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Research on Platform Safety Distance Based on Aerodynami Methods

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Abstract: This article mainly studies the impact of air flow generated by trains entering the station on passengers on the platform, and establishes a relationship model between the air flow velocity and the pressure on passengers during train entry. Firstly, a simplified model of the air velocity around the train was established by combining aerodynamics theory, Bernoulli principle, and relevant formulas, and the air pressure on passengers was calculated. Secondly, the rationality and feasibility of the model were verified through comparative analysis of mathematical models and experimental data. Finally, based on the results of the model, suggestions were put forward for the setting of safety markings for high-speed rail and high-speed train stations, including the relationship between safety distance and train speed, providing theoretical support and practical guidance for station safety management.

1. Introduction

At train stations or subway platforms, passengers are required to stand outside a yellow (or white) line approximately 1 meter from the edge of the platform. This line is called a safety line in the industry, which is commonly referred to as a safety line. The emergence of safety lines is to avoid the high-speed movement of nearby air caused by trains traveling at high speeds. [1]The principle of this physical phenomenon is the Bernoulli effect. As the fluid velocity increases, the pressure at the interface between the object and the fluid decreases, and vice versa, the pressure increases. That is to say, if the air flow velocity on the train side is high, the air pressure will decrease, otherwise. Therefore, because the person next to the platform may be sucked off the platform by a pushing force from the high-pressure area behind to the low-pressure area in front of the body, resulting in an accident. Therefore, Article 157 of the Railway Technical Management Regulations clearly stipulates that the distance between the edge of the high platform where passenger trains stop and the centerline of the line is 1750mm, and the safety marking line is 1000mm from the edge of the platform. The distance between the non high platform safety line and the edge of the platform is: 1000mm when the train passes at a speed not exceeding 120km/h; When the train passes at a speed of 120 km/h or above to 160 km/h, 1500mm; When the train passes at a speed of 160 km/h or above to 200 km/h, 2000mm; To study the impact of air flow generated by trains entering the station on passengers on the platform, we are required to explore factors such as passenger weight, volume, and distance when high-speed trains or high-speed trains pass by at full speed, and determine the magnitude of the fluid's "suction" or "thrust" on people standing on the platform. This is a complex fluid problem. To establish relevant models, we consulted physical relevant data,[2-4] combined with the Bernoulli effect, and introduced aerodynamic parameters. A solution proposed for simplified train and pedestrian models.[5] Based on the theory of unsteady incompressible potential flow, the irregular shape model of the human body is simplified into a regular three-dimensional cylinder, and a potential axisymmetric model is established for train motion.[6] In this way, we can establish a mathematical model from the above analysis to extract influencing factors: train speed, train body shape, passenger weight and volume, and distance from people. Evaluate these factors and solve them accordingly. Because the research focuses on the basis of setting up safety markings on train station platforms, and the distance between safety markings and the edge of the platform mainly depends on the magnitude of the thrust or suction received by the person standing on the train. The thrust or suction received by the person standing on the train is also related to factors such as the speed of the train, the weight and volume of the human body, etc. Therefore, using mathematical models to obtain the relationship between pressure, passenger weight and volume, as well as the distance between passengers and the platform, combined with Bernoulli's principle, friction coefficient, controller dynamics parameters, etc., a model is established between the distance between safety markings and the edge of the platform and the thrust or suction received by the person standing on the train. Based on the conclusion drawn from problem one, the safety marking distance is obtained.

2. The impact of air flow generated by trains entering the station on passengers on the platform

2.1 Determine the magnitude of the "suction" or "thrust" exerted on high-speed trains or high-speed trains at full speed

When a train enters a station, it generates air flow. Combining the aerodynamic correlation coefficient, gravity formula, relevant parameters of people on the platform, and Bernoulli principle (Bernoulli equation):

$$p+\frac{1}{2}\rho v^2+\rho gh=C \tag{1}$$

prepresents the pressure at a certain point in the fluid,v is the flow velocity of the fluid at that point,ρ is the fluid density,g is the gravitational acceleration,h is the height at which the point is located,c is a constant, which can also be represented as

$$p_1+\frac{1}{2}\rho v_1^2+\rho gh_1=p_2+\frac{1}{2}\rho v_2^2+\rho gh_2 \tag{2}$$

We establish a simplified model:

Step 1: Assuming high-speed rail or high-speed trains travel at a constant speed(v: U_∞), The air velocity(Q) around the train is uniform and stably incident.Because the people on the platform and the air below the train are both in the atmosphere.$p_1$andp_2 represents the position of people on the platform and the air pressure below the train. Assuming these two pressures are equal, the Bernoulli equation [2] is used to calculate the air velocity when the train passes through, According to the Bernoulli equation:$p_1+\frac{1}{2}\rho v_1^2=p_2+\frac{1}{2}\rho v_2^2$

Due to the fast normal running speed of the train, we believe that the air flow velocity around the vehicle body is infinitely close to the vehicle speed ($Q=U_\infty$), And establish a potential axisymmetric model. As shown in Figure 1, Establish a coordinate system for the unsteady flow field around the train, with the front of the train as the origin. The surface of the train body is regarded as the axisymmetric upper half, and the station platform is represented by the (x, y) plane.

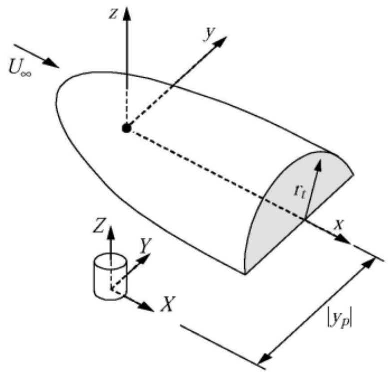

Figure 1: Modeling the flow around a train traveling at a speed of U_∞

(x, y, z) is the fixed reference frame for the train. (X, Y, Z) is the fixed reference frame for the platform.rt:The radius of the train cross-section.yv: Train path to pedestrian position.

The velocity is axisymmetric around the X-axis. Let's assume the existence of velocity potential φ, From this, the velocity component can be derived:

$$u = \varphi_x, w \leq \varphi_r \tag{3}$$

u and w are the longitudinal and radial components,respectively.radial coordinates (r, r_p), Based on the above assumption, the velocity field is expressed as follows:

$$u = U_\infty \left[1 + \frac{r_t^2 x}{4(x^2 + x^2)^{\frac{3}{2}}}\right] \tag{4}$$

$$w = U_\infty \frac{r_t^2 r}{4(x^2+r^2)^{\frac{3}{2}}} \tag{5}$$

$$X = x - U_\infty t, \cdots Y = y + y_p, \cdots Z = z, \tag{6}$$

Make the following expression true:

$$W = w = U_\infty \frac{r_t^2 r}{4[r^2+(X+U_\infty t)^2]^{\frac{3}{2}}} \tag{7}$$

$$U = u - U_\infty = U_\infty \frac{r_t^2 (X + U\infty t)}{4[r^2 + (X + U\infty t)^2]^{\frac{3}{2}}} \tag{8}$$

We can easily obtain that the airflow velocity around the car is the same as the velocity U_{∞_i} The vector (U, W) modulus is

$$V_p = \sqrt{U^2 + W^2} = U_\infty \frac{r_t^2}{4} \frac{1}{r^2 + (X + U\infty t)^2} \tag{9}$$

This is the speed of the stationary vehicle at point (X, Y) relative to the pedestrian standing on the platform.

Step 2: Calculate the pressure difference (Δp):

$$\Delta p = p_1 - p_2 = \frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2 \tag{10}$$

According to the pressure difference, the calculation formula for the air pressure (F) experienced by people on the platform is as follows:

$$\mathrm{F} = \Delta \mathrm{p} * \mathrm{A} \tag{11}$$

Let's represent this pedestrian as a cylinder with a circular cross-section, a radius of r_p, and an impact velocity of $v_p(t)$,As shown in Figure 2:

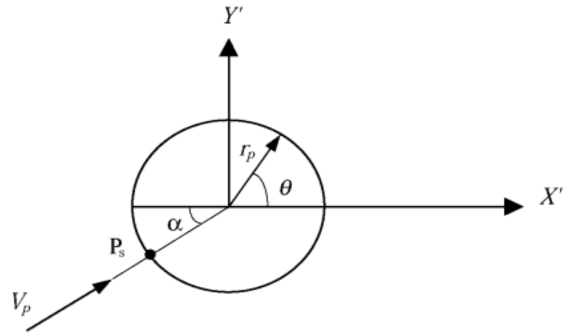

Figure 2: Pedestrian model: Uniform flow V_p impacting a cylinder with a radius of r_p

Due to r_p being much smaller in height than a cylinder (Human height), Therefore, we consider the cylinder as a two-dimensional model. In the above formula, A represents the area of people on the platform, so we can calculate it based on their height (h) and width (w),Namely$A = H * W$.It is calculated based on the height and diameter of the cylinder with the circular cross-section.Therefore, digital passengers can be represented in the reference frame. Assuming the X-axis is aligned with the train path, the collision velocity forms an angle a. Let's assume that the flow field around a cylinder is a non-stationary potential function $\phi(X', Y', t)$ 。 Since $V_P = V_p(t)$ is a function of time, the Bernoulli equation and potential unsteady incompressible flow can be used to obtain the pressure values of the surface distribution, as follows:

$$\phi_t + \frac{1}{2}|\Delta\phi|^2 + \frac{P}{\rho} = C(t) \tag{12}$$

By appropriately handling the boundary conditions, we can obtain variables on the right that are consistent with time. According to equation (12), with reference to the train speed U_∞, provide the expression for the pressure coefficient on the cylinder:

$$c_p = \frac{p - p_\infty}{\frac{1}{2}\rho {U_\infty}^2} = \left(\frac{V_p}{U_\infty}\right)^2 - \frac{2\phi_t + |\nabla\phi|^2}{{U_\infty}^2} \tag{13}$$

Based on V_p and the incident angle α , a parameter about time can be obtained, which is the expression for the velocity potential ϕ on a cylinder:

$$\phi(\theta, t) = 2r_p V_p(t) cos\big(\theta - \alpha(t)\big) \tag{14}$$

At stagnation point $P_s\big(\theta_{p_s} = \pi + \alpha(t)\big)$, the fluid velocity is zero, therefore:

$$c_p(p_s) = \left(\frac{V_p}{U_\infty}\right)^2 - \frac{2\varphi_t}{U_\infty^2} \tag{15}$$

$$\varphi_{t(P_s)} = -2r_p \frac{dV_p}{dt} \tag{16}$$

Here, evaluate the air velocity $V_p = V_p(t)$ at the pedestrian's location, assuming that the impact of a cylinder on the impact stream can be negligible (except when very close to the cylinder). Then, from equation (16), X=0,$r = V_p$ we obtain

$$V_p = U_\infty \frac{r_t^2}{4} \frac{1}{y_p^2 + U_\infty^2 t^2} \tag{17}$$

The pressure coefficient c_p at the stagnation point is

$$c_p(P_s) = \frac{\frac{R_t^4}{16} - 2R_p R_t^2 T}{(1+T^2)^2} \tag{18}$$

Where $T = tU_\infty/v$ is dimensionless time, $R_P = \frac{r_p}{y_p}$, $R_t = \frac{r_t}{y_p}$ are the dimensionless geometric parameter of the problem. The distance y_p is used as the feature length, Note that the pressure changes with the variation of the incident velocity V_p. The pressure coefficient $c_p$at the stagnation point varies with time T as shown in Figure 3, Where $T < 0$represents the origin of the moving reference frame (the position where the source is placed) passing through plane $X = 0$ (the position where pedestrians are placed).

The establishment of the model is used for data analysis. MATLAB is used to calculate and solve the relationship between speed and thrust, as shown in the figure:

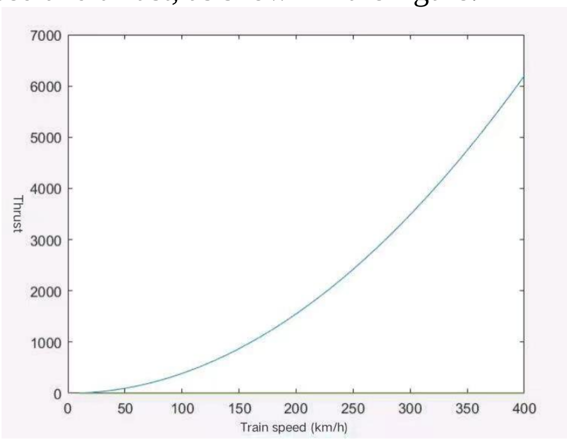

Figure 3: Two dimensional schematic diagram of velocity and thrust

By simplifying the train and human body model, [7] we have obtained the relationship between the "suction" and "thrust" of people on the platform when the train passes through at full speed, considering the volume and distance of people. The pressure rate rapidly decreases as the distance from the passenger to the train axis increases. That is to say, when the train speed is constant, as the train head approaches and moves away, the pressure increases with the distance of people and the volume of passengers. At this point, we need to consider the relationship between a person's weight W and "suction" and "thrust".

If the pressure difference Δp is the force pushing towards the direction of the train ("suction"), then the net force F_{net} that a person experiences can be expressed as:

$$F_{net} = F - W \tag{19}$$

If Δp is the force pulled from the direction of the train ("thrust"), the net force F_{net} that a person experiences is:

$$F_{net} = F + W \tag{20}$$

So, using Matlab to construct a three-dimensional relationship diagram of thrust, human volume, and train speed:

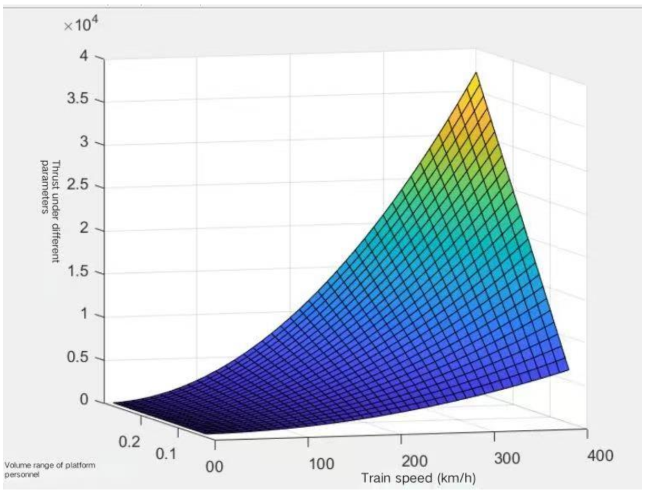

Figure 4: Three dimensional schematic diagram of thrust, human volume, and train speed

The conclusion can be drawn from Figure 4 above and its derivation, it can be concluded that when the train passes at full speed, if the net force experienced by passengers is "suction", the pressure increases with the increase of distance and passenger size, and decreases with the increase of weight.

When the train passes at full speed, if the net force experienced by the passengers is "thrust", the pressure increases with the distance and size of the passengers, and also increases with the weight of the passengers.

2.2 Reasons for setting safety markings on platforms of high-speed trains and high-speed train stations

In order to construct the 2.2 model reasonably, we need to process and analyze the data of 2.1, in order to establish the safety markings for the train stations. [8] Considering the practical situation of life, modeling is carried out based on the principles of friction theory, air fluid correlation coefficient, Bernoulli equation, and other factors to determine the stability and safety standards of human beings.

The setting of safety markings is based on the following principles:

1) Due to the existence of a certain friction force between humans and the ground [5], combined with the relevant definition of friction force (friction force can be expressed as the coefficient of friction multiplied by human weight, and thrust needs to be less than friction force) and the formula:

$$f = \mu N \text{ (μ is the dynamic friction coefficient)} \tag{21}$$

Therefore, the safe distance can be simply defined as the distance where the thrust or suction applied to a person is less than the frictional force.

2) According to the Bernoulli effect principle, the derivation of safety distance in the setting of safety markings requires a correlation analysis of the magnitude of train speed.

3) We consider the position of safety markings as a simple function, with the train's travel speed as input and the position (i.e. safety distance) between the train and passengers on the platform as output.

By establishing the above model, it can be obtained that the magnitude of the net force (combined external force) experienced by passengers on the platform will vary with the speed of the train. Through this property (i.e. the magnitude of external forces), we can evaluate the rationality of setting up safety markings. It is important to consider parameters such as train speed and platform structural design, and to analyze numerical calculations based on real-life situations, in order to determine the optimal position (safety distance) of safety markings. The above model provides a good basic framework for understanding the setting of safety markings on platforms.

In order to complete the solution of 2.2, we further analyzed the conclusions obtained in 2.1 and established a two-dimensional relationship diagram between the distance and speed of safety markings at high-speed rail and high-speed train stations, a three-dimensional relationship diagram between the distance and speed, and volume of safety markings at high-speed rail and high-speed train stations, a three-dimensional relationship diagram between the distance and speed, and weight of safety markings at high-speed rail and high-speed train stations, and a three-dimensional relationship diagram between the distance and force, and volume of safety markings at high-speed rail and high-speed train stations.

Due to the influence of passenger position, air flow velocity around the train, and train speed on the setting of safety markings on station platforms, in order to explain the basis for setting safety markings on high-speed rail and high-speed trains, we combined the problem with safety scope, engineering, and the model established by problem one. Based on the Bernoulli effect, basic principles of fluid mechanics, etc, [9-10] we established the following mathematical model for the force generated by high-speed rail activity vehicles passing through the platform at full speed.

Assuming the distance between the edge of the train and the passengers on the platform is L(unit:m), The speed of the train is V(unit:m/s) The weight of the person on the platform is W,(unit:N), Air density ρ(unit:Kg/m^3)

Based on the Bernoulli equation, we can obtain an expression for the relationship between train speed and the surrounding air velocity of the train:

$$P_{on\ the\ stage} + \frac{1}{2}\rho v_{air}^2 = P_{under\ the\ train} + \frac{1}{2}\rho v^2 \tag{22}$$

$P_{on\ the\ stage}$represents the position of passengers on the platform, $P_{under\ the\ train}$ represents the air pressure below the train.At the same time, passengers on the platform and trains in the same spatial state can consider the two air pressures to be consistent and equal($P_{on\ the\ stage} = P_{under\ the\ train}$)

Based on this assumption, we can calculate the difference in pressure experienced by passengers on the platform, which is the pressure difference $\Delta P_{passenger}$(unit:Pa), The expression for $P_{passenger}$ is

$$\begin{aligned} \Delta P_{passenger} &= P_{on\ the\ stage} - P_{under\ the\ train} \\ &= \frac{1}{2}\rho(v^2 - v_{air}^2) \end{aligned} \tag{23}$$

Next, for the calculation of air pressure$F_{passenger}$, we need to consider its correlation with the distance L of passengers on the platform, in order to obtain:

$$F_{passenger} = \Delta P_{passenger} * S_{passenger} \tag{24}$$

$S_{passenger}$represents the surface area of passengers on the platform, which can be estimated based on the three-dimensional cylindrical model established in problem one.

Finally, based on the estimation of the passenger's body weight$W_{passenger}$, we can obtain the expression for the combined external force (net force) F_h that passengers on the platform are subjected to:

$$F_h = F \pm W_{passenger} \tag{25}$$

This model can further simplify the human body into a three-dimensional cylinder, establish geometric rectangular shapes, and expand and advance them under the simulation of Matlab calculation software.

The purpose of setting safety markings is for passengers to stand outside the markings to ensure safety when the train passes. According to Bernoulli's principle, the faster the train speed, the greater the thrust or suction force on the person standing on the platform. Safety markings need to be set at a distance from the edge of the platform. Therefore, we can establish a model for the safe distance L of safety markings

$$L = S\left(\frac{F_{wind}}{F_m}\right) L_{reality} \tag{26}$$

F_{wind} is the wind force, $F_m$is the frictional force between passengers and the platform, $L_{reality}$ is the actual measured safe distance between the platform and the train.

As the train speed changes, we find that the actual measured safety distance of the safety line will further increase with the increase of train speed. According to the conclusion of the model in 2.1, an increase in train speed F_{wind} will result in an increase. Therefore, we assume the existence of an exponential or power function to describe this growth trend:

$$L(v) = L_0 + \gamma v^n \tag{27}$$

V represents the speed of the train,L_0 represents the basic safety distance,The distance when the train speed is 0, Here we assume that it is $500\text{mm}(v = 0, L_0 = 500)$.Assuming the existence of a proportional constant γ, and a n, In this way, we can effectively describe the safe distance using a function.

Based on the data provided by the existing regulations and rules (as specified in Article 157 of the Railway Technical Management Regulations provided in the question):

Article 157 of the Railway Technical Management Regulations clearly stipulates that the distance between the edge of the high platform where passenger trains stop and the centerline of the line is 1750mm, and the distance between the safety line and the edge of the platform is 1000mm. The distance between the non high platform safety line and the edge of the platform is: 1000mm when the train passes at a speed not exceeding 120km/h; When the train passes at a speed of 120 km/h or above to 160 km/h, 1500mm; When the train passes at a speed of 160 km/h or above to 200 km/h, 2000mm.

By using these data points and combining them with Matlab calculation software, we further fitted the relevant curves, as shown in the figure:

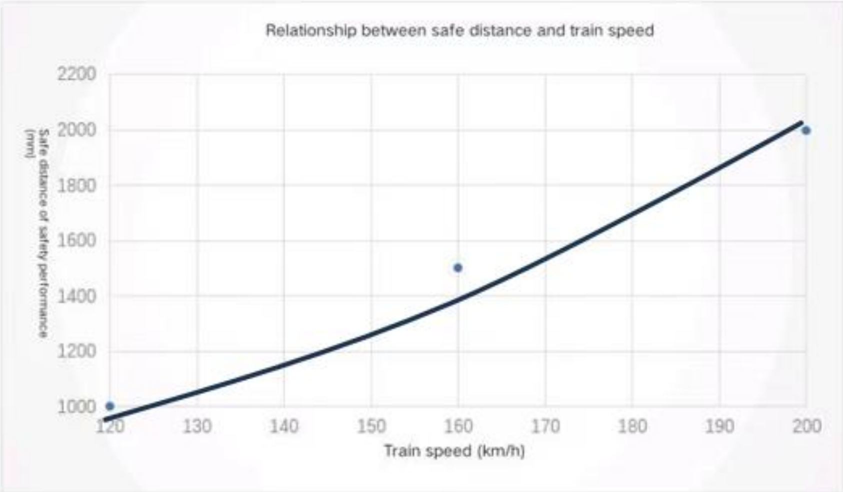

Figure 5: The relationship between safe distance and listed speed

According to Figure 5, after calculation, we obtained $k = 0.41, n = 2.25$, which shows a superlinear relationship. There is a significant correlation between the safety distance and the speed increase of the train, and the safety distance shows a functional growth trend with the increase of speed.

The overall increasing trend of the image results indicates that it is consistent with the data given in the railway technical management regulations. Based on the model, we can obtain reasonable data and further calculate the required safety distance under unknown settings.

3. Conclusions

With the continuous development of the Chinese economy and the continuous improvement of railway transportation, railways have gradually become an important means of transportation to improve people's material and cultural living standards, meet their travel needs, and strengthen national defense construction; Ensuring passenger safety is the most basic requirement of railway transportation. This article focuses on the safety standards of a specific railway station, and explores the size of the "suction" or "thrust" on passengers standing on the platform when high-speed trains or high-speed trains pass at full speed, based on factors such as weight, volume, and distance from people; And the basis for setting up safety markings on train platforms; By introducing aerodynamic parameters through the Bernoulli effect, solutions are proposed for simplified models of trains, high-speed trains, and pedestrians. A mathematical model is established to extract influencing factors and evaluate them to determine the "suction" or "thrust" on pedestrians; By combining the friction coefficient and controller dynamics parameters, a mathematical model is established based on the relationship between the force on the platform and the distance between the safety line on the train platform and the edge of the platform. The trend of the correlation is displayed using an exponential or power function to better describe the safety distance of the train, thus obtaining the basis for setting the safety line on the train platform.

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