Discussion on Design of Egress in Underground Inter-city Railway (UIR) Station in China
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Abstract
In China, the land availability for urban development is reducing progressively. The trend of construction of inter-city railway stations is moving towards underground structures in order to save space. This paper has posed a discussion on means of egress in an underground railway station. Due to the lack of specific guidance on design of underground inter-city railway (UIR) station, current design in China mainly refers to the Code for design of metro (GB50157-2003). The design Code provides an approach for calculation of the platform evacuation time in case of an emergency; especially it requires a safe egress from the most remote point on the platform in 6 minutes or even less. As the differences between metro station and UIR station, including the type of trains, passenger flow, waiting mode, etc., this paper also discusses the validity of the approaches for calculating the egress time provided by Metro Design Code. In the meantime recommendations are given on equation for calculating the platform evacuation time when considering design of egress in an UIR station. A feasibility analysis on this engineering approach has been carried out in accordance of an under construction project, the UIR stations on an intercity express rail link in Hunan province together with STEPS evacuation model.

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1. Introduction
During the last decade, the regional economy in China has been spurred by successful implementation of the regional economic development strategy. This resulted in traffic congestion and huge stress lying to the regional transit system. The demand to regional passenger transportation has soared, and it is urgently in need of increasing in the regional mass transit capability. In accordance of the “12thfive-year plan” for railway development, there are several passenger dedicated highspeed railway lines to be built for developed and population dense area, e.g. Yangtze River Delta, Pearl River Delta, Changsha-Zhuzhou-Xiangtan urban agglomeration, etc.[1]. This railway line is also named inter-city railway (IR) and aims to serve cities’ neighborhood. The typical length of an inter-city railway line is around 200~500km. As the land availability for urban development is reducing progressively, it is more and more difficult to introduce inter-city railway across the busy and dense cities. The trend of construction of inter-city railway stations is moving towards underground structures in order to save space as a solution to the shortage of land resource and transportation demand.

As widely known, the most distinct features of underground station are poor in both light and ventilation conditions, which make the accumulating hot-smoke to be an issue during a fire incident; especially smoke movement shares a common path with occupant egress route. Therefore, evacuee would be likely to expose to an untenable environment. At present time,
there is no specific code or guidance for fire safety design of UIR stations in China; hence most of fire engineers refer designs to Code for design of metro (GB50157-2003) due to the similar structure layout between UIR stations and Metro stations.

In fact, UIR and metro are similar but not necessarily the same. Showing in Table 1, there are differences in operating train, waiting mode, passenger characteristics, passenger flow, etc. These essential distinctions will significantly affect the time of platform evacuation. It would not appropriately represent the characteristics of UIR station, if simply referring design of egress to Metro Design Code without consideration of the differences. Design therefore will not be appropriate. It has raised a new challenge for fire safety engineering. This paper puts forward a suggestion on design of evacuation from platform in UIR stations with consideration of its characteristics as well as the relevant requirements or guidelines in Metro Design Code.

Table 1. Comparison between UIR and Metro [2]

| Item                  | UIR                                | Metro                                |
|-----------------------|------------------------------------|--------------------------------------|
| Passenger Flow        | Expected thousands to ten thousands of people per hour during the peak hour | More than 30,000 people per hour during the peak hour |
| Interior Finish       | Fixed soft wadding seats, have been fire-retardant finished | Fixed non-combustible seats |
| Passenger Characteristics | Longer Journey, possible with one or more pieces of luggage | Shorter journey, with no or less luggage |
| Waiting Mode          | Waiting at the concourse. For originating station, only allow entering the platform after clearing the train. For intermediate station, allow entering the platform before the train’s arrival | Do not have particular waiting area, passengers wait for trains at the platform level |
| Type                  | CRH1 Multiple Units (8 cars)       | Type A or B Metro train (4–6 cars)   |
| Operating train Capacity | Total Seating for 668 people in 8 cars, and first class car contains 72 seats; second class car contains 101 seats. | Type A: Each car has capacity of 310 people, 6 cars, 1,860 people in total Type B: Each car has capacity of 240 people, where 6 cars contain 1,440 people in total |
| Exits                 | One exit at each side of each car, with a width of 1.1 m | 4 or 5 exits for each side of each car, and each exit with a width of 2m |
2. Characteristics of UIR Stations

Typical UIR stations are comprised two floors i.e. platform level and concourse level. Passengers in concourse level can either descend to platform level for trains or ascend to ground floor for exits. An island-platform is positioned between two tracks on the platform level. According to the functionality, an UIR station is divided into two areas: public area and non-public area. In order to effectively utilizing space, and for the convenience of occupants’ movement, non-public areas (office & equipment area) are located at the secondary area at both end of the concourse and platform.

Passengers in an UIR station normally carry heavier and larger luggage. For people-oriented basis, stations are generally equipped with a number of escalators. Because of the confined underground spaces, UIR stations are difficult to use merely stairs for evacuation, therefore, referring to Metro Design Code, allow evacuation using escalators as means of escape.

3. Analysis of platform evacuation in UIR stations

As an underground structure, UIR stations and metro stations are buried underneath and surrounded by rock and earth. Exits connecting external street level are limited and relatively low and narrow. Accumulating smoke layer and hot gas within confined space would lead to rapidly increase in temperature of interior space and shorten the available escape time. Therefore the width of staircase and evacuation passage is important to enable all occupants on the platform to safely evacuate from the platform within 6 minutes in case of fire during the peak hour [3]. In addition, as stated in NPFA 130 (Standard for Fixed Guideway Transit and Passenger Rail Systems), the station shall be sufficient egress capacity to evacuate occupants from most remote point at the platform to a point of safety in 6 minutes or less[4]. Therefore this paper also adopts 6 minutes as a safety target.

3.1. Calculating method for platform evacuation time in UIR stations

According to clause 8.3.10 of Metro Design Code, the time for evacuation from platform during a fire incident can be calculated using Eq. (1) [5]:

\[
T = 1 + \frac{Q_1 + Q_2}{0.9[A_1(N-1)+A_2B]} \leq 6 \text{ min}
\]

Where:
- \(T\): Time for evacuation from platform in case of an emergency, (min);
- \(Q_1\): The occupant load in one train (person);
- \(Q_2\): The occupant load at platform including passengers and staffs (person);
- \(A_1\): The specific flow of escalators (person/(min·m)), not to exceed 9600 person/(min·m) when operating speed is 0.65 m/s;
- \(A_2\): The specific flow of stair (person/(min·m)), 3700 (person/(min·m)) for ascending;
- \(N\): The number of escalators;
- \(B\): Total width of stairs (m)

Note:
- Where “1” is the response time for occupants;
Calculation shall consider one of the escalators is broken and can’t be used during an emergency; and the specific flow of (N-1) escalators and stairs shall time a reduction factor of 0.9.

Known from Equation 1, Metro Design Code considers only the passenger load of one train for calculation of platform evacuation time the influence of egress width on the platform level. The effects of structure layout, “bottleneck” of crowd movement by narrow train doors as well as the horizontal travel distance at platform are excluded.

In the emergency evacuation process, besides stairs and escalates, train exits are also the congestion point of crowd movement in the UIR station. Evacuee flow is greatly reduced by the smaller available exits in CRH1 trains in comparison with metro trains. The CRH1 trains have doors about 1.1m wide and the longest travel distance inside the train is 13.3m, see Fig. 2 and Fig. 3. Moreover, due to high occupant load in a confined space inside trains, people’s walking speed is limited and the specific flow of train exits is then lowered. Passengers have to wait at train exit for a long time. So when calculating the platform evacuation time in UIR station, this is the key item which should be taken into account.

![a](image1.jpg) ![b](image2.jpg)

Fig. 2. Train exits for (a) metro and (a) CRH1 train.

![image3.jpg]

Fig. 3. Size of typical CRH1 train.

Similar to Metro, island-platform, short distance between intermediate stops, and high outbound and inbound frequency would lead to a high possibility of two trains to stop at station at the same time. It is necessary to estimate the train occupant load based on two trains.

Furthermore, Passengers who traveling by Inter-city railway, normally intend to have a longer journey, while those traveling by metro are likely for having a short journey perhaps city-wide, thus people in UIR station tends to carry more luggage than people in metro. Since this, walking speed during an emergency has been greatly affected by how much luggage along with passengers. So this effect shall be reflected in the parameter selection process when calculating the platform evacuation time.

Through the differences discussed above, i.e. the type of trains, passenger characteristics, operating mode, current design equation and parameter suggestion in Metro Design Code obviously do not suit for UIR stations. Based on the design equation of Metro Design Code, this paper has put forward an alternative approach. The approach considers the flow time
at the train doors and platform exits to reflect the effect of the bottlenecks and the horizontal travel time to represent the characteristics of the UIR stations. The alternative approach is as follows:

\[ T = 1 + \max\{F_p, F_i\} + \frac{t}{V} \leq 6\text{min} \]  

\[ F_p = \frac{2Q_1 + Q_2}{0.9[N_1(N_1-1) + A_2B_2]} \]  

\[ F_i = \frac{Q_1}{A_3N_2B_2} \]  

Where:
- \( T \): Time for evacuation from platform in case of an emergency (min);
- \( F_p \): Platform exits flow time (min);
- \( F_i \): Train doors flow time (min);
- \( Q_1 \): Occupant load in one train (person);
- \( Q_2 \): Occupant load at platform includes passenger and staff (person);
- \( A_1 \): Specific flow of escalators [person/(min·m)];
- \( A_2 \): Specific flow of stair [person/(min·m)];
- \( A_3 \): Specific flow of train exit [person/(min·m)];
- \( L \): The distance from most remote point at platform to the nearest stair/escalator (m);
- \( V \): Occupant walking speed (m/s);
- \( N_1 \): Number of escalators;
- \( N_2 \): Number of train door available for evacuation;
- \( B_1 \): Total effective width of stair (m);
- \( B_2 \): Effective width of one train door (m);

Note:
- Where “1” is the response time for occupants;
- Calculation shall consider one of the escalators is broken and can’t use in case of an emergency; and the specific flow of (N-1) escalators and stairs shall time a reduction factor of 0.9.
- Where \( B_2 \) in equation 2, is the effective width of each train door. In SFPE handbook, it suggested that the effective width of an exit path is the clear width of the path less the width of the boundary layers, 150mm for door boundary and 90mm when handrail is involved.

4. Case Study

Verification check is carried out for the alternative approach, through comparison with STEPS computational model and design equation of Metro Design Code based on an under construction UIR project in China.

4.1. Introduction of UIR Station Project

An UIR station in Hunan province consists of two floors underneath ground level. The upper floor is the concourse, and the lower floor is the island-platform. Platform spans 230 metres in length with 200 metres long platform screen doors (PSD) on each side. The platform effective width is 14.5 metres. As shown in Fig. 4, there are 2 stairs and 4 escalators connecting the station concourse level to the platform level. The width of two stairs is 3.5 metres. Each of escalators has a width of 1 metre. And the longest dead-end distance on the platform level is 26.5 metres.

![Fig. 4. The layout of platform.](image-url)
4.1.1. Occupant Load

Inter-city railway network equips with CRH1 multiple units which consist of 8 cars. A crush load of CRH1 train is 801 which is 20% overload upon 668 fixed seats. There are 10 pairs of trains on operation each hour. According to the station passenger flow prediction, see Table 2, plus 10 staffs at the platform level, the total occupant load on the platform as well as in train can then be obtained. The occupant load of platform level = \( \frac{810+752}{10} \times 1.3+10=214 \), see Table 3.

Table 2. Daily peak hour passenger flow prediction

| South Bound | North Bound |
|-------------|-------------|
| Departure   | Departure   |
| Arrival     | Arrival     |
| 810         | 752         |
| 756         | 958         |
| Peak Hour Factor | 1.3 |

Table 3: The total occupant load at platform and in train

| Boarding passenger | Staff | Passenger in two trains (Crush Load) | Total occupant load |
|--------------------|------|-------------------------------------|--------------------|
| 204                | 10   | 1602                                | 1816               |

4.1.2. Specific Flow at Stair and Escalator

Passengers in UIR station are likely to carry one or more pieces of luggage. Consideration of affected walking speed and occupied space by luggage, specific flow of stair and escalator therefore refers to Code for Design of High Speed Railway (TB10621-2009, J971-2009), see Table 4 [6].

Table 4. The maximum flow of stair and escalator

| Parts               | Stair with 1m width | Escalator with 1m width |
|---------------------|---------------------|-------------------------|
|                     | Descending          | Ascending               |                     |
| People per hour     | 2500                | 2300                    | 5800                |

4.1.3. Specific Flow at Train door

There is only one door on each side of the car, each with an effective width of 0.8 m. The specific flow of passengers getting through the train door is taken from SFPE Handbook. Harold E. etc. al concluded a parabolic relationship between specific flow and density, as shown in. From previous calculation, the occupant density for a second class car of CRH1 train set with “crush load” passengers is 3.4 person/m². According to Fig. 5, the specific flow of crowd moment through train door is 0.55 person/m/s.

Fig. 5. The relationship between density and specific flow of doorway [7]
4.1.4. Walking Speed
Walking speed closely relates to gender, age, health, piece of luggage handling. The test data of walking speed in train station with luggage are relatively insufficient. Reference to NPFA 130, the walking speed of passenger with luggage is suggested a value of 37.7 m/min.

4.2. Comparison between Suggested Alternative Approach and Computational Model

4.2.1. Computational Modeling
This paper has used STEPS software for simulation of passenger evacuation from platform. STEPS software specialises in simulation of evacuation, algorithm includes interaction between people, people and structure, people and surrounding environment. Users are able to adjust different character to evacuees, e.g. gender, size, walking speed, etc.

- Evacuation Scenario
In order to make the computational model comparable to hand calculation, one of the four escalators has been diminished. Due to the complexity of actual constitution of passenger group (age, gender), the suggested values by Simlux User Guide [8] are taken in the simulation. See Table 5 for the constitution of passenger group.

Table 5. The constitution of passenger group

|     | Male | Female | Children | Elder |
|-----|------|--------|----------|-------|
| Proportion (%) | 40   | 40     | 10       | 10    |

- Results of Computational Modelling
The evacuation model mainly focused on analysing the time that evacuee escapes from inside of a train to platform, and eventually ascending to upper level via stairs and escalators. See Table 6 for computational results.

Table 6. Results of evacuation simulation

| Occupant Load (Person) | Response Time (s) | Evacuation Time (s) | Total Platform Evacuation Time (s) |
|------------------------|-------------------|---------------------|-----------------------------------|
|                        | Exit Train        | Exit Platform       |                                  |
| 1914                   | 60                | 244                 | 267                               | 327                               |

The total platform evacuation time is 5.45 minutes from computational modelling, where 6 minutes safety target is achieved. Simulation also showed that a congestion point of crowd movement formed at the train door.

4.2.2. Calculation by Suggested Alternative Equations
Substituting parameters defined in the previous section to Eq. (3) and Eq. (4).

- The platform exit flow time: $F_p = 3.7\text{ min}$;
- And the CRH1 train door flow time: $F_t = 3.8\text{ min}$.

For the UIR station layout, the longest distance at platform is $L = 26.5\text{ m}$. The passenger average walking speed is 37.7m/min, thus the horizontal movement time during evacuation is 0.71 min. From Eq. (2), the time to fully clear of platform is 5.51 minutes in a fire emergency, which is less than 6 minutes.

In this case, the time that passengers spent to get through the train door is longer than they spent for passing the stair and escalator exits. The total evacuation time from the platform in this UIR station is dependent on the train door flow time.

The result from suggested equation is in consistence with the simulation results both in total platform evacuation time and flow time at the train door. This has shown that the alternative approach is appropriate for the design of the UIR station platform evacuation. It is also proven that if sufficient egress width is provided at platform level, the type of operating train and the platform horizontal travel distance are the key factors of evacuation time in emergency.
4.3. Comparison between Two Approaches

4.3.1. Calculation of minimum required egress width by Metro Design code
The minimum no. of escalators (N) and total egress width of stairs (B) that station have to provide for platform evacuation, is calculated from equation 1 by applying to the under-construction UIR station, under that 6 minutes evacuation requirement. See Table 7 for the parameters taken in calculation and Table 8 for the results.

Table 7. Parameter for calculation the platform evacuation time

| Total no. of evacuee (person) | Specific Flow (person/m/h) |
|-------------------------------|---------------------------|
| Occupant load in one train (Q1) | Occupant load of platform (Q2) | Stair (A2) | Escalator (A1) |
| 801                           | 214                        | 2300  | 5800      |

Table 8. The minimum required egress width

| No. of Escalator (N) | Total Egress Width of Stair (B) |
|----------------------|---------------------------------|
| 1                    | 5.9m                            |
| 2                    | 3.4m                            |
| 3                    | 0.9m                            |
| 4                    | 0m                              |

4.3.2. Calculation of minimum required egress width by Alternative Approach
Where Table 9 shows the parameters which were taken into account. Through equation 2, the required minimum no. of escalators (N1) and total egress width of stairs (B1) in order to meet the 6 minutes safety target are shown in Table 10.

Table 9. Parameter for calculation the platform evacuation time

| Total No. of Evacuee (Person) | Specific Flow (person/m/h) | Horizontal movement time (min) | Train doors flow time (min) |
|-------------------------------|-----------------------------|--------------------------------|-----------------------------|
| Occupant load in two trains (Q1) | Occupant load of platform (Q2) | Stair (A2) | Escalator (A1) |
| 1602                          | 214                        | 2300  | 5800      | 0.71 | 3.8    |

Table 10. The minimum required egress width

| No. of Escalator (N1) | Total Egress Width of Stair (B1) |
|-----------------------|---------------------------------|
| 1                     | 12.3m                           |
| 2                     | 9.8m                            |
| 3                     | 7.3m                            |
| 4                     | 4.8m                            |
| 5                     | 2.2m                            |

Results in Table 8 and Table 10 show that if platform egress design of UIR station refers to Metro Design Code, there only 4 escalators and 0 meter of stair are required for safe evacuation purpose, while alternative approach shows that another 4.8 meters wide stair have to be provided besides 4 escalators. Compared to current Metro design equation, the suggested equation is deemed to be more feasible for UIR station designs.

5. Conclusion & further research

The following points have been concluded:
- An alternative approach for calculation of the UIR platform evacuation time in emergency has been developed based on the Metro Design Code and through analyzing key factors that affect the platform evacuation time. The key factors include the type of trains, the number of evacuees and passenger characteristics. The alternative
approach has been adopted to analyze the passenger flows at the train doors and the platform exits, and to identify the movement bottleneck position.

- The case study of the UIR station indicates that the results of the alternative approach are in consistence with the results the computational simulation of STEPS model. Based on the analysis, the results demonstrate that the design of the specific UIR station meets the fire safety requirements. It is concluded that the alternative approach is suitable for the design of UIR stations. The case study reveals that the train door of the UIR stations is the bottleneck of the evacuation process. The Metro Design Code does not consider this factor, hence not appropriate for the design of UIR stations.

- This paper has put forward an alternative approach for egress design of UIR stations and successfully applied for the UIR stations in Hunan Province. Due to the complexity of UIR stations, it is recommended that the alternative approach be further verified by applying the model to assess different types of stations, train cars and passenger flows.

The approach suggested in this paper is deemed to be feasible in design of UIR station. However emergency movement of passenger is unpredictable which always results in uncertainty. Therefore more feasibility assessments by comparison to other commercial software are needed.

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