FOULED BALLAST AND GEOTECHNICAL ASSET MANAGEMENT OF RETAINING WALLS

by

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ABSTRACT

The objective of this thesis is to submit my work on two transportation geotechnics problems: unsaturated characteristics of fouled ballast and asset management for mechanically stabilized earth (MSE) walls. Ballast is the layer of aggregates that support railroad track; aggregates are used because of their high strength and because they are free-draining materials. Fouling occurs when fine-grained materials intrude into the ballast, which impedes drainage, reduces strength, and increases settlement. This reduces the service life of the track and can result in a train derailment. Researchers have studied ballast degradation for years; however, there has been limited research on the unsaturated characteristics of fouled ballast. This is likely because the relatively large aggregate limits the use of conventional soil testing and modeling. Therefore, this research focused on establishing the experimental and numerical results of unsaturated fouled ballast. This is the first time these types of measurements have been conducted for the railroad industry. Fouled ballast is an inherently unsaturated material. Establishing fouled ballast soil water retention curves is an important step in the experimental design and constitutive models to replicate field conditions. The results show that clay and coal fouling materials have similar water retention characteristics, despite having significantly different soil properties. The long-term goal of this research is to improve the ability of nondestructive methods to identify fouled ballast in situ. The MSE study will provide the Kansas Department of Transportation (KDOT) with an asset management program for MSE walls. MSE walls have been standing since the 1970s with little or no management after completing a wall unless it fails. Asset management techniques are a cost-effective way to show when maintenance is needed. There are many ways that an asset management program can be implemented. This study gives special consideration to other state departments of transportation and federal programs. Fourteen categories were selected as identifiable MSE elements for inspection and monitoring. The analytical hierarchy process method was used for a systematic weighting system for each category, along with additional risk-based factors determined by the MSE age, height, and average annual daily traffic. The new asset management system was used for 19 MSE walls in Kansas. The results show that two walls should be reinspected and closely monitored based on current deterioration. The most common defect was vegetation, which should be removed from the wall, but it does not significantly impact performance. A cost estimator tool was used so that KDOT can track the performance of the structure and tie deterioration to asset depreciation. This tool will give KDOT the ability to manage their MSE assets and therefore have a better return on investment in corrective actions.

1. INTRODUCTION

This thesis summarizes the research from two independent projects that address gaps in transportation geotechnics. The first was funded by the Federal Railway Administration (FRA) and involved unsaturated measurements of fouled ballast. This is a geotechnical project because when the ballast layer has severe fouling, it can cause track misalignment and train derailment. To detect fouling the FRA uses a tool called ground penetrating radar (GPR). If the fouling material is unsaturated the GPR can miss the fouling material and give poor readings. The FRA project has laid the groundwork for a constitutive unsaturated strength and permittivity model to describe track performance. The second project was funded by the Kansas Department of Transportation (KDOT) and addresses the performance measurement of geotechnical assets, specifically mechanically stabilized earth (MSE) walls. This is a geotechnical issue because MSE wall performances are not tracked after they were built unless a failure occurs. This portion of the thesis describes how a geotechnical management (GAM) program was developed for KDOT MSE walls. Each project was completed in one year for fulfillment of a MS degree. The unsaturated fouled ballast work has been disseminated through peer-reviewed conference papers (Feng, Radnor, Bernhardt-Barry, & Kulesza, 2022; Sarker, Radnor, Kulesza, & Barry, 2023) and a report to the FRA (Kulesza S. , et al., 2022). The MSE wall project will be submitted in a report to KDOT and included as part of a larger peer-reviewed journal article covering MSE wall asset management in Kansas. This thesis summarizes all work complete by myself for fulfillment of my MS degree. Within each chapter, the fouled ballast work is presented first, followed by the GAM work.

Fouled Ballast

The United States railroad has over 225,000 kilometers of track to maintain (Gupta A. , 2014). As shown in Figure 1-1, railroad track is composed of five components: rails, sleepers, ballast, sub-ballast, and natural or modified subgrade (Selig & Waters, 1994). Over time the ballast layer can become fouled. Fouling is defined as filling the ballast voids with fine particles (specifically material passing the 9.5mm sieve). Fouling occurs from three primary sources: breakdown of ballast from the cyclic loading of trains, pumping of fines from the subgrade, and infiltration of debris from the train into the railway (Li, Hyslip, Sussmann, & Chrismer, 2015). Fouling material is inherently an unsaturated material subject to continual wetting and drying based on the weather. Due to the constant fluctuation of moisture content this can cause a continual change in strength of the ballast layer and the ballast friction angle (Sussmann, Ruel, & Chrismer, 2012; Bruzek, Stark, Wilk, Thompson, & Sussmann Jr, 2016). When fouling becomes severe in the ballast layer, the ballast takes on the properties of the fouling material which can cause misalignment of the track (Selig & Waters, 1994; Li, Hyslip, Sussmann, & Chrismer, 2015).

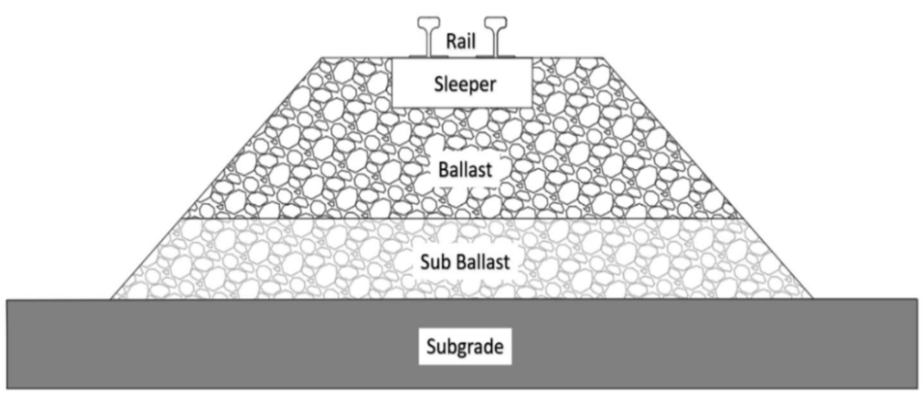


Figure 1-1 Cross Section of Railway

There are two approaches railroads use to detect fouling in the ballast layer, destructive and nondestructive techniques. The destructive techniques costs the railroad time and money by closing the track. Therefore, the rail industry has focused on nondestructive techniques to keep the track open. GPR is one highly pursued nondestructive method used to detect fouling. This method uses electromagnetic waves and their reflections with a known travel time based on the dielectric constant of the material. The dielectric constant is influenced by the fouling material characteristics, including its water content (De Chiara, Fontul, & Fortunato, 2014; Kashani, Ho, Oden, & Smith, 2015). Since fouling material is naturally an unsaturated material, it has highly variable water content which greatly influences GPR and its ability to identify fouling, (Sherwood, 2020)

Multiple different tests have been conducted on fully dry and fully saturated fouling materials (Huang, Tutumluer, & Dombrow, 2009; Indraratna, Ngo, Rujikiatkamjorn, & Vinod, 2014). In addition, many successful tests have been conducted on different fouling materials (Kashani, Ho, & Hyslip, 2018). However, little research is available on the unsaturated characteristics, specifically the soil water retention characteristics (SWRC) of fouling material or fouled ballast (Sherwood, Kulesza, & Bernhardt-Barry, 2020; Kulesza S. , Barry, Sherwood, & Santos, 2022). This research addresses this gap. The SWRC of four fouling materials were tested at different percentages of fouling and modeled. This thesis is a continuation of previous research conducted by Sherwood (2020) on unsaturated measurements of ballast fouling materials. The SWRC from the fouled ballast results in this thesis will be used for correlating suction, strength, and moisture content in a larger project for the Federal Railroad

Administration (FRA).

Mechanically Stabilized Earth Walls

The first MSE walls were constructed in France in the 1960s. MSE walls consist of alternating layers of soil and reinforcement with a fixed wall facing. The early design method used galvanized steel strips that reinforced the earth as designed by Henri Vidal. The first MSE wall built in the United States was by the California Department of Transportation (DOT) in 1972 for a road segment of highway 39 (Elias, Christopher, Berg, & Berg, 2001). Lee, Adams, & Vagneron (1973) showed the feasibility of using MSE walls in the United States. Since 1973 approximately 40,000 MSE walls have been built in the United States with a minimum design life of 75 years (Elias, Christopher, Berg, & Berg, 2001). After being constructed, many MSE walls have been left unchecked unless a failure occurs. Thus, there is a need for a systematic review of MSE walls in the United States.

While failure is uncommon, the economic impact of a single MSE wall failure can be in the millions. A recent MSE wall failure can be seen in Figure 1-2, costing Colorado DOT $20.5 million in repairs (Shaw, 2019). The investigation concluded that the failure was attributed to heavy rains during construction, and poor drainage (Minor, 2021). A contractor completed repairs to the failed section of the wall shown in Figure 1-2 within six months. The most frequent problems associated with MSE walls are loss of backfill, settlement, and drainage (Tarawneh, Al Bodour, & Masada, 2018). These problems can be identified by DOTs before there is considerable damage so that failures like the Colorado example can be avoided with a GAM program and routine inspection of the MSE wall.

Figure 1-2 Colorado U.S. 36 Bridge MSE Wall Collapse (Shaw, 2019)

The MSE wall schematic in Figure 1-3 shows a structure with a facing greater than 70 degrees, with internal reinforcement, and a facing element. The select backfill used in MSE walls is typically a clean granular backfill so that it is free draining. The select backfill reduces the pore water pressure that could be built up if water was retained in the wall. The wall facing is made of precast concrete panels. The coping on top of the wall is for aesthetics and weather protection of the panels (Elias, Christopher, Berg, & Berg, 2001).

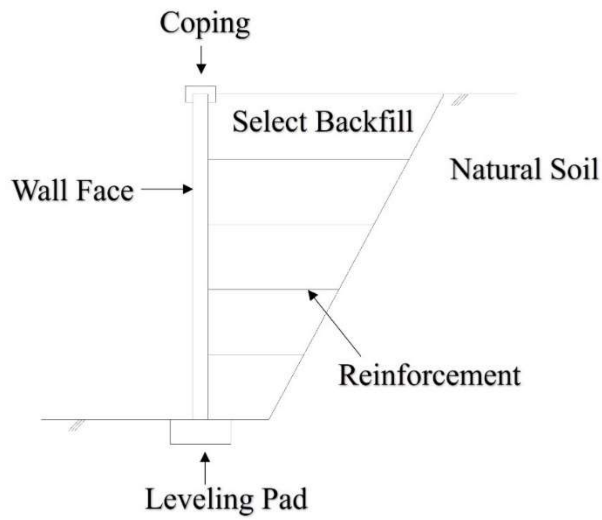


Figure 1-3 Schematic of an MSE wall

With passage of Moving Ahead for Progress in the 21st century (MAP-21) and in accordance with 23 U.S.C. 119(e)(4) state DOTs have used asset management techniques on bridges and roads called the transportation asset management (TAM) program (Hawkins, 2013). GAM is an extension of TAM which includes all geotechnical assets along the roadway, though this research focuses on MSE walls only. Many institutions have their own GAM programs. Some institutes are, but not limited to, Highway England, the National Park Service, and states in United States such as Ohio and Colorado.

In an effort to synthesize all these different programs so they can be readily adopted, the National Cooperative Highway Research Program (NCHRP) has produced several studies on what current international, federal and states level programs are doing as best practices. Brutus & Tauber (2009) first started the effort with obtaining information on all retaining wall assets. Gerber (2012) specifically focused on MSE wall assets and their performance issues. A more recent study conducted by Vessely et al.

(2019) provides an easily adoptable GAM program.

KDOT does not currently have a GAM, including an inspection system to understand if their walls are performing adequately. They only check MSE wall performance if there is something that has gone wrong. The objective of this research is to create an asset management system for MSE walls as a tool for assessment and inventory, specifically in Kansas. The focus is to understand the location of the asset and its current condition. After an inspection, a risk assessment of the wall is also conducted to understand importance of the asset. Based on this inspection, action may be required such as cleaning, repair, or reconstruction. Nineteen MSE walls were reviewed for KDOT in this research. The results of the inventory showed that most walls were performing adequately; however, two walls showed a need for further investigation based on panel bowing and severe misalignment of joints. This research has laid the groundwork for a GAM program in Kansas.

Organization of Thesis

This thesis is broken into four chapters after the introduction. Each section begins with the unsaturated fouled ballast and followed by the MSE wall project. Chapter 2 is a literature review on unsaturated soils, fouling material and its interaction in the ballast material. This is followed by the MSE wall work with current practices in geotechnical asset management, different inspectable elements, a weighting system known as the analytical hierarchy process (AHP), a risk-based approach to further assess the importance of the wall location and how rating occurs. Chapter 3 is the methods section; the first section is based on how the fouled ballast measurements were taken followed by the models used. The second section is dedicated to the MSE wall inspection checklist on how it is used. Chapter 4 is the results & discussion of the fouled ballast experiments and the MSE wall inspection and inventory. Chapter 5 is the conclusion of this thesis. The appendix is divided into two independent sections for each project.

2. LITERATURE REVIEW

This chapter focuses on the literature review of fouled ballast and current MSE wall asset management techniques. The fouled ballast portion focuses on what ballast is, how fouling is classified, with a background on unsaturated soils and it concludes with SWRC models reviewed. The second section focuses on current practices in geotechnical asset management. The rating system used, what elements are typically inspected and how a risk-based approach is used for assigning importance to an asset.

Ballast

Ballast is typically granite or dolomite rock, selected for its physical properties: hardness, angularity, and uniformity. (Indraratna, Buddhima, Wadud, & Salim, 2005; Li, Hyslip, Sussmann, & Chrismer, 2015). Ballast hardness and angularity function to resist the breakdown due to continually cyclic loading; railcars induce this over time. Ballast breakdown occurs at the sharp corners of the ballast, this decreases the angularity and increases track settlement of the ballast layer (Indraratna, Buddhima, Wadud, & Salim, 2005). Ballasted track's uniform gradation allows rapid drainage (Li, Hyslip, Sussmann, & Chrismer, 2015). However, over time drainage can degrade by different fouling methods. Three types are considered in this research. Fouling can happen from the breakdown of the ballast itself causing sand to build up in between the voids. The second type is from the subgrade itself such as the pumping of fines from the subgrade. The final fouling method can be from the train, such as coal dust and other materials going into the ballast voids. When fouling becomes severe, this can cause settlement, disrupt drainage, and comprise the existing track. Therefore, railroads are required to monitor their track for fouling and when, it is observed, the track must be remediated by cleaning the ballast layer. Fouling is characterized by various classification systems as described next.

Fouling Classification Systems

The fouling percentage can be defined differently; however, the fouling index developed by Selig and Waters (1994) called the Selig Fouling Index (FI) (1), is the most common. The FI considers the percent by mass of ballast passing the #4 sieve (4.75 mm) (P_4) plus the percent giving the #200 (0.075mm) P_{200}. The FI double counts for the fines passing the #200 because silt and clay affect the permeability and friction angle of the ballast (Selig & Waters, 1994). Since fines cause the most disruption in the ballast friction angle, the FI accounts for this in the fouling index rating chart shown in Table 2-1. Clean ballast has little to no fines and therefore has a low FI. As fines accumulate the FI increases to a fouled or highly foul state which is correlated to a lower track performance.

$$\mathrm{FI} = P_4 + P_{200} \tag{1}$$

Table 2-1 Comparison of Ballast Fouling and Fouling Index

Category	Fouling Index (%)	Relative Ballast Fouling Ratio (%)
Clean	<1	<2
Moderately Clean	1 to <10	2 to <10
Moderately Fouled	10 to < 20	10 to < 20
Fouled	20< 40	20 to < 50
Highly Fouled	>40	>50

A unique source of fouling is coal. Coal can disrupt the ballast layer to a greater degree than soil. However, the FI will give an artificially low estimation of coal fouling. This is due to the low specific gravity of pure coal which ranges from 0.8-1.3 versus most soil which ranges from 2.5-2.75. Thus, half the amount of coal will disrupt the ballast behavior compared to the average weight of clay or sand (Sussmann, Ruel, & Chrismer, 2012). To account for this, the relative ballast fouling index (R_{b-f}) as seen in (2) is used to give an improved estimate for coal fouled track (Indraratna, Su, & Rujikiatkamjorn, 2011) where M_f(kg) is the mass of the fines passing the 9.5mm sieve, M_{fb} (kg) is the

$$R_{b-f} = \frac{M_f\left(\frac{G_{b-f}}{G_{s-f}}\right)}{M_b} * 100\% \quad (2)$$

mass retained above the 9.5mm sieve, G_{b-f} (unitless) is the specific gravity of the ballast, and G_{s-f} (unitless) is the specific gravity of the fouling material. This allows for simple measurements to classify the fouling using specific gravity as a relevant soil parameter.

These are the most common method to classify fouling material. However, the method to determine the original degree of fouling M_f (kg) as seen in (3) was based off the clean weight of the ballast.

$$M_f = M_{cb} * X\% \quad (3)$$

To determine the degree of fouling, the weight of clean ballast M_{cb} (kg) was first determined and multiplied by the desired percentage *X%* (5,10, 15). This method allowed for replicates to be used based on grain size distribution passing the 9.5mm sieve for any fouling material.

Unsaturated Soil

Unsaturated soils generally occur in the vadose zone (wetting/drying zone) as shown in Figure 2-1. The vadose zone is measured from the ground surface to the groundwater table. Furthermore, the vadose zone area can be divided up into three subzones. The capillary zone above the groundwater table, the air-water phase zone, and the dry zone where water is no longer present (Fredlund D. G., 2006; Tuller, Or, & Hillel, 2004). The subzone of interest in this research is the air-water phase zone. This zone can be measured and shown as a SWRC. The soil is subject to varying degrees of saturation, never dry or fully saturated (Fredlund D. G., 2006; Tuller, Or, & Hillel, 2004). When the soil is unsaturated, it has a varying and complex response when loaded.

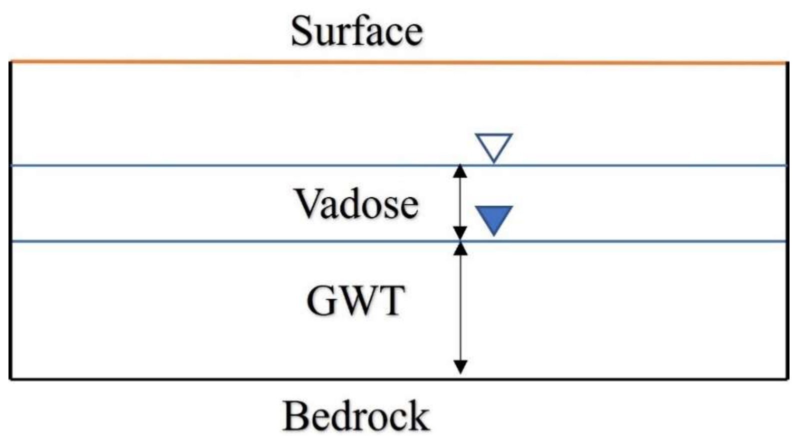


Figure 2-1 Representation of the Vadose Zone

When railroad track is laid, ballast becomes a natural extension of the surface thereby extending the vadose zone above the surface. Clean ballast is designed to drain freely and not retain water (Selig & Waters, 1994). When ballast becomes fouled, its saturation can range from completely dry to fully saturated causing the fouled ballast and similar materials to be in a constant state of moisture content fluctuation (Tutumluer, Dombrow, & Huang, 2008; Gupta, Kang, & Ranaivoson, 2009; Cui, 2016). Tutumluer et al. (2008) has demonstrated when different amounts of coal dust infiltrate the track at different amounts of moisture content it causes a decrease in strength in the ballast layer. Gupta et al. (2009) researched recycled asphalt pavement materials and showed that pavement materials are like fouled ballast in that they can have negative pore water pressure. Cui (2016) investigated the relationship between the number of clay fines and varying water contents. When the in situ and laboratory tests are compared, they found that the increasing number of fines with a low moisture content increased the resilient modulus of the track. However, when the fines became saturated the ballast layers resilient modulus loses strength.

Further, that when ballast becomes fouled, the interlocking friction angle is disrupted, and a strength loss occurs. When that fouling material undergoes a saturating event, this can further decrease the strength. When fouling becomes severe and saturated, the ballast strength is lost and takes on features of the fouling. To detect if fouling is occurring, the FRA uses a tool called ground penetrating radar (GPR). The GPR uses dielectric measurements to detect if fouling is occurring. It has multiple studies for fully saturated and fully dry measurements (De Chiara, Fontul, & Fortunato, 2014; Kashani, Ho, Oden, & Smith, 2015). However, few studies have been done for the unsaturated fouled ballast measurements (Sherwood, Kulesza, & Bernhardt-Barry, 2020; Kulesza S. , Barry, Sherwood, & Santos, 2022). Obtaining SWRC of fouled ballast will help further refine what the GPR can detect, when coupled with dielectric constants and strength measurements. Getting these measurements will allow a SWRC model to be generated for different fouling material that foul the ballast.

Soil Water Retention Curves

A SWRC, as shown in Figure 2-2, measures the soil volumetric water content versus the soil suction as the soil dries or wets (Fredlund D. G., 2006; Tuller, Or, & Hillel, 2004). Matric suction is the current stress state of the soil. Volumetric water as shown in (4) is found by taking the water contained in the soil pore network divided by the total volume of the soil. where θ is the volumetric water content (%), Gs is the specific gravity (unitless), e is the void ratio of

$$\theta = \frac{wGs}{1+e} \quad (4)$$

the soil (unitless), and w is the gravimetric water content of the soil (%).

The SWRC can be sigmodal or bimodal in shape. The SWRC describes three states: the fully saturated zone (capillary zone), the transition zone (air-water phase zone), and the residual zone. The parameters of a typical SWRC are fully saturated volumetric water content (Θ_s), air entry (α), the slope of the curve, and is related to pore size (n), residual volumetric water content (Θ_r).

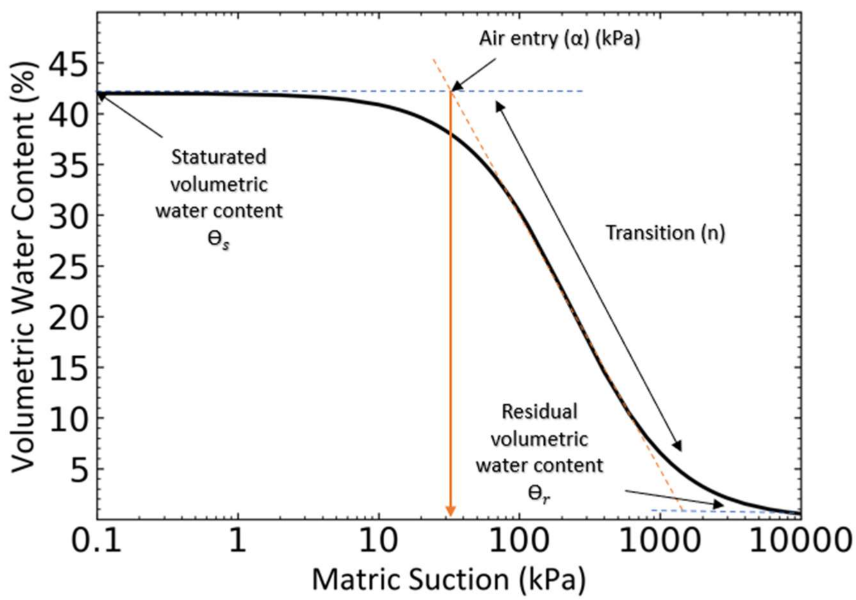


Figure 2-2 Description of SWRC

The saturated phase of the SWRC is the low suction range of the curve depending on soil type (Sherwood, 2020). When soil is fully saturated, all voids within the soil are filled with water. There are some pockets of air, however, they are discontinuous throughout the pore network. As more suction is applied to the soil, air entry can be seen in the curve. Air entry is when matric suction overcomes the soils' ability to stay fully saturated, and the air begins to displace water in the pore network. The transition zone in

Figure 2-2 is when matric suction becomes greater than air entry and water begins to flow out of the pore network. As liquid flows out, it is displaced by gas in the soil pore network. The slope of the SWRC is defined by gradation, mineralogy, and density of the soil. This transition zone shows the drainage path of a typical clay soil from the saturated phase to the residual phase. The residual zone has an inflection like air entry. There are still some pockets of liquid, however, they are discontinuous throughout the pore network. The liquid that remains becomes increasingly challenging to expel (Fredlund, Sheng, & Zhao, 2011). Overall, this SWRC represents how water leaves the soil.

The shape of the SWRC will change based on soil type and density, as shown in Figure 2-3. Typically, retain water over a narrow range of suction (0-10 kPa). This can be attributed to the much larger pore size distribution of sands. Silts and clays hold a large amount of water content over a greater range of suction (0-1000 kPa). Silt and clays have much smaller pore sizes relative to their soil type, gradation, and density, which can be correlated to greater water retention. Furthermore, most soil will exhibit hysteresis, the fluctuating state of a soil's wetting or drying path. They are similar in shape with the exception of the wetting curve being translated to the left of the drying curve. Figure 2-3 also shows the drying curve of typical soils.

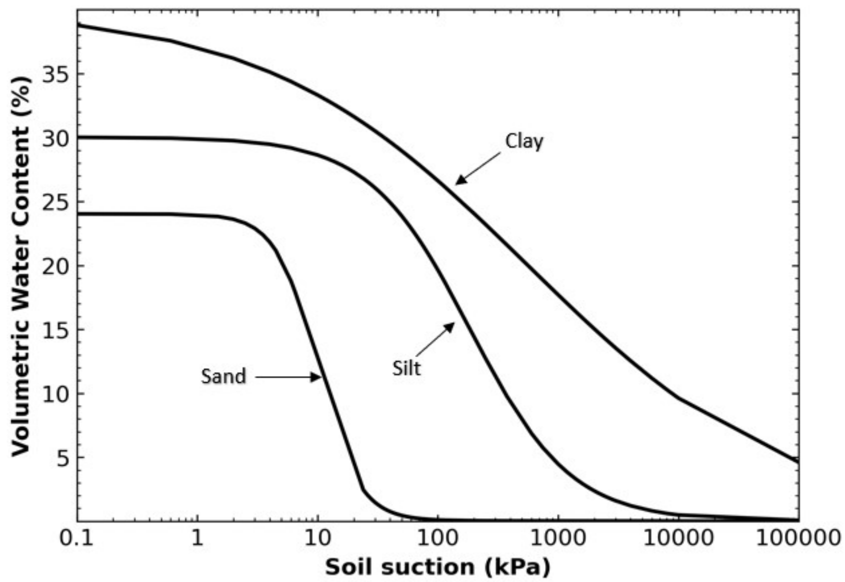


Figure 2-3 Typical SWRC for Different Soils

This research is unique in that the previous literature has focused on dry or fully saturated soils. Fouled ballast is inherently an unsaturated material, with limited information about its SWRC. This is likely because the size of the ballast is large compared to previous soil measurement of fouling material and soil. No direct measurement could be taken with the methods commonly associated with obtaining a SWRC. Such as hanging column, pressure chamber, centrifuge, and the chilled mirror method (ASTMD6836, 2016). Some intermediate measurements have been taken by Kashani et. al. (2015) on a modified triaxial machine at different water contents and strength. However, no SWRC were established when those measurements were taken. This research addresses this need.

Measuring SWRC

The definition of soil suction is the free energy state of water in the soil (Edlefsen & Anderson, 1943). Soil suction is measured in terms of total suction. Total suction (ψ) is comprised of two terms: matric and osmotic. Matric Suction is the difference between a specific pore water pressure (u_w) relative to a specific gas pressure (u_a) acting on the soil. Groundwater will rise above the groundwater table the same as it would in a capillary tube. This occurs due to the soil-water-air interface (surface tension, T_s). The soil-water-air interface will draw water up and hold it in place by the forces of surface tension. Osmotic suction (π) is the vapor pressure of water at equilibrium with a solution of pure water compared to an identical solution in its composition to the soil's water (Fredlund, Rahardjo, & Fredlund, 2012). It is well established by Krahn & Fredlund (1972) through laboratory data, that while both exist, a change in total suction is equivalent to a change in matric when moisture content is less than the residual water content value. Therefore, matric suction is the only suction considered in this research.

There are four classic methods to measure the SWRC drying curve. The hanging column, pressure chamber, centrifuge, and the chilled mirror method. The hanging column and centrifuge methods are used for a low range of suction measurements (0-80kPa and 0-120 kPa) and air entry determination. The pressure chamber is used to determine an intermediate range of suctions (0-1500kPa). The pressure chamber identifies the drying portion of the curve. The chilled mirror is used for a high range of suction (500 kPa-2000 kPa) and identifies the residual zone of the SWRC (ASTMD6836, 2016). Wayllace & Lu (2012) developed a simplified two-step method known as transit release and imbibition method (TRIM). This method allows for an expedient way to measure SWRC from 0-1500 kPa within 84-114 hours using the axis translation technique. Axis translation is the principle that steady pressure is maintained on one side of a ceramic disc, and on the other side pore, water pressure is maintained under atmospheric conditions (Hilf, 1956). The purpose of the ceramic disc is further explained in the methods section of this thesis.

Modeling SWRC

There are many hydraulic models available to simulate SWRC. The most common models used are the inverse models, also called parametric models. An inverse model is where the outputs are known such as moisture content and air entry and a back calculation is done to find the desired SWRC. The most widely used inverse models for SWRC are the Van Genuchten (1980) and the Fredlund Xing model (1994)

The Van Genuchten model (1980) has been widely used by agronomist and geotechnical engineers to understand the soil behavior (Fredlund, Rahardjo, & Fredlund, 2012). This model was developed to understand soil suction and available water for plant growth. The Van Genuchten model is shown in (5).

$$\boldsymbol{\theta}_{\psi} = \boldsymbol{\theta}_{r} + (\boldsymbol{\theta}_{s} - \boldsymbol{\theta}_{r})\left(\frac{\mathbf{1}}{\mathbf{1}+(\boldsymbol{\alpha}*\psi)^{\mathbf{n}}}\right)^{m} \tag{5}$$

Where θ_{ψ} is the SWRC θ_r is the residual moisture content θ_s is the saturated volumetric water content ψ is the suction at any point along the SWRC α is the air entry of the soil and n & m are fitting parameters that define the slope of the SWRC.

The Fredlund Xing model (1994) was developed for geotechnical engineers and commonly used by geotechnicall engieers in unsaturated soil mechanics (Fredlund, Rahardjo, & Fredlund, 2012)The Fredulnd Xing model is shown in.(6).

$$\boldsymbol{\theta}(\psi) = \boldsymbol{\theta}_s\left(\mathbf{1} - \frac{\ln\left(1+\frac{\psi}{\psi_r}\right)}{\ln\left(1+\frac{10^6}{\psi_r}\right)}\right)^{m}\left(\frac{1}{\left(\boldsymbol{ln}\left(e+\frac{\psi}{a}\right)^{n}\right)^{m}}\right) \tag{6}$$

Where $\theta(\psi)$ is the SWRC $\theta_s$is the saturated volumetric water content ψ is the suction at any point along the SWRC ψ_r is the residual soil suction to residual volumetric water content e is Euler's number (2.718) a is air entry of the soil and and n & m are fitting parameters that define the slope of the SWRC.

The main conceptual difference between the two models is the residual zone. The Van Genuchten model uses the residual water content as part of the inverse model. Whereas the Fredulnd Xing model forces the equation to zero at 1,000,000kPa (Leong & Rahardjo, 1997).

Li, Li, & Zhang (2014) developed a physically based SWRC model as shown in (7) to predict SWRC for unimodal or bimodal soils. Unimodal SWRC have one pore series which is uniform throughout the soil. Soils that have two pore series are called bimodal. They drain the macropores of the soil first followed by the micropores at a higher suction. Soils that are gap graded have two pore series, macropores and micropores. Water can be stored in both pores and expelled at different pressures. Ballast is naturally gap graded to allow for quick drainage of water. When fouling occurs in the ballast, it begins to exhibit two pores' series: ballast and fouling. All parameters of this model could be estimated through grain size distribution, making it a desirable model to compare with the measured results and to fully describe the SWRC. The parameters are shown in Table 2-2 and are described as follows: gravimetric water content (%) (w_s),

$$w(\psi) = l * \left(\frac{w_s}{l+1} - w_r\right) \frac{\sqrt{\psi_a \psi_t}^{\,n/\log\left(\frac{\psi_t}{\psi_a}\right)}}{\psi^{n/\log\left(\frac{\psi_t}{\psi_a}\right)} + \sqrt{\psi_a \psi_t}^{\,n/\log\left(\frac{\psi_t}{\psi_a}\right)}} + \left(\frac{w_s}{l+1} - w_r\right) * \frac{(l\psi_t)^m}{\psi^m + (l\psi_t)^m} + l * w_r * \frac{\sqrt{\psi_{a_2} \psi_r}^{\,n/\log\left(\frac{\psi_r}{\psi_{a_2}}\right)}}{\psi^{n/\log\left(\frac{\psi_r}{\psi_{a_2}}\right)} + \sqrt{\psi_{a_2} \psi_r}^{\,n/\log\left(\frac{\psi_r}{\psi_{a_2}}\right)}} + w_r * \frac{(l\psi_r)^m}{\psi^m + (l\psi_r)^m} \tag{7}$$

air entry (kPa) (ψ_a) of the soil, residual suction (kPa) (ψ_r) of the fouling material, residual water content (%) (w_r), residual suction of the ballast (kPa) (ψ_t), and air entry of the fouling material (kPa) (ψ_{a_2}) to be estimated. Four parameters suggested by Li, Li, &

Zhang (2014) are optimized as $l = 4$, $m = 0.8$, and $n = 2$ (unitless). Modeling for this method was done by determining the grain size distribution of the fouled ballast (Li, Li, & Zhang, 2014).

Table 2-2 Definition of Variables used in Li, Li, & Zhang

Macropores	Predicts the saturated gravimetric moisture content	$w_s = \frac{e}{G_s}$	(8)
	Predicts air entry of the macropores	$\psi_a = \frac{1.4^e}{3.6 d_{30} C_u^{0.25}}$	(9)
	Predicts residual suction of the macropores	$\psi_r = \frac{4{C_u}^{0.4}}{d_{10}^{0.57}}$	(10)
Micropores	Predicts air entry of the micropores	$\psi_t = 1.7 * C_u^{0.39} \psi_a$	(11)
	Predicts residual suction of the micropores	$\psi_{a_2} = \frac{0.11 d_{10}^{0.7}}{d_{30} d_{30}^{1.2}} \psi_r$	(12)
	Predicts residual of both macropores and micropores	$w_r = 0.03e + .005 \log(C_u)$	(13)

The SWRC developed by Wijaya & Leong (2016) is a graphically based method. This method utilizes curve fitting techniques and allows an uncomplicated way to plot the SWRC. However, a drawback to this technique is it cannot accurately predict beyond the measured data (Wijaya & Leong, 2016). As seen in (14) this was derived from the Heaviside function (Leong & Wijaya, 2015). This formula allows for the curves of the SWRC sigmoidal shape to be fit. The first part of the curve goes to zero when x is less than x_i. The second half of the curve goes towards one when x is larger than x_i. (Wijaya & Leong, 2016). Furthermore, the variables are as follows: x is the log of the current suction; x_1 is the log of the initial suction when water begins to flow at full saturation; x_i is the log of the intersection obtained graphically. c_i as seen in (15) is a curvature parameter determined from the graphical measurements. s_{i-} is measured graphically when suction begins to occur s_{i+} is the end of the curve for that bend.

$$\boldsymbol{R_i(x)} = \{(\mathbf{x} - \mathbf{x_1}) + \frac{\mathbf{1}}{\boldsymbol{c_i}} * \mathbf{ln}(\frac{\boldsymbol{cosh}[(\boldsymbol{c_i}(\boldsymbol{x}-\boldsymbol{x_i})]}{\boldsymbol{cosh}[(\boldsymbol{c_i}(\boldsymbol{x_i}-\boldsymbol{x_1})]} \tag{14}$$

$$\boldsymbol{c_i} = \frac{\mathbf{2}}{\boldsymbol{log}(\frac{s_{i+}}{s_{i-}})} \tag{15}$$

The SWRC formula following Wijaya and Leong (2016) is shown in (16). This formula can be used for unimodal or bimodal curves, where $\mathrm{w_{sat}}$ is the complete saturation of the sample. $\mathrm{m_1}$ is the steepness of the slope from $\mathrm{w_{sat}}$ to the start of air

$$\boldsymbol{w} = \mathrm{w_{sat}} - \mathrm{m_1}(\mathrm{x} - \mathrm{x_1}) + \sum_{i=2}^{n} R_i(x)(m_i - m_{i-1}) \tag{16}$$

entry. The following steps are used for this method. First, draw a best-fit straight line through each of the data sets. Next, determine the slope of the line segments and the matric suction at the intersection points. Go back from the intersection point and get s_{i-} and go down to the other curve and get s_{i+}. Then substitute the parameters into Eq. (14),(15), and (16) fit the SWRC.

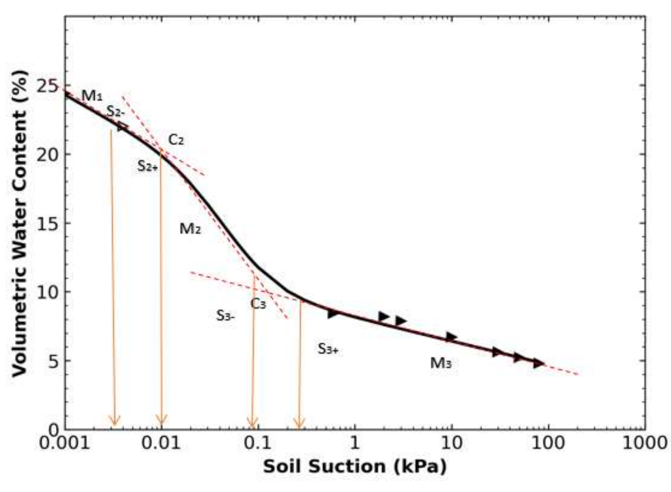


Figure 2-4 Graphically Curve Fitting Method (Wijaya & Leong, 2016)

MSE Walls

As previously described, MSE walls are a popular type of earth retention system, particularly in transportation systems designed by state DOTs. Failure of an MSE wall can be contributed to two types of failure, global or local failure. A global failure is a slope stability failure. A local failure is when a portion of the wall fails. Within those two failure modes, there are three categories of wall failure that is considered when designing an MSE wall. They are, sliding, wall tilting (eccentricity), and bearing capacity failure (Berg, Samtani, & Christopher, 2009). A sliding failure could occur if the active earth pressure on the wall overcomes the base frictional resistance. Wall tilting can occur if there is rotation about the toe of the wall or a bearing capacity failure. A bearing capacity failure is the wall has taken more load than it was designed for (Simac, Bathurst, Berg, & Lothspeich, 1993)

Since failures have been relatively rare, monitoring MSE walls was very limited until the early 2000s. The Moving ahead for progress in the 21st (MAP-21) century act was passed in June 2012. MAP-21 designated states to start an asset management program to monitor their ageing roadway infrastructure. An asset management program that came out of MAP-21 is called transportation asset management (TAM). TAM was specifically designed to monitor roads and bridges. Naturally, geotechnical structures are part of the roadway too. This led to the desire to monitor all assets within the right of way of the roadway. In response to the need for state DOTs to develop a GAM program, the National Cooperative Highway Research Program (NCHRP) funded a study to give guidance on how a GAM program could be implemented at the state level (Vessely, et al., 2019). The proactive measures of the NCHRP-903 help states implement their geotechnical assets along with the TAM program. This is a cost-effective way to incorporate it into TAM since KDOT received guidance on how to develop its TAM program in 2019 by WSP (Schwartz, 2019). KDOT extensively uses MSE walls in design and therefore will benefit from a GAM program to account for the monitoring and maintenance of MSE walls to be used in conjunction with their TAM program.

Existing Asset Management Programs

Existing asset management programs vary in their development. Mature GAM programs (10-20 years in service) such as the UK highway and the UK rail service are models to follow. Other less mature programs are leading the way in operation and maintenance (5–10-year years in service) programs. These programs show how to implement the program across the United States. For example, Ohio, Colorado, and Alaska have different systems of rating for geotechnical assets based on condition. New programs (i.e., 0-5 years in service) such as Michigan and New Jersey give a good comparison of what can be improved on in the existing literature on asset management

NCHRP-903 was a response to the TAM program for geotechnical assets. The implementation guide is provided to state DOT to quick start their asset management programs (Vessely, et al., 2019). This method involves a five-step process for any organization implementing a GAM program: objective, asset inventory, performance assessment, life cycle planning and risk management, and financial planning and investment strategies. The objective is an important part of the entire asset management process, it clearly defines what assets are going to be identified. Asset inventory prioritizes assets based on risk, allowing a total list of assets that need inventorying to be compiled. An inspection checklist is compiled for the location and baseline assessment of each asset. Next, a summary is compiled of assets inventoried for operation and maintenance (O&M), safety and risk (S&R) and mobility and economics (M&E) to be compared for asset spending. The third step is to address if the asset is performing as intended or if repairs are needed. The fourth step summarizes lifecycle planning based on asset type for a baseline performance over its lifetime. The fifth and last step in an asset management program is financial planning and investment strategies. The NCHRP-903 wants to track sources of funding, and the actual cost of an asset. This will help align with other departments within state DOT's, allowing money to be saved inter-departmentally. With this framework, any agency can establish its own asset management program.

Inventory Inspection Procedure

MSE walls are constructed to support roadways and bridges and hold back the earth (Vessely, et al., 2019). Inspecting the elements of a MSE wall is important because if the MSE wall fails the potential for the roadway and bridge to fail will increase. The NCHRP does not have an inspection checklist, however many states have developed their own. There is no federal uniform inspection system for MSE walls. Attempts have been made to rectify this gap at the federal level. The NCHRP published an initial guide to start the process of closing this gap. Brutus & Tauber (2009). This report was the first to send surveys out to state DOT's and ask what is important to track regarding all earth retaining structures. The findings include 96 potential action items in inventorying, inspection criteria, and risk management. The recommended inspection checklist was broken into four ratings: low, moderate, high, and urgent. The inspection included 22 inspectable items such as wall tilting, settlement, drainage, and vegetation. After the initial inspection, a recommendation is made if a structural review is needed. Later, at the federal level through NCHRP, Gerber (2012) focused on defining what MSE wall criteria should be inspected. This study included an extensive literature review of current practices of MSE wall inspections, they also surveyed DOTs from all 50 states. This questionnaire was an effort to get experts' opinions about common modes of failure and information about their MSE wall inventory. An inspection checklist was developed with a rating scale where one is poor and ten is excellent. The categories they included were similar to Brutus & Tauber (2009) with wall tilting, drainage, and settlement. From the lesson learned, experts concluded that failure of an MSE wall is a combination of factors such as poor drainage, wrong technical application, and selecting the right backfill (Gerber, 2012). The latest report by Vessely (2019) builds on the previous reports by providing the most current GAM recommendation. Additionally, it has paved the way for GAM programs to be adopted with very low investments by state DOT's.

Colorado has a well-developed asset management program that has a risk-based approach checklist (Walters, et al., 2016). The checklist has a one to four rating system where one is good and four is severe. The checklist considers two main categories on the wall, primary and secondary elements. A primary element is considered as the structural integrity of the wall and will have a greater priority for repair and cost. Secondary elements are considered aesthetic that cost little in comparison to repair. Likelihood to incur cost scores are assigned to each element inspected and incorporated into an overall cost that gives a monetary risk-based value.

Another well-developed asset management and inspection program is North Carolina's GAM program. This program breaks down the inspectable items of an earth retaining wall into four categories: facing, movement, drainage, and exterior. Those four categories have 17 subcategories split between them to inspect. To further refine how the wall is performing, North Carolina GAM rates how much of the wall is in four categories (good, fair, poor, and severe) by percentage (Butler, et al., 2016). This allows for a more precise rating of the wall to be assigned for each category. Defects may go unnoticed when a single rating is applied, however, the defect can be measured when an inspection occurs (Gabr, Rasdorf, Findley, Butler, & Bert, 2018).

Inspection Checklist Categories

The Gerber (2012) study sent out a survey to recipients to rate the importance of 37 different categories based on their experience. The recipients rated the categories based on their experience and were given a range of 1-5 rating where 1 is a low rating and 5 is a high rating. Those categories could be grouped into larger categories such as movement of the wall, drainage, backfill or soil, facing and exterior. Details of each category and why they are typically considered important details to inspect.

The movement category in inspection checklists consider wall tilting and settlement. Wall tilting is considered the most important because this could indicate a bearing capacity failure of the wall (Elias, Christopher, Berg, & Berg, 2001). However, it should be noted this could be a feature of the wall from the initial construction and should be recorded at the end of construction (Berg, Samtani, & Christopher, 2009). If the entire wall has excessive tilting (30 degrees or more) this could be considered a global failure (Passe, 2000). However, if a section of the wall is excessively out of alignment this could be considered an internal, or local, failure. If noticeable wall tilting was noted from a previous inspection, monitoring or remediation is recommended at the discretion of the engineer. Wall settlement is considered due to the impact on the roadway on top of the wall. Some short-term settlement is expected during and after construction, (Berg, Samtani, & Christopher, 2009) however, excessive short- and long-term settlement can cause issues with the roadway on top of the MSE wall. Settlement can also cause panels to bow or break if joints are not properly spaced. Assessing settlement can be done qualitatively or quantitatively. Qualitatively it is assessed based on roadway conditions, i.e., if it is impacting traffic. Quantitative settlement is determined by measuring and tracking the change in height of the MSE wall from each inspection. For a quantitative measurement, the initial inspection must collect these data for the start of the tracking.

Drainage deals with scour or soil erosion, internal drainage, and external drainage (Koerner & Koerner, 2018; Schmidt & GE, 2010). Scour will expose the leveling pad and undermine the wall panels causing panel failure and reinforcement exposure. Scour is measured from the relative depth of soil or riprap at the base of the wall from the original construction. If the MSE wall is founded on rock this can be ignored since the MSE wall will not be undermined regardless of scour. Internal drainage is designed to move water away that would normally infiltrate the MSE wall (Berg, Samtani, & Christopher, 2009). However, if drainage is damaged or not draining as intended, pore water pressure can build up behind the wall. Pore drainage can also cause backfill erosion of the fill material. Poor drainage may also lead to variable levels of saturation which can degrade the reinforcements from corrosion (Melchers & Petersen, 2018). Berg et al. (2009) suggested that drainage screens be checked to ensure rodents or other creatures are not nesting and causing blockage of internal drainage.

Soil categories can deal with panel bowing, resistivity, and backfill erosion. Panel bowing/bulging could indicate failure of reinforcement or pore water pressure buildup inside of the wall. This is measured as the visibility of how much the panels are bowing at the joints. Further, if the reinforcement is completely exposed, it is typically a severe condition and needs to be replaced. Resistivity is a specific measurement that is obtained by drilling holes in the facing and inserting stainless steel stakes (Parsons, Han, & Kulesza, 2021). The resistivity measurement indicates conditions that may lead to increased backfill corrosivity. A measurement of 2000 Ohms or less means the environment may have the conditions that lead to steel reinforcement corrosion and the MSE wall will have a shorter service life (Parsons, Han, & Kulesza, 2021). Backfill material loss can indicate reinforcement strips are being undermined, therefore reinforcing strength may be reduced (Elias, Christopher, Berg, & Berg, 2001)

Facing deals with the performance of the concrete panels and can be broken down into four sub-categories: joints, staining, cracking, and spalling. If joint spacing becomes too wide, backfill erosion can occur. When joints are initially placed the typical spacing is 1.9 cm (0.75 in). Over time this spacing can become disjointed or too wide. When this happens backfill, loss can occur (Berg, Samtani, & Christopher, 2009). Staining is an indicator that water is not properly drained. Over time staining can damage to the panels (Gerber, 2012). Cracking deals with the concrete facing of the panels. If cracking is severe backfill material can be lost. Spalling indicates failure of the panels from natural breakdown due to weathering or poor-quality concrete. The crumbling of the panel or section is an indication of spalling.

The exterior category deals with the aesthetics of the MSE wall such as coping on top of the wall and vegetation. Coping is placed on top of the MSE wall to protect the backfill from erosion. Coping cracking and spalling should be monitored because if they become severe it can cause backfill to erode. The vegetation category deals with plants growing from the wall. Vegetation, if left unchecked, can cause deterioration of the MSE wall. However, since it can be easily removed it is the least important category (Butler, et al., 2016; Gerber, 2012). Note that vegetation is often related to poor internal drainage.

Analytical Hierarchy Process

Rating systems lose their effectiveness when too many categories are considered (Saaty & Vargas, 2012; Butler, et al., 2016). A typical inspection checklist that allows for more critical wall elements to have the same weight as less critical wall elements may not accurately characterize the current condition of the wall. To address this, the Tennessee GAM program generated weighted averages from the analytical hierarchy process (AHP). AHP allows for weights to be assigned to categories based on experts' opinions (Saaty & Vargas, 2012). Tennessee used four categories to weight its inspection checklist: structure, auxiliary, surrounding setting, and functionality (Wu, Wang, Onyango, & Wu, 2021). The structure category considers the main elements such as the foundation or wall element. The auxiliary category deals with drainage such as external and internal drainage. The surrounding category considers aesthetics such as panels deterioration, coping, and vegetation. The final category service is a risk assessment category that checks if the wall is performing as intended. The AHP then weights these four categories based on expert judgment. The AHP uses a matrix piecewise comparison of one category to another by means of rating the first on a 1-9 scale of importance (Saaty

& Vargas, 2012). A one means that the two categories are equal whereas nine means that when A compared to B, A is extremely more important than the B category. The full range of ratings and their explanations can be seen in Table 2-3

Table 2-3 AHP Piecewise Rating System

Rating	Description
9.0	Extremely more important
7.0	Strongly more important
5.0	Moderately more important
3.0	Somewhat more important
1.0	Equal
0.33	Somewhat less important
0.20	Moderately less important
0.14	Strongly less important
0.11	Extremely less important

Note: Reprinted from "Models, Methods, Concepts and Applications of the Analytic Hierarchy Process," by Saaty, T., 2012, p. 6, New York, New York: Springer.

The Tennessee GAM program categories are weighted by the AHP method. The Tennessee GAM rated their structure category as having the largest impact 55%, risk functionality 25%, auxiliary 15%, and surrounding setting 5% being rated the lowest but still having an impact, (Wu, Wang, Onyango, & Wu, 2021).

Risk Based Approach & Rating Category

A final element to inspecting an asset is a risk management approach. This takes into account what risk the asset could have on the public if that asset fails. This includes height of the wall, how high of traffic area and wall age. To capture this aspect for an inspection, a risk-based approach taken by Tarawneh (2018) was developed to further modify general rating score ($MGRS$) the final rating score based on public safety. The additional criteria considered for the MSE wall are age, annual average daily traffic (AADT), and height. The age of the wall is important due to unknown deterioration of the wall (M_A). AADT accounts for how high of an impact it would have if failure did occur. This criterion is based on the FHWA's functional classification (Hawkins, 2013). The height of the wall (M_H) is considered because the higher the wall the higher the risk of failure. The modifiers for each category can be seen in Table 2-4, Table 2-5, and Table *2-6* respectively.

Table 2-4 Age Modifier

MSE wall Age (years)	Modifier Value
<10	1.00
10-15	0.98
15-20	0.96
>20	0.94

Note: Reprinted from "Inspection and risk assessment of mechanically stabilized earth walls supporting bridge abutments.," by Tarawneh, B., 2018, Journal of Performance of Constructed Facilities, 32(1) p. 04017131

Table 2-5 AADT Modifier

AADT	Modifier Value
<4,000	1.00
4,000-18,500	0.98
18,500-35,000	0.96
>35,000	0.94

Note: Reprinted from "Inspection and risk assessment of mechanically stabilized earth walls supporting bridge abutments.," by Tarawneh, B., 2018, Journal of Performance of Constructed Facilities, 32(1) p. 04017131

Table 2-6 Height Modifier

MSE Wall Height (m)	Modifier Value
<5	1.00
5-10	0.98
10-15	0.96
>15	0.94

Note: Reprinted from "Inspection and risk assessment of mechanically stabilized earth walls supporting bridge abutments.," by Tarawneh, B., 2018, Journal of Performance of Constructed Facilities, 32(1) p. 04017131

A rating scale was developed 4-1 (Tarawneh, Al Bodour, & Masada, 2018) with further definition of good through poor based on the modified rating scale as show in Table 2-7. Tarawneh (2018) developed a modified general rating score $MGRS$ as shown in Eq.2.17.

$$MGRS = GRS * M_T * M_H * M_A \tag{17}$$

Where GRS is the score based on the overall score from the inspection checklist. M_T us based on the annual average daily traffic (AADT). $M_H$is based on the height of the wall. $M_A$is an age based modifier on how old the wall is.

Table 2-7 Modified Rating Score Tarawneh (2018)

Modified general rating score (MGRS)	Category	Action
3.5 < MGRS ≤ 4.0	Very good	No action is needed.
3.0 < MGRS ≤ 3.5	Good	No immediate action is needed; specific notes should be recorded for special inspection during the next inspection
2.5 < MGRS ≤ 3.0	Satisfactor y	No immediate action is needed; maintenance should be performed before the end of next season. List an increased inspection schedule until maintenance is performed.
2.0 < MGRS ≤ 2.5	Poor/fair	Maintenance should be performed relatively quickly in the current season.
1.5 < MGRS ≤ 2.0	Serious	Perform necessary maintenance/repair as soon as possible.
1.0 < MGRS ≤ 1.5	Critical	Immediate maintenance should be performed. Traffic may be rerouted depending on the required maintenance.
0.5 < MGRS ≤ 1.0	Imminent failure	Emergency action is required to reroute the traffic and start major maintenance or full replacement.
0.0 < MGRS ≤ 0.5	Failed	The structure is closed for major maintenance or full replacement.

Note: Reprinted from “Inspection and risk assessment of mechanically stabilized earth walls supporting bridge abutments.,” by Tarawneh, B., 2018, Journal of Performance of Constructed Facilities, 32(1) p. 04017131.

It is suggested that if the wall is in good-fair condition and without any severe categories being rated, that every 6-12 years is good to reinspect the wall (Dimaggio &

MacMillan, 2018; Tarawneh, Al Bodour, & Masada, 2018). However, if it poor or lower, inspection should be yearly or close monitoring is suggested (Ramakrishna, Dimaggio, Sharp, & Mohab, 2021).

In general, the literature review for MSE walls shows that each state takes a different approach to inspection and asset management. However, the similarities cannot be overlooked with the same general numerically rating score (Brutus & Tauber, 2009)). A basic risk factor associated with importance of the wall (Tarawneh, Al Bodour, & Masada, 2018; Dimaggio & MacMillan, 2018). That nearly all states with the exception of Tennessee (2021) do not weight their inspection categories, this could hide performance issues if too many categories are considered. With a review of all MSE walls categories, they can be narrowed down to a few main categories such as movement, drainage, a backfill material, facing and any exterior problems with the MSE wall. Categories based on what can be visually inspected are chosen to understand how the wall is performing. Adjusting the final rating score of a wall based on impact to the public if it fails is important.

3. METHODOLOGY

This chapter focuses on the methodology and procedures for fouled ballast testing and MSE wall inspection sheet. The fouled ballast is discussed first with materials used, classification of fouling material procedures of test setup, measuring the SWRC and modeling the SWRC. The second section focuses on the inspection checklist by breaking down the checklist into different sections, a description on how to use the checklist and how the weighting factor has been used.

Methodology and Procedures for Fouled Ballast Testing

The experimental methodology is to measure the matric suction and volumetric water content of ballast with different degrees of fouling to support the modeled SWRC. Burlington Northern & Santa Fe Railway (BNSF) donated the fouling materials and ballast aggregates. A large flow cell was used to test the SWRC of fouled ballast. A modified TRIM technique was used to relate moisture and suction of the fouled ballast, which is described herein and validated. A graphical fitting method developed by Wijaya and Leong (2016) was used to obtain the SWRC of the fouled ballast.

Materials

The fresh granite ballast was obtained from a quarry in Oklahoma and three of the fouling materials were obtained from mainline track owned by BNSF. All fouling material gradations tested can be seen in Figure 3-1. Sand 1 and Sand 2 were taken from fouled track and washed of all fines that pass the #200 sieve. The third fouling material was taken from a track used to transport coal freight. It was black in appearance and classified as a silt according to ASTMD4318 (2022). The fourth fouling material was purchased so that we could test a clayey fouled sample. The “Redart clay” was obtained from Armadillo Clay & Supplies.

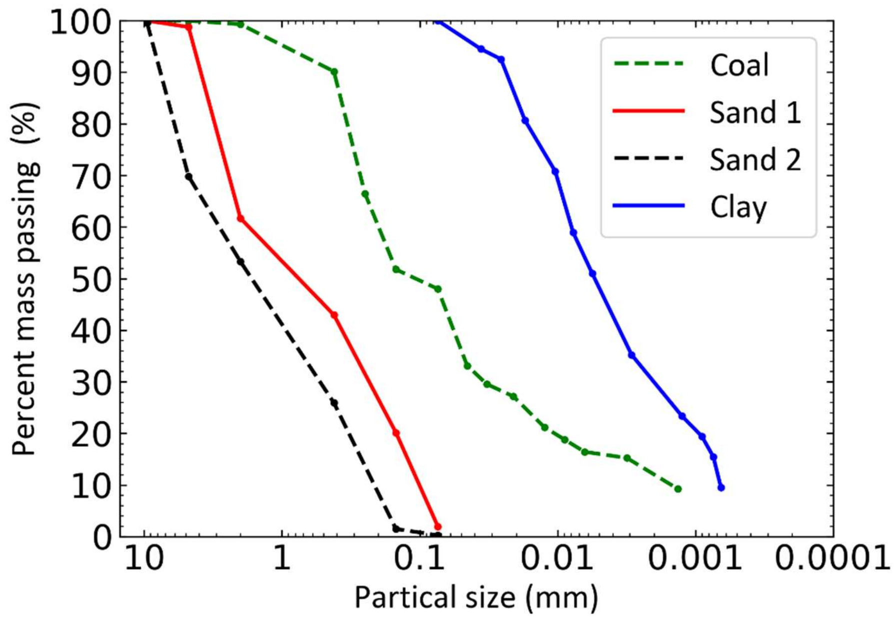


Figure 3-1 Grain Size Distribution of Fouling Material

Fouled ballast specimens were prepared by mixing clean ballast with various degrees of fouling using the four fouling materials. The clean ballast was prepared according to the AREMA #4 gradation (AREMA, 2020). The degree of fouling was the mass of fouling material relative to the mass of the clean ballast to ensure replicate samples could be efficiently made. Clay fouling specimens were prepared to 5%, 10%, and 15%. The sand fouling specimens were prepared to 5% and 10% for Sand 1 and10% and 15% for Sand 2. Sand 2 is a mixture of two sand fouling materials with similar gradations. Mixing the two gradations resulted in a different gradation than the original Sand 1. The mixture was required to have enough material for 15% sand fouling used by our research partner for the FRA study. The coal fouling was prepared to 5% and 10%.

Therefore, a total of nine specimens were prepared. The FI is shown along with the degree of fouling in Table 3-1.

Table 3-1 Degree of Fouling and FI for Laboratory Prepared Specimens

	Sand 1		Sand 2		Coal		Clay		
Degree of fouling	5	10	10	15	5	10	5	10	15
FI	3.73	7.07	6.33	8.22	7.36	13.3	11.1	19.7	27.4
SFI Category	MC	MC	MC	MC	MC	MF	MF	MF	F
RBF	6.4	11.5	11.4	15.8	6.6	11.9	6.1	10.9	15.7
RBF Category	MC	MF	MF	MF	MC	MF	MC	MF	MF

FI = Selig Fouling Index; VCI = Void Contamination Index; RBF = Relative Ballast Fouling Ratio.
C = Clean; MC = Moderately Clean; MF = Moderately Fouled; F=Fouled

Methods

The TRIM system developed by Wayllace & Lu (2012) was used to measure the volumetric water content and corresponding matric suction for the SWRCs. The TRIM system is a laboratory set up consisting of control panel, flow cell, high air entry (HAE) ceramic disc and a scale. A schematic of the TRIM system can be seen in Figure 3-2 and the modified setup for ballast can be seen in Figure 3-3. The control panel regulates the amount of pressure or vacuum applied at any given time. The flow cell contains the HAE disc and the soil sample. The HAE disc uses the principal of axis translation in which the HAE disc maintains a steady pressure on top of the disc while on the other side of the disc a steady pore water pressure is maintained at atmospheric conditions (Tarantino, Romero, & Cui, 2009; Hilf, 1956). The scale is used to measure how much water is imbibed into the specimen under vacuum and how much water is expelled under pressure.

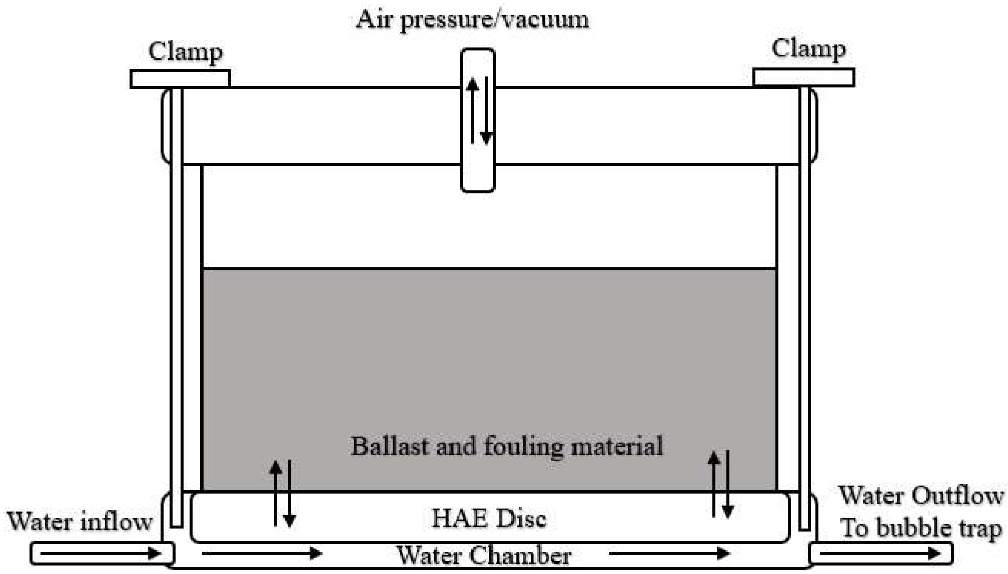


Figure 3-2 Theoretical Test Setup

Figure 3-3 Cell Setup with Scale

The TRIM method was used to measure SWRC of fouling materials in a standard flow cell with a height of 66 mm and a diameter of 61 mm Sherwood (2020) . It is widely accepted in geotechnical engineering is that specimen particles need to be six times smaller than the diameter of the measuring device (Holtz & Gibbs, 1956). The average ballast particle in this study was 38.1 mm in length with variable thickness and width, therefore a large flow cell was created with a height of 17.8 cm and a diameter of 25.5 cm (Sherwood, 2020). This large flow cell was used to determine unsaturated measurement of ballast with fouling material. The standard TRIM procedure was modified as described below to allow for additional measurements so that additional SWRC models more appropriate for ballast could be explored. The standard TRIM test simultaneously measures the hydraulic conductivity function and uses the Van Genuchten (1980) model to solve an inverse problem with only two direct measurements of suction; however, the Van Genuchten model was not appropriate for fouled ballast. Also, it was not possible in a standard test to obtain a measurement near air entry, which is required for successful Van Van Genuchten model.

The first step in running a TRIM test is saturating the high air entry (HAE) disk, shown in the bottom of the diagram in Figure 3-2. Two HAE discs were used in this research: a 1 Bar and 0.5 Bar. The HAE was selected based on the highest suction required to achieve residual volumetric water content. Saturation of the HAE disc was achieved via a vacuum pump and desiccator. The HAE disc was placed in a desiccator under 80 kPa of vacuum partially submerged for 30 minutes. Then the desiccator was gently tapped until the disc was fully submerged while still applying a vacuum. Full saturation of the disc was achieved when no more air bubbles could be seen escaping the disc (Wayllace & Lu, 2012). The flow cell was then assembled with the fully saturated disc. As shown in Figure 3-2 and Figure 3-3, the HAE disc was placed in the bottom of the cell. A light coat of vacuum grease was applied to an O-ring (not shown) placed on the stone. Then the cell was placed on top of the O-ring and rotated to seat the cell and the O-ring. Finally, the lid was placed on top of the cell and tightened with the clamps.

A leak test was conducted before each test to ensure the cell was assembled correctly, specifically that the cell would not leak water or air during the test at the target applied pressures, which would invalidate the test. After the cell was assembled, water was used to flush air below the HAE disc. The cell was then rotated up and down until no more air bubbles flowed from the cell. Then the cell pressure was raised to 20 kPa. After ten minutes or steady state outflow was achieved, the pressure was increased by 20 kPa and the process was repeated. This was done until the final pressure was achieved, which was limited by the HAE value of the disc. If at any time during the test water appeared on the outside of the cell between the cell walls and the base, a leak occurred, and the cell was disassembled and then reassembled. The test was repeated until a pass was achieved. A pass consisted of reaching the maximum final pressure and maintaining that pressure for ten minutes without additional water flow from the cell.

Sample Preparation

A 7.1±.1 kg sample clean ballast gradation was prepared according to AREMA No. 4 (AREMA, 2020; ASTM C136). The amount of fouling that was combined with the ballast was based on a percentage of the total clean ballast. The gradation and ballast were separated into three lifts. The ballast was placed in each lift and combined with the fouling material. Each lift had a target height of 3.2 cm per lift. The shape of ballast is that it is longer than its width. Lift height was achieved by orienting the ballast on its side when required. Each lift was measured from the top of the cell to the top of the ballast layer with a ruler. Nine measurements were taken of each layer and then averaged to find the relative density of the layer. The target relative density of 85% was used the lifts were placed within ± 2 mm to obtain a relative density of 85% ± 2%. The specimen was hand placed and patted into position. Then nine measurements were recorded for each layer and averaged. A target 85% relative density was used to be consistent with previous research. This target relative density was the maximum relative density that could be achieved during SWRC testing without breaking the large ceramic stone at the bottom of the flow cell (Sherwood, 2020).

SWRC Measurements

The porosity of the clean ballast placed in the cell was used to calculate the approximate amount of water needed to fill the voids to achieve full saturation. Water was imbibed via vacuum through the HAE disc and was tracked with a scale as shown in Figure 3-3. The total water imbibed was compared with the theoretical needed and was ±10g off theoretical for each test. At the end of imbibition, water was allowed to freely outflow and was tracked via logging software (Wayllace & Lu, 2012). Due to negative pore water pressure of the stone, some water was still retained on top of the stone that was not necessarily retained by the fouling material. This was apparent because a layer of water was retained on top of the HAE disc that would have otherwise freely drained. The first pressure step of 0.4 kPa was used to expel the remaining water ponded on the stone. This was the lowest pressure that could be maintained consistently with the pressure regulator. Next the pressure was slowly increased until water began to outflow from the fouling material, typically 0.4-0.6 kPa. Increasing the pressure slowly allowed for air entry of the fouling material to be estimated. Next, eight increasing pressure steps were recorded from the first step to the final pressure (dictated by the stone). For a 0.5 Bar stone, the final pressure was 30 kPa. For a 1 Bar, stone the final pressure was 80 kPa. The multiple pressure steps allowed for measuring the decrease in volumetric water content with the corresponding matric suction. In a small flow cell experiment, Eching & Hopmans (1993) suggest that 0.05 g/hour is steady state. Due to the large amount of water imbibed, typically 2000g in the ballast experiment, the steady state condition was set to less than 1g/hour outflow (Sherwood, Kulesza, & Bernhardt-Barry, 2020). This was comparable to the approximate 40g of total water outflow for samples in the small flow cell. The ratio of outflow for both experiments were close to 0.1% and assumed acceptable for steady state conditions. When the steady state condition was reached, the pressure step was incremented until the final pressure step. The specimen was removed from the cell and placed in the oven to find the final gravimetric water content. In addition, a sub sample of fouling was also taken to measure the final gravimetric water content of the fines (ASTM D2216-19).

The volumetric water content was calculated for each step by total outflow divided by total water imbibed. The volumetric water content was calculated and converted to gravimetric water content as seen in (17) for each pressure increment, where θ is the volumetric water content (%), Gs is the specific gravity (unitless), e is the void

$$\theta = \frac{\mathrm{wGs}}{1+e} \tag{17}$$

ratio of the ballast (unitless), and w is the gravimetric water content of the ballast with fouling material (%). Each volumetric water content was recorded and correlated with the current pressure step. The points were plotted on a graph of volumetric water content verse matric suction. This was done to validate an SWRC model for fouled ballast.

SWRC Modeling

The Van Genuchten (1980) model was first attempted to be used however it would not fit the data. The SWRC chosen to model the volumetric water content of the fouled ballast was a graphical fitting model developed by Wijaya & Leong (2016). This model eliminates the unique parameters approach that the Van Genuchten or Fredlund Xing models require (Leong & Rahardjo, 1997). The Wijaya & Leong (2016) model allowed for a strictly graphical approach to modeling the SWRC of the fouled ballast. This approach was needed because ballast typically retained negligible water unless fouled (Selig & Waters, 1994). The degrees of fouling used varied by weight of the ballast from 5% to 15%. The SWRC for each fouling material was similar in shape, however, the amount of water content retained changed based on the fouling material. Due to the limitations of the control panel pressure regulator, measurements below 0.4 kPa were not possible. However, the Wijaya & Leong (2016) model allowed for the limitations of the equipment to be overcome. The model required at least one point before or near air entry. By assuming a moisture content at a low suction value, the ballast portion of the SWRC was modeled. The assumed moisture content point was calculated from Li et al. (2014). The Li et al. (2014) SWRC model was first used as a best fit model and was later scrapped do to the poor prediction of the fouling material's water retention. However, the Li et al. (2014) model estimated the ballast portion of the SWRC based on gradation. Due to the difficulty of measuring at low suction, this estimate was used in place of an actual measurement. A limitation to the Wijaya & Leong (2016) model is it must have points to shape the curve. Meaning it is a poor predictor of anything past the last measured matric suction value (Wijaya & Leong, 2016). Nevertheless, the Wijaya &

Leong (2016) model met the requirements of this research and was used for all results herein.

Methodology for KDOT Inventory Inspection Procedure and Rating System

The beginning phase of a GAM program for any asset consists of creating an inspection checklist and inventory procedure. The assets chosen to start the KDOT GAM program are MSE walls because they are prevalent geotechnical infrastructure in Kansas and KDOT has invested heavily in studying the deterioration of MSE walls, particularly as related to corrosion (Parsons, Han, & Kulesza, 2021). The inspection checklist shows the location, condition, and assessment of the performance of the MSE wall. This allows the inventory to begin with a uniform rating system between the walls inspected.

Inspection Checklist

The KDOT inspection checklist shown in Figure 3-4 incorporates five core categories: movement, drainage, soil, facing, exterior, and resistivity (to incorporate ongoing KDOT research). These categories were developed from synthesizing existing DOT's inspection checklist. Each category has sub-categories to further define what aspect of the wall is being rated. A catch-all non-weighted category is listed as other and is dependent on the inspector's judgment when inspecting the wall. This category was included so the inspector can add a category that might be a feature of the MSE wall that is not normally part of an MSE wall. A four-one rating system is used where four is good, three is fair, two is poor, and one is severe. The percentage of the wall under each rating is also measured to show how much of the wall is in each condition state. The sum of the percentages must add up to 100%. For example, within one category, such as drainage, 75% of the wall may be rated in good condition and 25% in fair condition. An additional weighted rating system was developed to accurately describe the wall's serviceable condition. This weighting system was developed using the analytical hierarchy process (AHP) which uses input from engineers to weight each category. Finally, a risk-based approach is taken based on the average annual daily traffic, the height, and the age of the wall to further assess the overall wall condition. The AADT can be found through the KDOT's own website (KDOT, 2022)). The age of the wall must be obtained from plans internally from KDOT. The height, length and width of the wall can be estimated if no plans are available from Google Earth or a mapping software such as GIS. Additional information that needs to be collected is the KDOT Wall ID, GPS coordinates to input the wall information into GIS, ambient temperature and backfill temperature if resistivity data are collected, and pictures to record a visual record. All wall faces should be photographed if it is a three-sided structure. The inspection checklist was designed so that structural integrity was the most important factor based on previous research (e.g., Colorado, Tennessee, and other case histories presented in the literature review). Pictures, written descriptions of the categories and a problem that will teach inspectors how to use the inspection checklist can be found in Appendix B.

KDOT MSE Wall Inspection Form				**Survey Date:**					
Height (ft)		**GPS Coordinate**						**County**	
Length (ft)									
Width (ft)		% of Wall Condition				W%	Score	**Wall ID**	
Category	**Rating**	4 Good	3 Fair	2 Poor	1 Severe			Notes	
Movement	Wall Tilting					19%			
	Backfill Settlement					10%			
Drainage	Scour/Soil Erosion					8%			
	Exterior Drainage					7%			
	Internal Drainage					16%			
Backfill	Panel Bowing / Bulging					18%			
	Resistivity					6%		T:: R:	
	Backfill Material					5%			
Facing	Joints					3%			
	Staining					2%			
	Cracking					2%			
	Spalling					2%			
Exterior	Coping					2%			
	Vegetation					2%			
Other									
Engineer inspection	*If category was rated 50% > Poor	Yes or No							
Score	**Rating Score**							Wall Data	
	Height of Wall								(ft)
	AADT								
	Age of Wall								(yr)
	Risk Adjusted Rating Score								

Figure 3-4 MSE Wall Inspection Checklist

Analytical Hierarchy Process

MSE wall performance can be hidden when too many categories are considered. One method to eliminate this loss of performance is the AHP method. The AHP can assign a weight for each category and give a more precise assessment of wall performance. The first trial for assigning weights was through a literature review and to rate the categories based on importance. Brutus & Tauber (2009) sent out questionaries to rate categories followed by Utah (2009), Gerber (2012) and Tennessee (2021). After the literature review was completed a second round to optimize the AHP weighting system was conducted through two interviews with experts in the field of Geotechnical engineering and a final round with KDOT. The final criterion comparison matrix compiled can be seen in appendix B.

Inventory Procedure

Nineteen walls were selected for the pilot GAM Program. They were selected based on a previous studies conducted by Parsons (2021). Data was collected in two ways a site visit and google earth. A site visits to the MSE wall was conducted using the inspection checklist shown in Figure 3-4. If data could not be obtained in the field, it was retrieved from google maps using the earth view and street view tools.

Cost Estimation

Geotech Tools (GeoInstitute, 2022) considers many different construction methods on its website. A tool on the Geo Institutes website called MSEW cost tool was used to find estimate values of the MSE walls owned by KDOT. This tool uses an average cost from several different studies based on MSE wall construction. The MSEW cost tool considers the height width and length of the wall. It estimates the embankment and vertical face of the MSE wall. Then it's multiples by a cost associated with the embankment in (yd^3) and the MSE wall facing to give an estimated cost of the wall. The embankment cost used was $7.50 and the MSE wall facing cost used was $40.00. This was developed in 2012 and does not consider inflation.

4. RESULTS AND DISCUSSION

The results of the fouled ballast tested and MSE walls are presented in this chapter. The fouled ballast results contain the material used in testing, the makeup of the fouled ballast, the results of the first test with a verification test to ensure that the results were repeatable, further the results of the different fouled ballast tested and the SWRC models applied to the fouled ballast specimens. The MSE section contains an overview of two walls that should be reinspected, results of the nineteen walls inventoried, the most common type of defect noted for KDOT when inspecting, and the estimated cost of assets inventoried.

Results of Fouled Ballast

Classification of the fouling material can be seen in Table 4-1. Both sands classified as poorly graded sand (SP), the clay and coal were classified similarly as a low plasticity silt (ML) (ASTMD4318, 2022). When prepared to the target degrees of fouling, the fouled ballast classified as poorly graded gravel (GP), with the exception of the 10% and 15% clay fouled ballast. The 10% clay fouled ballast had a dual classification of well graded gravel with clay (GW-GC). The 15% clay fouled ballast classified as a clayey gravel (GC).

Table 4-1 Fouled Ballast & Fouling Material USCS

Specimen	USCS	Cu	Cc	D60	D30	D10	LL	PI
5% Sand 1	GP	2	1.05	40	29	20	N/A	N/A
10% Sand 1	GP	3.33	1.75	40	29	12	N/A	N/A
10% Sand 2	GP	3.33	1.75	40	29	12	N/A	N/A
15% Sand 2	GP	8	4.20	40	29	5	N/A	N/A
Clay 5%	GP	2	0.66	40	23	20	N/A	N/A
Clay 10%	GW-GC	8	2.42	40	22	5	N/A	N/A
Clay 15 %	GC	533.33	147	40	21	0.075	N/A	N/A
Coal 5%	GP	2	1.05	40	29	20	N/A	N/A
Coal 10%	GP	2.66	1.40	40	29	15	N/A	N/A
Sand 1 Fouling Material	SP	14.85	0.541	1.04	0.2	0.07	N/A	N/A
Sand 2 Fouling Material	SP	13.88	0.55	2.5	0.5	0.18	N/A	N/A
Clay Fouling Material	CL	8.33	0.33	0.01	0.001	0.0006	38	19
Coal Fouling Material	ML	142.85	5.71	0.2	0.04	0.0014	31	13

Volumetric water contents recoded by the large flow cell were first verified through two clay fouling tests, shown in Figure 4-1. The first test was to measure different matric suctions and volumetric water contents from 0.4-80 kPa. The second was taken to one pressure step 30 kPa, where a gravimetric water content was obtained and converted to volumetric (ASTM D2216-19). The volumetric results from the two tests, the 80 kPa test was 6.68 % and for the incremental test at 30 kPa was 7.74%. The two tests had a difference of ±1.5% of the calculated volumetric water content, thus the test method was validated based on anticipated variability between specimens.

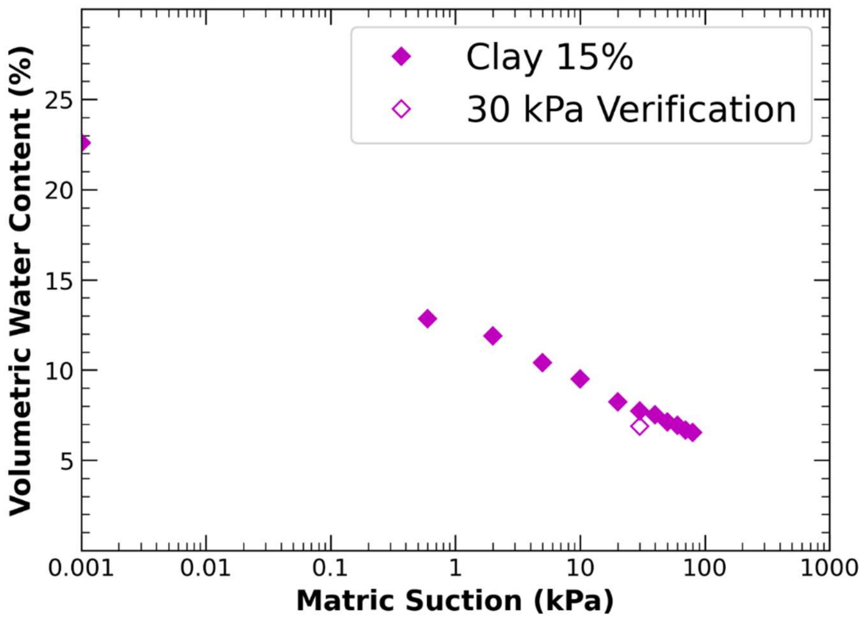


Figure 4-1 First Clay Test with a Verification Test

SWRC Model Discussion

A preliminary analysis was conducted to select the appropriate model for this research. When modeling SWRC data, Wayllace & Lu (2012) used the Van Genuchten (1980) model. However, this model did not predict the ballast portion of the SWRC accurately and the TRIM program did not give a valid output. An excel form of the Van Genuchten model was attempted to be optimized. However, this did not show meaningful shape or information when modeled. Thus, the Van Genuchten model was not an acceptable model of the ballast and fouling material. Further investigation of the Van Genuchten model showed that it was a parametric model. Parametric models are good predictors of the SWRC where large and medium amount of water are stored in the soil pores. However, the parametric models are poor predictors of the SWRC when minimal amount of moisture is stored in the soil (Rossi & Nimmo, 1994).

The next model used was the Li, Li, & Zhang (2014) model which predicts the SWRC based on grain size distribution. The regression coefficient (R^2) was used to calculate the optimization of the Li, Li, & Zhang (2014) model as shown Table 4-2. The 15% clay fouled

Table 4-2 Comparison of the Regression Coefficient for SWRC Models

Fouled Ballast	Wijaya	Li optimized	Li Based on Gradation
Clay 15%	0.999	0.991	0.997
Clay 10%	0.999	0.972	0.787
Clay 5%	0.999	0.901	0.715
Coal 10%	0.999	0.844	0.605
Coal 5%	0.999	0.903	0.736
Sand 2 15%	0.999	0.926	0.979
Sand 2 10%	0.999	0.801	0.776
Sand 1 10%	0.999	0.950	0.981
Sand 1 5%	0.999	0.988	0.974

ballast was the only SWRC that Li, Li, & Zhang (2014) predicted with a R^2 greater than 95%. When the fouling material for any of the samples tested was less than 15%, the SWRC R^2 was less than 95%. The Wijaya & Leong (2016) graphical curve fitting method could be optimized to have a R^2 which was greater than 95% for all fouled ballast tested. Therefore, the Wijaya & Leong (2016) model was chosen to model the ballast due to the simplicity of optimization.

There are several models that can be used to assess normal SWRC inverse models such as Van Genuchten (1980) and Fredlund & Xing (1994). However, when larger diameter particles are involved or low moisture content, the parametric models were not the most appropriate model to simulate the SWRC (Rossi & Nimmo, 1994). Empirical models such as Li, Li, & Zhang (2014) based on soil properties were specifically designed for gap graded soil and models based graphical interpretation such as Wijaya & Leong (2016) can also be used on gap graded soils.

Discussion of Fouled Ballast

A general fit of Wijaya & Leong (2016) was used on the ballast portion of the SWRC and fitted to the fouling material. The starting water contents for each fouling material changes due to how much water can fill the voids. Therefore, when fouling is added to the ballast, a decrease in fully saturated volumetric water content is seen, as expected. Figure 4-2 are the results of the sand fouled tests. The Sand 2 15% sand fouled held a maximum of 4% volumetric water content, with a residual 0.75% volumetric water content. The Sand 2 10% sand fouled held a maximum of 2.5% volumetric water content, with a residual 0.25% volumetric water content. The Sand 1 10% sand fouled held a maximum of 2.6% volumetric water content, with a residual 0.075% volumetric water content. The Sand 1 5% sand fouled held a maximum of 1% volumetric water content, with a residual 0.20% volumetric water content. Sand 1 10%, Sand 2 10%, and Sand 2 15% plot very close in water retention, very little difference can be observed.

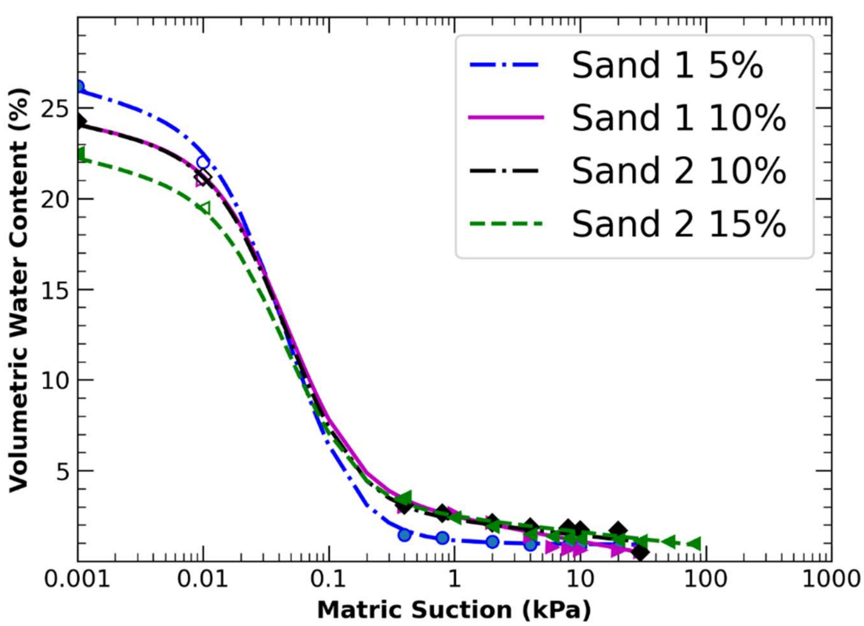


Figure 4-2 SWRC of Sand Fouling

Figure 4-3 shows the results of the coal fouled tests. The 10% coal fouled held a maximum of 8% volumetric water content, with a residual 4.5% volumetric water content. The 5% coal fouling held a maximum of 3% volumetric water content, with a residual 1.5% volumetric water content.

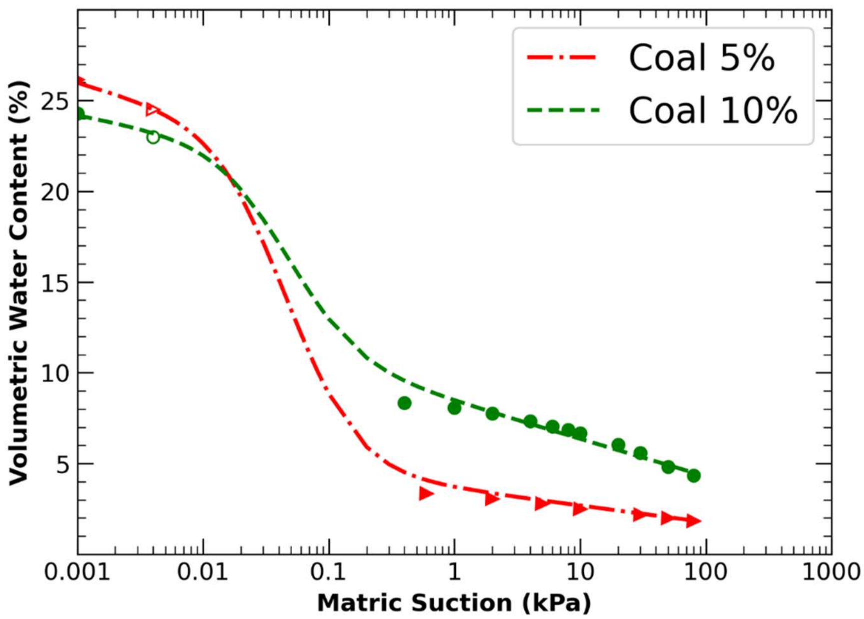


Figure 4-3 SWRC of Coal Fouling

Figure 4-4 shows the SWRC and volumetric water contents of the clay fouled ballast. The 15% clay fouled held a maximum of 13.5% volumetric water content, with a residual 7% volumetric water content. As shown in Figure 4-4 when fouling increased, an increase in water retention can be seen. Note that residual volumetric water content is still very high in the clay fouling material. To find the final residual water content of the clay fouled ballast, a higher matric suction is needed. A test will need to be run to using a 3-bar stone however this was not possible within the time frame of this research due to equipment delays.

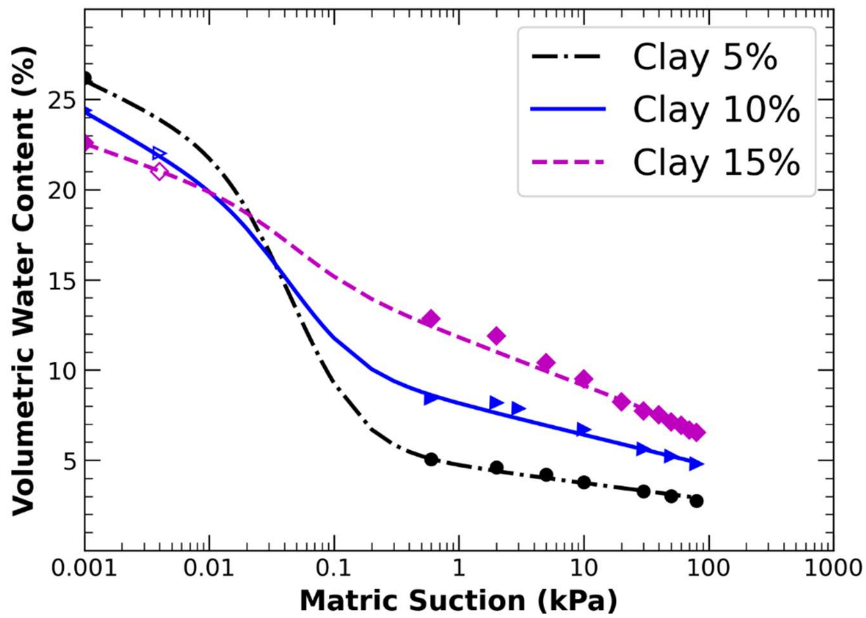


Figure 4-4 SWRC of Clay Fouling

In Figure 4-2, it can be seen that sand fouling retains negligible water content even at higher degrees of fouling. However, this could be attributed to the fact that the sand fouling was washed of all fines passing the #200 sieve before the materials were donated for this research and may not reflect field conditions. As seen in Figure 4-2, only a 3% volumetric water content increase occurred from the 5% to the 15% by weight sand fouled ballast. Comparing Figure 4-3 and Figure 4-4, an increase in fouling of the coal and clay from 5% to 10% can be correlated with an increase in residual moisture content; 3% for the 5% coal and clay fouling and 4-5% moisture content in the 10% coal and clay fouling. Figure 4-5 compares all materials at 10%, note that at 10% coal fouled and clay fouled have very similar water retention capability. This was unexpected due to the coal fouling material being made up of mostly sand. Previous research conducted by Paiva (2015) showed that break down ballast (sand) or fouling material that infiltrated from the train itself would have a higher hydraulic conductivity and allows water to drain more rapidly and store less water than clay fouling at the same percentage. The coal fouled sand water retention is likely due to the low specific gravity of coal (0.8-1.3) when compared to clay (2.3-2.7). With coal infiltration of the sand, its ability to retain water is drastically increased and is similar to the track being fouled by clay (Sussmann, Ruel, & Chrismer, 2012; Tennakoon, Indraratna, Rujikiatkamjorn, Nimbalkar, & Neville, 2012).

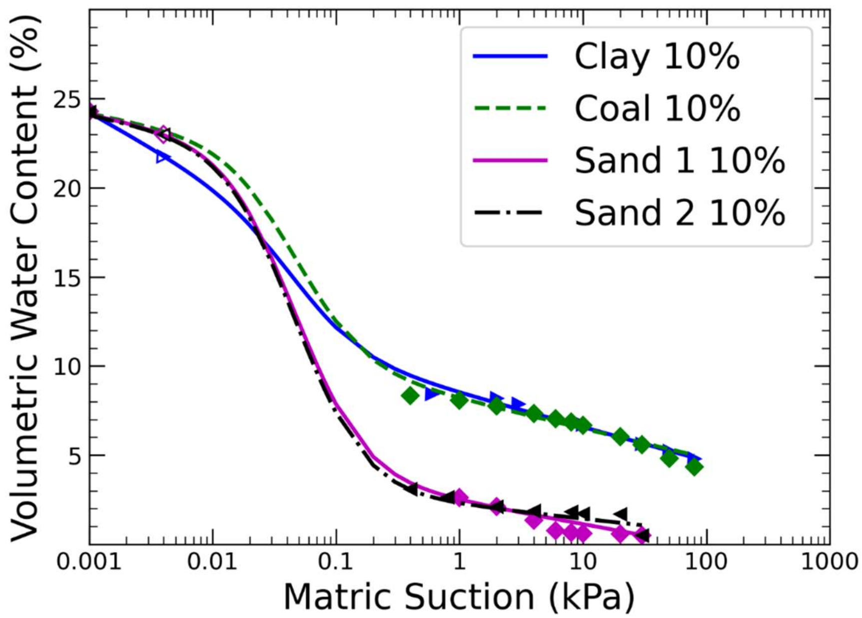
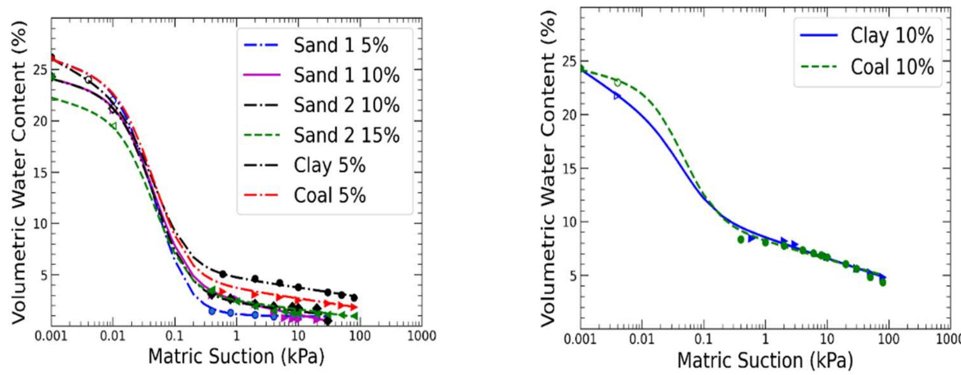


Figure 4-5 Comparison of the 10% Fouled Ballast

Figure 4-6 compares the moderately clean to moderately fouled samples according to the FI. It can be seen that with coal and clay fouling the FI increase and sand does not. This can be contributed to the washing of fines passing the #200 sieve by BNSF before being tested in this research. Moderately fouled ballast in Figure 4-6b shows that coal fouling can retain just as much water as 10% clay which was discussed previously.



a b

Figure 4-6: SWCR for (a) Moderately Clean FI and (b) Moderately fouled FI

Results & Discussion of KDOT MSE Wall Inventory & Inspection

Case 1 US-81 Over Railroad

An onsite inspection in March 2022 was conducted on the US-81 over Railroad MSE wall. The complete inspection checklist can be found in Appendix B. This wall was rated as the worst of all the walls and warrants a reinspection. In Figure 4-8 of the east side of the wall the coping was moving away from the wall and the panels are misaligned

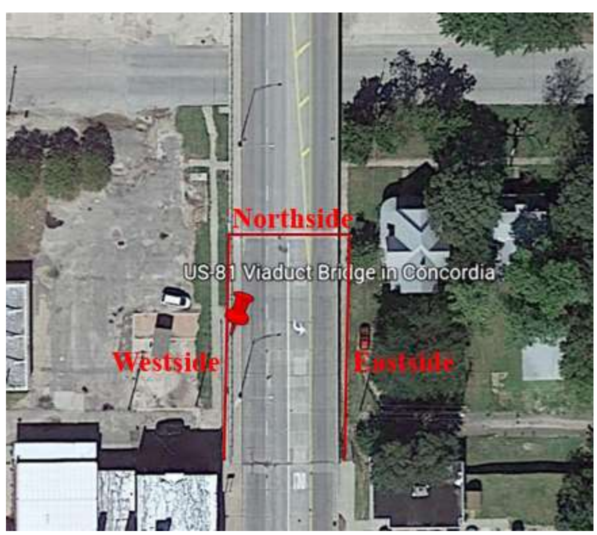


Figure 4-7 US-81 Over Railroad MSE wall

with large gaps between them. The west side of the wall had similar problems with panels moving away from each other and vegetation such as trees growing from them. This is shown in Figure 4-9. This wall has noticeable panels bulging and misalignment of joints Figure 4-10.

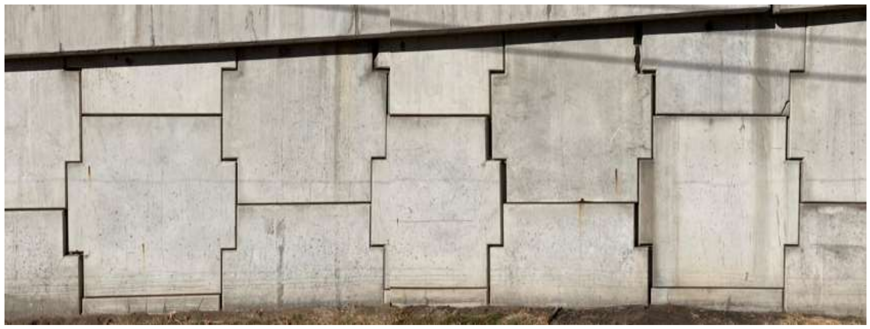


Figure 4-8 East side US-81 over Railroad

Figure 4-9 West Side US-81 over Railroad

a	b

Figure 4-10 Wall issues a) panel bowing, b) misalignment of joints

The condition of the wall was rated as satisfactory but when the risk assessment calculated the wall falls into a fair/poor condition. With these noticeable defects and an adjusted wall rating of 2.39 this wall should be revisited by an engineer and assessed whether repairs are needed.

Case 2 US-54 W to S Eisenhower Airport Pkwy

On April 24, 2022, a site visit was conducted on US-54 W to S Eisenhower airport Pkwy Figure 4-11. The retaining wall was rated in satisfactory conditions however the inspector noted some defects. The inspector reported no internal drainage could be found on the bridge and they saw severe staining occurring on the outside of the wall as shown Figure 4-12. The poor internal drainage is thought to be behind the cause of the spalling shown in Figure 4-13. Additionally spalling and cracking to the coping was though to be from the poor drainage as well. Resistivity tests were conducted on the backfill and they

Figure 4-11 US-54 W to S Eisenhower Airport Pkwy

Figure 4-12 US-54 W to S Eisenhower Airport Pkwy Staining

showed very low resistivity measurements. Further testing of the backfill was conducted and iron particles were found. This is thought to be because of the highly corrosive nature of the backfill which is breaking down reinforcement of the wall. The had an adjusted rating of 2.91 this wall should be revisited by an engineer and assessed whether repairs are needed.

Figure 4-13 US-54 W to S Eisenhower Airport Pkwy Spalling

Results of Inventory and Inspection

The nineteen walls selected by KDOT are shown in Figure 4-14. Many of the walls are still in good to fair condition. Figure 4-15 is a comparison of the nineteen walls with and without the AHP method. The comparison shows on average a 0.1 increase in performance of the MSE wall when the AHP method is applied. This was expected since Gerber (2012) had vegetation rated the least impactful to the overall rating of an MSE wall.

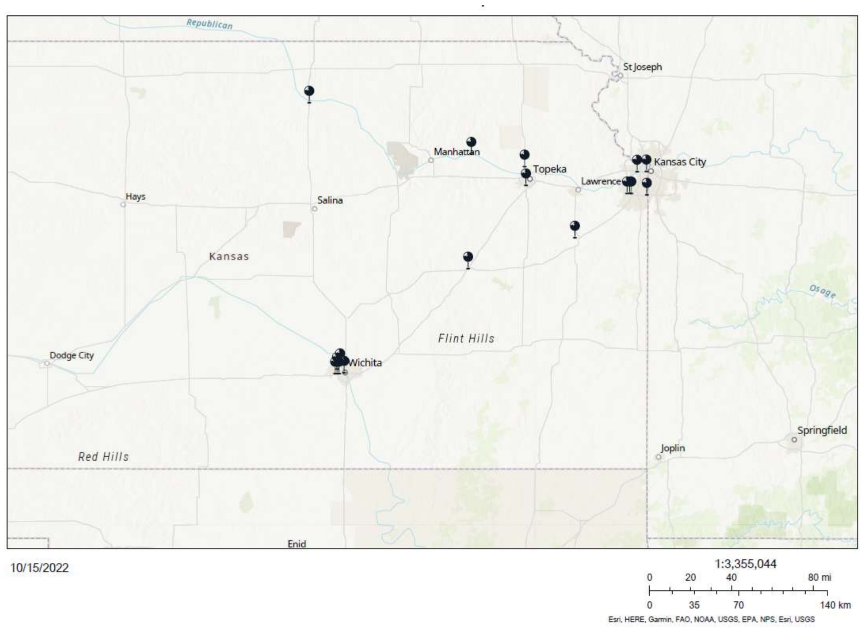


Figure 4-14 Location of MSE Walls Inventoried

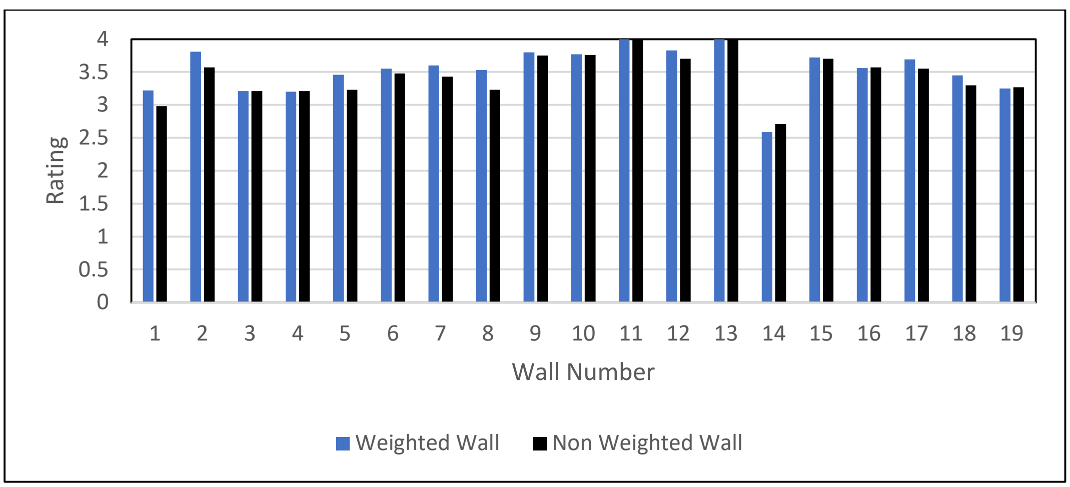


Figure 4-15 AHP Weighting comparison

The AHP was initially weighted based on engineering judgment and through a literature review (Saaty & Vargas, 2012; Butler, et al., 2016; Brutus & Tauber, 2009; Elias, Christopher, Berg, & Berg, 2001). Then revisions were made by experts in the field of geotechnical engineering. The weighting system was further refined by an interview with KDOT. The final weighing system that was developed, is based on the 14 individual categories. The weighted rating system can be seen in Table 4-3.

Table 4-3 AHP Final Breakdown Weighting

Group	Percentage	Category	Percentage
Movement	29.56%	Wall Tilting	19.29%
		Backfill Settlement	10.28%
Drainage	30.30%	Scour/Soil Erosion	7.71%
		Exterior Drainage	6.98%
		Internal Drainage	15.61%
Backfill	29.06%	Panel Bowing / Bulging	17.97%
		Resistivity	5.71%
		Backfill Material	5.39%
Facing	8.01%	Joints	3.47%
		Staining	1.51%
		Cracking	1.51%
		Spalling	1.51%
Exterior	3.06%	Coping	1.51%
		Vegetation	1.55%

The risk assessment that was added based onto the inspection checklist included height, age and AADT (Tarawneh, Al Bodour, & Masada, 2018). On average this risk assessment decreased the wall rating by of 0.2. This was expected because most of the walls are in either high traffic areas, % are older than 20 years and some are very tall. Typically, a rating of 0.96 was applied to each of the modifying factors.

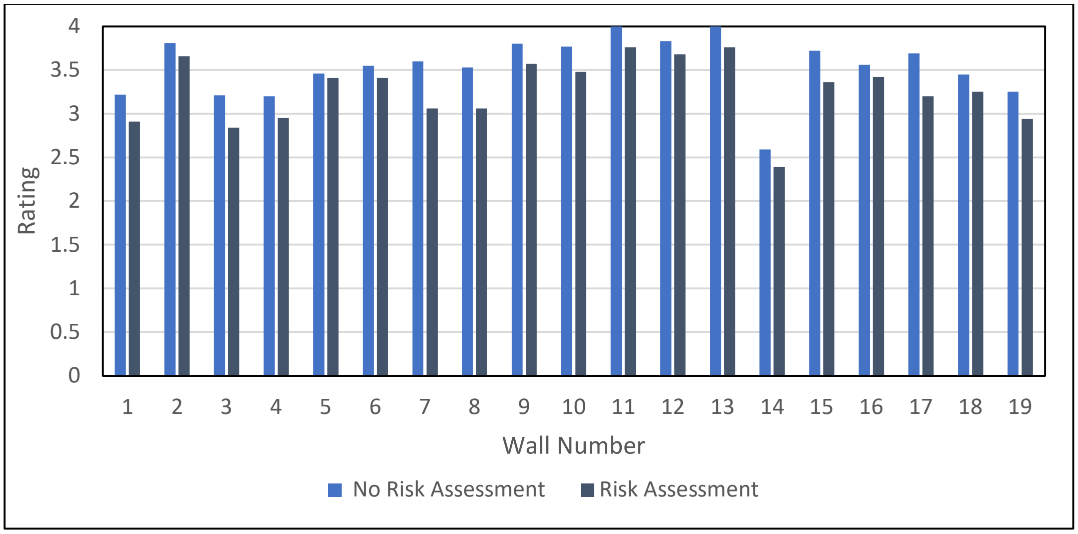


Figure 4-16 Initial Inspection of KDOT MSE Walls

As seen in Table 4-4 the performance of the MSE wall categories is shown. Vegetation on average was the worst performing category, almost every wall containing some type of vegetation growing from it. The best rated category was scour/soil erosion, this category was only occurring at one of the MSE walls it was overall the highest rated category.

Table 4-4 Average Rating of KDOT MSE Walls

Average Rating	Category
3.04	Vegetation
3.21	Internal Drainage
3.25	Cracking
3.25	Exterior Drainage
3.32	Joints
3.37	Coping
3.38	Staining
3.42	Resistivity
3.49	Backfill Material
3.54	Spalling
3.61	Wall Tilting
3.79	Panel Bowing / Bulging
3.86	Backfill Settlement
3.87	Scour/Soil Erosion

5. CONCLUSION

Fouled Ballast

The railroad industry designs ballast to be a free draining material, however, when ballast becomes fouled, ballast inherently becomes an unsaturated material. In order to quantify this, fouled ballast SWRC become necessary to explain the new properties of the fouled ballast. This research presented a new measurement technique that allows for any fouled ballast to be tested for the SWRC at any fouling percentage. The new method was first validated by running one complete test and then a replicate at one suction value. The measured replicate moisture content was compared to the modeled water content. This was done as an assurance that replication of the method was valid.

Four different fouling materials were tested at three different degrees of fouling. Three models were evaluated to simulate the SWRC; however, the Wijaya & Leong, (2016) graphical model was the only model that could be used for all specimens based on a high R^2.value. The fouled ballast experiment in total had nine separate tests conducted with the different fouling material. These tests gave a better understanding of how coal and clay fouling can be similar in water retention but different in gradation and material properties. Further the testing showed that getting the sand samples and making sure they have not been washed of fines. From previous research it has been understood that fines mostly dictate moisture retention in the ballast layer. Moisture measurements are very similar if no fines are passing the #200 sieve (0.075mm). This was seen in the sands SWRC results.

During testing a few limitations were encountered. The first limitation was the lowest suction that could be achieved was 0.4 kPa, this was due to the pressure gauge on the TRIM equipment. A hanging column test is needed to be run to get these lower points. These lower points are key in the second limitation, The Li et al. (2014) model was used to get the estimation of the low suction measurement. The hanging column method is needed to validate this measurement; however, the point was used for modeling the Wijaya & Leong (2016) SWRC. The final limitation encountered was the residual water content of the clay fouled material. A 3-bar stone is needed to take the clay fouling material to residual water content and finish modeling the fouled ballast. Overall, this research has laid the groundwork for the next phase of the larger FRA project of relating dielectric constants to moisture and suction measurements.

MSE Wall

Transportation asset management programs have been adopted by all 50 as mandated under the MAP-21 act. The TAM programs consider all assets of the roadway above there foundation. However, it does not consider the foundation or anything next to the roadway assets such as earth retaining structures. The GAM program addresses this need by being proactive in the inspection and inventory of earth retaining assets. The construction of MSE walls began in the 1970's, however, little has been done in order to inspect or maintain those MSE walls. An inspection checklist, weighted score, and risk assessment sheet was developed for the inspection of MSE walls in Kansas. The second phase of this research focused on asset management of an earth retaining structure, MSE walls.

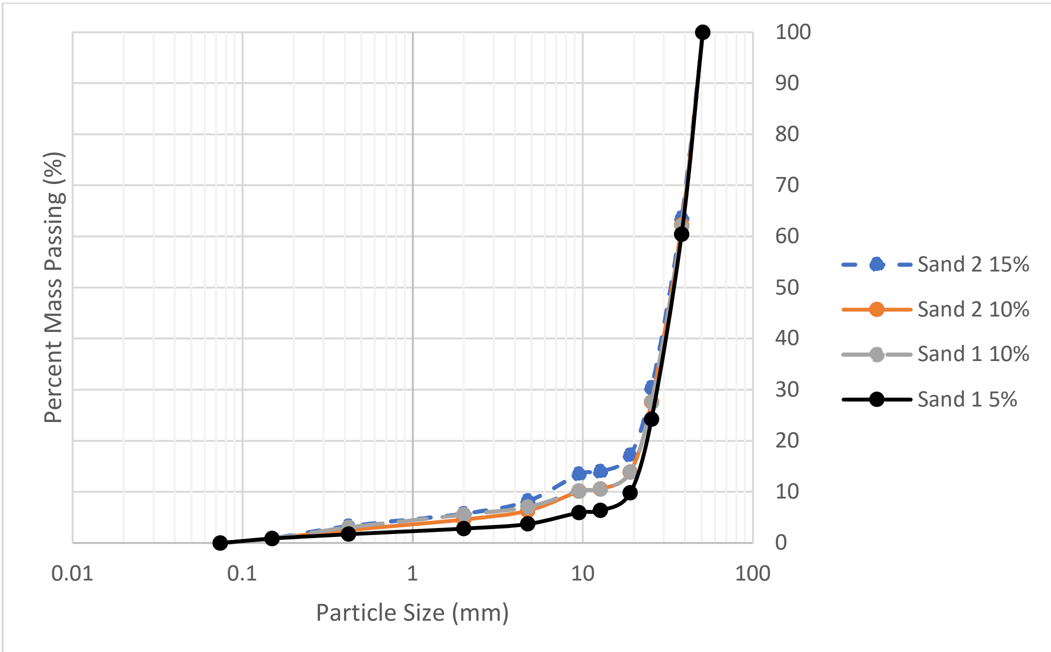
This inspection sheet allows KDOT to begin inventorying and assessing the walls with a common framework to compare between each wall. Out of the nineteen walls inspected, only two walls are suggested to be reinspected as discussed in the results and discussion. The other walls that need to be reinspected are mainly due to vegetation growth. Vegetation growth can be solved by simply, spraying the vegetation with herbicide or by physically removing the vegetation from the wall. The other defects were not affecting the performance but should be monitored with an inspection every six years (Dimaggio & MacMillan, 2018). To help gauge performance of the walls the AHP method was used to delineate the effectiveness of using a weighting system for the categories. The rated weighting system allows for the importance of each component to be compared and weighted allowing overall performance to be addressed. The risk assessment was added to adjust for the importance of a wall based on the AADT, age and height of the wall. A wall that has a low AADT will be rated better than a wall that is heavily trafficked. Further the risk assessment adjusts the score based on height and age of the wall. This will allow KDOT to be better informed on deciding if they should perform maintenance on the MSE wall based on importance. Since costs of building the wall were not readily available the estimation of the cost of the MSE walls were necessary. The estimation was based on the MSEW tool from the GeoInstitute (2022) website. This gives a starting estimation of the MSE wall asset prices and starts an estimated total cost of the MSE wall inventory. The excel used in tracking and inspection sheets will be provided to KDOT to help start their asset management program.

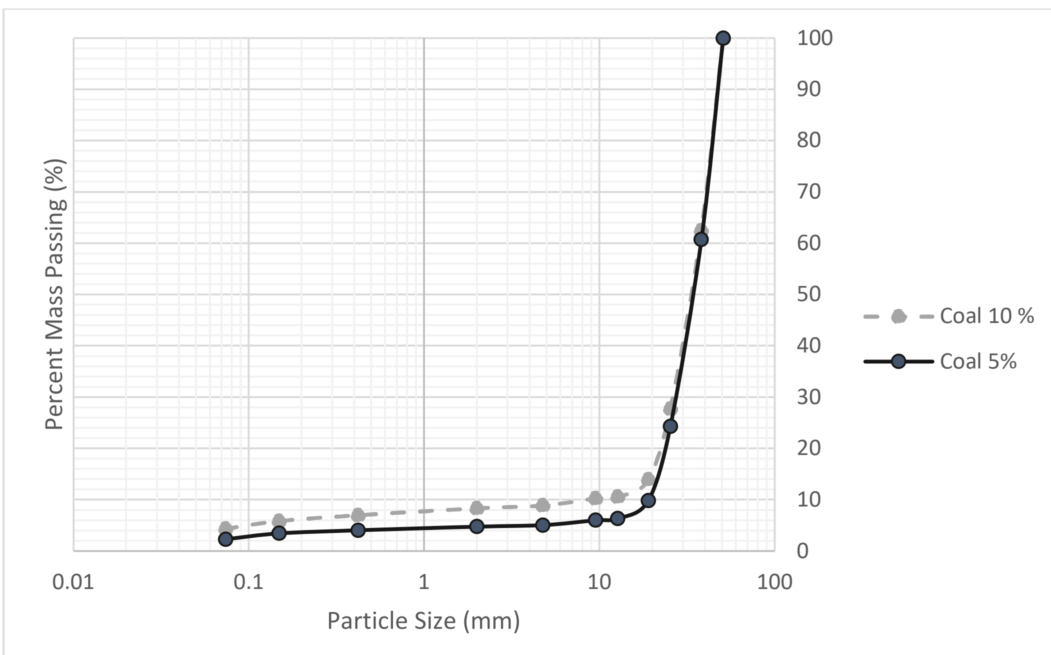
KDOT will need to begin an extensive inventory of MSE walls with this inspection checklist and inventory system. Once the inventory is underway more data can be gathered to further refine their inspection procedures, such as resistivity testing, to find out if there is a relation between the failure of the reinforcement and a potentially corrosive environment. In addition, each wall could have a specific defect, this inspection checklist can record, measure and compare those defects for future inspections.

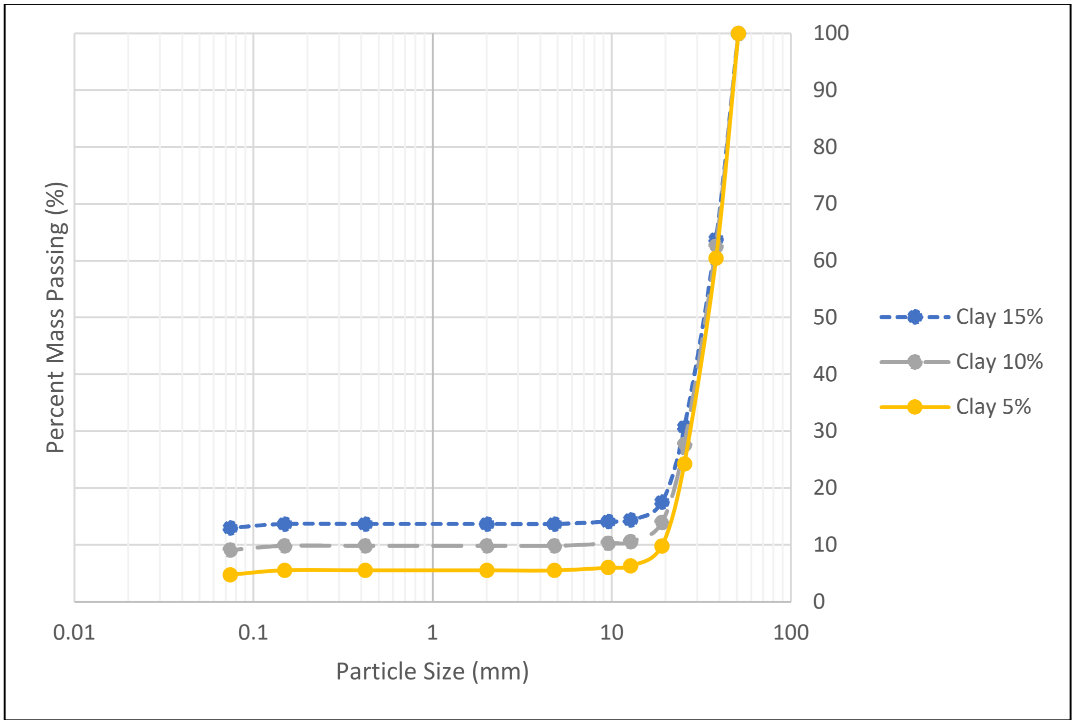
APPENDIX SECTION

Appendix A Fouled Ballast

Fouled Ballast Gradation






100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Percent Mass Passing (%)
Particle Size (mm)
Clay 15%
Clay 10%
Clay 5%

Li Parameters

Clay 15%	saturated gravimetric moisture content	0.275	air entry of the micropores	0.300
	air entry of the macropores	0.001	residual suction of the micropores	280.000
	residual suction of the macropores	0.010	residual of both macropores and micropores	0.038
Clay 10%	saturated gravimetric moisture content	0.279	air entry of the micropores	0.200
	air entry of the macropores	0.001	residual suction of the micropores	80.000
	residual suction of the macropores	0.010	residual of both macropores and micropores	0.034
Clay 5%	saturated gravimetric moisture content	0.280	air entry of the micropores	0.020
	air entry of the macropores	0.001	residual suction of the micropores	80.000
	residual suction of the macropores	0.010	residual of both macropores and micropores	0.017
Coal 10%	saturated gravimetric moisture content	0.261	air entry of the micropores	0.400
	air entry of the macropores	0.010	residual suction of the micropores	80.000
	residual suction of the macropores	0.029	residual of both macropores and micropores	0.016
Coal 5%	saturated gravimetric moisture content	0.275	air entry of the micropores	0.200
	air entry of the macropores	0.012	residual suction of the micropores	80.000
	residual suction of the macropores	0.027	residual of both macropores and micropores	0.038
Sand 2 15%	saturated gravimetric moisture content	0.278	air entry of the micropores	0.400
	air entry of the macropores	0.012	residual suction of the micropores	80.000
	residual suction of the macropores	0.050	residual of both macropores and micropores	0.005
Sand 2 10%	saturated gravimetric moisture content	0.289	air entry of the micropores	0.100
	air entry of the macropores	0.012	residual suction of the micropores	30.000
	residual suction of the macropores	0.050	residual of both macropores and micropores	0.006
Sand 1 10%	saturated gravimetric moisture content	0.289	air entry of the micropores	0.200
	air entry of the macropores	0.012	residual suction of the micropores	30.000
	residual suction of the macropores	0.050	residual of both macropores and micropores	0.006
Sand 1 5%	saturated gravimetric moisture content	0.282	air entry of the micropores	0.010
	air entry of the macropores	0.012	residual suction of the micropores	30.000
	residual suction of the macropores	0.050	residual of both macropores and micropores	0.004

Wijaya Parameters

	Slope		Intersection 2			Intersection 3		
15 % Clay	M1	2.4	S2	0.022	C2	S3	0.1	C2
	M2	7.3	S2-	0.0025	1.966504	S3-	0.01	2
	M3	2.7	S2+	0.026		S3+	0.1	
	Slope		Intersection 2			Intersection 3		
10 % Clay	M1	3.8	S2	0.022	C2	S3	0.1	C2
	M2	14	S2-	0.0025	1.966504	S3-	0.01	2
	M3	1.8	S2+	0.026		S3+	0.1	
	Slope		Intersection 2			Intersection 3		
5 % Clay	M1	3	S2	0.022	C2	S3	0.1	C2
	M2	24.5	S2-	0.0025	1.966504	S3-	0.01	2
	M3	1.1	S2+	0.026		S3+	0.1	
	Slope		Intersection 2			Intersection 3		
10 % Coal	M1	1.2	S2	0.022	C2	S3	0.1	C2
	M2	18	S2-	0.0025	1.966504	S3-	0.01	2
	M3	2.2	S2+	0.026		S3+	0.1	
	Slope		Intersection 2			Intersection 3		
5 % Coal	M1	1.7	S2	0.022	C2	S3	0.1	C2
	M2	28.5	S2-	0.0025	1.966504	S3-	0.01	2
	M3	1.15	S2+	0.026		S3+	0.1	
	Slope		Intersection 2			Intersection 3		
15 % Sand 2	M1	1.4	S2	0.022	C2	S3	0.1	C2
	M2	25.5	S2-	0.0025	1.966504	S3-	0.01	2
	M3	1	S2+	0.026		S3+	0.1	
	Slope		Intersection 2			Intersection 3		
10 % Sand 2	M1	1.2	S2	0.022	C2	S3	0.1	C2
	M2	29	S2-	0.0025	1.966504	S3-	0.01	2
	M3	1	S2+	0.026		S3+	0.1	
	Slope		Intersection 2			Intersection 3		
10 % Sand 1	M1	1.2	S2	0.022	C2	S3	0.1	C2
	M2	28	S2-	0.0025	1.966504	S3-	0.01	2
	M3	1.5	S2+	0.026		S3+	0.1	
	Slope		Intersection 2			Intersection 3		
5 % Sand 1	M1	1.5	S2	0.022	C2	S3	0.1	C2
	M2	34	S2-	0.0025	1.966504	S3-	0.01	2
	M3	0.35	S2+	0.026		S3+	0.1	

Appendix B MSE wall

Wall Information

Number	Date Inventoried	Previous wall name	Adjusted wall name
1	4/24/2022	Kellogg/US-54 and Ridge Road	US-54 W to S Eisenhower Airport Pkwy
2	4/24/2022	K-10 and Ridgeview	Ridgeview over K-10
3	4/5/2022	Lee BLVD and I-435	Lee Blvd over I-435
4	3/3/2022	US-24 over Railroad/Camp Creek RD	US-24 over Railroad
5	4/24/2022	Kellogg/US-54 and West St	US-54 over West St
6	4/5/2022	670 @ RR Service RD/S 5th st	S 70th St to I-70 E
7	4/5/2022	K-32 over RR @ S 55th St	K-32 over Kansas River
8	4/5/2022	69 NB to 435 EB	US-69 N to I-435 E
9	4/24/2022	Unmarked place	Old US-59 over Railroad
10	4/24/2022	I-35 and US-50 interchange	I-35 over US-50
11	4/24/2022	I-235 and 25th St	W 25th St over I-235
12	4/24/2022	US-54/Kellogg over Mclean Blvd	US-54 over McLean Blvd
13	4/24/2022	NB I-235 to W 13th St N	I-235 N to W 13th St N
14	3/15/2022	US-81 Viaduct Bridge in Concordia	US-81 over Railroad
15	4/24/2022	US-54/Kellogg over S Hoover RD	US-54 over Hoover Rd
16	3/3/2022	Ramp from 75 NB to 470 WB	US-75 N to I-470 W
17	4/5/2022	K-10 EB to 435 NB	K-10 E to I-435 N
18	4/5/2022	I-435 over Lackman	I-435 over Lackman Rd
19	3/15/2022	US75 & 46th St	US-75 over NW 46th St

Number	Height (ft)	Length (ft)\	Width (ft)	Embankment (yd³):	Vertical Face (ft²):	Estimated Cost
1	36.3	470	33	20852	17061	$ 838,832.50
2	23.1	40	240	8213	924	$ 98,560.00
3	16.5	350	30	6417	5775	$ 279,125.00
4	29.7	290	40	12760	8613	$ 440,220.00
5	26.4	930	100	90933	24552	$ 1,664,080.00
6	10.725	1151	60	27432	12344	$ 699,520.25
7	49.5	590	60	64900	29205	$ 1,654,950.00
8	66	750	70	128333	49500	$ 2,942,500.00
9	9.9	170	6.93	432	1683	$ 70,559.78
10	26.4	600	60	35200	15840	$ 897,600.00
11	26.4	60	220	12907	1584	$ 160,160.00
12	19.8	555	140	56980	10989	$ 866,910.00
13	21.45	470	33	12322	10082	$ 495,673.75
14	19.8	130	60	5720	2574	$ 145,860.00
15	26.4	1000	60	58667	26400	$ 1,496,000.00
16	13.2	280	60	8213	3696	$ 209,440.00
17	42.9	25	102	4052	1073	$ 73,287.50
18	26.4	623	177	107821	16447	$ 1,466,542.00
19	26.4	690	120	80960	18216	$ 1,335,840.00

Number	GPS		County	Reinspection
1	37° 40' 32" N	97° 25' 20" W	Sedgwick	Yes
2	38° 56' 27" N	94° 47' 49" W	Johnson	Yes
3	38° 55' 54" N	94° 37' 07" W	Johnson	Yes
4	39° 12' 59" N	96° 11' 54" W	Pottawatomie	Yes
5	37° 40' 25" N	97° 23' 18" W	Sedgwick	Yes
6	39° 05' 45" N	94° 37' 25" N	Wyandotte	Yes
7	39° 05' 30" N	94° 42' 20" W	Wyandotte	No
8	38° 55' 49" N	94° 41' 48" W	Johnson	Yes
9	38° 37' 34" N	95° 10' 07" W	Franklin	No
10	38° 24' 50" N	96° 13' 38" W	Lyon	No
11	37° 43' 52" N	97° 22' 49" W	Sedgwick	No
12	37° 40' 42" N	97° 20' 37" W	Sedgwick	Yes
13	37° 42' 19" N	97° 24' 27" W	Sedgwick	No
14	39° 34' 18" N	97° 39' 25" W	Cloud	Yes
15	39° 40' 24" N	97° 24' 27" W	Sedgwick	No
16	38° 59' 58" N	95° 42' 23" W	Shawnee	Yes
17	38° 56' 34" N	94° 46' 24" N	Johnson	No
18	38° 56' 28" N	94° 45' 28" W	Johnson	Yes
19	39° 07' 39" N	95° 41' 34" W	Shawnee	No

Number	Built	Height (m)	Traffic AADT	Resistivity (ohm-cm)
1	1980	11.00	12000.00	2264.4
2	2014	7.00	15000.00	16822.08
3	1995	5.00	22000.00	14714.099
4	1989	9.00	1000.00	18556.56
5	0	8.00	12700.00	2055.075
6	0	3.25	24000.00	8043.175
7	2000	15.00	22000.00	5055.1776
8	2005	20.00	22000.00	5206.45248
9	1982	3.00	4000.00	11185.0752
10	2006	8.00	16800.00	5197.50675
11	2016	8.00	12500.00	27627.84
12	0	6.00	12500.00	2449.7
13	2012	6.50	12500.00	37190.02
14	1994	6.00	7000.00	8962.4
15	1994	8.00	12000.00	28899.36
16	0	4	23000	2962.5
17	1996	13.00	23000.00	10907.438
18	2014	8.00	23000.00	4485.62
19	2002	8.00	12900.00	0

Number	Wall before Non-risk assessment	Wall with Risk assessment	Non-Weighted Wall Non-risk assessment	Non-Weighted Wall with Risk Assessment
1	3.22	2.91	2.98	2.86
2	3.81	3.66	3.57	3.43
3	3.21	2.84	3.21	2.84
4	3.20	2.95	3.21	2.96
5	3.46	3.41	3.23	3.34
6	3.55	3.41	3.48	3.34
7	3.60	3.06	3.43	2.91
8	3.53	3.06	3.23	2.80
9	3.80	3.57	3.75	3.53
10	3.77	3.48	3.76	3.46
11	4.00	3.76	4.00	3.76
12	3.83	3.68	3.70	3.55
13	4.00	3.76	4.00	3.76
14	2.59	2.39	2.71	2.50
15	3.72	3.36	3.70	3.34
16	3.56	3.42	3.57	3.43
17	3.69	3.20	3.55	3.08
18	3.45	3.25	3.30	3.11
19	3.25	2.94	3.27	2.95

Criterion Comparison Matrix

	Wall tilting	Panel Bowing / Bulging	Internal Drainage	Backfill Settlement	Scour/Soil Erosion	Exterior Drainage	Backfill Material	Joints	Cracking	Spalling	Coping	Vegetation	Resistivity
Wall Tilting	1.00	1.00	1.00	3.00	5.00	5.00	5.00	5.00	9.00	9.00	9.00	9.00	7.00
Panel Bowing / Bulging	1.00	1.00	1.00	3.00	3.00	5.00	5.00	5.00	9.00	9.00	9.00	9.00	5.00
Internal Drainage	1.00	1.00	1.00	3.00	3.00	3.00	5.00	3.00	7.00	7.00	7.00	7.00	5.00
Backfill Settlement	0.33	0.33	0.33	1.00	3.00	1.00	3.00	5.00	7.00	7.00	7.00	7.00	3.00
Scour/Soil Erosion	0.20	0.33	0.33	0.33	1.00	1.00	3.00	5.00	5.00	5.00	5.00	5.00	3.00
Exterior Drainage	0.20	0.20	0.33	1.00	1.00	1.00	3.00	3.00	5.00	5.00	5.00	5.00	1.00
Backfill Material	0.20	0.20	0.20	0.33	0.33	0.33	1.00	3.00	5.00	5.00	5.00	5.00	1.00
Joints	0.20	0.20	0.33	0.20	0.20	0.33	0.33	1.00	3.00	3.00	3.00	3.00	0.20
Staining	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.20
Cracking	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.20
Spalling	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.20
Coping	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.20
Vegetation	0.11	0.11	0.14	0.14	0.20	0.20	0.20	0.33	1.00	1.00	1.00	1.00	0.33
Resistivity	0.14	0.20	0.20	0.33	0.33	1.00	1.00	5.00	5.00	5.00	5.00	3.00	1.00

Wall Inspections

KDOT MSE Wall Inspection Form				**Survey Date:**				4/24/2022		
Height (ft)	36.3	**GPS Coordinates**		37° 40' 32" N 97° 25' 20" W				**County**	Sedgwick	
Length (ft)	470									
Width (ft)	33	% of Wall Condition				W%	Score	**Wall ID #**	US-54 W to S Eisenhower Airport	
Category	**Rating**	4	3	2	1					
		Good	Fair	Poor	Severe			Notes		
Movement	Wall Tilting	100%				19%	0.77			
	Backfill Settlement	100%				10%	0.41			
Drainage	Scour/Soil Erosion	100%				8%	0.31			
	Exterior Drainage	100%				7%	0.28			
	Internal Drainage				100%	16%	0.16	No internal Drainage		
Backfill	Panel Bowing / Bulging	100%				18%	0.72			
	Resistivity			100%		6%	0.11	T: R:2264 ohm-cm		
	Backfill Material			100%		5%	0.16			
Facing	Joints		100%			3%	0.10			
	Staining		50%	50%		2%	0.04			
	Cracking		50%	50%		2%	0.04			
	Spalling			100%		2%	0.03			
Exterior	Coping		75%	25%		2%	0.04			
	Vegetation		100%			2%	0.05			
Other										
Engineer Inspection	*If category was rated 50% > Poor	Yes								
Score	**Rating Score**						3.22	Wall Data	Unit	
	Height of Wall						0.98	36.3	(ft)	
	AADT						0.98	12,000		
	Age of Wall						0.94	1980	(yr)	
	Risk Adjusted Rating Score						2.91			

<table>
<tr><td colspan="2">KDOT MSE Wall Inspection Form</td><td colspan="5">Survey Date:</td><td colspan="2">4/24/2022</td></tr>
<tr><td>Height (ft)</td><td>23.1</td><td rowspan="2">GPS Coordinates</td><td colspan="4" rowspan="2">38° 56' 27" N 94° 47' 49" W</td><td rowspan="2">County</td><td rowspan="2">Johnson</td></tr>
<tr><td>Length (ft)</td><td>40</td></tr>
<tr><td>Width (ft)</td><td>240</td><td colspan="4">% of Wall Condition</td><td rowspan="3">W%</td><td rowspan="3">Score</td><td rowspan="2">Wall ID #</td><td rowspan="2">Ridge View Over K-10</td></tr>
<tr><td rowspan="2">Category</td><td rowspan="2">Rating</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Good</td><td>Fair</td><td>Poor</td><td>Severe</td><td colspan="2">Notes</td></tr>
<tr><td rowspan="2">Movement</td><td>Wall Tilting</td><td>100%</td><td></td><td></td><td></td><td>19%</td><td>0.77</td><td colspan="2"></td></tr>
<tr><td>Backfill Settlement</td><td>100%</td><td></td><td></td><td></td><td>10%</td><td>0.41</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Drainage</td><td>Scour/Soil Erosion</td><td>100%</td><td></td><td></td><td></td><td>8%</td><td>0.31</td><td colspan="2"></td></tr>
<tr><td>Exterior Drainage</td><td>25%</td><td>75%</td><td></td><td></td><td>7%</td><td>0.23</td><td colspan="2"></td></tr>
<tr><td>Internal Drainage</td><td>100%</td><td></td><td></td><td></td><td>16%</td><td>0.62</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Backfill</td><td>Panel Bowing / Bulging</td><td>100%</td><td></td><td></td><td></td><td>18%</td><td>0.72</td><td colspan="2"></td></tr>
<tr><td>Resistivity</td><td>100%</td><td></td><td></td><td></td><td>6%</td><td>0.23</td><td colspan="2">T: RR:16,822 ohm-cm</td></tr>
<tr><td>Backfill Material</td><td></td><td>100%</td><td></td><td></td><td>5%</td><td>0.16</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Facing</td><td>Joints</td><td>25%</td><td>75%</td><td></td><td></td><td>3%</td><td>0.11</td><td colspan="2"></td></tr>
<tr><td>Staining</td><td></td><td>50%</td><td>50%</td><td></td><td>2%</td><td>0.04</td><td colspan="2"></td></tr>
<tr><td>Cracking</td><td>100%</td><td></td><td></td><td></td><td>2%</td><td>0.04</td><td colspan="2"></td></tr>
<tr><td>Spalling</td><td></td><td>75%</td><td>25%</td><td></td><td>2%</td><td>0.03</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Exterior</td><td>Coping</td><td>100%</td><td></td><td></td><td></td><td>2%</td><td>0.04</td><td colspan="2"></td></tr>
<tr><td>Vegetation</td><td>25%</td><td>75%</td><td></td><td></td><td>2%</td><td>0.05</td><td colspan="2"></td></tr>
<tr><td>Other</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>Engineer Inspection</td><td>*If category was rated 50% > Poor</td><td colspan="8">Yes</td></tr>
<tr><td rowspan="5">Score</td><td colspan="5">Rating Score</td><td></td><td>3.81</td><td>Wall Data</td><td>Unit</td></tr>
<tr><td colspan="5">Height of Wall</td><td></td><td>0.98</td><td>23.1</td><td>(ft)</td></tr>
<tr><td colspan="5">AADT</td><td></td><td>0.98</td><td>15,000</td><td></td></tr>
<tr><td colspan="6">Age of Wall</td><td>1</td><td>2014</td><td>(yr)</td></tr>
<tr><td colspan="5">Risk Adjusted Rating Score</td><td></td><td>3.66</td><td></td><td></td></tr>
</table>

KDOT MSE Wall Inspection Form				**Survey Date:**				4/24/2022	
Height (ft)	23.1	**GPS Coordinates**		38° 56' 27" N 94° 47' 49" W				**County**	Johnson
Length (ft)	40								
Width (ft)	240	% of Wall Condition				W%	Score	**Wall ID #**	Lee Blvd over I-435
Category	**Rating**	4	3	2	1				
		Good	Fair	Poor	Severe			Notes	
Movement	Wall Tilting		100%			19%	0.77	Coping bowing out about two inches at south end	
	Backfill Settlement	100%				10%	0.41		
Drainage	Scour/Soil Erosion	100%				8%	0.31	*if founded on rock rating is automatically a 4	
	Exterior Drainage			100%		7%	0.28	Multiple areas of standing water next to wall	
	Internal Drainage			100%		16%	0.16	Multiple areas of standing water next to wall	
Backfill	Panel Bowing / Bulging	100%				18%	0.72		
	Resistivity	100%				6%	0.11	T: RR:14,714 ohm-cm	
	Backfill Material		100%			5%	0.16	Deposit of sand/soil observed at drainage pipe	
Facing	Joints		100%			3%	0.10		
	Staining		100%			2%	0.04	staining near standing water	
	Cracking		100%			2%	0.04		
	Spalling	100%				2%	0.03		
Exterior	Coping		100%			2%	0.04		
	Vegetation		100%			2%	0.05		
Other									
Engineer Inspection	*If category was rated 50% > Poor	Yes							
Score	**Rating Score**						3.21	Wall Data	Unit
	Height of Wall						0.98	16.5	(ft)
	AADT						0.96	22,000	
	Age of Wall						0.94	1995	(yr)
	Risk Adjusted Rating Score						2.84		

KDOT MSE Wall Inspection Form							Survey Date:		4/24/2022	
Height (ft)	29.7	GPS Coordinates	38° 56' 27" N 94° 47' 49" W						County	Johnson
Length (ft)	290									
Width (ft)	40	% of Wall Condition				W%	Score		Wall ID #	Lee Blvd over I-435
Category	Rating	4	3	2	1					
		Good	Fair	Poor	Severe				Notes	
Movement	Wall Tilting		100%			19%	0.58			
	Backfill Settlement	100%				10%	0.41			
Drainage	Scour/Soil Erosion	100%				8%	0.31			
	Exterior Drainage		100%			7%	0.21			
	Internal Drainage		100%			16%	0.47			
Backfill	Panel Bowing / Bulging		100%			18%	0.54			
	Resistivity	100%				6%	0.23		T: RR:18,557 ohm-cm	
	Backfill Material			100%		5%	0.11			
Facing	Joints		100%			3%	0.10			
	Staining	100%				2%	0.06			
	Cracking		100%			2%	0.05			
	Spalling	100%				2%	0.06			
Exterior	Coping		100%			2%	0.05			
	Vegetation			100%		2%	0.03			
Other										
Engineer Inspection	*If category was rated 50% > Poor	Yes								
Score	Rating Score						3.2		Wall Data	Unit
	Height of Wall						0.98		29.7	(ft)
	AADT						1		1,000	
	Age of Wall						0.94		1989	(yr)
	Risk Adjusted Rating Score						2.95			

<table>
<tr><th colspan="4">KDOT MSE Wall Inspection Form</th><th colspan="4">Survey Date:</th><th colspan="2">4/24/2022</th></tr>
<tr><td>Height (ft)</td><td>26.4</td><td rowspan="2">GPS Coordinates</td><td colspan="5" rowspan="2">37° 40' 25" N 97° 23' 18" W</td><td rowspan="2">County</td><td rowspan="2">Sedgwick</td></tr>
<tr><td>Length (ft)</td><td>930</td></tr>
<tr><td>Width (ft)</td><td>100</td><td colspan="4">% of Wall Condition</td><td rowspan="3">W%</td><td rowspan="3">Score</td><td rowspan="2">Wall ID #</td><td rowspan="2">US-54 over West St</td></tr>
<tr><td rowspan="2">Category</td><td rowspan="2">Rating</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Good</td><td>Fair</td><td>Poor</td><td>Severe</td><td colspan="2">Notes</td></tr>
<tr><td rowspan="2">Movement</td><td>Wall Tilting</td><td></td><td>50%</td><td>50%</td><td></td><td>19%</td><td>0.48</td><td colspan="2">North side poor, south side good</td></tr>
<tr><td>Backfill Settlement</td><td>100%</td><td></td><td></td><td></td><td>10%</td><td>0.41</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Drainage</td><td>Scour/Soil Erosion</td><td>100%</td><td></td><td></td><td></td><td>8%</td><td>0.31</td><td colspan="2"></td></tr>
<tr><td>Exterior Drainage</td><td>100%</td><td></td><td></td><td></td><td>7%</td><td>0.28</td><td colspan="2"></td></tr>
<tr><td>Internal Drainage</td><td>100%</td><td></td><td></td><td></td><td>16%</td><td>0.62</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Backfill</td><td>Panel Bowing / Bulging</td><td>100%</td><td></td><td></td><td></td><td>18%</td><td>0.72</td><td colspan="2"></td></tr>
<tr><td>Resistivity</td><td></td><td></td><td>100%</td><td></td><td>6%</td><td>0.11</td><td colspan="2">T:
RR: 2,055 ohm-cm</td></tr>
<tr><td>Backfill Material</td><td>100%</td><td></td><td></td><td></td><td>5%</td><td>0.22</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Facing</td><td>Joints</td><td></td><td>50%</td><td>50%</td><td></td><td>3%</td><td>0.09</td><td colspan="2">North side poor, south side good</td></tr>
<tr><td>Staining</td><td></td><td>100%</td><td></td><td></td><td>2%</td><td>0.05</td><td colspan="2"></td></tr>
<tr><td>Cracking</td><td></td><td>50%</td><td>50%</td><td></td><td>2%</td><td>0.04</td><td colspan="2">North side poor, south side good</td></tr>
<tr><td>Spalling</td><td></td><td>100%</td><td></td><td></td><td>2%</td><td>0.05</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Exterior</td><td>Coping</td><td></td><td>75%</td><td>25%</td><td></td><td>2%</td><td>0.04</td><td colspan="2">North side fair, south side good</td></tr>
<tr><td>Vegetation</td><td></td><td>100%</td><td></td><td></td><td>2%</td><td>0.05</td><td colspan="2"></td></tr>
<tr><td>Other</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>Engineer Inspection</td><td>*If category was rated 50% > Poor</td><td colspan="8">Yes</td></tr>
<tr><td rowspan="5">Score</td><td colspan="5">Rating Score</td><td></td><td>3.46</td><td>Wall Data</td><td>Unit</td></tr>
<tr><td colspan="5">Height of Wall</td><td></td><td>0.98</td><td>26.4</td><td>(ft)</td></tr>
<tr><td colspan="5">AADT</td><td></td><td>0.98</td><td>12,700</td><td></td></tr>
<tr><td colspan="5">Age of Wall</td><td></td><td>1</td><td></td><td>(yr)</td></tr>
<tr><td colspan="5">Risk Adjusted Rating Score</td><td></td><td>3.32</td><td>Wall Data</td><td>Unit</td></tr>
</table>

KDOT MSE Wall Inspection Form			Survey Date:					4/24/2022	
Height (ft)	10.73	**GPS Coordinates**	39° 05' 45" N 94° 37' 25" N					**County**	Wyandotte
Length (ft)	1151								
Width (ft)	60	% of Wall Condition				W%	Score	**Wall ID #**	S 70th St to I-70 E
Category	**Rating**	4	3	2	1				
		Good	Fair	Poor	Severe			Notes	
Movement	Wall Tilting	75%	25%			19%	0.72		
	Backfill Settlement	100%				10%	0.41		
Drainage	Scour/Soil Erosion	100%				8%	0.31		
	Exterior Drainage		100%			7%	0.21		
	Internal Drainage		100%			16%	0.47		
Backfill	Panel Bowing / Bulging	100%				18%	0.72		
	Resistivity		100%			6%	0.17	T: R: 8,043 ohm-cm	
	Backfill Material		100%			5%	0.16		
Facing	Joints	100%				3%	0.14		
	Staining		100%			2%	0.05		
	Cracking	100%				2%	0.06		
	Spalling	50%	50%			2%	0.05		
Exterior	Coping	75%		25%		2%	0.05		
	Vegetation			100%		2%	0.03		
Other									
Engineer Inspection	*If category was rated 50% > Poor	Yes							
Score	**Rating Score**						3.5	Wall Data	Unit
	Height of Wall						1	10.73	(ft)
	AADT						0.96	24,000	
	Age of Wall						1		(yr)
	Risk Adjusted Rating Score						3.4		

KDOT MSE Wall Inspection Form				Survey Date:					4/5/2022	
Height (ft)	49.5	**GPS Coordinates**		39° 05' 30" N 94° 42' 20" W					**County**	Wyandotte
Length (ft)	590									
Width (ft)	60	% of Wall Condition				W%	Score		**Wall ID #**	K-32 over Kansas River
Category	**Rating**	4	3	2	1					
		Good	Fair	Poor	Severe				Notes	
Movement	Wall Tilting	100%				19%	0.77			
	Backfill Settlement	100%				10%	0.41			
Drainage	Scour/Soil Erosion	100%				8%	0.31			
	Exterior Drainage		100%			7%	0.21			
	Internal Drainage		100%			16%	0.47			
Backfill	Panel Bowing / Bulging	100%				18%	0.72			
	Resistivity		100%			6%	0.17		T: R: 8,043 ohm-cm	
	Backfill Material		100%			5%	0.16			
Facing	Joints	100%				3%	0.14			
	Staining		100%			2%	0.05			
	Cracking		100%			2%	0.05			
	Spalling	100%				2%	0.06			
Exterior	Coping		100%			2%	0.05			
	Vegetation		100%			2%	0.05			
Other										
Engineer Inspection	*If category was rated 50% > Poor	Yes								
Score	**Rating Score**						3.6		Wall Data	Unit
	Height of Wall						0.94		49.5	(ft)
	AADT						0.96		22,000	
	Age of Wall						0.94		2000	(yr)
	Risk Adjusted Rating Score						3.06			

KDOT MSE Wall Inspection Form				Survey Date:			4/5/2022	
Height (ft)	66	**GPS Coordinates**		38° 55' 49" N 94° 41' 48" W			**County**	Johnson
Length (ft)	750							
Width (ft)	70	% of Wall Condition				W%	Score	**Wall ID #** US-69 N to I-435 E
Category	**Rating**	4 Good	3 Fair	2 Poor	1 Severe			Notes
Movement	Wall Tilting	100%				19%	0.77	
	Backfill Settlement	100%				10%	0.41	
Drainage	Scour/Soil Erosion	25%	75%			8%	0.31	
	Exterior Drainage		100%			7%	0.28	Exposures of unpainted concrete is significant on east side
	Internal Drainage		100%			16%	0.16	
Backfill	Panel Bowing / Bulging	100%				18%	0.72	
	Resistivity		100%			6%	0.11	T: R: 5206 ohm-cm
	Backfill Material	100%				5%	0.16	
Facing	Joints		100%			3%	0.10	
	Staining		100%			2%	0.04	
	Cracking		100%			2%	0.04	
	Spalling		100%			2%	0.03	
Exterior	Coping		100%			2%	0.04	
	Vegetation			100%		2%	0.05	
Other								
Engineer Inspection	*If category was rated 50% > Poor	Yes						
Score	**Rating Score**						3.53	Wall Data / Unit
	Height of Wall						0.94	66 (ft)
	AADT						0.96	22,000
	Age of Wall						0.96	2005 (yr)
	Risk Adjusted Rating Score						3.06	

KDOT MSE Wall Inspection Form		Survey Date:		4/24/2022	
Height (ft)	9.9	**GPS Coordinates**	38° 37' 34" N 95° 10' 07" W	**County**	Franklin
Length (ft)	170				
Width (ft)	6.93			**Wall ID #**	Old US-59 over Railroad

Category	**Rating**	% of Wall Condition: 4 Good	3 Fair	2 Poor	1 Severe	W%	Score	Notes
Movement	Wall Tilting	100%				19%	0.77	
	Backfill Settlement	25%	75%			10%	0.33	
Drainage	Scour/Soil Erosion	100%				8%	0.31	
	Exterior Drainage	25%	75%			7%	0.23	misalignment of some of the drainage
	Internal Drainage	100%				16%	0.62	
Backfill	Panel Bowing / Bulging	100%				18%	0.72	
	Resistivity	100%				6%	0.23	T: R: 11,185 ohm-cm
	Backfill Material	25%	75%			5%	0.18	
Facing	Joints	25%	75%			3%	0.11	
	Staining	100%				2%	0.06	
	Cracking	75%	25%			2%	0.06	
	Spalling	100%				2%	0.06	
Exterior	Coping	100%				2%	0.06	
	Vegetation	75%	25%			2%	0.06	
Other								
Engineer Inspection	*If category was rated 50% > Poor	No						

Score				
Rating Score		3.8	Wall Data	Unit
Height of Wall		1	9.9	(ft)
AADT		1	4,000	
Age of Wall		0.94	1982	(yr)
Risk Adjusted Rating Score		3.57		

KDOT MSE Wall Inspection Form						Survey Date:			4/24/2022	
Height (ft)	26.4	**GPS Coordinates**	38° 24' 50" N 96° 13' 38" W						**County**	Lyon
Length (ft)	600									
Width (ft)	60	% of Wall Condition				W%	Score		**Wall ID #**	I-35 over US-50
Category	**Rating**	4 Good	3 Fair	2 Poor	1 Severe				Notes	
Movement	Wall Tilting	25%	75%			19%	0.63			
	Backfill Settlement	100%				10%	0.41			
Drainage	Scour/Soil Erosion	100%				8%	0.31			
	Exterior Drainage	100%				7%	0.28			
	Internal Drainage	100%				16%	0.62			
Backfill	Panel Bowing / Bulging	100%				18%	0.72			
	Resistivity		75%			6%	0.17		T: R: 5,198 ohm-cm	
	Backfill Material	100%				5%	0.22			
Facing	Joints	100%				3%	0.14			
	Staining	100%				2%	0.06			
	Cracking	25%	75%			2%	0.05			
	Spalling	100%				2%	0.06			
Exterior	Coping	10%	90%			2%	0.05			
	Vegetation	100%				2%	0.06			
Other										
Engineer Inspection	*If category was rated 50% > Poor	No								
Score	**Rating Score**						3.77		Wall Data	Unit
	Height of Wall						0.98		26.4	(ft)
	AADT						0.98		16,800	
	Age of Wall						0.96		2006	(yr)
	Risk Adjusted Rating Score						3.48			

KDOT MSE Wall Inspection Form			Survey Date:						4/24/2022	
Height (ft)	26.4	**GPS Coordinates**	37° 43' 52" N 97° 22' 49" W						**County**	Sedgwick
Length (ft)	60									
Width (ft)	220	% of Wall Condition				W%	Score		**Wall ID #**	W 25th St over I-235
Category	**Rating**	4 Good	3 Fair	2 Poor	1 Severe				Notes	
Movement	Wall Tilting	100%				19%	0.77			
	Backfill Settlement	100%				10%	0.41			
Drainage	Scour/Soil Erosion	100%				8%	0.31			
	Exterior Drainage	100%				7%	0.28			
	Internal Drainage	100%				16%	0.62			
Backfill	Panel Bowing / Bulging	100%				18%	0.72			
	Resistivity	100%				6%	0.23		T: R: 2264 ohm-cm	
	Backfill Material	100%				5%	0.22			
Facing	Joints	100%				3%	0.14			
	Staining	100%				2%	0.06			
	Cracking	100%				2%	0.06			
	Spalling	100%				2%	0.06			
Exterior	Coping	100%				2%	0.06			
	Vegetation	100%				2%	0.06			
Other										
Engineer Inspection	*If category was rated 50% > Poor	No								
Score	**Rating Score**						4		Wall Data	Unit
	Height of Wall						0.98		26.4	(ft)
	AADT						0.98		12,500	
	Age of Wall						0.98		2016	(yr)
	Risk Adjusted Rating Score						3.76			

KDOT MSE Wall Inspection Form					Survey Date:			4/24/2022	
Height (ft)	19.8	**GPS Coordinates**		37° 40' 42" N 97° 20' 37" W				**County**	Sedgwick
Length (ft)	555								
Width (ft)	140	% of Wall Condition				W%	Score	**Wall ID #**	US-54 over McLean Blvd
Category	**Rating**	4	3	2	1				
		Good	Fair	Poor	Severe			Notes	
Movement	Wall Tilting	100%				19%	0.77		
	Backfill Settlement	100%				10%	0.41		
Drainage	Scour/Soil Erosion	100%				8%	0.31		
	Exterior Drainage	100%				7%	0.28		
	Internal Drainage	100%				16%	0.62		
Backfill	Panel Bowing / Bulging	100%				18%	0.72		
	Resistivity			100%		6%	0.11	T: R: 2450 ohm-cm	
	Backfill Material	100%				5%	0.22		
Facing	Joints		100%			3%	0.10		
	Staining	100%				2%	0.06		
	Cracking		100%			2%	0.05		
	Spalling	100%				2%	0.06		
Exterior	Coping	100%				2%	0.06		
	Vegetation	75%	25%			2%	0.06		
Other									
Engineer Inspection	*If category was rated 50% > Poor	Yes							
Score	**Rating Score**						3.83	Wall Data	Unit
	Height of Wall						0.98	19.8	(ft)
	AADT						0.98	12,500	
	Age of Wall						1		(yr)
	Risk Adjusted Rating Score						3.68		

<table>
<tr><td colspan="2">KDOT MSE Wall Inspection Form</td><td colspan="4">Survey Date:</td><td colspan="2">4/24/2022</td></tr>
<tr><td>Height (ft)</td><td>21.45</td><td rowspan="2">GPS Coordinates</td><td colspan="4" rowspan="2">37° 42' 19" N 97° 24' 27" W</td><td rowspan="2">County</td><td rowspan="2">Sedgwick</td></tr>
<tr><td>Length (ft)</td><td>255</td></tr>
<tr><td>Width (ft)</td><td>60</td><td colspan="4">% of Wall Condition</td><td rowspan="3">W%</td><td rowspan="3">Score</td><td rowspan="2">Wall ID #</td><td rowspan="2">I-235 N to W 13th St N</td></tr>
<tr><td rowspan="2">Category</td><td rowspan="2">Rating</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td>Good</td><td>Fair</td><td>Poor</td><td>Severe</td><td colspan="2">Notes</td></tr>
<tr><td rowspan="2">Movement</td><td>Wall Tilting</td><td>100%</td><td></td><td></td><td></td><td>19%</td><td>0.77</td><td colspan="2"></td></tr>
<tr><td>Backfill Settlement</td><td>100%</td><td></td><td></td><td></td><td>10%</td><td>0.41</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Drainage</td><td>Scour/Soil Erosion</td><td>100%</td><td></td><td></td><td></td><td>8%</td><td>0.31</td><td colspan="2"></td></tr>
<tr><td>Exterior Drainage</td><td>100%</td><td></td><td></td><td></td><td>7%</td><td>0.28</td><td colspan="2"></td></tr>
<tr><td>Internal Drainage</td><td>100%</td><td></td><td></td><td></td><td>16%</td><td>0.62</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Backfill</td><td>Panel Bowing / Bulging</td><td>100%</td><td></td><td></td><td></td><td>18%</td><td>0.72</td><td colspan="2"></td></tr>
<tr><td>Resistivity</td><td>100%</td><td></td><td></td><td></td><td>6%</td><td>0.23</td><td colspan="2">Temperature:
R: 2264 ohm-cm</td></tr>
<tr><td>Backfill Material</td><td>100%</td><td></td><td></td><td></td><td>5%</td><td>0.22</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Facing</td><td>Joints</td><td>100%</td><td></td><td></td><td></td><td>3%</td><td>0.14</td><td colspan="2"></td></tr>
<tr><td>Staining</td><td>100%</td><td></td><td></td><td></td><td>2%</td><td>0.06</td><td colspan="2"></td></tr>
<tr><td>Cracking</td><td>100%</td><td></td><td></td><td></td><td>2%</td><td>0.06</td><td colspan="2"></td></tr>
<tr><td>Spalling</td><td>100%</td><td></td><td></td><td></td><td>2%</td><td>0.06</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Exterior</td><td>Coping</td><td>100%</td><td></td><td></td><td></td><td>2%</td><td>0.06</td><td colspan="2"></td></tr>
<tr><td>Vegetation</td><td>100%</td><td></td><td></td><td></td><td>2%</td><td>0.06</td><td colspan="2"></td></tr>
<tr><td>Other</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>Engineer Inspection</td><td>*If category was rated 50% > Poor</td><td colspan="8">No</td></tr>
<tr><td rowspan="5">Score</td><td colspan="5">Rating Score</td><td></td><td>4</td><td>Wall Data</td><td>Unit</td></tr>
<tr><td colspan="5">Height of Wall</td><td></td><td>0.98</td><td>21.45</td><td>(ft)</td></tr>
<tr><td colspan="5">AADT</td><td></td><td>0.98</td><td>12,500</td><td></td></tr>
<tr><td colspan="5">Age of Wall</td><td></td><td>0.98</td><td>2012</td><td>(yr)</td></tr>
<tr><td colspan="5">Risk Adjusted Rating Score</td><td></td><td>3.76</td><td></td><td></td></tr>
</table>

KDOT MSE Wall Inspection Form			Survey Date:					3/15/2022	
Height (ft)	19.8	**GPS Coordinates**	39° 34' 18" N 97° 39' 25" W					**County**	Cloud
Length (ft)	130								
Width (ft)	60	% of Wall Condition				W%	Score	**Wall ID #**	US 81, over Railroad
Category	**Rating**	4	3	2	1				
		Good	Fair	Poor	Severe			Notes	
Movement	Wall Tilting			100%		19%	0.39		
	Backfill Settlement			100%		10%	0.21		
Drainage	Scour/Soil Erosion	100%				8%	0.31		
	Exterior Drainage		100%			7%	0.21		
	Internal Drainage		100%			16%	0.47		
Backfill	Panel Bowing / Bulging			100%		18%	0.36		
	Resistivity	100%				6%	0.23	Temperature: R: 8,962 ohm-cm	
	Backfill Material		100%			5%	0.16		
Facing	Joints			100%		3%	0.07		
	Staining		100%			2%	0.05		
	Cracking			100%		2%	0.03		
	Spalling	100%				2%	0.06		
Exterior	Coping			100%		2%	0.03		
	Vegetation			100%		2%	0.03		
Other									
Engineer Inspection	*If category was rated 50% > Poor	Yes							
Score	**Rating Score**						2.59	Wall Data	Unit
	Height of Wall						0.98	19.8	(ft)
	AADT						1	7,000	
	Age of Wall						0.94	1994	(yr)
	Risk Adjusted Rating Score						2.39		

KDOT MSE Wall Inspection Form						Survey Date:		3/15/2022	
Height (ft)	26.4	**GPS Coordinates**		39° 40' 24" N 97° 24' 27" W				**County**	Sedgwick
Length (ft)	1000								
Width (ft)	60	% of Wall Condition				W%	Score	**Wall ID #**	US-54 over Hoover Rd
Category	**Rating**	4	3	2	1				
		Good	Fair	Poor	Severe			Notes	
Movement	Wall Tilting	100%				19%	0.77		
	Backfill Settlement	100%				10%	0.41		
Drainage	Scour/Soil Erosion	100%				8%	0.31		
	Exterior Drainage		100%			7%	0.21	A couple south side spots where water from bridge ran over wall	
	Internal Drainage		100%			16%	0.47	A couple south side spots where water from bridge ran over wall	
Backfill	Panel Bowing / Bulging	100%				18%	0.72		
	Resistivity	100%				6%	0.23	Temperature: R: 28,899 ohm-cm	
	Backfill Material	100%				5%	0.22		
Facing	Joints		100%			3%	0.10		
	Staining	75%	25%			2%	0.06		
	Cracking		100%			2%	0.05		
	Spalling	100%				2%	0.06		
Exterior	Coping	100%				2%	0.06		
	Vegetation	100%				2%	0.06		
Other									
Engineer Inspection	*If category was rated 50% > Poor	No							
Score	**Rating Score**						3.72	Wall Data	Unit
	Height of Wall						0.98	26.4	(ft)
	AADT						0.98	12,000	
	Age of Wall						0.94	1994	(yr)
	Risk Adjusted Rating Score						3.36		

<table>
<tr><td colspan="3">KDOT MSE Wall Inspection Form</td><td colspan="4">Survey Date:</td><td colspan="2">3/3/2022</td></tr>
<tr><td>Height (ft)</td><td>13.2</td><td rowspan="2">GPS Coordinates</td><td colspan="4" rowspan="2">38° 59' 58" N 95° 42' 23" N</td><td rowspan="2">County</td><td rowspan="2">Shawnee</td></tr>
<tr><td>Length (ft)</td><td>280</td></tr>
<tr><td>Width (ft)</td><td>60</td><td colspan="4">% of Wall Condition</td><td rowspan="3">W%</td><td rowspan="3">Score</td><td>Wall ID #</td><td>US-75 to I-470 W</td></tr>
<tr><td rowspan="2">Category</td><td rowspan="2">Rating</td><td>4</td><td>3</td><td>2</td><td>1</td><td colspan="2" rowspan="2">Notes</td></tr>
<tr><td>Good</td><td>Fair</td><td>Poor</td><td>Severe</td></tr>
<tr><td rowspan="2">Movement</td><td>Wall Tilting</td><td>100%</td><td></td><td></td><td></td><td>19%</td><td>0.77</td><td colspan="2"></td></tr>
<tr><td>Backfill Settlement</td><td>100%</td><td></td><td></td><td></td><td>10%</td><td>0.41</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Drainage</td><td>Scour/Soil Erosion</td><td>75%</td><td>25%</td><td></td><td></td><td>8%</td><td>0.29</td><td colspan="2"></td></tr>
<tr><td>Exterior Drainage</td><td></td><td>100%</td><td></td><td></td><td>7%</td><td>0.21</td><td colspan="2"></td></tr>
<tr><td>Internal Drainage</td><td></td><td>100%</td><td></td><td></td><td>16%</td><td>0.47</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Backfill</td><td>Panel Bowing / Bulging</td><td>100%</td><td></td><td></td><td></td><td>18%</td><td>0.72</td><td colspan="2"></td></tr>
<tr><td>Resistivity</td><td></td><td></td><td>100%</td><td></td><td>6%</td><td>0.11</td><td colspan="2">Temperature:
R: 2,963 ohm-cm</td></tr>
<tr><td>Backfill Material</td><td>100%</td><td></td><td></td><td></td><td>5%</td><td>0.22</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Facing</td><td>Joints</td><td></td><td>100%</td><td></td><td></td><td>3%</td><td>0.10</td><td colspan="2"></td></tr>
<tr><td>Staining</td><td></td><td>100%</td><td></td><td></td><td>2%</td><td>0.05</td><td colspan="2"></td></tr>
<tr><td>Cracking</td><td></td><td>100%</td><td></td><td></td><td>2%</td><td>0.06</td><td colspan="2"></td></tr>
<tr><td>Spalling</td><td>100%</td><td></td><td></td><td></td><td>2%</td><td>0.05</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Exterior</td><td>Coping</td><td></td><td>100%</td><td></td><td></td><td>2%</td><td>0.06</td><td colspan="2"></td></tr>
<tr><td>Vegetation</td><td></td><td>100%</td><td></td><td></td><td>2%</td><td>0.05</td><td colspan="2"></td></tr>
<tr><td>Other</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>Engineer Inspection</td><td>*If category was rated 50% > Poor</td><td colspan="8">Yes</td></tr>
<tr><td rowspan="5">Score</td><td colspan="5">Rating Score</td><td></td><td>3.6</td><td>Data</td><td>Units</td></tr>
<tr><td colspan="5">Height of Wall</td><td></td><td>1</td><td>13.2</td><td>(ft)</td></tr>
<tr><td colspan="5">AADT</td><td></td><td>0.96</td><td>23,000</td><td></td></tr>
<tr><td colspan="5">Age of Wall</td><td></td><td>1</td><td></td><td>(yr)</td></tr>
<tr><td colspan="5">Risk Adjusted Rating Score</td><td></td><td>3.4</td><td></td><td></td></tr>
</table>

KDOT MSE Wall Inspection Form			Survey Date:					3/15/2022	
Height (ft)	42.9	GPS Coordinates	38° 56' 34" N 94° 46' 24" N					County	Johnson
Length (ft)	25								
Width (ft)	102	% of Wall Condition				W%	Score	Wall ID #	K-10 E to I-435 N
Category	Rating	4	3	2	1				
		Good	Fair	Poor	Severe			Notes	
Movement	Wall Tilting	100%				19%	0.77		
	Backfill Settlement	100%				10%	0.41		
Drainage	Scour/Soil Erosion	75%	25%			8%	0.29		
	Exterior Drainage		100%			7%	0.21		
	Internal Drainage		100%			16%	0.47	Poor drainage by wall on west side causing erosion	
Backfill	Panel Bowing / Bulging	100%				18%	0.72		
	Resistivity	100%				6%	0.23	Temperature: Resistivity Reading: 10,907 ohm-cm	
	Backfill Material	100%				5%	0.22		
Facing	Joints	100%				3%	0.14		
	Staining		100%			2%	0.05		
	Cracking		100%			2%	0.05		
	Spalling	100%				2%	0.06	Spalling on coping on west side	
Exterior	Coping		100%			2%	0.05		
	Vegetation		100%			2%	0.05		
Other									
Engineer Inspection	*If category was rated 50% > Poor	Yes							
Score	Rating Score						3.69	Wall Data	Unit
	Height of Wall						0.96	42.9	(ft)
	AADT						0.96	23,000	
	Age of Wall						0.94	1996	(yr)
	Risk Adjusted Rating Score						3.20		

KDOT MSE Wall Inspection Form			Survey Date:		3/15/2022	
Height (ft)	26.4	**GPS Coordinates**	38° 56' 28" N 94° 45' 28" W		**County**	Johnson
Length (ft)	623					
Width (ft)	177	% of Wall Condition			**Wall ID #**	I-435 over Lackman Rd

Category	**Rating**	4 Good	3 Fair	2 Poor	1 Severe	W%	Score	Notes
Movement	Wall Tilting	100%				19%	0.77	
	Backfill Settlement	100%				10%	0.41	
Drainage	Scour/Soil Erosion	25%	50%	25%		8%	0.23	
	Exterior Drainage		75%			7%	0.16	Southwest column (corner)
	Internal Drainage		100%			16%	0.47	
Backfill	Panel Bowing / Bulging	100%				18%	0.72	
	Resistivity			100%		6%	0.11	Temperature: Resistivity Reading: 4,486 ohm-cm
	Backfill Material	100%				5%	0.22	
Facing	Joints		100%			3%	0.10	Southwest column and two panels on west side
	Staining	100%				2%	0.06	
	Cracking	100%				2%	0.06	
	Spalling		100%			2%	0.05	Two sections on west side
Exterior	Coping	100%				2%	0.06	
	Vegetation			100%		2%	0.03	Multiple large trees growing adjacent to foundation
Other								
Engineer Inspection	*If category was rated 50% > Poor	Yes						

Score				Wall Data	Unit
	Rating Score		3.45		
	Height of Wall		0.98	26.4	(ft)
	AADT		0.96	23,000	
	Age of Wall		1	2014	(yr)
	Risk Adjusted Rating Score		3.25		

KDOT MSE Wall Inspection Form				Survey Date:				3/15/2022	
Height (ft)	26.4	**GPS Coordinates**		39° 07' 39" N 95° 41' 34" W				**County**	Shawnee
Length (ft)	690								
Width (ft)	120	% of Wall Condition				W%	Score	**Wall ID #**	US-75 over NW 46th St
Category	**Rating**	4	3	2	1			Notes	
		Good	Fair	Poor	Severe				
Movement	Wall Tilting		100%			19%	0.58		
	Backfill Settlement	100%				10%	0.41		
Drainage	Scour/Soil Erosion	75%	25%			8%	0.29		
	Exterior Drainage		100%			7%	0.21		
	Internal Drainage		100%			16%	0.47		
Backfill	Panel Bowing / Bulging		100%			18%	0.54		
	Resistivity	100%				6%	0.23	Temperature: R: 2264 ohm-cm	
	Backfill Material		100%			5%	0.16		
Facing	Joints	100%				3%	0.14		
	Staining		100%			2%	0.05		
	Cracking		100%			2%	0.05		
	Spalling		100%			2%	0.05		
Exterior	Coping		100%			2%	0.05		
	Vegetation		100%			2%	0.05		
Other									
Engineer Inspection	*If category was rated 50% > Poor	No							
Score	**Rating Score**						3.25	Wall Data	Unit
	Height of Wall						0.98	26.4	(ft)
	AADT						0.98	12,900	
	Age of Wall						0.94	2002	(yr)
	Risk Adjusted Rating Score						2.94		

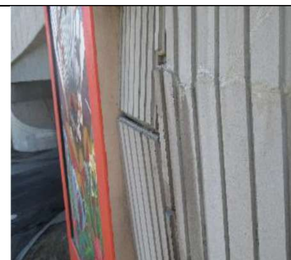
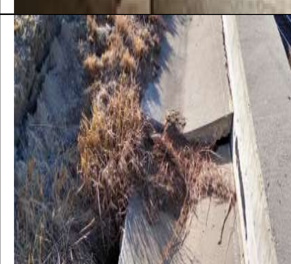
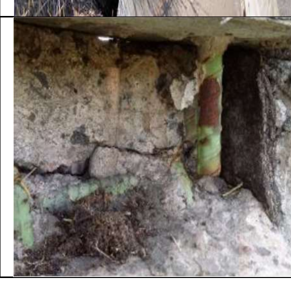
MSE Wall Walkthrough Problem

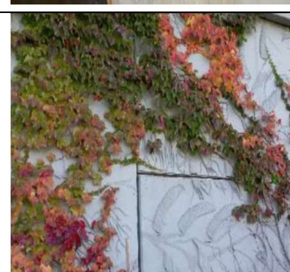
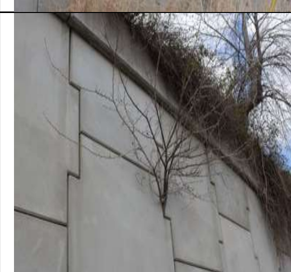
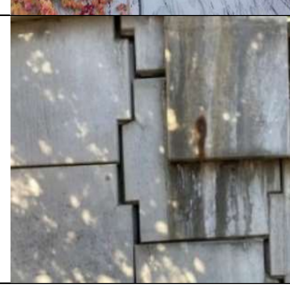
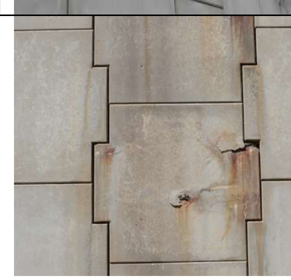
A recent inspection was conducted on an MSE wall. You are providing quality assurance to an inspector by rating images pulled from Google Earth. Background information of the wall was pulled from a plan set. The wall is 20 years old and 15' high. The Wall is in the interstate corridor and has an AADT of 8000 vehicles a day. Fill out the form provide this will be compared to the inspector's report. The form is based on a rated weighing scale, four is good, three is fair, two is poor, and one is severe. In addition, what percentage of the wall is in good to poor condition. For example, if 75% of the coping is in good condition (not cracked), 25% of the coping is in fair condition (minor cracking) that would be the total rating of one category, with the score adding up to 100%. An explanation of each category is provided with picture examples of what is good fair poor severe. In addition to the rating, a weighting scale has been computed to adjust the overall score. Multiplying the 75% * 4 + 25% *3 * (weight of the category) will result in the weighted score. Fill out the rest of the inspection sheet until all categories have been reviewed if a category can't be computed it must be assumed based on your judgment. Sum up the ratings to a final value. If any value is rated at 50% poor or less a reinspection is needed. The risk assessment category will finalize the inspection. A set of tables is provided to adjust for age height and traffic. Look up these values in the table and multiply them by the score to give a final modified score to the MSE wall. If this score is 2.5 or below another inspection will need to be conducted.


Kellog/US 54 and Ridge Road
U.S. Route 400
W Kellogg Ave

KDOT MSE Wall Inspection Form				**Survey Date:**					
Height (ft)		**GPS Coordinate**						**County**	
Length (ft)									
Width (ft)		% of Wall Condition				W	Score	**Wall ID**	
Category	**Rating**	4	3	2	1				
		Good	Fair	Poor	Severe			Notes	
Movement	Wall Tilting					19%			
	Backfill Settlement					10%			
Drainage	Scour/Soil Erosion					8%			
	Exterior Drainage					7%			
	Internal Drainage					16%			
Backfill	Panel Bowing / Bulging					18%			
	Resistivity					6%		Temp: RR:	
	Backfill Material					5%			
Facing	Joints					3%			
	Staining					2%			
	Cracking					2%			
	Spalling					2%			
Exterior	Coping					2%			
	Vegetation					2%			
Other									
Engineer inspection	*If category was rated 50% > Poor	Yes or No							
Score	**Rating Score**							Wall Data	
	Height of Wall								(ft)
	AADT								
	Age of Wall								(yr)
	Risk Adjusted Rating Score								

Rating		4 Good	3 FAIR	2 POOR	1 SEVERE
Movement	Wall tilting	none	minor uniform titling of the wall section. Minor wall misalignment	moderate uniform tilting of the wall section. Moderate wall misalignment	extreme uniform tilting of the wall section. Extreme wall misalignment
	Settlement	none	some settlement but no effect on the roadway	moderate settlement roadway moderately affected	extreme settlement roadway affected, and traffic is completely impeded
Drainage	Scour/Soil Erosion	riprap in place *if founded on rock rating is automatically a 4	some riprap missing	moderate amount of riprap missing with moderate soil erosion	riprap is gone with extreme soil erosion exposing wall toe
	Exterior Drainage	free draining	water is not ponded with slow drainage	water is ponded with little drainage from the roadway above the wall	water is ponded with no drainage from the roadway
	Internal Drainage	free draining	some debris in the drain, drainage from the wall still occurring	drains contain debris with some drainage occurring	drain completely full of debris no drainage occurring
Backfill	Panel Bowing / Bulging	none	panel joints have bowed without geotextile fabric exposure	panel joints have bowed with some geotextile fabric and soil exposure	panel joints have bowed with complete geotextile fabric and soil exposure
	Resistivity *to be finalized upon completion of current corrosion of MSE backfill project	Greater than 10,000Ohm-cm (laboratory drained or in situ)	5,000 – 10,000 Ohm-cm (laboratory drained or in situ)	2,000 -5,000 Ohm-cm (laboratory drained or in situ)	Less than 2,000 Ohm-cm (laboratory drained or in situ)
	Backfill Material	none	minor backfill erosion visible	moderate backfill erosion visible	extreme backfill erosion visible structural integrity is compromised
Facing	Joints	wall panel joint spacing is uniform (0.75")	wall panel joint width exceeds as-built spacing without geotextile exposure (1.5")	wall panel joint width exceeds as built spacing or is irregular with exposed geotextile fabric (3"-6")	wall panel joint width exceeds as-built spacing large gaps with the erosion of backfill (6"-12")
	Staining	none	some staining	moderate staining	wall is completely or near completely stained
	Cracking	none	insignificant nonstructural cracks	structural cracks or cracking	reinforcement is showing, losing backfill or so cracked panel itself will fail
	Spalling	none	small deterioration	moderate deterioration with soil, geotextile, or rebar is visible	soil or geotextile is completely exposed, or visibly corroded rebar
Exterior	Coping	none	minor cracks or spalling	moderate cracks or spalling	Coping is missing, severe cracks or spalling
	Vegetation	none	some vegetation	moderate vegetation growth; unchecked, grass or small shrubs	extreme vegetation growth; overgrown wall with trees

Category	Fair	Poor	Severe
Cracking			
Joints			
Panel Bowing or Bulging			
Backfill Erosion			
Exterior Drainage			
Spalling			

Category	Fair	Poor	Severe
Internal Drainage			
Scour/Soil Erosion			
Coping			
Vegetation			
Staining			

Risk Assessment Tables

AADT	Modifier Value
<4,000	1
4,000-18,500	0.98
18,500-35,000	0.96
>35,000	0.94

MSE Wall Height (m)	Modifier Value
<5	1
5-10	0.98
10-15	0.96
>15	0.94

MSE wall Age (years)	Modifier Value
<10	1
10-15	0.98
15-20	0.96
>20	0.94

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