EFFECTS OF HEAVY VEHICLE PERCENTAGE AND DIVERGE FLOW CHARACTERISTICS ON BREAKDOWN PHENOMENA AT A DIVERGE SECTION

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1. Introduction

On Japan's inter-city expressways, breakdown phenomena at diverge sections have drawn a growing attention. For planning relief countermeasures, it is quite necessary to clarify how traffic flow characteristics like heavy vehicle (HV) percentage and diverge flow characteristics can impact on breakdown phenomena. However, to date, there are few study[1)] that analyzed a relationship between diverge rate and breakdown occurrence at diverge sections. Considering quite small sample numbers at the test bed, the finding requires further confirmation.

This paper aims to investigate the effects of HV percentage and diverge flow characteristics on breakdown phenomena at a diverge section on Tomei Expressway.

2. Test bed description

A recurrent bottleneck at a diverge section of Toyota JCT in the westbound direction of Tomei Expressway is selected as a test bed. Particularly after operation of Shin-meishin expressway in March, 2008, frequent breakdown events have been observed at this diverge section. Layout of the test bed, lane configuration and detector locations are shown in Fig.1 and Fig.2, respectively. Detector data aggregated in a 5-min interval from 01/03/2008 to 12/31/2009 are used. Breakdown events due to other non-recurrent causes such as roadway maintenance works and accidents are excluded.

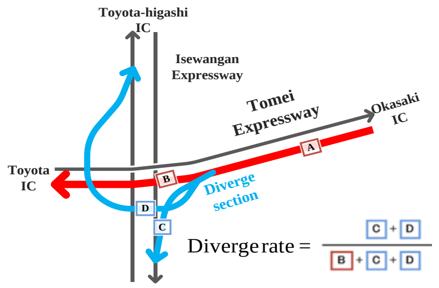

Fig.1 Illustration of the test bed (Toyota Junction, westbound)

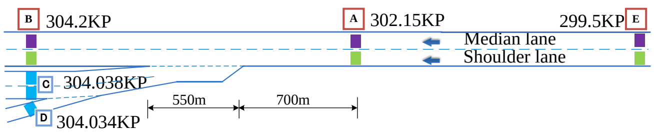

Fig.2 Lane configuration and detector installations

3. Methodology

3.1 Lane-based analysis

Since at diverge sections, individual lanes are differently preferred by drivers dependent on their destinations, the conventional cross-section-based analysis is not appropriate. Therefore traffic flow characteristics are analyzed based on individual lanes (lane-based analysis) in this study.

3.2 Breakdown identification method

Breakdown is identified by adopting critical speed (v_{cr}). As illustrated in Fig.3, a breakdown event on shoulder lane in AM peak hours on 04/30/2008 is utilized to introduce identification of an individual lane's breakdown. The identification is done through defining the following conditions: speed measured by detector A (302.15kp in Fig.2) needs to be lower than the shoulder lane's critical speed and this condition continues over 15 minutes as illustrated in Fig.3 to guarantee queue formation. In addition, traffic conditions at downstream detector B (304.2kp) and upstream detector E (299.5kp) are referred to filter their impacts. The timing of breakdown occurrence is defined as the time immediately before the speed becomes lower than v_{cr}.

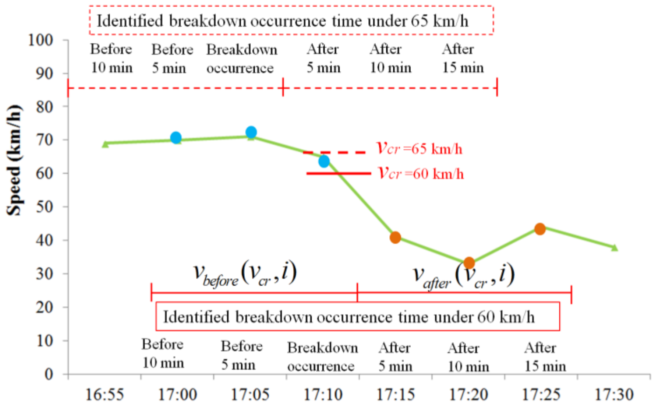

Fig.3 Breakdown identification

In the method mentioned above, the timings of breakdown occurrence depend on the settings of v_{cr}. According to the definition, a significant speed reduction is expected immediately after the breakdown occurrence. In this paper, the optimal critical speed on each lane is calibrated by the following procedure, so that the most significant speed reductions can be measured at the identified timings of breakdown occurrence.

Firstly, as illustrated in Fig.3, speed reduction $\Delta v_i(v_{cr})$ is computed by Equation (1) for breakdown event i under given v_{cr} (i.e. 60 km/h in Fig.3).

$$\Delta v_i(v_{cr}) = v_{before}(v_{cr}, i) - v_{after}(v_{cr}, i) \tag{1}$$

Where $v_{before}(v_{cr},i)$ and $v_{after}(v_{cr},i)$ are mean speed values of 15-minute intervals immediately before and after the identified breakdown occurrence respectively.

Improper identification of the breakdown occurrence time due to inappropriate v_{cr} values is introduced by an example shown in Fig. 3. When v_{cr} is 65 km/h, the time interval 17:10 is regarded as the interval after breakdown occurrence as its speed is a bit lower than 65 km/h. This treatment is unfavorable as the significant speed reduction was not observed between 17:05 and 17:10 but between 17:10 and 17:15. This inappropriate identification causes lower $\Delta v(v_{cr})$ due to higher $v_{after}(v_{cr},i)$ value which is contributed by high speed at time interval 17:10. Such situations are observed at several other breakdown events if v_{cr} is not properly chosen.

By summing up all identified values of $\Delta v_i(v_{cr})$ ($1 \leq i \leq n$, n is the total number of breakdown events) under 65 km/h and 60 km/h respectively, their mean and standard deviation, $\mu(\Delta v(v_{cr}))$ and $\sigma(\Delta v(v_{cr}))$, are computed as listed in Table 1.

Table 1 Impact of v_{cr} on $\Delta v(v_{cr})$ distribution

v_{cr} value	$\Delta v(v_{cr})$ (km/h)	
	Mean value $\mu(\Delta v(v_{cr}))$	Standard deviation $\sigma(\Delta v(v_{cr}))$
High value: 65km/h	22.02	11.02
Medium value: 60km/h	24.11	7.93
Low value: 55km/h	20.34	10.58

Under 65 km/h, the effect of the lower $\Delta v(v_{cr})$ due to the improper breakdown identification results in smaller $\mu(\Delta v(v_{cr}))$. Furthermore, the frequent observation of lower $\Delta v(v_{cr})$ causes higher value of $\sigma(\Delta v(v_{cr}))$. This kind of inappropriate breakdown identification also occurs under low v_{cr}, such as v_{cr} = 55 km/h.

Considering effects of both $\mu(\Delta v(v_{cr}))$ and $\sigma(\Delta v(v_{cr}))$, $CV(\Delta v(v_{cr}))$ (coefficient of variation) is defined as the normalized measure to represent dispersion of $\Delta v(v_{cr})$ as shown in Equation (2).

$$CV(\Delta v(v_{cr})) = \sigma(\Delta v(v_{cr})) / \mu(\Delta v(v_{cr})) \qquad (2)$$

Finally, the optimal critical speed (v_o) which achieves the most preferable $\Delta v(v_{cr})$ distribution is estimated by minimizing $CV(\Delta v(v_{cr}))$. At the test bed, various values of v_{cr} (shoulder lane: 55-65km, median lane: 75-85km) were tested. 59 km/h and 82km/h were computed as the optimal critical speeds for shoulder and median lane respectively.

3.3 Breakdown type classification

Besides effect of lane usage preference, HV percentage and some other diverge flow characteristics also influence on breakdown phenomena like different time lags of breakdown occurrence between individual lanes. Therefore breakdown types are classified by judging breakdown occurrence on each lane and time lag between them.

Three breakdown types are classified after summing up all identified breakdown events on shoulder and median lanes under their optimal critical speeds. As illustrated in Fig.4, for type "S", the breakdown only occurs on shoulder lane. For type "SAM", the breakdown simultaneously occurs on both of shoulder and median lanes. As for type "STM", the breakdown starts from the shoulder lane and then spread to the median lane after a certain time lag.

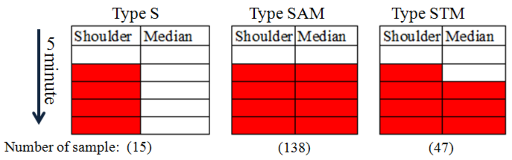

Fig.4 Breakdown type classification

4. Analysis results

After classifying types, breakdown phenomena are analyzed regarding effects of 1) HV percentage on individual lanes and 2) diverge flow characteristics such as diverge rate and diverge HV percentage. Time intervals of 15 minutes immediately before and after the interval of breakdown occurrence on shoulder lane are chosen as the analysis period.

4.1 HV percentage on each lane

With respect to the aforementioned three breakdown types, change tendencies of HV percentage are analyzed for each lane. As for type STM, considering its number of samples (38), dataset of 5-minute time lag is chosen. Results of the investigation are summarized as follows.

1) Each lane's HV percentage is found to change significantly after breakdown occurrence. As illustrated in Fig.5, on shoulder lane, HV percentage decreases after breakdown occurrence for all types. While regarding median lane in Fig.6, it increases for SAM and STM. This indicates that after breakdown occurrence on shoulder lane, some heavy vehicles (which do not intend to diverge) would shift onto median lane for a favor of relatively higher speed and avoidance of disturbance from diverge area. Thus this shift will contribute to spread of breakdown from shoulder lane to median lane.

2) HV percentage is found to impact on breakdown types. Through a t-test at a confidence level 95%, on shoulder lane, HV percentage under SAM is significantly different from those under S and STM. On median lane, its difference

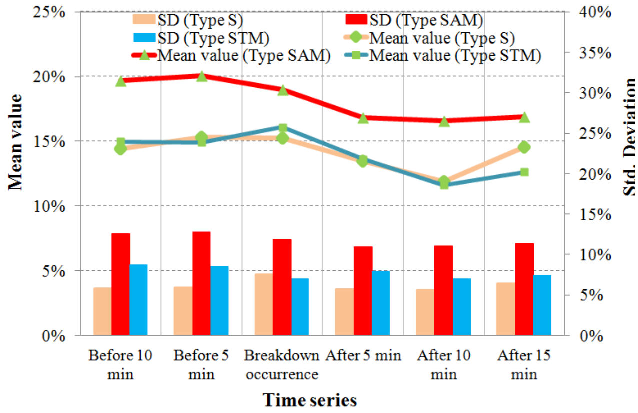

Fig.5 HV percentage on shoulder lane

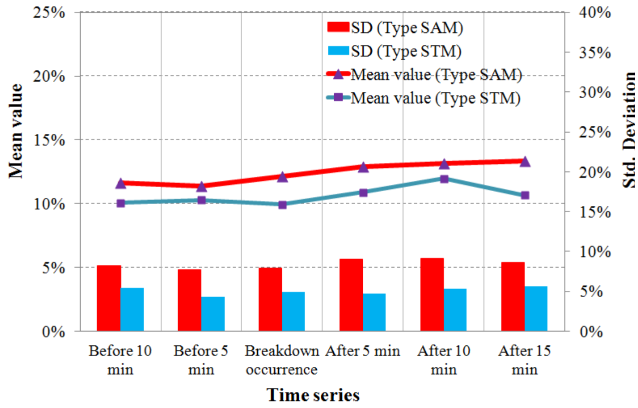

Fig.6 HV percentage on median lane

between SAM and STM is also significant. HV percentage is found to influence on spread of breakdown from shoulder lane to median lane. Type SAM is caused by quick breakdown spread which results from shift of more heavy vehicles onto median lane under higher HV percentage condition.

4.2 Diverge rate and diverge HV percentage

Diverge rate and diverge HV percentage are also analyzed for the three breakdown types. Due to their stabilities immediately before and after the breakdown occurrence, the interval of breakdown occurrence on the shoulder lane is analyzed. As listed in Table 2, for type SAM, though its diverge rate is a bit smaller than that of STM, its diverge HV percentage is significantly higher than the other types. This reflects significant impact of HV on spread of breakdown from diverge area to shoulder lane, then to median lane.

Table 2 Diverge characteristics at breakdown occurrence

Type	Diverge rate		Diverge HV percentage		Number of samples
	Mean	SD	Mean	SD	
S	0.487	0.048	34.9%	12.8%	15
SAM	0.488	0.061	41.4%	15.8%	138
STM	0.521	0.060	35.6%	13.4%	38

5. Conclusions and future work

This paper investigated how HV percentage and diverge flow characteristics impact on breakdown phenomena at a diverge section. HV percentage on individual lanes and diverge flow are found to have significant impacts on formation of breakdown type S, SAM and STM. The results presented above are based on the analysis at a specific site. As future works, these findings need to be validated at other diverge sections as well.

Acknowledgment

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Reference

1) Muñoz, J. C., Daganzo, C. F. : The bottleneck mechanism of a freeway diverge, Transportation Research, Vol. 36A, pp. 483-505, 2002