Performance-based analysis for life safety from fire, Case study; large structural steel manufacturing building

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Abstract. This study simulate the evacuation from structural steel manufacturing building and verified with Thai’s regulation. According to the regulation, all occupants shall be in safe place within 5 minutes in case of fire incident. Two simulation scenarios were selected for this simulation. First, all exits can be used for evacuation; evacuation time is 4.23 minute after announcement. Second, fire caused by explosion of compressed air tank near Exit A, which completely block this exit A. Simulation result shown that evacuation time for this particular case is 7.06 minute, which is exceed maximum evacuation time defined in the regulation. Therefore, the following countermeasures are propose: Expand existing stair from 1.0 m to 1.5 m., Install an additional stair with the same width on the opposite side and modify firefighting procedure.

1. Introduction

Since fire incident in large facility building could cause huge property damage or even loss of employee’s life. Allocating evacuation path to assembly point that use minimum time is important [1]. Focused their attention on analyzing the impacts of different evacuation behaviors and measuring their efficiency in terms of the evacuation rate [2]. Although the station covers large area and accommodates a large number of people, a peak passengers flow is relatively small. Therefore, the safety egress time is shorter [3]. A research of evacuation plan [4] for single floor administration office. As fire occurred with smoke and people nearby realized the situation. Therefore, they start to move away using an exit they familiar with. Test by varying number of occupants in each area to evaluate time of each scenarios. As stated in item 8 of government regulation in safety, health and environment management regarding fire prevention and counter measure [5]. Factory must provide evacuation routes which capable of handling all employees to safe place within 5 minute. The rule applied equally to any kind of factory, regardless of size nor type of industry. All industrial plant must comply with this standard. Pathfinder is a tool for simulate evacuation time and behavior of workers in predefined scenarios. In-depth analytical data will show if there is a bottleneck. These information is useful for evacuation paths improvement. Correction of bottleneck to comply with government regulation will finally result in a safer place for all employees.

2. Model building and calculation
2.1. Model building
Pathfinder by Thunderhead Engineering Consultants, is an emergency egress simulator that includes an integrated user interface and animated 3D results [6]. The software supports two movement simulation modes, "Steering" mode and “SFPE” mode. In “Steering” mode, occupants use a steering system to move and interact with others. This mode tries to emulate human behavior and movement as much as possible. SFPE mode uses a set of assumptions and hand-calculations as defined in the Engineering Guide to Human Behavior in Fire [7].

In a large structural steel manufacturing building, spark and hot particle always present in nearly every production phases. There are a lot of used gloves and rags contaminated with oil and grease. Furthermore, high power gas burners are also used with oxygen mixed and maintenance worker use LPG tank for cutting in the plant. Facility have total area of 23,526 m2, 4 floors and one gateway for overhead crane (named A1 and A2) at 24 m height. Production of steel involve 7 process as shown in figure 1, Electric arc furnace (EAF), Ladle furnace (LF), Continuous casting machine (CCM), Mold preparation, Refractories and Discharge area. The building has 6 exit as shown in table 1.

![Diagram](image)

Figure 1. Layout of structural steel manufacturing.

| Area                | Sector  | Width(cm.) |
|---------------------|---------|------------|
| CCM                 | Exit A  | 430        |
| Office              | Exit B  | 150        |
| LF process          | Exit C  | 120        |
| Mould preparation   | Staircase | 100      |
| Refractory          | Exit D  | 950        |
| Cabin Crane         | Exit E  | 760        |
|                     | Exit F  | 200        |

2.2. Simulation settings
1. In this simulation, 478 Employees (including outsource worker) are involve. This number derived from occupant load factor (m^2 /person) as defined in NFPA 101 [8]. Employees divided into 2 groups, production workers and maintenance workers by ratio of 70% and 30% respectively.

2. All employees and outsource workers are gentle with shoulder width of 45.58 cm., 182 cm. height, and walking speed is 1.19 m/s [7].

3. Behavior model has been set to “Steering” mode, Jam velocity is 0.25 m/s; controls the speed threshold at which occupants are recorded as being jammed at exit [7].

4. Maintenance workers must first go to control rooms they responsible for power source isolation. This should take approximately 1 minute before evacuate from the building. In contrast, production workers will evacuate instantly with nearest path to assembly point (if available).
5. There are two simulation scenarios, performance based analysis of the building and fire caused by explosion of high-pressure gas tank near exit A. In later scenario, exit A become unusable.

3. Simulation result and analysis

3.1. Simulation result

![Simulation result](image1)

**Figure 2.** Simulate the evacuation from structural steel manufacturing building.

![Bottleneck evacuation](image2)

**Figure 3.** Bottleneck evacuation at Exit C.

| Person | Exit B | Exit C | Exit D | Exit E | Exit F |
|--------|--------|--------|--------|--------|--------|
|        | 32     | 240    | 97     | 59     | 39     |

**Table 2.** Number of occupant of each Exit.

There are two simulation scenarios, performance based analysis of the building as illustrated in figure 2 with evacuation time of 4.23 minute. In another scenario, fire caused by explosion of high-pressure gas tank near exit A. In later scenario, exit A become unusable. As shown in table 2, vast majority of workers (240 persons) appears to use exit C instead as can be seen in figure 3. In this case, bottleneck at exit C occurred with total evacuation time of 7.06 minute. Production worker who wait for longest period is from CCM 1st floor. He wait for 275.8 s. for evacuation at exit C. Total evacuation time of
421.15 s. and distance of evacuation 118 m. Maintenance worker who responsible for electrical system isolation at CCM 2nd floor (same level with exit C) use exit C with waiting time of 194 s. and distance of 135 m. (which is longest waiting time among maintenance workers).

3.2. Analysis of simulation result

![Figure 4](image4.png) (1) Extend width of stair from 1 m. to 1.5 m.

![Figure 5](image5.png) (2) Construct additional stair.

![Figure 6](image6.png) (3) Explicitly define evacuation path of workers who working at discharge and air compressor room to used exit E.

Evacuation in case of blocked exit A is fail to comply with regulation because bottleneck happens at exit C. Improvement of exit C can be made with 3 options, (1) Extend width of stair from 1 m to 1.5 m as in figure 4. (2) Construct additional stair shown in figure 5. (3) Explicitly define evacuation path of workers who working at discharge and air compressor room to used exit E which locate in opposite side of factory. Therefore, this exit will be a bit more crowded as show in figure 6. Simulation result for each improvement is 4.32 minute, 4.46 minute and 4.55 minute respectively, thus comply with this regulation.
Figure 7. Average waiting time, exit time and distance at exit A and after improvement.

From figure 7, evacuation time after exit C was improved indicate that option 1, 2 and 3 reduce average waiting time from 30.72 s/person to 17.17, 17.49 and 14.70 s/person (44.15%, 43.05% and 52.13%) respectively. Total evacuation also reduce from 108.26 s/person (base case) to 106.94 and 104 s/person or 1.2% and 3.93%.

4. Results and discussion

Further consideration for option 1 shown in figure 8. With the same amount of occupants, all exit handle nearly the same amount of persons but average flow rate (person/s) of exit C (bottleneck) is increase from 0.58 person/s to 0.94 person/s.

When consider option 2, the building has additional stair named exit X shown in figure 8. Occupants sharing between the 2 stairs can be realized. As a result, exit C become less chaos with amount of occupants reduced from 240 persons to 146 person (39% less) and flow rate at exit C and exit X is 0.54 and 0.39 person/s as shown in figure 9. Total evacuation time for this case is 4.46 min.

In option 3, there is no modification on physical structure of the building. Workers at discharge refractory and air compressor somehow inform to use exit E as shown in figure 8. This option reduce workload of exit C from 240 persons to 159 person. Even though workload of exit E increase from 0.41 person/s to 0.93 person/s as shown in figure 9, but overall evacuation time is, reduce to 4.55 min.

Figure 8. Number of occupants at each exit.

Figure 9. Average flow rate for each improvement.
5. Conclusion
Simulation result indicate that present fire evacuation paths of the building might not meet maximum time as state in Thai’ regulation. Width of stair for exit C should be expand from 1 m to 1.5 m. or provide additional stair for exit C. Firefighting procedures and evacuation plan should be review and practice for real workers and real site should be setup properly for each scenarios. Fire exit sign should be clearly visible add proper lighting for evacuation paths should be consider and maintained.

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