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A Method Study on the Optimal Ground Clearance of Truck Under-run Protector

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Abstract *:*

Background: R*ear-end collision were one of the important types of road traffic accidents with the characteristics of heavy casualties. Among the accidents, it was caused greater casualties and higher mortality in the passenger car crashes into truck accidents. According to the analysis of lots of traffic accidents, it's found that the Under-run protector has a good protective effect and can reduce casualties in this kind of accidents.

Objective: O*nly the analysis based on the actual accidents data was able to provide real foundation for improving the Under-run Protector. So this paper would, on the basis of actual accidents data, study the determination method of the Optimal Ground Clearance of the truck under-run protector.

Method and material: Accident data were from China In-Depth Accident Study (CIDAS). In order to study a method on the optimal ground clearance of truck under-run protector, some accidents were appropriately chosen as data samples of the passenger car crashing into truck and the passenger car participating in the accident.

Results: The relationship among the protection height difference, the crash-in depth, the head length and other parameters was analyzed, and the cumulative probability distribution was introduced into the study. Through derivation and transformation, the determination method of the optimal ground clearance was finally found out to be about 385mm.

Conclusions: This paper focused on method exploration of the automotive safety technology as well as the vehicle standard key parameters on the basis of the actual traffic accidents data, so it can also provide a reference for other key parameters to be studied.

Keywords: Truck, Passenger Car, Under-run Protector, Optimal Ground Clearance;

1 Preface

Rear-end collision were one of the important types of road traffic accidents with the characteristics of heavy casualties. Among the accidents, it was caused greater casualties and higher mortality in the passenger car crashes into truck accidents. Because the total height of the driver and passenger's sitting height and the passenger car's chassis height was almost equal to the height of the truck's chassis, the passenger car was more likely to crash into the truck's underrun part and thus the possibility of straight impact of the passenger car's driver and passenger into the truck chassis would increase, which might lead to high mortality, as was shown in Fig. 1.

According to the analysis of lots of traffic accidents, it's found that the Under-run protector has a good protective effect and can reduce casualties in this kind of accidents. The technical requirements for the Under-run protector was stated in GB 11567.2-2001"Motor vehicle and trailers-rear underrun protection requirements": the protector must have sufficient capacity to stop the rear-end vehicle and prevent it from crashing into its underrun part. As far as the protective effect was concerned, the ground clearance of Under-run Protector was one of the most important factors.

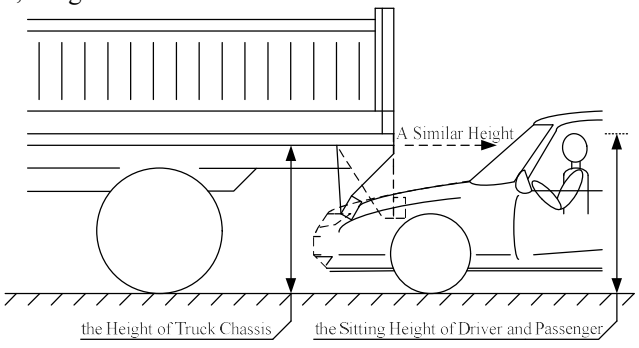


Fig. 1. Diagram of the sitting height of driver and passenger in passenger car and the height of truck chassis

In order to improve the protective effect of truck under-run protector, experts and scholars all around the world have worked on a great deal of research, but most of them were based on theoretical analysis or experimental simulation and few were based on actual traffic accidents data. However, only the analysis based on the actual accidents data was able to provide real foundation for improving the Under-run Protector. So this paper would, on the basis of actual accidents data, study the determination method of the Optimal Ground Clearance of the truck under-run protector.

2 Data

Accident data were from China In-Depth Accident Study(CIDAS). In July of 2011, the CIDAS Working Group started to conduct in-depth accident investigation in Changchun, Beijing, Weihai, Ningbo, Changsha and Foshan, and collected 1700 accidents as of June of 2014. In order to study a method on the optimal ground clearance of truck under-run protector, some accidents were appropriately chosen as data samples of the passenger car crashing into truck and the passenger car participating in the accident.

3 Research approach and model building

3.1 Determine the relationship between the protection height difference and crash-in depth

The truck's Under-run Protector were designed to protect the passenger car driver from crashing into the truck's underrun part and at the same time mitigate the car's impact. Therefore, the relationship between the depth of the car crashing into the truck's underrun part and the ground clearance of truck's Under-run Protector needs identifying and then can be used for the study on the determination method of the Optimal Ground Clearance. The depth of the car crashing into the truck's underrun part was called as "crash-in depth" in this paper.

According to the statistical analysis of the passenger car crashing into truck's tail, it's found that the passenger car's crash-in depth had something to do with the ground clearance of truck under-run protector as well as the ground clearance of the car's front protector. The difference between the ground clearance of truck's under-run protector and the ground clearance of the passenger car's front protector was called as "protection height difference" in this paper, as was shown in Fig. 2. The protection height difference was extracted as independent variable and The crash-in depth was extracted as dependent variable from the actual traffic accidents data, then fitted these data and determined their relationship. Their relation function was shown in Formula 1.

$$S = f_1\left(\Delta h\right) \qquad \text{.....(1)}$$

Notes: S —— crash-in depth, units are in mm;

Δh —— protection height difference, units are in mm.

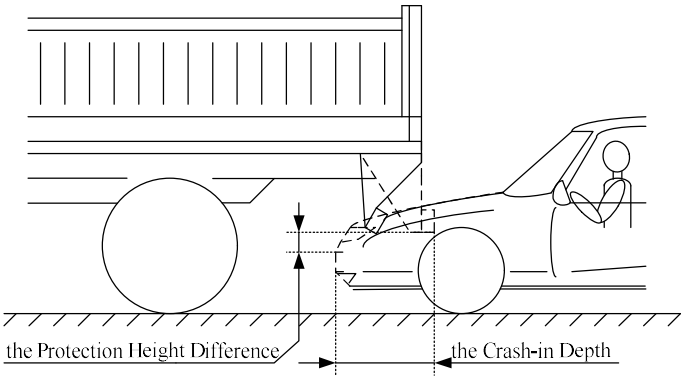


Fig. 2 Diagram of the protection height difference and crash-in depth

3.2 Determine the relationship between protection height difference and safe crash-in

The structural features of the passenger car's front part and the truck's underrun part showed that when the passenger car's crash-in depth was less than the length from the passenger car's front point to its front windshield, the driver and passengers in the passenger car were relatively safe. The length from the passenger car's front point to its front windshield was called as "head length" and in the meantime calls the above situation was called as "safe crash-in" in this paper. To determine safe crash-in proportion, the distribution of the head length should be first studied. the head

length was extract as independent variable and the cumulative probability was extract as dependent variable from the actual traffic accidents data, and then fit these data to determine the cumulative distribution. Their relation function is shown in Formula 2.

$$P_{ct} = f_2(l) \quad (2)$$

Notes: P_{ct} —— cumulative probability while head length $\le l$ ，$0 \le P_{ct} \le 100$, unit is %;

l —— head length of passenger car; unit: mm;

Based on the relationship between protection height difference and crash-in depth, the crash-in depth could be estimated correspondingly by the protection height difference. When the protection height difference was Δh, l> s, then it could be inferred to be safe crash-in; when l< s, then it could be inferred that it's not safe crash-in. Based on the above analysis, the relationship between protection height difference and safe crash-in could be derived combined with the relationship between protection height difference and crash-in depth and the cumulative distribution of head length.

According to Formula 1 and Formula 2, we have derived the relation function of protection height difference and safe crash-in, as was shown in Formula 3.

$$P_{aq} = f_3(\Delta h) = 100 - P_{ct} = 100 - f_2(S) = 100 - f_2(f_1(\Delta h)) \quad (3)$$

Notes: P_{aq} —— the proportion of safe crash-in when the protection height difference is Δh, $0 \le P_{aq} \le 100$, unit is %;

3.3 Determine the distribution of the protection height difference

When the truck was equipped with the same under-run protector, the protection height difference would be changed with the ground clearance of the upper edge of the passenger car's front protector. In actual traffic environment, there were many types of passenger cars that might happen to crash into truck's tail and thus the protection height difference varies a lot. As for a truck, the possible protection height difference varies with different passenger cars.

In order to determine the distribution of protection height difference, we had to at first know about the distribution of the ground clearance of the passenger car's front protector. So extract the ground clearance of the passenger car's front protector as independent variable and take the cumulative probability as dependent variable from the actual traffic accidents data, fit these data and then determine the cumulative distribution. Their relation function was shown in Formula 4.

$$P_{sb} = f_4(h_{sb}) \ldots \quad \ldots(4)$$

Notes: P_{sb}—— the cumulative probability when the ground clearance of the passenger car's front protector $\le h_{sb}$, $0 \le P_{aq} \le 100$, unit is %;

h_{sb} —— the ground clearance of the passenger car's front protector; unit: mm.

When the ground clearance of the truck's under-run protector equals *H* and the ground clearance of the passenger car's front protector which happened to crash into its tail is h_{sb}, then the protection height difference is $\Delta h = H - h_{sb}$. Above all the analysis, the distribution of protection height difference could be derived combined with $\Delta h = H - h_{sb}$ and the cumulative distribution of the ground clearance of passenger car's front protector.

According to Formula 4, we have derived the relation function of the distribution of protection height difference, as was shown in Formula 5.

$$P_{\Delta} = f_5(\Delta h) = 100 - P_{sb} = 100 - f_4(H - \Delta h) \ldots \quad \ldots(5)$$

Notes: P_{Δ}—— the proportion of the passenger cars when the ground clearance of the truck's under-run protector is H, the protection height difference between it and the truck is Δh, $0 \le P_{\Delta} \le 100$; unit: %;

3.4 Determine the relationship between the ground clearance and safe crash-in

As for a truck, the higher proportion the safe crash-in among possible passenger cars crashing into it takes, the more reasonable the ground clearance of the truck's under-run protector is. When a passenger car crashes into a truck's tail, the protection height difference between them and the car's head length exercise influence on whether the car can crash into it safely or not and even decide the casualties in this accident.

When the ground clearance of the truck's under-run protector is H, the passenger car's proportion is P_{Δ} and the protection height difference $\leq \Delta h$. Among these passenger cars, the crash-in depth is S corresponding to the max-difference between the car and the truck. And then, we get the proportion of passenger cars with its head length over S is P_{aq}. Above all the analysis, the proportion of safe crash-in could be derived when the ground clearance of the truck's under-run protector is H and the protection height difference $\leq \Delta h$, combined with the relationship between the protection height difference and safe crash-in and the distribution of protection height difference.

According to Formula 3 and Formula 5, we have derived the proportion of safe crash-in under the above-mentioned condition, as was shown in Formula 6.

$$P_{H,\Delta h} = f_6(\Delta h) = P_{aq} \times P_{\Delta} = \left[100 - f_2\left(f_1(\Delta h)\right)\right] \times \left[100 - f_4\left(H - \Delta h\right)\right] \ldots \quad \ldots(6)$$

Notes: $P_{H,\Delta h}$ ——the proportion of passenger car's safe crash-in when the ground clearance of the truck's under-run protector is H and the protection height difference $\leq \Delta h$, $0 \leq P_{H,\Delta h} \leq 10000$, unit is ‰.

In actual traffic environment, when a truck with the ground clearance of the under-run protector H compare with all the passenger cars, we can get a minimum and maximum of protection height difference between, which provides the value range of protection height difference. $\left[\Delta h_{H\bullet\min}, \Delta h_{H\bullet\max}\right]$ is used to stand for the value range of protection height difference and then the proportion of all kinds of passenger cars' safe crash-in of the relationship between the ground clearance and safe crash-in when the ground clearance of the truck's under-run protector is H.

According to Formula 6, we have derived the relationship model of ground clearance and safe crash-in, as was shown in Formula 7.

$$P_H = f_7(H) = P_{H,\Delta h}\Big|_{\Delta h_{H\bullet\min}}^{\Delta h_{H\bullet\max}} = \left[\left(1 - f_2\left(f_1(\Delta h)\right)\right) \times \left(1 - f_4\left(H - \Delta h\right)\right)\right]\Big|_{\Delta h_{H\bullet\min}}^{\Delta h_{H\bullet\max}} \ldots \quad (7)$$

Notes: P_H ——the proportion of passenger cars that can be prevented from totally crashing into the truck's tail, when the ground clearance of the truck's under-run protector is H, $0 \leq P_H \leq 10000$; unit: ‰;

$\Delta h_{H\bullet\max}$ ——the possible maximum protection height difference, when the ground clearance of the truck's under-run protector is H;

$\Delta h_{H\bullet\min}$ ——the possible minimum protection height difference, when the ground clearance of the truck's under-run protector is H;

3.5 Determine the solution of the Optimal Ground Clearance

Owing to different values of H, then P_H is different. When P_H is the maximum value, the corresponding H is the optimal ground clearance. H is used to represent the optimal ground clearance of the truck's under-run protector and $\max\left(P_H\right)$ stands for the maximum value of the proportion of safe crash-in, then the solution of the optimal ground clearance is shown in Formula 8.

$$H_r = f_7^{-1}\left(\max\left(P_H\right)\right) \ldots \quad \ldots (8)$$

Notes: f_7^{-1} ——inverse function of the function of the proportion of safe crash-in;

$\max\left(P_H\right)$ ——the maximum value of the proportion of safe crash-in, unit is ‰;

H_r —— the Optimal Ground Clearance of the truck's under-run protector; unit: mm;

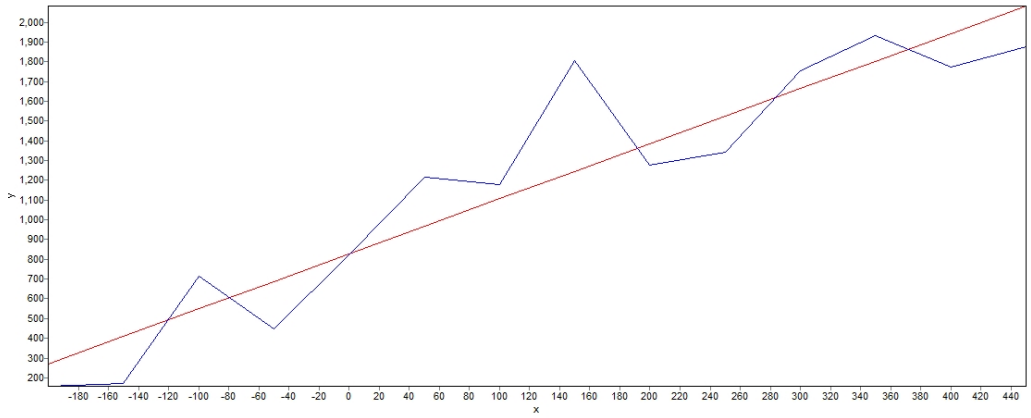
4 Data analysis

4.1 Establish a relation function of protection height difference and crash-in depth

Extract the accidents that passenger cars crashed into the truck's tail from large amounts of traffic accidents data, get data of protection height difference and crash-in depth by statistics, fit these data and then establish a relation function. The fitting figure is shown in Fig. 3 and the relation function is shown in Formula 9.

$$S = 2.7886\Delta h + 827.3818 \ldots \quad \ldots\ldots(9)$$

In actual traffic accidents, the minimum value of crash-in depth are 0 mm, accordingly the minimum value of Δh while $S \geq 0$ could be used as the actual minimum value of protection height difference. Then the actual minimum value of protection height difference could be calculated according to the above formula, $\Delta h_{\min} = -296mm$.

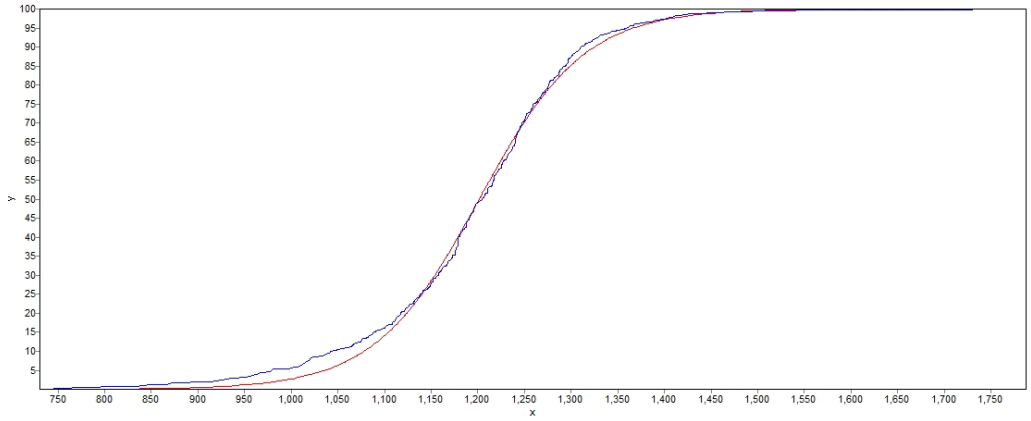


Notes: The broken line is the actual distribution map while the straight line is the fitting distribution map.

Fig. 3 Diagram of the protection height difference and crash-in depth

4.2 Establish a relation function of protection height difference and safe crash-in depth

Extract the data of head length from large amounts of traffic accidents data, fit these data and then establish a relation function as shown in Fig. 4 and Formula 10.



Notes: The broken line is the actual distribution map while the curve is the fitting distribution map.

Fig. 4 Cumulative probability distribution of passenger cars' head length

$$P_{ct} = \frac{100}{1 + 1943693820.6282e^{-0.01780l}} \ldots\ldots \quad \ldots (10)$$

According to Formula 9 and Formula 10, we could derive the relation function of the protection height difference and crash-in depth, as is shown in Formula 11.

$$P_{aq} = 100 - \frac{100}{1 + 780.9101e^{-0.04964\Delta h}} \ldots \quad \ldots(11)$$

4.3 Establish a distribution function of the protection height difference

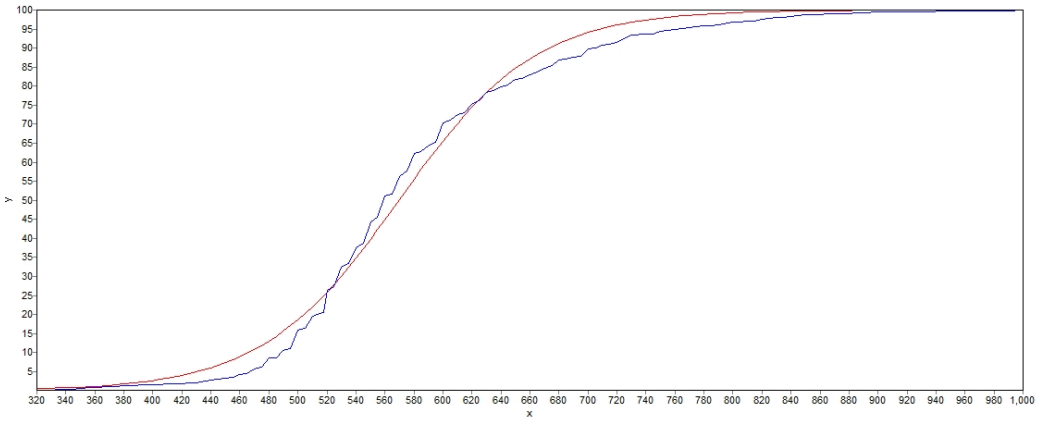
Extract the data of ground clearance of the passenger car's front protector from large amounts of traffic accidents data, fit these data and then establish a relation function, as are shown in Fig. 5 and Formula 12.

$$P_{sb} = \frac{100}{1+179309.9533e^{-0.02124h_{sb}}} \cdots \quad \text{……(12)}$$

In actual data, the minimum value of the ground clearance of passenger car's front protector is $h_{sb\cdot\min} = 320mm$.

According to Formula 12, the distribution function of the protection height difference can be derived as Formula 13.

$$P_{\Delta} = 100 - \frac{100}{1+179309.9533e^{-0.02124(H-\Delta h)}} \cdots \quad \text{…(13)}$$



Notes: The broken line is the actual distribution map while the curve is the fitting distribution map.

Fig. 5 Cumulative probability distribution of the ground clearance of passenger car's front protector

4.4 Establish a relation function of ground clearance and safe crash-in

According to Formula 12 and Formula 13, the proportion of safe crash-in of passenger cars can be derived when the ground clearance of truck's Under-run protector is H and the protection height difference $\leqslant \Delta h$, as is shown in Formula 14.

$$P_{H,\Delta h} = \left(100 - \frac{100}{1+780.9101e^{-0.04964\Delta h}}\right) \times \left(100 - \frac{100}{1+179309.9533e^{-0.02124(H-\Delta h)}}\right) \cdots \quad (14)$$

It's known from the former text, the minimum value of the protection height difference is $\Delta h_{\min} = -296mm$ and the minimum value of the ground clearance of the upper edge of passenger car's front protector is $h_{sb\cdot\min} = 320mm$ and accordingly the value range of protection height difference is $[-296, H-320]$. Combined with Formula 14, the model of ground clearance and the proportion of safe crash-in can be derived, as is shown in Formula 15.

$$P_H = \left[\left(100 - \frac{100}{1+780.9101e^{-0.04964\Delta h}}\right) \times \left(100 - \frac{100}{1+179309.9533e^{-0.02124(H-\Delta h)}}\right)\right]\Bigg|_{\Delta h=-296}^{\Delta h=H-320} \quad \text{.....(15)}$$

4.5 Solve the Optimal Ground Clearance

Draw a graph according to Formula 15, as is shown in Fig. 6.

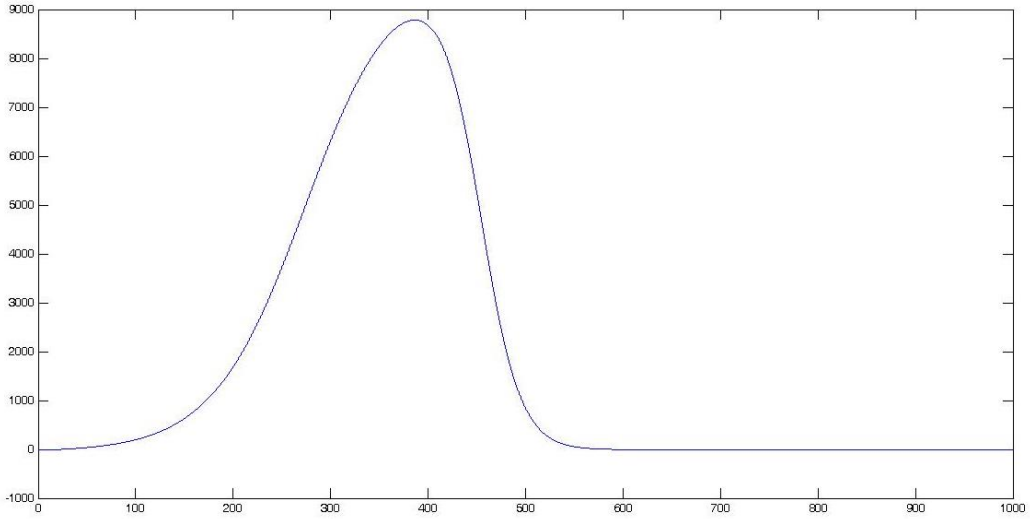


Fig. 6 Relationship graph of the ground clearance and safe crash-in

By solving this function model, we can get the maximum value $\max\left(P_H\right)=8783.9682‰$ and the optimal solution $H_r=385.68mm$. Therefore, the optimal ground clearance of truck's under-run protector is 385.68mm by calculation in accordance with the actual traffic accidents data.

5 Conclusions

This paper, on the basis of actual traffic accidents data and by analysis and deduction, comes up with the determination method of the optimal ground clearance of truck's under-run protector based on actual traffic accidents data. The relation function of protection height difference and crash-in depth, the relation function of protection height difference and safe crash-in, the distribution function of protection height difference and the relation function of ground clearance and safe crash-in are established in this paper based on the data analysis, and finally this function model was solved to get the optimal ground clearance of truck's under-run protector, which effectively verifies the determination method of the optimal ground clearance.

The results of this method could be provided reference to parameter revision in the GB 11567.2-2001"Motor vehicle and trailers-rear underrun protection requirements". This paper focuses on method exploration of the automotive safety technology as well as the vehicle standard key parameters on the basis of the actual traffic accidents data and this paper can also provide a reference for other key parameters to be studied.

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