Performance of Large Culverts in Virginia

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EXECUTIVE SUMMARY

In recent years Virginia has made a concerted effort to reduce the number of Structurally Deficient structures in the inventory of the Structure and Bridge Division (Inventory). A disproportionate number of the structures requiring replacement due to their structurally deficient (SD) status have been steel Large Culverts. The term "Large Culvert" applies to culverts that are large enough to be included in the Inventory, as defined in the current version of IIM-S&B27.

In order to better understand culvert performance on a statistical basis, VDOT conducted an analysis of the nearly 7,000 Large Culverts in the Inventory. The analysis determined the rates of deterioration rates of Large Culverts constructed with various material types and evaluated service life based on historical performance. The primary goal of the analysis was to provide an objective, mathematically-based understanding of the behavior of these structures and to inform future guidance regarding their rehabilitation or replacement.

The study also cataloged the number of structures replaced due to poor condition over the past five years. Of these structures, the majority had been in service for less than 50 years, and a significant number had been in service for less than 25 years. Finally, the study evaluated the performance of culverts built in the past 20 years to determine whether new technologies have provided improved performance.

Some of the more significant findings of the study are provided below:

- Steel culverts represented the vast majority of Large Culverts requiring condition-based replacement over the past five years. Over the past five years VDOT has replaced 101 SD Large Culverts. Ninety-nine of these structures were steel and two were concrete.
- Despite the above-noted recent effort to replace many structurally deficient steel Large Culverts, 8.4% of the current steel culverts are still structurally deficient, while 0.3% concrete Large Culverts are in poor condition.
- Of the Large Culverts introduced into the inventory of the Structure and Bridge Division over the past 20 years, the following percentages are SD:
    - Steel: 5.9%
    - Concrete: 0.0%
- Based on historical data, the average service life of Large Culverts was 75 years for concrete and 26 years for steel. Insufficient data were available to provide meaningful estimates of service life for aluminum culverts.

1.0 INTRODUCTION

This report summarizes the findings of a study of Large Culverts performed by VDOT to compare rates of deterioration for culverts constructed with different materials, anticipated service life based on historical data, and to recommend types of materials to be used in future culverts.

The term “Large Culvert” applies to culverts that are large enough to be included in the inventory of the Structure and Bridge Division (Inventory), as defined in the current version of IIM-S&B27. The key requirement for a Large Culvert is that the area of the opening(s) must exceed 36 square feet. Large Culverts include multiple box or pipe culverts meeting the opening requirements as long as the clear distance between openings is less than half of the smaller contiguous opening.

The analysis was performed in order to develop a statistical understanding of the service life performance of various material types when used for Large Culverts in Virginia. The study analyses the rates of deterioration rates of Large Culverts of various material types.

The study relied primarily on data in the Pontis database as of July 1, 2015, which contains detailed information on the nearly 7,000 Large Culverts in the Inventory. Data in the Pontis database include General Condition Ratings, Element Conditions States (collected in accordance with VDOT’s *Element Data Collection Manual*), and inventory data. The analysis of current data was supplemented with an investigation of structures recently removed or replaced in the previous 5 years (2011-2015) as well as an evaluation of structures built within the past 20years. Additional information was obtained when needed from recent safety inspection reports.

Durability and strength are more critical for Large Culverts than for smaller culverts because the consequences of poor performance are more significant with respect to safety, cost, traffic impact, and effects on the environment. Accordingly, VDOT has established separate standards for the two categories of culverts, with stricter requirements for the design and construction of Large Culverts. The greater significance of Large Culverts has also been acknowledged at the national level through FHWA’s definition of certain larger culverts as “bridges” for the purposes of the National Bridge Inventory (NBI). This definition necessitates greater performance and reliability with commensurately higher standards for inspection and design.

AASHTO LRFD Bridge Design Specifications require that new structures be designed for a Service Life of 75-years. VDOT has established a Performance Measure requiring that no more than 6.0% of structures (including Large Culverts) may be SD. Additionally, MAP 21 performance requirements limit the structurally deficient deck area of National Bridge Inventory (NBI) structures (including Large Culverts) to 10% for all states.

2.0 BACKGROUND

Some key definitions can be found in the Structure and Bridge Division Instructional and Informational Memorandum IIM S&B 27 and are also provided below:

> NBI: *"Abbreviation for "National Bridge Inventory." In the context of this memorandum when a structure is referred to as an NBI structure it meets the federal definition of a bridge as defined in the NBIS."*
>
> Non-NBI: *"A structure that does not meet the NBI definition above. Structures in this category include, but are not limited to, culverts that do not meet the NBI definition and have an opening equal to or greater than 36 square feet, bridges less than or equal to 20 feet between undercopings of abutments or between springlines of arches and structures which do not carry highway traffic (railroad structures, pedestrian structures, footbridges, etc.)."*
>
> Large Culvert: *"A culvert that either meets the definition of a Non-NBI structure in this IIM (IIM S&B 27) or a culvert that meets the definition of a structure as defined in Federal item 112 in the Recording and Coding Guide for the Structure Inventory and Appraisal of The Nation's Bridges."*
>
> Culvert: *"Any structure which has an integral floor system that supports the sidewalls and provides a lined channel. A culvert has no distinction between substructure and superstructure and typically has no deck. Multiple box or pipe culverts will be considered a single structure where the clear distance between openings is less than half of the smaller contiguous opening."*

VDOT inspects both NBI and Non-NBI Large Culverts in accordance with the requirements of the National Bridge Inspection Standards (NBIS). The inspection frequency for Large Culverts is prescribed in I&IM 27 as shown in Table A-1 in Appendix A.

Culverts are assigned a General Condition Rating (GCR) per Federal Item 62 of the VDOT Coding Manual dated 07/10/2015. Key excerpts from the above manual are below.

> GCR: *Condition ratings are used to describe the existing, in-place bridge as compared to the as-built condition. Evaluation is for the materials related, physical condition of the deck, superstructure and substructure components of a bridge. The condition evaluation of channels and channel protection and culverts is also included. Condition codes are properly used when they provide an overall characterization of the general condition of the entire component being rated. Conversely, they are improperly used if they attempt to describe localized or nominally occurring instances of deterioration or disrepair. Correct assignment of a condition code must, therefore, consider both the severity of the deterioration or disrepair and the extent to which it is widespread throughout the component being rated.*
>
> Culvert GCR: *"This item evaluates the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. The rating code is intended to be an overall condition evaluation of the culvert. Integral wingwalls to the first construction or*

expansion joint shall be included in the evaluation. For a detailed discussion regarding the inspection and rating of culverts, consult Report No. FHWA-IP-2, Culvert Inspection Manual, July 1986."

GCRs are assigned to each Large Culvert during structure safety inspections using a scale of 9 to 0. The definitions of the 10 GCR designations are provided in Table A-2 of Appendix A. VDOT groups structures into condition categories of Good, Fair and Poor as indicated below:

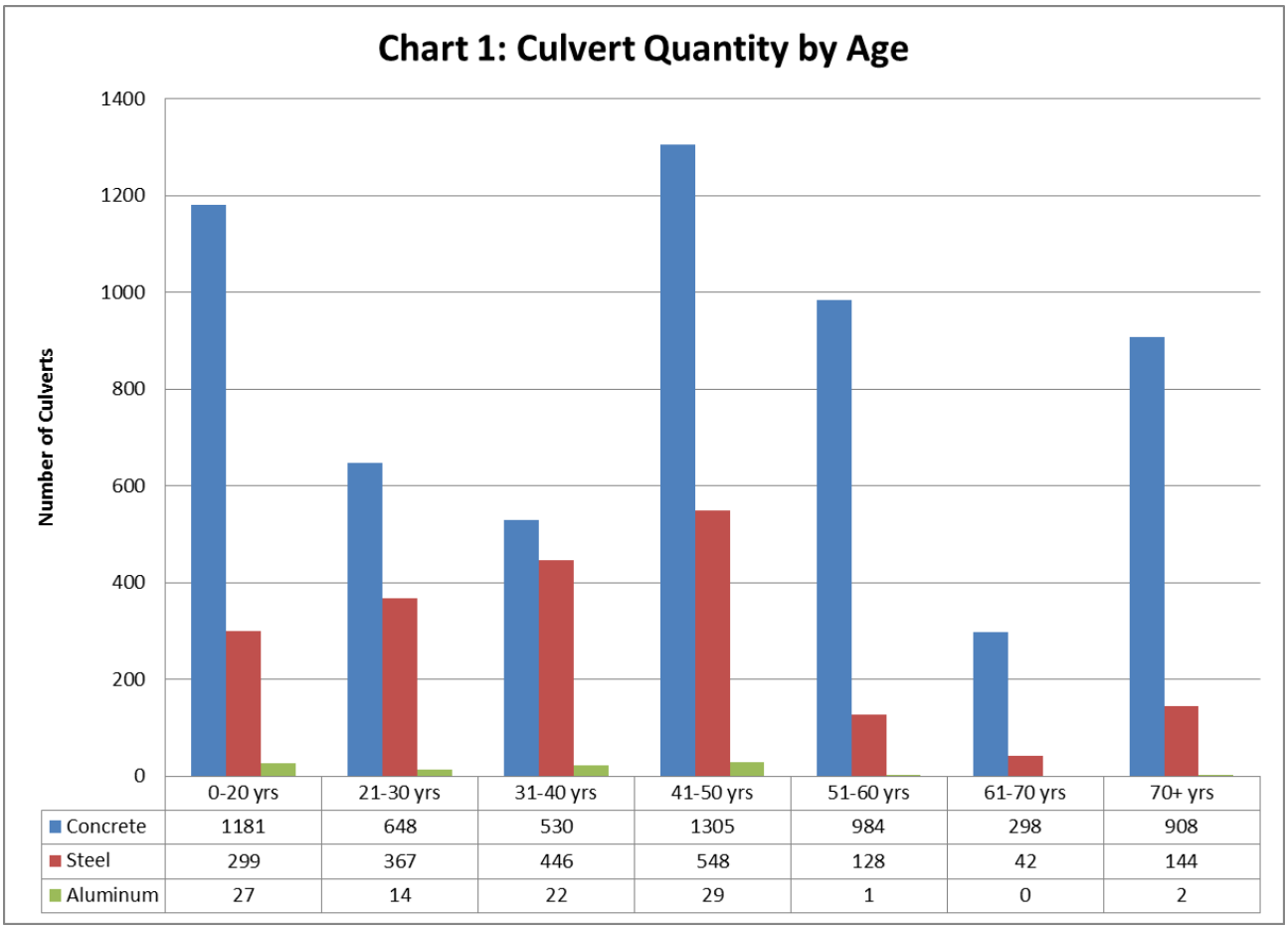
Condition Category	Range Of General Condition Ratings
Good	**GCR ≥ 6**
Fair	**GCR = 5**
Poor	**GCR ≤ 4**

A Large Culvert with a poor rating is assigned the designation of Structurally Deficient (SD). Large Culverts in Fair or Good condition can also be rated as SD if either their Structural Evaluation (Federal Item 67) or Waterway Adequacy (Federal Item 71) is rated of 2 or less, although the alternate definitions of SD apply to a small percentage of SD Large Culverts. Currently, 97.6% of VDOT's SD Large Culverts are in the Poor Condition Category.

In addition to General Condition Ratings, inspectors evaluate individual elements of culverts using Condition State (CS) ratings, which are collected in accordance with VDOT's *Element Data Collection Manual*. Condition State data provide more detailed condition data than GCRs. Condition states for Large Culverts vary from 1 to 4, with 1 representing no defects and 4 representing a severe condition. Table A-3 provides detailed descriptions of the condition states as they have been defined in VDOT since 1995.

3.0 Analysis of Inventory Data

Chart 1 displays the number, age and material type of the Large Culverts in the inventory. Approximately 15% of the concrete Large Culverts in the inventory still in place (908 of 5,854) were built over 70 years ago.



	0-20 yrs	21-30 yrs	31-40 yrs	41-50 yrs	51-60 yrs	61-70 yrs	70+ yrs
Concrete	1181	648	530	1305	984	298	908
Steel	299	367	446	548	128	42	144
Aluminum	27	14	22	29	1	0	2

Table 1 provides information about VDOT's current Large Culvert inventory by type, GCR, and average year built:

Table 1: Condition of Large Culverts by Type				
	Concrete	**Steel**	**Aluminum**	**Plastic/FRP**
Total #:	5,049	1,838	92	3
SD #	14	155	4	0
Fair #	425	398	20	0
Good #	4,610	1,285	67	3
SD %	0.3%	8.4%	4.3%	0.0%
Fair %	8.4%	21.7%	21.7%	0.0%
Good %	91.3%	69.9%	72.8%	100.0%
Average Year Built	1977.1	1980.3	1984.7	2000.4
Average GCR	6.57	6.13	6.33	7.00

The percentage of structurally deficient steel Large Culverts is 28 times greater than that for concrete. Also, while concrete Large Culverts outnumber steel by a factor of 3, there are 10% as many SD concrete Large Culverts as steel Large Culverts. It should also be noted that steel Large Culverts tend to be replaced at an earlier age due to accelerated deterioration, so if VDOT had not recently conducted an aggressive replacement program, the percentage of structurally deficient steel culverts would be significantly higher. Concrete culverts show the highest average GCR and the highest percentage in "good" condition, despite having the oldest average age. The percentage of structurally deficient aluminum culverts is relatively high, but the sample size is small when compared to other material types.

There have been new developments in coatings for metal culverts in the recent past, so a separate investigation was performed analyzing only Large Culverts constructed in the last 20 years to determine if the newer coatings provide improved performance. The findings of the investigation are provided in Table 2:

Table 2: CONDITION OF LARGE CULVERTS CONSTRUCTED FROM 1995-2015				
	Concrete	**Steel**	**Aluminum**	**Plastic/FRP**
Total #	1184	305	26	3
SD #	0	18	0	0
Fair #	7	22	3	0
Good #	1177	265	22	3
SD %	0.0%	5.9%	0.0%	0.0%
Fair %	0.6%	7.2%	11.5%	0.0%
Good %	99.4%	86.9%	84.6%	100.0%
Average Year Built	2002.5	2002.1	2002.5	2011.8
Average GCR	7.32	6.82	6.96	7.00

Table 2 shows that steel and aluminum Large Culverts are more likely to experience early degradation than concrete. As is the case with the overall inventory, steel and aluminum Large Culverts are more likely to be rated “fair” or SD than concrete Large Culverts of similar age.

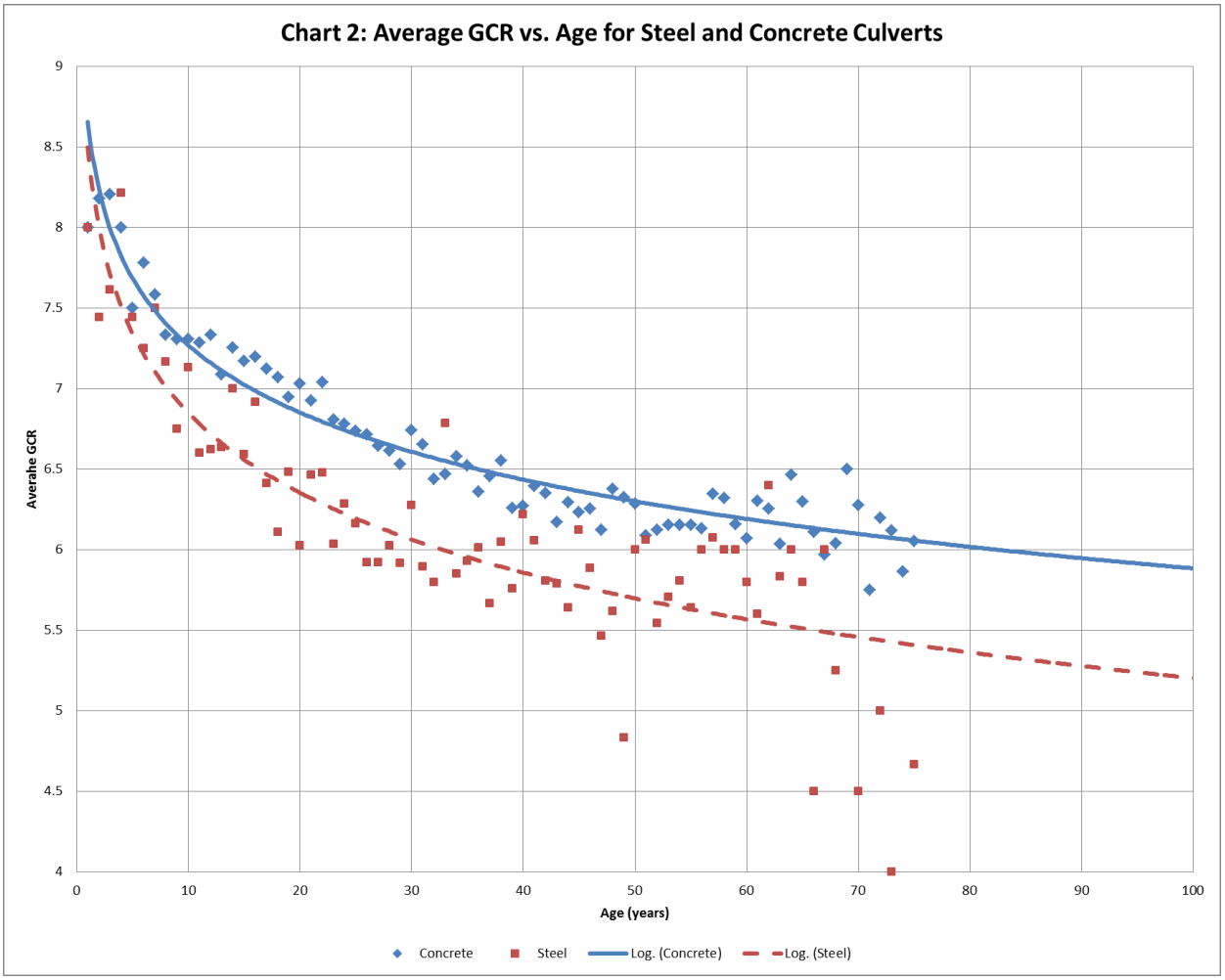
Because only 7 concrete Large Culverts constructed in the last 20 years are rated fair, the inspection reports for these culverts were reviewed to determine the cause of the fair rating. In general, they had minor spalls, delaminations, and headwall separations that did not lead to overall structural concerns. The total quantity of each culvert in each condition state was recorded from the inspection reports. In one instance a concrete Large Culvert was rated fair due to channel misalignment. Table 3 shows a summary of comments from the inspection reports for these 7 culverts:

Table 3

ELEMENT CONDITION STATES FOR CONCRETE LARGE CULVERTS RATED “FAIR”, BUILT WITHIN LAST 20 YEARS *(BY TOTAL QUANTITY)*

Structure Number	Quantity CS 1	Quantity CS 2	Quantity CS 3	Quantity CS 4	Total Quantity	Comments:
25190	485	17	0	0	502	Minor undermining at outlet, minor delaminations
	97%	3%	0%	0%	100%	
25209	824	0	0	0	824	Hairline cracks with efflorescence, hairline cracks in wingwalls
	100%	0%	0%	0%	100%	
25237	295	272	23	7	597	Joint separation, minor spalling, hairline cracking
	49%	46%	4%	1%	100%	
26827	187	30	13	6	236	Minor delaminations and spalls, headwall separation
	79%	13%	6%	3%	100%	
26962	1121	1	12	0	1134	Minor delaminations and spalls, wingwall settlement
	99%	0%	1%	0%	100%	
29950	57	40	24	0	121	Minor delaminations and spall
	47%	33%	20%	0%	100%	
30400	490	0	0	0	490	Rated “fair” due to channel drift
	100%	0%	0%	0%	100%	

The trend of GCRs for steel and concrete Large Culverts placed into service in the last 75 years is shown in Chart 2:



As shown by the downward trendlines, concrete Large Culverts tend to degrade more slowly than steel. The average GCR for concrete Large Culverts is more than one half point greater than steel culverts that are still in place at age 75. Although both show adequate performance in the first decade of service life, the GCR of steel drops off rapidly at about the 10 year mark.

The GCR is a relatively rough measure, and a localized problem can result in a reduction in the value assigned by the inspector. So in order to gain an improved understanding of Large Culvert deterioration, element condition states were also analyzed. Condition state data provide a more detailed representation of the amount of deterioration relative to the overall length of any Large Culvert.

Chart 3 depicts the changes in the average element condition state over time. The higher average condition states of steel Large Culverts establishes a more rapid rate of deterioration than for concrete.

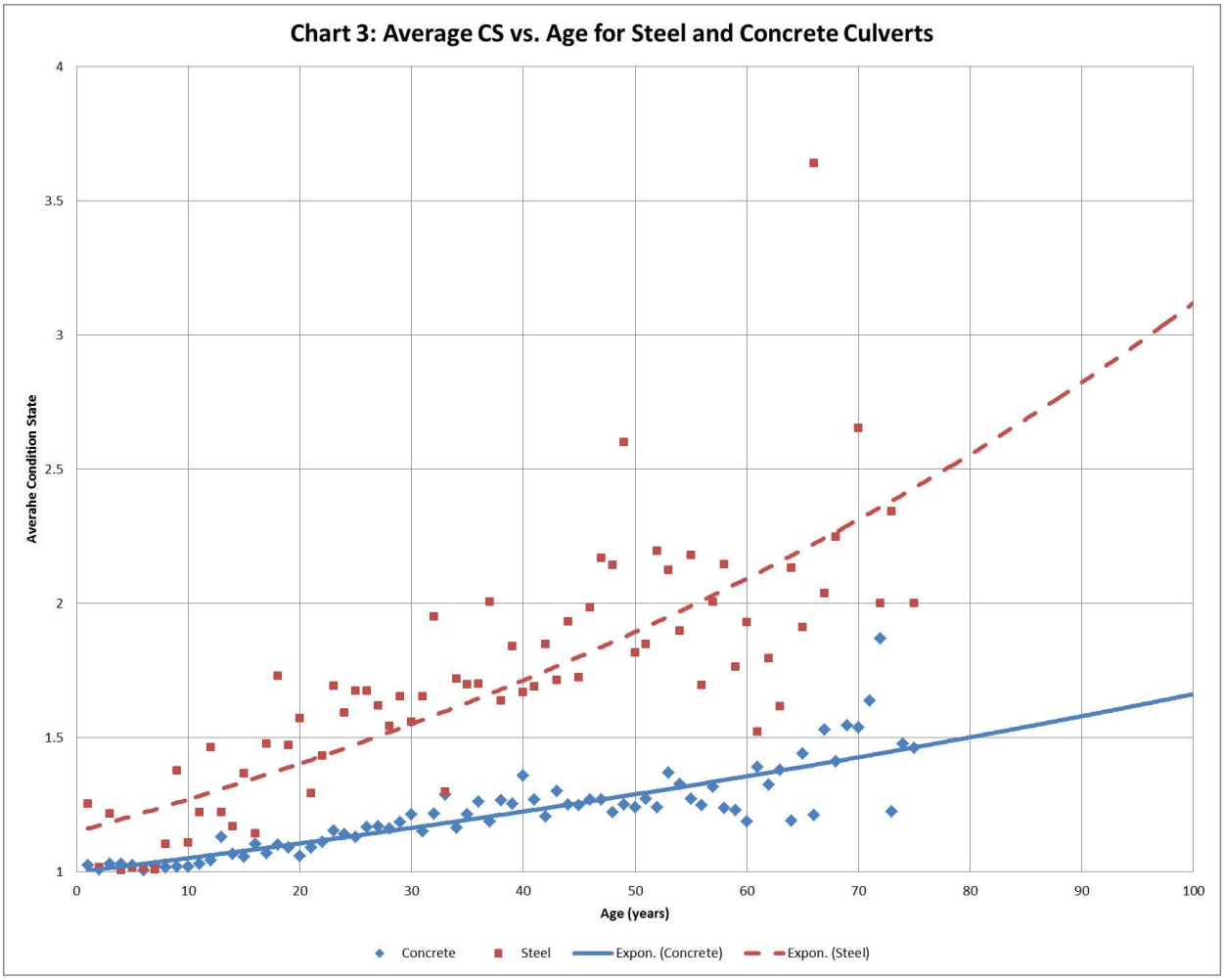


Chart 3: Average CS vs. Age for Steel and Concrete Culverts
Averahe Condition State
4
3.5
3
2.5
2
1.5
1
0
10
20
30
40
50
60
70
80
90
100
Age (years)
Concrete
Steel
Expon. (Concrete)
Expon. (Steel)

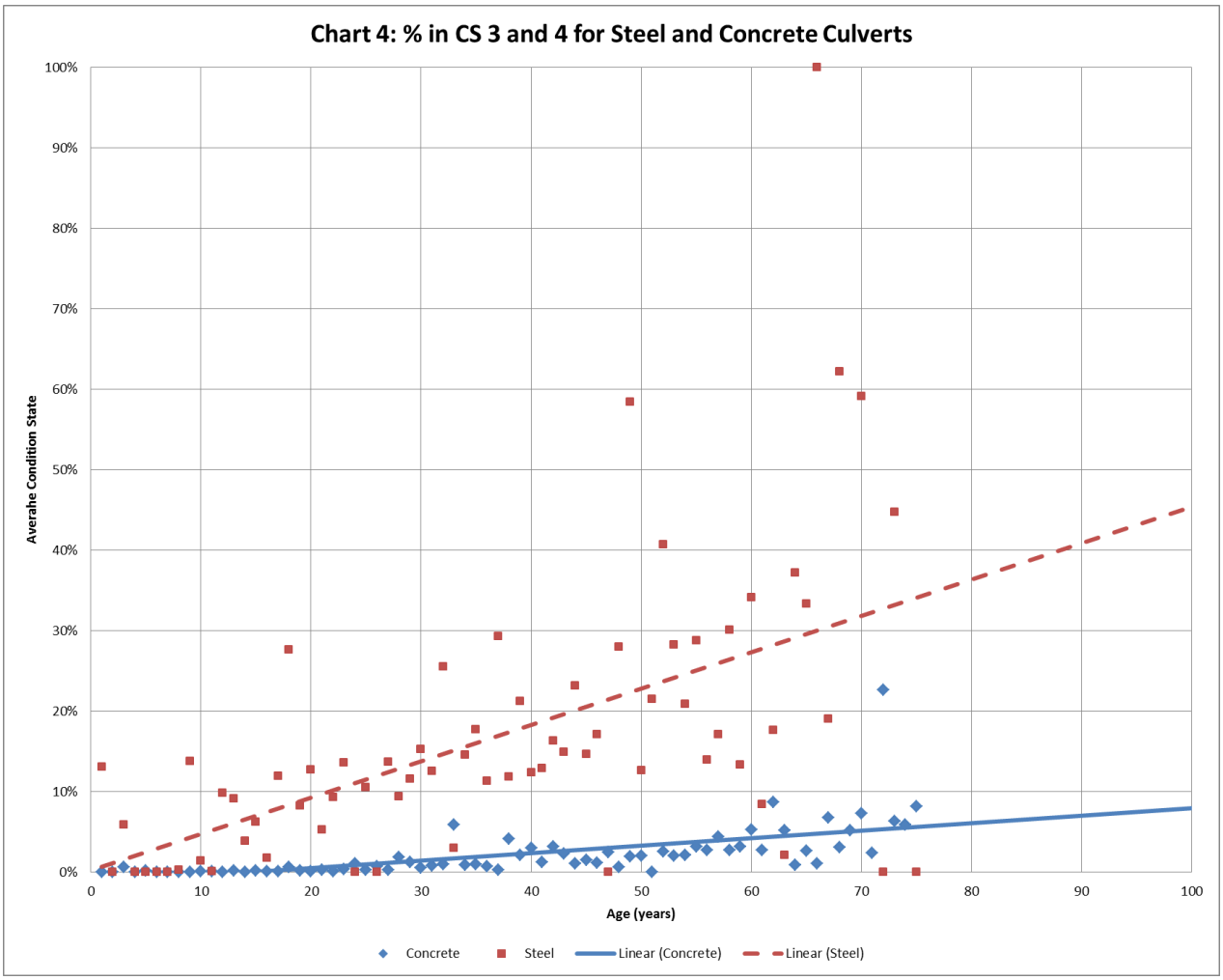
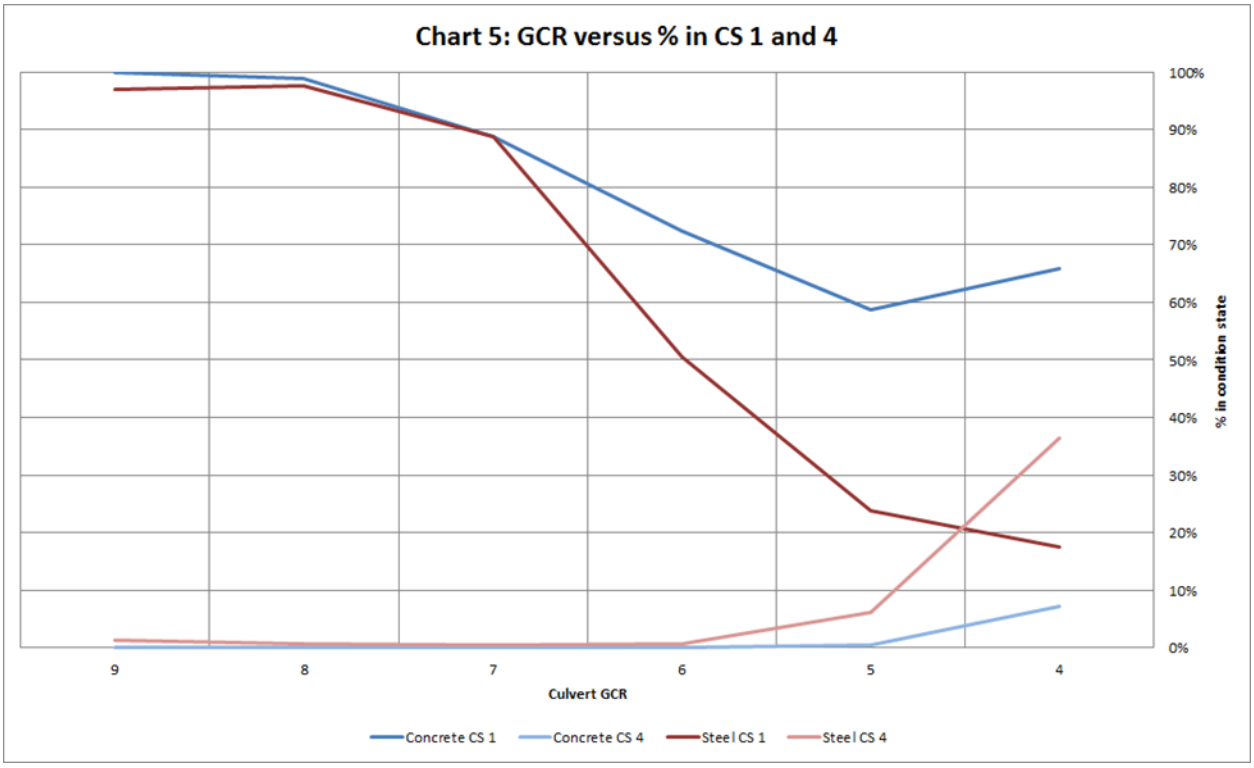


Chart 4 provides the percentage of the culverts in condition states 3 and 4 while comparing the deterioration rates of concrete and steel Large Culverts over time. After 75 years less than 10% of total length of concrete culverts is in a higher condition state (CS 3 or 4), as compared with over 30% for steel Large Culverts at the same age.

This is displayed in a slightly different manner in Chart 5, which shows that steel culverts exhibit greater percentages in poor condition states than concrete Large Culverts. Additionally, the percentage of steel Large Culverts in good condition states is smaller than that of concrete.



Over the last 5 years of record keeping (2011-2015), there have been at least 99 steel Large Culverts removed due to poor condition, versus 2 for concrete. There is only one documented case of an aluminum Large Culvert being replaced due to condition over the past 5 years. It was 16 years old at the time of replacement. The distribution of the Large Culverts' age at replacement is shown in Chart 6.

The average age of the steel Large Culverts at replacement is 43 years – substantially less than the desired 75 year service life. The one concrete Large Culvert replaced over the past 5 years was eighty years old at the time of replacement

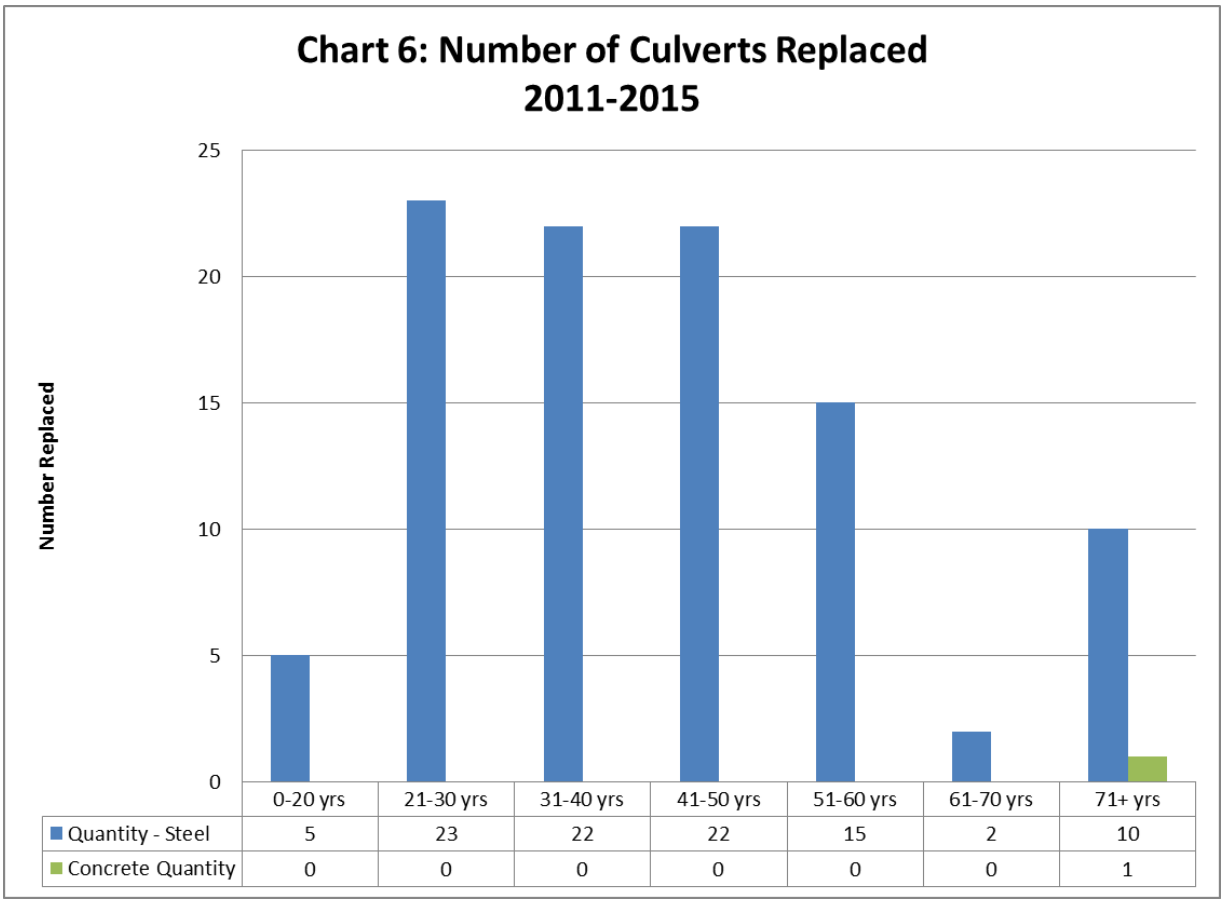
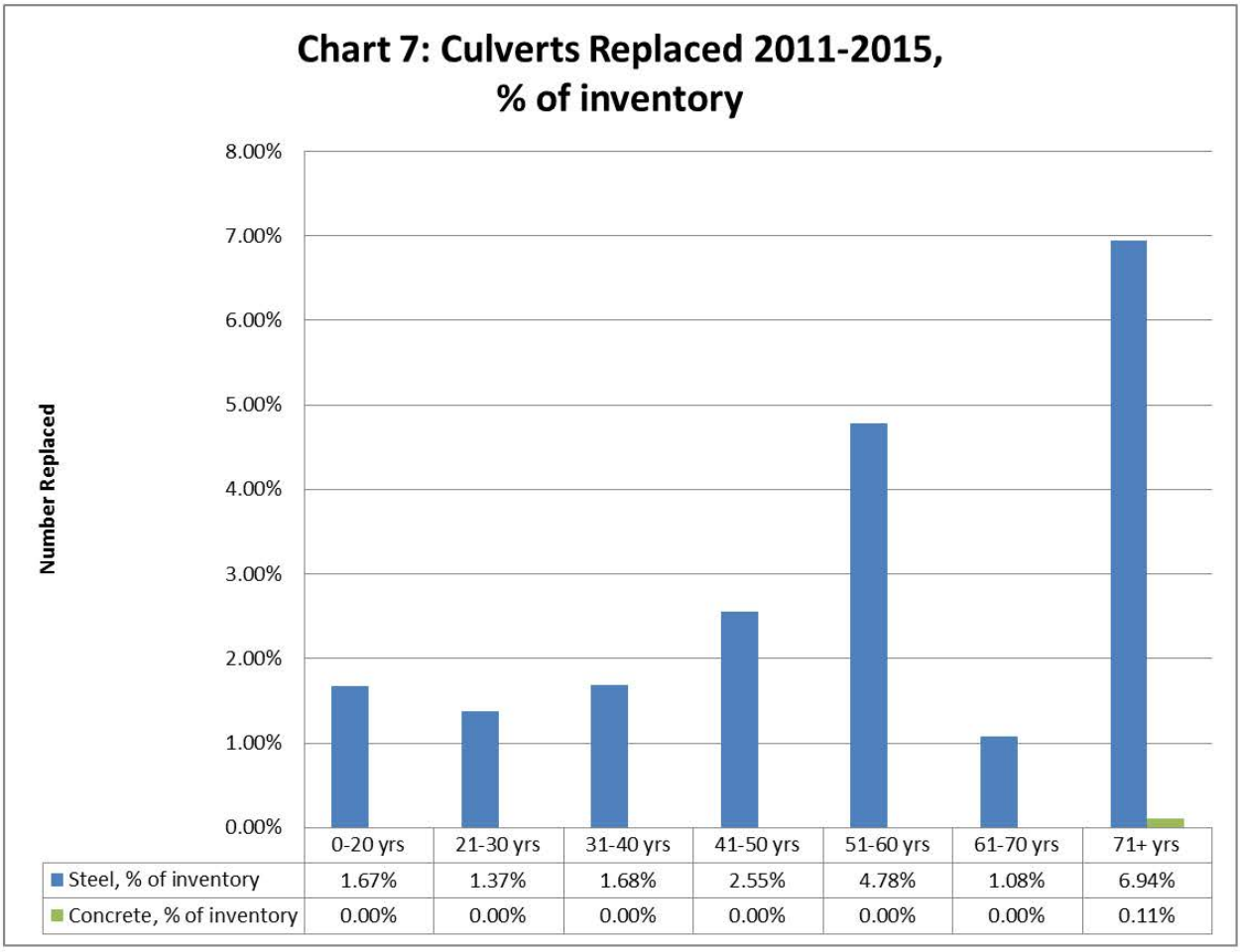


Chart 7 shows the number of Large Culverts replaced by age group as a percentage of VDOT's overall inventory. Both Charts 6 and 7 establish that a relatively high percentage of VDOT's steel Large Culvert inventory required condition-based replacement over the past 5 years. One concrete culvert had to be replaced during the same interval.



	0-20 yrs	21-30 yrs	31-40 yrs	41-50 yrs	51-60 yrs	61-70 yrs	71+ yrs
Steel, % of inventory	1.67%	1.37%	1.68%	2.55%	4.78%	1.08%	6.94%
Concrete, % of inventory	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.11%

4.0 Conclusions

For the purposes of this study, the expected service life for a Large Culvert is defined as the average number of years at which 90% of the structures remain in good or fair condition. The expected service life of steel and concrete culverts as determined by the data analysis are shown in the table below.

Expected Service Life of Steel and Concrete Culverts (years)					
Percentage in Fair or Better Condition					
	90%	**80%**	**70%**	**60%**	**50%**
Concrete	75	100+	100+	100+	100+
Steel	26	34	48	75	100+

As shown, 90% of concrete Large Culverts can be expected to last 75 years, while 90% of steel Large Culverts are expected to last 26 years. By the target 75 year design service life, approximately 40% of steel culverts are expected to have deteriorated into poor condition.

The following conclusions for Virginia's Large Culverts can be drawn from the data analysis:

- Steel Large Culverts have historically deteriorated more rapidly than concrete Large Culverts.
- Aluminum Large Culverts should not be considered as having equal longevity to concrete. Further performance data are required in order to fully evaluate their performance.
- Steel Large Culverts can be expected to regularly provide 26 years of service life.
- Approximately 60% of steel Large Culverts can be expected to provide a 75 year service life.
- Concrete Large Culverts can be expected to regularly provide 75 years of service life.

5.0 RECOMMENDATIONS

The following recommendations are based on the statistical analysis detailed herein:

- Guidance should be developed requiring service life design of new culverts
- Based on past performance, concrete Large Culverts can be expected to provide 75 years of service life
- Large Culverts constructed from materials other than concrete should be designed to meet the specific durability criteria associated with the demands required to attain an expected service life of 75 years. While this is potentially achievable with materials other than concrete, the performance record of metal Large Culverts requires a higher burden of proof that the materials will perform in the future.

APPENDIX A: INSPECTION FREQUENCY AND CONDITION SCALES

Table A-1: Frequency of Large Culvert Inspections *Annotated from I&IM 27*		
Frequency	**NBI Culverts**	**Non-NBI Culverts**
12 months	Culverts having a culvert General Condition Rating (GCR) of 4 or less	Culverts having a culvert General Condition Rating (GCR) of 4 or less
24 months	Culverts except as noted above	Culverts having a culvert General Condition Rating (GCR) of ‘5’
48 months		Culverts, except as noted above
60 months	Underwater inspections of culverts	Underwater inspections of culverts

TABLE A-2: CULVERT GENERAL CONDITION RATING DEFINITIONS	
Code	**Code Description**
N	Not applicable. Use if structure is not a culvert.
9	No deficiencies.
8	No noticeable or noteworthy deficiencies that affect the condition of the culvert. Insignificant scrape marks caused by drift.
7	Shrinkage cracks, light scaling, and insignificant spalling which does not expose reinforcing steel. Insignificant damage caused by drift with no misalignment and not requiring corrective action. Some minor scouring has occurred near curtain walls, wingwalls, or pipes. Metal culverts have a smooth symmetrical curvature with superficial corrosion and no pitting.
6	Deterioration or initial disintegration, minor chloride contamination, cracking with some leaching, or spalls on concrete or masonry walls and slabs. Local minor scouring at curtain walls, wingwalls, or pipes. Metal culverts have a smooth curvature, non-symmetrical shape, significant corrosion or moderate pitting.
5	Moderate to major deterioration or disintegration, extensive cracking and leaching, or spalls on concrete or masonry walls and slabs. Minor settlement or misalignment. Noticeable scouring or erosion at curtain walls, wingwalls, or pipes. Metal culverts have significant distortion and deflection in one section, significant corrosion or deep pitting.
4	Large spalls, heavy scaling, wide cracks, considerable efflorescence, or opened construction joint permitting loss of backfill. Considerable settlement or misalignment. Considerable scouring or erosion at curtain walls, wingwalls or pipes. Metal culverts have significant distortion and deflection throughout, extensive corrosion or deep pitting.
3	Any condition described in Code 4 but which is excessive ins cope. Severe movement or differential settlement of the segments, or loss of fill. Holes may exist in walls or slabs. Integral wingwalls nearly severed from culvert. Severe scour or erosion at curtain walls, wingwalls or pipes. Metal culverts have extreme distortion and deflection in one section, extensive corrosion, or deep pitting with scattered perforations.
2	Integral wingwalls collapsed, severe settlement of roadway due to loss of fill. Section of culvert may have failed and can no longer support embankment. Complete undermining at curtain walls and pipes. Corrective action is required to maintain traffic. Metal culverts have extreme distortion and deflection throughout with extensive perforations due to corrosion.
1	Bridge closed. Corrective action may put back in light service
0	Bridge closed. Replacement necessary

TABLE A-3: CoRe CONDITION STATE DESCRIPTIONS	
State	**Description**
1	• The element shows little or no deterioration. • Only surface defects are evident. • Some discoloration or surface corrosion may exist but there is no metal pitting. • Little or no separation of joints or seams • No misalignment problems are evident. • Superficial cracks and spalls may be present, but there is no exposed reinforcing or evidence of rebar corrosion. • Timber and fasteners are in sound condition.
2	• In metal culverts, corrosion and minor pitting may have begun especially in the invert. • In timber culverts, corrosion at fasteners and connections may have begun. • Deterioration, decay, weathering, minor chloride contamination, abrasion, cracking and/or leaching may have begun. • Little or no distortion and/or deflection exist. • Minor separation of joints or seams.
3	• In metal culverts, corrosion, deep pitting and/or some holes in the invert may exist. • In timber culverts, significant decay, weathering and warped or broken timbers. • In timber culverts, significant decay and corrosion at fasteners and connections may be evident. • Moderate to major deterioration, abrasion, extensive cracking and/or leaching and large areas of spalls. • Minor to moderate distortion or misalignment may have occurred. • Minor cracking or abrasion of the metal may exist. • There may be considerable separation of joints or seams.
4	• In metal culverts, corrosion, extreme pitting and/or holes in the barrel may exist. • In timber culverts, major decay and many warped, broken or missing timbers exist. • In timber culverts, major decay and corrosion at fasteners and connections exist. • Major deterioration, abrasion, spalling, cracking, major distortion, deflection, or misalignment of the barrel may be in evidence. • Major cracking or abrasion of the metal may exist. • Major separation of joints or seams may have occurred. • Holes may exist in floors and walls.