AN ANALYSIS OF TRAFFIC CHARACTERISTICS AT FREEWAY MERGING SECTION

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abstract : Few systematic researches have been undertaken on merging sections on freeways in Korea due to difficulties in analyzing various traffic characteristics. This paper has three goals: (1) analysis of relations among various traffic flow variables(speed, volume), (2) interpretation of breakdown, and (3) influence of ramp volume on breakdown at merging sections. This paper observes traffic flows at basic and merging sections, evaluates the traffic breakdown in traffic flow relations, and analyzes and determines the relations between different levels of capacity. The operations which reflect traffic characteristics at merging sections can apply to ramp metering, which is a method of controlling traffic flows. According to the results of this study, the approach considering the influence of ramp volumes and different traffic characteristics on merging sections is much more efficient for the traffic opreation at merging area.

1. INTRODUCTION

Various traffic variables have been used to describe the traffic characteristics on freeways. Most of the studies which have been undertaken on the traffic characteristics are focused on basic sections of freeway. The traffic characteristics at merging sections may be different from that of basic section due to the influence of ramp flow.

The merging sections are typical bottlenecks where mainline freeway flow and ramp flow collide with each other, and the capacity happens to be reduced in these sections. The difficulty of identifying traffic characteristics has been the obstacle to the research on this subject. Two factors, the geometric structure and the traffic condition, affect the traffic behaviors at merge areas. To analyze the effects of two factors correctly, a new methodology must be developed. Some ramp-freeway junctions designed improperly should be caused accidents and congestion. Therefore it is necessary to solve these problems and specify the rational and efficient design standard.

Through analysis of traffic characteristics at merging sections, mathematical models to describe the relationships among flow, speed and density are developed to provide the basis for selecting measures of effectiveness and defining the level-of-service ranges. These models are also used for estimating the capacity and operating conditions under which the capacity is reached.

Because of the vague range of observed data before-and-after breakdown occurrence, the process of breakdown at merge areas has not been described adequately. In addition, the mechanism which the flow state switches from stable to unstable has not been modeled effectively.

This study aims to analyze traffic charateristics at merging sections compared with basic sections, the process of traffic breakdown around entrance ramps and the influence of ramp flow to mainline freeway flow. It can also help establishing control strategies to maximize flow and optimize operations on the freeway.

Researches on merge area have been performed around two methodologies; the regression model of HCM and the gap acceptance model. The gap acceptance model is based on mathematical probability model, while HCM model had been studied using field data. Also the gap acceptance model, microscopic approach method, was used to consider the behaviors of individual vehicle and the geometric conditions of the connecting area.

The gap acceptance model was built by D.R. Drew systematically. He introduced the idea of a critical gap for the gap acceptance behavior. If the provided gap is greater than the critical gap, a ramp vehicle in an acceleration lane can merge into traffic stream of mainline freeway. The critical gap has usually been selected among median and mean of accepted gaps and the gap value which two curves such as the cumulative curve of accepted gaps and the cumulative curve of rejected gap cross each other. To resolve the difficulty of determining the critical gap, Drew has developed a regression model which can calculate the critical gap using variables such as nose angle(θ), acceleration length(L), type of acceleration lane(S).

Capacity related merging section is expressed in three ways. One is a capacity which can be accommodated in other lanes except merging lane. This capacity is the same as the capacity of the basic section. Another is a merging capacity which can be accommodated in merging lane which a outer lane in mainline freeway and a lane on ramp is merged each other. This value is the same as capacity of basic section at LOS E of ideal condition and the values indicated at other LOS are lower than the values of basic section. The other is a ramp capacity which a lane on ramp can accommodate. The capacity in US HCM(1994) was proposed 2,200～2,300 veh/hr/lane in merging lane. In addition, maximum service volume(capacity) of merge area proposed in Korean Highway Capacity Manual (KHCM) in 1992 is shown as Table 1.

<Table 1> Maximum service volumes in merge area

(Unit : pcphpl)

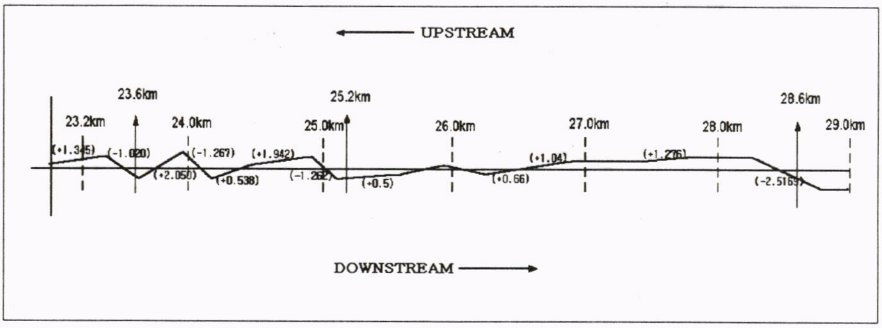
Level of service	Merge area	Basic section
A	≤650	≤750
B	≤1,050	≤1,150
C	≤1,450	≤1,550
D	≤1,800	≤1,900
E	≤2,200	≤2,200
F	-	-

2. DATA COLLECTION AND ANALYSIS

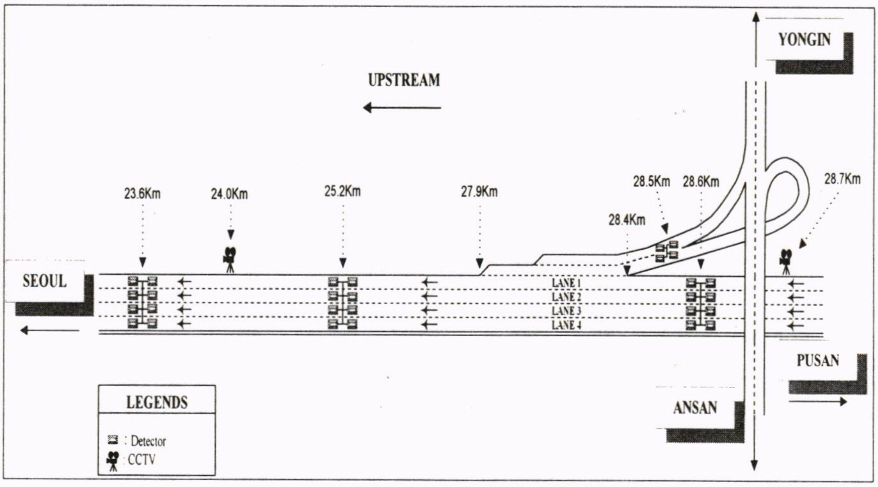
For analyzing the traffic charcteristics correctly at ramp-freeway merge junctions, the selection of study site is critical. The section downstream of the merge should be free of constraints. A downstream bottleneck would cause spillback of queues into the merge area and give the impression that the speed-flow and flow-density relationships are discontinuous near capacity. The merge area must regularly experience breakdown conditions as a direct result of the ramp volume, but not because of geometric design deficiencies.

The data were obtained in a Singal junction on Kyungbu expressway in Korea which has a freeway-ramp junction with directional 4-lane mainline and 2-lane ramp as shown in Figure 1 and 2. The length of acceleration lane is 500m. There are 4 detectors and 2 CCTVs installed in the study site. Loop detectors are located at 23.6km, 25.2km, 28.5km and 28.6km from beginning point of Kyungbu expressway. The detectors used in this study are 28.5km, 28.6km for merging section (28.5km for ramp data and 28.6km for mainline freeway data) and 25.2km for basic section. The lane beside median is lane 4 and successively lane 3, lane2 and there is lane 1 which is a outside lane beside shoulder lane. As it is shown in Figure 1 and 2, terrain of study site is near level and horizontal alignment is linear. Therefore, alignment conditions have no influences on traffic flow of study site due to good geometric conditions.

The data were collected for each 30 second and each lane. The field data were collected using loop detectors at various locations along the mainline freeway in the vicinity of the ramp. Points selected in this study were four locations: 23.6Km, 25.2Km for basic section and 28.5km, 28.6Km for merging section. Detailed diagrams of this study site can be shown in Figures 1 and 2.



<Figure 1> Vertical alignment diagram

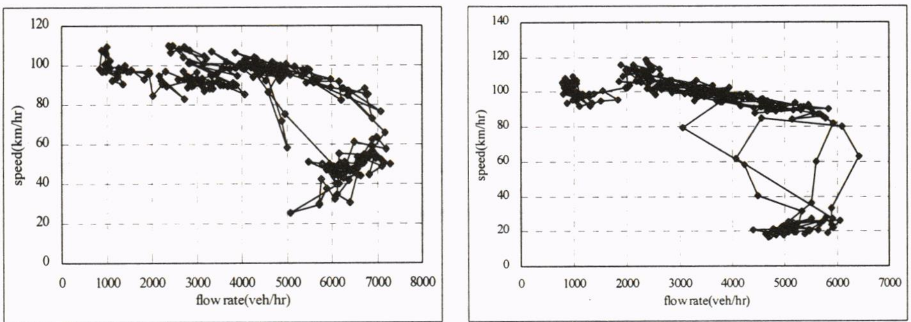


<Figure 2> Schematic diagram of study site

3. TRAFFIC FLOW CHARACTERISTICS

3.1 Relations of Traffic Variables Using Data from All Lanes

To analyze the traffic characteristics, this study considered the relations of traffic variables about basic sections and merging sections. The sites selected for basic sections is 25.2km from beginning point for inbound on Kyungbu expressway and 28.6km for merging sections. Through the relations of traffic variables, the phenomena of a traffic breakdown were observed, and the differences of traffic characteristics between basic sections and merging sections were explained.
As the results of this analysis, it can be assumed that the shape of plots is continuous single-regime for basic section as is shown in Figure 3(a), and for merging section it is shaped two-regime model which occurs discontinuity near capacity as is shown in Figure 3(b). Data observed near maximum flowrate are rare due to abrupt breakdwon occurrence caused by ramp flow at merge area, while lots of data are observed in basic section.

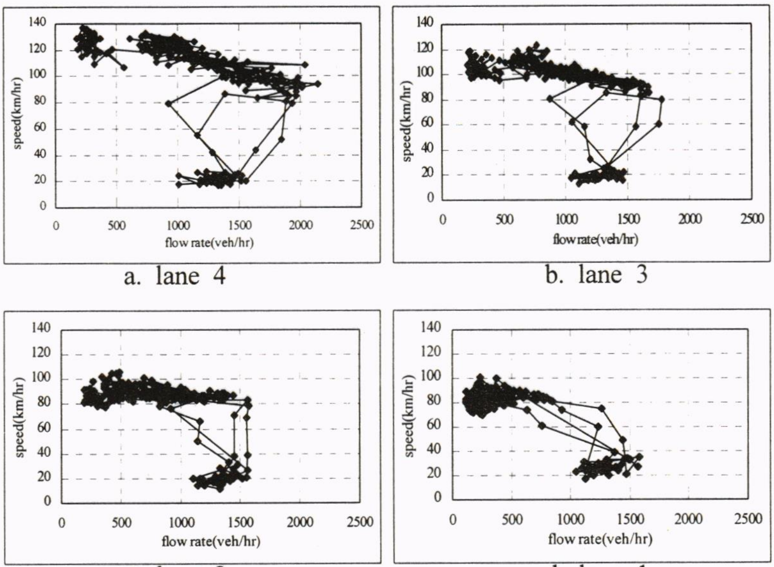


a. basic section b. merging section

<Figure 3> Speed-flow relationship using data of all lanes

3.2 Speed-Flow Relationship Using Individual Lane Data

Considering same flowrate level (lane by lane), speed of lane 4 which is a median lane is the highest because most of vehicles are composed of automobiles and the speed has been decreased from lane 3 to lane 1 in consecutive as is shown in Figure 4. In addition, speed in free flow has also been decreased in order of lane 4, lane 3, lane 2 and lane 1. In terms of volume, volume in lane 4 is the highest of all lanes and the volume has been decreased in the same way as speed. Once a breakdown occurs at a specific lane in multilane freeway, the effect of breakdown transfer to a side lane. Due to these phenomena, the breakdown occurrence disperse in all lanes. These results are confirmed through observed data and field survey. The observed volumes which breakdown occurs in each lane is very various. In case of lane 1 which is an outer lane, a traffic breakdown occurs before the observed volume reaches the capacity which can be accommodated in a lane generally. In addition, this volume in lane 1 is much lower than volume in lane 4. In order to find out a lane capacity compared with basic section, the difference of maximum volume (lane by lane) has been analyzed. The maximum volume observed in lane 4 at merging section is similar to that of lane 4 at basic section. The maximum volumes of other lanes are lower than those of basic section, especially in lane 1. It means that the volumes in other lanes except lane 4 have been affected by ramp volume directly.

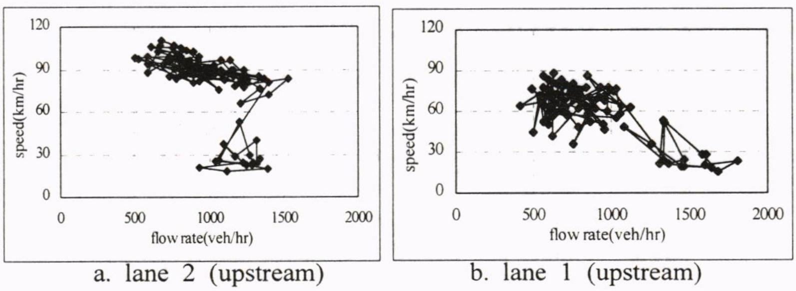


a. lane 4 b. lane 3

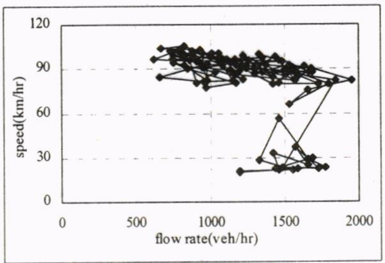
c. lane 2 d. lane 1

<Figure 4> Speed-Flow Relationship using data of each lane

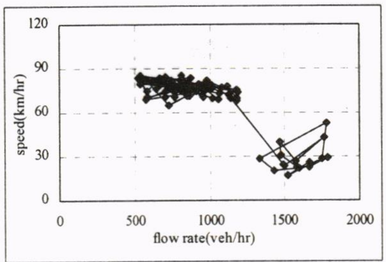
For analysis of the speed-flow relationships within the merging section, several points such as upstream, 50m, 100m and downstream in the center around acceleration lane have been selected at a merging section in Kwangju interchange. This site has acceleration lane of 150m, and 50m (or 100m) is the length from gore in acceleration lane. Overall, as is shown in Figure 5, the volume of lane 2 on the left portion is greater than that of lane 2 on the right portion. In addition, The more the observation point is downstream, the more the volume observed increases due to merging of ramp vehicles. Speed of each point is not different distinctly. In stable flow, speed deviation of upstream before the nose of ramp is the highest because lane changing and turbulence happen severely at this point. In additon, speed deviation of lane 2 is higher than that of lane 1 at upstream.



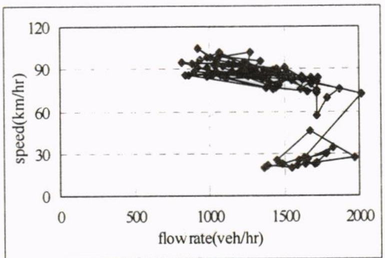
a. lane 2 (upstream) b. lane 1 (upstream)



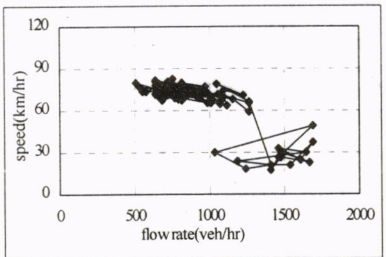
c. lane 2 (50m)



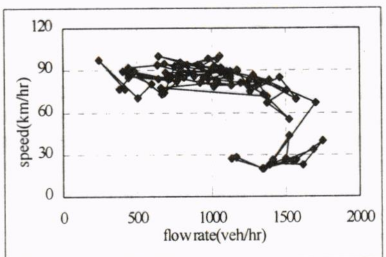
d. lane 1 (50m)



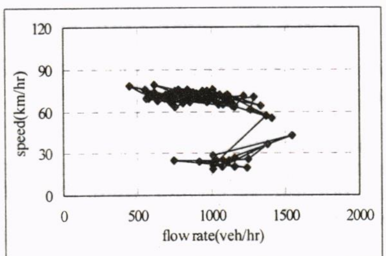
e. lane 2 (100m)



f. lane 1 (100m)



g. lane 2 (downstream)



h. lane 1 (downstream)

<Figure 5> Speed-flow relationship within merging section

4. ASSESSMENT OF TRAFFIC BREAKDOWN

A traffic breakdown means that traffic flow is being disturbed due to the interaction of vehicles. Breakdown in this study is defined as the state that the abrupt speed decrease from the continuous traffic data is over 10 km/hr and the condition of traffic flow before breakdown is stable and the condition of traffic flow after breakdown is unstable or forced.

After a traffic breakdown occurs, the traffic flow becomes unstable or forced. In general, if the traffic volume exceeds the capacity under stable flow, a traffic breakdown begins. The behavior of traffic flow during and immediately after a breakdown occurrence is not well understood. This study has performed an assessment on the traffic breakdown. For performance of this assessment, the data around breakdowns were used in this study. The data range used in this section includes all data including from the data before the breakdown occurrence to the data recovering to stable flow.

4.1 Breakdown at Basic Sections

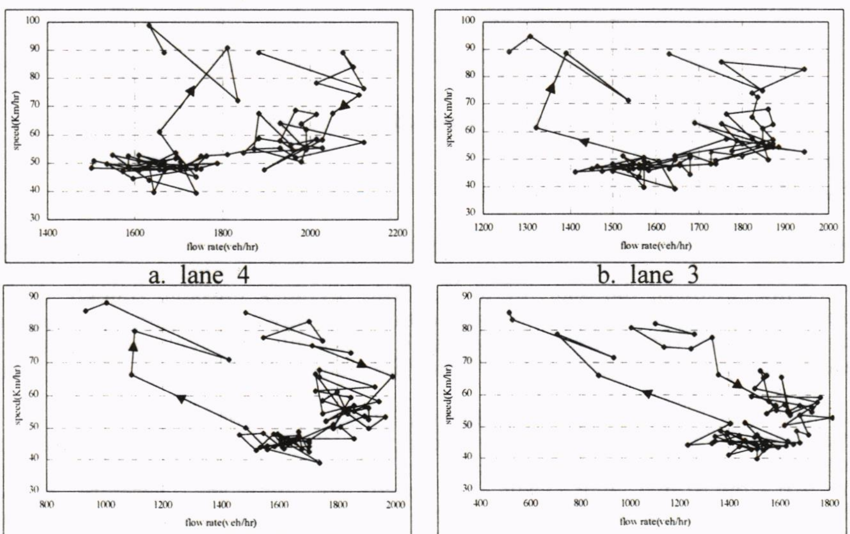
The speed at breakdown occurrence is almost around 65km/hr regardless of day and location. This means that the equilibrium of traffic flow is achieved over 65km/hr and in stable state, if not traffic flow will proceed in unstable state because traffic flow does not maintain interaction among vehicles in terms of headway, speed and safety distance, etc.

As is shown in Table 2, the time when breakdown occurs on each lane is different a little. When the breakdown occurs on each lane, the observed volumes are different one another from lane to lane. The data show that breakdown occurs after only lane 4 reaches a lane capacity as shown in Figure 6(a,e). This means that the breakdown in other lanes excluding lane 4 was affected by the breakdown of a side lane regardless of allowable lane capacity.

The transition of traffic flow state progresses very slowly, and breakdown may occur after the volume increases continuously and the effect of breakdown reduces the speed of traffic flow. In case flow state changes from stable to unstable, speed variation is greater than the other way around as shown in Figure 6.

<Table 2> The Time of Breakdown Occurrence at Basic Section

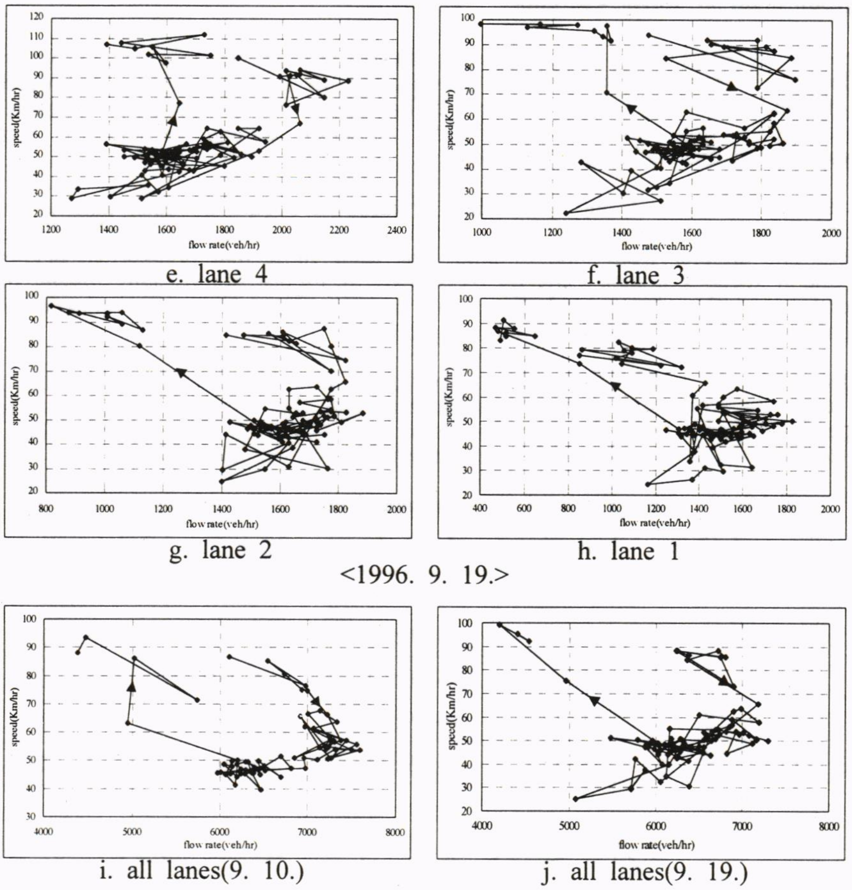
Observed Date	Lane 4	Lane 3	Lane 2	Lane 1
96. 7. 29.	17:53:30	17:53:00	17:53:00	17:53:00
96. 8. 7.	15:38:00	15:39:00	15:37:00	15:37:00
96. 8. 12.	15:50:30	15:50:30	15:50:30	15:50:30
96. 9. 10.	16:39:00	16:39:00	16:40:00	16:40:30
96. 9. 19.	15:39:00	15:39:00	15:41:00	15:41:30



a. lane 4 b. lane 3

c. lane 2 d. lane 1

<1996. 9. 10.>

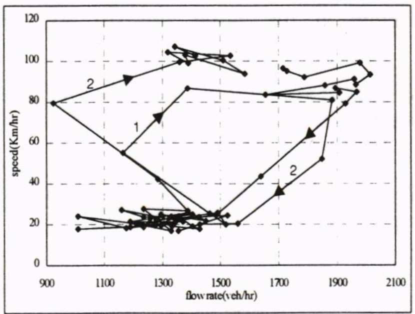


<Figure 6> Traffic Breakdown at Basic Sections

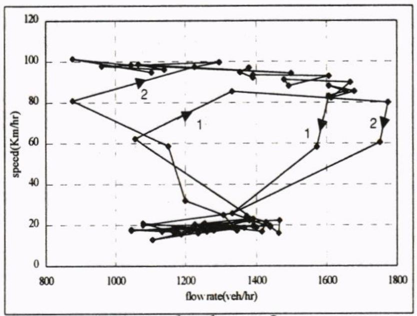
4.2 Breakdowns at Merging Section

Breakdown process at merging sections is nearly similar to that at basic sections in terms of transition's shape except variation of speed decrease. Once breakdown occurs at merge areas, the state of traffic flow becomes unstable quickly and speed variation is greater than that of basic section as shown in Figure 7. The data in Figure 7 show that breakdown occurs twice. Especially, the volumes on lane 1 are increased greatly by volume entering from side lanes after breakdown has occurred.

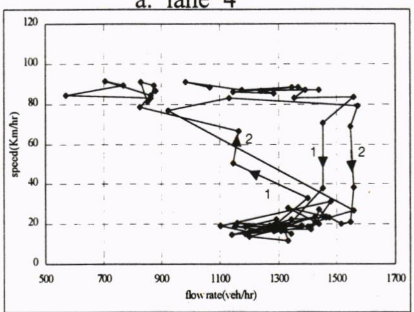
As is shown in Figure 7(a), the transition shape of traffic flow on lane 4 where flowrate reaches lane capacity is like a diamond shape(◇), which is caused by the interaction between volume and speed. In other words, if the volume increases continuously, breakdown will occur and speed will diminish. Therefore, breakdown may be explained by this process. Unstable flow discharge is interpreted as follows: If traffic demand is lower than capacity, speed may recover and traffic flow may rush in stable state.



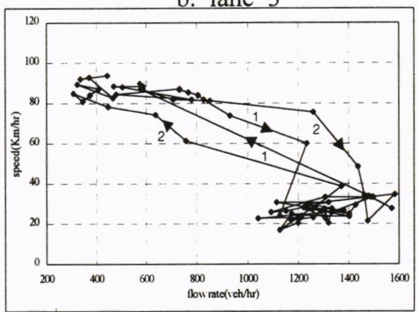
a. lane 4



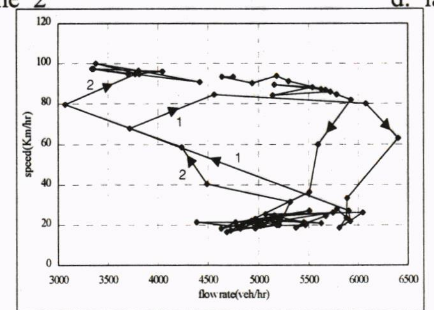
b. lane 3



c. lane 2



d. lane 1



b. all lanes

<Figure 7> Traffic Breakdown at Merging Section

5. CAUSE OF BREAKDOWN AT MERGE AREAS

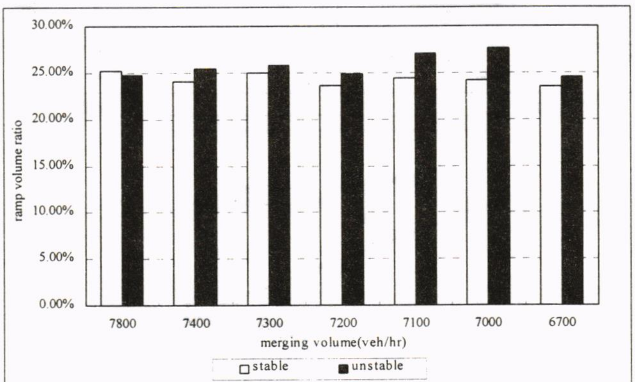
Ramp volume ratio by total merging volume(mainline+ramp) using before and after data of breakdown can be calculated and is shown in Table 3. Inspecting the ratios of ramp volume to the same merging volume, ratio of ramp volume in unstable is always greater than that of ramp volume in stable except the merging volume indicated 7,800 veh/hr. Therefore, relative proportion of ramp volume at the same merging volume should be the main cause of breakdown at merge area.

As it is shown in Table 3, the data showed that the range of merging volumes where breakdown has occurred is from 6,700 vph to 7,800 vph. Breakdown at merge area can occur at low volume relatively due to the influence of ramp flow such as volume, entering pattern and platoon size, etc. It means that breakdown does not always occur at given volumes, even at the same site. In addition, the breakdown is not a deterministic variable.

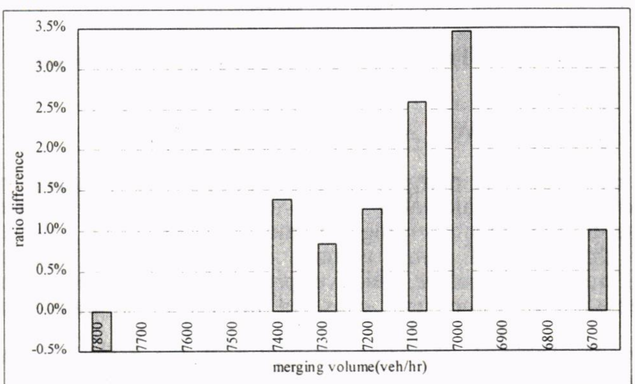
Because the variance of ratio difference of ramp volume to merging volume level dosen't have a specific form as is shown in Figure 9, no interreleation is determinable between ramp flow ratio and total merging flow level.

<Table 3> Proportion of ramp volume before and after breakdown

Merging flow (Veh/hr)	Ramp ratio before breakdown	Ramp ratio after breakdown	Ratio difference (after - before)
7800	25.26%	24.78%	-0.48%
7400	24.10%	25.47%	1.38%
7300	24.95%	25.78%	0.83%
7200	23.62%	24.88%	1.26%
7100	24.40%	26.98%	2.59%
7000	24.13%	27.58%	3.45%
6700	23.48%	24.48%	1.00%



<Figure 8> Ramp volume ratio to merging volume



<Figure 9> The difference of ratio(unstable - stable)

6. CONCLUSIONS

Field data, taken continuously during period of 3 months at two sections(basic and merging) were examined to analyze traffic characteristics and breakdown issues at merging sections.

This paper consists of three major parts using field data. Traffic flow relation(speed-flow) is firstly presented to establish traffic characteristics at merging sections. Secondly, interpretation of breakdown is presented with emphasis on flow patterns which change from stable to unstable and the other way around. Finally, the cause of breakdown occurrence is assessed in terms of relative ratio of mainline freeway volume and ramp volume.

Compared with basic sections, traffic flow at merging sections are extremely influenced on traffic breakdown. For this reason, the shapes of traffic flow at merging sections are not continuous. Because breakdown greatly affects traffic flow of merging sections, few data can be observed near the capacity. In general, the following conclusions may be drawn:

- Inspecting speed-flow relationship, the shape of plots is continuous single-regime at basic section and is two-regime model at merging section, which means discontinuity near capacity.
- At upstream of mainline freeway just before nose at enterance ramp, the standard deviation of speed indicates the highest among several points in the adjacent mainline freeway lane, and it is why vehicles in mainline freeway have done the lane change to inner lane in order to avoid the conflict by ramp vehicles entering mainline freeway.
- In multilane freeway, once a traffic breakdown occurs at a certain lane, this effect should transfer to a side lane. By these phenomena, the breakdown in all lanes may occur not simultaneously but orderly.
- In case volume exceeds capacity, the shape of breakdown, which is described the change of traffic flow state(either from stable to unstable or the other way around), should be like a diamond, and it is caused by interactions among traffic variables such as volume and speed.
- In case the same merging volume, the ratios of ramp volume in stable is mostly greater than that of ramp volume in unstable. Therefore, the probability of breakdown occurrence should be higher when the ratio of ramp volume to same merging volume increase.
- Breakdown occurrence at merge area should be caused by the relative ratio of ramp volume to the same merging volume.

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- In case the same merging volume, the ratios of ramp volume in stable is mostly greater than that of ramp volume in unstable. Therefore, the probability of breakdown occurrence should be higher when the ratio of ramp volume to same merging volume increase.
- Breakdown occurrence at merge area should be caused by the relative ratio of ramp volume to the same merging volume.

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