LITERATURE REVIEW: CONCRETE GRINDING RESIDUE DISPOSAL AND REUSE

Final Report
August 2018

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Sponsored by
Recycled Materials Research Center (RMRC)

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ACKNOWLEDGMENTS

The authors gratefully acknowledge the Recycled Materials Research Center (RMRC) for financial support of this study and MnDOT for CGR materials supplying. Funding support for RMRC is provided through the Transportation Pooled Fund, TPF-5(352). Partner state DOTs for the TPF include: Illinois, Iowa, Minnesota, North Carolina, Pennsylvania, Virginia, Washington, and Wisconsin.

EXECUTIVE SUMMARY

Concrete grinding residue (CGR) is a slurry byproduct created from diamond grinding operations that is used to smooth concrete pavement surface. As a waste material, CGR consists of cooling water for grinding blades and concrete fines from the removed concrete layer. Since the CGR has high pH, it can be a critical environmental issue and should be managed properly to reduce its impact to the ecological system. To understand the current management practices of CGR throughout United States (US), a comprehensive review of state regulations and a survey of Departments of Transportation (DOTs) and contractors were conducted in this study, with results showing that in many states detailed guidance for disposal of CGR to reduce risks was lacking. In addition to more common disposal methods, the unreacted cement, high pH and pozzolans in CGR may have a potential for being recycled and reused to stabilize roadbed soil (referred to as soil stabilization). To evaluate the preliminary performance of CGR for soil stabilization purpose, this study mixed 10%, 20%, 30%, and 40% of CGR collected from Minnesota by weight with soil to stabilize two types of Iowa soils classified as A-4 and A-6 according to the American Association of State Highway and Transportation Officials (AASHTO). Unconfined compressive strength (UCS) tests for CGR-treated soil showed that a 20% CGR addition was the optimum content that resulted in the highest strength, and other laboratory testing results revealed that CGR treatment could reduce the maximum dry density and plasticity and increase the pH, alkalinity and electrical conductivity of soils. Preliminary results of this study was promising indicating that CGR may be used for soil and slope stabilization. However, it requires more detailed further research.

INTRODUCTION

Diamond grinding is a widely-used rehabilitation technique usually referred to as resurfacing of Portland cement concrete (PCC) pavement. As a maintenance operation, diamond grinding can provide a smooth PCC surface with enhanced texture and skid resistance and less road noise. Typically, this operation uses a truck equipped with grinding heads at the ground level to saw the thin layer of concrete and grind it into fine particles, mix with cooling water for blades, then generate a slurry byproduct known as concrete grinding residue (CGR).

The composition of CGR can vary widely due to use of different Portland cement products and supplementary materials in concrete. Generally, CGR has a basic pH and is rich in metal content (e.g. chromium (Cr), iron (Fe)) which comes from fly ash and/or steel slag embedded during cement production or concrete mix preparation. Thus, their inappropriate disposal may cause critical environmental issues at environmentally sensitive nearby areas (farmlands, lakes, creeks, rivers, and high groundwater table presence, etc.). On the other hand, CGR may have a significant potential for reuse as construction materials, liming products, and/or stabilizing agents.

This study conducted a detailed literature reviews about the properties of CGR and its effect on the environment. A summary based upon several previous studies shows that CGR may pose some environmental concerns even though in some cases it seems to be environmentally friendly. In this study, a comprehensive review related to state regulations governing CGR management practices in all 50 state was conducted to understand the issues and concerns regarding the CGR disposal in the concrete industry and DOTs, and the surveys for DOT and industry contractors were distributed to get more information. The properties of CGR such as high CaO and pozzolanic mineral contents makes it attractive for recycling it in soil, concrete, and other applications which can be used to improve roadway sustainability, long-term performance, and reduce life-cycle cost of pavements. For this purpose, this study also preliminarily evaluated the possibilities for reuse of CGR in soil applications. Laboratory tests were including unconfined compressive strength (UCS), Atterberg limits, alkalinity, EC, and pH were conducted on soils stabilized with CGR at different percentages by weight.

LITERATURE REVIEW

Properties of CGR

To understand the characteristics of CGR, several studies have been conducted with various CGR slurries. Holmes and Narver (*1*) reported that CGR samples collected from a grinding operation in California had initial pH at the ranges of 9.4 to 11.1, and showed no toxicity based on the 96-hour Acute Toxicity test. Volatile organic compounds in the solid phase and the liquid phase of CGR did not exceed detection limits of the equipment. However, semi-volatile compounds were detected in the liquid phase of the samples. In addition to that, the cation and anion concentrations of aluminum (Al), iron (Fe), and SO_4 (sulfate) exceeded the California Drinking Water Standard.

DeSutter et al. (*2*) and DeSutter et al. (*3*) analyzed CGR slurry samples from grinding practices in California, Minnesota, Nebraska, Washington and Michigan. The pH of CGR in those studies ranged from 11.6 to 12.5, with detected concentrations of arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), selenium (Se), and silver (Ag) that were below the 40 CER 261 standard toxic limits. The concentration values of the toxic elements in slurry solid phase were smaller than the values reported for the surface soil at the sampling locations, indicating that CGR slurry was not the dominant contaminant portion of the soil. Based on the particle size distribution analysis, silt-sized particles were the major constituent of the CGR samples (Figure 1).

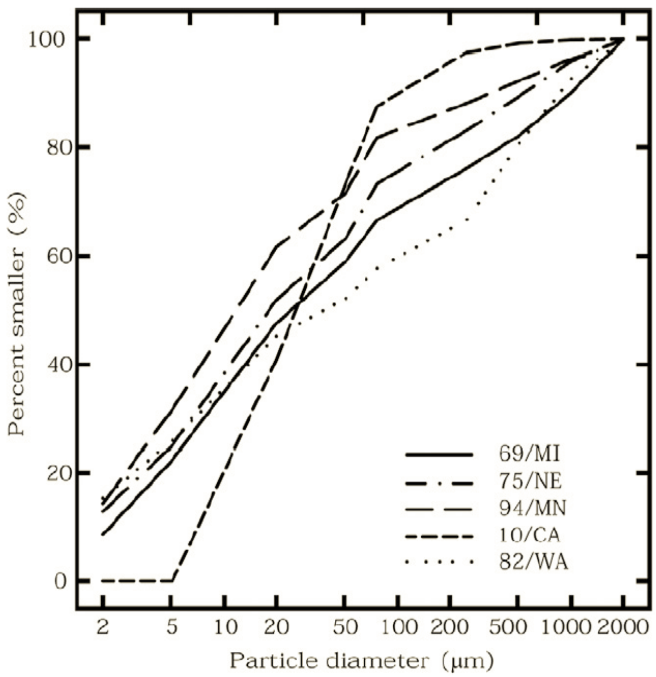


Figure 1. Particle size distributions for five CGR samples from five roadway sites (DeSutter et al., 2010 (*2*)).

Other researchers also reported similar results regarding the properties of concrete residues. For example, in concrete residue recycling, Goodwin and Roshek (*4*) reported the pH of concrete residues from multiple sources within the ranges of 12 to 12.6. Hanson et al. (*5*) reported pH values of CGR samples from Washington State to be 10.2 and 10.9. Druschel et al. (*6*) reported several concrete residue properties including the CGR slurry in Minnesota in their research of concrete wastewater and the best management practices project. The pH of a reconstituted slurry sample was 9.4, and it contained predominantly silt-sized or finer particles. Chini and Mbwambo (*7*) reported the pH values in concrete wastewater samples as 11 to 12. Sulfates, hydroxides, chlorides, as well as small quantities of both hydrocarbons and admixture compounds were also found in the concrete wastewater. Young and Shanmugam (*8*) reported that pH values of slurry in Washington State ranged from 11.9 to 12.1 in a slurry neutralization experiment. Based on the previous investigations it could be noted that CGR is a fine material with high pH and alkalinity and its improper disposal may be a critical issue to the environment.

Soil and Plant Responses to CGR Application

To understand how CGR affected the environment, some efforts have been made to analyze the soil and plants responses to the offloading of CGR. Young and Shanmugam (*8*) investigated the long term (6 to 10 years) effects of slurry on soil`s pH. The pH values of soil without CGR slurry were 6.3 to 7.2; while the pH of soil with CGR slurry increased by 1 to 2 units as shown in Figure 2. The concentration of Pb, Cu (Copper), Zn (Zinc) and Cd were measured at different soil depths, and there were no significant differences between the soil background value and the values of soil in slurry disposal areas. However, the concentrations of Mg (magnesium) and Ca (Calcium) increased due to the slurry application.

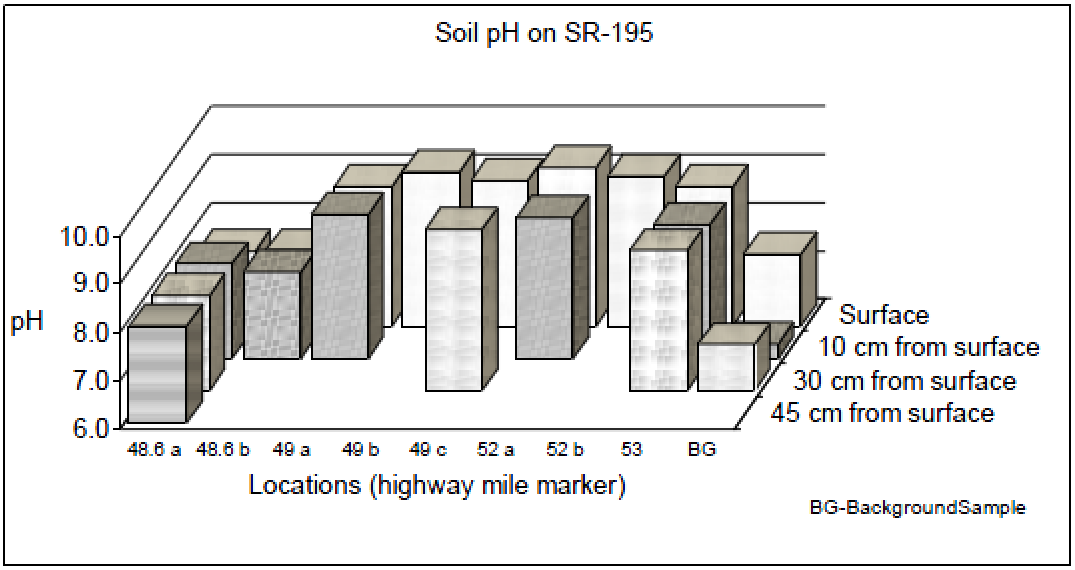


Figure 2. Soil pH at I-90 sample sites as a function of depth. In this figure, a, b and c refer to replicate samples collected within in 1 ft. of each other (Young and Shanmugam, 2005 (*8*)).

DeSutter et al. (*2*) summarized the effects of CGR on water infiltration time in soil. Results of this study showed that the infiltration time of soil with slurry was longer than the soil alone. DeSutter et al. (*3*) reported the short-term (99 days) soil and plant responses to CGR slurry. The shoot growth was promoted for low slurry rates (8%), while it was inhibited for high slurry rates (25%). Soil pH after CGR application was higher than that of soil alone, while EC (electrical conductivity) increased significantly at higher CGR application rates. Concentrations of non-trace (Ca, Cd, Pb and Sr) and trace metals (Cr) in smooth brome grass were also significantly increased by CGR rate, and the factor of CGR type only significantly increased Ca and Sr concentrations in soils. Soil types affected the Cd, Cr, Pb and Sr concentrations in biomass. On the other hand, Hg concentrations in soils were not affected by any factors studied previously.

Mamo et al. (*9*) studied both short-term (1 month) and long-term (1 year) effects of CGR on soil properties and roadside plants located at HWY 31 Milepost 34 and 36 in Nebraska. This study summarized that slurry, slope, depth, and slurry-depth interaction were the most significant factors affecting the soil pH, EC, Ca, K, Mg, and Na concentrations for the first month after slurry application. After a one-year period, slurry effects shown in Table 1 were not significant ($p < 0.05$).

Table 1. Impacts of CGR slurry application on two site experiments, with loam and silt loam soil textures, at NE State HWY 31 sites (Mamo et al., 2015 (*9*)).

CGR (Ton/acre)	pH	EC dS m^{-1}	K mg Kg^{-1}	Ca mg Kg^{-1}	Mg mg Kg^{-1}	Na mg Kg^{-1}
0	8.1	0.74	259	3835	162	1031
5	8.1	0.57	300	4434	206	647
10	8.2	0.58	305	4390	175	638
20	8.2	0.59	301	4498	179	736
40	8.2	0.60	314	4946	197	681
Effect	P > F					
Slurry	0.5927	0.1867	0.4896	0.0078	0.4225	0.1970
Slope	0.0008	0.3171	0.0002	0.0325	<0.0001	0.2236
Depth	<0.0001	0.4920	0.0003	0.0007	<0.0001	<0.0001
Slurry*Slope	0.8609	0.7677	0.6685	0.9023	0.8778	0.0184
Slurry*Depth	0.7901	0.0011	0.7768	0.0002	0.1726	0.8506

Kluge et al. (*10*) discussed the environmental concerns of disposal of CGR along the roadside by conducting X-ray fluorescence (XRF), X-ray diffraction (XRD) and leaching test on CGR samples collected from Jacksonville, Florida. Test results showed that leached concentrations of twenty five elements (Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sn, Sr, Ti, V and Zn) didn't exceed the Florida soil clean-up target levels (SCTLs) and indicated that direct exposure should not be a major limitation to the management of CGR, especially when it is placed next to a roadway or on an agricultural area.

Wingeyer et al. (*11*) reported that after a four-week period after the application of slurry (9 kg/m^2), the soil pH increased by 0.11 unit compared to the control site. Compared to the control site, there was also a significant decrease in Mg and K concentrations at the depth of 0-20 cm. Exchangeable Na level in the 0-20 cm depth increased due to CGR application. In addition, the exchangeable Ca level increased in 0-10 cm depth compared to the control site. The botanical compositions of the treated plots were not affected by the slurry application.

Overall, previous studies presented that CGR slurries could increase soil pH, EC and concentrations of metals (Ca, Mg, Na, etc.) in soils. Based on these results it should be noted that, CGR should be managed properly to avoid the contamination of soil and waterbodies.

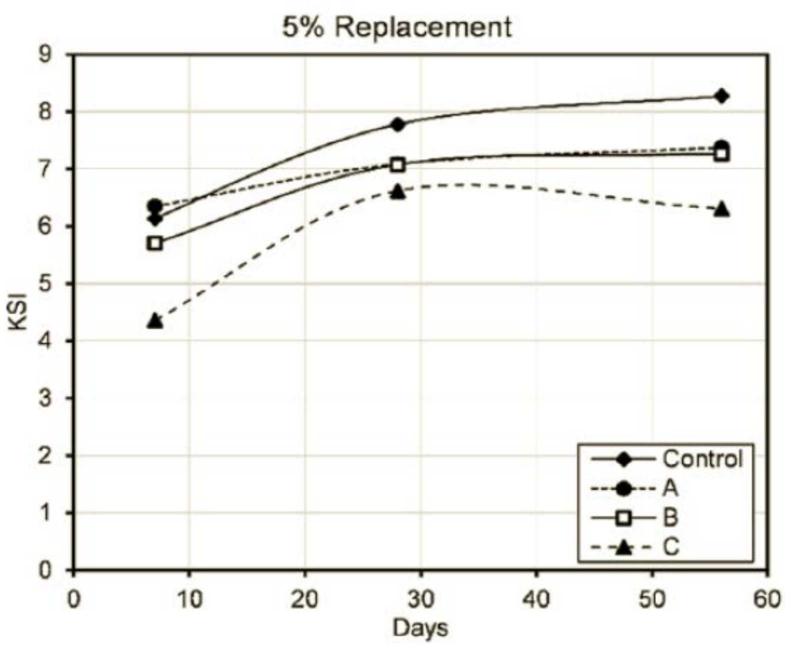
Recycle and Reuse of CGR in Various Applications

Reuse of CGR as Construction Materials

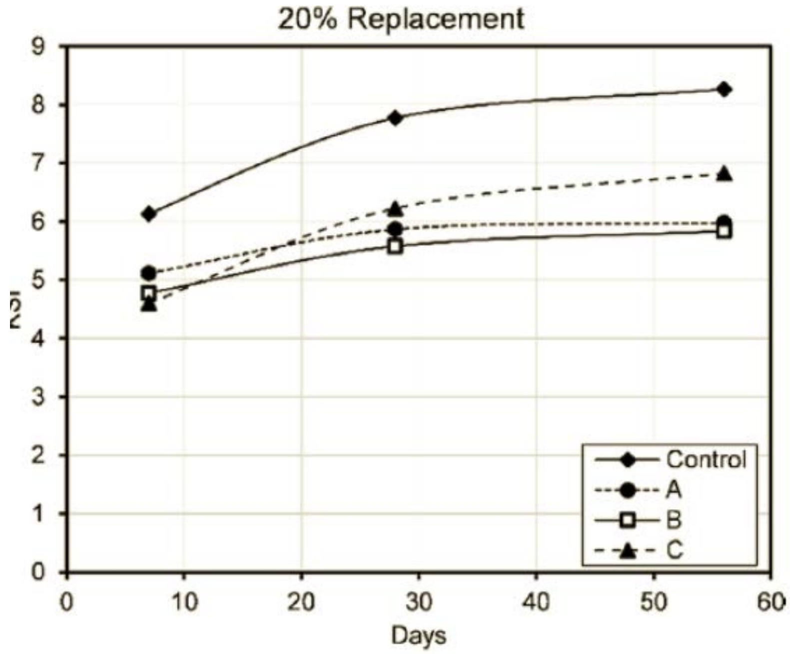
In addition to the common CGR disposal methods (offloading along roadside, decanting in pond or processing in waste facilities), recycling and reuse of CGR are strongly recommended for achieving the goal of sustainable pavements. Some studies were carried out to evaluate the reuse of CGR or other recycled concrete fines as an additive in construction materials or liming products.

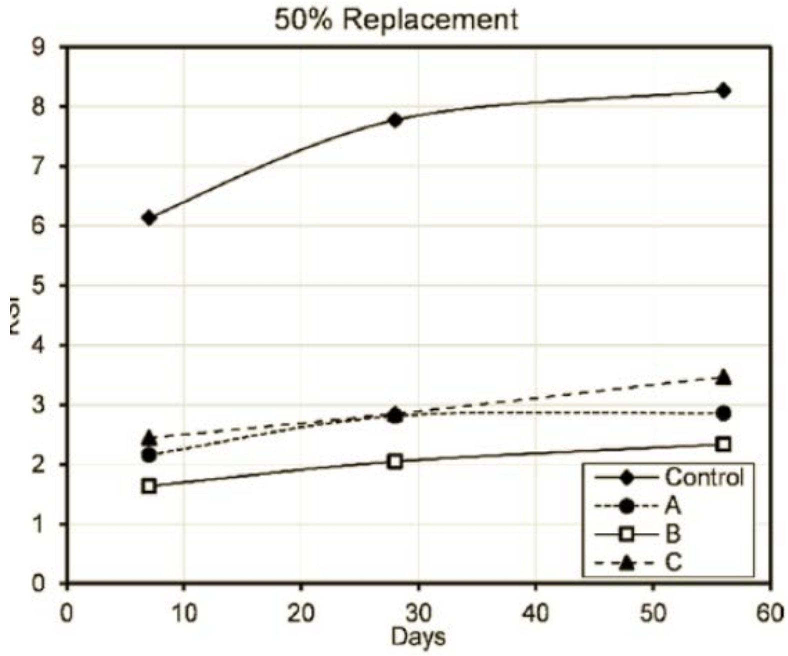
Concrete waste can typically be used for partial replacement in concrete mixing or filling materials in construction. Goodwin and Roshek (*4*) evaluated the recycling of CGR as a filler into the cement-treated base course in Utah. At the grinding project site, CGR was collected and hauled to the temporary storage for filtering, and pH control action was conducted through the addition of acid to reduce pH to the ranges of 7 to 9. The separated slurry water was hauled to wastewater treatment plant for treatment and discharging, and the solid waste was reused into a construction of cement-treated base. This study concluded that recycling of CGR as a filler in cement-treated base resulted in lower construction cost with a similar mechanical performance compared to the industrial treatments and disposal of CGR in waste facilities for processing.

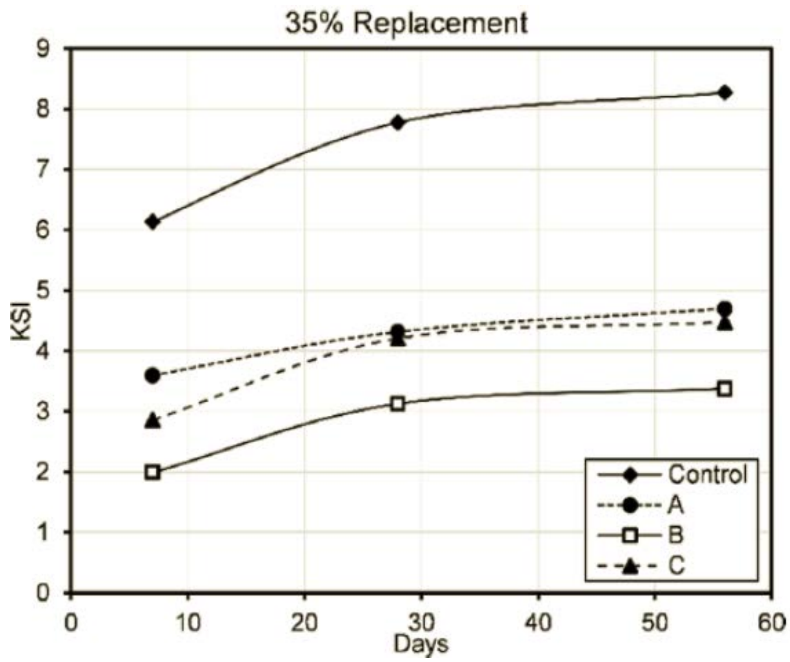
Kluge et al. (*10*) examined the CGR collected from Jacksonville, Florida for potential use as a partial replacement of cement in new mortar and found no dramatic reactivity or improvement in mortar strength as shown in Figure 3. Ravindrarajah and Tam (*12*) obtained similar results after they used recycled concrete fines for concrete mixing. Results of this study showed that the early-age strength and modulus of elasticity of cement paste were reduced with addition of recycled concrete fines while dry shrinkage and creep potentials increased. On the other hand, the studies of Hanson et al. (*5*) and Janssen et al. (*13*) presented opposite trends compare to those of Kluge et al. (*10*) and Ravindrarajah and Tam (*12*).



(a)


20% Replacement
Control
A
B
C
Days
(b)


50% Replacement
Control
A
B
C
Days
(c)



(d)

Figure 3. Three CGR samples (A, B and C) were used as cement replacements in 2-inch cubes and subjected to compressive strength tests (Kluge et al., 2018 (*10*)).

Amin et al. (*14*) investigated the reuse of recycled concrete fines from demolished concrete for strength gain within a cement mortar matrix (Figure 4), and showed that the rehydration of these fines was observed through electron microscopy in the mortar. Thus, it resulted in strength gain.

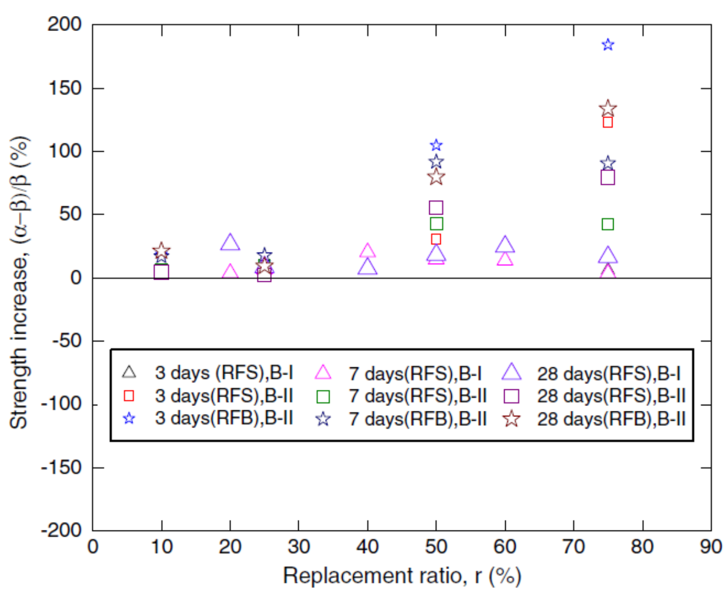


Figure 4. Percentage strength increases caused by replacement of recycled fines from brick aggregate concrete (RFB) and stone aggregate concrete (RSB) at different ages (Amin et al., 2016 (*14*)).

Cavalline and Albergo (*15*) performed a benefit-cost analysis on CGR disposal to investigate the potential savings. They concluded that use of decanting ponds was the most cost-effective method of handling CGR slurries. Disposal options for CGR solids vary across the country and are highly dependent on the tipping fees of the waste disposal facilities. Based upon this study, the disposal of CGR as a solid beneficial fill material was determined to be the least expensive.

Other studies also evaluated the use of recycled concrete fines for soil stabilization applications. Kerni et al. (*16*) concluded that the use of demolished concrete waste in soil stabilization not only helped to reduce the hazardous environmental impacts of the waste, but also improved the engineering properties of soil which ultimately reduced the cost of construction and increased the life of the structure built on the stabilized soil. Lindeman et al. (*17*) investigated the use of recycled crushed concrete (RCC) fines for soil stabilization. It summarized that the compressive strength of the soil with 3% RCC waste material did not cause any significant effect on soil mechanical characteristics. Ransinchung et al. (*18*) reported reductions in dry densities and plasticity indices of clayey soils mixed with both cement and recycled concrete fines. On the other hand, this study observed that the admixing of concrete fines improved the soaked CBR value, unconfined compressive strength and split-tensile strength of soils. Twagirimana et al. (*19*) determined the optimum lime and concrete contents needed to be added to maximize the CBR of silty sand as 6% and 8% respectively. At these percentages, improvements on shear strength, fatigue cracking and rutting resistance of soil were observed. Engelsen et al. (*20*) monitored the release of major and trace elements from recycled concrete aggregates used in an asphalt covered road sub-base over 4 years. Based upon their findings, the levels of Cd, Ni, Pb and Zn at the subbase did not exceed the acceptance criteria of groundwater and surface water. They also observed the levels of Cr and Mo increased in the winter, and it was assumed this was caused by using of de-icing salt. Townsend et al. (*21*) evaluated the possible impact of using recycled concrete aggregate as a road base in the subsurface environment. In this study, the reduction of pH of recycled concrete aggregates was observed due to some environmental factors such as carbonation from atmospheric carbon dioxide, neutralization with soil acidity, and neutralization with groundwater.

Reuse CGR for Soil Amendment

In addition to the investigation of CGR as construction materials, some studies evaluated the use of CGR as a soil amendment. Berger and Carpenter (*22*) suggested the reuse of recycled concrete waste to neutralize acidic soils. Scott (*23*) and Scott (*24*) investigated that a forest site was covered with concrete dust derived from the resurfacing operation for an overpass above. The thickness of concrete dust was about 2 mm, and the covered forest showed a flourished condition which was probably caused by the addition of Ca from concrete dust into the soil. Hansen (*25*) discussed a variety of potential uses for CGR, including wastewater treatment filters, poultry grit, limestone substitution in SO_2 scrubbers, and stabilizing sewage sludge. Hanson and Angelo (*26*) concluded that the addition of crushed concrete fines may have improved engineering properties of clayey soils for earthwork purposes. While the literature indicates that CGR can have a beneficial utilization in soil amendment, soil testing and risk assessment at each specific site prior to applying CGR is strongly recommended to determine an optimum application rate.

The literature shows that while concrete fines may be a useful waste product for many applications including producing new concrete, filling road base and stabilizing subgrade soil. The solid phase of CGR can be utilized in similar applications due to its composition. In addition to reuse of CGR as construction materials, the previous studies also highlighted that it can be reused as a soil amendment. Reuse of waste materials like CGR in different applications not only reduces the environmental risks that may be encountered due to their improper disposal methods, but also contributes to the sustainability of concrete and pavement designs.

REVIEW OF MANAGEMENT PRACTICES OF CGR

Technical Guidance

Grooving and grinding pavement surfaces developed into global activities during the previous century. In 1972, International Grooving and Grinding Association (IGGA), a non-profit industry trade association, was founded to provide technical and professional guidance for properly grinding and grooving pavement surfaces. Based on several studies related to CGR characteristics, it can be concluded that the major negative consideration related to slurry waste is the contamination potential of the local environment, especially bodies of water (*10*). To prevent such contamination, the IGGA developed the best management practices (BMPs) for proper disposal of slurry by-products. The IGGA BMPs (*27*) provided three methods shown in Table 2 to manage CGR disposal. In some cases, CGR can be spread along roadsides in rural areas, while CGR generated in the urban area can be hauled and transported to chosen ponds for decanting or to waste treatment facilities for processing. It should be noticed that spreading of CGR in sensitive areas or drainage facilities (e.g. culverts, drain inlets) is prohibited by the BMPs due to CGR`s high pH and metal contents. Numerous previous tests have verified that CGR is a nonhazardous material (*1*, *28*-*29*) and some studies conducted by DeSutter et al. (*3*) and Mamo et al. (*9*) pointed out that CGR application may even have a positive impact on plant growth. In addition to the recommended proper disposal methods of CGR, the BMPs also proposed that pH values of CGR should be monitored and maintained at the ranges of 2 to 12.5.

Table 2. Guidelines for CGR disposal methods in IGGA BMPs.

Disposal Methods	Applicable Cases	Precautions
Spread CGR along roadsides.	In rural areas, CGR can be dumped along vegetated roadsides.	1. Do not allow CGR to flow across the roadway into adjacent lanes. 2. Do not allow CGR to enter a closed drainage system. 3. Identify the wetlands and other sensitive areas before discharge of CGR. 4. CGR shall be spread with a minimum 0.3 m distance from shoulder. 5. Do not spread CGR within 30.5 m of sensitive areas or within 0.9 m of water-filled ditch.
Collect slurry for pond decanting.	In urban area and other areas with closed drainage system or sensitive environment, CGR can be	1. The location of pond shall be approved by engineer. 2. Water in the pond can be decanted for reuse in the grinding operation.

Disposal Methods	Applicable Cases	Precautions
	disposed in a constructed pond.	3. Solids in the pond after drying can be reused as fill material or other useful applications. 4. The pond area shall be reclaimed and vegetated to avoid erosion.
Collect slurry for plant processing.	In urban area and other areas with closed drainage system or sensitive environment, CGR can be disposed in a constructed pond.	1. The plant processing shall be in accordance with state regulation. 2. The processed water and solids can be reused in the same applications as the decanting pond.

State Management Practices

Although IGGA developed BMPs as the technical guidance to manage CGR, some states have their own regulations for guiding CGR disposal which vary slightly from each other. Variations in CGR management practices in different states are a result of historical practices and variation in environments, construction materials, and design methods. Table 3 summarizes the local regulations for CGR disposal in all 50 state DOTs. Based upon the review, 8 of the 50 states, including Indiana, Maryland, and a few others, have no regulations for managing CGR. For the other 42 states, cleaning CGR from the road surface is a basic requirement, with 19 states requiring continuous CGR removal, and 29 states emphasize prohibition of CGR flow into drainage facilities or sensitive areas. The purpose of the cleaning requirement is to avoid CGR remaining on a pavement surface becoming airborne by the wind. Of the 42 states, 12, 11, and 8 states, respectively, allow the roadside offloading, pond decanting and waste-facility processing. Table 3 also shows that 8 state require to dispose of CGR off-site, and it means the methods such as decanting in off-site ponds, waste plant processing and off-site burial are acceptable. In other 12 states, contractors and engineers are required to provide a methodology for CGR disposal to minimize the risk to environment. It should be noticed that 5 states follow the general protocols of waste management in their manuals to dispose of CGR. In this study, a survey distributed to the grinding contractors showed that following the state guidelines to manage CGR is a priority. If no state regulations are available, contractors generally either offload CGR along the roadsides or dispose it to pond or waste facilities. Since CGR slurry in general has high pH, 7 states ask contractors to control the CGR pH (general below 12.5) prior to its disposal. There are 3 states providing relevant guidelines with respect to land application of CGR. Michigan (*49*) not only allows reuse of CGR solids as construction fill material or a liming product with a maximum rate of 5 dry ton/acre, but also approves reuse of water after decanting for blade cooling. In Nebraska, a permit (*54*) allows use of CGR up to 40 dry ton/acre for land application. North Carolina (*59*) approves recycling of CGR for land application, irrigation, or dust control on NCDOT projects. The review of state practices results revealed that in many states CGR disposal methods are flexible and lack detailed guidelines and control actions.

Table 3. CGR management practices in different states.

State	Reference	Prohibitive area to offload CGR	Disposal methods of CGR	Road surface clean	Control CGR properties
AK	ASK DOTandPF (*30*)			Remove CGR continuously.	
AL	ALDOT (*31*)	Drainage facilities	Determine by contractor and engineer.	Remove CGR continuously.	
AR	AHTD (*32*)	Drainage facilities and sensitive areas	Determine by contractor and engineer; Disposal in pond*; Disposal in pre-approved flat vegetated area*.	Clean CGR.	
AZ	ADOT (*33*)	Drainage facilities and sensitive areas	Determine by contractor and engineer.	Clean CGR.	
CA	Caltrans (*34-35*)	Drainage facilities	Disposal in pond.	Clean CGR.	
CO	CDOT (*36*)		Disposal off-site.	Remove CGR continuously.	
DE	DelDOT (*37*)		Determine by contractor and engineer.	Remove CGR continuously.	
FL	FDOT (*38*)	Drainage facilities and sensitive areas	Determine by contractor and engineer; Follow IGGA BMPs*.	Remove CGR continuously.	Metal concentrations*; pH*
GA	GDOT (*39*)	Drainage facilities		Clean CGR.	
HI	HDOT (*40*)			Remove CGR continuously.	
IA	Iowa DOT (*41-42*)	Drainage facilities	Spread along roadsides.	Remove CGR continuously.	
ID	IDT (*43*)	Drainage facilities	Determine by contractor and engineer; Disposal in pond*; Disposal in waste plant*.	Clean CGR.	
IL	IDOT (*44*)		Follow general waste management practices.	Remove CGR continuously.	
KS	KDOT (*45*)	Drainage facilities and sensitive areas		Remove CGR continuously.	
KY	KYTC (*46*)	Drainage facilities	Determine by contractor and engineer.	Clean CGR.	
LA	Louisiana DOTD (*47*)	Drainage facilities	Spread along roadsides; Disposal in pond*.	Clean CGR.	
MI[a]	MDOT (*48*); MDEQ (*49*)	Drainage facilities and sensitive areas	Spread along roadsides (≥ 1.5-m from curb); Disposal in pond; Disposal in waste plant.	Clean CGR.	pH: ≤ 12.5
MN	MPCA (*50*)		Spread along roadsides; Disposal in pond; Disposal in waste plant.	Clean CGR.	pH: 6 - 12
MO	MoDOT (*51*)	Drainage facilities and sensitive areas	Disposal off-site; Spread along roadsides.	Clean CGR.	

State	Reference	Prohibitive area to offload CGR	Disposal methods of CGR	Road surface clean	Control CGR properties
MS	MDOT (*52*)	Drainage facilities	Determine by contractor and engineer.	Clean CGR.	
MT	MDT (*53*)	Drainage facilities and sensitive areas	Disposal in pond.	Clean CGR.	
NE[a]	NDEQ (*54*)	Drainage facilities and sensitive areas	Discharge along roadsides (≤ 8.96 kg/m^2 (40 ton/acre) by CGR dry weight).	Clean CGR.	pH: ≤ 12.5*; TSS*
NV	NDOT (*55*)	Drainage facilities and sensitive areas	Disposal off-site; Disposal in pond; Disposal in waste plant*.	Clean CGR.	
NJ	NJDOT (*56*)		Follow general waste management practices.	Remove CGR continuously.	
NM	NMDOT (*57*)	Drainage facilities		Remove CGR continuously.	
NY	NYSDOT (*58*)	Drainage facilities and sensitive areas	Disposal off-site.	Remove CGR continuously.	
NC[a]	NCDOT (*59*)	Drainage facilities and sensitive areas	Disposal off-site; Spread along roadsides; Disposal in waste plant	Clean CGR.	pH: 10 - 12
ND	NDDOT (*60*)		Follow general waste management practices.	Remove CGR continuously.	
OH	Ohio DOT (*61*)	Drainage facilities	Soil testing prior to a disposal plan needs to be provided and approved*.	Clean CGR.	PH: ≤ 11.5*
OK	OKDOT (*62*)		Spread along roadsides.	Remove CGR continuously.	
OR	Oregon DOT (*63*)		Follow general waste management practices.	Clean CGR.	
PA	Penn DOT (*64*)	Drainage facilities	Follow general waste management practices (≥ 15.2-m from bodies of water or sewer system).	Remove CGR continuously.	
RI	RIDOT (*65*)	Drainage facilities	Disposal off-site.	Remove CGR continuously.	
SC	SCDOT (*66*)	Drainage facilities	Follow IGGA BMPs.	Clean CGR.	pH: 2 - 12.5
SD	SDDOT (*67*)			Clean CGR.	
TN	TDOT (*68*)	Drainage facilities	Spread along roadsides; Disposal in pond.	Clean CGR.	
TX	TxDOT (*69*)	Drainage facilities	Determine by contractor and engineer.	Remove CGR continuously.	
UT	UDOT (*70*)		Determine by contractor and engineer.	Clean CGR.	
WA	WSDOT (*71*)	Drainage facilities and sensitive areas	Disposal off-site.	Remove CGR continuously.	
WI	WisDOT (*72*)	Drainage facilities and sensitive areas	Disposal off-site.	Clean CGR.	
WV	WVDOT (*73*)	Drainage facilities	Determine by contractor and engineers; Spread along roadsides*;	Clean CGR.	TSS*

State	Reference	Prohibitive area to offload CGR	Disposal methods of CGR	Road surface clean	Control CGR properties
			Disposal in waste plant*.		
WY	WYDOT (*74*)		Determine by contractor and engineer.	Remove CGR continuously.	

Statements with superscript "*" are responses from survey distributed to DOT engineers.
States with superscript "a" mean they recycle and reuse of CGR in some applications.
TSS: total suspended solids.

Survey Responses

To understand the perspectives of DOTs and industry contractors, a survey created by the Iowa State University (ISU) was sent to 50 state DOTs and 30 contractors. 12 state DOTs (Arkansas, Florida, Idaho, Iowa, Louisiana, Nebraska, Nevada, Ohio, Pennsylvania, Washington, West Virginia and Wyoming) and 7 contractors (Girard Resources & Recycling LLC, Quality Saw and Seal Inc. and more) responded it. The survey questions covered the specifications, methods, control actions, and recycling practices regarding CGR management, and results are shown in Figure 5 through Figure 24. Survey questions can be found in Appendix A. Based on the survey responses, CGR is regarded as a hazardous waste in 3 states (Figure 5). The personnel from local state highway agencies (SHAs) in 2 states responded that they didn't have guidelines to manage CGR (Figure 6). Only one of the state DOTs indicated that they followed IGGA BMPs (Figure 7), and only two of the state DOTs indicated that they recycled CGR for other purposes (Figure 9). In Figure 8 and Figure 10, all states indicated that they did not monitor the long-term impacts of CGR when it was offloaded onto soil and could not estimate how much money were spent to dispose of CGR. Figure 11 presents that 6 contractors follow the state guidelines to dispose of CGR, and if those guidelines are not available, the contractors would chose to dump slurries along roadside, decanting in ponds or haul it to processing in waste facilities (Figure 12). Figure 13 presents how SHAs and contractors dispose of CGR if the state guidelines are not available, and 2 states and 1 contractor choose to dump it along roadsides. Figure 14 and Figure 15 exhibit that some states try to control the pH, metal concentrations and total suspended solids (TSS) of CGR. Figure 16 through Figure 24 show that many DOTs and contractors don't have any control action plan to manage the disposal of CGR slurries, and lack the detailed guidelines such as dumping area and distance from road surface when they offloaded CGR along roadsides. Although some studies (*3*, *9*) did not expressly describe the negative impacts of CGR on plant growth, the variable characteristics of CGR may cause environmental issues depending on the materials used during concrete production. In conclusions, survey results show that overall majority of the DOTs and contractors don't have proper guidelines to manage and mitigate the effects of CGR on surrounding environment. Based on the results of this survey, it is recommended that CGR disposal should be managed by following the IGGA BMPs or be recycled for other applications in combination with a pH control plan, or, if needed, with other control plans (TSS and Metals) to minimize its risk to the environment.

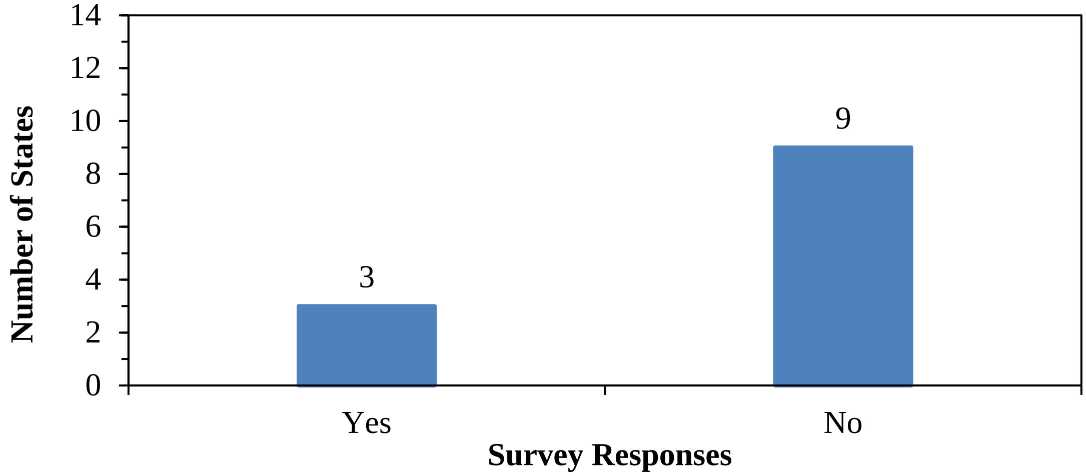


Figure 5. Survey question for DOTs: how many local SHAs consider CGR as the hazardous waste?

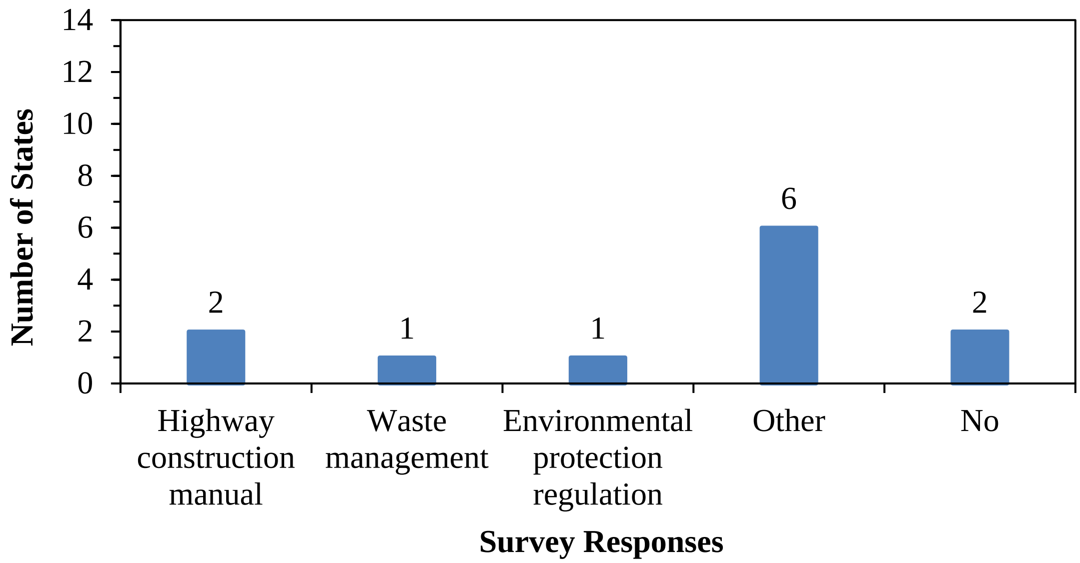


Figure 6. Survey question for DOTs: what specifications were followed to dispose of CGR?

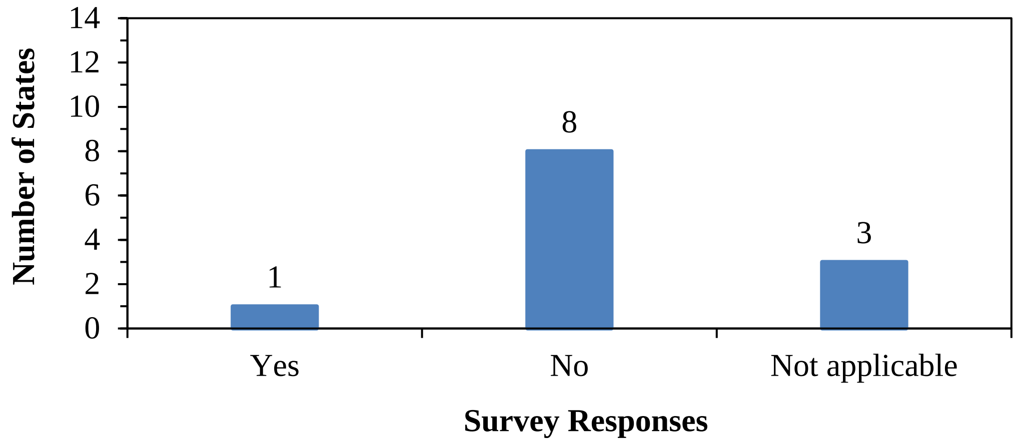


Figure 7. Survey question for DOTs: how many local SHAs follow IGGA BMP if they do not have their own specifications?

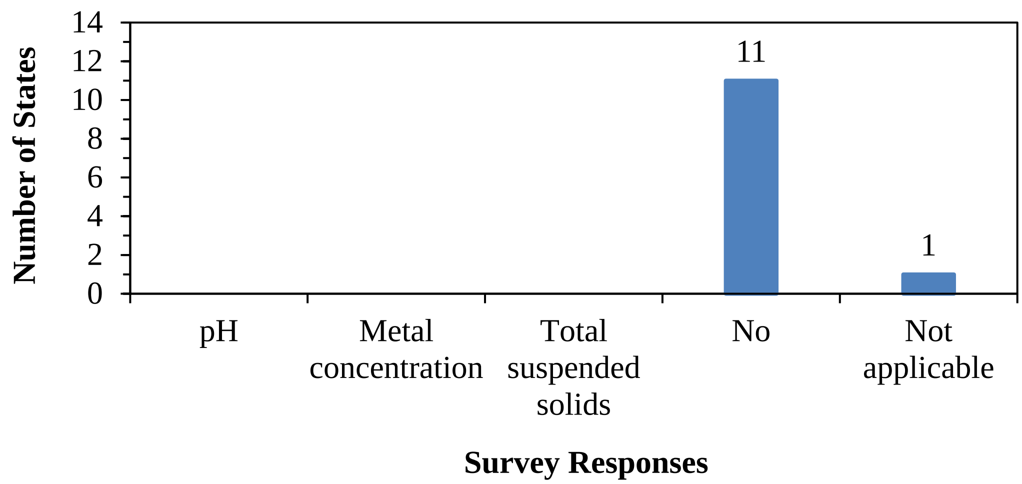


Figure 8. Survey question for DOTs: what long-term environmental impacts are required to be monitored when CGR is discharged on the roadside, median swale, or any other soil-based areas?

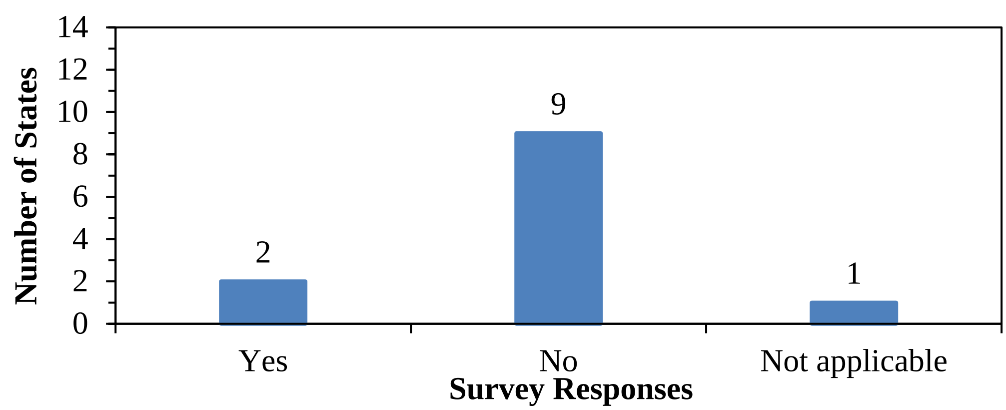


Figure 9. Survey question for DOTs: how many local SHAs have specifications about recycling or reusing CGR?

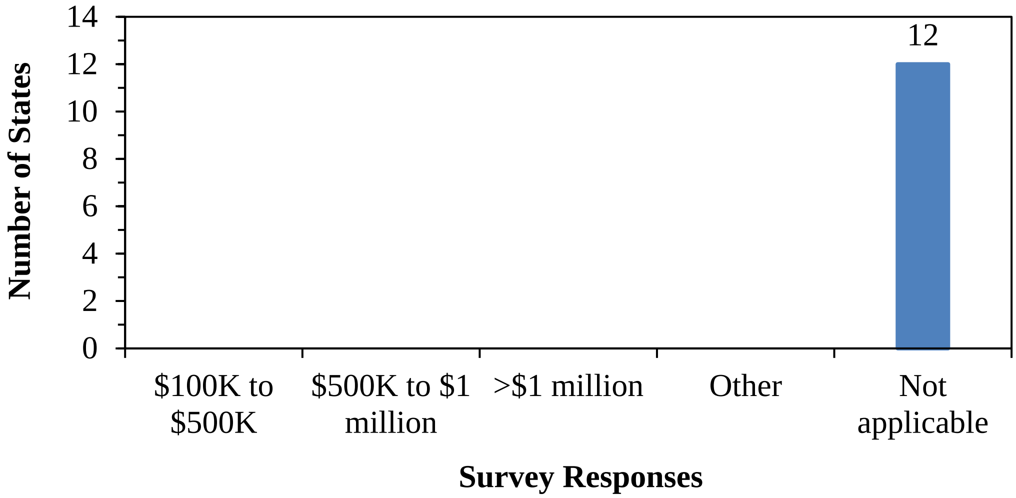


Figure 10. Survey question for DOTs: what is the annual cost of disposal of CGR?

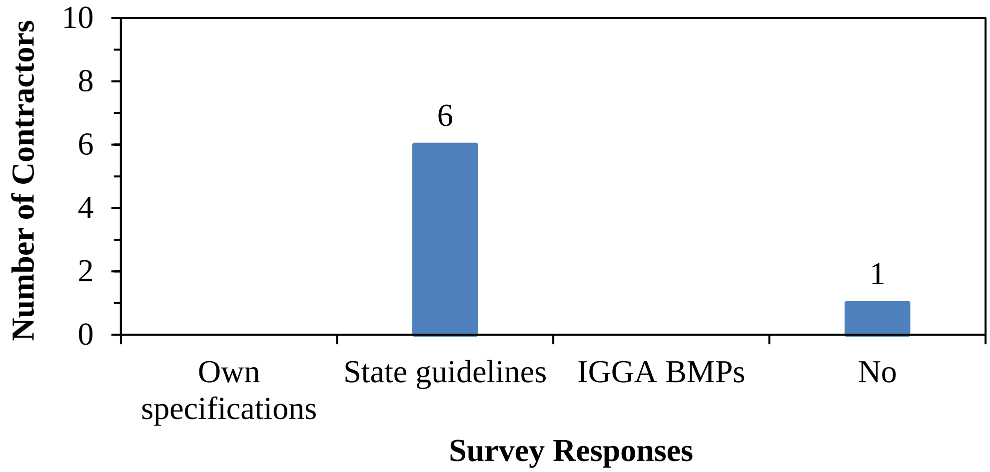


Figure 11. Survey question for contractors: what specifications are followed to dispose of CGR?

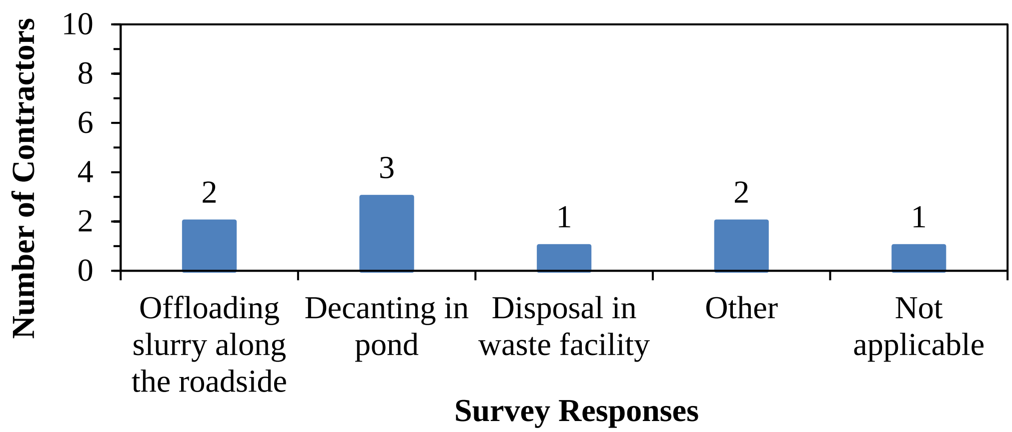


Figure 12. Survey question for contractors: how to dispose of CGR if the contractor follows their own specifications and doesn't follow the state guidelines?

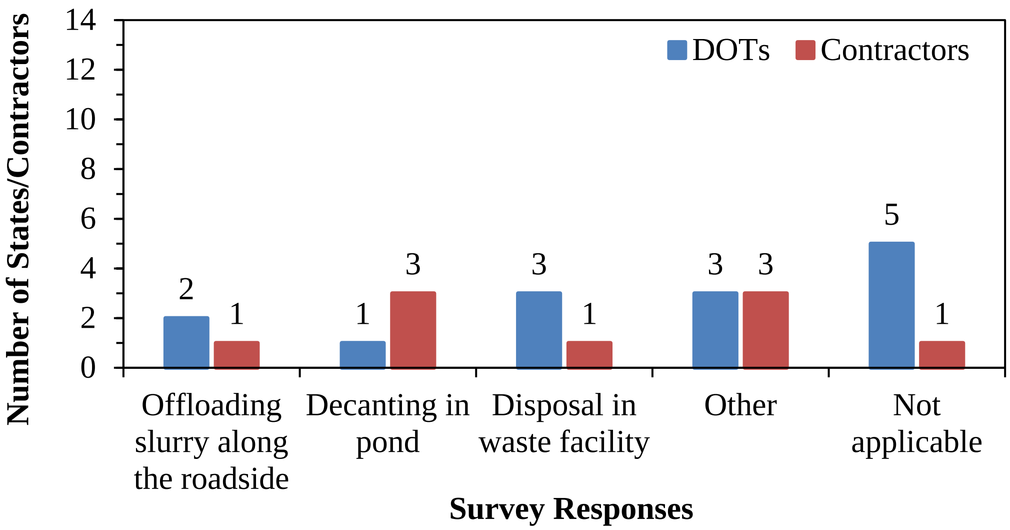


Figure 13. Survey question for DOTs and contractors: how to dispose of CGR if the SHAs/contractors don't have their own specifications and don't follow the state guidelines?

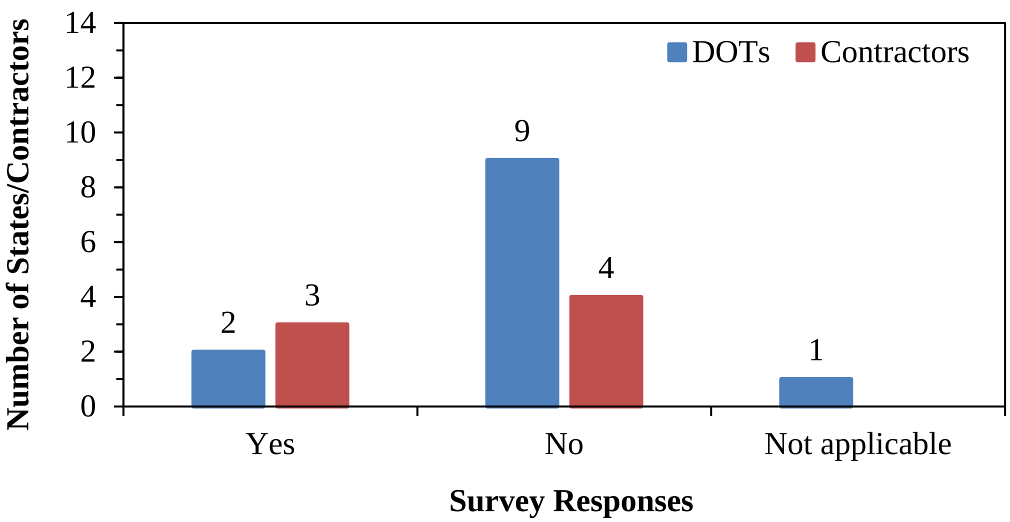


Figure 14. Survey question for DOTs and contractors: do they need to control pH of CGR before its disposal?

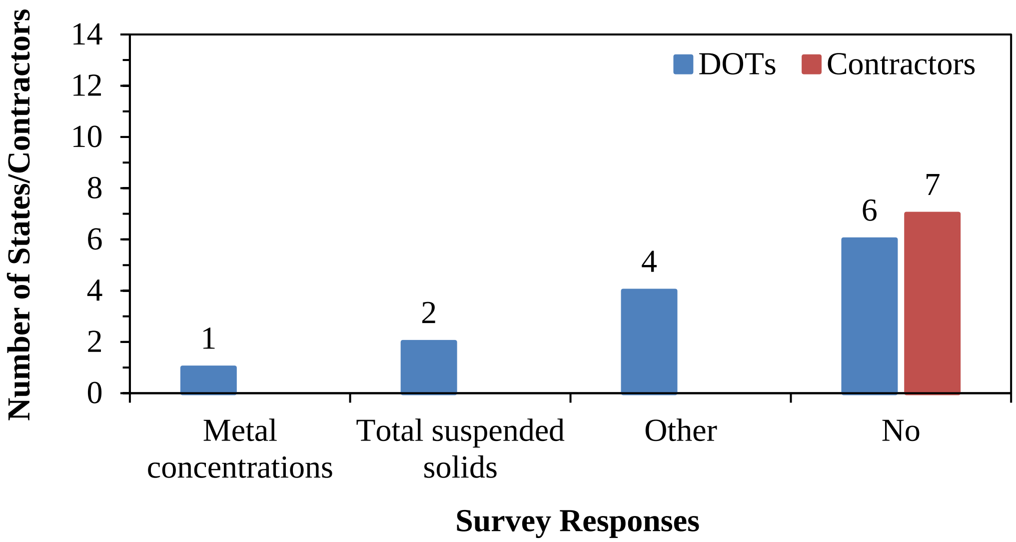


Figure 15. Survey question for DOTs and contractors: what other properties of CGR should be controlled before disposal except pH?

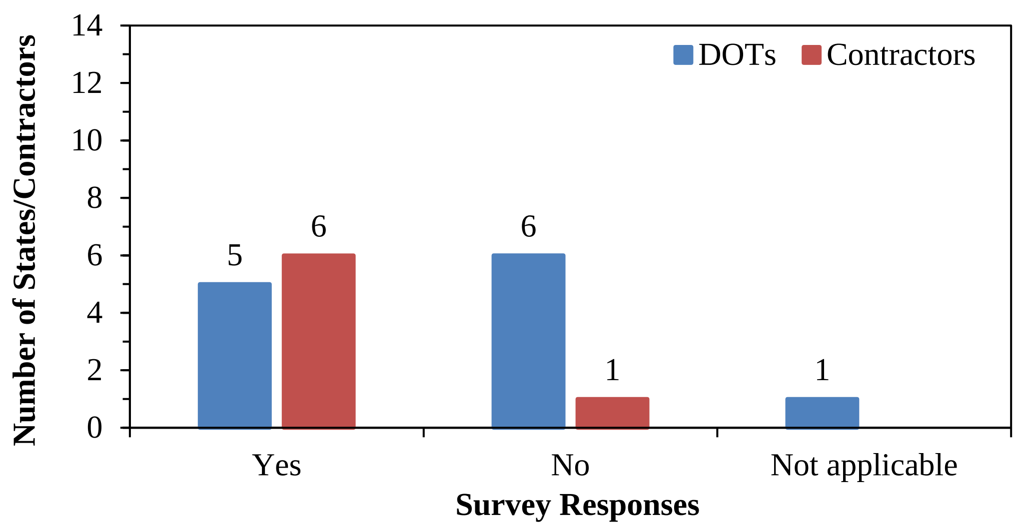


Figure 16. Survey question for DOTs and contractors: does the disposal method of CGR take the distance from the dumping area to the body of water or sewer system into account?

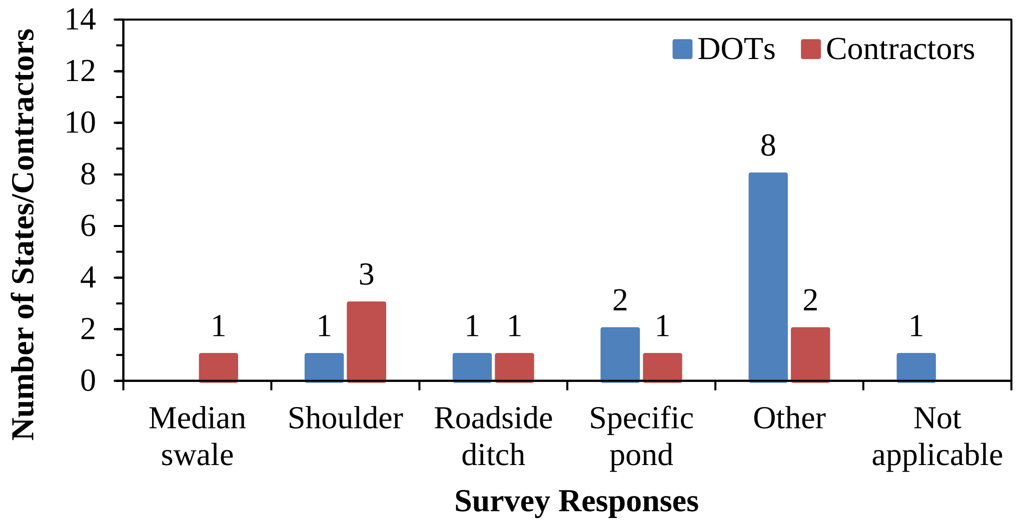


Figure 17. Survey question for DOTs and contractors: where is the suggested place to dispose of CGR?

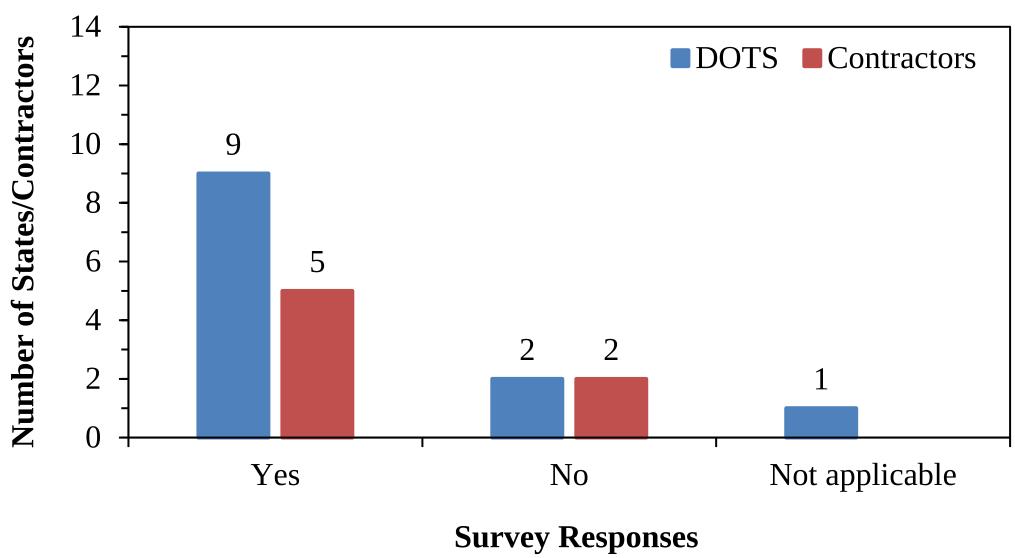


Figure 18. Survey question for DOTs and contractors: do they allow to dispose of the CGR within the right-of-way?

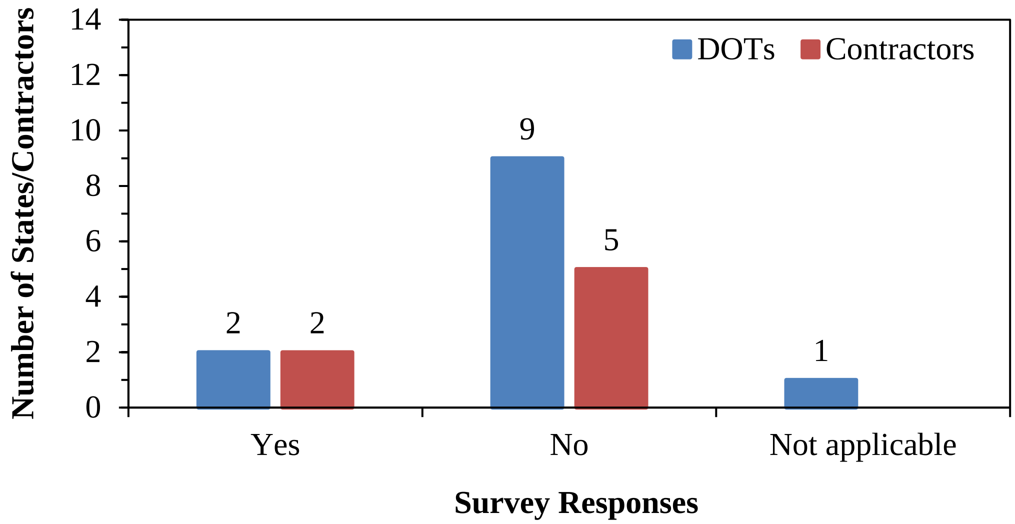


Figure 19. Survey question for DOTs and contractors: do they have any further treatment and/or operation when CGR is discharged on the roadside, median swale, or any other soil-based areas?

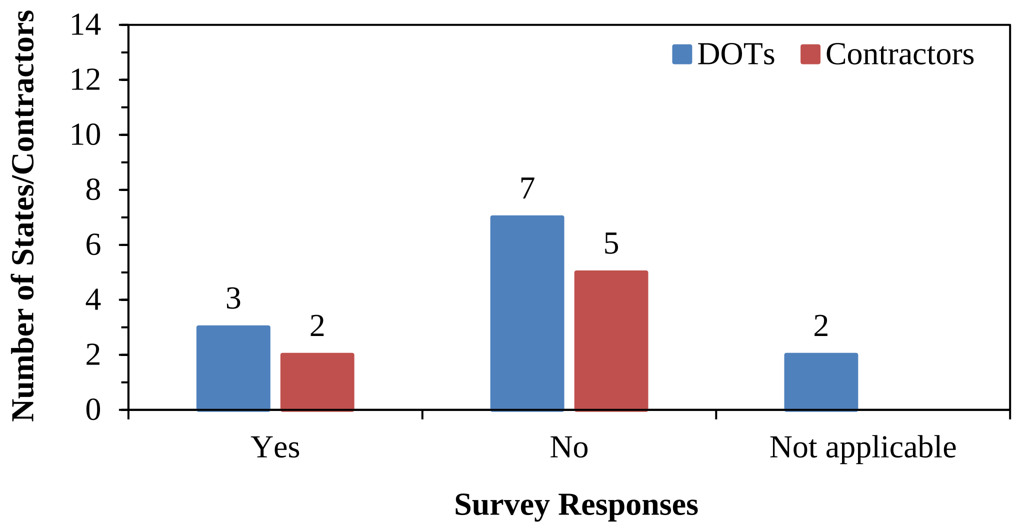


Figure 20. Survey question for DOTs and contractors: if the CGR is discharged into a specific pond, are there any further treatment and operation?

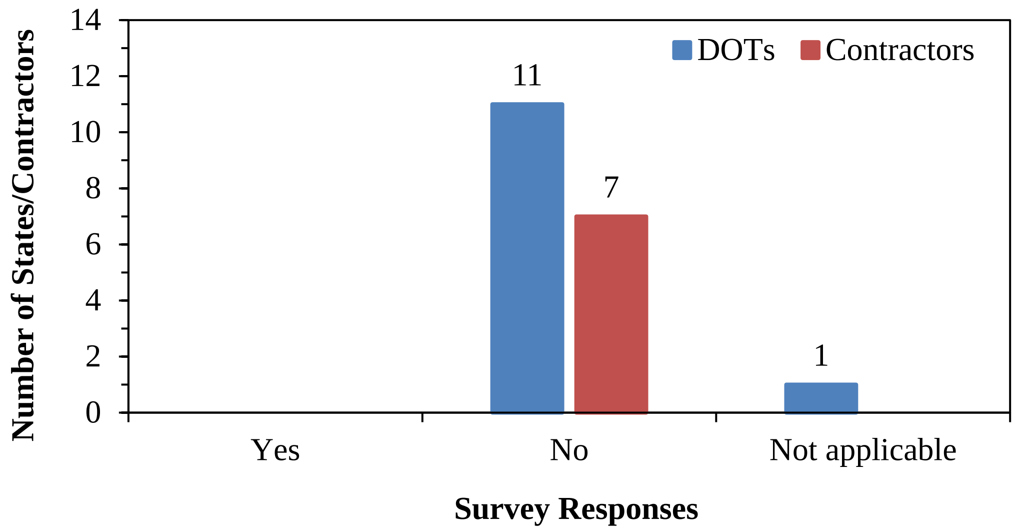


Figure 21. Survey question for DOTs and contractors: do they require to separate the wastewater from CGR and transport it to wastewater treatment facilities?

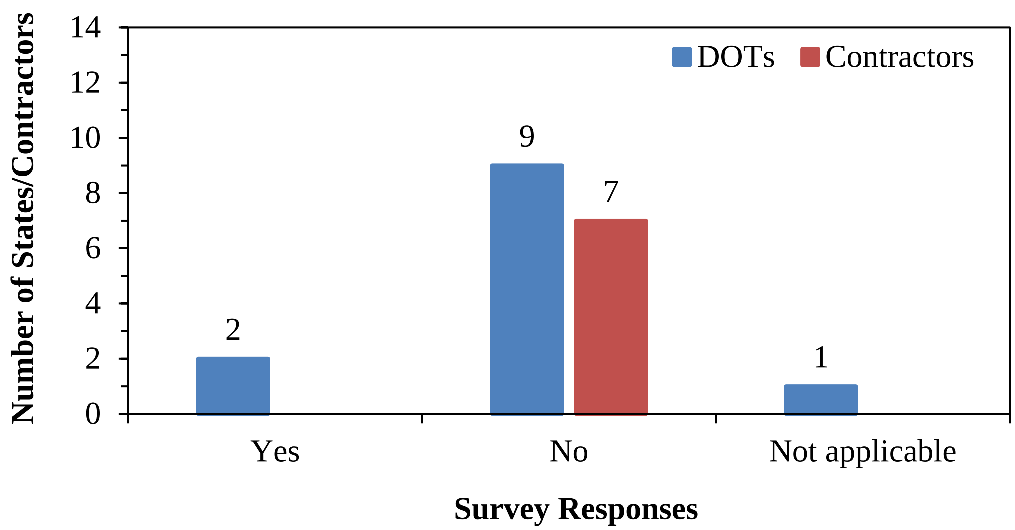


Figure 22. Survey question for DOTs and contractors: are any pretreatments applied to CGR before it is recycled or reused.

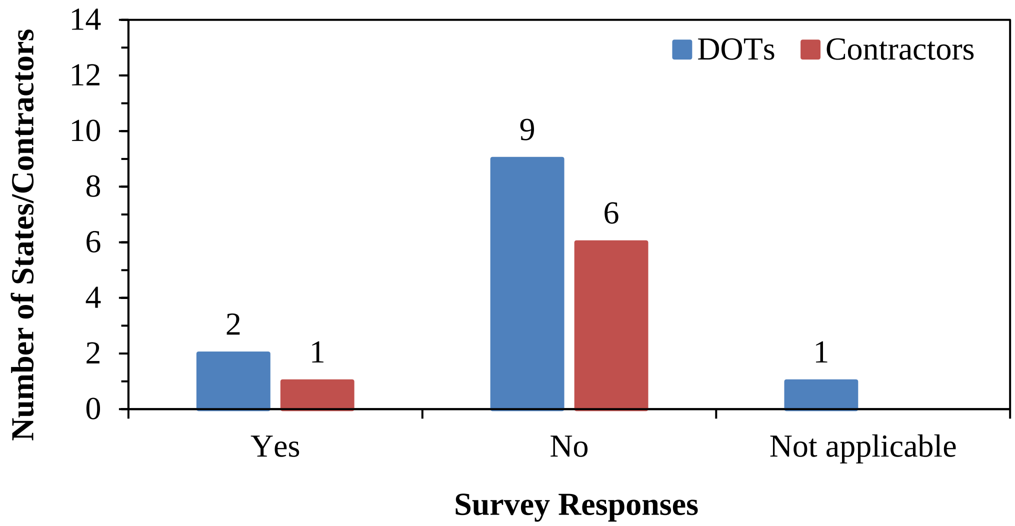


Figure 23. Survey question for DOTs and contractors: do they recycle and reuse CGR and other concrete slurries.

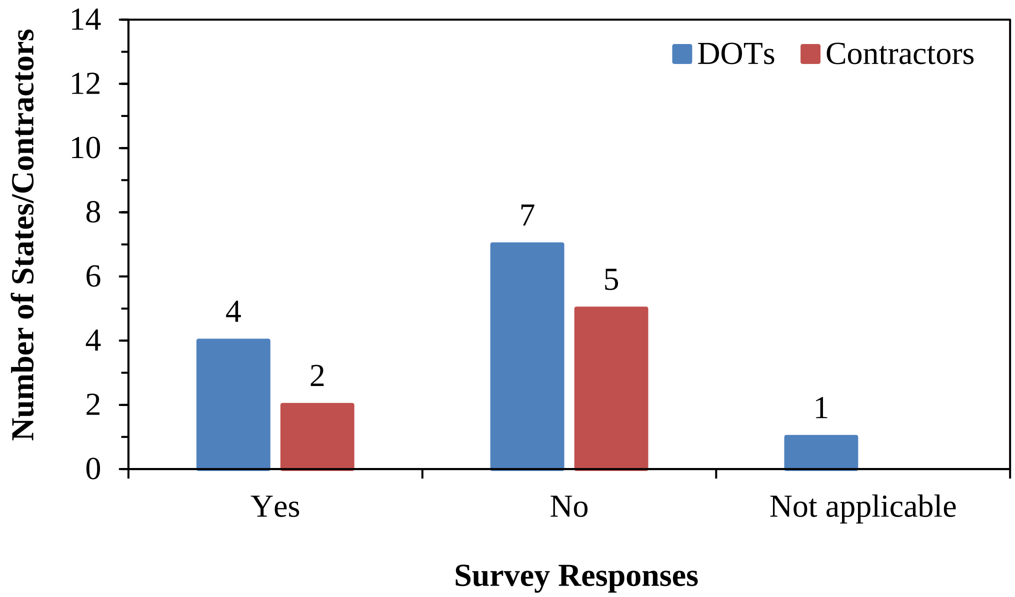


Figure 24. Survey question for DOTs and contractors: does the generation, disposal and application of CGR require a permit by any governing agencies.

USE OF CGR FOR SOIL STABILIZATION

The previous sections already summarized the concerns of CGR disposal and the great potential for reuse of CGR in different applications. The use of CGR slurries as a roadbed soil stabilizer is one of the alternatives for disposal of CGR. To investigate the feasibility of the reuse of CGR as a stabilizing agent, a preliminary laboratory tests were conducted to evaluate the performance of CGR-treated soils.

Materials

Two types of Iowa soils (Soil 1 and Soil 2) were collected in the current study. Index properties of these soils along with their pH values are given in Table 4. Soil 1 and Soil 2 were classified as A-6 and A-4, respectively, according to the AASHTO while they were classified as SC and CL-ML, respectively, according to the Unified Soil Classification System (USCS). Fresh CGR materials were obtained from an ongoing concrete pavement grinding project located in Apple Valley, Minnesota (Mn). Table 2 also shows the properties of CGR materials. CGR used in this study is a fine material with a pH value of 11.65. Table 5 shows that CGR is rich in SiO_2 (53%) and CaO (16.8%) contents. Other detected specific metallic oxides, including Al_2O_3, Fe_2O_3, and MgO, were probably introduced by supplementary materials such as fly ash and steel slag used during cement production or concrete mixture preparation (*75-76*). Figure 25 shows that the major crystal structures of CGR used in this study consist of calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), quartz (SiO_2), albite ($NaAlSi_3O_8$), and microcline ($KAlSi_3O_8$). Both coarse and fine aggregates used for concrete production could contribute to the presence of dolomite, quartz, albite, and microcline in CGR, and some aggregates such as limestone has calcite.

Table 4. Properties of soil and CGR investigated.

Characterizations		Soil 1	Soil 2	CGR
Classification	AASHTO	A-6	A-4	-
	USCS group symbol	SC	CL-ML	-
	USCS group name	Clayed sand	Sandy silty with clay	-
Grain size distribution	Gravel (> 4.75 mm), %	7.1	0.1	0
	Sand (4.75–0.075 mm), %	54.9	37.2	43
	Silt and clay (< 0.075mm), %	38.0	54.9	57
Engineering properties	Specific gravity, G_s	2.70	2.76	2.4
	Liquid limit, %	32.8	29.1	-
	Plastic limit, %	17.4	22.9	-
	Plastic index, %	15.4	6.2	-
	Optimum moisture content, %	14.4	18.2	-
	Maximum dry density, kg/m^3	1,728	1,631	-
Chemical Property	$pH_{1:1}$	7.19	7.91	11.65

Table 5 X-ray fluorescence analysis for CGR.

SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	SO_3 (%)	CaO (%)	MgO (%)	K_2O (%)	Na_2O (%)	P_2O_5 (%)	TiO_2 (%)	BaO (%)	SrO (%)	Mn_2O_3 (%)	LOI[a] (%)
53	8	3.8	0.68	16.8	2.8	1.5	1.8	0.1	0.4	0.04	0.04	0.07	11

LOI[a]: Loss on ignition.

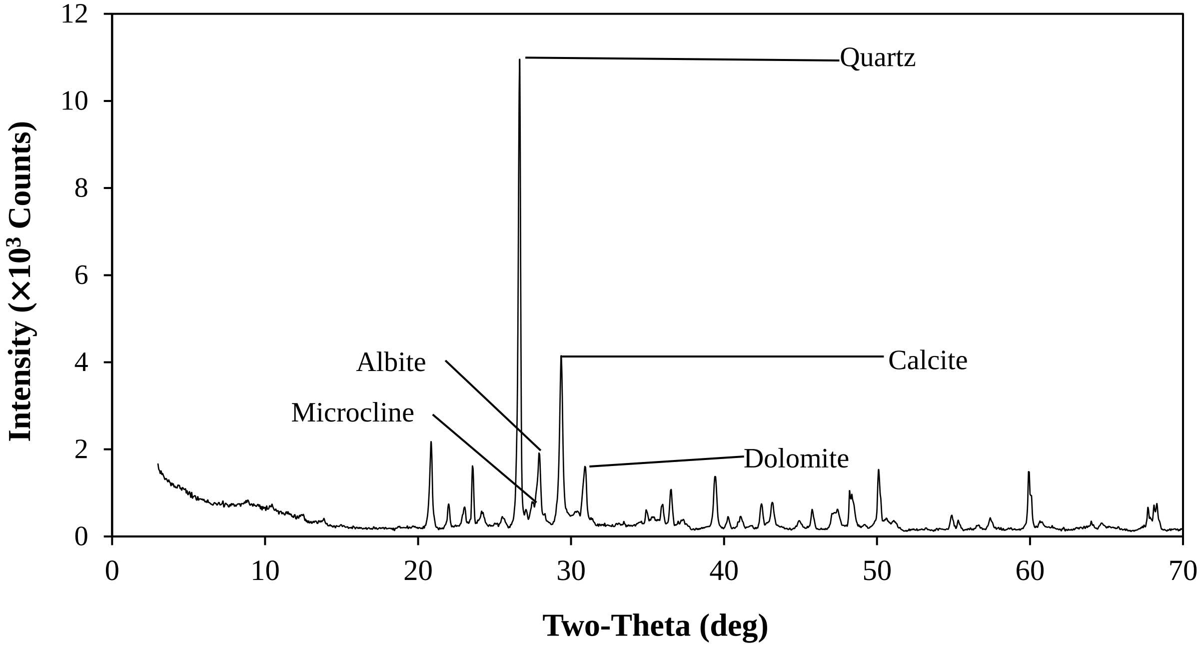


Figure 25. X-ray diffraction pattern for CGR.

Experimental Plan

The experimental plan for this study consisted of conducting Atterberg limits, compaction, unconfined compressive strength (UCS), alkalinity tests and measuring the EC and pH values. Soils were mixed with CGR at four different rates by weight: (a) 10%; (b) 20%; (c) 30%; and (d) 40%. Appropriate ASTM standards (*77-79*) were followed to measure the Atterberg limits (liquid limit (LL), plastic limits (PL) and plastic index (plasticity, or PI, the difference between LL and PL)), compaction properties (max dry density and optimum moisture content (OMC)), and UCS of soils treated with CGR. Specimens were prepared with a 1:1 ratio of soil to deionized water (S/L) for pH and EC measurements using an Oakton PC2700 meter, and the specimens with a 1:10 S/L ratio were prepared for alkalinity measurements using Hach alkalinity test kit No. 24443-01. For all tests, three replicates were carried out in this study.

Specimen Preparation

In this study, air-dried (at 25°C) soils and CGR materials were mixed at three different moisture contents (OMC-4%. OMC, and OMC+4%) and compacted at standard Proctor compaction energy in 5.08 cm (2 in.) diameter and 5.08 cm (2in.) in height for UCS testing. This compaction method, developed by O'Flaherty (*80*), has the primary benefit of producing more specimens with less effort. The compaction procedures involved loading loose soil-CGR mixture into a 5.08 cm (2 in.) diameter steel mold and dropping a 2.27 kg (5 lb.) hammer from a 30.48 cm (12 in.) height with 6 and 7 blows for the Soil 1 and the Soil 2, respectively. After compaction, the fabricated specimens were sealed in plastic wrap and aluminum foil, then stored in Ziploc bags at 25°C for 7-day and 28-day curing periods.

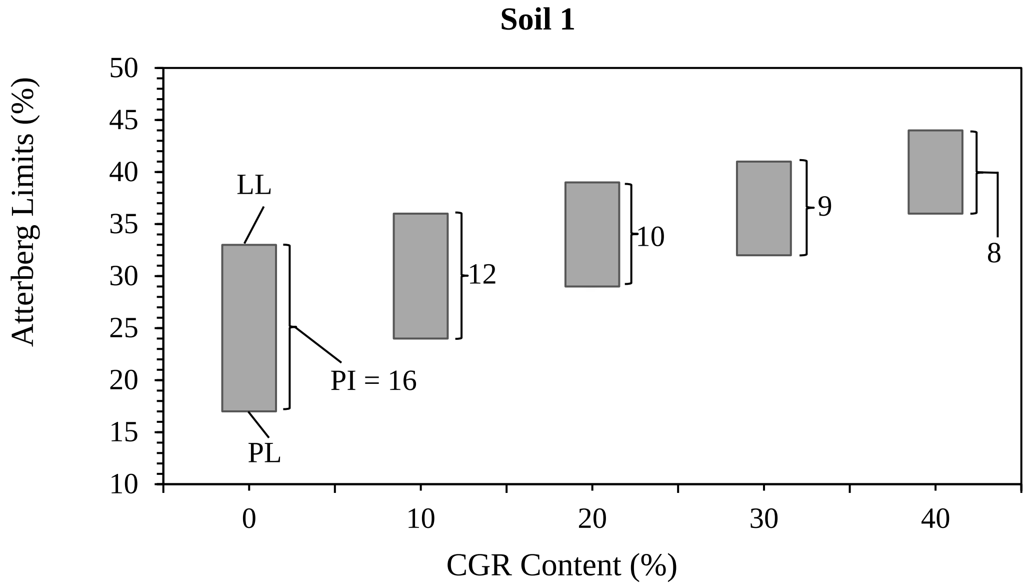
Results and Discussion

Atterberg Limits

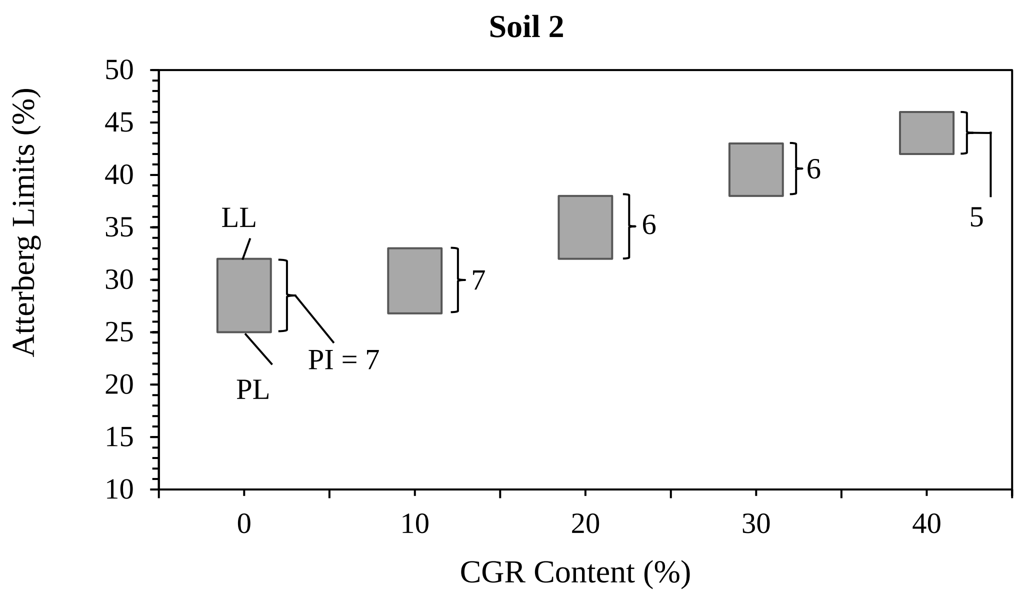
All specimens were subjected to the Atterberg limits tests. The effects of different CGR application rates on Atterberg limits of the soils are shown in Figure 26. For Soil 1, both liquid limit (LL) and plastic limit (PL) increased with an increase in CGR rate while the plasticity index (PI) of the soil 1 decreased from 16 to 8 (Figure 2a). Soil 2 showed a similar trend with the addition of CGR with relatively lower impact compared to those Soil 1 mixtures (Figure 2b). The change in the plasticity of soil after CGR treatment can be attributed to the cation exchange activities between the divalent ions (e.g. Ca^{2+}) derived from CGR and the monovalent ions (e.g. K^+, Na^+ and H^+) surrounding the surface of clay particles in soils, resulting in flocculation of clay particles (*81*-*82*). The other factors related to clay mineralogy such as cation exchange capacity, specific area, and hygroscopic moisture may result in the different effects of CGR addition on different soil types (*83*). Figure 2 shows that CGR addition does not impact the PI of soils with lower PIs. This effect of CGR on the reduction of the plasticity of soils suggests that CGR is a promising additive to be used for stabilization purposes (*81*). Dayioglu et al. (*84*) showed that a decrease in PI of fine-grained soils yielded an increase in shear strength of those soils.

Compaction Characteristics

Figure 27 shows that the addition of CGR reduces the maximum dry density (γ_{dmax}) and increases the optimum moisture contents (OMC) of soils. Untreated Soil 1 had a γ_{dmax} of 1728 kg/m^3 (107.8 pcf) with 14.4% of OMC, and 40% CGR reduced γ_{dmax} to 1625 kg/m^3 (101.4 pcf) and increased the OMC to 19.5%. For Soil 2, the highest rate (40%) of CGR additions caused 79 kg/m^3 (4.9 pcf) reduction in γ_{dmax} and 4.3% increase in OMC. The different angularities and mineralogy of soil particles in Soil 1 and Soil 2 may result in the different changes of compaction characteristics after addition of CGR. The coarser material (Soil 1) was likely to have higher angular materials due to its higher sand and gravel contents (Table 1) which may be the reason for the compaction characteristics of Soil 1 to be influenced by addition of CGR compared to the Soil 2. The decreased densities of soils were probably caused by the light weight of CGR since. The specific gravity (G_s) of CGR is 2.44 (Table 2), lower than those of two soils. On the other hand, more flocculated structures were formed due to Ca derived from CGR which increased the resistance against the compaction process and resulted in lower γ_{dmax} (*85*). Moreover, the formed flocculated structures increased the void ratio of soil matrix, combined with the enlarged specific area of particles due to finer CGR materials, resulted in additional water required to reach the OMC (*85*). For soil stabilization purposes, an increase in maximum dry density and a decrease in OMC of soil is desired for stabilizers, so CGR could be added into the soil at a proper rate to minimize its negative impacts on compaction characteristics of original soils.



(a)



(b)

Figure 26. Effects of CGR on Atterberg limits of (a) Soil 1 and (b) Soil 2.

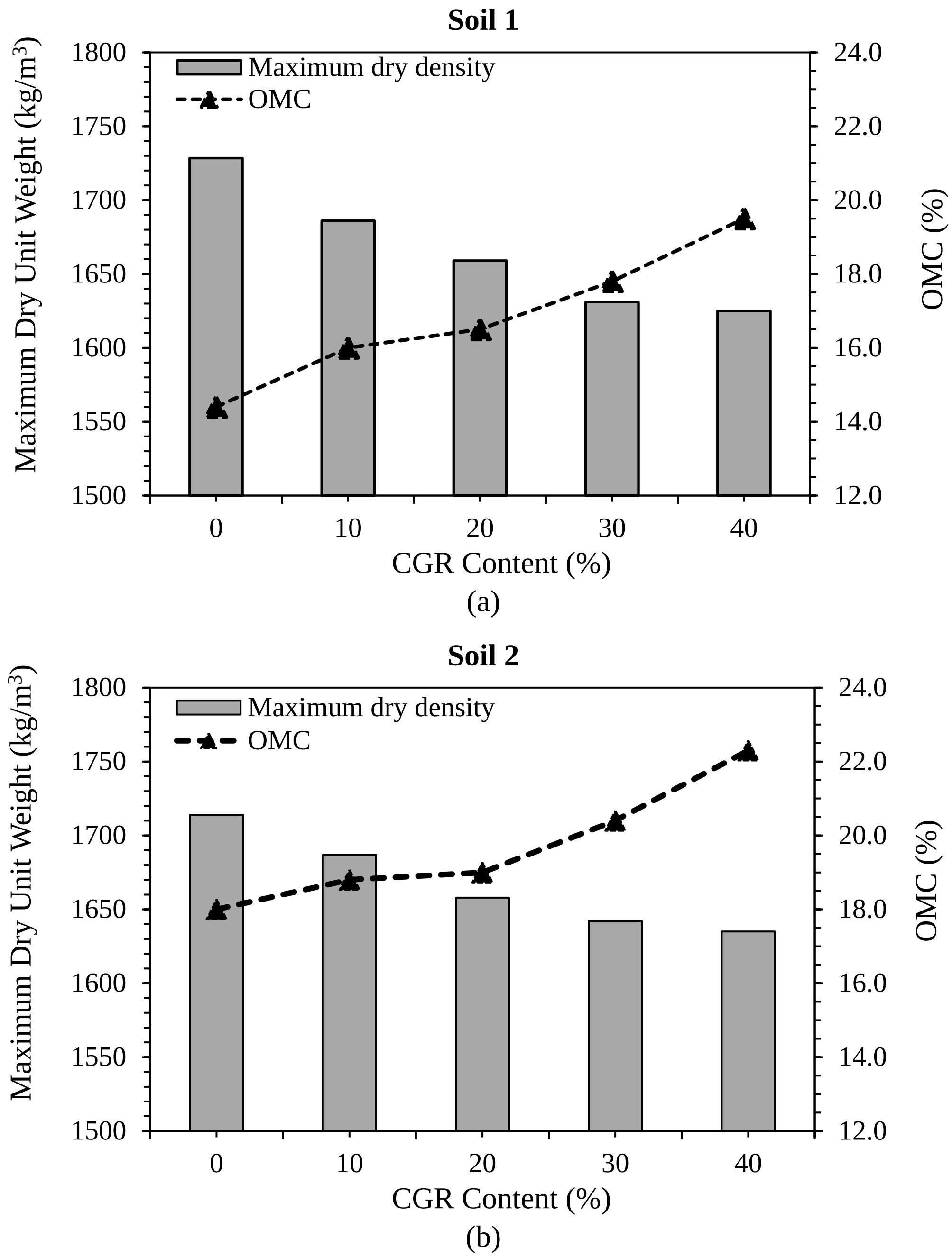


Figure 27. Effects of CGR on moisture-density relationship of (a) Soil 1 and (b) Soil 2.

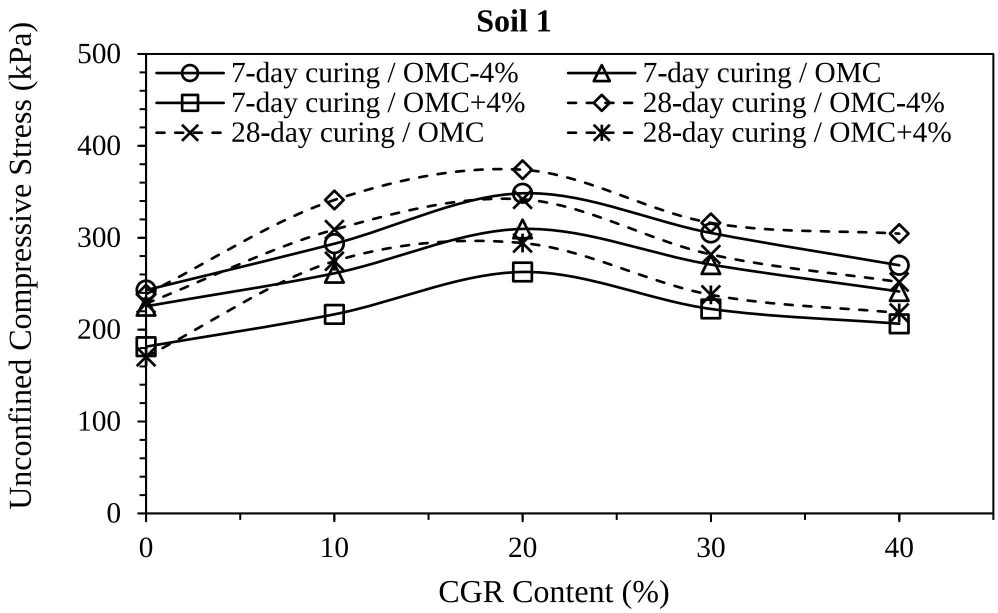
Unconfined Compressive Strengths (UCS)

Figure 28 shows the effects of CGR on strength of both soils. UCS tests were conducted to evaluate the impact of soil types, CGR rates, moisture contents, and curing periods on the CGR-treated soils. UCS results show that Soil 1-CGR mixtures had the higher strength for all treatment rates than those Soil 2-CGR mixtures (Soil 1). All CGR-treated specimens showed higher UCS values than the UCS of Soil 1 and Soil 2 alone. The highest UCS for both soils (374 kPa for Soil 1 and 305 kPa for Soil 2) were observed at 20% CGR addition rate (Figure 28). With respect to the fines content of soils, CGR is more effective on the relatively “finer” soil because it produced up to a 139% increase in UCS of Soil 2 compared to the untreated specimens, while for Soil 1 there was only a 57% increase. UCS tests were conducted at three different moisture levels to determine the sensitivity of the CGR stabilized soils to the change in moisture. While all specimens showed a reduction in UCS with an increase in moisture, 20% of the CGR-treated specimens at OMC+4% exhibited the highest UCS than those untreated specimens at the dry side of OMC, suggesting that CGR treatment at a proper rate can help to keep soil strength at higher moisture contents. Curing-period is another factor that influences the strength of CGR-treated soils. In this study, UCS of all CGR-treated specimens improved with longer curing periods. This behavior was attributed to both the physical and chemical reactions occurring between soil and CGR particles.

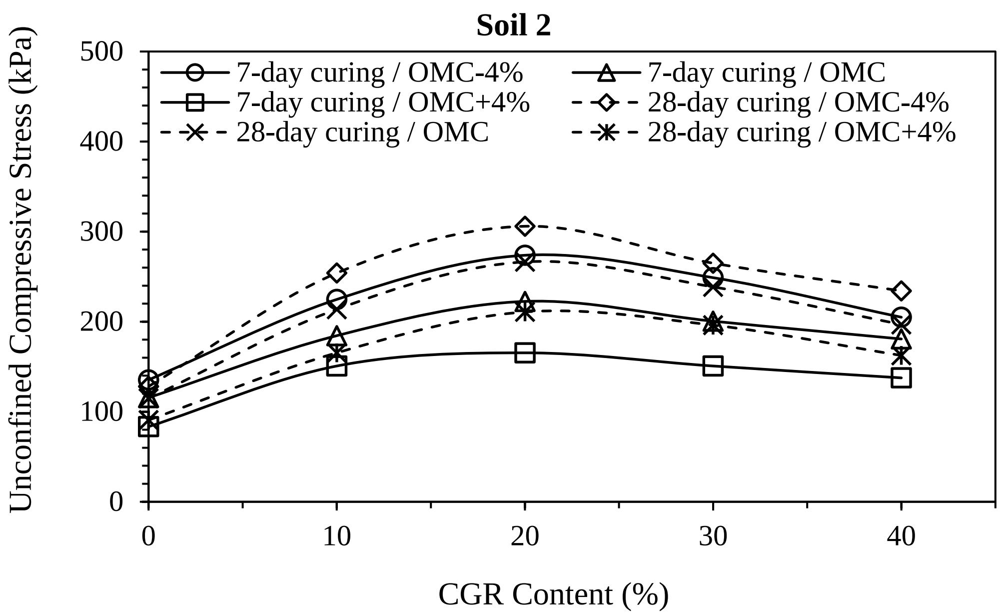
With reflect to the CGR composition (e.g. CaO, MgO, SiO_2), a combination of the following mechanisms involved in the stabilization of a subgrade are proposed: (a) cation exchange; (b) flocculation; (c) hydration and rehydration; and (d) pozzolanic reaction. In general, the surface of clay particles is negatively charged due to the isomorphic substitutions, resulting in the attraction to the cations to neutralize the negatively-charged surface. When CGR is added to the soil, strong cations from CGR like Ca^{2+} and Mg^{2+} can be attracted to the surface of clay particles to replace H^+, Na^+, and K^+, regarded as weak cations. Furthermore, strong cations such as Ca^{2+} can contribute to the flocculation process between particles due to the reduced double diffuse layer (DDL) and their divalence, resulting in more flocculated structures and higher surface tension that can improve soil strength, especially early strength (*86*). Soil with the higher specific area can also benefit more in terms of strength improvement due to Ca^{2+} absorption on soil particles and this can explain why CGR is more effective in improving the strength of finer soils (Soil 2). Long-term strength improvement was also observed in CGR-treated specimens, and hydration and rehydration of cementitious materials and unreacted cement in CGR were hypothesized to be the contributor (*14*). Pozzolanic reactions between calcium and silica may be another contributor to achieving long-term strength. On the other hand, it should be pointed out that since an excessive amount of CGR could limit the strength gain in soil, UCS tests with varied CGR rates are recommended to identify the optimum content of CGR for the soil stabilization purpose.

pH

Figure 29 indicates that the CGR rate positively correlates with the soils` pH values, a result similar to that of previous studies (*3, 8*). The CaO and MgO compounds in CGR are soluble in water, resulting in the generation of a massive number of hydroxide ions to elevate pH to basic conditions (*3, 9-10*). In Figure 29, the addition of CGR increased the pH of soil from 7.19 to 9.83 after 0 days (immediately measure), while a pH reduction was observed for the same CGR rate after 7 days and 28 days curing periods. The reduction of pH in soil-CGR mixtures with time was probably caused by the adsorption of Ca^{2+} cations onto the surface of clay particles and/or hydration and pozzolanic reactions occurring the soil matrix (*87*). Since CGR-treated soil exhibited a high pH at the initial stage, actions related to pH monitoring and control are recommended before its application.

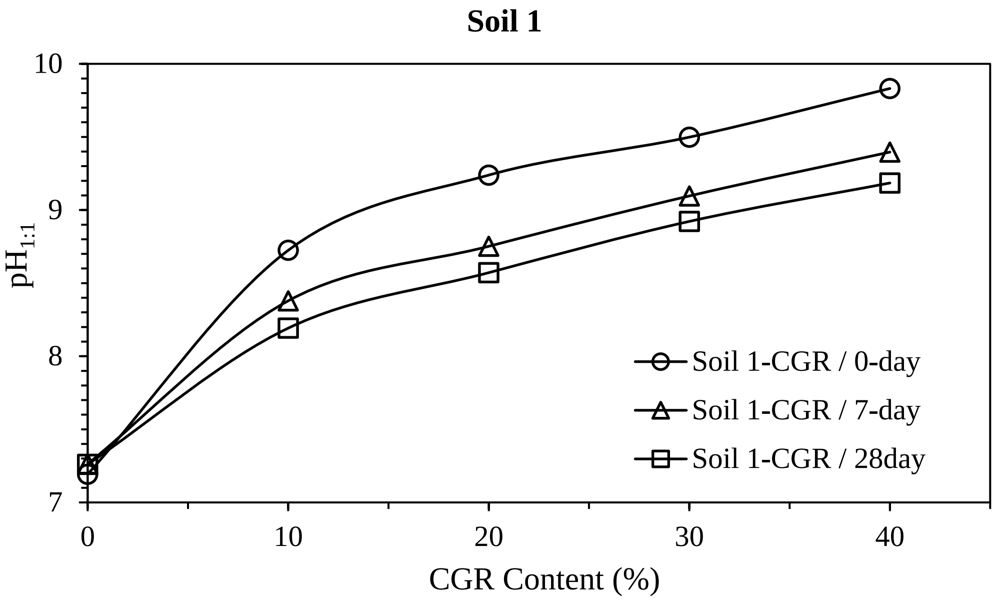


(a)



(b)

Figure 28. Effects of CGR on unconfined compressive strength of (a) Soil 1 and (b) Soil 2.



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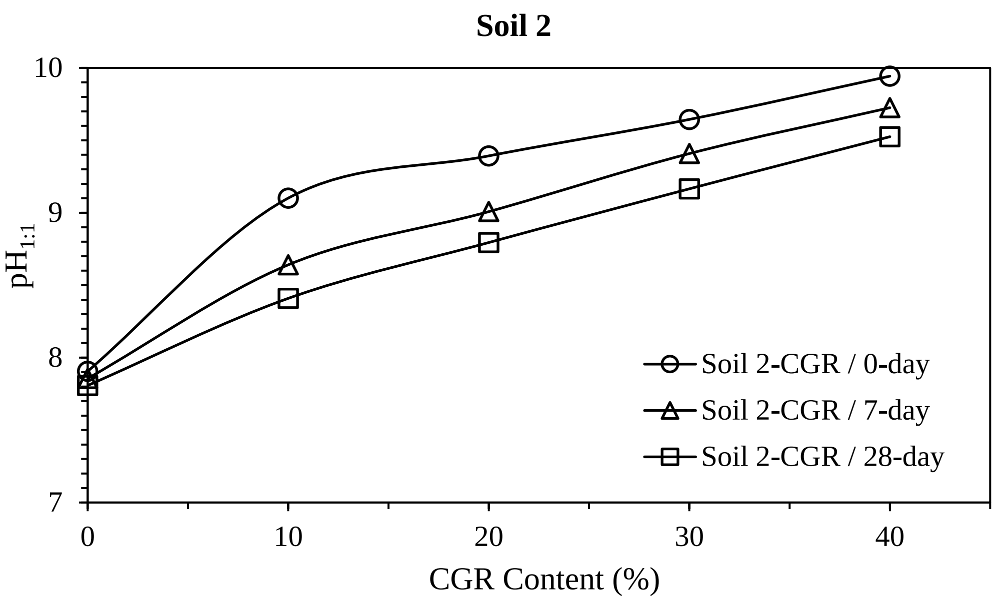
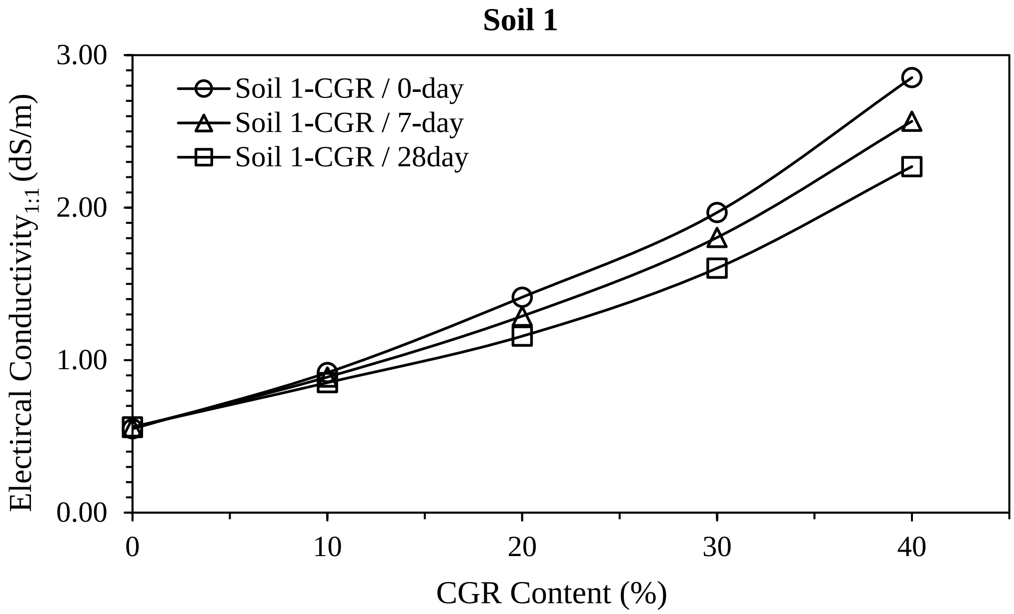


(b)

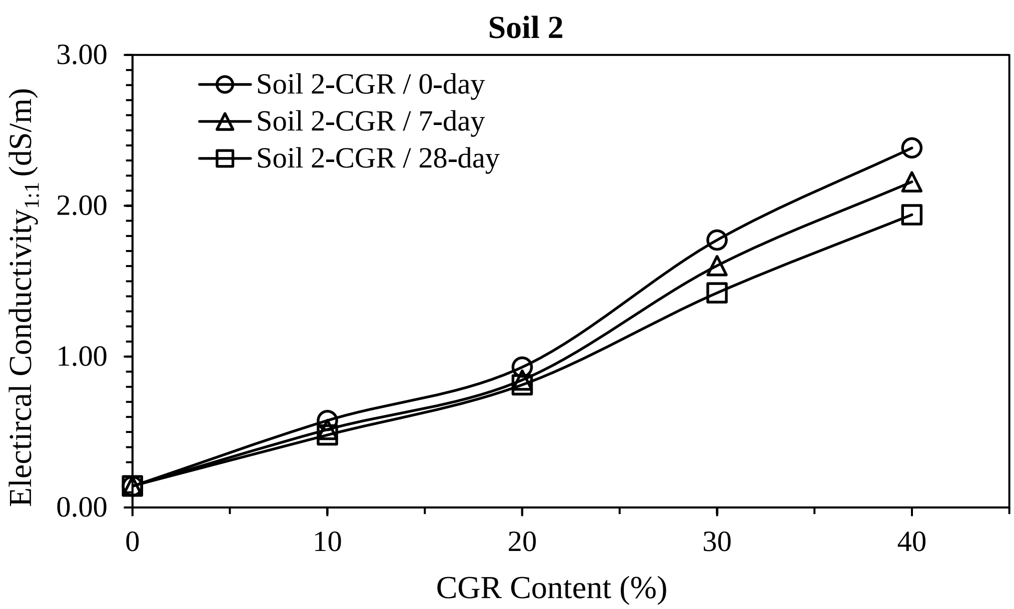
Figure 29. Effects of CGR on soil pH.

Electrical Conductivity (EC)

Electrical conductivity (EC) of soils is used as a measure of salt content in soils. Figure 31 shows that the highest CGR rate (40% of CGR) increase the soil EC from 0.55 to 2.85 and 0.14 to 2.38 dS/m for Soil 1 and Soil 2, respectively. Similar to the results of pH measurements, the highest EC values occurred with the highest CGR rate and at the stage of 0-day, and then EC decreased with curing time. The increase in soil EC is attributed to the massive soluble salts such as NaCl and KCl from CGR and massive alkali salts derived from the hydration of abundant metallic oxides such as CaO, MgO, K_2O and others in CGR (*3*, *9*), and the reduction in EC with time is due to the absorption of metal cations (Ca^{2+} and Mg^{2+}) through cation exchange, hydration, rehydration and pozzolanic reactions (*88-90*). The salts from CGR initiates the chemical reactions in soil matrices, and the decreased EC with time indicates the consumption of ions in solution due to the multiple reactions occurrence which ultimately leads to an increase in UCS after 28-day curing period (*91*).



(a)

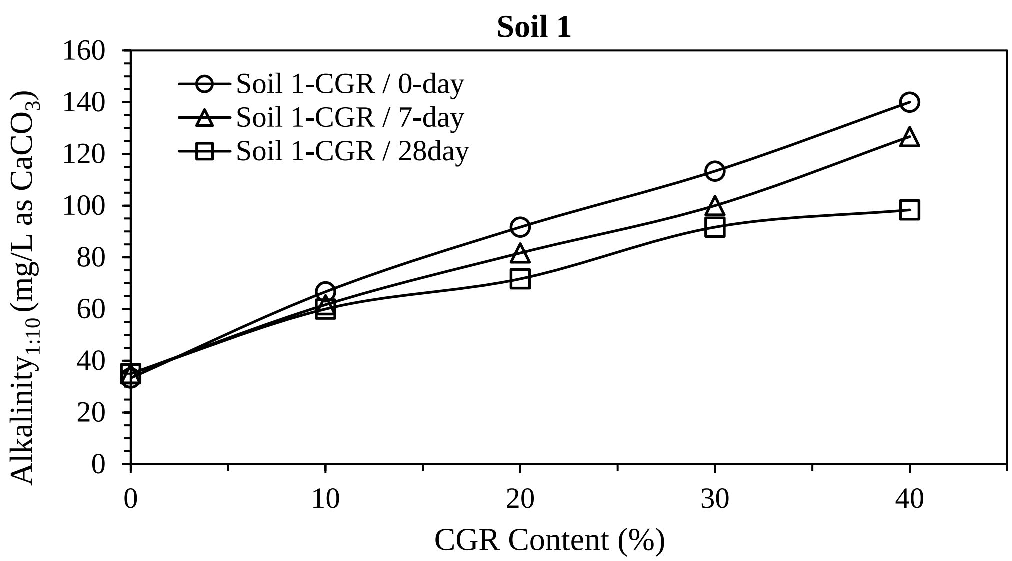


(b)

Figure 30. Effects of CGR on soil electrical conductivity.

Alkalinity

Alkalinity is the ability of a soil to neutralize the acidity of a solution and generally expressed as the measurement of a concentration of $CaCO_3$. Figure 31 presents the alkalinity measurements for both soils treated with varied rates of CGR, showing that CGR rate increased the alkalinity for both Soil 1 and Soil 2 dramatically, up to 140 and 147 mg/L as $CaCO_3$, respectively. The alkalinity of all mixtures decreased with higher curing time. The primary contributor of the high alkalinity is the presence of alkaline earth (e.g. Ca and Mg) minerals and alkali metals (e.g. Na and K) in CGR which can highly dissociate in aqueous solution to form the ions float freely. The reduced alkalinity after long-term can be explained with the same reasons for pH and EC which was due to chemical reactions occurring in the soil matrices.



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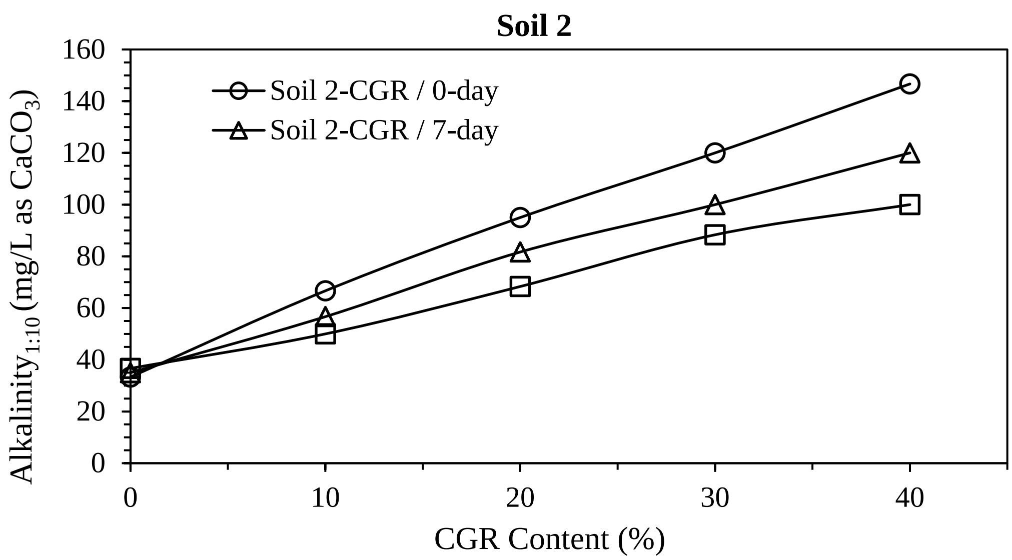

(b)

Figure 31. Effects of CGR on soil alkalinity.

CONCLUSIONS

This paper reviewed the current practices of the management of CGR throughout the United States. It also conducted a preliminary laboratory study in an effort to evaluate the reuse of CGR for soil stabilization purposes. A comprehensive literature review and survey were conducted to understand the different disposal methods of CGR applied by DOTs and industrial contractors. Environmental concerns regarding the disposal of CGR were also discussed. Several practices for properly managing of CGR with respect to its reuse through soil and concrete amendment were discussed, and preliminary laboratory tests related to stabilization of soils with CGR were evaluated. Based upon the results of this, the primary findings and recommendations are provided as follows:

- The management methods of CGR varied between states, and many SHAs and industrial contractors do not have detailed guidelines for dealing with its associated environmental concerns. Following the IGGA BMPs is recommended for disposal of CGR if detailed state guidelines are lacking.
- Based on the literature review results, it is recommended that the fresh CGR should be disposed to a specific pond for future uses such as soil and concrete amendment and soil stabilization.
- CGR treatment increased the soil strength, OMC, pH, EC, and alkalinity and decreased the γ_{dmax} and PI of the soils. 20% of CGR was the optimum rate found to gain strength for both types of soil tested in the current study. It was also found that CGR is more effective for improving the strength of finer soils.
- The strength gain for CGR-stabilized soil is hypothesized to be due to a combination of cation exchange, flocculation, hydration, and rehydration and pozzolanic reactions.
- Future studies related to the evaluation of the combination of cementitious materials and CGR in soil stabilization is recommended.

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APPENDIX A: SURVEY QUESTIONS

Survey Questions for Engineers in DOTs

1. Concrete grinding residue (CGR) is a slurry consisting of water, concrete and aggregate generated from diamond grinding of concrete pavement. Is this material considered hazardous waste by the local state highway administration (SHA)?
   a. Yes ☐
   b. No ☐

2. Does the local SHA have their own specifications to dispose of the CGR? If yes, please specify the documents (e.g., highway construction manual, waste management practice and environmental protection regulation).
   a. Yes
      a) Highway construction manual ☐
      b) Waste management practice ☐
      c) Environmental protection regulation ☐
      d) Others: ____________________
   b. No ☐

3. Does the local SHA follow any national guidelines if they do not have their own specifications?
   a. Yes ☐
   b. No ☐

4. How CGR disposed of if the local SHA doesn't have their own specifications and doesn't follow the national guidelines?
   a. Offloading slurry along the roadside, ☐
   b. Decanting in pond, ☐
   c. Disposal in waste facility? ☐
   d. Other:________

5. Does the local SHA especially the environment division require control of the pH of CGR before its disposal? If yes, what is the accepted pH value?
   a. Yes – pH: ________
   b. No ☐

6. What other properties of CGR should be controlled before disposal besides pH??
   a. Metal concentrations ☐
   b. Total suspended solids (TSS) ☐
   c. Other:___________

7. Does the disposal method of CGR take the distance from the dumping area to the body of water or sewer system into account? If yes, what is the allowed distance?
   a. Yes – allowed distance:___________
   b. No ☐

8. Where is the suggested place to dispose of CGR? Median swale, shoulder, roadside ditch, or specific pond for storage and decanting?
   a. Median swale ☐
   b. Shoulder ☐
   c. Roadside ditch ☐
   d. Specific pond ☐
   e. Others:______________

9. Does the local SHA allow the disposal of the CGR within the right-of-way?
   a. Yes ☐
   b. No ☐

10. Does the local SHA have any long-term monitoring for environmental impact when CGR is discharged on the roadside, median swale, or any other soil-based areas? If yes, what is it?

a. Yes

a) pH ☐

b) Metal concentrations ☐

c) Total suspended solids (TSS) ☐

b. No ☐

11. Does the local SHA have any further treatment and/or operation when CGR is discharged on the roadside, median swale, or any other soil-based areas? If yes, what is it?

a. Yes: ___________

b. No ☐

12. If the CGR is discharged into a specific pond, are there any further treatment and operation? If yes, what is it?

a. Yes: ___________

b. No ☐

13. Does the local SHA require separating the wastewater from CGR and transporting it to wastewater treatment facilities?

a. Yes ☐

b. No ☐

14. Does the local SHA have any specifications about recycling or reusing CGR?

a. Yes ☐

b. No ☐

15. Are any pretreatments applied to CGR before it is recycled or reused? If there is, please explain. (For example, some DOTs ask to control the pH of CGR below 12 (pH<12) for reusing and recycling)

a. Yes: __________
b. No ☐

16. What's the annual cost of disposal of CGR?

a. $100K to $500K, ☐
b. $500K to $1 million, or ☐
c. >$1 million. ☐
d. Other: __________
e. Not applicable ☐

17. Does the local concrete industry recycle and reuse CGR and other concrete slurries? If yes what's the application?

a. Yes: ___________
b. No ☐

18. Does the generation, disposal and application of CGR require a permit by any governing agencies?

a. Yes ☐
b. No ☐

Survey Questions for Industrial Contractors

1. Does the contractor follow any guidelines to dispose of CGR? If yes, what kind of guidelines are followed?
   a. Yes
      a) Own specifications ☐
      b) State guidelines ☐
      c) National guidelines ☐
   b. No ☐

2. How CGR disposed of if the contractor follow their own specifications and doesn't follow the state and national guidelines?
   a. Offloading slurry along the roadside, ☐
   b. Decanting in pond, ☐
   c. Disposal in waste facility? ☐
   d. Other:________
   e. Not applicable ☐

3. How CGR disposed of if the contractor doesn't have their own specifications and doesn't follow the state and national guidelines?
   a. Offloading slurry along the roadside, ☐
   b. Decanting in pond, ☐
   c. Disposal in waste facility? ☐
   d. Other:________
   e. Not applicable ☐

4. Does the contractor need to control of the pH of CGR before its disposal? If yes, what is the accepted pH value?
   a. Yes – pH: _______
   b. No ☐

5. What other properties of CGR should be controlled before disposal besides pH?
    a. Metal concentrations ☐
    b. Total suspended solids (TSS) ☐
    c. Other:___________
    d. No ☐

6. Does the disposal method of CGR take the distance from the dumping area to the body of water or sewer system into account? If yes, what is the allowed distance?
    a. Yes – allowed distance:___________
    b. No ☐

7. Where is the suggested place to dispose of CGR? Median swale, shoulder, roadside ditch, or specific pond for storage and decanting?
    a. Median swale ☐
    b. Shoulder ☐
    c. Roadside ditch ☐
    d. Specific pond ☐
    e. Others:______________

8. Does the contractor allow the disposal of the CGR within the right-of-way?
    a. Yes ☐
    b. No ☐

9. Does the contract need to do any further treatment and/or operation when CGR is discharged on the roadside, median swale, or any other soil-based areas? If yes, what is it?
    a. Yes:________
    b. No ☐

10. If the CGR is discharged into a specific pond, are there any further treatment and operation? If yes, what is it?
    a. Yes:________
    b. No ☐

11. Does the contractor need to separate the wastewater from CGR and transport it to wastewater treatment facilities?
    a. Yes ☐
    b. No ☐

12. Does the contractor recycle or reuse CGR? If yes, what is the application?
    a. Yes:________
    b. No ☐

13. Are any pretreatments applied to CGR before it is recycled or reused? If there is, please explain. (For example, some DOTs ask to control the pH of CGR below 12 (pH<12) for reusing and recycling)
    a. Yes: ___________
    b. No ☐

14. Does the generation, disposal and application of CGR require a permit by any governing agencies?
    a. Yes ☐
    b. No ☐