	
17	2004/07/13	Electrical and Mechanical Factory at Sanxia District, New Taipei City	1	metal house
18	2005/03/25	A furniture factory on Boai Road, Kaohsiung City	2	metal house
19	2013/02/12	A frozen food factory at Wuku Industrial District, New Taipei City	1	
20	2013/07/06	A factory warehouse at Taishan District, New Taipei City	2	metal house
21	2014/03/27	A basement on Renai Road, Zhongzheng District, Taipei City	1	
22	2014/06/27	Huaxia Zhixing underground parking at Zhonghe District, New Taipei City	1	
23	2015/01/20	Hsinwu Bowling Alley at Hsinwu District, Taoyuan City	6	metal house

III. Analysis of Causes of Metal House Collapses in Fire Incidents

Presently, most metal houses in Taiwan have no more than two floors, and their structure is mostly a mountain shaped structure made with steel columns and beams as shown in Fig. 1. Some metal houses also have an intermediate layer room as shown in Fig. 2. When the house is on fire, the steel structural members will undergo heat-induced deformation as shown in Fig. 3, causing the center of gravity of the entire building structure to shift. This condition generates a great pulling force that acts on the joints of the steel beams and columns of the roof and puts more force on the bolts of these joints. If these heated bolts are rapidly cooled down by water sprayed to extinguish the fire, the ductility of these bolts drops quickly, and when the force exceeds what the bolts can tolerate, the bolts will break, and the pulling force originally acting on the broken bolts will now act on the remaining bolts. As more and more bolts are broken, the force acting on the remaining bolts will be greater, and more bolts will be broken. Eventually, there will be a point when all joints connecting steel columns and beams are broken, and the roof will collapse. This is the situation, i.e., broken bolts at joints, found by the study from examining numerous metal house fire scenes. See the dotted circle in Fig. 4.

Figure 1. Mountain-shaped structural system of metal houses.

Figure 2. Structural frame system of metal house with an intermediate layer room.

According to the above analysis, fire fighters should be more cautious about spraying water, especially on the structural joints of metal houses. In addition, one can use the tactic of reducing the temperature of steel structural components of metal houses to minimize the deformation of structural components and reduce the risk of building collapse. Because a rapid cooling of the joints of the steel structure may affect the mechanical properties, fire fighters should first make lots of openings by destroying the outer walls, doors and windows of the metal house to allow for natural cooling, which is beneficial for reducing the temperature of the steel structural components of the metal house and effective in preventing sudden explosion, expelling smoke for better visibility, and providing more time for planning the water attack route. The key point here is to avoid going into the fire scene abruptly.

Figure 3. Mountain-shaped structural system of metal houses.

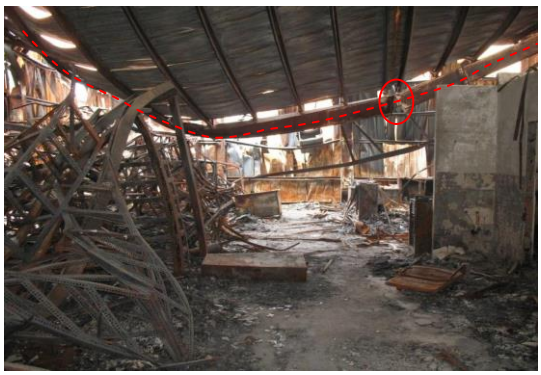

Figure 4. Broken bolts at the joint of roof steel beams from a metal house fire incident.

IV. Conclusion and Suggestions

The light steel structure of metal houses in Taiwan is not commonly used in other countries, and therefore, few papers from international journals have examined the topic. This topic, however, is also rarely discussed by researchers in Taiwan. To analyze hazards associated with metal house fire disasters and develop corresponding strategies, the present study reviewed relevant laws and regulations and statistical data on fire incidents, inspected several fire scenes, and conducted a literature review [8] on mechanical impacts from fires on the metal house steel structure and the effects of cooling at high temperatures. The objective of the study is not to revise the present protocols or standards for handling metal house fire incidents currently used by firefighting and rescue departments but to provide systematic and scientific research findings to reduce or eliminate irrational blame and unnecessary pressure from the general public on fire fighters. According to the research findings, the investigators suggest that Taiwan's building and construction authority should amend Article 69 of

Architectural Technical Specifications as soon as possible to improve the fire resistant quality of metal houses in Taiwan. The investigators also provide the following fire fighting strategies.

1) There are too many potential risks associated with metal houses, and if a metal house is on fire, it is incorrect to go inside for rescue.
2) If the commander considers it necessary to go inside for rescue, a very important task here is to measure the temperature, i.e., measuring the temperature at the top layer (i.e., the hot layer) of the metal house at all times. It is also recommended to use the temperature between 550 and 600 ℃ as an indicator for withdrawing personnel from the fire scene.
3) When entering the fire scene, firefighters should be equipped with adequate rescue equipment, such as a thermal imaging instrument, a radio communication device, a personal alert safety system or an electronic respirator. If not, the commander should not send personnel into the fire scene.
4) Firefighters should create lots of openings (more than 1/16) for natural cooling. The measure is excellent for reducing the temperature, preventing flashover, and improving visibility inside the building.
5) Firefighters should be cautious about spraying water. It is especially important to avoid spraying water on steel structure joints at high temperatures.
6) Most buildings have a "strong columns but weak beams" structural design, and therefore, when fire fighters go into the fire scene, they should move slowly and stay close to the columns of the outer walls.
7) Commanding personnel should know the rescue route used by firefighters inside the building at all times as well as the direction and path of the spread of fire and have a rescue plan ready before sending firefighters to the fire scene. When personnel go into a fire scene, concentrate the supply of water, and if necessary, a search and rescue team should be set up in advance and be on standby.
8) Commonly, a search and rescue team should comprise at least two people, and an officer or a senior staff member should be assigned to be the leader of the team. Do not go into the fire scene alone abruptly, and entering into the fire scene should be coordinated with water spray for protection.
9) Rescue personnel should pay attention to the structural components of the building at all times as well as to any changes at high temperatures. Pay special attention to the deformation of steel structure joints or the falling of big masses from the roof. If any of the above is observed, notify the commanding personnel and quickly withdraw from the fire scene.
10) The firefighting and rescue department should complete the metal house rescue safety manual as soon as possible and routinely carry out fire drills. Local firefighting and rescue agencies should administer and monitor metal houses in their district, especially those metal houses with more than two floors (including those with an intermediate layer room), with a vertical depth of 15m or greater, or with a building area of 500m^2 or greater. These agencies also should obtain and keep the interior floor plan of these buildings as well as information on materials stored in such buildings.

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