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Optimized Design on the Width and Spacing of the Cross Passageway in Tunnels

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Abstract

Cross passageways have been commonly applied in the evacuation system of tunnels, and the width and spacing of the cross passageways decide the evacuation capacity of the tunnel. In design, increasing the width of the cross passageways and reducing their spacing can improve the evacuation ability of tunnels. However, it will certainly increase the cost of the project. Under the precondition of meeting evacuation requirements, an optimization model was established in this article, which aimed at reducing the cost of the project. Finally, discussions on the application of this optimization model were carried on, and this method may provide reference for designing cross passageways.

"Keywords: tunnel, cross passageway, evacuation, optimize"

1. Introduction

With the rapid development of the road tunnels and city underwater tunnels, the tunnel safety has received increasing attention. Since the tunnel space is relatively closed and exits of the tunnel are less, so scientific and reasonable evacuation system is important to ensure tunnel users escaping from the tunnel safely in fire. There are three types of evacuation in the tunnel, which are the corridor neighbor tunnel evacuation, the special horizontally tunnel evacuation and the inner vertically evacuation [1]. In the former two evacuation types, the cross passageways are used as emergency escape path. The appearance of the cross passageway is shown in figure 1.

At present, there are no uniform standards for designing the cross passageways in tunnel. In the abroad, since each country has its own national condition and traffic condition, the recommended design values of the spacing of the cross passageways are range from 100 to 500 meters. In China, there is no specific method of designing the cross passageways, and the designs tend to benefit from the overseas experience data. The recommended design values of the spacing of the cross passageways are range from 250 to 500 meters in China[2].

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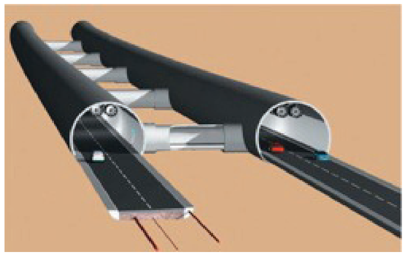

Fig. 1 the cross passageways in tunnels

2. optimization model

2.1. Objective function

In this optimization model, the objective function is the minimum cost of the cross passageways, which can be divided into the construction cost and risk cost. Obviously, the length of the cross passageway is decided by the distance between the two tunnel tubes, and construction cost of the cross passageway is basically proportional to the cross section of the cross passageway. Meanwhile, when the cross passageway is build in a poor geological condition, there would have a big construction risk, which can also increase the risk cost. Therefore, the project cost have a close relationship with the cross section of the cross passageway and the geological condition. Accordingly, establishing the objective function is given in the following formula 1.

$$P_{total} = nE \quad B \quad H \quad l +$$

(*1)* where P_{total} (in \$), N(in Number), B(in m), B(in m), H(in m), l(in m), E(in \$$m^{-3}$) and K(in \$$Number^{-1}$) are the total cost of the cross passageways in a tunnel, the number of the cross passageways in a tunnel, the width of the cross passageway, the height of the cross passageway, the length of the cross passageway, the cross passageway construction cost per unit volume and the risk cost in building a cross passageway.

Each side of the formula 1 is divided by the E. So the result can be expressed as the following formula 2.

(*2)*

Since the E is positive number, when P'_{total} is the minimum, P_{total} is also the minimum. Therefore, the minimal P'_{total} is the optimization objective in this model.

2.2. constraints

The basic function of the cross passageways in tunnel is to provide safe emergency escape path for the tunnel users. In order to assure safe evacuation, the available safe evacuation time (TRSET) should be less than the required safe evacuation time (TASET) in the fire scenario, and a safe margin (TASET-TRSET) considered as $0.5 \times T_{RSET}$ is introduced in this model. It is clear that the safe evacuation is advanced with the growth of the safe margin. Therefore, the first constraint condition is given in the following formula 3.

$$T_{ASET} - T_{RSET} \geq 0.5 \times T_{RSET}$$

(3)

The parameter T_{R} is defined as

$$T_{RSET} = T_A + T_R + T_M \qquad (4)$$

where the T_A (in s), T_R (in s) and T_M (in s) are the awareness time, behavior and response time and movement time. The T_M can be calculated from formula 5, which is an evacuation calculation model from Japan in 2000[6].

(5) where L(in m), v(in ms^{-1}), P(in $personm^{-1}$) and N_{eff} (in $personm^{-1}s^{-1}$) are the spacing of the cross passageways, the walk velocity, the number of people per unit length of the tunnel and the effective flow factor.

L in formula 5 can be expressed as

$$L = \frac{L_{total}}{n+1}$$

(6) where L_{total} (in m) is the tunnel length.

The set of formula (3), (4), (5) and (6) can be rewritten as

(7)

In addition, considering more than three people flows come across a cross passageway at the same time, and the width value interval is 0.5m. So the second constraint condition is that the width of the cross passageways can be 1.5m, 2m, 2.5m, 3m, 3.5m, 4m, 4.5m, 5m.

Therefore, the optimization model can be expressed as

(8)

3. Example application

There is a city under-water tunnel, the length of which is 6050m. This tunnel has three tunnel tubes, and the middle one is used for evacuation, which is connected to the side tunnel tubes by the cross passageways. The side tunnel tube is used for traffic, and each side tunnel tube has three lanes. The distance between the two side tunnel tubes is 30m. The size of the fire in this tunnel is designed to be 20MW, and the tunnel traffic condition in 2029 is shown in table 1.

Table 1 the tunnel traffic volume (vehicles/h)

Vehicles	Number (vehicles/h)
Diesel vehicle	950
Small bus	1320
freight car	240
Truck	49
large bus	303

In this example, using a $30m \times 2m \times 2.5m$ cross passageway as a reference, the construction cost of it will be =150E. The risk cost K is considered to be 0.1-2 times as great as the 150E (). For this, discussions on the optimized design in different risk cost conditions are carried on.

(1) the determination of the number of people per unit length of the tunnel

The person number per unit length of the tunnel can be calculated from table 1. Considering that tree road lane in a tunnel tube are full of parked vehicles, and the spacing of the parked vehicles are 10m (including the vehicle length), the number of the vehicles in 300m length of tunnel can be calculated as

$$m=300\times3/10=90\text{(vehicles)}$$

According to the automobile classification national standard in China (GB9417-89), the number of people in the large bus, small bus, car and freight car is 45 people, 25 people, 5 people and 5 people respectively. So the total number of people in 300m length of tunnel is shown in table 2.

Table 2 the total number of people in 300m length of the tunnel

Types of vehicles	Number of the vehicles (vehicle)	Number of the people in a vehicle (people/vehicle)	Number of the people （people）
Diesel vehicle（33%）	30	5	150
Small bus（46%）	41	5	205
freight car（8%）	7	25	175
Truck（2%）	2	5	10
large bus（11%）	10	45	450
Total person			990

Therefore, the number of people per unit length of the tunnel can be $\rho = \frac{990}{300} = 3.3\ \frac{people}{m}$

(2) the determination of TASET

Since the design fire size of the tunnel is 20MW, a 20MW fire in tunnel was simulated by the FDS software. The results showed the smoke parameters (gas temperature, radiation, visibility, etc.). Compared the results with performance-based criterion, the TASET can be 1000 seconds.

(3) the determination of other parameters in the model

In this example, TA and TR can be 60s, and the person walk velocity can be 1.5m/s. the height of the cross passageway is considered to be 2.5m.

(4) optimization calculation

A solution program is developed by the language C. The optimization calculation results of different risk costs of the cross passageway is shown in the table 3.

Table 3 the optimized design results of the cross passageways in different risk costs

$\frac{K}{150E}$	K/E	n	The width of the cross passageway (m)	The spacing of the cross passageway (m)	Objective function value P^{r}_{total}	$\frac{K}{150E}$	K/E	n	The width of the cross passageway (m)	The spacing of the cross passageway (m)	Objective function value P^{r}_{total}
0.1	15	23	1.5	252	2933	1.1	165	15	3	342	5850
0.2	30	23	1.5	252	3278	1.2	180	15	3	342	6075
0.3	45	23	1.5	252	3623	1.3	195	15	3	342	6300
0.4	60	23	1.5	252	3968	1.4	210	15	3	342	6525
0.5	75	19	2	302	4275	1.5	225	12	4.5	465	6750
0.6	90	19	2	302	4560	1.6	240	12	4.5	465	6930
0.7	105	19	2	302	4845	1.7	255	12	4.5	465	7110
0.8	120	19	2	302	5130	1.8	270	12	4.5	465	7290
0.9	135	15	3	342	5400	1.9	285	12	4.5	465	7470
1	150	15	3	342	5625	2	300	12	4.5	465	7650

From results in the table 3, the objective function value, the optimized width and spacing of the cross passageways are advanced with the growth of the risk cost of the cross passageway. On the contrary, the number of the cross passageways is reduced. These results can be expressed in the figure 2 － figure5.

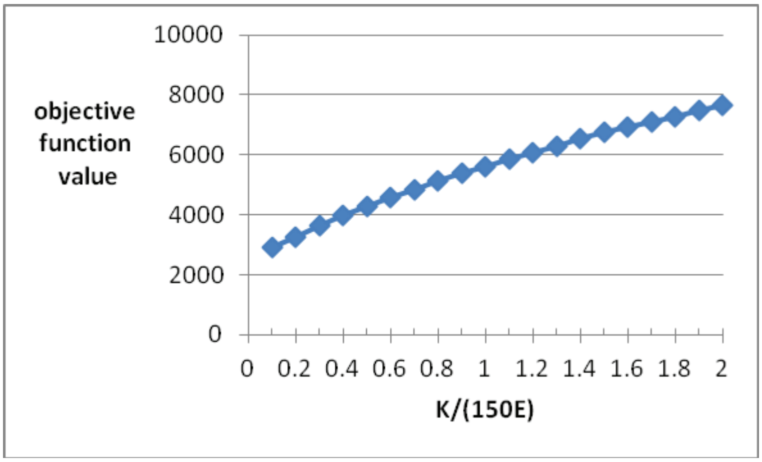

Fig. 2. the objective function value in different risk costs

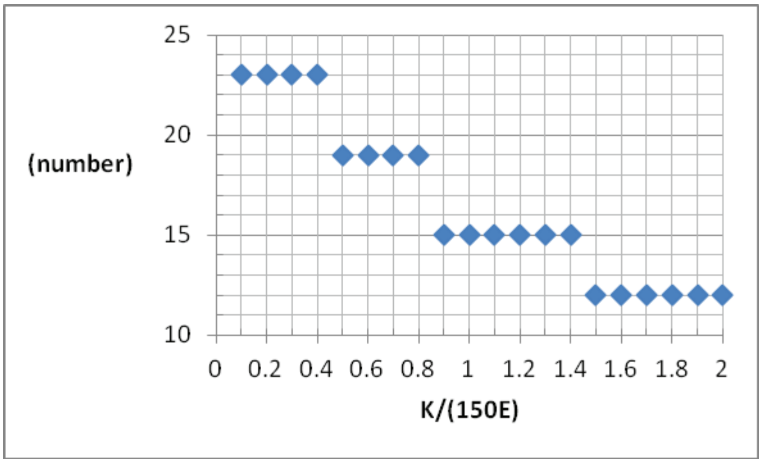

Fig. 3. the optimized number of the cross passageways in different risk costs

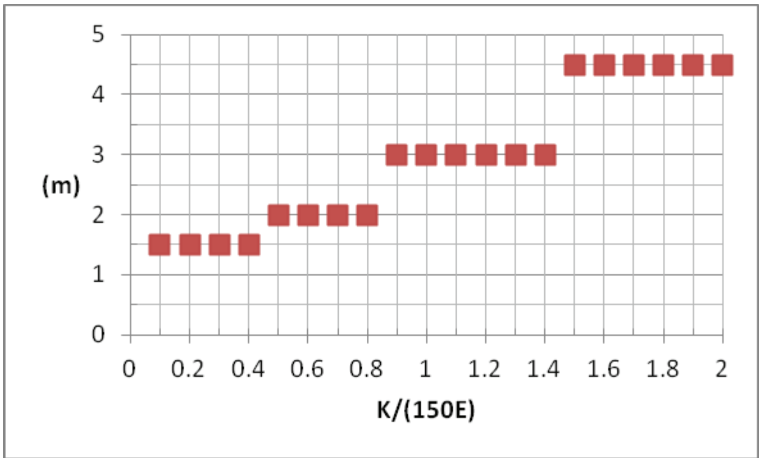

Fig. 4. the optimized width of the cross passageways in different risk costs

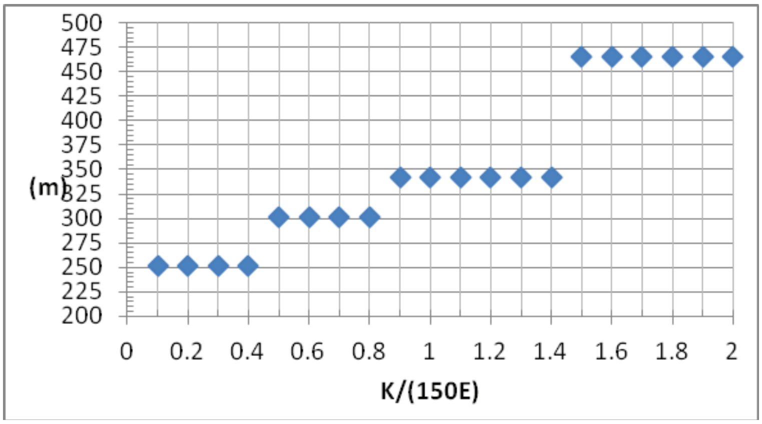

Fig. 5. the optimized spacing of the cross passageways in different risk costs

4. conclusion

With the rapid development of tunnel construction in China, cross passageways have been widely used in tunnels to provide the emergency escape path. Reasonable and scientific design of the cross passageway can assure the safe evacuation and make the cost be economic. In this paper, an optimization model for design of the cross passageway is proposed, which is related to safe evacuation, the construction cost of the cross passageways and the risk cost. This method may provide reference for designing cross passageways.

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