DEVELOPMENT OF 90 Kg/KW (150 lbs/HP) TRUCK CLIMBING PERFORMANCE CURVE

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ABSTRACT: The truck climbing performance curves presently used in korea are originated from the American design standards. Therefore these curves do not properly reflect Korean conditions such as topography and the truck weight-to-power ratio. It seems that the design of climbing lanes based on the existing curves results in an excess in the length of the climbing lanes. In this study, the standard truck is selected through an analysis of the distribution of weight-to-power ratio of trucks being operated in Korea. Using the selected standard truck, field studies are undertaken on freeway sections of various grades. These grades includes 6 upgrades ranging from 2.25% to 7.3%, and 3 downgrades ranging from 0.85% to 5.3%. Based on the results of the field studies, deceleration and acceleration curves are developed for various upgrades and downgrades. It is expected based upon the new performance curves that the demand for the provision of climbing lane will be reduced and that the required length of the climbing lane will be shortened significantly.

1. INTRODUCTION

1.1 BACKGROUND

The truck climbing performance curves presently used in Korea (MOCT,1992) are originated from American design standard (AASHTO,1990). Since American design standard adopts the weight-to-power ratio of 300 lbs/hp as the standard truck, the performance curves have following fundamental problems.

(1) The curves do not properly reflect Korean conditions in terms of topography and truck performances.
(2) Without sufficient analysis of truck distribution in Korea, weight-to-power ratio of 300 lbs/hp is used as standard truck.
(3) Initial speed of the curves is the same as the American speed limit of 88 km/h(55 mph) which is different from the Korean speed limit.

Due to the above problems it seems that the climbing lanes designed so far have been somewhat longer than they should be.

1.2 OBJECTIVES

For the efficient climbing lane design and highway operation, the truck climbing performance curves considering Korean conditions should be developed. The objectives of this study are :

(1) to select the standard truck through the analysis of the distribution of weight-to-power ratio of trucks being operated in Korea,
(2) to develop truck climbing performance curves considering Korean topography and the selected standard truck, and
(3) to set up the field study methodology for the analysis of the truck climbing performances.

1.3 SCOPE

The scope of this study can be summarized as follows :

(1) selection of proper weight-to-power ratio of the Korean standard truck using the recent truck distribution,
(2) field test for the truck climbing performance measurement, using the selected standard truck, on freeway sections of various grades, and
(3) development of deceleration and acceleration performance curves for various upgrades and downgrades.

2. SELECTION OF STANDARD TRUCK

Procedures for determination of standard truck can be summarized as follows :

(1) to survey the total weight(weight of empty truck plus maximum payload) and maximum engine power of every type of truck registered in Korea,
(2) to draw a cumulative frequency distribution of weight-to-power ratio in ascending order, and
(3) to select a weight-to-power ratio for a proper decision value(cumulative percentage), as a standard truck.

Table 1 shows weight-to-power ratio and the number of vehicles registered for each type of truck. It was found that 73% of the registered trucks are light trucks(pickup, van and cargo) as shown in Figure 1.

In this study, weight-to-power ratio of 150 lbs/hp, which represents 90 percentile of the cumulative distribution, is selected as a standard truck. At first 85 percentile value had been tried. However, it was discarded because the weight-to-power ratio associated with 85 percentile was only 88 lbs/hp which was too light to be a standard truck for highway design. Figure 2 shows the cumulative distribution curve and weight-to-power ratios associated with 85, 90, and 95 percentile, respectively.

3. FIELD TESTS

Test sections were selected from freeways considering following factors :

(1) grade : various grades to cover wide range of the grades
(2) section length : the longer the better
(3) geometry : tangent preferably

Selected sections are shown in Table 2.

Table 1. Weight-to-power ratio and the number of vehicles registered for each type of truck.

Truck Types			Max. payload (kg)	Total wt. (kg)	Engine Power (Hp)	wt./power		No. of Veh.		Typical type of truck	Remark
						kg/Hp	lbs/Hp	No. of Veh.	%		
General truck	Pickup		540	980	92	10.6	23.4	11,599	0.7		
General truck	Cargo	≥1t	1,000	2,505	74.1	33.8	74.4	964,741	56.5	1t	
General truck	Cargo	≥3t	1,415	3,020	76.1	39.7	87.3	186,963	10.9	1.4t	
General truck	Cargo	>5t	4,250 (4000~ 4,500)	8,015 (7,470~ 8,560)	135.4 (106.5~ 164.3)	59.2 (70.2~ 52.1)	130.2 (114.6~ 154.3)	48,386	2.8	4t, 4.5t	
General truck	Cargo	>8t	5,000	9,060	167.3	54.2	119.1	38,203	2.2	5t	
General truck	Cargo	>10t	8,415 (8,165~ 8,665)	15,575 (15,210~ 15,940)	206.4 (184.6~ 228.2)	75.5 (69.9~ 82.4)	166.0 (153.7~ 181.3)	14,066	0.8	8t, 8.5t	
General truck	Cargo	>12t	11,165	21,690	294.4	73.6	162.1	21,208	1.2	11t	
General truck	Cargo	≤12t	12,665	23,065	324.8	71.0	156.2	7,190	0.4	12.5t	
Dump		≥1t	1,000	2,760	74.1	37.2	81.9	7,390	0.4	1t	
Dump		>5t	2,665	5,395	101.4	53.2	117.0	17,536	1.0	2.5t	
Dump		>12t	8,165	14,960	190.7	78.4	172.6	5,085	0.3	8t	
Dump		≤12t	15,165	25,785	324.5	79.5	174.8	386	0.0	15t	
Van			1,000	2,430	73.0	33.3	73.2	277,876	16.3	2400cc	
Special Truck			11,000	22,992	299.2	76.8	169.1	108,123	6.3	refrigerator Tanker etc.	
Total								1,708,562	100		

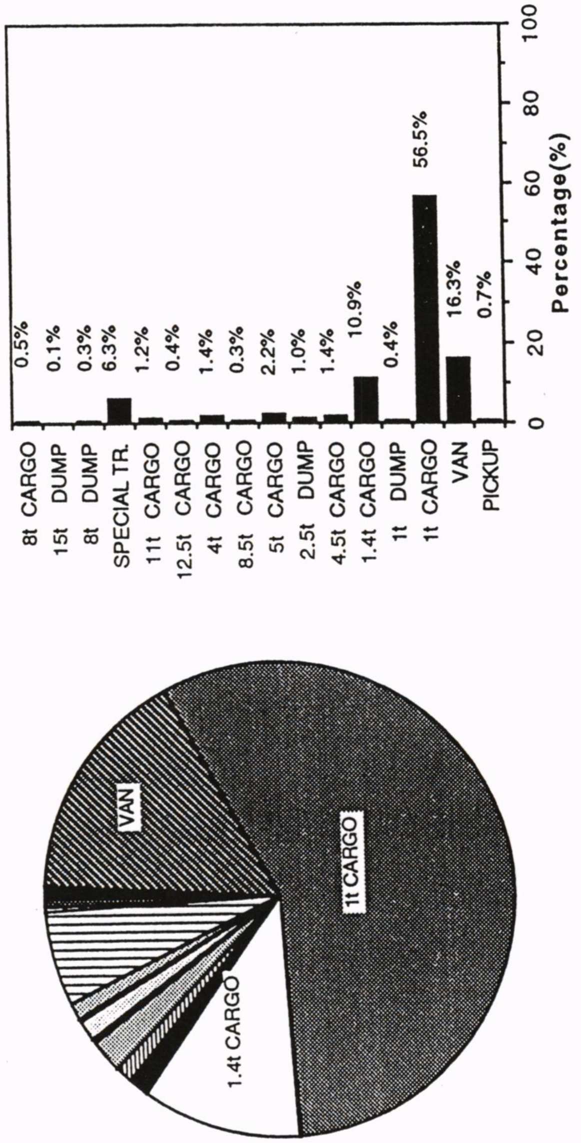

Figure 1 Truck distribution

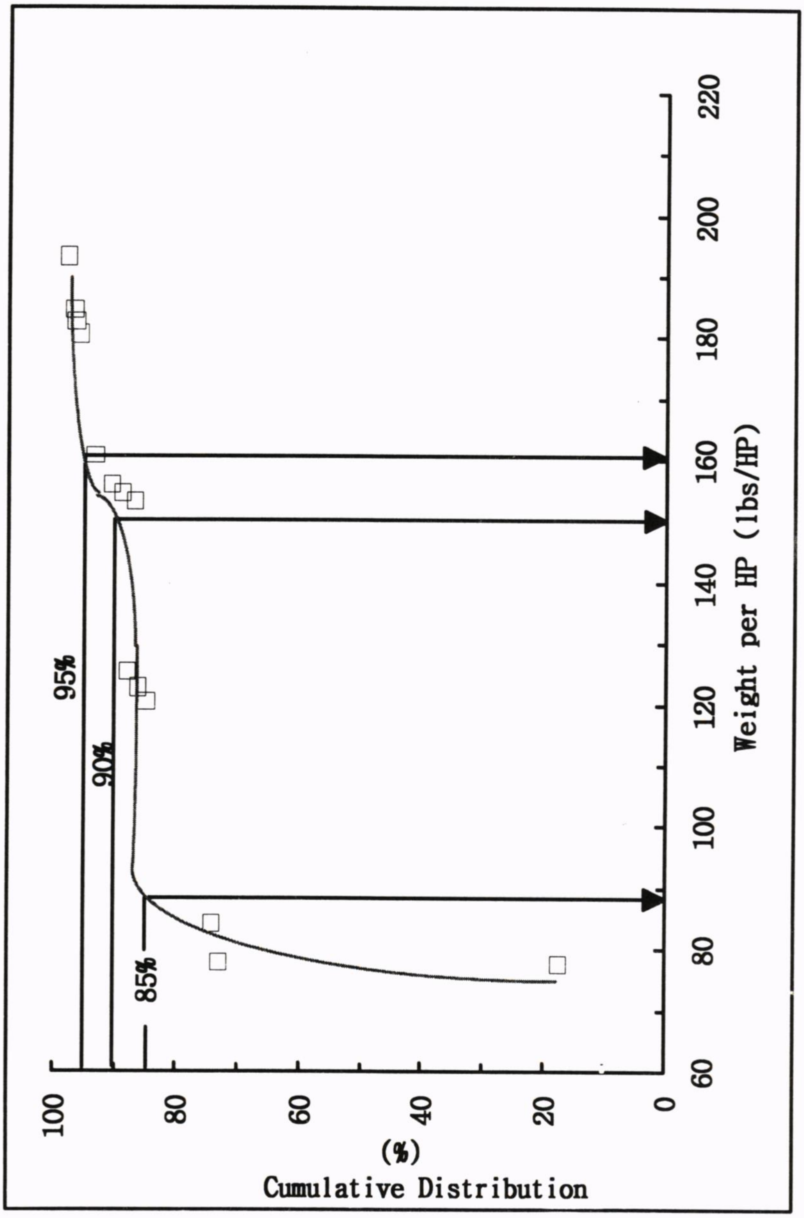

Figure 2 Cumulative distribution of weight-to-power ratio

Table 2 Test sections

location	length(km)	grade(%)*
Yongdong 59.5-62.2 k	2.7	+0.85(WB) -0.85(EB)
Yongdong 106.8-108.4 k	1.6	+7.30(EB) -7.30(WB)
Jungang 192.6-197.8 k	5.2	+2.78(NB) -2.78(SB)
Jungang 276.0-277.9 k	1.9	+5.30(SB) -5.30(NB)

* upgrade(+), downgrade(-)

Truck climbing performances were surveyed during the time the traffic volume is very low in order not to be interrupted by traffic. Performance surveys were conducted by reading the truck speed within the truck at every 100 meter driven as climbing the test sections. Surveys for each grade included 9 runs(3 replications of 3 different trucks with same weigh-to-power ratio).

4. DATA REDUCTION

Following data reduction steps were taken to develop the truck climbing performance curve for each grade.

(1) to average the results of 3 replications for each grade and truck,
(2) to average the results of 3 trucks obtained from (1) for each grade, and
(3) to eliminate any unnecessary data(i.e., data collected before and after the test sections).

Figures 3 and 4 show speed change patterns obtained from the field test for deceleration and acceleration respectively.

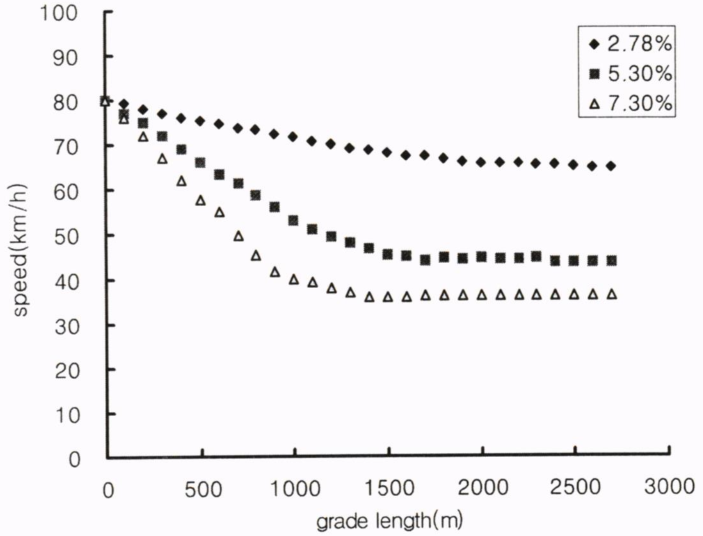

Figure 3 Deceleration patterns obtained from the field tests

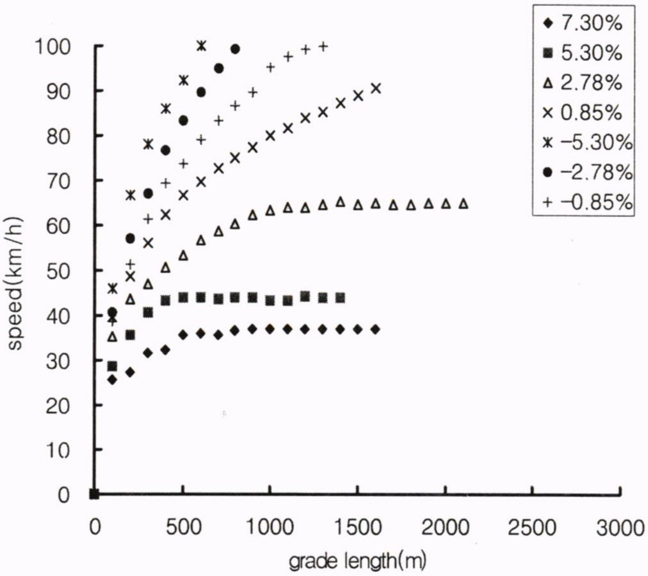

Figure 4 Acceleration patterns obtained from the field tests

5. DEVELOPMENT OF TRUCK CLIMBING PERFORMANCE CURVES

5.1 PERFORMANCE CURVES

Using interpolation, deceleration curves for 2, 3, 4, 5, 6, 7, and 8 % were developed from the performance curves obtained from field test results(Figure5). Acceleration curves were also developed in the same way for various grades(from downgrade of 6 % to upgrade of 8 %) as shown in Figure 6.

Figure 7 shows critical lengths of grades for design. Critical length represents the length of any given grade that will cause the speed of the standard truck entering the grade at 80 km/h to be reduced by various amount shown on the Figure. When the length of any given grade is longer than the critical length, the addition of climbing lane may be considered.

5.2 EVALUATION OF THE PERFORMANCE CURVES

Table 3 shows comparison of critical length between current and new performance curves.

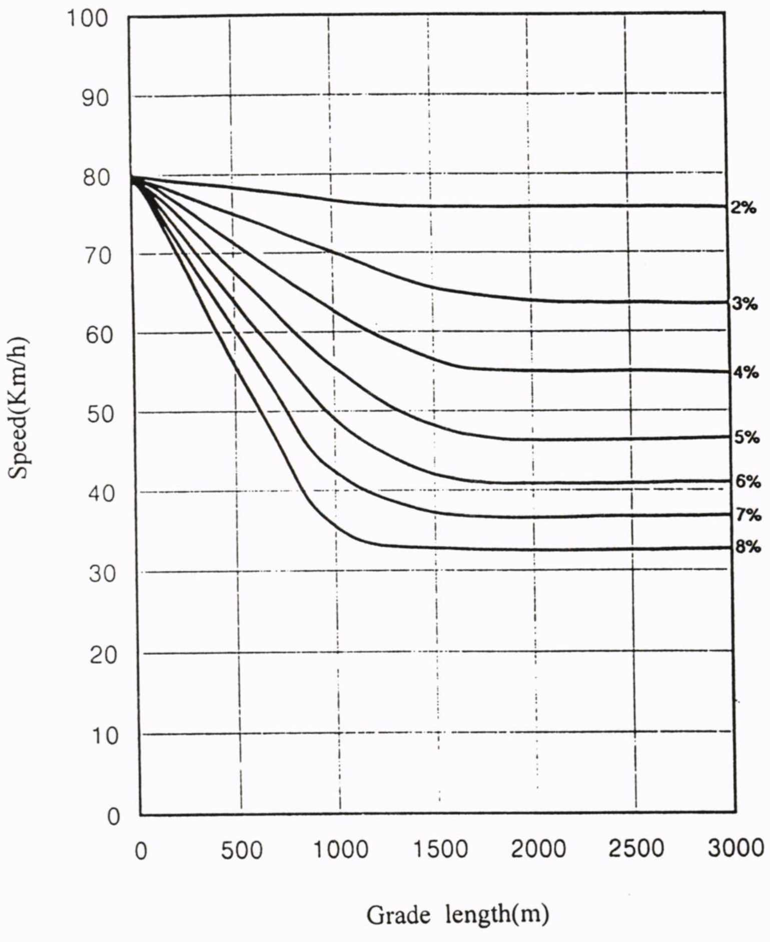

Figure 5 Deceleration curves for 150 lbs/hp standard truck on percent upgrade

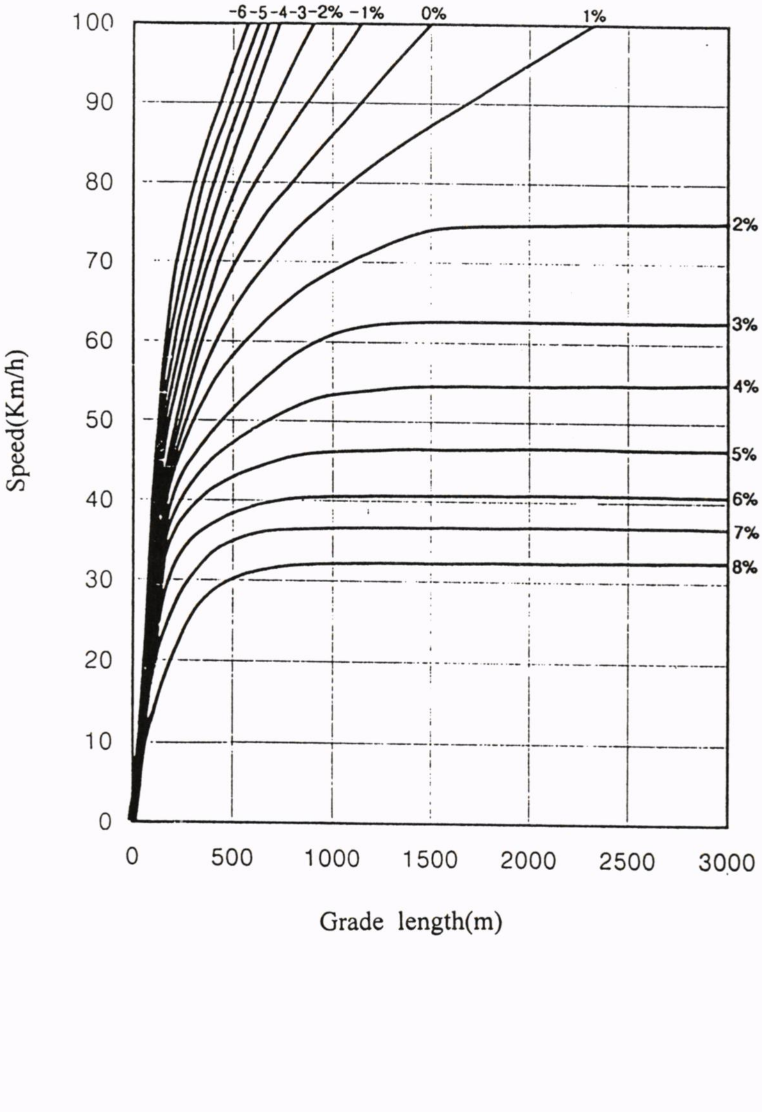

Figure 6 Acceleration curves for 150 lbs/hp standard truck on percent grade up and down

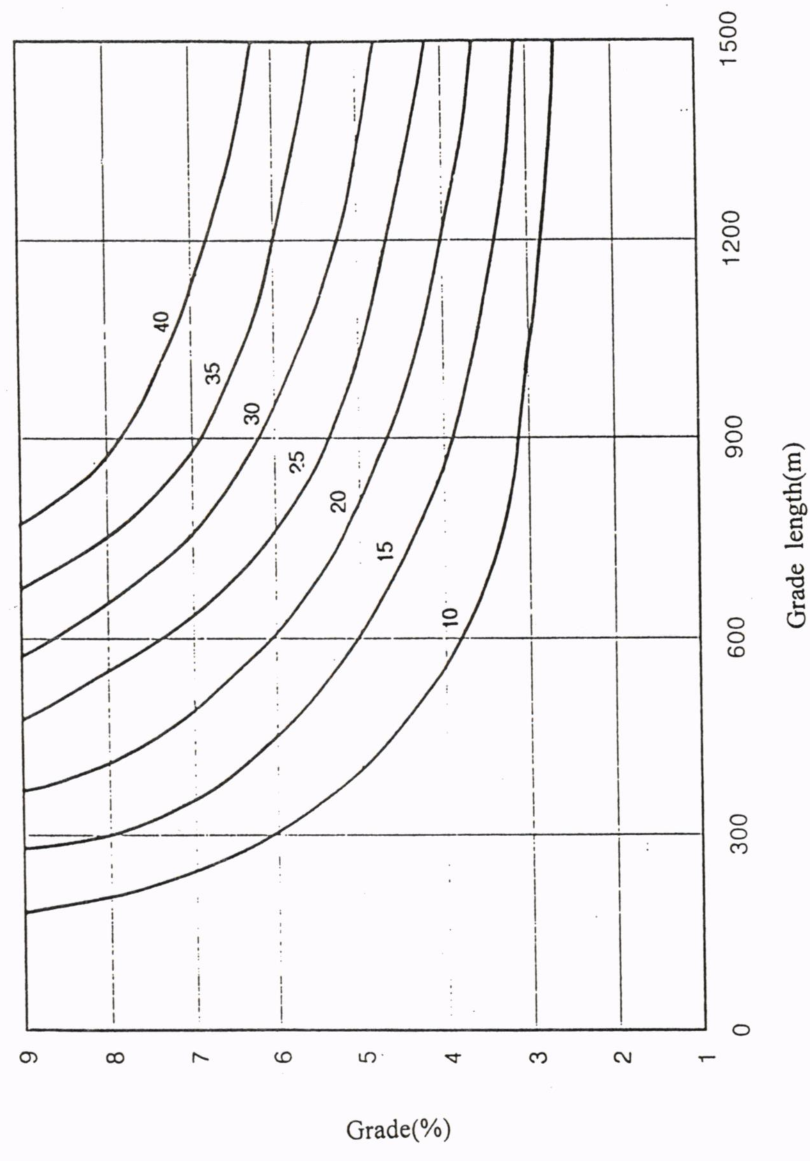

Figure 7 Critical lengths of grades for 150 lbs/hp standard truck entering at 80 km/h

Table 3 Comparison of critical length for 20 km/h speed reduction (from 80 to 60 km/h)

(Unit : m)

Grade	Current curves (300 lbs/hp)	New curves (150 lbs/hp)
2%	1200	-
3%	520	-
4%	370	1200
5%	280	800
6%	230	600
7%	190	500
8%	160	400

In general critical lengths obtained from the new performance curves are much longer than those from the current performance curves. In other words, warrants for the climbing lane would be significantly limited when the new performance curves are applied in the design. It also should be noted that climbing lane is not necessary in the grades less than or equal to 3 % when 20 km/h speed reduction is considered as the critical value for the warrant of the climbing lane.

Verification of the newly developed performance curves is conducted to see if they predicted the speed changes of the standard truck properly. Speed changes of the standard trucks for a certain distance with various grades are measured and compared with those predicted using the new performance curves. Field measurements were conducted in 3.3 km section of Jungang Highway(276.8～273.5 km, southbound) using the same 3 trucks used in the development of the new curves. Figure 8 shows the grades and lengths of the verification section.

Figure 9 shows the comparison between the predicted and measure speed changes. In order to see if the difference is statistically small enough to regard the two speed change patterns as the same, a Chi square test is conducted. Null and alternative hypotheses are as follows :

H_0 : Measured speed change pattern is the same as predicted.
Ha : Measured speed change pattern is not the same as predicted.

Test statistic(χ^2_T) can be represented as follows :

$$\chi^2_T = \sum \frac{(M-P)^2}{P} \qquad (df = n-1) \qquad \cdots\cdots\cdots\cdots \quad (1)$$

where M : measured speed
P : predicted speed

Calculated χ^2_T is 2.83. Considering that the $\chi^2_{0.05}$ is 48.6 and that $\chi^2_{0.1}$ is 44.9, the alternative hypothesis is rejected at α level of 0.1, which means the predicted speed change pattern is well fit for the measured pattern.

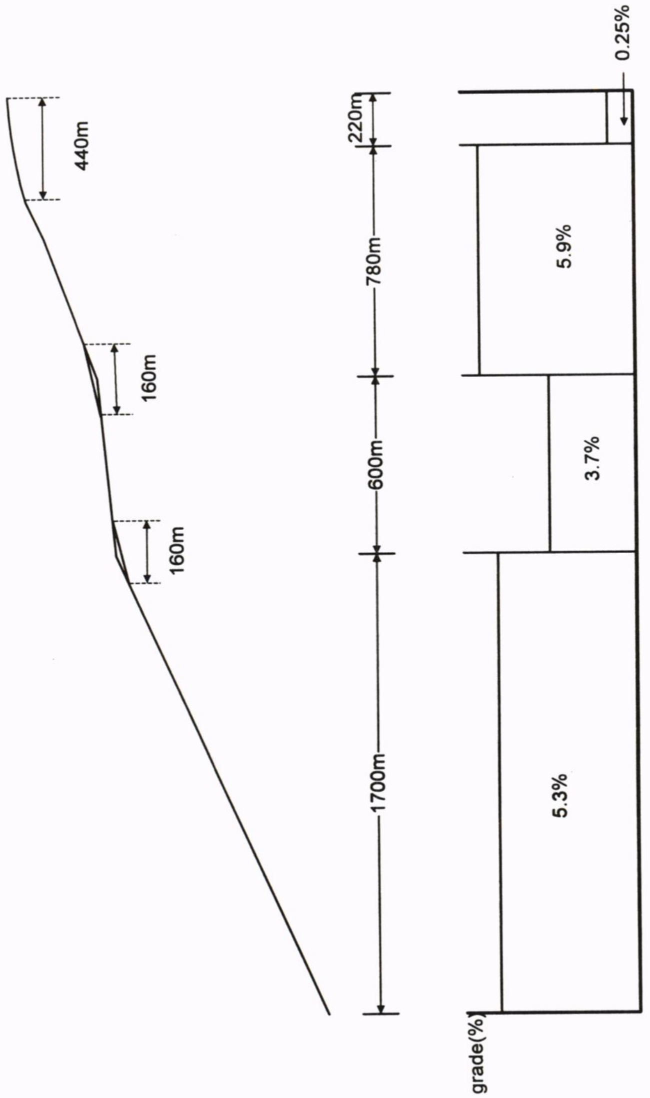

Figure 8 grades of the verification section

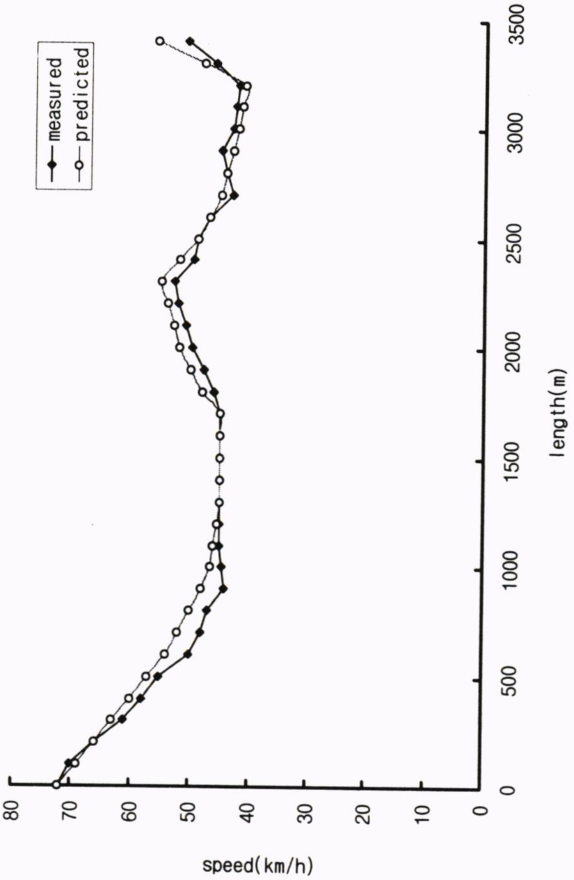

Figure 9 Comparison between the predicted and measured speed changes

6. CONCLUSIONS AND RECOMMENDATIONS

In this study truck climbing performance curves are developed considering Korean conditions. Standard truck is selected through the analysis of the distribution of weight-to-power ratio of trucks being operated in Korea. From a series of field tests using the standard truck, truck climbing performance curves for various grades are developed.

Conclusions from this study can be summarized as follows :

(1) A weight-to-power ratio of 150 lbs/hp, which represents 90 percentile of the cumulative truck distribution, is recommended as the standard truck for the Korean conditions.

(2) Truck climbing performance curves for both deceleration and acceleration are developed through the field tests using the standard trucks of 150 lbs/hp(as shown in Figure 5 and 6). When using the newly developed curves, the crawl speed for 3 % upgrade is found to be higher than 60 km/h which is the critical speed of warrants for climbing lane. This means that climbing lane is not necessary in the grades less than or equal to 3 %, regardless of the grade length, when 60 km/h is the critical speed.

(3) Critical lengths for various grades obtained from the new curves are shown in Figure 7. Critical lengths are much longer than those from the current performance curves. Warrants for the climbing lane would be significantly limited when the new performance curves are applied in the design.

Recommendations are summarized as follows :

(1) It is recommend that 150 lbs/hp be used as standard truck in Korea.

(2) It is recommend to adopt the performance curves and chart for critical length(Figure 5, 6 and 7) in the following revision of current geometric design guide.

(3) Further researches on the design details and operation of the climbing lane are recommended in the future.

REFERENCE

1. AASHTO (1990), **A policy on Geometric Design of Highways and Stress**

2. MOCT (1992), **Guide Specification of the Geometric Design of Highways,** Korea Ministry of Construction and Transportation