Research Report
KTC-10-03/KH58-07-1F

KENTUCKY TRANSPORTATION CENTER

PAVEMENT SETTLEMENT ISSUES AND HYDRO-GEOCHEMICAL WATER TESTING RESULTS FOR THE CUMBERLAND GAP TUNNEL

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16. Abstract

Both Ground Penetrating Radar (GPR) surveys and Hydro-Geochemical Water Testing (HGWT) have been performed at the Cumberland Gap Tunnel to determine why the reinforced concrete pavement has settled in various areas throughout both tunnels. To date, approximately 7,300 total square feet of pavement surface has voids beneath it that range from 0.05 to 40 inches in depth. Both GPR and HGWT results indicate that approximately 0.75 to 1.5 cubic yards of limestone sub-base material leaves the tunnel in solution form on a monthly basis. Furthermore, HGWT results indicate that the ground water beneath the tunnels is calcium deficient. Thus allowing the water to dissolve the limestone sub-base. Approximately 500,000 to 1 million gallons of water flows through the tunnel's ground water collection system on a daily basis.

Attempts to fix/shore-up the settled pavement areas were performed in 2002, 2007, and 2008. In 2002, UreTek foam was placed beneath approximately 2000 square feet of settled pavement for shoring purposes. In 2007, approximately 150 lineal feet of both pavement and backfill were removed and replaced with inert granite backfill material and a new reinforced concrete pavement. In 2008, approximately 51 cubic yards of cement grout material was placed beneath approximately 7,400 total square feet of settled pavement for shoring purposes.

There are several strategies outlined in this report to address both short-term and long-term remediation. However, there are certain strategies that may prevail over others. It is proposed that grout material should be placed beneath the pavement structure, at an estimated cost of $50,000 to $100,000/year, as a short term assurance measure. It is proposed that approximately 2,800 lineal feet of pavement and backfill material be removed in both tunnels and replaced with an inert granite backfill and a new 10 inch reinforced concrete pavement be installed for a long-term remediation (estimated costs $10,000,000).

17. Key Words
Ground penetrating radar, Tunnel, Water Chemistry Testing

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FINAL REPORT

KTC-10-03/KH58-07-1F

PAVEMENT SETTLEMENT ISSUES AND HYDGRO-GEOCHEMICAL WATER TESTING RESULTS FOR THE CUMBERLAND GAP TUNNEL

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Commonwealth of Kentucky

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ACKNOWLEGEMENTS

The authors of this report would like to acknowledge the members of the technical advisory group that has been both an instrumental part throughout the discovery process of this project and made contributive efforts in producing this report. The technical advisory group has been comprised of members from the following: Kentucky Transportation Cabinet; Tennessee Department of Transportation; Federal Highway Administration (Eastern Federal Lands Division); Federal Highway Administration (Kentucky Division); National Park Service; Cumberland Gap Tunnel Authority.

EXECUTIVE SUMMARY

The concrete pavement structure at the Cumberland Gap Tunnel has been showing signs of pavement distress since 2001. The primary distress observed has been vertical displacement (settling) throughout various areas of both the north and southbound tunnels. To date approximately 7,400 square feet of continuously reinforced concrete pavement (CRCP) has voids beneath it. These voids range from 0.05 inch to 40 inches in depth.

In 2007 an investigative repair was conducted in the southbound tunnel to repair the most severely damaged section and to provide insight into the potential cause of the settlement issues. From this investigation, it was determined through hydro-geochemical water-chemistry testing that the ground water in-flow throughout both tunnels is aggressive to calcite. Therefore, the 4-6 feet of calcium rich limestone backfill material placed beneath the concrete pavement is dissolving and leaving the tunnel through the ground water collection system on a daily basis. The calculated rate of removal has been estimated to be between 0.75 and 1.5 cubic yards per month or approximately 70 to 150 square surface feet of new void area is opening up beneath the concrete pavement on a monthly basis.

It has been proposed by a technical advisory group that the concrete pavement and limestone backfill material be removed from station 140+50 to the Kentucky Portal approximately 2,800 lineal feet in both tunnels. This removed material would be replaced by an inert granite backfill material and a new 10 inch continuously reinforced concrete pavement (CRCP). Preliminary construction estimates taken from previous unit-bid-pricing of the investigative repair, estimate that the repair will cost approximately $10,000,000. It is also proposed that annual maintenance be performed in the settled areas in efforts to avoid any potential pavement collapse until a long

term fix is put into place. An approximate annual maintenance cost would be from $50,000-$100,000 per year.

INTRODUCTION

This is a summary report of the pavement settlement issues (distressed areas) and hydro-geochemistry (water quality testing) results from the recent Cumberland Gap Tunnel pavement inspection project. This report will briefly highlight the following:

a. History of the distresses incurred to the pavement structure
b. Quantify the settlement areas (void areas)
c. Explain the hydro-geochemical water testing results
d. Discuss the traffic impacts in the event that the tunnel would need to be closed for emergency repairs
e. Discuss future traffic impacts
f. Offer suggestions for short-term remediation efforts (maintenance)
g. Offer recommendations for long-term remediation efforts for the settled areas
h. Provide preliminary costs estimates for both the short and long term repair recommendations

BACKGROUND

The Cumberland Gap tunnel is a twin-bore-four-lane mountain tunnel that carries US 25E from southeastern Kentucky into Tennessee. It resides within the Cumberland Gap National Park, and carries an average annual daily traffic (AADT) volume of 22,500 vehicles bi-directionally per day. Approximately ten percent of the AADT volume is trucks, which predominately transport fuel and coal between the two states.

Both the design and construction oversight for the tunnel was performed under the direction of Eastern Federal Lands, a division of the Federal Highway Administration. The tunnel was completed in 1996 with an approximate total project cost of 260 million dollars.

Currently, the tunnel is maintained and operated by the Cumberland Gap Tunnel Authority (CGTA). The CGTA performs its duties as an over-site agency for the maintenance and operation of the tunnel under a joint contract with both the Kentucky Transportation Cabinet and the Tennessee Department of Transportation.

HISTORY OF DISTRESS

Distresses were first noticed in 2001 by the CGTA to the CRCP. These distresses consisted of multiple areas starting to settle in the southbound tunnel between stations 119+50 and 140+50. The magnitude of the pavement settlement was approximately 1-3 inches at that time. In efforts to bring the pavement structure back into proper elevation, it was suggested that an expansive foam material be installed beneath the pavement to lift the pavement back into proper elevation in the settled areas. This process worked with limited success. The foam material only filled the void space between the concrete pavement and the aggregate sub-base. Therefore it was unable to lift the pavement into proper elevation.

In 2005, the Kentucky Transportation Center (KTC) conducted an experimental research project using ground penetrating radar (GPR) to determine if there were voids beneath the CRCP pavement in the distressed areas. This inspection determined that approximately 6,000 square feet of pavement surface between the north and southbound tunnels had some type of void beneath it. These voids ranged from 2 to 40 inches in depth. Figure 1 below displays a 40 inch deep void located beneath the left driving lane of the southbound tunnel at approximately station 128+90. It can be inferred that the concrete pavement is essentially performing as a bridge in these void locations. Only because reinforcing steel was placed inside the concrete, is the pavement structure able to be in-service without complete failure today. Structural loading calculations indicate that the concrete pavement should only be able to span 6 feet before permanent deformation of the steel takes place. As seen in Appendix A, some of the void areas are spanning across both lanes (30 feet wide) and extending 1 to 70 feet in length.

Figure 1: Forty-inch void beneath concrete pavement

In April of 2007, a technical group was formed to study the pavement settlement issues at the Cumberland Gap Tunnel. This group consisted of representatives from the following: Kentucky Transportation Cabinet (KYTC), Tennessee Department of Transportation (TDOT), Federal Highway Administration-Kentucky Division (FHWA), Federal Highway Administration-Eastern Federal Lands Division, National Park Service (NPS)-Cumberland Gap National Park, Cumberland Gap Tunnel Authority (CGTA), Kentucky Transportation Center (KTC), and the Kentucky Geological Survey (KGS). It was determined in that meeting that a significant amount of settlement was taking place in the southbound tunnel from stations 122+24 to 123+41 and that an investigative repair would be necessary to eliminate a potential pavement collapse and to gain a better understanding of the mechanisms which may have been causing this distress.

A new discovery was determined during this investigative repair. It was found that the ground water inflow into the tunnel backfill material beneath the concrete pavement was aggressive to calcite. The tunnel backfill material is a limestone material (approximately #57 size aggregate) that is rich in calcium. Figure 2 displays the ground water inflow into the repaired area. Approximately 500,000 to 1.2 million gallons of ground water flows beneath the tunnels on any given day depending on the rainfall events.

Figure 2: Water inflow into the repaired area

This limestone backfill material ranges from 4-6 feet in depth by design throughout both tunnels. The technical advisory group determined that the appropriate repair would be to replace the excavated material with an inert granite backfill material. The backfill material consisted of a number 57 size aggregate, overlaid by a six inch layer of dense-graded-aggregate (DGA) separated by a geo-grid fabric. Next, a new 10 inch CRCP pavement was installed (Figure 3).

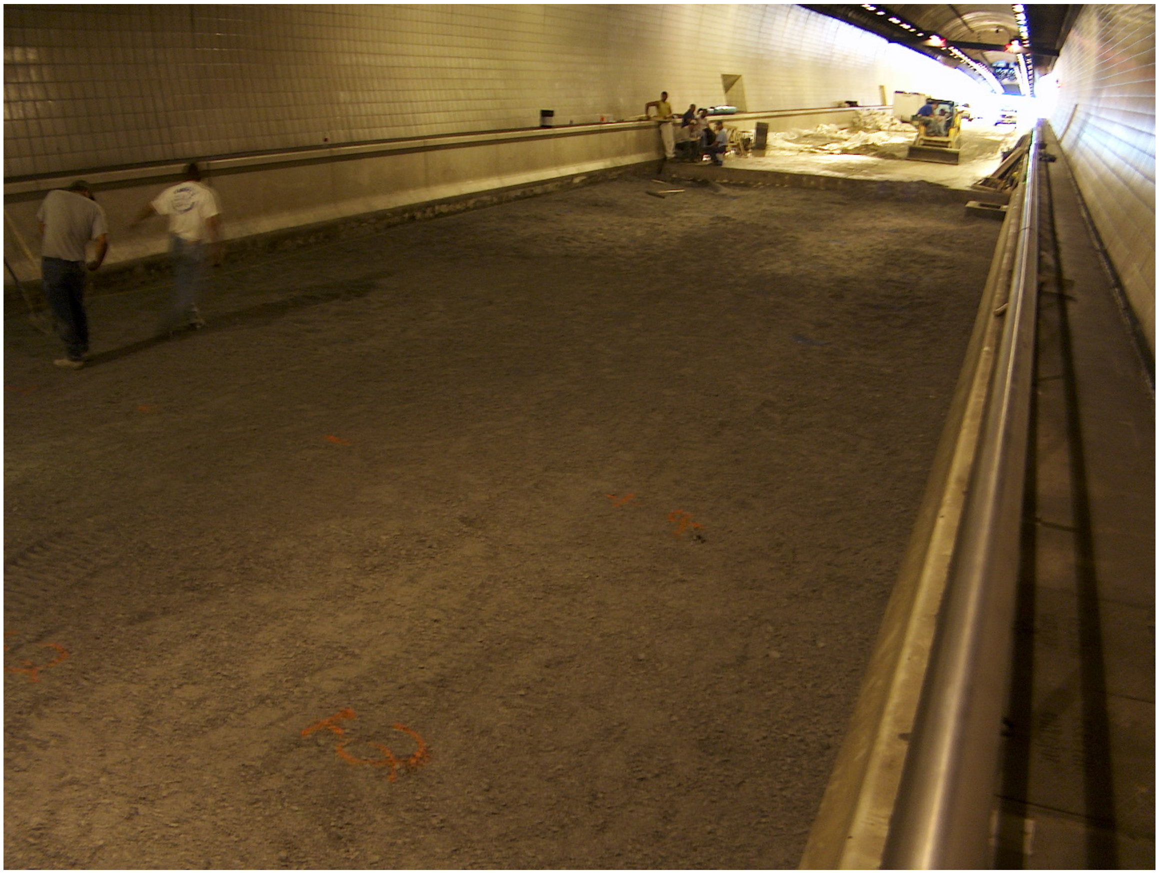


Figure 3: Repair area with granite backfill and DGA prior to concrete pavement placement

A more detailed summary of the hydro-geochemical water testing results will be provided in the hydro-geochemistry section of this report.

Another discovery made during the investigative repair was that the groundwater collection system is elevated approximately 2 to 3 feet above the invert of the tunnel (Figure 4). The ground water collection pipe can be seen in Figure 4 as the green pipe on the left side of photo.

Figure 4: Groundwater collection pipe location in relation to tunnel invert

For convenience of construction, the elevation of the groundwater collection system was constructed higher than the invert of the tunnel. Thus, the limestone backfill material throughout the tunnel was constructed to act as a natural drainage structure for the ground water in-flow to pass through. It has been presumed, after research of both design and construction documents, that no water test were conducted to measure calcium deficiency during either the design or construction phase of the tunnel.

In the spring of 2008, as a precautionary measure to avoid further settlement, both the KYTC and TDOT decided that the other void areas (approximately 7,460 square feet) needed to be filled with cementatious grout. Approximately 51 cubic yards of cement grout was placed into all known void areas at that time. As of August 2009, approximately 90% of the voids grouted in the spring of 2008 have reappeared and the repaired area with the granite backfill appears to be unchanged and performing well.

QUANTIFICATION OF SETTLEMENT (DISTRESSED AREAS)

The distressed areas started to appear in the southbound tunnel in 2001, just five years after completion of construction. The distress was first noticed by the Cumberland Gap Tunnel Authority during routine maintenance. In an attempt to monitor the progression of void growth, the Cumberland Gap Tunnel Authority asked the Kentucky Transportation Cabinet to involve the Kentucky Transportation Center in its use of its falling-weight deflectormeter (FWD) and ground penetrating radar (GPR) equipment to monitor and evaluate void growth. As mentioned above, approximately 7,300 square feet of void space are present today. However, the voids are not as deep as they were in 2005 because of the grouting that took place in the spring of 2008. Preliminary GPR results obtained from the latest survey performed in August 2009 indicate that the void depths range from 0.5 to 6 inches deep depending on their location in respect to the hydro-geochemical data (Appendix A). Figure 5 outlines the time line of combined void growth for both tunnels. The green bar indicates the quantity of voids that were removed during the investigative repair in the summer of 2007. This figure demonstrates that even with the reduction in total void surface area of 1,419 square feet in August 2007, the total void space in December 2007 had surpassed the quantity from January 2007.

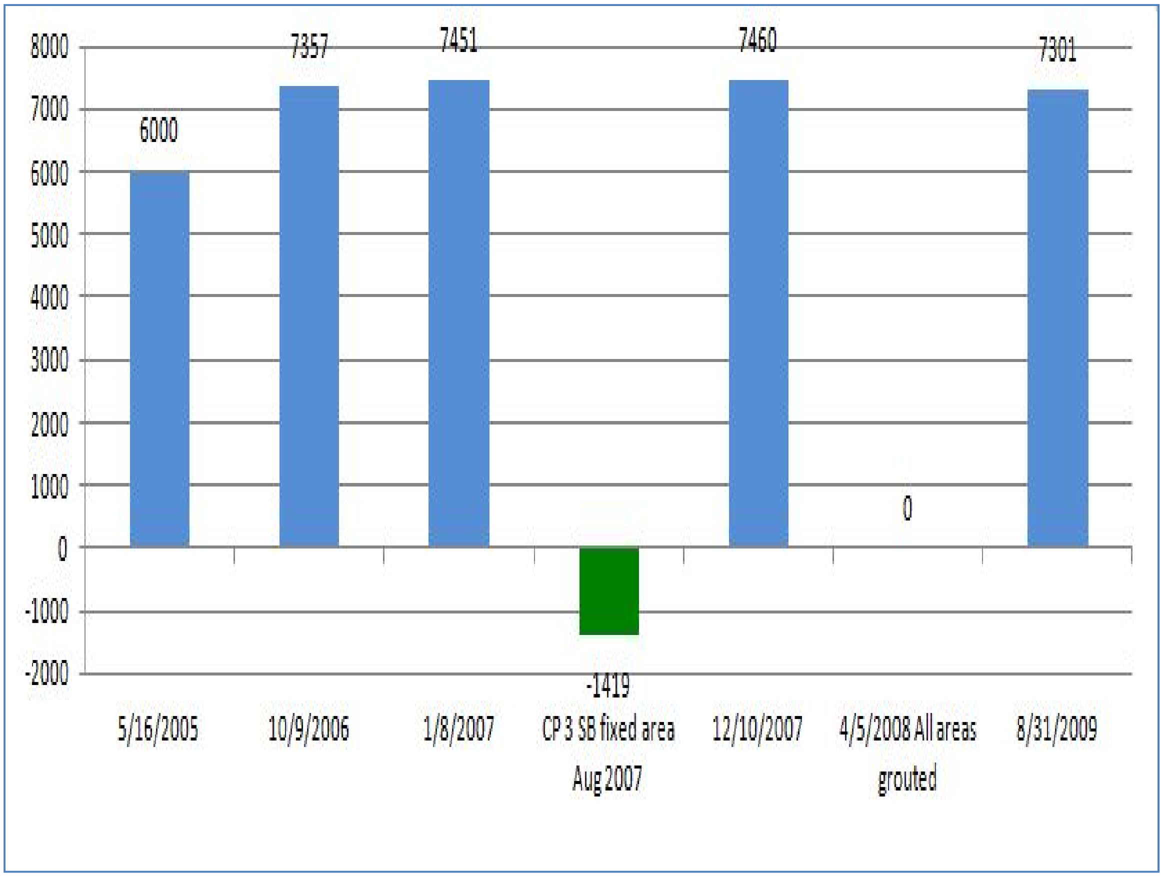


Figure 5: Total square feet of void surface areas

HYDRO-GEOCHEMISTRY RESULTS

After the investigative repair was completed in 2007, the technical group decided that a much broader hydro-geochemical water-chemistry testing study was needed. This study was conducted to validate the extent of the calcium deficient water entering into the tunnel. Laboratory tests have confirmed that water samples that have a calcium deficiency less than 0.10 will start to dissolve limestone material.

Approximately 120 water-sampling wells were drilled and instrumented in both tunnels during the fall of 2008. As shown in Figure 6, the geological composition of the rock material from stations 140+50 to 160+00 (Tennessee portal) consists of limestone composition while the composition from the Kentucky portal to station 140+50 is sandstone.

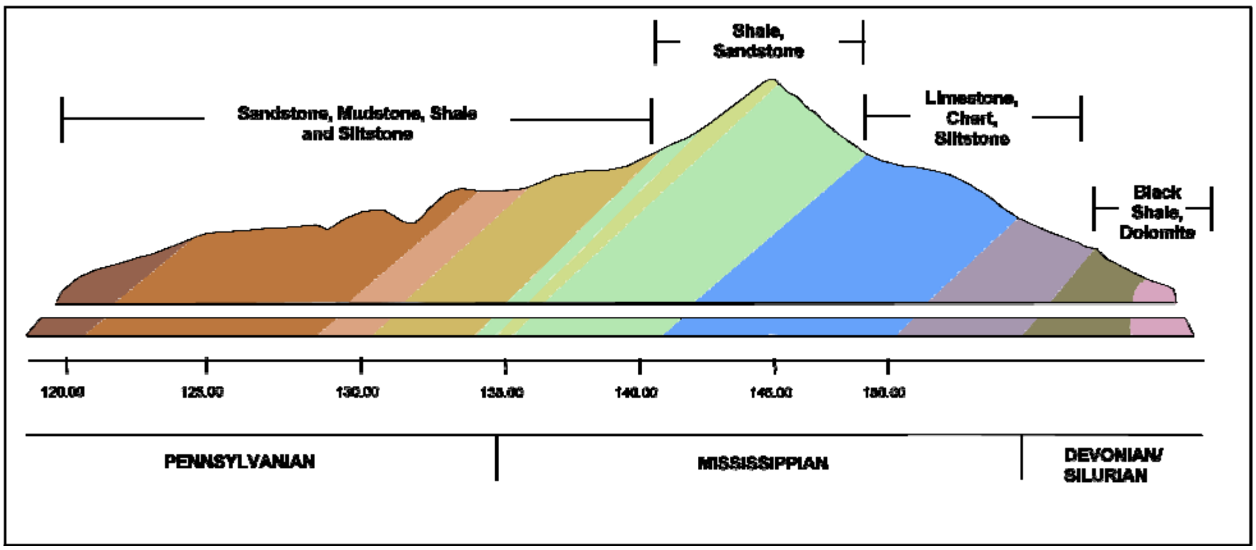


Figure 6: Geologic map of Cumberland Gap Tunnel

Water samples obtained between stations 140+50 to 160+00 appear to be chemically balanced with respect to calcite (Appendix B). Thus, there was no noticeable chemical breakdown noted in the limestone backfill beneath the pavement in this area. The water is apparently naturally aggressive in this location and is using the native formation of limestone to balance itself with respect to calcite. This gives rational to the presence of the cave systems located in these areas. However, the remainder of the tunnel has a different geological composition (i.e. siltstones, mudstones, sandstones, etc.) that is incapable of chemically balancing the water with respect to calcite before entering the limestone road-base aggregate. In these locations (stations 119+50 to

140+50) water samples collected and analyzed by KGS appear to be aggressive with respects to calcite (Appendix B). Figure 7 summarizes the hydro-geochemical water- testing data. Figure 7 demonstrates that 84% of the southbound and 77% of the northbound water samples are aggressive to calcite.

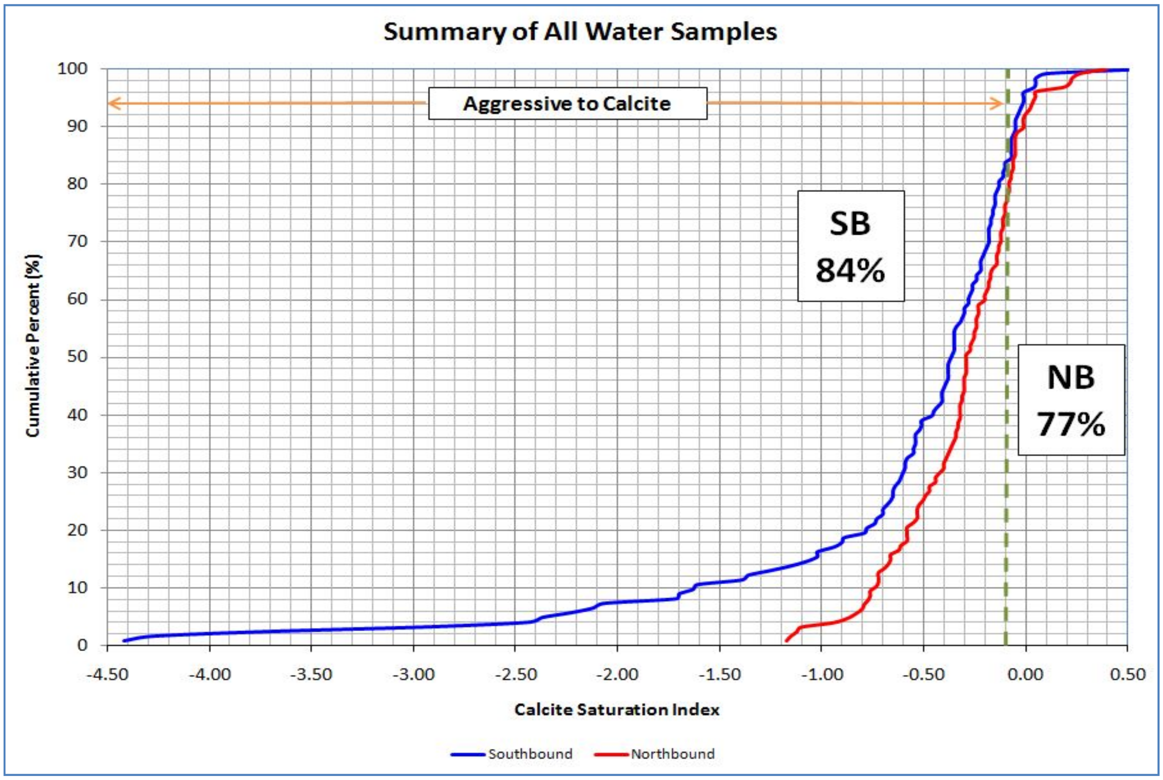


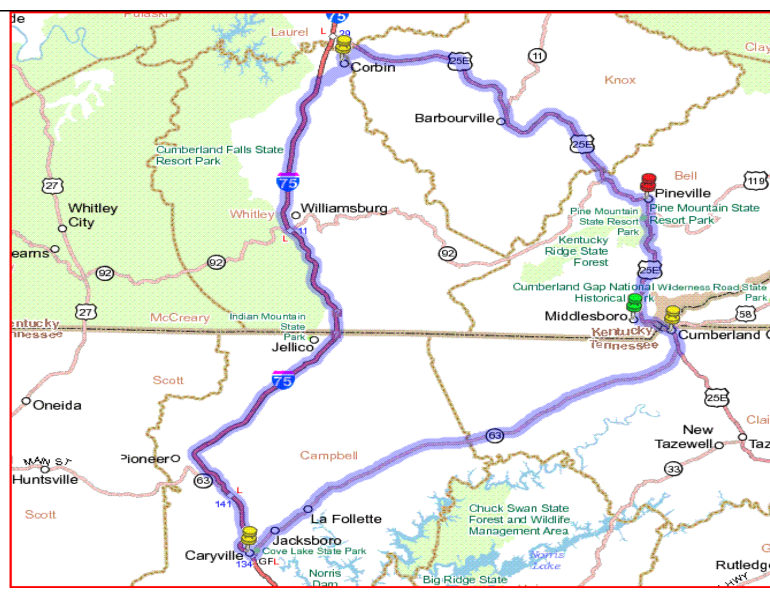
Figure 7: Summary of Water Samples

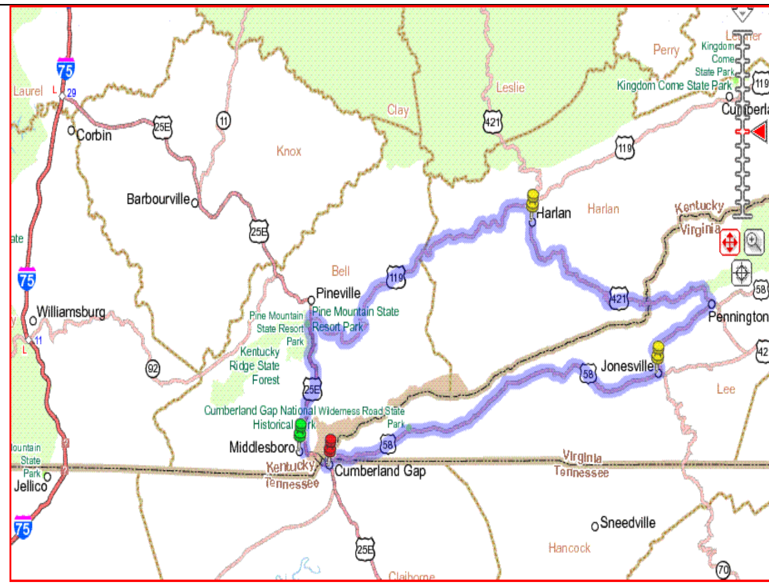
Therefore, the majority of the ground-water samples between stations 119+50 and 140+50 have the potential to chemically dissolve the limestone aggregate backfill. This material then exits the tunnel in solution through the ground water collection system on a continual basis. Preliminary results of the amount of material leaving the tunnel in solution have been quantitatively compared between mass-flux models, ground penetrating radar results, and visional calculations during the grouting process. These preliminary results estimate that approximately 0.75 to 1.25 cubic yards of limestone material are being removed in solution from beneath the concrete pavement on a daily basis. This also translates into approximately 70 to 150 square feet of new void space opening up beneath the pavement surface on a monthly basis.

TRAFFIC IMPACTS FOR DIVERTED TRAFFIC

Considerations were made for the impacts imposed on the traveling public (approximately 22,500 AADT) during the repair conducted in 2007. These considerations for complete traffic diversion can also be used to guide future repairs and or emergency maintenance repairs (Table 1). All dollar values have been adjusted using the 2007 consumer price index published by the Bureau of Labor Statistics.

Table 1: Diversion routes and daily user costs 2007 dollars

Via La Follette, TN and Williamsburg, Ky **130 miles, 3 hrs 6 min,** **<u>User Cost -- $1,197,096 (daily)</u>**	

<table>
<tr>
<td>Via Pennington Gap, VA and Harlan, Ky
110 miles, 2 hrs 50 min
<u>User Cost --</u>
<u>$1,071,085 (daily)</u></td>
<td>
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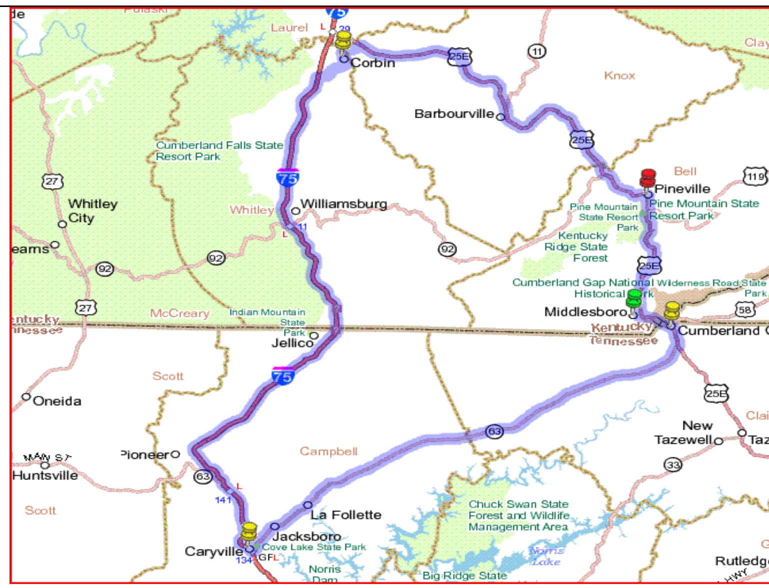
<tr>
<td>Via La Follette, TN and Corbin, KY
140 miles, 3 hrs
<u>User Cost --</u>
<u>$1,134,091(daily)</u></td>
<td>
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Alternate Long Haul Interstate Route,
30 additional miles,
30 minutes
<u>User Cost -- $189,015 (daily)</u>

However, no complete diversion of traffic was necessary to the general population of traffic during the repair. Only wide load cargo vehicles were subject to the complete diversion routes as mentioned above. During the construction phase of the repaired area, the southbound traffic was diverted over to the northbound tunnel, with traffic running bidirectional in the northbound tunnel. No noticeable delays in traffic were experienced in the northbound tunnel despite the reduced travel speed of 25 mph.

Figure 8 displays the maximum work zone capacity of 1,300 vehicles-per-hour-per-lane (vphpl), ref. 2001 Highway Capacity Manual that can be processed in a single lane on an hourly basis without backups. The hourly traffic distribution for the 22,500 ADT can also be found in Figure 8, which identifies that the traffic would have to increase by an approximate 30 percent before backups would occur.

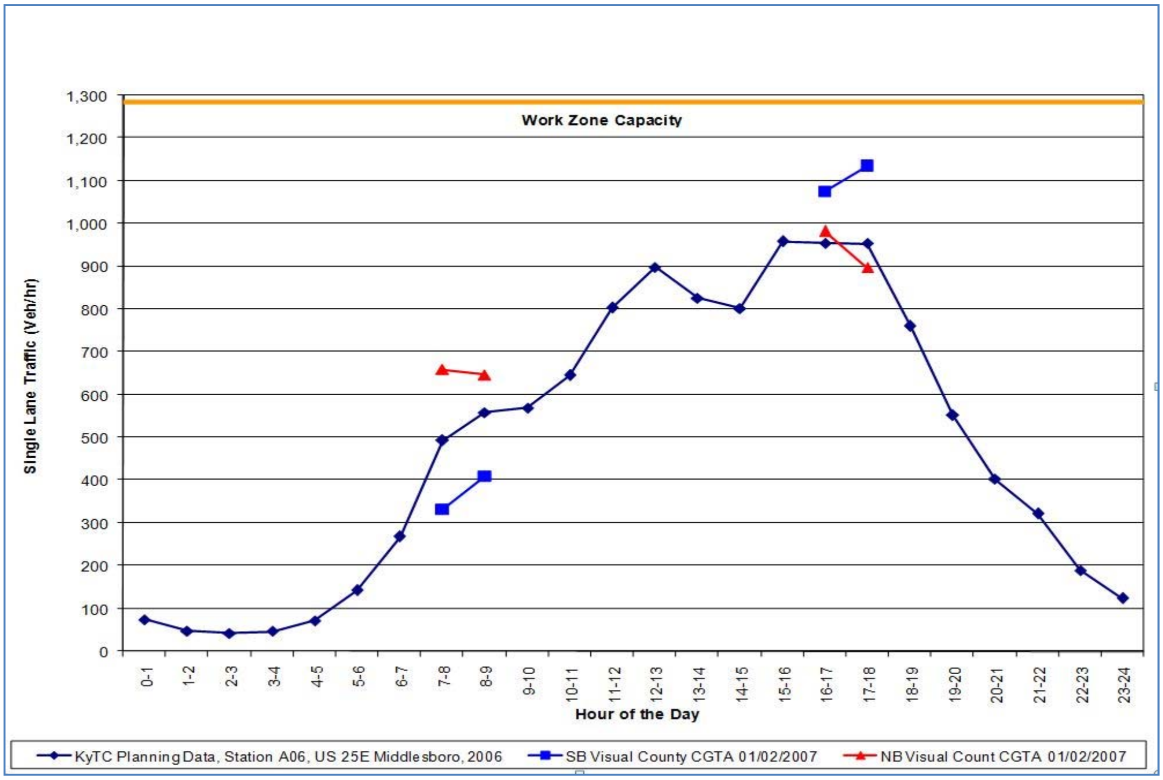


Figure 8: Single lane work zone capacity vs. hourly traffic distribution US 25 East Cumberland Gap Tunnel

FUTURE TRAFFIC IMPACTS

With the near completion of US 25E widening project from Harrogate, Tennessee to I-81 near Morristown Tennessee, it is conceivable that the traffic flow on US 25E will increase throughout the Cumberland Mountain Region in the near future. Once this construction is completed in late 2010, a driver will be able to reduce their driving time by an approximate 45 minutes when traveling from I-81 to I-75. With this reduction in travel time between the two major interstates, it is highly probable that the total volume of vehicles passing through the Cumberland Gap Tunnel will increase. Consideration should be given to construction scheduling in an effort to avoid excessive delays as traffic volumes increase. In addition, consideration for diverting traffic during the NASCAR racing season hosted in Bristol, Tennessee, also needs to be reviewed prior to scheduling of construction.

SHORT TERM REMEDIATION (MAINTENANCE)

Table 2: Short term remediation estimates for the settled areas may consist of the following

Maintenance Item	**Construction Costs provided by KYTC Division of Highway Design**
Grout all void areas on annual basis (consideration needs to be made for potential damming the ground water over repeated grouting sessions)	\$1300/cubic yard. (includes coring, ground penetrating radar, and placing grout) Total annual costs \$40-70K depending on void depth/growth
Remove concrete pavement (major settled area) northbound tunnel approximately 1,500 square feet and backfill with concrete (consideration needs to be made for potential damming the ground water for full depth concrete)	\$150/square yard Total cost \$25,000
Micro-piles, spaced 6 feet on center in void areas (see attached quote from Rembco Appendix C)	\$35/square feet (approximate areas 7300 square feet) Total Costs: \$255,500

LONG TERM REMEDIATION

Based on the findings from the investigative repair, the hydro-geochemical water-chemistry data, and the continual growth of the void areas, it is of opinion that both the pavement and backfill material should be completely removed and replaced starting at approximate station 140+50 and proceeding to the Kentucky portal. It is also believed that a trench be excavated out in the invert of the tunnel to allow a majority of the ground water to channel through the tunnel (Figure 9). This trench would have to be of sufficient depth and width to lower the water table beneath the tunnels' concrete sidewall structure. All backfill material must be inert granite material, and the paved surface would be a CRCP pavement (Figure 9). An approximate construction cost of $10,000,000 has been estimated by the KYTC Division of Highway Design based from recent unit-bid-pricing to perform such tasks. However, this estimate may vary depending on the economic climate and contractor availability.

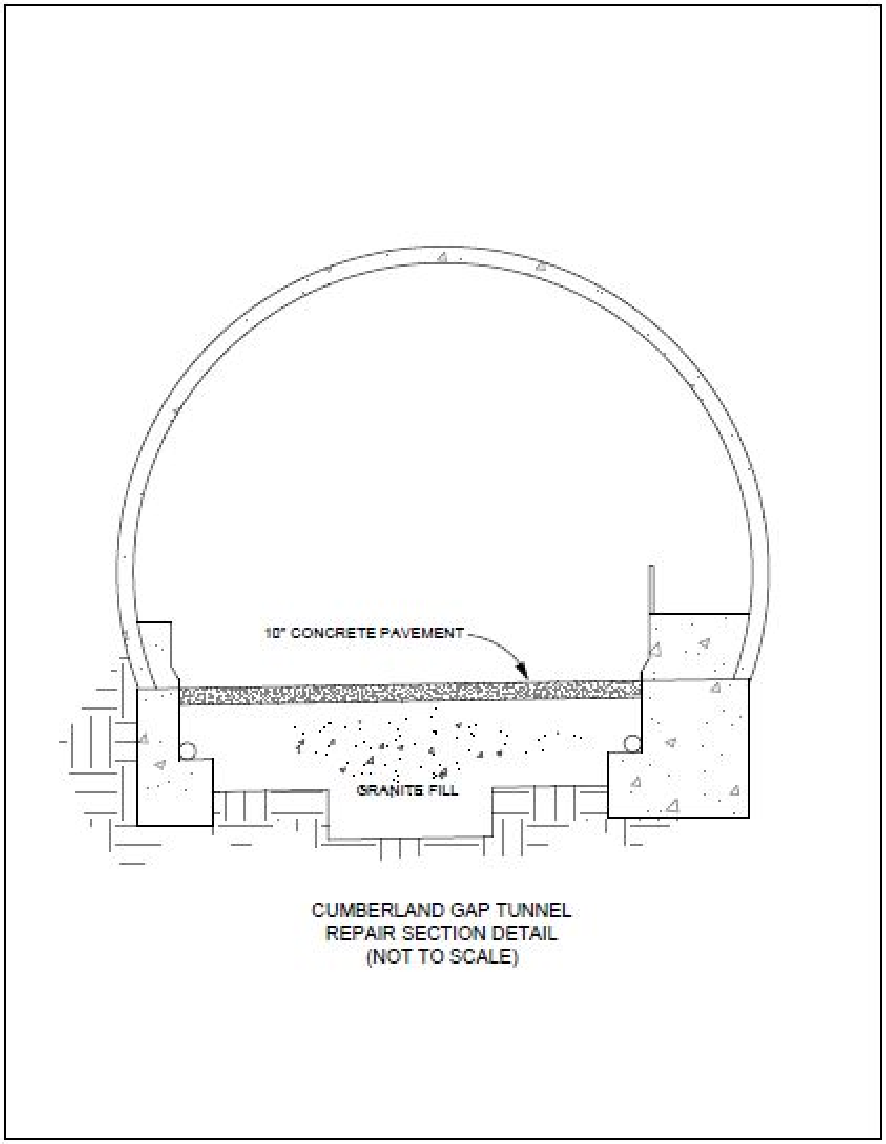
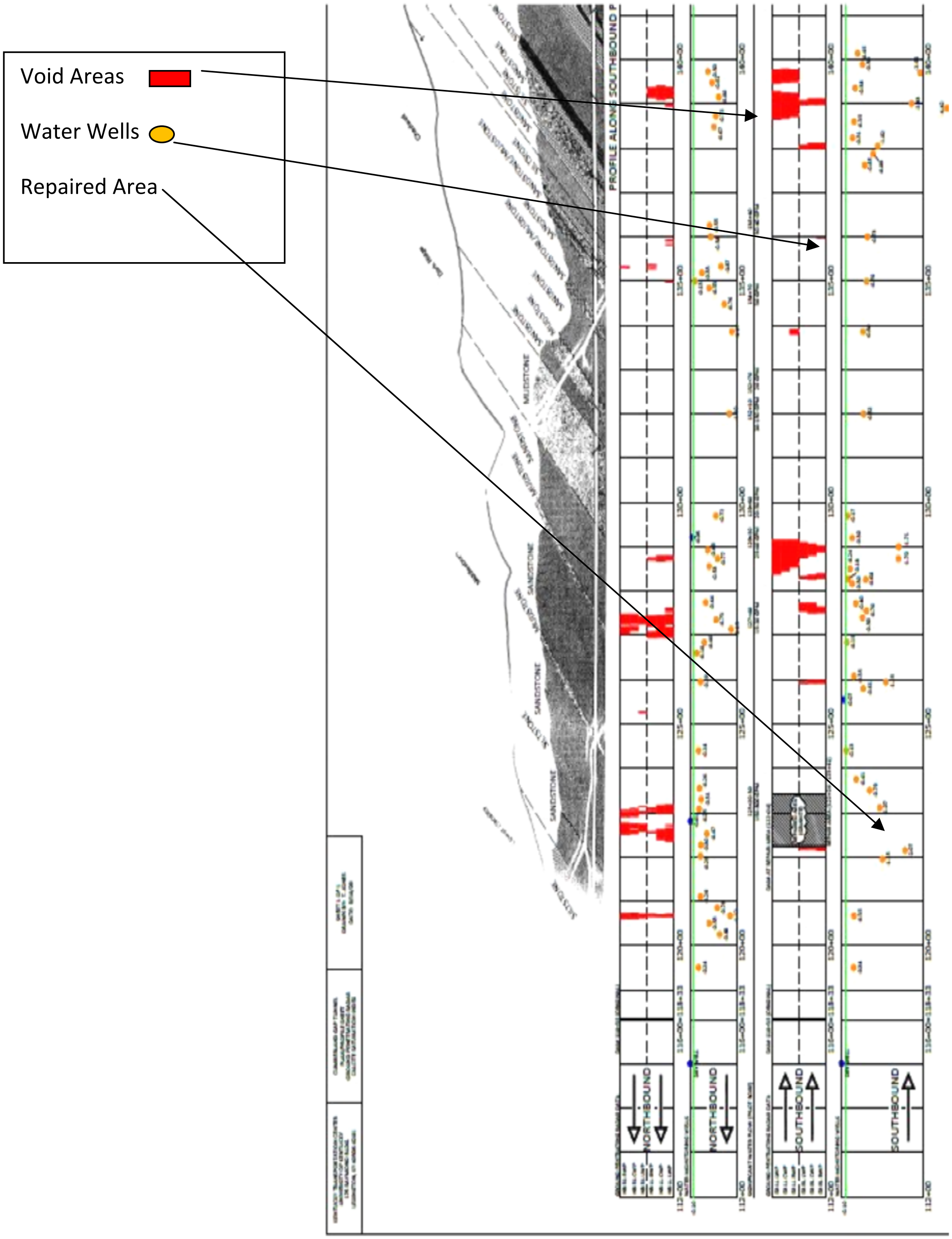


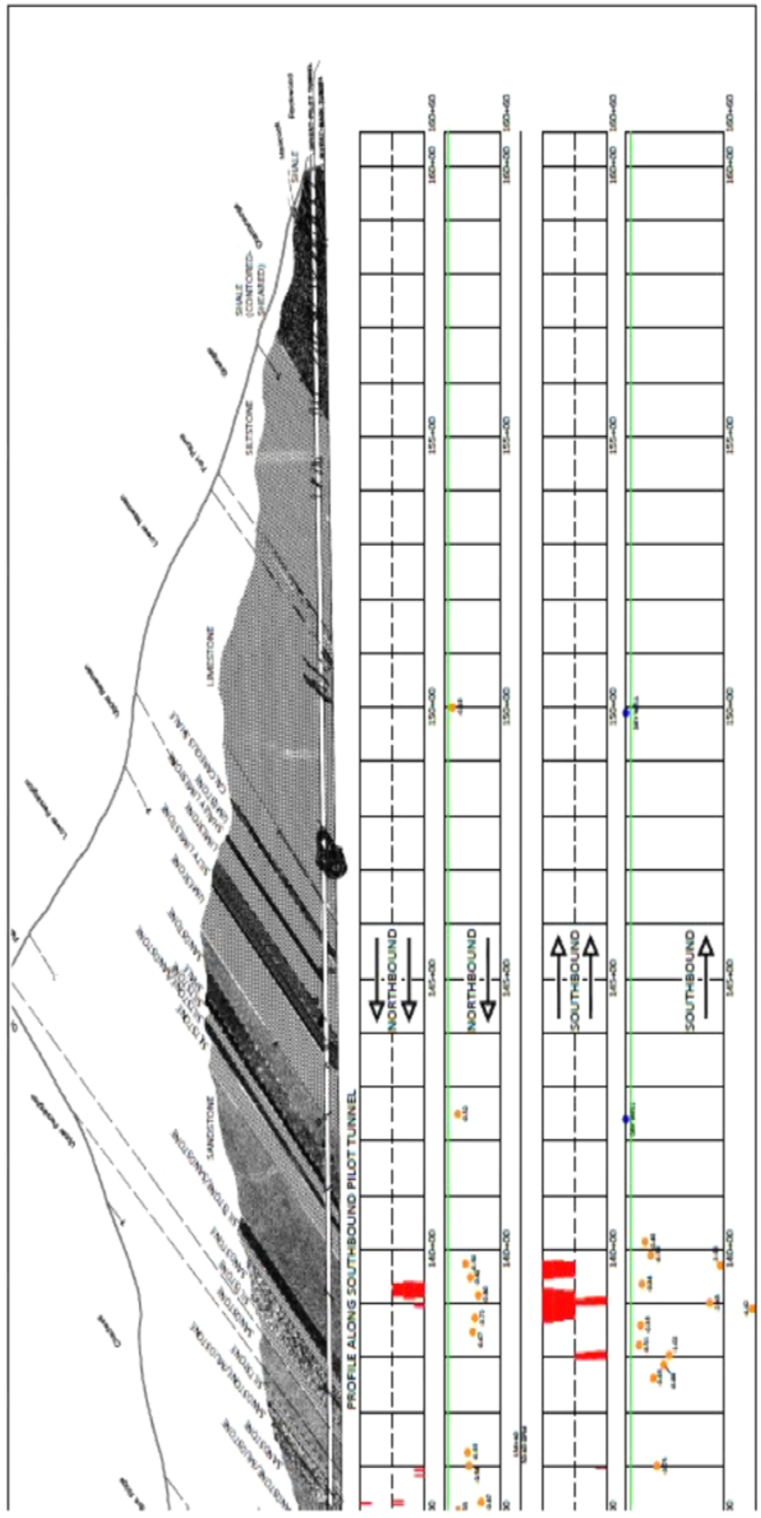
Figure 9: Conceptual long-term fix design--not intended for construction purposes.

CONCLUSIONS

In conclusion, there are many contributing factors that have caused the current pavement distresses seen at the Cumberland Gap Tunnel. It is the opinion of the technical group that a long-term fix is desperately needed to insure the future serviceability of the Cumberland Gap Tunnel. As has been done in the past, annual maintenance needs to be performed in efforts to avoid any potential pavement collapse until a long term fix is put into place.

APPENDIX A: Void and Water Well locations on strip map of tunnel.




PROFILE ALONG SOUTHBOUND PILOT TUNNEL
SHALE (CONTORTED-SHEARED)
SILTSTONE
LIMESTONE
SANDSTONE
NORTHBOUND
NORTHBOUND
SOUTHBOUND
SOUTHBOUND

APPENDIX B Calculated calcite saturation indices of south bound from 2007 to 2009

Site ID	Station Number	Calcite Saturation Index of South Bound*					Worst Value
		Oct-2007	Nov-	Apr-	Jun-2009	Aug-	
SB1A	115.01				Dry	Dry	Dry
SB1B	119.5				-0.05	-0.34	-0.34
SB1C	120.67				-0.07	-0.35	-0.35
SB1D	121.95				-0.41	-1.15	-1.15
SB01	122.15	-0.22	-0.55	-0.64	-0.74	-2.07	-2.07
SB02	123.11	-0.39	-0.35	-1.07			-1.07
SB03	123.5	-0.38	-0.32	-0.41	-0.02	-0.79	-0.79
SB4A	123.75				-0.10	-0.41	-0.41
SB4B	124.4				0.60	-0.13	-0.13
SB4C	125.55				-0.07	-0.07	-0.07
SB04	125.8	-0.18	-0.18	-0.61	-0.22	-0.36	-0.61
SB05	125.95	-0.52	-0.26	-1.25			-1.25
SB06	126.08	-0.22	-0.01	-0.35	-0.06	-0.35	-0.35
SB7A	126.84				-0.05	-0.15	-0.15
SB07	127.4	-0.51	-0.26	-0.58	-0.59	-0.38	-0.59
SB08	127.56	0.10	0.05	-0.70		-0.54	-0.70
SB09	127.72	-0.38	-0.01	-0.40		-0.24	-0.40
SB10	128.17	-0.11	-0.13	-0.30			-0.30
SB11	128.26	-0.68	-0.07	-0.65			-0.68
SB12	128.27	-0.18	-0.07	-0.10			-0.18
SB13	128.5	-0.24	-0.16	-0.20			-0.24

SB14	128.73	-1.02	-0.94	-1.63	-1.70	-1.39	-1.70
SB15	129	-1.36	-1.61	-1.71			-1.71
SB16	129.2	-0.30	-0.01	-0.16	-0.27	-0.05	-0.30
SB17A	129.7				-0.17	-0.03	-0.17
SB17B	132				-0.62	-0.55	-0.62
SB17C	133.86				-0.54	-0.60	-0.60
SB17D	134.99				-0.70	-0.14	-0.70
SB17E	136				-0.73	-0.15	-0.73
SB17F	137.62				-0.65	-0.15	-0.65
SB17	137.87	-0.28	-0.51	-0.54	-0.89	-0.46	-0.89
SB18	138.05	-0.90	-0.78	-1.02			-1.02
SB19	138.23	-0.19	-0.28	-0.31			-0.31
SB20	138.6	-0.17	-0.21	-0.35			-0.35
SB21	138.9	-4.28	-3.71	-4.42			-4.42
SB22	139.01	-2.43	-2.23	-2.12			-2.43
SB23	139.36	-0.37	-0.11	-0.38			-0.38
SB24	139.7	-2.37	-2.92	-0.66			-2.92
SB25	139.89	0.04	-0.59	-0.18	-0.43	0.05	-0.59
SB26A	140.14				-0.45	-0.04	-0.45
SB26	142.4	Dry	Dry	Dry	Dry	Dry	Dry
SB27	149.9	Dry	Dry	Dry	Dry	Dry	Dry

* blank: data not collected

Calculated calcite saturation indices of north bound from 2007 to 2009

Site ID	Station Number	Calcite Saturation Index of North Bound*					Worst Value
		Oct-2007	Nov-	Apr-2008	Jun-2009	Aug-	
NB1A	115.01				Dry	Dry	Dry
NB1B	119.5				-0.07	-0.24	-0.24
NB1C	120.25				-0.62	-0.83	-0.83
NB01	120.5	-0.53	-0.30	-0.29	-0.44	-0.34	-0.53
NB02	120.67	-1.12	-0.79	-0.94			-1.12
NB03	120.85	-0.47	-0.01	-0.32	-0.72	-0.76	-0.76
NB4A	121.1				-0.10	-0.29	-0.29
NB4B	122.02				-0.05	-0.29	-0.29
NB04	122.27	-0.11	-0.10	-0.07	-0.14	-0.30	-0.30
NB05	122.52	-0.47	-0.06	-0.39			-0.47
NB06	122.81	-0.01	0.00	0.03			-0.01
NB07	123.08	-0.05	-0.25	-0.01			-0.25
NB08	123.3	-0.08	-0.23	-0.31	-0.04	-0.30	-0.31
NB9A	123.55				-0.26	-0.23	-0.26
NB9B	124.4				-0.17	-0.24	-0.24
NB9C	125.95				-0.05	-0.29	-0.29
NB9D	126.6				-0.18	-0.12	-0.18
NB09	126.84	-0.35	-0.34	-0.40	-0.18	-0.14	-0.40
NB10	127.14	-0.52	-0.58	-1.15			-1.15
NB11	127.35	-0.58	-0.11	-0.73			-0.73
NB12	127.74	-0.44	-0.33	-0.13			-0.44
NB13	128.56	-0.53	-0.29	-0.32			-0.53

NB14	128.73	-0.77	-0.40	-0.66			-0.77
NB15	128.92	-0.49	-0.38	-0.30	-0.27	-0.20	-0.49
NB16A	129.21				-0.06	-0.05	-0.06
NB16B	129.7				-0.72	-0.06	-0.72
NB16C	132				-1.10	-0.20	-1.10
NB16D	133.86				-1.17	-0.27	-1.17
NB16E	134.48				-0.76	-0.24	-0.76
NB16	134.84	-0.53	-0.14	-0.10	-0.36	-0.25	-0.53
NB17	134.99	-0.09	-0.13	0.02			-0.13
NB18	135.18	-0.16	-0.33	-0.08			-0.33
NB19A	135.33				-0.87	-0.69	-0.87
NB19B	136				-0.58	-0.31	-0.58
NB19C	136.25				-0.55	-0.05	-0.55
NB19D	138.48				-0.67	-0.17	-0.67
NB19	138.73	-0.58	-0.32	-0.66	-0.72	-0.11	-0.72
NB20	139.15	-0.42	-0.12	-0.80			-0.80
NB21	139.48	-0.61	-0.37	0.19	-0.23	0.05	-0.61
NB22A	139.73				-0.50	0.05	-0.50
NB22	142.5	-0.32	-0.09	0.22	-0.12	0.04	-0.32
NB23	150	-0.19	-0.08	0.40	0.23	0.27	-0.19

* blank: data not collected

APPENDIX C: Micro-pile quote from Rembco Geotechnical Contractors

www.rembco.com

Fax

To: Lewis N. (Nick) Melton, P.E.
Vaughn & Melton
From: Mike Bivens
Fax: 606-248-0372 Pages: 4
Phone: 800-388-6660
606-269-4167 cell
Date: 12/7/2005
Re: Cumberland Gap Tunnel
Pavement Settlement
CC:
□ Comments:
Nick,
Please find attached a letter outlining conceptual options and preliminary budget estimates for remedying the
situations you have regarding pavement settlement.
Thanks,
R. Michael Bivens, P.E.
Project Engineer
www.rembco.com
December 6, 2005
Vaughn & Melton – Consulting Engineers
P.O. Box 1425
Middlesboro, KY 40965
Attn: Nick Melton
Re: Pavement Settlement – Cumberland Gap Tunnel
Dear Nick,
Per your request, Rembco Geotechnical Contractors, Inc. is pleased to provide you with this letter
summarizing concepts that you may find useful for repair of the settling concrete pavement areas
inside the Cumberland Gap Tunnel.
We understand that the mechanism for soil loss at the settled areas is suspected to be erosion of fines
from the subgrade due to groundwater movement. We understand that two types of repair options are
being considered. The first option involves the complete removal and reconstruction of the existing
concrete pavement and drainage system in the affected areas. The second option involves supporting
the concrete pavement on drilled micropiles or compaction grout piles. The following text summarizes

the extents of the problem areas and describes each of the two conceptual approaches outlined above.

Extent of Problem Areas

Based on information provided by you following our site visit, we understand that there are three major
areas where loss of subgrade is occurring. The major problem areas occur in both NB and SB bores at
CP's 3, 5, and 8 ½.

Near CP3, it appears that a 100-feet long area of the SB bore requires treatment. Two smaller areas of
void were found in the NB bore, but the total treatment area may be about 100 feet long, corresponding
to the similar areas in the SB lanes.

At CP5, a large void area was found in the SB lanes. The total length of treatment in the SB lanes may
be about 100-feet. The problem areas in the SB lanes are not mirrored in the NB lanes at the same
station, although there is a small area around station 128.70 about 10-feet long in the left lane, LWP.
Some treatment may be necessary in that area, but the larger area requiring treatment in the NB lanes
at this location is further north at station 127.00, covering a length of about 60-feet.

At CP 8 ½, multiple areas were found in both bores around station 138.5 that may require treatment. A
second area was found in the SB bore near station 138. It appears that treatment of both areas may
be combined and extend for a total length of 110 feet. A smaller area was found in the right SB lane
near station 138.0 for a length of about 15-feet. Voids were found in the left NB lane near station 139
for a length of about 25-ft.

If we assume that the treatment used for the problems will treat the entire tunnel width at each affected
area, the total length of treated length in both bores is about 520 feet. Assuming the goal of the
remediation efforts will be to bound the areas where voids were found, the final treated length may be
as much as 600-lineal feet.

We understand that your desired approach may be to perform a trial repair program in the SB lanes
near CP3 where visual evidence of settlement is observable. Such a trail program may be performed
on a 100-foot length from Station 122.37 to Station 123.34.

Proposed Treatment Methods

Regardless of the type of treatment method used, it is necessary to maintain operation of one traffic
lane through the work area. Both recommended repair options provide this capability.

Option 1 – Subgrade Reconstruction

The first treatment option we are considering is the reconstruction of the subgrade including the

implementation of a filtration blanket to prevent piping of fines from the subgrade. In order to maintain
one traffic lane through the area, it is necessary to underpin the edge of the remaining pavement lane
so excavation can occur during removal of the existing under-drain materials prior to filter construction.
We understand that excavation depths up to 4-feet below pavement level may have to occur adjacent
to the undisturbed operational traffic lane. Our underpinning efforts will focus on preventing raveling of
the existing stone under-drain materials, maintaining pavement support of the working traffic lane while
the new filter is constructed. We recommend that a cement grouting program be used to cement the
existing under-drain stone together, preventing raveling of the existing stone and maintaining support of
the pavement.
We believe that grout injections on 3-foot center to center spacing between the traffic lanes would
perform adequately. If 2-foot diameter grout columns are created on 3-foot center to center spacing,
then water from the drainage layer under the existing pavement could continue to flow between
columns. The columns could be removed during construction of the second traffic lane or remain inplace
if desired. We suggest that it may take less than one-week to underpin the required 100-foot
length through holes cored in the existing pavement slab. Our crew would complete the work and
demobilize prior to pavement demolition. The pricing of such work would consist of a
mobilization/demobilization pay item and payment for the grouting on a lineal-foot basis. Based on a
shoring length of 100-feet, we anticipate a total lineal-footage of grout injection to be about 140 lineal
feet if the depth of the injections average 4-feet below the surface of the pavement and are competed
on 3-foot centers. The cost of mobilization and demobilization for our crew and equipment may be
about $7,000. Grout injection of 2' diameter columns in #57 stone has a cost of about $70 per lineal
foot of grout injected. The total estimated cost of the grouting describe above is estimated at $17,300
for the proposed100-foot long shored length.

Option 2 – Micropile Foundation Support

The second treatment option we recommend is to support the pavement slab on micropiles drilled into
the rock subgrade. For permanent support, the piles must be installed into the rock, rather than endbearing
on the eroding rock surface. During our meeting, you suggested that support spacing would
be determined by your structural engineering staff, but the spacing may be up to 9-feet. We believe
that the controlling factor in a micropile design may be the ability of the pile top connection to transfer

load to the slab. For the purposes of this preliminary estimate, we will assume that a 6-foot spacing will
be used between micropiles. If the length of the supported area is 100-feet and the width is 30-feet, a
total of 84 micropiles may be used to satisfy the assumed 6-foot spacing.

While the required load capacity of the piles is unknown for the assumed 6-foot spacing, we can provide up to 100-k of capacity or greater if required, depending on the dimensions of the drilled holes
and the type of reinforcing steel used.

We suggest that the top-connection between the piles and the slab could be completed by grouting the
piles to the slab. In order for this type of connection to be constructed, the existing voids below the slab
will need to be filled. We recommend that a cement-based grout be used for void filling, since it will
become part of the top-connection of the micropiles. Assuming that the required capacity for the micropiles is 50-kips, the estimated cost per lineal foot of micropile is $75/LF. Based on an assumed
length of 10' per micropile, including mobilization, demobilization, and design engineering, the total cost
of micropile installation is about $85-95k for treating 3,000 SF with a 6-foot spacing, including void
filling. We believe the work could be performed in about two weeks. A significant advantage of this
type of system is that no significant excavation will be required and the existing drainage system will
remain undisturbed. Also, it is likely that the total time of lane closures required for this method will be
less than what is required for subgrade reconstruction (option 1).

We appreciate the opportunity to provide assistance with this project. Please contact us at your convenience with questions or information regarding this submittal. We are looking forward to working
with you during your selection of a repair option.

Sincerely,

Rembco Geotechnical Contractors, Inc.

R. Michael Bivens, P.E.
Project Engineer

For more information or a complete publication list, contact us at:

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