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16. Abstract

Following the wide and successful use of continuous shoulder rumble strips, many state departments of transportations (DOTs) installed centerline rumble strips (CLRS) on rural two-lane and undivided multilane highways in an effort to reduce cross-over-the-centerline (COCL) crashes. COCL crashes include head-on, sideswipe opposite direction, fixed object run-off-the-road left, and non-collision.

The purpose of this research was to develop guidelines for using CLRS in Virginia based on a review of best practices and the analysis of Virginia COCL crash data from 2001 through 2003. The analysis procedures included data query and analyses of crash frequency, density, and rate. Areas and route locations with the highest COCL crashes and densities were identified as potential candidate sites for CLRS.

As of 2003, 24 state DOTs and two Canadian provinces were using CLRS. They are generally installed on a case-by-case basis. CLRS design patterns vary greatly among states, but the most commonly used types are continuous grooves 12 to 16 inches in length, 6 to 7 inches in width, and 0.5 inch in depth spaced 12 or 24 inches apart. The optimal CLRS patterns remain unknown.

Data analyses revealed that the distribution of COCL crashes in Virginia varied significantly with roadway system, road type, jurisdictional area, and road location. The statewide COCL crash densities were 0.13 and 0.71 crash per mile for secondary and primary roads, respectively. Fixed object run-off-the-road left was the predominant type of COCL crash followed by sideswipe opposite direction and head-on for undivided roads. The crash density of the primary system was 4.5 times higher than that of the secondary system.

Guidelines were developed that outline the application of CLRS, design dimensions, installation and maintenance, and other issues. The authors recommend that the Virginia Department of Transportation's Traffic Engineering Division implement the guidelines as a division memorandum. Although a benefit-cost ratio for this recommendation will vary with each site, a sample estimated benefit-cost ratio was at least 7.6 per mile.


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**FINAL REPORT**

# GUIDELINES FOR USING CENTERLINE RUMBLE STRIPS IN VIRGINIA

**C. S. Chen, P.E.**
**Senior Transportation Engineer**
**Traffic Engineering Division**
**Virginia Department of Transportation**

**B. H. Cottrell, Jr.**
**Senior Research Scientist**
**Virginia Transportation Research Council**

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## DISCLAIMER

**ABSTRACT**

Following the wide and successful use of continuous shoulder rumble strips, many state departments of transportations (DOTs) installed centerline rumble strips (CLRS) on rural two-lane and undivided multilane highways in an effort to reduce cross-over-the-centerline (COCL) crashes. COCL crashes include head-on, sideswipe opposite direction, fixed object run-off-the-road left, and non-collision.

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Guidelines were developed that outline the application of CLRS, design dimensions, installation and maintenance, and other issues. The authors recommend that the Virginia Department of Transportation's Traffic Engineering Division implement the guidelines as a division memorandum. Although a benefit-cost ratio for this recommendation will vary with each site, a sample estimated benefit-cost ratio was at least 7.6 per mile.

## FINAL REPORT

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**C. S. Chen, P.E.**
**Senior Transportation Engineer**
**Traffic Engineering Division**
**Virginia Department of Transportation**

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## INTRODUCTION

Following the wide and successful use of continuous shoulder rumble strips,[1] many state departments of transportation (DOTs) installed centerline rumble strips (CLRS) on rural two-lane and undivided multilane highways in an effort to reduce cross-over-the-centerline (COCL) crashes. COCL crashes include head-on (HO), sideswipe opposite direction (SW-OP), fixed object run-off-the-road left (FO ROTR-L), and non-collision (NON-CO). CLRS were first installed on a 2.9-mile testing roadway section in Delaware in 1994.[2] Twenty-four states have since installed CLRS.[3]

The Virginia Department of Transportation (VDOT) has installed CLRS at Route 15 north of Lucketts in Loudoun County (1.5-mile, two-lane section installed October 1999) (see Figure 1); Route 1 near Fort Belvoir in Fairfax County (4.5-mile, four-lane section installed May 2003) (see Figure 2); and two sites on Route 460 between Suffolk City and Sussex County (9.4-mile, four-lane section installed August 2004) (see Figure 3).

CLRS is a relatively new technology because most installations have been completed since 2000.[3] As a result, most CLRS evaluations are recent. Although the research on its technical and practical aspects remains in its initial stage, there is sufficient evidence to suggest that the use of CLRS has the potential to reduce traffic crashes.[3] Several state DOTs claim positive results on safety in their crash data analyses.[3]

The VDOT draft strategic highway safety plan defines a system, organization, and process for managing the attributes of the roadway to achieve the highest level of safety by integrating the disciplines of other safety partners. This plan includes roadway departures as an emphasis area, and the target crashes are HO, SW-OP, and ROTR. Implementing roadway safety countermeasures including CLRS was listed as a strategy to address lane departures.[4]

Figure 1.  CLRS on Route 15 in Loudoun County


Figure 2.  CLRS on Route 1 in Fairfax County

**Figure 3. CLRS on Route 460 in Sussex County**

Undivided highways in the primary and secondary (P&S) systems make up the majority of the miles of highways in Virginia. In 2003, undivided P&S highways totaled 53,248 miles, accounting for 74.7 percent of the total highway mileage (71,243 miles) and 95 percent of the P&S systems (55,859 miles).[5] These numbers include local roads and subdivision streets. Given the magnitude of the percentage of undivided highways in Virginia, the potential for enhancing safety by using CLRS presents a challenging opportunity for VDOT.

## PURPOSE AND SCOPE

The purpose of this research was to develop guidelines for using CLRS in Virginia. The guidelines were to be based on a review of best practices and comprehensive analyses of COCL crash data in Virginia.

## METHODS

The study objectives were achieved through five tasks:

1. Conduct a review of the literature on the use of CLRS.

2. Conduct an email survey of state DOTs to inventory their practices with regard to CLRS.

3. Obtain Virginia COCL crash data for the P&S systems.

4. Analyze the data to identify the crash distributions and patterns in Virginia, and identify those road types, design conditions, and areas with high COCL crashes.

5. Develop guidelines for the use of CLRS in Virginia.

## Review of the Literature

The literature search was conducted through the use of computerized literature databases such as the Transportation Research Information Services.

The sample sizes, evaluation procedures, and conclusions of the studies were reviewed to assess their accuracy and reliability. This assessment was necessary because the analysis procedures and study conclusions addressed in the reports tended to vary significantly.

## E-Mail Survey of State DOTs

An email survey was sent to the state DOT traffic engineers of all 49 states other than Virginia to determine which states use CLRS and to obtain information on how they are being used. The intent of the survey was to obtain best practices that might not have been uncovered in the literature review.

The email survey asked six questions:

1. Does your state DOT use centerline rumble strips?

2. When (under what conditions) do you install centerline rumble strips?

3. What do you install and where (design details including type of rumble strip, width, depth, spacing, location relative to centerline markings, median width, etc.)?

4. Have you done any studies on your centerline rumble strip experience?

5. Approximately how many miles of centerline rumble strips has your state DOT installed as of today?

6. Please provide any comments.

## Virginia Crash Data

COCL crash data for the P&S systems were obtained from VDOT's highway and traffic information system (HTRIS) database using a query procedure to filter COCL crashes on paved undivided primary and secondary highways. In addition to HO and SW-OP crashes, the procedure filtered the FO and NON-CO crashes to capture single-vehicle ROTR-L. The 3-year period for the data collected was 2001 through 2003. The system roadway mileages for all undivided paved roads were obtained from 2002 VDOT mileage data.

## Data Analysis

The purpose of the crash data analysis was to identify the crash distributions and patterns in Virginia and identify those road types, design conditions, and areas that had a high number of COCL crashes in past years. The majority of undivided P&S roads are in rural areas, and their volume to capacity ratio is relatively low. However, the segments with higher numbers and densities of COCL crashes tend to be the roadways with higher volumes.

The COCL crash density, that is, total COCL crash frequency of study area divided by total road length, or the area average COCL crashes per mile, was the primary index used to identify the COCL crash experience for each study area for undivided roads. The four study areas identified were (1) statewide, (2) the VDOT district, (3) the county/city, and (4) the roadway section. Calculations were performed and completed using an Excel spreadsheet. The output of the analyses included COCL crash frequencies, COCL density, crash rates in some cases, and COCL crash types. The analysis focused on the following:

1. Two-way, undivided paved roadways in the P&S systems.

2. Crash types including HO, SW-OP, FO ROTR-L, and left-side NON-CO. The numbers do not include any angle, deer, or other animal crashes that could be associated with COCL collisions.

To quantify the COCL crash features and patterns on the P&S roads, the analyses included the following five categories:

1. *System analysis,* i.e., analyses of crash frequency and crash density and rates on P&S systems at the district and statewide levels.

2. *Jurisdictional analysis,* i.e., analyses of P&S roadway crash frequency and density on P&S roads by county/city.

3. *Route analysis,* i.e., analyses of P&S crash frequency and density on all route networks in Virginia.

4. *Priority analysis,* i.e., analyses of the top P&S COCL crash counties and routes. The top routes were defined in a two-step screening process. First, route sections with six or more crashes for the study period were identified. Second, these sites were further screened to identify road sections where the crash density was 1 or more crashes per mile. There were no rules governing the length of a section.

5. *Pattern analysis,* i.e., analyses including crash types and their percentages in COCL crashes; crash distributions on roadway categories and the relationship between crash frequencies and variables; etc.

### Development of Guidelines

Information on the best practices of other state DOTs and VDOT's experience with CLRS was used to establish the guidelines. Developing the guidelines included identifying CLRS patterns, design standards, implementation concerns, maintenance criteria, and crash data collection procedures for safety analysis, public information approaches, cost estimates and possibly cost benefit analysis. Other issues addressed included pavement durability especially along the centerline joints, passing zones, use of CLRS with markings, adjacent land uses and the impact of other users along a road section with CLRS.

## RESULTS AND DISCUSSION

### Literature Review

#### CLRS Research/Practices

A total of 21 articles and reports were reviewed to identify the state of CLRS practices. The findings are discussed here.

- As of 2003, 24 state DOTs and two provinces in Canada had installed CLRS on their highways. The 24 states include Pennsylvania, Massachusetts, Minnesota, Colorado, Kansas, New Hampshire, California, Washington, Delaware, Maryland, Nevada, Virginia, Ohio, Idaho, and Wyoming. The states with the larger number of miles of CLRS are Pennsylvania, 1,500 miles; Minnesota, 66 miles; California, 48 miles; Washington, 44 miles; Maryland, 31 miles; and Colorado, 21 miles.[3]

- CLRS installations are composed of milled CLRS except for those in California, which are a mix of milled and raised types, and Virginia, which has both milled and rolled patterns in place.[3]

- CLRS design patterns vary greatly: 14 types are in practice nationwide. The groove lengths range from 8 to 18 inches; the two most commonly used lengths are 12 and 16 inches; the widths range from 5 to 7 inches; 6.5 inches is most common; the depth is typically 0.5 inch except in Oregon where 0.63 inch is the practice. Most state DOTs space CLRS 12 or 24 inches apart and use this spacing continuously. Some state DOTs use an alternating spacing pattern of 12 and 24 inches or 24 and 48 inches. Most state DOTs use CLRS only in no passing zones, although some also use them in passing zones. [3]

- Based on a Nevada survey report, four state DOTs (Pennsylvania, Oregon, Nebraska and Utah) have established CLRS specifications/criteria. Pennsylvania and Oregon have developed written draft guidelines.[6]

- Some reports/articles document the effect of CLRS installation on highway safety based on data analysis. Although the conclusions vary, some reports with larger sample sizes conclude that using CLRS has reduced related road crashes 12 to 29 percent.[3]

Five studies were of particular interest with regard to best practices:

1. A study by Persaud, Retting, and Lyon reported on the installation of centerline rumble strips on rural two-lane roads.[7] This report was the only one reviewed that included statistical testing to determine the significant difference of crashes before and after CLRS installation. Data were obtained from seven states with a total of 210 miles of 98 CLRS (treated) sites on rural two-lane highways. The empirical Bayes procedure was used to control for the regression-to-the-mean effect, a major issue affecting the validity of a highway safety study. The study concluded that CLRS reduced frontal/sideswipe crashes by 21 percent and all types of crashes by 14 percent.

2. A study by Outcalt[8] compared before and after crash data on a 17-mile road section in Colorado over a 44-month period. The installation of CLRS reduced HO and SW-OP crashes by 34 and 36.5 percent, respectively.

3. A study by Russell and Rys[9] on the U.S. experience with centerline rumble strips on two-lane roads included a detailed survey regarding CLRS design standards. No conclusions about their use and effectiveness were presented. Additional research was suggested for two CLRS designs (i.e., continuous spacing of 12 inches on center and 12 inches long, and alternating spacing of 12 and 24 inches and 12 inches long with 0.5 inch depth for each).

4. A study by the Delaware DOT[7] reported on the first recorded installation of CLRS in the United States; the installation was on a road section 2.9 miles long. The average annual crash frequency for 3 years before installation was compared to that for 8 years after installation. The CLRS installation was found to reduce HO crashes by 95 percent and drove-left-of-center crashes by 60 percent.

5. A study by Noyce[10] based on several roadway sections less than 10 miles in length each found no significant change in crash frequencies before and after CLRS installations.

## Issues Requiring Consideration

The literature review revealed the following issues that can be construed as problematic or at the very least unresolved with respect to the study at hand.

- Although a variety of CLRS patterns have been used, the optimal types have not been statistically identified. One study selected two patterns for additional testing based on noise and vibration tests.[6] Although some findings were revealed, the optimal patterns remain unknown as the test results were inconclusive.

- Most evaluation results of the safety effects of CLRS were based on simple comparisons of crash data between before and after periods. This approach can overestimate or underestimate the magnitude of crash reductions because it fails to control the regression-to-the-mean effect. The conclusions regarding a reduction of crash rates vary greatly, from a 90 percent to a negative number.

- Although one research study (Persaud et al.)[7] presented a statistical analysis, this study involved many variables and the crash reduction model employed makes some assumptions that may weaken the statistical analysis.

- Issues such as minimum requirements of road width and pavement structure for CLRS installation, maintenance activities, snowplowable markers, installation on roadway zones such as passing zones and special areas, use of CLRS with markers and pavement markings, bicycle traffic, special traffic control devices, noise effect on residences, etc., have not been considered thoroughly in any research effort.

**Rumble Stripes**

Several efforts are underway to demonstrate rumble stripes.[11,12] Rumble stripes are pavement marking materials installed over rumble strips. Their purpose is to provide improved visibility of pavement markings especially under wet, night conditions. The audible warning provided when the stripes are crossed may be viewed as equally important or secondary to the visibility of the pavement marking, depending on the application. In the case of CLRS, enhanced wet night visibility is an added benefit. Several states are demonstrating or piloting rumble stripes, including Mississippi and Texas.[11,12] The Mississippi DOT has experimented with rumble stripes on edgelines at several sites and concluded that in addition to the excellent audible warning, rumble stripes provide increased retroreflectivity of pavement markings similar to that of profiled markings. In a survey of motorists, it was concluded that the markings provided improved visibility of the markings under wet night conditions. Further information is available at http://tcd.tamu.edu/documents/rumble/rumble1.htm; see the Mississippi presentation and video clips.[11]

**Guidelines for Use of CLRS**

The National Cooperative Highway Research Program (NCHRP) is planning a study, NCHRP Project 17-32, Guidance for the Design and Application of Shoulder and Centerline Rumble Strips,[13] to provide guidance for the design and application of shoulder and centerline rumble strips. The objective of this project is to develop guidance for the design and application of shoulder and centerline rumble strips as an effective motor vehicle crash reduction measure while minimizing adverse operational effects for cyclists and adjacent property owners.

Although they have proven to be cost-effective countermeasures for reducing COCL collisions, there are specific concerns regarding pavement durability at centerline joints, their use in passing zones, and their impact on motorcyclists.

Installing rumble strips to reduce ROTR or COCL crashes, with no consideration of impacts to other users, may lead to unintended outcomes. Some of the unresolved issues with installing either device include:

- minimum dimensions of the rumble strips necessary for effective vehicular warning with least potential for adverse effects
- optimal placement, including minimum criteria for lane and shoulder widths
- optimal longitudinal gaps in rumble strips to provide accessibility for cyclists while maintaining the effectiveness in reducing lane departures
- effectiveness and alternative designs for various speeds
- physical design of rumble strips with respect to "rideability" for motorcyclists and bicyclists
- noise produced by rumble strips on adjacent residents.

The study team will conduct a literature review of completed and ongoing studies on shoulder and centerline rumble strips and a survey of state and Canadian provincial transportation agencies to identify existing policies/guidelines governing the design and installation of shoulder and centerline rumble strips on rural and urban highways. The first major deliverable is an interim report documenting the results of these tasks and the following:

- the state of the practice in regard to rumble strips
- recommended practices based on the available information
- identification of issues that remain to be resolved through research
- a revised work plan, including an experimental design to address unresolved issues.

The study is expected to begin in spring 2005.

## Survey of State DOTs

Responses were received from 21 of the 49 state DOTs for a 43 percent return rate. Eleven do not use CLRS (Georgia, Illinois, Iowa, Louisiana, Maine, Mississippi, New Hampshire, North Dakota, Ohio, Rhode Island, and South Dakota). Interestingly, 1 DOT had installed CLRS at two locations but did not plan to use them in the future. The installation was political and not supported by the traffic engineering staff. Two DOTs have written guidelines for CLRS deployment, 5 decide on using CLRS on a case-by-case basis, and 3 use other means to decide when to use CLRS. The Pennsylvania DOT's (PennDOT) guidelines encourage the use of CLRS on all two- and four-lane rural undivided 3R (Resurfacing, Rehabilitation & Reconstruction) projects where the annual average daily traffic (AADT) is greater than 1,500 and the pavement width is 20 ft or more.[14] PennDOT concluded that CLRS is cost-effective at this AADT when a crash reduction factor of 20 percent is assumed. Oregon's guidelines state that to be eligible for CLRS installation, the crash history of a location should include a large number of crashes treatable by CLRS.[15]

The average CLRS groove design for the DOTs was 14.4 inches wide, 7 inches long, and 0.5 inch deep with 12-inch spacing. The mode for the CLRS groove design was similar to the mean with the exception of the width being 16 inches. Only PennDOT used an alternating spacing pattern with 24 and 48 inches as a standard, whereas the Kansas DOT used 12- and 24-inch alternating spacing as an alternative pattern. Oregon used 24-inch spacing as a standard but used 48-inch spacing in no passing zones. Two DOTs Oregon and Minnesota reported the use of two parallel sets of CLRS when a median at least 4 feet wide is present.

The results of the survey are summarized in Table A-1 in Appendix A.

## Crash Data Analysis

### COCL Crashes by VDOT District

Total COCL crashes and crash densities by VDOT district on the undivided P&S systems are shown in Tables 1 and 2, respectively:

- The total mileages of Virginia two-way, undivided paved roads are 5,826 miles and 37,703 miles the P&S systems, respectively. Undivided paved roads are 79.2 percent of the secondary and 75.1 percent of the primary systems.

- There were 8,919 COCL crashes statewide on a portion of the P&S paved roads in Virginia from 2001 to 2003. The total length of undivided paved roads cited in the query that produced 8,919 crashes is 19,782 miles or 45.5 percent (19,782/43,445) of total P&S undivided paved road mileages. This total excludes some roads such as those with pavement designated as light bituminous treatments and unimproved and some kinds of COCL crashes such as those involving angle and animal collisions. The split of P&S COCL crashes is 4,872 crashes, or 55 percent total, on secondary roads and 4,047 crashes, or 45 percent total, on primary roads. The split is within 10 percent, although the number of miles of secondary road system is 7.4 times greater than that for primary roads. The likely reason for this is the large differences in AADT between the two systems. That is, although the primary system has fewer miles, its typical traffic volume is greater than that of the secondary system.

- The COCL crash trends increased over time, especially for primary roads. From 2001 through 2003, the statewide COCL crashes increased 11.65 percent and 20.69 percent for secondary and primary roads, respectively.

- The COCL crash frequencies among the nine VDOT districts from the highest to the lowest, as shown in Table 1, were NOVA, Bristol, Salem, Staunton, Richmond, Culpeper, Fredericksburg, Lynchburg, and Hampton Roads.

The computed system COCL crash densities summarized in Table 2 reveal the following:

- The statewide undivided paved road COCL crash densities were 0.13 and 0.70 crashes per mile for the secondary and primary systems, respectively. The primary system crash density was thus 4.5 times higher than that of secondary system.

- The Virginia statewide undivided paved P&S system average COCL crash density was 0.21.

**Table 1. P&S COCL Crash Frequencies by VDOT District**

| District | Secondary | | | Primary | | | District Total |
|---|---|---|---|---|---|---|---|
| | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | |
| NOVA | 400 | 410 | 429 | 143 | 145 | 136 | 1663 |
| Bristol | 222 | 236 | 252 | 194 | 249 | 212 | 1365 |
| Salem | 194 | 185 | 225 | 134 | 162 | 187 | 1087 |
| Staunton | 166 | 193 | 196 | 136 | 154 | 183 | 1028 |
| Richmond | 169 | 142 | 174 | 127 | 141 | 169 | 922 |
| Culpeper | 92 | 114 | 125 | 128 | 147 | 172 | 778 |
| Fredericksburg | 126 | 118 | 151 | 128 | 100 | 136 | 759 |
| Lynchburg | 102 | 106 | 94 | 124 | 144 | 140 | 710 |
| Hampton Roads | 74 | 98 | 79 | 105 | 115 | 136 | 607 |
| Statewide | 1545 | 1602 | 1725 | 1219 | 1357 | 1471 | 8919 |

**Table 2. P&S COCL Crash Densities by VDOT District for 2001–2003**

| District | Secondary | | | Primary | | | District P&S | | | Ranks in S/P |
|---|---|---|---|---|---|---|---|---|---|---|
| | Crashes | Miles | Density | Crashes | Miles | Density | Crashes | Miles | Density | |
| NOVA | 1239 | 4182 | 0.3 | 424 | 946 | 0.45 | 1663 | 5128 | 0.32 | 1/9 |
| Bristol | 710 | 5490 | 0.13 | 655 | 697 | 0.94 | 1365 | 6187 | 0.22 | 5/1 |
| Culpeper | 331 | 4782 | 0.07 | 447 | 730 | 0.61 | 778 | 5512 | 0.14 | 7/8 |
| Fredericksburg | 395 | 5548 | 0.07 | 364 | 508 | 0.72 | 759 | 5912 | 0.13 | 6/7 |
| Hampton Roads | 251 | 3657 | 0.07 | 356 | 490 | 0.73 | 607 | 4147 | 0.15 | 9/5 |
| Lynchburg | 302 | 3909 | 0.08 | 408 | 508 | 0.81 | 710 | 4417 | 0.16 | 3/6 |
| Richmond | 485 | 2824 | 0.17 | 437 | 547 | 0.79 | 922 | 3371 | 0.27 | 4/2 |
| Salem | 604 | 3676 | 0.16 | 483 | 826 | 0.58 | 1087 | 4502 | 0.24 | 3/8 |
| Staunton | 555 | 3635 | 0.15 | 473 | 574 | 0.82 | 1028 | 4108 | 0.25 | 2/4 |
| Statewide | 4872 | 37703 | 0.13 | 4047 | 5826 | 0.7 | 8919 | 43,444 | 0.21 | |

- For the secondary system, the COCL crash densities among the nine VDOT districts from the highest to the lowest were NOVA, Richmond, Salem, Staunton, Bristol, Lynchburg, Fredericksburg, Culpeper, and Hampton Roads. The NOVA, Richmond, Salem, Staunton, and Bristol districts exceeded the average statewide secondary system crash density of 0.13. The NOVA crash density was 1.29 times higher than the average statewide secondary system crash density. This is likely due to the higher traffic volumes on NOVA roads.

- For the primary road system, the COCL crash densities among the nine VDOT districts from the highest to the lowest were Bristol, Staunton, Lynchburg, Richmond, Hampton Roads, Fredericksburg, Culpeper, Salem, and NOVA. Six districts exceeded the average statewide primary system crash density of 0.7: Bristol, Staunton, Lynchburg, Richmond, Hampton Roads, and Fredericksburg.

- For the total secondary and primary systems combined, the COCL crash densities densities among the nine VDOT districts from the highest to the lowest were NOVA), Staunton, Richmond, Salem, Bristol, Lynchburg, Hampton Roads, Culpeper, and Fredericksburg. District densities exceeding the statewide average of 0.21 included those of NOVA, Richmond, Staunton, Salem, and Bristol.

**COCL Crashes in Terms of Road Jurisdiction Features**

To focus analyses on areas with a higher number of COCL crashes and to identify their crash characteristics, the top crash counties, those with the highest frequencies, densities, and rates in each district, were verified in the analyses and summarized in Table 3.

- For the primary road system, the 10 highest COCL crash frequency counties/cities were Fairfax (185), Prince William (129), Albemarle (118), Suffolk (111), Augusta (108), Loudoun (88), Dickenson (82), Washington (82), Bedford (79), and Rockingham (79).

- For the primary road system, the 10 highest COCL crash density counties/cities were Prince William (1.37), Fairfax (1.21), Dickenson (1.04), Suffolk (0.99), Spotsylvania (0.94), Albemarle (0.86), Stafford (0.85), Powhatan (0.79), Carroll (0.74), and Washington (0.72).

- For the secondary road system, the 10 highest COCL crash frequency counties/cities were Fairfax (869), Chesterfield (345), Prince William (262), Buchanan (196), Augusta (158), Spotsylvania (144), Rockingham (137), Pittsylvania (119), Loudoun (108), and Washington (99).

- For the secondary road system, the 10 highest COCL crash density counties/cities were Buchanan (0.43), Fairfax (0.34), Prince William (0.3), Chesterfield (0.24), Spotsylvania (0.22), Montgomery (0.22), Stafford (0.21), Dickenson (0.17), Augusta (0.16), Roanoke (0.15), and Rockingham (0.15).

Table 3. Counties/Cities with Highest COCL Crashes on P&S Undivided Roads

| District/ County/City | Primary Crashes | Primary Road Length | Density (Crash/Mi) | Primary Crash Rate | Secondary Crashes | Secondary Road Length | Density (Crash/ Mi) | Secondary Crash Rate | Total Crashes | % of District | Primary DVMT | Secondary DVMT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NOVA** | | | | | | | | | 1663 | | | |
| *County/City* | | | | | | | | | | | | |
| Fairfax | 185 | 152.28 | 1.21 | 7.2 | 869 | 2524.44 | 0.34 | 27.5 | 1054 | 63.38 | 7,013,162 | 8,671,822 |
| Prince William | 129 | 94.14 | 1.37 | 20.2 | 262 | 885.3 | 0.30 | 25.3 | 391 | 23.51 | 1,748,332 | 2,832,027 |
| Loudoun | 88 | 137.73 | 0.64 | 8.0 | 108 | 834.68 | 0.13 | 21.6 | 196 | 11.79 | 3,031,615 | 1,372,485 |
| *Cumulative* | 402 | 384.15 | 1.05 | 9.3 | 1239 | 4244.42 | 0.29 | 26.4 | 1641 | 98.68 | 11,793,109 | 12,876,334 |
| **Bristol** | | | | | | | | | 1351 | | | |
| *County/City* | | | | | | | | | | | | |
| Buchanan | 47 | 71.83 | 0.65 | 32.5 | 196 | 459.02 | 0.43 | 173.5 | 243 | 17.99 | 396,374 | 309,550 |
| Washington | 82 | 113.59 | 0.72 | 43.1 | 99 | 747.44 | 0.13 | 70.4 | 181 | 13.4 | 521,400 | 385,131 |
| Dickenson | 82 | 78.9 | 1.04 | 121.3 | 68 | 402.96 | 0.17 | 146.2 | 150 | 11.1 | 185,143 | 127,452 |
| *Cumulative* | 211 | 264.32 | 0.80 | 52.4 | 363 | 1609.42 | 0.23 | 121.0 | 574 | 42.49 | 1,102,917 | 822,133 |
| **Culpeper** | | | | | | | | | 778 | | | |
| *County/City* | | | | | | | | | | | | |
| Albemarle | 118 | 136.65 | 0.86 | 20.5 | 114 | 821.72 | 0.14 | 36.5 | 232 | 29.82 | 1,578,114 | 855,020 |
| Fauquier | 54 | 104.61 | 0.52 | 8.8 | 76 | 788.73 | 0.10 | 39.6 | 130 | 16.71 | 1,688,321 | 525,560 |
| Louisa | 71 | 119.4 | 0.59 | 46.9 | 26 | 503.19 | 0.05 | 30.5 | 97 | 12.47 | 414,992 | 233,592 |
| Culpeper | 51 | 74.97 | 0.68 | 16.3 | 43 | 470.56 | 0.09 | 50.8 | 94 | 12.08 | 857,683 | 231,721 |
| *Cumulative* | 294 | 435.63 | 0.67 | 17.7 | 259 | 2584.2 | 0.10 | 38.4 | 553 | 71.08 | 4,539,110 | 1,845,893 |
| **Fredericksburg** | | | | | | | | | 759 | | | |
| *County/City* | | | | | | | | | | | | |
| Spotsylvania | 63 | 67.23 | 0.94 | 17.2 | 144 | 667.82 | 0.22 | 45.1 | 207 | 27.27 | 1,003,557 | 874,469 |
| Stafford | 39 | 45.77 | 0.85 | 12.4 | 103 | 487.58 | 0.21 | 39.4 | 142 | 18.71 | 863,705 | 716,469 |
| Caroline | 56 | 97.27 | 0.58 | 28.6 | 36 | 469.38 | 0.08 | 49.8 | 92 | 12.12 | 535,537 | 198,029 |
| *Cumulative* | 158 | 210.27 | 0.75 | 18.0 | 283 | 1624.78 | 0.17 | 43.3 | 441 | 58.10 | 2,402,799 | 1,788,967 |
| **Hampton** | | | | | | | | | 606 | | | |
| *County/City* | | | | | | | | | | | | |
| Suffolk | 111 | 112.53 | 0.99 | 18.9 | 59 | 542.95 | 0.11 | 46.4 | 170 | 28.05 | 1,607,923 | 348,725 |
| Isle of Wight | 45 | 81.37 | 0.55 | 15.5 | 41 | 433.69 | 0.09 | 50.1 | 86 | 14.19 | 796,419 | 224,029 |
| Accomac | 39 | 101.87 | 0.38 | 11.6 | 31 | 560.73 | 0.06 | 37.0 | 70 | 11.55 | 920,782 | 229,698 |
| York | 21 | 46.38 | 0.45 | 6.3 | 35 | 272.84 | 0.13 | 31.7 | 56 | 9.24 | 913,291 | 302,242 |
| Southampton | 27 | 95.1 | 0.28 | 10.5 | 27 | 671.71 | 0.04 | 29.7 | 54 | 8.91 | 701,690 | 249,298 |
| *Cumulative* | 243 | 437.25 | 0.56 | 13.5 | 193 | 2481.92 | 0.08 | 39.1 | 436 | 71.95 | 4,940,105 | 1,353,992 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lynchburg** | | | | | | | | | 710 | | | |
| *County/City* | | | | | | | | | | | | |
| Pittsylvania | 75 | 181.8 | 0.41 | 19.0 | 119 | 1444.81 | 0.08 | 43.8 | 194 | 27.32 | 1,079,185 | 744,802 |
| Campbell | 38 | 112.93 | 0.34 | 8.7 | 79 | 661.87 | 0.12 | 47.9 | 117 | 16.48 | 1,192,444 | 451,593 |
| Halifax | 50 | 159.09 | 0.31 | 19.6 | 33 | 835.26 | 0.04 | 28.2 | 83 | 11.69 | 697,346 | 320,874 |
| *Cumulative* | 163 | 453.82 | 0.36 | 15.0 | 231 | 2941.94 | 0.08 | 41.7 | 394 | 55.49 | 2,968,975 | 1,517,269 |
| **Richmond** | | | | | | | | | 922 | | | |
| *County/City* | | | | | | | | | | | | |
| Chesterfield | 41 | 129.89 | 0.32 | 3.0 | 345 | 1453.72 | 0.24 | 41.7 | 386 | 41.87 | 3,768,306 | 2,268,352 |
| Powhatan | 38 | 47.95 | 0.79 | 25.3 | 45 | 282.12 | 0.16 | 52.3 | 83 | 9 | 411,060 | 235,517 |
| *Cumulative* | 79 | 177.84 | 0.44 | 5.2 | 390 | 1735.84 | 0.22 | 42.7 | 469 | 50.87 | 4,179,366 | 2,503,869 |
| **Salem** | | | | | | | | | 1087 | | | |
| *County/City* | | | | | | | | | | | | |
| Bedford | 79 | 152.44 | 0.52 | 20.7 | 84 | 952.53 | 0.09 | 48.1 | 163 | 15 | 1,045,664 | 478,871 |
| Henry | 59 | 106.29 | 0.56 | 14.1 | 89 | 684.73 | 0.13 | 50.4 | 148 | 13.62 | 1,147,030 | 484,233 |
| Roanoke | 41 | 67.37 | 0.61 | 9.8 | 87 | 561.3 | 0.15 | 59.1 | 128 | 11.78 | 1,142,699 | 403,331 |
| Montgomery | 24 | 51.48 | 0.47 | 10.1 | 98 | 444.64 | 0.22 | 87.3 | 122 | 11.22 | 649,658 | 307,533 |
| Franklin | 55 | 94.82 | 0.58 | 18.6 | 63 | 1048.16 | 0.06 | 35.0 | 118 | 10.86 | 810,315 | 493,304 |
| Carroll | 68 | 91.66 | 0.74 | 46.9 | 44 | 837.71 | 0.05 | 51.3 | 112 | 10.3 | 396,824 | 234,910 |
| *Cumulative* | 326 | 564.06 | 0.58 | 17.2 | 465 | 4529.07 | 0.10 | 53.0 | 791 | 72.77 | 5,192,190 | 2,402,182 |
| **Staunton** | | | | | | | | | 1028 | | | |
| *County/City* | | | | | | | | | | | | |
| Augusta | 108 | 168.3 | 0.64 | 29.9 | 158 | 1000.87 | 0.16 | 78.8 | 266 | 25.88 | 990,425 | 549,009 |
| Rockingham | 79 | 156.04 | 0.51 | 22.1 | 137 | 887.67 | 0.15 | 66.3 | 216 | 21.01 | 979,646 | 565,783 |
| Frederick | 22 | 99.77 | 0.22 | 5.2 | 78 | 584.39 | 0.13 | 44.8 | 100 | 9.73 | 1,161,070 | 477,517 |
| Rockbridge | 47 | 113.5 | 0.41 | 38.2 | 51 | 612.2 | 0.08 | 80.2 | 98 | 9.53 | 337,305 | 174,222 |
| *Cumulative* | 256 | 537.61 | 0.48 | 20.2 | 424 | 3085.13 | 0.14 | 65.8 | 680 | 66.15 | 3,468,446 | 1,766,531 |

## COCL Crashes by Route in Counties/Cities

COCL crashes on all route sections in counties/cities were analyzed, screened in a two-step process, and summarized in Tables B-1 and B-2 in Appendix B for primary and secondary roads, respectively. The top route COCL crashes and densities in the districts are listed in Tables 4 and 5. In the route density calculation, the route section length is the distance between the starting and ending points of COCL crashes on routes, not the distance between intersecting points of route and the county lines.

Tables 4 and 5 illustrate the following:

- The crash distributions of routes varied significantly with areas and locations, particularly for secondary roads. The sections of COCL crashes on primary roads tended to be longer than on secondary roads.
- The average crash density of the top 12 highest crash secondary routes was 5.53**,** which is 42 times higher than the statewide system average; the crash density of the top 12 primary routes was 3.73, 5.3 times higher than its statewide system average crash density.

**Table 4. Twelve Top Primary Route COCL Crash Locations**

| District | Route No. | County | HO | FO ROTR | SW-OP | NON-CO | Total COCL Crashes | MP Begin | MP End | Section (mi) | Density |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NOVA | 193 | Fairfax | 19 | 13 | 29 | 1 | 62 | 1.14 | 8.69 | 7.55 | 8.21 |
| NOVA | 1 | Fairfax | 14 | 3 | 23 | 1 | 41 | 178.2 | 186.9 | 8.66 | 4.73 |
| Culpeper | 53 | Albemarle | 4 | 10 | 23 | 0 | 37 | 0 | 9.39 | 9.39 | 3.94 |
| Richmond | 33 | Henrico | 10 | 5 | 7 | 0 | 22 | 3.97 | 9.59 | 5.62 | 3.91 |
| Staunton | 50 | Frederick | 0 | 3 | 3 | 0 | 6 | 0.42 | 2.31 | 1.89 | 3.17 |
| Richmond | 145 | Chesterfield | 2 | 2 | 9 | 0 | 13 | 0.82 | 5.01 | 4.19 | 3.10 |
| Salem | 108 | Henry | 3 | 1 | 2 | 0 | 6 | 2.25 | 4.24 | 1.99 | 3.02 |
| NOVA | 1 | P. William | 12 | 8 | 11 | 1 | 32 | 165.7 | 176.5 | 10.81 | 2.96 |
| Salem | 220 | Henry | 4 | 3 | 3 | 0 | 10 | 6.54 | 10.01 | 3.47 | 2.88 |
| Hampton Roads | 13 | Suffolk | 0 | 19 | 8 | 5 | 32 | 0.33 | 13.08 | 12.75 | 2.51 |
| Bristol | 80 | Buchanan | 1 | 9 | 5 | 0 | 15 | 38.91 | 44.91 | 6 | 2.50 |
| Frederick | 30 | Caroline | 1 | 6 | 5 | 0 | 12 | 2.3 | 7.25 | 4.95 | 2.42 |
| Total | | | 70 | 82 | 128 | 8 | 288 | | | 77.27 | 3.73 |
| Percent | | | 24 | 28 | 44 | 4 | 100 | | | | |

**Table 5. Twelve Top Secondary Route COCL Crash Locations in Rank Order**

| District | Route No. | County | HO | FO ROR | SW-OP | NON-CO | COCL Crash | MP Begin | MP End | Section Mi | Density |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NOVA | 639 | P. William | 2 | 3 | 3 | 1 | 9 | 0.42 | 1.44 | 1.02 | 8.82 |
| Salem | 615 | Montgomery | 1 | 7 | 2 | 1 | 11 | 0.23 | 1.54 | 1.31 | 8.4 |
| NOVA | 906 | P. William | 6 | 1 | 1 | 0 | 8 | 0 | 1.1 | 1.1 | 7.27 |
| NOVA | 790 | Fairfax | 2 | 4 | 1 | 0 | 7 | 0.5 | 1.55 | 1.05 | 6.67 |
| NOVA | 636 | Fairfax | 1 | 5 | 3 | 0 | 9 | 1.21 | 2.57 | 1.36 | 6.62 |
| Hampton Roads | 688 | Suffolk | 0 | 2 | 5 | 0 | 7 | 1.88 | 2.98 | 1.1 | 6.36 |
| Hampton Roads | 620 | York | 0 | 6 | 3 | 0 | 9 | 0.02 | 1.56 | 1.54 | 5.84 |
| NOVA | 642 | Fairfax | 4 | 4 | 7 | 0 | 15 | 0.04 | 2.8 | 2.76 | 5.43 |
| Richmond | 638 | Chesterfield | 4 | 5 | 5 | 0 | 14 | 3.17 | 5.84 | 2.67 | 5.24 |
| Staunton | 644 | Rockingham | 2 | 2 | 2 | 0 | 6 | 2.3 | 3.5 | 1.2 | 5.0 |
| Bristol | 642 | Lee | 1 | 6 | 2 | 0 | 9 | 3.82 | 5.66 | 1.84 | 4.89 |
| NOVA | 633 | Fairfax | 4 | 3 | 2 | 0 | 9 | 0.01 | 1.88 | 1.87 | 4.81 |
| Total | | | 27 | 48 | 36 | 2 | 113 | | | 18.82 | 5.53 |
| Percent | | | 24 | 43 | 31 | 2 | 100 | | | | |

## COCL Crash Type Distributions by Road Categories

Distributions of COCL crashes on road systems and on collision types also vary greatly among all. These results are summarized in Table 6 and reveal the following:

- Primary two-lane roads account for 90 percent of total COCL system crashes. The remaining percentages by number of lanes are three-lane road, 2 percent, and four-lane road, 8 percent.

- Secondary two-lane roads account for 96 percent of total COCL system crashes. The remaining percentages by number of lanes are three-lane road, 1 percent, and four-lane road, 2 percent. The two-lane road has been the predominant roadway category for COCL crashes for P&S systems. This is not surprising since the majority of undivided P&S roads are two-lane roads.

**Table 6. COCL Crash Type Distributions by Road Categories**

| Road System | Crash Type | Number of Lanes 2 | 3 | 4 | >4 | Total | % |
|---|---|---|---|---|---|---|---|
| Primary | HO | 510 | 10 | 96 | 2 | 616 | 15 |
| | SW-OP | 960 | 9 | 98 | 1 | 1067 | 26 |
| | NON-CO | 206 | 4 | 7 | 1 | 217 | 5 |
| | FO ROTR-L | 1978 | 51 | 118 | 2 | 2147 | 54 |
| | Total | 3654 | 74 | 319 | 6 | 4047 | |
| | % | 90 | 2 | 8 | | | 100 |
| Secondary | HO | 730 | 15 | 48 | 2 | 795 | 16 |
| | SW-OP | 1279 | 10 | 50 | 2 | 1342 | 28 |
| | NON-CO | 255 | 1 | 2 | 0 | 258 | 5 |
| | FO ROTR-L | 2428 | 12 | 35 | 2 | 2477 | 51 |
| | Total | 4692 | 38 | 135 | 6 | 4872 | |
| | % | 96 | 1 | 2 | | | 100 |
| Total | | | | | | 8919 | |

*Note:* One SW-OP crash was recorded as occurring on a one-lane road.

- For primary roads, the crash distribution among COCL types is HO, 15 percent; SW-OP, 26 percent; NON-CO, 5 percent; and FO ROTR–L, 54 percent.

- For secondary roads, the crash distribution among COCL types is HO, 16 percent; SW-OP, 28 percent; NON-CO, 5 percent; and FO ROTR-L, 51 percent.

As Table 6 displays, the crash distribution is similar for the two systems. The FO ROTR-L crashes account for more than half of total COCL crashes for P&S systems. HO crashes account for 16 percent.

### COCL Crash Frequencies by Seasons and Time of Day

Crash distributions by season and time of day were not significantly different (see Table B-3 in Appendix B). However, the highest number of crashes occurred from 3 P.M. to 6 P.M. and between October and December.

### COCL Crash Analysis for Subdivision Streets and Rural and Urban Local Roads

The COCL crash analysis database included rural and urban local roads in the secondary road system. Subdivision streets are included in the rural and urban local roads functional classification groups. Unfortunately, the database does not include the subdivision street administrative classification; therefore, it was not possible to extract subdivision streets from the database. However, the following is known about the rural and local roads that include subdivision streets as a subset: Rural local roads added 711 crashes, or 14.6 percent, and urban local roads contributed 548 crashes, or 11.2 percent, to the COCL secondary road total. In total, local roads accounted for 1,259 crashes, or 25.8 percent, of the secondary roads. Local roads account for 65.1 percent, or 24,570 miles, of the 33,703 miles of secondary roads statewide.

## GUIDELINES FOR CLRS

Detailed guidelines for the application, design, installation, and maintenance of CLRS are provided in Appendix C. The objective of the guidelines is to enhance safety on undivided, paved, primary and secondary highway systems in Virginia through the use of this effective and low-cost measure. The implementation of the guidelines should reduce crashes related to vehicles crossing the centerline.

## CONCLUSIONS

- Twenty-four state DOTs and two provinces in Canada use CLRS.

- The state of the practice is to install CLRS on a case-by-case basis without the use of written guidelines.

- There are 14 types of CLRS in practice nationwide, but the most commonly used are continuous grooves 12 to 16 inches in length, 6 to 7 inches in width, and 0.5 inch in depth spaced 12 or 24 inches apart. The optimal patterns remain unknown.

- Most evaluation results of the safety effects of CLRS were based on simple comparisons of crash data between before and after periods. This approach can overestimate or underestimate the magnitude of crash reductions because it fails to control the regression-to-the-mean effect. The conclusions regarding a reduction of crash rates vary greatly, from a 90 percent to a negative number.

- For undivided roads, FO ROTR-L is the predominant type of COCL crash. The second and third most prevalent types are SW-OP and HO.

- For the primary system, the COCL crash distributions are FO ROTR-L, 54 percent; HO, 15 percent; SW-OP, 26 percent; and NON-CO, 5 percent.

- For the secondary system, the COCL crash distributions are FO ROTR-L, 51 percent; HO, 16 percent; SW-OP, 28 percent; and NON-CO, 5 percent.

- This study is the first documented analysis to include FO ROTR-L and NON-CO crashes in the COCL crash analysis.

- COCL crash features and distributions among road types and location features are

  — crash trends increase over time, especially for primary roads
  — crash density (i.e., crashes in 1 mile) is an important index
  — undivided road crash densities are 0.13 for secondary roads and 0.71 for primary roads
  — crash distributions for locations vary significantly; the average densities for the top 12 route sections were 42 times and 5.3 times higher than the statewide average indexes for secondary and primary roads, respectively.

  The distributions of COCL crashes vary significantly with roadway system, road type, jurisdictional area, and the road location.

## RECOMMENDATIONS

1. VDOT's Traffic Engineering Division (TED) should adopt the guidelines for CLRS provided in Appendix C. The guidelines should be designated as a TED memorandum.

2. When they are available, TED safety section staff should review the results of NCHRP Project 17-32[13] to determine if and how the proposed guidelines should be revised.

3. CLRS should be installed on a case-by-case basis based on further study by the district traffic engineers.

## COSTS AND BENEFITS ASSESSMENT

The costs and benefits of implementing CLRS were estimated based on best practices and experience in Virginia. The cost of installing rumble strips is about $1 per foot, or about $5,280 per mile. Depending on the type of pavement marking used, VDOT's installation cost is estimated to be $5,600 to $7,400 per mile. The maintenance cost over a 3-year period is estimated at $2,000 per mile (an expected high estimate). Thus, if the damage caused by a crash that might be prevented is greater than this estimated cost of $9,400, the estimated benefits will have exceeded the cost, as is desirable for any safety improvement measure.

For analysis purposes, the second site, Route 1, Northern Virginia District, in Table 4 was used. The crash density for this site is 4.73 COCL crashes per mile in a 3-year period for an 8.66-mile section. An accident reduction factor for CLRS of 20 percent is used. The Persaud et al. study with the largest sample size concluded a 21 percent reduction of frontal/sideswipe crashes.[7] PennDOT uses a 20 percent reduction in its analysis.[14] Although these reductions are based on HO and SW-OP crashes, our analyses used additional COCL crashes such as FO ROTR-L and NON-CO. For this analysis, only HO and SW-OP crashes were used to apply the crash reduction factor available. The crash density for HO and SW-OP is 4.27. A 20 percent reduction would yield a decrease of 0.85 crash per mile in 3 years.

In a review on paved shoulders, Cottrell estimated the average cost per crash for HO, sideswipe same direction, SW-OP, and FO ROR on the primary system to be $46,135 for 1988.[16] In the Federal Highway Administration's technical advisory on motor vehicle accident costs, injury crashes are categorized by the severity of injury, ranging from the lowest possible injury to an incapacitating injury.[17] The cost considered in this simplified estimate considered only the value of the lowest possible injury cost. Therefore, this cost estimate is low. If this estimate is updated to reflect average accident cost figures from an FHWA report in 2002, the cost becomes $83,763.[18]

Therefore, the benefit cost ratio for this example is estimated to be at least $83,763 x 0.85/$9400 = 7.6 per mile. For this example, the ratio clearly indicates that implementation is recommended.

Society in general and the motoring public that uses a road section with CLRS benefit by the reduction in crashes and the subsequent costs of recovery.

## IMPLEMENTATION PLAN

TED safety section staff should take the lead in this implementation. The final product should be a TED memorandum.

## ACKNOWLEDGMENTS

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# APPENDIX A
# SUMMARY OF SURVEY OF STATE DOTS

**Table A-1. Summary of Survey of State DOTs**

| Data | Delaware | Kansas | Kentucky | Michigan | Minnesota | Nevada |
|---|---|---|---|---|---|---|
| **Guidelines/Policy** | | | | | | |
| **Case-by-Case** | 1 | | 1 | | | 1 |
| **Other: Describe** | | Still evaluating | 1 | Test installation | History of HO/SW-OD crashes | |
| **Any Studies on CLRS?** | | | | | | |
| Yes | 1 | 1 | 1: Study underway | | 1: Participated in Insurance Institute for Highway Safety study; are monitoring all installations | |
| No | | | | 1 | | 1 |
| **Miles CLRS Installed** | 2.9 | 15 | 75 | 7 | 250 | 10 |
| **Comments** | | Completing research; will have policy | | | | |
| **CLRS Design** | | | | | 2 sets inside lane on each side of centerline markings | |
| Width (in) | 16 | 12 | 24 | | 6 | 16 |
| Length (in) | 7 | 6.5 | 7 | 7 | 7 | 7 |
| Depth (in) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Spacing (in) | 12 | 12 | 24 | 12 | 12 | 12 |
| Pattern B | | | | | | |
| Width (in) | | 12 | | | | |
| Length (in) | | 6.5 | | | | |
| Depth (in) | | 0.5 | | | | |
| Spacing (in) | | 12 and 24 alternating | RPMs 12 in from strips | | | |

| Data | Oregon | Pennsylvania | Washington | Wyoming |
| --- | --- | --- | --- | --- |
| **Guidelines/Policy** | 1 | rural 2- and 4-lane undivided roads with AADT>1500 and pavement width 20 ft or more | | |
| **Case-by-Case** | | | 1 | 1 |
| **Other: Describe** | | | | Only have one |
| **Any Studies on CLRS** | | | | |
| Yes | 1 | 1: Studies on short-term effectiveness; most assumptions based on studies of our shoulder rumble strips or research in other states | 1: Recently became high profile; only 1 in place long enough to gain any information | |
| No | | | | 1 |
| **Miles CLRS Installed** | 34 | 1500 | 75 | 10 |
| **CLRS design** | w/o median | lane width 11-12 ft and minimum 3 ft paved shoulder | | |
| width (in) | 16 | 16 | 12 | 12 |
| length (in) | 7 | 7 | 7 | 7 |
| depth (in) | 0.5 | 0.5 | 0.5 | 0.5 |
| spacing (in) | 24 (48 for no passing zones) | 24 and 48 alternating | 12 (or 24) | 12 |
| Pattern B | w/ median | lane width 10 or 11 ft w/ <3-ft shoulder | w/ 4-ft median | |
| width (in) | 16 | 14-18 | 16 | |
| length (in) | 7 | 7 | 7 | |
| depth (in) | 0.5 | 0.5 | 0.5 | |
| spacing (in) | 12 | 24 | 12 | |
| | CLRS between double yellow lines; 2 sets if median > 4 ft | | CLRS in passing zones | |

| | Total | Mean | Std. Dev. | Mode |
|---|---|---|---|---|
| **Guidelines/Policy** | 2 | | | |
| **Case-by-Case** | 5 | | | |
| **Other: Describe** | 3 | | | |
| **Any studies on CLRS** | | | | |
| Yes | 6 | | | |
| No | | | | |
| **Miles CLRS Installed** | 1978.9 | 197.9 | 463.5 | 75 |
| **CLRS design** | | | | |
| width (in) | | 14.4 | 4.9 | 16 |
| length (in) | | 7.0 | 0.2 | 7 |
| depth (in) | | 0.5 | 0.0 | 0.5 |
| spacing (in) | | 13.7 | 4.5 | 12 |
| **Pattern** | | | | |
| width (in) | | 14.7 | 2.3 | 16 |
| length (in) | | 6.9 | 0.3 | 7 |
| depth (in) | | 0.5 | 0.0 | 0.5 |
| spacing (in) | | 16.0 | 6.9 | 12 |

# APPENDIX B
# CROSS OVER CENTERLINE CRASHES

**Table B-1. COCL Crashes on Primary Route Sections in Counties/Districts with >1 crash/mi**

| Route No. | County | HO | FO ROTR | SW-OD | NON-CO | Total | MP Begin | MP End | Total Mi. | Crash/ Mi. |
|---|---|---|---|---|---|---|---|---|---|---|
| **Bristol** | | | | | | | | | | |
| 352 | Lee | 1 | 3 | 2 | 0 | 6 | 0.04 | 2.02 | 1.98 | 3.03 |
| 80 | Buchanan | 1 | 9 | 5 | 0 | 15 | 38.91 | 44.91 | 6.00 | 2.50 |
| 72 | Dickenson | 0 | 6 | 2 | 4 | 12 | 41.71 | 48.99 | 7.28 | 1.65 |
| 63 | Russell | 2 | 3 | 3 | 0 | 8 | 5.13 | 10.41 | 5.28 | 1.52 |
| 80 | Washington | 0 | 8 | 10 | 0 | 18 | 2.26 | 14.21 | 11.95 | 1.51 |
| 80 | Dickenson | 1 | 15 | 6 | 0 | 22 | 45.21 | 61.17 | 15.96 | 1.38 |
| 421 | Lee | 3 | 7 | 6 | 0 | 16 | 1.27 | 13.09 | 11.82 | 1.35 |
| 71 | Scott | 0 | 11 | 2 | 0 | 13 | 7.11 | 16.95 | 9.84 | 1.32 |
| 21 | Grayson | 0 | 12 | 1 | 5 | 18 | 2.23 | 15.97 | 13.74 | 1.31 |
| 94 | Grayson | 0 | 5 | 2 | 1 | 8 | 0.00 | 6.18 | 6.18 | 1.29 |
| 68 | Wise | 1 | 4 | 1 | 0 | 6 | 0.07 | 4.92 | 4.85 | 1.24 |
| 67 | Russell | 4 | 6 | 4 | 0 | 14 | 0.40 | 12.05 | 11.65 | 1.20 |
| 83 | Dickenson | 5 | 15 | 10 | 1 | 31 | 3.68 | 30.83 | 27.15 | 1.14 |
| 83 | Buchanan | 2 | 17 | 7 | 6 | 32 | 32.29 | 61.10 | 28.81 | 1.11 |
| 71 | Russell | 1 | 8 | 3 | 2 | 14 | 19.31 | 32.42 | 13.11 | 1.07 |
| 75 | Washington | 1 | 4 | 1 | 0 | 6 | 2.09 | 8.08 | 5.99 | 1.00 |
| **Culpeper** | | | | | | | | | | |
| 53 | Albemarle | 4 | 10 | 23 | 0 | 37 | 0.00 | 9.39 | 9.39 | 3.94 |
| 50 | Fauquier | 3 | 4 | 6 | 0 | 13 | 37.69 | 43.68 | 5.99 | 2.17 |
| 211 | Rappahannock | 4 | 7 | 3 | 0 | 14 | 24.66 | 31.14 | 6.48 | 2.16 |
| 28 | Fauquier | 7 | 5 | 11 | 0 | 23 | 1.80 | 13.58 | 11.78 | 1.95 |
| 22 | Albemarle | 3 | 1 | 8 | 1 | 13 | 0.03 | 8.67 | 8.64 | 1.50 |
| 229 | Culpeper | 0 | 10 | 3 | 1 | 14 | 3.20 | 14.71 | 11.51 | 1.22 |
| 22 | Louisa | 4 | 13 | 2 | 3 | 22 | 9.68 | 28.80 | 19.12 | 1.15 |
| 20 | Albemarle | 7 | 10 | 18 | 0 | 35 | 19.96 | 53.63 | 33.67 | 1.04 |
| 15 | Fluvanna | 3 | 10 | 4 | 0 | 17 | 101.55 | 118.33 | 16.78 | 1.01 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fredericksburg** | | | | | | | | | | |
| 30 | Caroline | 1 | 6 | 5 | 0 | 12 | 2.30 | 7.25 | 4.95 | 2.42 |
| 1 | Spotsylvania | 4 | 13 | 3 | 2 | 22 | 133.31 | 143.20 | 9.89 | 2.22 |
| 208 | Spotsylvania | 3 | 12 | 6 | 3 | 24 | 30.93 | 43.16 | 12.23 | 1.96 |
| 216 | Gloucester | 2 | 2 | 2 | 0 | 6 | 0.10 | 3.61 | 3.51 | 1.71 |
| 1 | Stafford | 5 | 12 | 7 | 0 | 24 | 148.66 | 163.69 | 15.03 | 1.60 |
| 218 | Stafford | 4 | 5 | 1 | 1 | 11 | 0.01 | 7.21 | 7.20 | 1.53 |
| 2 | Caroline | 0 | 10 | 4 | 0 | 14 | 34.36 | 45.02 | 10.66 | 1.31 |
| 17 | Caroline | 2 | 5 | 0 | 0 | 7 | 157.25 | 162.95 | 5.70 | 1.23 |
| 198 | Mathews | 1 | 3 | 2 | 1 | 7 | 13.46 | 19.20 | 5.74 | 1.22 |
| 3 | King George | 0 | 5 | 0 | 2 | 7 | 55.12 | 61.19 | 6.07 | 1.15 |
| 3 | Westmoreland | 3 | 13 | 4 | 0 | 20 | 65.40 | 84.94 | 19.54 | 1.02 |
| **Hampton Roads** | | | | | | | | | | |
| 460 | Suffolk | 1 | 2 | 5 | 0 | 8 | 0.76 | 2.55 | 1.79 | 4.47 |
| 337 | Suffolk | 3 | 11 | 15 | 3 | 32 | 2.08 | 12.68 | 10.60 | 3.02 |
| 13 | Suffolk | 0 | 19 | 8 | 5 | 32 | 0.33 | 13.08 | 12.75 | 2.51 |
| 10 | Isle of Wight | 1 | 12 | 1 | 0 | 14 | 66.18 | 72.78 | 6.60 | 2.12 |
| 238 | York | 1 | 3 | 4 | 0 | 8 | 3.12 | 7.13 | 4.01 | 2.00 |
| 10 | Suffolk | 0 | 5 | 6 | 3 | 14 | 83.24 | 91.25 | 8.01 | 1.75 |
| 125 | Suffolk | 0 | 3 | 4 | 1 | 8 | 0.47 | 5.51 | 5.04 | 1.59 |
| 258 | Southampton | 1 | 6 | 3 | 1 | 11 | 0.18 | 8.74 | 8.56 | 1.29 |
| 175 | Accomack | 1 | 3 | 3 | 2 | 9 | 0.30 | 7.92 | 7.62 | 1.18 |
| 173 | York | 0 | 2 | 4 | 1 | 7 | 4.46 | 10.57 | 6.11 | 1.15 |
| 258 | Isle of Wight | 1 | 21 | 2 | 4 | 28 | 13.68 | 38.83 | 25.15 | 1.11 |
| **Lynchburg** | | | | | | | | | | |
| 20 | Buckingham | 2 | 7 | 3 | 3 | 15 | 0.50 | 8.30 | 7.80 | 1.92 |
| 60 | Cumberland | 3 | 12 | 3 | 0 | 18 | 135.83 | 150.35 | 14.52 | 1.24 |
| 15 | Prince Edward | 3 | 9 | 3 | 1 | 16 | 44.40 | 57.41 | 13.01 | 1.23 |
| 40 | Pittsylvania | 1 | 17 | 9 | 2 | 29 | 50.83 | 74.43 | 23.60 | 1.23 |
| **Northern Virginia** | | | | | | | | | | |
| 193 | Fairfax | 19 | 13 | 29 | 1 | 62 | 1.14 | 8.69 | 7.55 | 8.21 |
| 1 | Fairfax | 14 | 3 | 23 | 1 | 41 | 178.22 | 186.88 | 8.66 | 4.73 |
| 1 | Prince William | 12 | 8 | 11 | 1 | 32 | 165.67 | 176.48 | 10.81 | 2.96 |
| 50 | Loudoun | 2 | 9 | 10 | 0 | 21 | 46.81 | 55.27 | 8.46 | 2.48 |
| 9 | Loudoun | 5 | 10 | 12 | 2 | 29 | 0.26 | 12.52 | 12.26 | 2.37 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 244 | Arlington | 7 | 2 | 4 | 0 | 13 | 0.10 | 7.08 | 6.98 | 1.86 |
| 234 | Prince William | 13 | 9 | 30 | 0 | 52 | 0.06 | 31.44 | 31.38 | 1.66 |
| 215 | Prince William | 1 | 4 | 1 | 0 | 6 | 3.06 | 7.60 | 4.54 | 1.32 |
| 28 | Prince William | 6 | 1 | 10 | 0 | 17 | 14.00 | 27.07 | 13.07 | 1.30 |
| 123 | Fairfax | 7 | 11 | 17 | 1 | 36 | 0.01 | 28.86 | 28.85 | 1.25 |
| 15 | Prince William | 3 | 3 | 4 | 1 | 11 | 192.76 | 202.28 | 9.52 | 1.16 |
| 29 | Fairfax | 11 | 3 | 4 | 0 | 18 | 223.43 | 239.01 | 15.58 | 1.16 |
| 55 | Prince William | 3 | 2 | 1 | 0 | 6 | 59.75 | 64.99 | 5.24 | 1.15 |
| 15 | Loudoun | 4 | 6 | 18 | 0 | 28 | 204.37 | 230.68 | 26.31 | 1.06 |
| **Richmond** | | | | | | | | | | |
| 33 | Henrico | 10 | 5 | 7 | 0 | 22 | 3.97 | 9.59 | 5.62 | 3.91 |
| 145 | Chesterfield | 2 | 2 | 9 | 0 | 13 | 0.82 | 5.01 | 4.19 | 3.10 |
| 60 | Powhatan | 1 | 7 | 6 | 1 | 15 | 151.42 | 159.32 | 7.90 | 1.90 |
| 13 | Powhatan | 1 | 11 | 4 | 0 | 16 | 13.30 | 22.56 | 9.26 | 1.73 |
| 144 | Chesterfield | 1 | 2 | 6 | 0 | 9 | 7.50 | 13.48 | 5.98 | 1.51 |
| 307 | Nottoway | 1 | 6 | 0 | 0 | 7 | 2.89 | 7.68 | 4.79 | 1.46 |
| 153 | Nottoway | 0 | 7 | 0 | 0 | 7 | 0.50 | 5.48 | 4.98 | 1.41 |
| 157 | Henrico | 4 | 2 | 1 | 0 | 7 | 1.45 | 6.59 | 5.14 | 1.36 |
| 153 | Amelia | 1 | 2 | 2 | 1 | 6 | 11.83 | 16.65 | 4.82 | 1.24 |
| 36 | Chesterfield | 3 | 0 | 3 | 1 | 7 | 0.06 | 5.81 | 5.75 | 1.22 |
| 522 | Powhatan | 1 | 3 | 2 | 1 | 7 | 0.32 | 6.64 | 6.32 | 1.11 |
| 522 | Goochland | 0 | 3 | 4 | 1 | 8 | 8.90 | 16.52 | 7.62 | 1.05 |
| **Salem** | | | | | | | | | | |
| 108 | Henry | 3 | 1 | 2 | 0 | 6 | 2.25 | 4.24 | 1.99 | 3.02 |
| 220 | Henry | 4 | 3 | 3 | 0 | 10 | 6.54 | 10.01 | 3.47 | 2.88 |
| 87 | Henry | 1 | 4 | 1 | 0 | 6 | 0.02 | 2.47 | 2.45 | 2.45 |
| 221 | Carroll | 0 | 8 | 2 | 0 | 10 | 33.25 | 37.69 | 4.44 | 2.25 |
| 100 | Giles | 1 | 3 | 2 | 0 | 6 | 36.89 | 39.92 | 3.03 | 1.98 |
| 122 | Franklin | 5 | 10 | 4 | 2 | 21 | 1.76 | 15.89 | 14.13 | 1.49 |
| 8 | Montgomery | 3 | 4 | 5 | 0 | 12 | 45.82 | 54.20 | 8.38 | 1.43 |
| 311 | Craig | 2 | 16 | 1 | 2 | 21 | 13.43 | 30.15 | 16.72 | 1.26 |
| 501 | Bedford | 3 | 3 | 5 | 2 | 13 | 84.56 | 94.94 | 10.38 | 1.25 |
| 100 | Carroll | 0 | 5 | 1 | 2 | 8 | 0.71 | 7.61 | 6.90 | 1.16 |
| 58 | Carroll | 0 | 9 | 3 | 0 | 12 | 206.81 | 217.42 | 10.61 | 1.13 |
| 221 | Roanoke | 7 | 7 | 4 | 1 | 19 | 79.82 | 96.80 | 16.98 | 1.12 |
| 24 | Bedford | 5 | 22 | 1 | 3 | 31 | 9.73 | 37.45 | 27.72 | 1.12 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Botetourt | 0 | 6 | 2 | 0 | 8 | 165.76 | 173.06 | 7.30 | 1.10 |
| 52 | Carroll | 8 | 13 | 5 | 2 | 28 | 0.23 | 27.07 | 26.84 | 1.04 |
| 58 | Patrick | 1 | 7 | 3 | 2 | 13 | 224.33 | 237.05 | 12.72 | 1.02 |
| **Staunton** | | | | | | | | | | |
| 50 | Frederick | 0 | 3 | 3 | 0 | 6 | 0.42 | 2.31 | 1.89 | 3.17 |
| 211 | Shenandoah | 0 | 6 | 0 | 1 | 7 | 2.60 | 5.13 | 2.53 | 2.77 |
| 42 | Shenandoah | 2 | 6 | 1 | 0 | 9 | 265.24 | 270.45 | 5.21 | 1.73 |
| 340 | Warren | 1 | 6 | 8 | 0 | 15 | 84.04 | 92.77 | 8.73 | 1.72 |
| 55 | Warren | 3 | 11 | 5 | 1 | 20 | 19.37 | 35.57 | 16.20 | 1.23 |
| 33 | Rockingham | 4 | 10 | 6 | 2 | 22 | 0.75 | 19.08 | 18.33 | 1.20 |

Table B-2. COCL Crashes on Secondary Route Sections in Counties/Districts with >1 crash/mi

| Route No. | County | HO | FO ROTR | SW-OD | NON-CO | Total | MP Begin | MP End | Total Mi. | Crash/ Mi. |
|---|---|---|---|---|---|---|---|---|---|---|
| **Bristol** | | | | | | | | | | |
| 642 | Lee | 1 | 6 | 2 | 0 | 9 | 3.82 | 5.66 | 1.84 | 4.89 |
| 645 | Buchanan | 2 | 2 | 1 | 2 | 7 | 1.59 | 3.19 | 1.60 | 4.38 |
| 680 | Buchanan | 0 | 11 | 4 | 1 | 16 | 0.3 | 4.6 | 4.30 | 3.72 |
| 706 | Wise | 0 | 4 | 2 | 0 | 6 | 6.89 | 9.12 | 2.23 | 2.69 |
| 640 | Washington | 1 | 5 | 3 | 1 | 10 | 0.5 | 4.29 | 3.79 | 2.64 |
| 627 | Tazewell | 0 | 5 | 3 | 0 | 8 | 0.2 | 3.3 | 3.10 | 2.58 |
| 624 | Buchanan | 3 | 3 | 7 | 0 | 13 | 2.6 | 8.04 | 5.44 | 2.39 |
| 642 | Buchanan | 1 | 0 | 6 | 0 | 7 | 0.2 | 3.6 | 3.40 | 2.06 |
| 643 | Buchanan | 3 | 12 | 11 | 2 | 28 | 0.06 | 13.92 | 13.86 | 2.02 |
| 646 | Buchanan | 0 | 5 | 1 | 0 | 6 | 2.88 | 5.88 | 3.00 | 2.00 |
| 803 | Washington | 0 | 5 | 1 | 0 | 6 | 0.05 | 3.1 | 3.05 | 1.97 |
| 645 | Washington | 1 | 11 | 2 | 0 | 14 | 0.43 | 8 | 7.57 | 1.85 |
| 647 | Washington | 1 | 11 | 3 | 0 | 15 | 0.88 | 9.21 | 8.33 | 1.80 |
| 616 | Russell | 0 | 6 | 0 | 0 | 6 | 3.75 | 7.44 | 3.69 | 1.63 |
| 652 | Dickenson | 2 | 7 | 1 | 0 | 10 | 0.53 | 7.01 | 6.48 | 1.54 |
| 609 | Washington | 0 | 10 | 1 | 0 | 11 | 0.18 | 8 | 7.82 | 1.41 |
| 638 | Buchanan | 2 | 9 | 7 | 0 | 18 | 5.09 | 18.8 | 13.71 | 1.31 |
| 624 | Russell | 1 | 5 | 2 | 0 | 8 | 0.25 | 6.57 | 6.32 | 1.27 |
| 606 | Bland | 2 | 7 | 3 | 1 | 13 | 0.35 | 10.98 | 10.63 | 1.22 |
| 631 | Dickenson | 0 | 5 | 0 | 1 | 6 | 1.06 | 6.13 | 5.07 | 1.18 |
| 620 | Buchanan | 1 | 1 | 2 | 2 | 6 | 10.35 | 15.59 | 5.24 | 1.15 |
| **Culpeper** | | | | | | | | | | |
| 620 | Albemarle | 2 | 3 | 5 | 0 | 10 | 1.91 | 5.71 | 3.80 | 2.63 |
| 631 | Albemarle | 5 | 4 | 3 | 0 | 12 | 8.64 | 15.16 | 6.52 | 1.84 |
| 601 | Albemarle | 1 | 4 | 3 | 0 | 8 | 3.08 | 7.77 | 4.69 | 1.71 |
| 743 | Albemarle | 5 | 5 | 7 | 0 | 17 | 0 | 10.79 | 10.79 | 1.58 |
| 676 | Albemarle | 2 | 4 | 2 | 0 | 8 | 3.36 | 8.84 | 5.48 | 1.46 |
| 729 | Culpeper | 0 | 4 | 3 | 0 | 7 | 0.2 | 6.09 | 5.89 | 1.19 |
| **Fredericksburg** | | | | | | | | | | |
| 620 | Spotsylvania | 3 | 8 | 4 | 1 | 16 | 8.77 | 13.3 | 4.53 | 3.53 |
| 639 | Spotsylvania | 3 | 10 | 6 | 0 | 19 | 0.89 | 7.01 | 6.12 | 3.10 |
| 607 | Stafford | 2 | 3 | 3 | 0 | 8 | 0 | 2.71 | 2.71 | 2.95 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 616 | Stafford | 1 | 11 | 6 | 2 | 20 | 0 | 7.49 | 7.49 | 2.67 |
| 610 | Stafford | 5 | 7 | 7 | 0 | 19 | 0.8 | 9.8 | 9.00 | 2.11 |
| 636 | Spotsylvania | 2 | 3 | 2 | 0 | 7 | 0.73 | 4.22 | 3.49 | 2.01 |
| 614 | Gloucester | 0 | 4 | 4 | 0 | 8 | 7.267 | 11.67 | 4.40 | 1.82 |
| 639 | Caroline | 2 | 12 | 2 | 2 | 18 | 0 | 10.17 | 10.17 | 1.77 |
| 627 | Stafford | 0 | 3 | 3 | 0 | 6 | 0 | 3.89 | 3.89 | 1.54 |
| 610 | Spotsylvania | 0 | 5 | 2 | 1 | 8 | 2.9 | 8.69 | 5.79 | 1.38 |
| 721 | Caroline | 0 | 7 | 1 | 0 | 8 | 0.85 | 8.51 | 7.66 | 1.04 |
| 606 | Spotsylvania | 1 | 7 | 3 | 0 | 11 | 9.2 | 20.05 | 10.85 | 1.01 |
| **Hampton Roads** | | | | | | | | | | |
| 688 | Suffolk | 0 | 2 | 5 | 0 | 7 | 1.88 | 2.98 | 1.10 | 6.36 |
| 620 | York | 0 | 6 | 3 | 0 | 9 | 0.02 | 1.56 | 1.54 | 5.84 |
| 600 | York | 0 | 3 | 5 | 1 | 9 | 0.1 | 2.12 | 2.02 | 4.46 |
| 669 | Isle of Wight | 0 | 7 | 4 | 1 | 12 | 0.5 | 4.34 | 3.84 | 3.13 |
| 665 | Isle of Wight | 0 | 8 | 1 | 1 | 10 | 1.66 | 5.28 | 3.62 | 2.76 |
| 679 | Accomack | 0 | 3 | 2 | 1 | 6 | 15.62 | 18.42 | 2.80 | 2.14 |
| 627 | Suffolk | 1 | 2 | 3 | 1 | 7 | 0.7 | 4.77 | 4.07 | 1.72 |
| **Lynchburg** | | | | | | | | | | |
| 844 | Pittsylvania | 0 | 5 | 0 | 1 | 6 | 0.01 | 0.89 | 0.88 | 6.82 |
| 685 | Campbell | 0 | 6 | 1 | 0 | 7 | 0.3 | 3 | 2.70 | 2.59 |
| 664 | Nelson | 0 | 6 | 0 | 2 | 8 | 0.1 | 3.43 | 3.33 | 2.40 |
| 680 | Campbell | 1 | 4 | 1 | 0 | 6 | 0 | 2.85 | 2.85 | 2.11 |
| 683 | Campbell | 0 | 4 | 2 | 1 | 7 | 3.99 | 9.17 | 5.18 | 1.35 |
| 682 | Campbell | 1 | 9 | 2 | 0 | 12 | 9.58 | 18.51 | 8.93 | 1.34 |
| 726 | Pittsylvania | 0 | 12 | 0 | 0 | 12 | 3.43 | 12.56 | 9.13 | 1.31 |
| 622 | Campbell | 3 | 9 | 1 | 1 | 14 | 0.09 | 10.94 | 10.85 | 1.29 |
| 750 | Pittsylvania | 3 | 13 | 4 | 2 | 22 | 0.12 | 17.6 | 17.48 | 1.26 |
| 729 | Pittsylvania | 0 | 8 | 0 | 3 | 11 | 1.78 | 10.82 | 9.04 | 1.22 |
| 703 | Pittsylvania | 2 | 7 | 1 | 1 | 11 | 4.25 | 14.57 | 10.32 | 1.07 |
| **Northern Virginia** | | | | | | | | | | |
| 702 | Fairfax | 3 | 2 | 5 | 0 | 10 | 0 | 0.66 | 0.66 | 15.15 |
| 723 | Fairfax | 2 | 5 | 6 | 0 | 13 | 0.39 | 1.25 | 0.86 | 15.12 |
| 634 | Fairfax | 1 | 2 | 4 | 0 | 7 | 0.37 | 1 | 0.63 | 11.11 |
| 639 | Prince William | 2 | 3 | 3 | 1 | 9 | 0.42 | 1.44 | 1.02 | 8.82 |
| 906 | Prince William | 6 | 1 | 1 | 0 | 8 | 0 | 1.1 | 1.10 | 7.27 |
| 790 | Fairfax | 2 | 4 | 1 | 0 | 7 | 0.5 | 1.55 | 1.05 | 6.67 |
| 636 | Fairfax | 1 | 5 | 3 | 0 | 9 | 1.21 | 2.57 | 1.36 | 6.62 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1401 | Loudoun | 3 | 0 | 3 | 0 | 6 | 0.03 | 0.94 | 0.91 | 6.59 |
| 642 | Fairfax | 4 | 4 | 7 | 0 | 15 | 0.04 | 2.8 | 2.76 | 5.43 |
| 633 | Fairfax | 4 | 3 | 2 | 0 | 9 | 0.01 | 1.88 | 1.87 | 4.81 |
| 649 | Fairfax | 6 | 2 | 6 | 0 | 14 | 1.03 | 4.01 | 2.98 | 4.70 |
| 775 | Loudoun | 0 | 2 | 4 | 0 | 6 | 0.38 | 1.69 | 1.31 | 4.58 |
| 637 | Loudoun | 0 | 2 | 4 | 0 | 6 | 0.67 | 2.04 | 1.37 | 4.38 |
| 1279 | Prince William | 4 | 1 | 2 | 0 | 7 | 1.08 | 2.68 | 1.60 | 4.38 |
| 657 | Fairfax | 10 | 6 | 13 | 2 | 31 | 0.2 | 8.36 | 8.16 | 3.80 |
| 660 | Fairfax | 1 | 6 | 1 | 0 | 8 | 0.83 | 3.08 | 2.25 | 3.56 |
| 650 | Fairfax | 10 | 7 | 8 | 0 | 25 | 0.01 | 7.49 | 7.48 | 3.34 |
| 681 | Fairfax | 2 | 5 | 5 | 0 | 12 | 0.01 | 3.72 | 3.71 | 3.23 |
| 638 | Fairfax | 2 | 7 | 5 | 0 | 14 | 0.5 | 5.14 | 4.64 | 3.02 |
| 1530 | Prince William | 4 | 0 | 2 | 0 | 6 | 0.29 | 2.28 | 1.99 | 3.02 |
| 608 | Fairfax | 3 | 3 | 10 | 0 | 16 | 1.34 | 7.61 | 6.27 | 2.55 |
| 621 | Fairfax | 2 | 1 | 4 | 0 | 7 | 2 | 4.75 | 2.75 | 2.55 |
| 665 | Fairfax | 6 | 4 | 6 | 2 | 18 | 2.82 | 9.93 | 7.11 | 2.53 |
| 695 | Fairfax | 6 | 4 | 6 | 0 | 16 | 1.09 | 7.49 | 6.40 | 2.50 |
| 643 | Fairfax | 8 | 7 | 3 | 1 | 19 | 2.74 | 10.59 | 7.85 | 2.42 |
| 674 | Fairfax | 4 | 7 | 13 | 0 | 24 | 0.7 | 10.8 | 10.10 | 2.38 |
| 658 | Fairfax | 3 | 3 | 3 | 1 | 10 | 0.04 | 4.25 | 4.21 | 2.38 |
| 640 | Prince William | 9 | 1 | 7 | 0 | 17 | 0.66 | 8.05 | 7.39 | 2.30 |
| 738 | Fairfax | 2 | 2 | 3 | 0 | 7 | 1.54 | 4.82 | 3.28 | 2.13 |
| 617 | Fairfax | 5 | 4 | 9 | 0 | 18 | 0.26 | 9.24 | 8.98 | 2.00 |
| 652 | Fairfax | 3 | 3 | 4 | 0 | 10 | 0 | 5.14 | 5.14 | 1.95 |
| 612 | Fairfax | 2 | 11 | 4 | 0 | 17 | 0.39 | 9.17 | 8.78 | 1.94 |
| 675 | Fairfax | 3 | 2 | 8 | 0 | 13 | 1.33 | 8.21 | 6.88 | 1.89 |
| 655 | Fairfax | 3 | 3 | 1 | 0 | 7 | 0.77 | 4.52 | 3.75 | 1.87 |
| 629 | Fairfax | 2 | 3 | 4 | 0 | 9 | 0.95 | 5.8 | 4.85 | 1.86 |
| 694 | Fairfax | 5 | 2 | 2 | 0 | 9 | 1.08 | 6.03 | 4.95 | 1.82 |
| 621 | Prince William | 2 | 1 | 5 | 0 | 8 | 0.2 | 4.62 | 4.42 | 1.81 |
| 674 | Prince William | 4 | 2 | 0 | 1 | 7 | 2.39 | 6.3 | 3.91 | 1.79 |
| 643 | Prince William | 2 | 6 | 5 | 0 | 13 | 0.06 | 7.6 | 7.54 | 1.72 |
| 613 | Fairfax | 4 | 3 | 10 | 0 | 17 | 2.56 | 12.54 | 9.98 | 1.70 |
| 600 | Fairfax | 10 | 3 | 1 | 0 | 14 | 0.72 | 9.27 | 8.55 | 1.64 |
| 789 | Fairfax | 1 | 0 | 5 | 0 | 6 | 0 | 4.1 | 4.10 | 1.46 |
| 606 | Loudoun | 0 | 2 | 3 | 1 | 6 | 0.89 | 5.11 | 4.22 | 1.42 |
| 673 | Fairfax | 1 | 5 | 3 | 0 | 9 | 0.81 | 7.15 | 6.34 | 1.42 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 603 | Fairfax | 1 | 3 | 4 | 0 | 8 | 1.55 | 7.31 | 5.76 | 1.39 |
| 646 | Prince William | 6 | 6 | 3 | 0 | 15 | 0.32 | 11.16 | 10.84 | 1.38 |
| 619 | Prince William | 8 | 10 | 11 | 1 | 30 | 4.31 | 27.11 | 22.80 | 1.32 |
| 611 | Fairfax | 5 | 6 | 9 | 0 | 20 | 0.11 | 16.21 | 16.10 | 1.24 |
| 641 | Fairfax | 3 | 1 | 4 | 1 | 9 | 3.58 | 11.73 | 8.15 | 1.10 |
| 620 | Fairfax | 6 | 6 | 7 | 0 | 19 | 4.01 | 22.09 | 18.08 | 1.05 |
| **Richmond** | | | | | | | | | | |
| 718 | Chesterfield | 4 | 1 | 0 | 2 | 7 | 1.03 | 1.34 | 0.31 | 22.58 |
| 638 | Chesterfield | 4 | 5 | 5 | 0 | 14 | 3.17 | 5.84 | 2.67 | 5.24 |
| 641 | Chesterfield | 7 | 3 | 6 | 0 | 16 | 0.34 | 4.49 | 4.15 | 3.86 |
| 616 | Chesterfield | 0 | 3 | 3 | 0 | 6 | 1.61 | 3.21 | 1.60 | 3.75 |
| 649 | Chesterfield | 1 | 10 | 2 | 0 | 13 | 0.25 | 4.3 | 4.05 | 3.21 |
| 714 | Chesterfield | 0 | 3 | 4 | 0 | 7 | 0 | 2.79 | 2.79 | 2.51 |
| 620 | Chesterfield | 3 | 2 | 1 | 0 | 6 | 0.38 | 2.9 | 2.52 | 2.38 |
| 647 | Chesterfield | 5 | 4 | 3 | 0 | 12 | 0.27 | 6.09 | 5.82 | 2.06 |
| 653 | Chesterfield | 5 | 6 | 3 | 0 | 14 | 5.83 | 12.76 | 6.93 | 2.02 |
| 626 | Chesterfield | 1 | 2 | 5 | 1 | 9 | 7.36 | 11.94 | 4.58 | 1.97 |
| 651 | Chesterfield | 4 | 1 | 6 | 3 | 14 | 0.13 | 8.21 | 8.08 | 1.73 |
| 688 | Mecklenburg | 0 | 6 | 1 | 0 | 7 | 8.04 | 12.35 | 4.31 | 1.62 |
| 637 | Chesterfield | 3 | 3 | 3 | 0 | 9 | 0.35 | 5.98 | 5.63 | 1.60 |
| 623 | Goochland | 3 | 3 | 3 | 0 | 9 | 0.2 | 5.87 | 5.67 | 1.59 |
| 678 | Chesterfield | 5 | 1 | 3 | 1 | 10 | 1.38 | 7.73 | 6.35 | 1.57 |
| 654 | Chesterfield | 0 | 4 | 2 | 0 | 6 | 7.05 | 11.02 | 3.97 | 1.51 |
| 604 | Chesterfield | 4 | 9 | 9 | 2 | 24 | 0.82 | 16.81 | 15.99 | 1.50 |
| 711 | Powhatan | 2 | 12 | 3 | 2 | 19 | 0.5 | 14.03 | 13.53 | 1.40 |
| **Salem** | | | | | | | | | | |
| 689 | Roanoke | 1 | 2 | 4 | 0 | 7 | 1.32 | 1.91 | 0.59 | 11.86 |
| 615 | Montgomery | 1 | 7 | 2 | 1 | 11 | 0.23 | 1.54 | 1.31 | 8.40 |
| 658 | Montgomery | 0 | 9 | 4 | 1 | 14 | 0.01 | 2.96 | 2.95 | 4.75 |
| 642 | Montgomery | 1 | 3 | 2 | 0 | 6 | 1.32 | 2.82 | 1.50 | 4.00 |
| 652 | Montgomery | 3 | 2 | 1 | 0 | 6 | 5.62 | 7.2 | 1.58 | 3.80 |
| 688 | Roanoke | 1 | 4 | 1 | 0 | 6 | 0.2 | 2.68 | 2.48 | 2.42 |
| 684 | Henry | 0 | 5 | 0 | 3 | 8 | 1.07 | 4.82 | 3.75 | 2.13 |
| 697 | Franklin | 0 | 4 | 2 | 1 | 7 | 5.39 | 8.88 | 3.49 | 2.01 |
| 643 | Pulaski | 0 | 6 | 0 | 0 | 6 | 1.7 | 4.75 | 3.05 | 1.97 |
| 609 | Henry | | 7 | 4 | 0 | 12 | 0.6 | 6.85 | 6.25 | 1.92 |
| 603 | Montgomery | 5 | 13 | 3 | 2 | 23 | 0.48 | 13.61 | 13.13 | 1.75 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 670 | Franklin | 2 | 7 | 2 | 0 | 11 | 1.44 | 7.81 | 6.37 | 1.73 |
| 721 | Carroll | 2 | 3 | 0 | 1 | 6 | 0.2 | 3.7 | 3.50 | 1.71 |
| 611 | Pulaski | 0 | 4 | 2 | 2 | 8 | 1.46 | 6.16 | 4.70 | 1.70 |
| 785 | Montgomery | 0 | 3 | 2 | 1 | 6 | 0.81 | 4.75 | 3.94 | 1.52 |
| 600 | Pulaski | 1 | 4 | 1 | 0 | 6 | 1.29 | 5.25 | 3.96 | 1.52 |
| 730 | Giles | 1 | 5 | 3 | 0 | 9 | 4.48 | 10.45 | 5.97 | 1.51 |
| 637 | Montgomery | 0 | 5 | 1 | 0 | 6 | 1.83 | 5.81 | 3.98 | 1.51 |
| 634 | Bedford | 2 | 2 | 2 | 1 | 7 | 0.02 | 4.88 | 4.86 | 1.44 |
| 684 | Franklin | 0 | 6 | 0 | 0 | 6 | 1.57 | 5.97 | 4.40 | 1.36 |
| 757 | Bedford | 1 | 6 | 5 | 1 | 13 | 0.1 | 9.96 | 9.86 | 1.32 |
| 687 | Henry | 0 | 15 | 3 | 1 | 19 | 2.53 | 18.83 | 16.30 | 1.17 |
| 674 | Henry | 1 | 3 | 3 | 0 | 7 | 0.4 | 6.83 | 6.43 | 1.09 |
| **Staunton** | | | | | | | | | | |
| 910 | Rockingham | 1 | 3 | 1 | 1 | 6 | 0.85 | 1.99 | 1.14 | 5.26 |
| 644 | Rockingham | 2 | 2 | 2 | 0 | 6 | 2.3 | 3.5 | 1.20 | 5.00 |
| 710 | Rockbridge | 1 | 7 | 2 | 0 | 10 | 1.1 | 5.17 | 4.07 | 2.46 |
| 753 | Rockingham | 0 | 6 | 0 | 1 | 7 | 5.85 | 8.8 | 2.95 | 2.37 |
| 864 | Roanoke | 1 | 3 | 2 | 0 | 6 | 1.45 | 3.99 | 2.54 | 2.36 |
| 612 | Augusta | 2 | 10 | 4 | 0 | 16 | 7.18 | 15.42 | 8.24 | 1.94 |
| 602 | Rockingham | 2 | 6 | 0 | 3 | 11 | 0.5 | 7.56 | 7.06 | 1.56 |
| 662 | Augusta | 0 | 5 | 1 | 1 | 7 | 0.76 | 5.3 | 4.54 | 1.54 |
| 664 | Augusta | 0 | 10 | 2 | 0 | 12 | 2.44 | 11.05 | 8.61 | 1.39 |
| 659 | Rockingham | 2 | 6 | 2 | 0 | 10 | 0.89 | 8.75 | 7.86 | 1.27 |
| 608 | Augusta | 5 | 14 | 1 | 3 | 23 | 11.9 | 31.59 | 19.69 | 1.17 |

**Table B-3. COCL Crashes on Primary and Secondary Roads by Times/Seasons**

| Season | Time of Day | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | 0:00-3:00 | 3:00-6:00 | 6:00-9:00 | 9:00-12:00 | 12:00-15:00 | 15:00-18:00 | 18:00-21:00 | 21:00-24:00 | |
| **Primary Two-Lane Undivided Season by Time of Day 2001-2003** | | | | | | | | | |
| January-March | 82 | 88 | 178 | 158 | 166 | 163 | 147 | 122 | 1104 |
| April-June | 80 | 90 | 139 | 94 | 124 | 172 | 127 | 130 | 956 |
| July-September | 89 | 69 | 105 | 104 | 143 | 174 | 127 | 117 | 928 |
| October-December | 104 | 102 | 134 | 116 | 147 | 191 | 142 | 123 | 1059 |
| Total | 355 | 349 | 556 | 472 | 580 | 700 | 543 | 492 | 4047 |
| **Secondary Two-Lane Undivided Season by Time of Day 2001-2003** | | | | | | | | | |
| January-March | 105 | 82 | 192 | 164 | 156 | 204 | 181 | 175 | 1259 |
| April-June | 116 | 73 | 111 | 138 | 149 | 179 | 171 | 160 | 1097 |
| July-September | 119 | 83 | 98 | 110 | 162 | 219 | 160 | 190 | 1141 |
| October-December | 142 | 81 | 179 | 144 | 181 | 225 | 226 | 197 | 1375 |
| Total | 482 | 319 | 580 | 556 | 648 | 827 | 738 | 722 | 4872 |

## APPENDIX C
## GUIDELINES FOR THE USE OF CENTERLINE RUMBLE STRIPS

### Objective

The objective of these guidelines is to enhance safety on undivided, paved, primary and secondary highway systems in Virginia through the use of an effective and low-cost measure: centerline rumble strips (CLRS). These two road systems include all paved undivided multilane and two-lane highways in the state. The implementation of CLRS should reduce crashes related to crossing the centerline including head-on, sideswipe opposite direction, fixed object run-off-the-road left collisions, and non-collisions (run-off-the-road left).

### Application

1. CLRS should be considered as one countermeasure available in the toolbox of district traffic engineers to reduce crashes caused by vehicles crossing the centerline.

   - *Locations where studies by district or central office staff indicate an abnormally high number of cross over the centerline (COCL) crashes should be considered.* These may include road locations with sharp vertical and horizontal alignments, poor sight distance, etc. Locations with higher numbers of severe crashes resulting in injuries or fatalities should be prioritized. If centerlines are not present, TE Memorandum TE 251, Pavement Marking Policy, should be used to determine if pavement markings are appropriate.[1]

   - *Priority should be given to roads in the primary system because of the higher functional classification and service they provide in the road network.*

### Site-Specific Conditions

1. CLRS should be used only under certain conditions:

   - *On asphalt concrete pavements.*

   - *On roads at least 20 feet wide.*

   - *On roads with good structure and good pavement.* Pavement durability along the CLRS, especially if the CLRS is on the centerline joint, is a concern. A minimum depth of 3.5 in has been suggested for shoulders by VDOT Materials staff when shoulder rumble strips are being considered. The district pavement engineer should be consulted to verify that the pavement condition and structure are suitable for CLRS installation.

2. CLRS should not be used under certain conditions:

- *In passing zones, especially passing zones on two-lane roads.* However, if there are COCL crashes that are unrelated to passing maneuvers in a passing zone, a CLRS with a reduced depth of 3/8 inch may be considered.

- *On bridge decks.*

- *In narrow road sections without pavement markings.*

- *On subdivision streets.*

- *Within the limits of center two-way turn lanes.*

3. At locations where CLRS is being considered, the noise impact on adjacent residences should be taken into account. The frequency of noise caused by vehicles traversing CLRS is unknown.

4. On roads where bicycle use is frequent, the impact of vehicle-bicycle interaction should be considered in the decision on whether to install CLRS. Motorists often cross the centerline when passing a bicyclist riding to their right. When CLRS are present, motorist may tend to avoid the CLRS by not moving over to the left as far as they would otherwise. Thus, vehicles may be positioned closer to bicyclists as they are passing them

## Study

Reviewing sites with respect to these guidelines is in essence determining the feasibility of CLRS. The district traffic engineer should conduct a study and field review to verify that CLRS is an appropriate measure to implement based on the described application and site-specific conditions. The study should include the traffic volumes, posted speed, roadway geometry, adjacent land use, existing traffic control, and pavement condition. The study should include a benefit-cost analysis.[2]

## CLRS Design

VDOT's preferred CLRS design pattern is as follows: The pattern is milled. The groove specifications are 12 inches long, 7 inches wide, and 0.5 inch deep with a uniform interval or spacing of 12 inches. This design is shown in Figure C-1. Note the layout of CLRS with double-yellow line markings along the road center and, if present, raised pavement markers (RPMs). RPMs are present as an option only; the district traffic engineer is to decide on their use.

At the intersections of roads and commercial entrances, a gap or break in CLRS should be provided to allow for turning movements of vehicles. The size of the gap should be determined by the district traffic engineer for each location. Discontinuing the CLRS for the last 25 feet of pavement marking before the intersection should be typical so that turning vehicles are less likely to transverse the CLRS (see Figure C-2). At the discretion of the district traffic engineer, a break in CLRS may be considered for driveways.

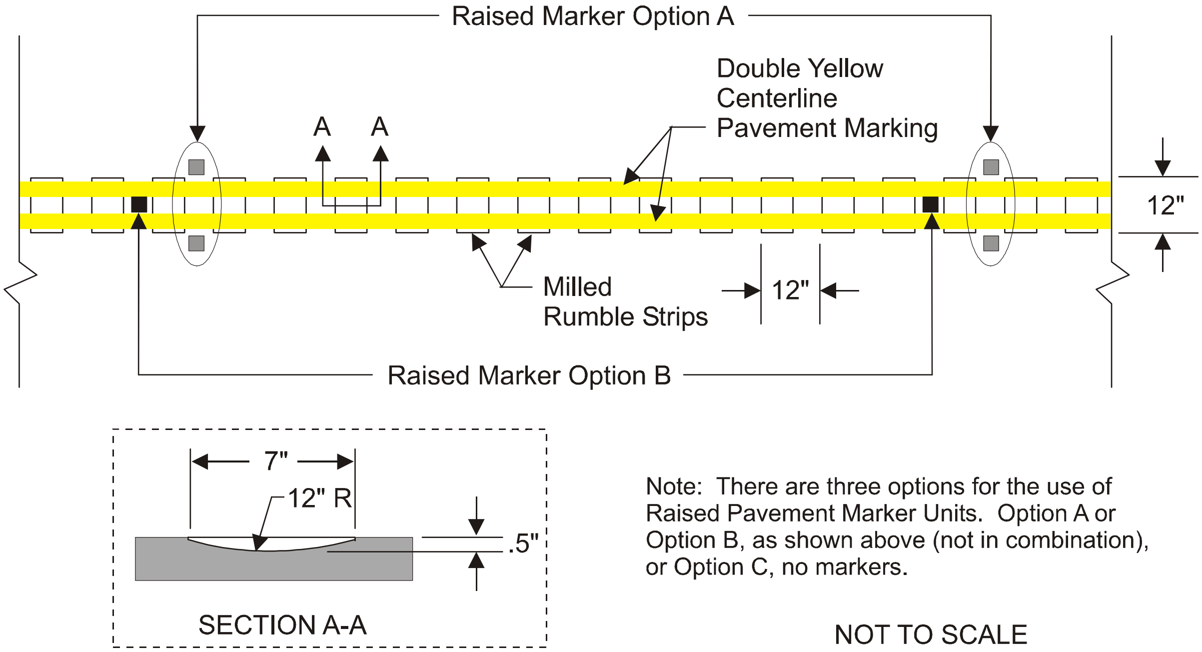


**Figure C-1. CLRS Design Criteria**

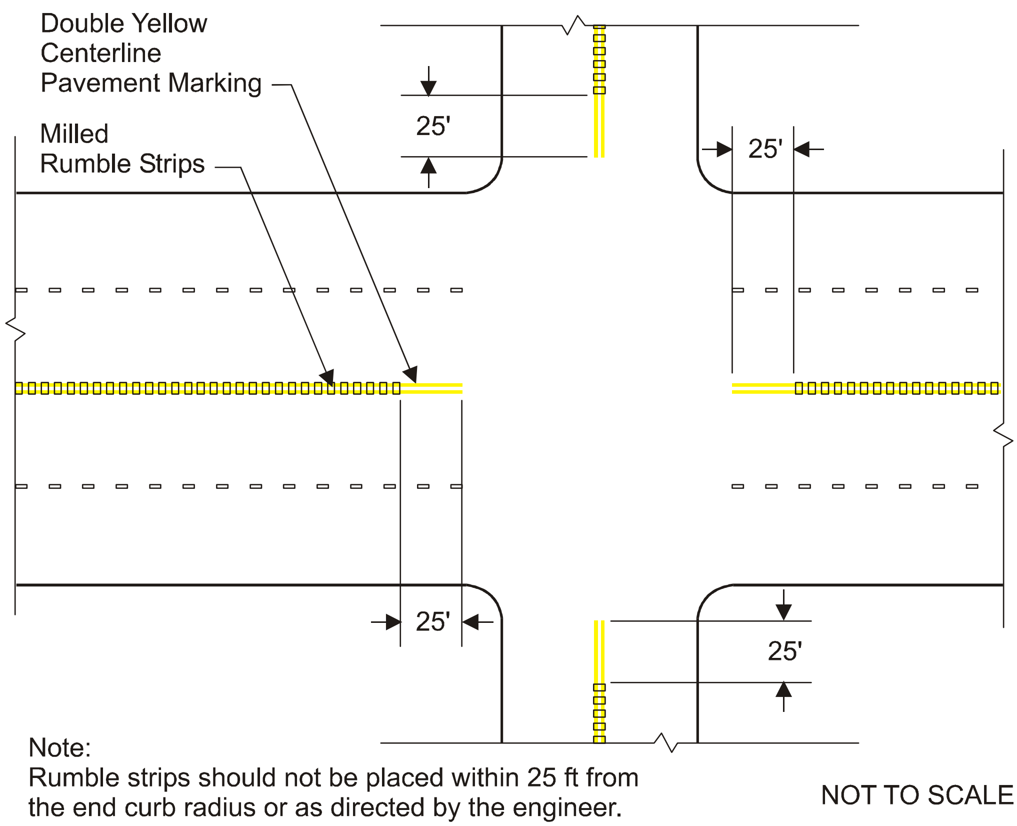


**Figure C-2. CLRS Breaks at Intersections**

### Installation and Maintenance

1. The installation and maintenance of the CLRS should be included as part of the regional contracts for shoulder rumble strip installation. This should provide the economies of scale for a lower cost.

2. The suggested sequence of CLRS installation is as follows: (1) prepare the temporary traffic control plan; (2) set up lane closures using the traffic control plan; (3) install the rumble strip; (4) vacuum and remove waste in cut areas; (5) apply asphalt sealant to vacuumed grooves [if RPMs are present, cover them before applying the sealant]; (6) after the sealant is dry, install double-yellow markings on the road centerline; (7) remove the covers on any RPMs (if present); and (8) remove temporary traffic control.

3. CLRS should be well maintained to ensure the function of reducing crashes. The grooves should be sealed periodically, depending on the condition of centerline markings as determined by the districts.

## REFERENCES


1. Virginia Department of Transportation, Traffic Engineering Division. 1994. *Traffic Engineering Memorandum TE-251: Pavement Marking Policy.* Richmond.

2. Chun, C.S., and Cottrell, B.H. 2005. *Guidelines for Centerline Rumble Strips in Virginia.* VTRC 05-R30. Virginia Transportation Research Council, Charlottesville.