Study on the Optimal Safety Distance for Turn-back Line of Regional Railway

Haiou Shi1, Hui Zhang2*, Shuang Li2, Jiaqian Chen2 and Yuanguang Sun1

1 Guangzhou Metro Design & Research Institute Co., Ltd., Guangzhou, Guangdong, 510010, China
2 State Key Laboratory of Railway Traffic Control and Safety, Beijing Jiaotong University, Beijing, 100044, China
*Corresponding author’s e-mail: m18293540120@163.com

Abstract. At the same time of large-scale development of trunk railway and urban rail transit, Regional Railway will gradually enter the stage of large-scale construction. Post-station turn-back is one of the most frequently used forms for regional railways, the length of turn-back line and safety distance directly affects the scale of station and construction investment. However, the provision for safety distance of turn-back line is relatively broad in the current design specifications, and there is margin for further refinement. Based on the safety braking model, starting from the fundamental reasons for setting the safety distance, this paper studies the calculation method of safety distance and turn-back capability by analyzing the factors affecting the safety distance. Combining with the actual operation requirements, considering both train operation safety and turn-back capacity, the optimal safety distance model of turn-back line is constructed by selecting the post-station turn-back. The actual station is analyzed and the research results have positive significance.

1. Introduction

Regional railway, also known as the suburban railway and the commuter railway, refers to the passenger rail transit system within the metropolitan area, which meets the traffic demand of urban agglomerations such as passenger transportation between the central city and the surrounding cities. It is the focus of future development and construction of key areas of rail transportation. The design speed of the regional railway is 100-160km/h [1]. Compared with the subway, the regional railway has the characteristics of long distance between stations and fast running speed. However, its line configuration basically refers to the design of the subway line, such as setting up a turn-back line at the terminal station or some large repeater stations to supply train return to change the running direction. The design of the turn-back line needs to meet the requirements of the line turn-back capacity. The "Code for Design of the Metro" (GB 50157-2013) stipulates that: 6.4.3-7 the effective length of the end-type return line (excluding the buffer stop indicator) should not be less than the distance (50m), which present the length of the extension of a single-train. The safety distance of the through-type turn-back line is 60m [2].

The existing design specifications have macroscopically provisions on safety distance. The length of the safety distance specified in the “Code for Design of Regional Railways” is designed to be 50 meters, but the reason why the safety distance is set to 50 meters is not clearly stated. Moreover, the length of safety distance is required to be 50 meters in both “Code for Design for National railway”
and “Code for Design for Subway”. The regional railway, subway, and national railway have obvious differences in line conditions, signal system, vehicle performance, train running speed and other aspects. Whether the safety distance can satisfy the safety operation of the train under extraordinary conditions and whether there is unnecessary margin are worthy of further study.

This paper takes a typical “one island with two sides” platform in original railway as an example, aiming at the safety distance length of the post-station turn-back, considering the safety of train operation and the efficiency of turn-back from the perspective of train running speed, the design and research of the optimal safety distance of post-station turn-back for the regional railway are carried out. At present, the research on safety distance of turn-back line is mostly focused on the necessity of setting safety line [3][4], the improvement of turn-back capacity and the optimization design of safety line wiring type [5][6]. The research on safe distance of turn-back line is relatively less. Reference [7] specifically analysed the influence of protected sections on the turn-back capacity, pointing out that too small protection sections will reduce turn-back efficiency. From the perspective of optimizing the signal system, Dong Song put forward a method to improve the turn-back capacity from the perspective of optimizing the signal system [8]. Reference [9] set the type of station where there is a parking situation when the train prepare to run from the access line to the main line, and calculated the braking distance under the most unfavourable conditions of the train, which provided a reference for the line designer.

2. Influencing factors for the Safety distance of turn-back line

In order to give full play to the operation capacity of rail transit and ensure the flexibility of operation, in addition to the main line, urban rail transit stations also set up some auxiliary wiring. The configuration of the turn-back line is based on station position and turn-back capacity. In general, the turn-back mode of terminal station is more flexibly, which mainly adopts turn-back before station and post-station turn-back. As shown in Fig.1 and Fig.2. The turn-back train before station has a shorter travel distance and shorter train turnaround time. However, the way of turn-back before the station requires passengers to go through the turnout, which has certain impact on the safety and the comfort of passengers. Meanwhile, it is not conducive to the organization and management of passenger transport. The turning lines are set specially for post-station turn-back, which can accommodate multiple trains for turn-back at the same time, which makes transportation organization relatively smooth. However, it need longer distance and time to complete the turn-back operation.
3. Calculation of Safety Distance and Turn-back Capacity

Research on train braking distance and turning-back capacity has been mature. Reference [10] designed case studies of various factors affecting train braking, and obtained the influence of each factor on train braking problems through the research. Wu Qinghai was based on the design principle of the braking system of urban rail transit, and analyzed the impact of various brake system failures on train operation [11]. Reference [12] calculated the interval time of turn-back trains for different turn-back modes which put forward and compared the methods of calculating the turn-back capacity of terminal trains under different turn-back modes. Reference [13] [14] adopted the method of computer simulation to analyse the characteristics of the turn-back capacity of different types of turn-back stations, and put forward measures to optimize the turn-back capacity to improve the line carrying capacity. This paper combines the characteristics of the study on safety distance of turn-back lines, and uses the following method to calculate the braking distance and turn-back capacity of trains.

3.1. Calculation of safety distance

As can be seen from Section 2, the calculation of safety distance is essentially to calculate the distance that the actual parking point exceeds the specified parking point after the train braking system fails. Under the protection of ATP (Automatic Train Protection) system, the train has two braking systems: common braking system and emergency braking system. The braking principles adopted by the two systems are different, and they do not affect each other when the train is running normally. Generally, the train deceleration and braking orders are completed by the common braking system. When the train in the braking process has a common brake failure, and the common brake is insufficient to provide the braking force required by the train, the emergency braking system is triggered to control the train to decelerate and stop. Therefore, the difference between the end point of the emergency braking curve of the train and the end point of the common braking curve after the failure of the brake is the required safety distance of the turn-back line. The principle is shown in Figure 3.

The establishment of emergency braking includes traction abscission phase, the coasting phase after traction abscission and braking phase. Therefore, the emergency braking distance consists of the following parts: the running distance of the train during the traction abscission time, the move distance of the train during the idle time, and emergency braking distance. The equation for calculating the emergency braking distance is as follows:

\[ S_e = \left( v_0 \cdot t_d + \frac{1}{2} a_{\text{max}} \cdot t_d \right) + v_r \cdot t_e + \left( \frac{v_r}{3.6} \right)^2 / 2a_e + S_r \]  \hspace{1cm} (1)

\[ v_0 = v_i + 5 \]  \hspace{1cm} (2)

Where 3.6 is the conversion factor between speed units km/h and m/s; \( v_i \) is the train running speed, \( v_0 \) is the emergency braking initial speed, \( v_r \) is the speed after the braking is effective, \( v_{\text{re}} \) is the speed tolerance, and all speed units are km/h; \( t_d \) is the delay time required for the traction abscission process, \( t_e \) is the emergency braking effective time, and all the time units are s; \( a_{\text{max}} \) is the maximum
acceleration of the train, $a_c$ is the emergency brake deceleration, and the units are m/s^2; $S_c$ is the distance from the nearest transponder and the measure error.

The equation for calculating the common braking distance is as follows:

$$S_b = \left( \frac{v_f}{3.6} \right)^2 / 2a$$

(3)

In the equation, $a$ is the actual train braking rate. When the current braking rate and running speed of the train are given, the Equation (2) is substituted into the Equation (1), and the emergency braking distance of the train can be obtained. Then combine the Equation (3) and calculate the safety distance according to the calculation principle shown in Fig. 3.

![Figure 3. The calculation principle of turn-back line safety distance.](image1)

![Figure 4. The train enters the turn-back line and stops.](image2)

3.2. Calculation of Turn-Back Capacity

Turn-back capacity calculation refers to the maximum number of trains that the turn-back station can complete the turn-back operation in unit time at in urban rail transit. The commonly used equation is $n_z = 3600 / I_z$, the unit is pair/hour, where $I_z$ indicates the time interval of turn-back operation and the unit is second. The turn-back capacity of the station mainly depends on the arriving time of the train, the time that the train stops at the station, the time that the train entering the turn-back line and the time of signal system conversion and confirmation.

There are four processes for a train to complete a turn-back operation. In the first stage, the route of the first train from the platform to the turn-back line has been arranged. The train enters the turn-back line from the platform and stops. The train operation process in this stage is shown in Fig. 4. In the second stage, the station handles the route for the first train leaving the turn-back line. In the third stage, the first train leaves the turn-back line and runs to platform. Finally, in the fourth stage, the station handles the route for the second train from the platform to the turn-back line, and then a turn-back operation is completely finished. The sum of the running time of the train in these four stages is the turn-back headway.

Among them, the time of handling turning-back route at the station is 13 seconds, and the actual run time of the train at the station can be acquired by analysing the traction calculation process of the train. The calculation process of the train heading to the turning-back line is contrary to the process of the leaving from the turn-back line. Fig.4 is the stop indication of the train entering the turn-back line. Because of the restriction speed of the switch at the entrance of the turn-back line, the train starts from the platform and accelerates (AB). When the speed reaches the restriction speed of the switch, the train runs at a uniform speed until it receives the braking order (BC). After excising the traction (CD), non-braking-coasting and braking establishment process (DE), the train starts braking to stop at the end of turn-back line (EF).
The time that the train enters the turn-back line from the platform is calculated according to the following equation:

\[
S = \left(\frac{1}{2} a_{\text{max}} \cdot t_y\right) + \frac{v_c}{3.6} \cdot t_y + \left(\frac{v_c}{3.6}\right)^2 / 2a_{\text{max}} + \frac{v_c}{3.6} \cdot t_k + \left(\frac{v_c}{3.6}\right)^2 / 2a_c
\]

(4)

\[
I_z = t_y + t_x + t_k + t_h
\]

(5)

\(v_c\) is the speed at which the train runs through the switch at the entrance of the turn-back line, the other parameters in the equation are the same as those in Equation (1). Combining Fig.5 and the kinematics equation, the turn-back headway of the station can be calculated.

4. Optimal Safety Distance

For CBTC (Communication Based Train Control System) system which is widely used in urban rail transit system at present, the ability of train running in difference sections has been brought into play greatly, so the ability of train to carry out the turn-back operation at the turn-back station is usually the restriction of entire line transport capacity. For the post-station of station studied in this paper, after determining the train type, the most important factor affecting the turn-back capacity of the train is the lateral speed limit of the switch at the entrance of the turn-back line. At the same time, if the lateral allowable speed of turnout is higher and the train running speed is faster, the longer the safety distance required after turn-back line, which increases the actual project cost and economic investment.

According to the actual operation situation, the length of safety distance should satisfy the requirement of safe parking when the train braking system fails 1/4. At the same time, according to the specifications and actual operation requirements, the turn-back capacity of the train should not be less than 30 pairs per hour. According to this, the calculation model of safety distance for the turn-back line is established as follows:

\[
\left\{ \begin{array}{l}
S(v) \geq S(v)_{|b=0.25} \\
I_z(v) \leq 120
\end{array} \right.
\]

(6)

Combining Equation (1) (5), according to the actual operation, the train braking failure ratio is 1/4, and substituting relevant parameters for calculation, the result is shown in Figure 5.

Taking Chaoyang Station of Guangzhou Metro Line 13 as an example, the safety distance of the turn-back line is analyzed. Chaoyang Station is the starting point, using the turn-back line after the station for turn-back operation. Switch No.12 is used for turn-back line, and the lateral speed limit of the switch is 50 km/h. There is a certain amount of affluence when calculating the turn-back capacity, which is analyzed according to 42km/h. From Figure 5, it can be concluded that the safety distance of the turn-back line of Chaoyang Station should be set to 42.04m, which can meet the requirements of
the safety distance and the ability of the train to turn-back at the same time. This length is the safest distance actually needed.

5. Conclusion
In this paper, the description of the safety distance of the turn-back line is relatively weak in the actual use specification. Starting from the factors affecting the length of the turn-back line and the fundamental reasons for setting safety distance, the speed is taken as the connection point to comprehensively consider the actual operation demand, the train operation safety and the turn-back capacity. Based on this, the concept of optimal safety distance is proposed. At the same time, the calculation method of safety distance and turn-back capacity of turn-back line is studied, and the train return process is analyzed in combination with the station configuration to calculate the return interval time. Based on this, the optimal safety distance calculation model of the turn-back line is established, and taking the actual station as an example to calculate the optimal safety distance of the turn-back line after Chaoyang Station.

References
[1] T/CRS C0101-2016 Code for Design of Regional Railways. (2017) Beijing: China Railway Society.
[2] GB 50157-2013 Code for Design of Metro. (2013) Beijing: Beijing Urban Engineering Design & Research Institute Co.,Ltd.
[3] QI J., LIANG G.S. (2008) Options for Track Connection with Transfer Tracks of Depot. Urban Rapid Rail Transit, 21(6):23-26.
[4] ZHENG Z.T. (2014) Discussion on Problems Existing in Setting up of Safety Siding and Successive Route of High-speed Railways. Railway Transport and Economy, 36(1):14-17.
[5] CAO H.L. (2018) Impact Analysis and Optimization of Turn-back Capacity in Rear of a Station in Urban Rail Transit. Railway Signalling & Communication, 54(03):93-95.
[6] DONG S. (2019) Study of Improving Turn-back Capability of Turn-back Station through Signal System. Railway Signalling & Communication, 55(01):70-74.
[7] CHEN W.H., ZHANG C.G. (2017) Impact of overlap to driving turn-back efficiency. Railway Computer Application, 26(09):60-63.
[8] GAO C.M., (2015) Study on the Design Scheme of Railway Safety Siding Spatial Alignment. Railway Standard Design, 10:49-53.
[9] LAN S., LIN Z.L., ZHANG P. (2010) Computation Formula for Transient Braking Distance on Outbound and Inbound Tracks of Metro. Journal of Railway Engineering Society, 27(4):87-90.
[10] LIU H.D., S.M., PENG H.Q., ZHANG Z.Y., XING H.L. (2011) Braking Performances of Urban Rail Trains. Journal of Transportation Systems Engineering and Information Technology, 11(06):93-97.
[11] WU Q.H. (2017) Urban Rail Brake System Mode Based on Safety and Operation Requirements. Urban Mass Transit, 20(03):51-55.
[12] WANG X.K. (2018) Analysis of Turn-back Capability of Metro Terminal. Technology and Economic Guide, 26(13):213-214.
[13] XU Y. (2017) Analysis on Turnaround Capacity of Urban Rail Transit Line and Its Optimization Measures. Railway Transport and Economy, 39(03):96-102.
[14] SUN W. (2018) Turn-back Schedule Optimization based on the Particle Swarm Genetic Optimization. Railway Transport and Economy, 40(04):107-114.