PAVEMENT MARKING TREATMENTS ON INTERSECTION APPROACHES WITH EXCLUSIVE RIGHT-TURN LANES*

by Dang minh TAN**, Miho ASANO***, Wael ALHAJYASEEN**** and Hideki NAKAMURA*****

1. Introduction

A transition segment is necessary when adding an exclusive right-turn lane at any intersection approaches. This segment is used to provide through and right-turn (left-turn in U.S.) traffic with guidance to smoothly move into their appropriate lane respectively. The segment is usually formed by tapers. In general, there are two types of tapers, transition taper and entering taper as shown in **Figure 2**. Tapers can be designed by using curbs and/or pavement markings.

In Japan, zebra marking tapers are extensively used at transition segments as shown in **Figure 1**. However, the guidance regarding how to pass through the segment with zebra marking is unclear. Therefore, drivers intending to turn right are likely to ignore the marking. These drivers divert at various points in the transition segment. This might lead to the disturbance of trajectories and more conflict points, and then lead to more risk of rear-end and sideswipe collisions. Moreover, the guidance regarding the usage of transition segment in the Japanese pavement marking manual 1999[1)] remains uncertain. For instance, it is unclear in which case the zebra making tapers can be used appropriately. Furthermore, there are two types of transition segment configurations available in this manual, however how to choose a rational treatment among them is really a question.

Tsutsui 3 chorome, Nagoya

Figure 1: An example of transition segment with zebra marking tapers in Japan (source: Google Earth)

This paper presents a review and comparison of guidelines and manuals from several countries such as U.S., Germany, Australia and Japan in order to find out how transition segment design features are considered when pavement markings are used. Meanwhile, the global objective behind this study is to provide a rational design specification and propose a new pavement marking treatment for these arrangements.

2. Basic concepts and scope

Before making the review and comparison, components of the exclusive right-turn lane shown in **Figure 2** are defined as follows:

Transition taper is located at the beginning of the transition segment and is used to shift through traffic laterally to the left. It is needed when through lane is deviated from normal path on roadway.

Entering taper is located at the beginning of the right-turn lane to clear right-turn traffic from through lane when decelerating.

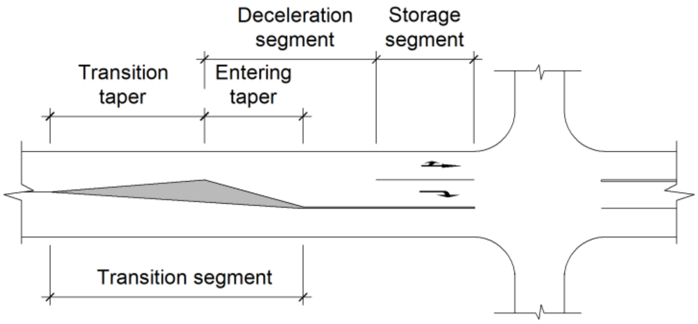

Figure 2: The exclusive right turn lane with tapers at transition segment

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Deceleration segment is installed to provide for a comfortable deceleration to a stop from approach speed.

Storage segment is used to store vehicles likely to accumulate during critical period.

So far, this study focuses on the design features and pavement marking usage of the transition segment only.

3. Review and comparison

(1) Design features

In U.S., several manuals provide general guidance regarding the components of the transition segment as shown in **Figure 3**. MUTCD 2009[2] provides a methodology to estimate the length of the transition taper by **Equations (1)** and **(2),** depending on approach speed and the width of offset distance.

$$L_t = 0.6V\Delta w \qquad \text{if } V \geq 70 \text{ km/h} \tag{1}$$

$$L_t = \Delta w V^2/100 \qquad \text{if } V < 70 \text{ km/h} \tag{2}$$

Where L_t is the length of the transition taper (m), Δw is the width of offset distance (m) and V is the 85th percentile speed or the posted speed or speed limit (km/h), whichever is higher.

According to AASHTO 2004[3], the length of the entering taper is commonly calculated by **Equation (3)**:

$$L_e = 8W \sim 15W \tag{3}$$

Where L_e is the length of the entering taper (m), W is the width of the exclusive right-turn lane (m). AASHTO 2004[3] also states that too long entering taper makes the drivers drift inadvertently into the exclusive right-turn lane (left-turn in U.S). Short entering taper produces better "targets" for drivers and gives more positive identification to an exclusive right-turn lane. However, too short entering taper may make vehicles stop suddenly, which increases the potential of rear-end collisions.

In Germany, RAS-K-1 1988[7] suggests two treatments of the transition segment in order to provide an exclusive right-turn lane (left-turn in Germany). In general, the treatment, as shown in **Figure 4a)**, is used for streets/highways with design speed greater than or equal to 70 km/h and high volume of through and right-turn traffic. The other treatment as shown in **Figure 4b)** is used for street/highways with design speed less than 70 km/h and low volume of through and right-turn traffic. In addition, RAS-K-1 1988[7] provides a methodology to calculate the length of the transition taper and the entering taper as shown in **Equations (4)** and **(5)**.

$$L_t = V\sqrt{\Delta w / 3} \tag{4}$$

$$L_e = 0.463 L_t \tag{5}$$

Where V is design speed of streets/highways (km/h).

In Australia, Road Planning and Design Manual, Chapter 13 (RPDM-13) 2006[9] provides detailed guidance on the design principles and the application of the transition segment treatments. According to this manual, the transition segment is basically divided into two types as shown in **Figures 5a)** and **b).** The application of each type depends on design speed of streets/highways and traffic volume of through and right-turn traffic. RPDM-13 2006[9] also provides a methodology to estimate the length of the transition taper and the entering taper as shown in **Equations (6)** and **(7)** respectively.

$$L_t = \frac{A\Delta w}{W} \tag{6}$$

$$L_e = 0.33\frac{VW}{3.6} \tag{7}$$

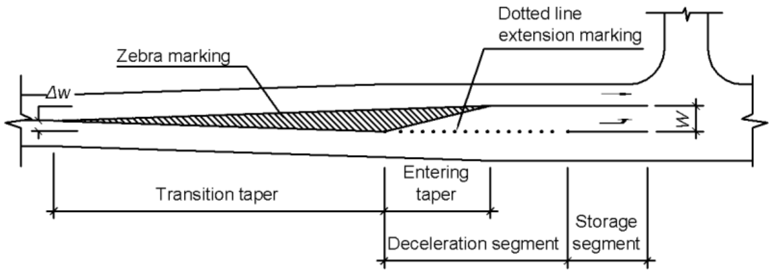
Where A is lateral movement distance (A = 40, 50, 60, 65, 75, 85, 95, 100 m for design speed of 50, 60, 70, 80, 90, 100, 110, 120 km/h, respectively).

In Japan, according to Japanese pavement marking manual 1999[1], configurations of the transition segment are classified in two types with zebra marking tapers as shown in **Figure 6**. The length of the transition taper and the entering taper in Japan is calculated by **Equations (8)** and **(9)**, respectively.

$$L_t = \frac{V\Delta w}{3} \sim \frac{V\Delta w}{2} \tag{8}$$

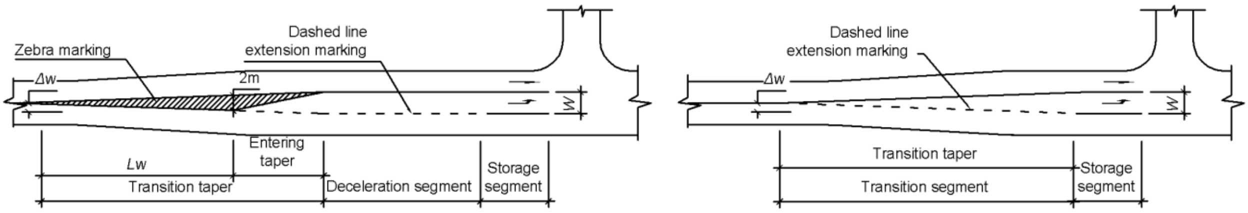
$$L_e = \frac{VW}{6} \tag{9}$$

Where Δw equals to the maximum of $|\Delta w_1, \Delta w_2|$ (m) and V is 85th percentile speed or design speed (km/h).



Where *W* is width of right-turn lane(Left-turn in U.S) and *Δw* is the offset distance

Figure 3: The transition segment in U.S[5)]

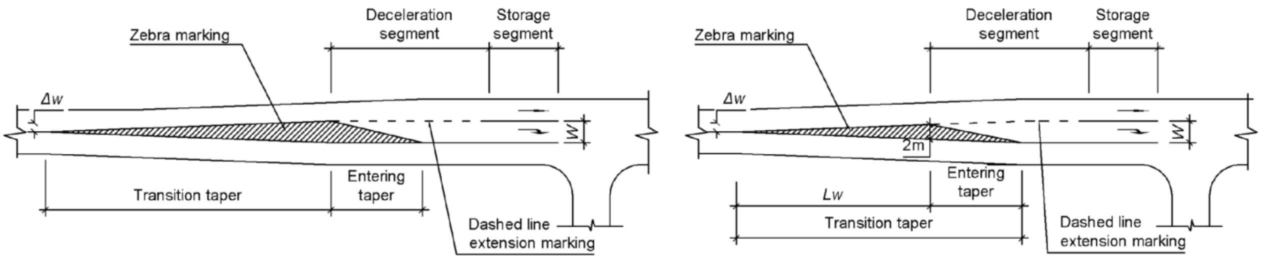


a) An exclusive right-turn (Left-turn in Germany) lane with deceleration segment

b) An exclusive right-turn (Left-turn in Germany) lane without deceleration segment

Where L_w is the distance from the beginning of transition segment to 2m widening.

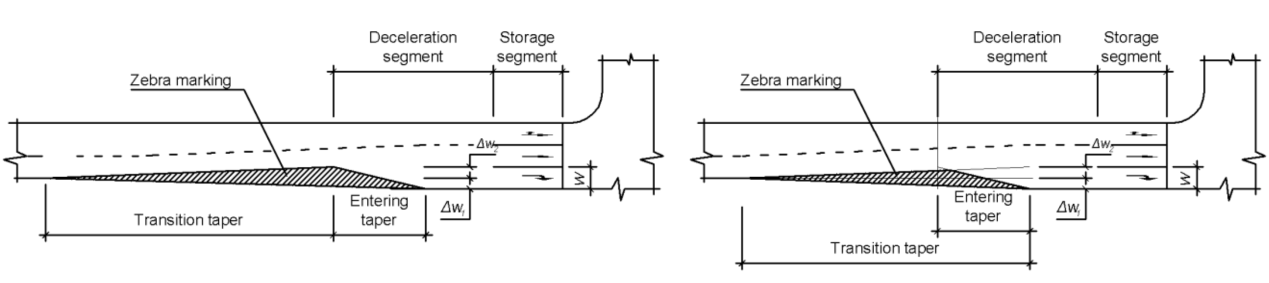
Figure 4: The transition segment in Germany[7)]



a) Channelized right turn treatment

b) Channelized right turn treatment with a short transition segment

Figure 5: The transition segment in Australia[9)]

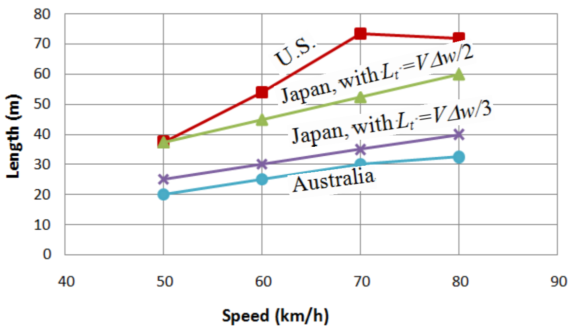


a) The long transition segment

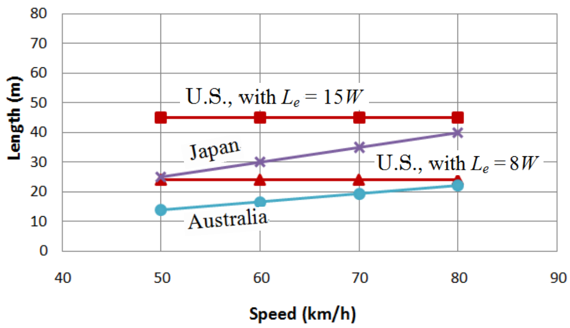
b) The short transition segment

Δw_1 and Δw_2 are offset distance to right and left respectively

Figure 6: The transition segment in Japan[1)]



a) Length of transition taper (L_t)



b) Length of entering taper (L_e)

Figure 7: Comparison of taper configurations

In summary, there are some different types of the transition segment configurations. In some treatments, the transition taper and entering taper are separated as shown in **Figure 3, 5a)** and **6a)**, which form a longer transition segment. In other treatments in **Figure 4a), 5b)** and **6b)**, the entering taper is considered as a part of the transition taper which forms a shorter transition segment. According to RPDM-13 2006[9)], the longer transition segment has a significant safety benefit over the shorter one. However, it states that the shorter transition segment is developed for streets/highways at some area in which it is not practical to provide the long transition treatment. The shorter transition segment is also considered to reduce cost where through and turning traffic volumes are low.

Regarding the methodology for estimating the configuration of the transition segments, generally, the lengths of the transition taper and the entering taper are calculated depending on the speed and the lateral offset distance of tapers. It can be easily noticed that these methods are established depending on the desirable objective. It means that when changing lane, drivers need a reasonable amount of time to change lane laterally. If the time is too short, drivers may feel uncomfortable to control the vehicles. This will make vehicles stop suddenly, and thus leads to a higher risk of rear-end collisions. However, the German methods, as shown in **Equation (4)** and **(5)**, are more different than other methods. For example, the length of entering taper is calculated depending on the length of the transition taper.

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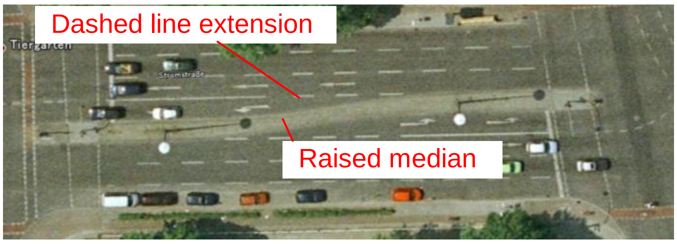
Figure 8: Pavement marking at transition segment in U.S. (Source: Google Earth)



Beusselstraße, Berlin

Figure 9: Pavement marking at transition segment in Germany (Source: Google Earth)

Anzac Pde, Kingsford, Sydney

Figure 10: Pavement marking at transition segment in Australia (Source: Google Earth)

In order to compare the differences between various calculation methods for estimating the transition segment configuration, we assume that an exclusive right-turn lane is added with the width W of 3 m. This lane is widened into both sides, each side with 1.5 m offset from the median (Δw = Δw_1 = Δw_2 = 1.5 m). According to the different design speeds in various countries, a design speed range within 50 km/h to 80 km/h is chosen to estimate the length of the transition taper and the entering taper as presented in **Figure 7a)** and **7b),** respectively. The comparison is conducted with the types of the transition segments only, in which the transition taper and the entering taper are separate (available in U.S., Japan and Australia, as shown in **Figure 3**, **5a)** and **6a)**).

As shown in **Figure 7a) and 7b)**, the length of the transition taper and the entering taper according to the U.S. method is the longest among all methods. The length estimated by Japanese method is in the moderate range while the shortest length corresponds to Australian method.

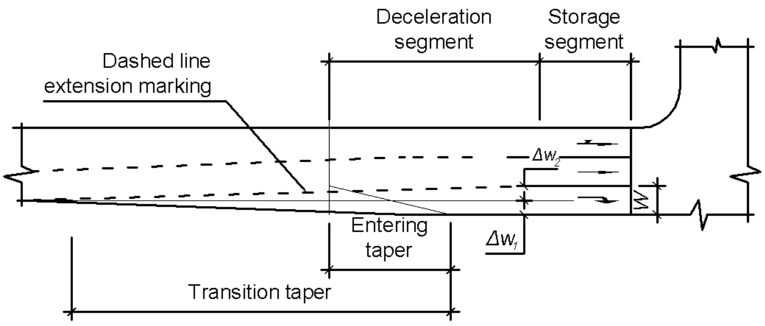


Figure 11: Proposed pavement marking treatment at the transition

(2) Pavement marking usage

Regarding pavement marking usage at the transition segment, in U.S., Germany and Australia, zebra marking tapers are mainly used on streets/highways without raised median. In addition, in all these countries, dotted or dashed line extension markings are used before the storage segment, between the right-turn lane and the adjacent through lane (see **Figure 8, 9** and **10**). These types of marking are used even for the exclusive right-turn lanes that are formed by tapers as shown in **Figure 3, 4** and **5**. In contrast, zebra marking tapers are used extensively in Japan without clear reason. It is considered that the zebra marking tapers might be unnecessary when a raised median exists or the right-turn lane is deviated completely to the right, as presented in **Figure 1**. In these cases, the role of the zebra marking tapers might be negligible and lead to the negative effects on traffic safety performance. Furthermore, dotted or dashed line extension marking has not been used in Japan.

Based on the comparison results, we propose a new pavement marking treatment at the transition segment in Japan as presented in **Figure 11**. This treatment is applied only when $\Delta w_1 \geq \Delta w_2$. In this treatment, instead of zebra marking tapers, the dashed line extension marking is used in order to provide guidance for shifting through traffic laterally to the left. Furthermore, it might have an important role in separating through traffic and right turn traffic which might prevent drivers from moving unintentionally into the wrong lane. This might provide better guidance and reduce the disturbance of vehicle trajectories, and thus improve traffic safety. The calculation method for the new treatment is similar to the current method in Japanese pavement marking manual 1999[1] with the short transition segment. Because with this configuration, the length of transition segment, as shown in **Figure 11**, provides a sufficient distance for both right-turn and through traffic moving laterally into their lane.

4. Discussion and conclusion

By reviewing and comparing the transition segment design policies in U.S., Germany, Australia and Japan across several manuals, this study provides better understanding on the transition segment design principles. It concludes that the existing specifications and treatments for the design of transition segment are still unclear. Therefore we can emphasize several points for discussion. First, there are many factors that can be considered when estimating and choosing the configuration of the transition segment. The common factors are known as the design speed, the offset distance of the exclusive right-turn lane and traffic volumes. The question is how to optimize the configuration of this segment based on the view point of traffic safety and operation performance. Second, the transition segment must be considered as part of the exclusive right-turn lane in the design process. However, the role of the transition segment in the exclusive right-turn lane should further be discussed. Third, further empirical study should be conducted to examine how the proposed treatment performs under different traffic conditions in Japan.

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