Study of TODs Tall Building Fire Evacuation: Refuge Floor Utilities

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Abstract. Life safety has to be prior objective due to TODs tall buildings increment, for instance, mixed-use tower or integrated superblock estate, may cause fire accident. Refuge floor provision often met spatial issues according to define its configuration. Refuge floors are more relevant to the RSET factor because of the objectives. This study focused on identification of affecting factor using refuge floors with help of RSET factor from certain relevant three case studies of TODs tall buildings increment. The highlighted findings from certain case study plays important role to clarify the RSET factor on using refuge floor. Building height shows significant utility for refuge floor occupancies in accordance to refuge due to density control inside vertical egress.

1. Introduction

Burgeoning urban mass development coexists amidst major cities. Land and property index relatively increased along with the proximity to the Central Business District (CBD) area. About 1,100,000 commuters were pursued to travels around Jakarta peripheral area to their office under daily basis. Transit-Oriented Development (TOD) helps to enhance productivity through human travel effectiveness (i.e. public mass rapid transport system and mixed-use building plan). Nevertheless, the increment demand of housing, office, and public space under scarce of land circumstance becomes apparent. As per 2010, United Nation categorized Jakarta as the worlds’ fastest growing capital city. And this number will lead by the 67% urban growth rate per year for incoming 2025 [1]. The growth of tall building established as the answer to housing and office space demand under land scarcity. Recently from 2009-2012, tall building in Jakarta (150m height criteria and over) increased from 40 to 75 units. These amounts will nearly reach 250 units by the end of 2020 [2].

Life safety has to be prior objective due to TODs tall building increment, for instance, mixed-use tower or integrated superblock estate, may cause fire accident. The notable 24-story Grenfell Tower fire case (2017) was one of the most lethal fire accident in UK tall building has ever happen since the US 9/11 World Trade Centre devastation. Quick fire spread took very long time burnout due to the building envelope combustion (mostly consist of cladding with low fire resistance) as shown in Figure 1. Although structural building endured for hours, 72 occupants had severe respiration due to insufficient oxygen supply that contained with the burnt product gas [3]. This phenomenon proves that evacuation procedure is an inseparable matter with the increment of TODs tall building fire risk.
2. Background study

There are at least three evacuation strategies to its reciprocal situation: (1) full evacuation, (2) delayed/staged evacuation, and (3) defend-in-place. These evacuation strategies shall supported by passive fire protection system. The full evacuation is a direct evacuate to ground level exit using stairwell or elevator, while the two remaining strategies are intended to remain stay or refuge to safe place inside the building (i.e area of refuge or refuge area/refuge floor) [4]. Refuge floor attempts two main objectives, to relocate any occupants with such mobility impairments in a transient safe place during help is on the way and to maintain occupant density inside vertical egress [5], as shown in Figure 2, otherwise, panic behavior in terms of evacuate may affect density problem such as crowding [6] or bottleneck [7] inside the means of egress. Not to mention, the hazard of smoke spread that shorten untenable condition also terminate the available time to evacuate [8].

Refuge floor provision often met spatial issues according to define its configuration. Code observations among countries are described in Table 1. There are various refuge floor provision codes, especially about the ‘minimum building height should apply refuge floor’ and ‘interval floor range/height between refuge floors’ [9] [10] [11]. Research statement has Indonesia’s refuge floor code was obtained from relevant codes of Asian countries (Singapore & India) without any empirical approach but economic justification [9]. These spatial and effectiveness issue draws several attention into research problem to related field. This study aims to extract affecting factor on using refuge floor during evacuation.
Table 1. Comparison of refuge floor configuration among countries [12]

| Country                      | Configuration                                                                 |
|------------------------------|------------------------------------------------------------------------------|
| USA                          | • Every floor should be considered as the refuge area                         |
| Korea [13]                   | • Range of refuge floor every 30 floors applied for 50-story (200m) or more   |
| Hong Kong                    | • Range of refuge floor between every 10-14 floor depends on its height (45 m) |
| Gulf cooperation council     | • Range of every 20 floor                                                     |
| Singapore                    | • Range of every 20 floors applied for 40-story or more depend on its floor-to-floor height |
| India                        | • Every 15 floor depends on its floor-to-floor height. Can be minimum 4-5 floor. Applied at 24-story or more |
| Indonesia [14]              | • Every 16-floor interval with the application for 24-story or more            |

3. Method setup

The heterogeneous of fire risk originated from the building characteristic. Although building height shows no significant effect to its fire risk [15], building type with various occupancy and human factor shows discrepancy of evacuation procedure due to certain situation [4], as shown in Figure 3. A decent evacuation procedure shall involve performance-based approach. The ideal life safety measurement considers the Required Safe Egress Time (RSET) value with the untenable condition or Available Safe Egress Time (ASET) value [16].

Figure 3. Underlying attributes of building fire evacuation [4]

The acknowledged RSET<ASET safety criteria are very useful approach to determine life risk problem with reciprocal fire risk [16]. These safety criteria often apply within the evacuation model. It represent whether evacuee manage to move to safe place inside/outside the building by how the required egress time (RSET) satisfy the prior untenable condition (ASET). The RSET value more likely depends to human factor, while ASET value more likely depends to the fire behavior and building characteristic (shown in Figure 4). Refuge floors are more relevant to the RSET factor because of the objectives. This study focused on identification of affecting factor using refuge floors with help of RSET factor from certain relevant case studies of TODs tall building increments [9] [10] [11].
4. Discussion

There are three relevant case studies [9] [10] [11] of refuge floor utilities in TODs tall building. The research narratives are useful to extract the utility of refuge floor. The highlighted findings from certain case study plays important role to clarify the RSET factor on using refuge floor.

4.1 111-story mixed-use high-rise building design phase in Jakarta

This study starts with the problem of specific code about refuge floor configuration in Jakarta high-rise buildings. This research uses evacuation model with several iterations to obtain range data of ‘occupant movement capabilities’ and ‘optional choosing behavior’. The optional behavior tends to utilize of egress component: stairwell, evacuation lift, and refuge floor. The egress component utility constraint with optional choosing behavior scenario, such as: through, stay, fixed delay, distributed delay, and clearance scenario.

The ‘utility rate’ obtained using the constraint from these scenarios, as shown in Table 2. The objective of study is to examine refuge floor utility rate respectively for each compartment of floors with 100 occupants each floor. The refuge floors plan list nine refuge floors with certain occupational purpose. According to Table 2, the results show that occupant profile (public, office, or resident) draws significant effect to the refuge utility. This interpretation proved by the ease ‘way finding’ factor from RSET value [16]. However, the building height also draws particular factor to the refuge floor utility. Building height or floor height can be expressed as occupant ‘movement time’. Occupant initial location plays an important role to understand the RSET value.

| Refuge | Utility (%) | Clearance (s) | Comments |
|--------|-------------|---------------|----------|
| 110    | 25          | 1200          | Mostly members of the public so less likely to be used to refuge functionality and usage |
| 91/92  | 80          | 5000          | Members of the public but sleeping, so considered likely to follow instruction and an element of wanting to remain in the building being more likely |
| 83     | 25          | 2000          | Mostly members of the public so less likely to be used to refuge functionality and usage |
| 72     | 80          | 3600          | Office workers so utility based on height only. Clearance after one hour |
| 58/59  | 60          | 3600          | Office workers so utility based on height only. Clearance after one hour |
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| Room | Height | Time | Clearances |
|------|--------|------|------------|
| 47   | 40     | 3600 |            |
| 33/34| 20     | 3600 |            |
| 22   | 10     | 3600 |            |
| 10   | 0      | NA   |            |

No usage of refuge so close to bottom.

4.2 Study of 40-story office high-rise building in Tehran

This study also starts with the unclear legal code about refuge floor in Iran tall building. This research uses existing 40-story office building with 100 occupants at each floor. Research aims to examine refuge floor configuration effect to the amount of evacuated people within the related egress components. Model was simulated into three scenarios for 1 hour time stamps, as shown in Figure 5.

Figure 5. Proposed evacuation scenario using egress components of 40-story office building case [10]

The third scenario objective is to examine the interval factor of refuge floor. This scenario used to study the utility of refuge floor, according to the underlying RSET factors. However, the simulated scenario shows that number of refuge floors does not guarantee more evacuated occupants (one refuge: 3900/4000; two: 3565/4000; three: 3290/4000). The occupancy of refuge floor can be examined with the refuge floor utility as shown on Table 3. Mostly occupancy increased at second time slot (1000s). The occupancy stands as refuge floors utility. This study can prove that one embedded refuge floor in the middle section for 40-story office is the most efficient egress solution for transient refuge. Location of refuge floor shows reciprocal number of occupancies. This proves that building height as movement range will affect the ‘occupant movement’ as underlying RSET factors.
Table 3. Refuge floor utilities of 40-story office building case based on its occupancy

| Scenario      | Floor    | 1 (500s) | 2 (1000s) | 3 (1500s) | 4 (2000s) | 5 (2500s) | 6 (3000s) | 7 (3600s) | Evacuated % |
|---------------|----------|----------|-----------|-----------|-----------|-----------|-----------|-----------|-------------|
| 1-refuge floor| 20th floor| 31.25    | 35        | 27.5      | 18.75     | 10        | 0         | 0         | 97.5        |
| 2-refuge floors| 13th floor| 17.5     | 20        | 18.75     | 15        | 12.5      | 6.25      | 0.62      | 89.1        |
|                | 26th floor| 30       | 23.75     | 18.75     | 12.5      | 6.25      | 0.12      | 0         |             |
| 3-refuge floors| 10th floor| 18.75    | 20        | 18.75     | 15        | 12.5      | 11.25     | 3.75      | 82.2        |
|                | 20th floor| 20       | 16.25     | 8.75      | 2.5       | 0         | 0         | 0         |             |
|                | 30th floor| 30       | 23.75     | 18.75     | 12.5      | 6.25      | 0.12      | 0         |             |

4.3 Hypothetical study of 56-story office high-rise building

This case study forms a hypothesis of egress component utility, including the refuge floor. The study extends hypothetical model with probabilistic approach due the utility objectives of 1 hour evacuation. The 56-story building occupied with 100 occupants each floor (except the refuge floor, total of 5400 occupants) contains two stairways (25 occupant capacities) and two refuge floors (200 occupant capacities) integrated with one evacuation lift respectively, as shown in Figure 6. This research uses 26 time-based mathematical constraint underlying the four evacuation options: ‘people movement to populated floor’, ‘people wait for evacuation lift’, ‘people movement to stairwell’, and ‘people movement to refuge floor’.

Two scenarios were made with two objectives. Evacuation objective (1) is to use refuge floor as transient refuge due to maintain vertical egress density (stairwell and evacuation lift), while the evacuation objective (2) is to remain stay inside refuge floors for the rest time stamps. The first scenario conducts evacuation objective (1) and (2), while the second scenario conducts only evacuation objective (1). 100 occupants rate each floor distributed randomly within 20 times iterations, as the result shown in Figure 8. In this case, the ‘occupant behaviour’ factors underlying RSET value can be explained in

![Figure 6. Hypothetical model of 56-story office building. The refuge floor evenly distributed (19th and 38th floor) integrated with respective evacuation lift [11]](image-url)
the four evacuation options [4]. The utility of refuge floor can be subtle due to research aim of egress component optimal egress. Nevertheless, the graph in Figure 7 can interpret the discrepancy of occupied refuge floor. Different refuge floor occupancy at 19th and 38th floor shows that building height plays important role as the reciprocal factor with ‘occupant movement’ to the underlying RSET value.

![Figure 7. Amount of people occupy refuge floor under two scenarios of 56-story office building case. First scenario conducts all two objectives. The second one conducts only one objective [11].](image)

5. Conclusion
This study intended to find the underlying factor of refuge floor utility due to contribution to the RSET values. However, RSET value for refuge floor contextually stands as time-based factor due to trim the evacuation range to safe place. As an early study, three relevant research articles are used as case study to examine if there is any related factor to the underlying RSET value, such as: ‘occupant movement’, ‘movement time’, ‘way finding’ and ‘detection time’ [16]. Refuge floor are very useful for occupant density control. The underlying factors mostly discussed in refuge floors are ‘occupant movement’, ‘movement time’, and ‘way finding’ factors according to the RSET value. Building height interpreted as reciprocal factor for refuge floor optimum location. Building height represented as movement range, shows significant utility for refuge floor in accordance to refuge due to the density control inside vertical egress. Nevertheless, pre-movement issue as ‘detection time’ still needs to be involved in early study. Numerous building codes needs to involve performance-based approach in order to satisfy the egress component requirement. The unclear and generic code of refuge floors building regulation needs to involve human and building character within underlying evacuation limit to safe place.

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