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The Study of Evacuation Times from the Multiplex Theatres

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Abstract: Problem statement: The suniqueness of the Theatres in the Bangkok Metropolitan Area lies in the multiplex theatres. The enactment of law requires the theatre's entrepreneur to show the calculation lists of fire evacuation. The means of egress should have an ability to evacuate the people from the theatre within an hour. However, the restrictions to calculate the evacuation time and the number of person occupying the building are not well proposed. **Approach:** The suitable occupant load factor is investigated by areas of the multiplex Theatres. In addition, the calculation of evacuation time by the hydraulic flow calculations is also presented under assumptions for calculation conveniences. **Results:** The result of the study provides the suitable occupant load factor for multiplex theatres. The standard methods of calculation are used to determine the evacuation time from multiplex theatres. **Conclusion:** The calculation of evacuation time was conducted by using the data from 10 multiplex theatres in the Bangkok Metropolitan Area. The results show that the evacuation time is fallen between 8.2 and 84.9 min. Only 3 theatres have the evacuation time more than an hour. If these results are compared with the calculated evacuation time from the theatres that have a permission document, there is no data of evacuation time from theatres more than 60 min.

Key words: Evacuation time, multiplex theater, hydraulic flow calculation, occupant load factor, modern theatres, Bangkok Metropolitan

INTRODUCTION

The characteristics of modern theatres are changed from the past in which the single theater has rather large size. Whereas the modern theatres are gathered in the same location including the shopping mall or located near the shopping centers. These theatres are always located in the topmost of the building. Generally, the theatres are located in the higher floors of the building. The law is restricted for new theater's entrepreneur to inform the calculation lists of means of egress that is able to evacuate people from the theater to outside building within an hour. However, there is no restriction informed the evacuation time.

So, the objective of this research is to propose the suitable occupant load factor for areas in the multiplex Theatres. This occupant load factor will be used to calculate the number of people that can occupy the building by the NFPA 101, Life Safety Code. In addition, this research also proposes the calculation of evacuation time by using the equation of hydraulic flow in which the assumptions are made for calculation convenience. The results will be compared with the evacuation time at the beginning of the permission to do the theater business.

The evacuation time is concerned since the beginning of the flames to the time that the people has already been leaved the building or arrived to the safe place. The evacuation time includes of 4 components, which are (1) the perceived time of fire situation (2) the reaction time (3) the preparation time for fire evacuation and (4) the travel time. The total of the perceived time, the reaction time and the preparation time is called the delay time, which is difficult to calculate. Then, only the travel time is calculated in this research. A lot of researchers contributed to the evacuation such as, Shields and Boyce (2000); Olsson and Regan (2001); Chow (2007); Zhang *et al*. (2008); Pursals and Garzon (2009); Xu and Song (2009); Chen and Feng (2009); Wu *et al*. (2010); Fang *et al*. (2010; 2011) and Jirasingha and Patvichaichod (2011).

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MATERIALS AND METHODS

In this research, the data of the 10 multiplex theatres in the Bangkok Metropolitan Area are used to calculate the evacuation time to ask for the permission document to do the theater business, whereas Table 1 shows the results of 8 theatres.

From Table 1, it can be seen that all evacuation times are less than an hour. However, the methods used to determine the results in Table 1 are different and are not accepted by the international standard. The calculation of people flow by the hydraulic flow calculation, which presented in (NFPA, 2002), uses various factors, which are the effective width (We), Density (D), Speed (S), specific flow (Fs), calculated flow (Fc) and evacuation Time (Tp).

Effective width: The effective width is a clear width subtracted by the boundary layer. The clear width of the corridor is measured from wall to wall, whereas the clear width of stair is measured from the edge of the stair to the next edge. And the clear width of the door is an exact width during the door is opening. Table 2 shows the boundary layer of stair's components.

Density: The density is a measure of condensation along with the evacuation route. The unit of density is a number of person per square meter. The density is related to the evacuation speed. If the density is low, the evacuation speed will be high. On the contrary, when the density is high, the evacuation speed will be low.

Speed: If the speed is less than 0.54 per square meter, the people will evacuate with independent speed, which does not depend on the other persons. If the density is more than 3.8 persons per square meter, the people will be tied up until the density is decreased because the people begins to move out from that place.

In case of the density boundary is between 0.54 and 3.8 persons per square meter, the relationship between speed and density is a linear function as shown in Eq. 1:

$$S = k\text{-}akD \tag{1}$$

Where:

S = Speed (m sec^{-1})
D = Density (persons sec^{-1})
A = Constant = 0.266
k = Constant, which is shown in Table 3

Table 1: shows the results of evacuation time of 8 theatres

Name of theater	Evacuation time (min)
A	-
B	55.46
C	17.24
D	47.89
E	45.20
F	-
G	26.40
H	40.03
I	11.70
J	-

Table 2: shows the boundary layer

Components	The boundary Layer (m.)
Door	0.15
Stair (Distance is measured from edge to edge)	0.15
Stair (Distance is measured from handrail to handrail)	0.09
Corridor	0.20
Obstruction	0.10

Table 3: shows the values of k by maximum speed

Components		k	Maximum specific flow, Fsm
Passageway, door and ramp		1.40	1.32
Stair			
Tread (mm)	Riser (mm)		
190	254	1.00	0.85
178	279	1.08	0.94
165	305	1.16	1.00
165	330	1.23	1.05

Table 4: shows the conversion factors

Riser (mm)	Tread (mm)	Conversion factors
190	254	1.000
178	279	1.080
165	305	1.160
165	330	1.230

The distance of stair is considered by multiplying the distance from floor to floor with the conversion factors shown in Table 4 in which the distance of the landing has also to be concerned.

Specific flow: The specific flow is the number of people passing through specific location per unit of time per unit of effective width as shown in Eq. 2:

$$Fs = SD \tag{2}$$

The maximum specific flow will occur when the density is 1.9 persons per square meter.

Calculated flow: The calculated flow is the expected number of persons passing specific location. The unit of calculated flow is number of person sec^{-1}. which is shown in Eq. 3:

$$Fc = FsWe \quad (3)$$

Evacuation time: The evacuation time is shown in Eq. 4:

$$Tp = P / Fc \quad (4)$$

Whereas, P = number of person.

RESULTS

The results of the survey from 10 multiplex theatres are found that the occupant load factor under the NFPA 101, Life Safety Code, 2009 Edition (NFPA, 2006), by areas of the theatres, which are theatres, shops, offices and waiting areas, are shown in Table 5.

In addition, the staffs of the theater, for examples, ticket staff, guiding staff, projector staff and housemaid are considered in this research. In case of the exact number of staffs are known, this number will be further used. If the exact number of staffs is unknown, the suggestion of 2 persons for each theater will be used.
For the convenience of calculation, the assumptions are made as followings:

- The waiting location is occurred at the fire stair or the entrance door or the exit from fire stair. At this location, Fs = Fsm. The value of Fs should not more than Fsm. In case of Fs > Fsm the Fsm will be used
- All people in the building start escaping from fire simultaneously. The numbers of people using each fire stair are equally
- The lower floor, which is not the theater, has the area as same as the upper area of theater.
- The area of theater composes of the aisles and the barriers to separate the waiting customer until the movie is shown
- The waiting area has to be investigated from the real place whether
- The fire stair is in good condition.
- The discontinuous fire stair is not concerned as the fire stair
- The fire stair, which is located in specific area, is not also concerned as the fire escaping stair

The example of the calculation will present the calculation of evacuation time of a case study theater. The selected theater is located on the 4th floor of a shopping mall. The area of the theater is 4,370 square meters. The areas of the 2nd and the 3rd floor of the shopping mall are the same as the calculated results of building's user as shown in Table 6.

Table 5: shows the occupant load factor of the survey

Areas	Occupant load factor
Theater area:	
-Area inside theater	Number of seats
-Aisle and toilet	9.30
Shop area:	
-Shop area, 1st floor	2.80
-Shop area, 2nd floor	5.60
- Shop area, upper floor	3.70
- Store in the shop	27.90
Office	9.30
-Store outside the shop	45.50
Waiting area	0.28

On the 2nd and the 3th floor, the number of occupant is calculated from the assumptions in that the shops are located at the ground floor and the area of each floor equals to the floor of the theater. The calculated of occupant on the 1st floor is not required because the occupant could directly evacuate from the exit door and does not pass the fire stair.

The theater has 5 fire stairs with the assumptions of all stairs are in good condition. The discontinuous fire stair to the ground floor or the stair in the specific area is not concerned as the fire stair. In this research, the 3rd fire stair is discontinuously linked to the ground floor. The assumption is made that all people in the building begin escaping simultaneously. In addition, the people in each floor use the stair in the same amount. Thus, the numbers of people escaping at each stair by different floors are separated as shown in Table 7.

After that, the evacuation time is calculated. At first, the effective width of the stair (We (stair)) is calculated by the clear width minus with the boundary layer, which is 0.152 m. from the wall of the stair. Then, the result is compared with the case of minus with 0.089 m. from the handrail (if available). The smaller value of width will be further used.

The next step, the we (stair) is determined. If the distance between walls is subtracted by boundary layer with 0.152 m. for each side, the we (stair) will be 1.376 m. If the distance between handrails is subtracted by boundary layer with 0.089 m. for each side, the we (stair) will be 1.152 m. So, the we (stair) at 1.152 m. is selected.

The we (door) is to subtract the clear width of the door by the boundary layer for 0.152 m. at each side. Then the we (door) is 1.396 m. The assumption is further made in that the waiting is occurred at the fire exit and fire escaping stair and Fs = Fsm. The distance of the stair tread is 0.25 m. and the riser is 0.18 m. The distance of the riser and the tread can be considered as a slope of the stair to select the Fsm as in Table 3:

Fsm (stair) = 0.94 (person/sec.)/meter
Fsm (door) = 1.32 (person/sec.)/meter

Table 6: Shows the occupant load factor and number of occupants of different floors

Floor	Types of area	Area	Occupant load factor		Building occupant
4th	Theater area	3947	945	Seats	945
	Shop area	69	3.7	Sq.m^2 per person	19
	Office	94	9.3	Sq.m^2 per person	11
	Store	60	46.5	Sq.m^2 per person	2
	Waiting area	200	0.28	Sq.m^2 per person	715
	Staff	-	Number of people	12	
Total number of people on the 4th floor					1704
3th	Shop area	4370	3.7	Sq.m^2 per person	1182
2nd	Shop area	4370	5.6	Sq.m^2 per person	781

Table 7: Shows the numbers of people escaping at each stair by different floors

Floor	Stair 1	Stair 2	Stair 3	Stair 4	Stair 5
4	426	426	0	426	426
3	296	296	0	296	296
2	196	196	0	196	196
Total	918	918	0	918	918

Table 8: Shows the evacuation time of all stairs

Stair	Evacuation time (min)
1	14.7
2	22.5
3	Discontinuous stair
4	22.5
5	27.0

From Equation Fc = Fs x we:

Fc (stair) = 0.94×1.152 = 1.083 person/sec
Fc (stair) = 1.32×1.396 = 1.843 person/sec

After comparing the calculated flow between the exit and the fire escaping stair, the smaller value is selected because this value is used to define the flow rate of the fire escaping stair. So, Fc = 1.083 person/sec:

From Equation S = k -akD

Where:

a = 0.266 and k = 1.0 from Table 2

The maximum speed is occurred when D = 1.9 person/square meter:

$S = 1.0- (0.266\times1.0\times1.9) = 0.495 \text{ m sec}^{-1}$

So, the people evacuate from fire escaping stair with speed of 0.495 m $\sec^{-1}$.

The distance used to calculate the evacuation route is the horizontal distance, which is the stair platform.

All distances in the horizontal direction has to be accumulated with the adjusted distance by the stair path. The vertical distance then is multiplied with the factor as shown in Table 3, which is varied by the riser and the tread of the stair.

The distance of the stair platform between the 4th and 3rd floor is 9.36 m.

The height between the 4th and 3rd of the 1st stair is 5.26 m. The factor is 1.66. The evacuation distance that is derived from the distance of stair path is 5.26×1.66 = 8.73 m. So, the evacuation distance among floors is 9.36+8.73 = 18.09 m.

The travel time per floor can be calculated as following:

Travel Time = Travel Distance/Speed
= 18.09 / 0.495 = 37 sec

To evacuate all people from the building to the ground floor, the assumption is made in that all people from every floor evacuate simultaneously. Then, Fc = 1.083 person/sec. Number of people in the 1st stair path is 918 persons.

The evacuation time for all people through the paths is Tp = 918/1.083 or 848 sec. The total time of evacuation for the 1st stair path is 37+ 848 sec. or 14.7 min.

From the above example, the calculation of evacuation time is presented for only the 1st stair path. However, the evacuation time for different stair types has to be further investigated. The time duration that is used as an evacuation time for each building will be selected from the fire stair that has the largest evacuation time.

From Table 8, it can be seen that the 5th fire stair has the largest evacuation time. It can be concluded that the total evacuation time is 27 min.

The results of evacuation time for 10 buildings by standard method are calculated the evacuation time from areas with every stairs. As earlier mentioned assumptions, details and methodologies used in this research, the results are further compared with the evacuation time in which the entrepreneur asks for the permission to do the business. The results are shown in Table 9.

Table 9: Compares the evacuation time between the standard method and the permission method

Theater	Standard method, Duration (min)	Duration (min) Permission method
A	76.9	-
B	52.5	55.46
C	8.2	17.24
D	55.5	47.89
E	20.2	45.20
F	70.6	-
G	20.7	26.40
H	55.0	40.03
I	84.9	11.70
J	27.0	-

From Table 9, the results show that the evacuation time of each building is significantly different by each other. The differentiation is varied from 5.6-123%. There are 3 theatres using standard method that has the evacuation time more than 60 min. This is not allowed by the law, whereas there has not got any theater that asks for the permission to do the business has the evacuation time more than 60 min.

DISCUSSION

In this research, various assumptions, calculation methods and factors are used to determine the permission evacuation time. For example, some buildings consider the number of person is the number of customers who watch the movie, which is the same amount of number of seats. However, some other methods consider also the people in other areas. Every place considers the number of people that locate in the same floor of the theater, whereas the people in the other floors that use the same fire stair are not considered. There are different in calculation to determine the number of evacuating people that use each of stairs. In addition, the calculation of evacuation speed is also different. The speed of 6 km h^{-1} or 3 km h^{-1} may be used. The differentiations are found because there are no any specific calculation methods or conditions ever defined. So, the requirement, that indicates the entrepreneur has to send the calculation list by assigned criteria, is still not along with the objective, which requires the safety for building user.

CONCLUSION

In this research, the evacuation time of 10 multiplex theatres in the Bangkok Metropolitan Area is investigated by using the standard method. The results provide only the travel not and does not include the delay time. The evacuation time is found falling between 8.2 and 84.9 min. There are 3 theatres having the evacuation time more than 60 min. If the results are compared with the permission calculation list of evacuation time, there has not got any theater using the evacuation time more than 60 min. If the evacuation time is compared with other methods that are used by the entrepreneur, the differentiation is from 5.6-123%. The main reason is the differences in the assumptions, calculation methods and factors. The differentiations are occurred because the law does not indicate the calculation criteria or any condition. So, the Ministry's announcement in that "the fire exit must have an ability to evacuate the people from the theater to the outside building within an hour" by no more additional regulations is not sufficient.

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