

# COMPARISON OF THE SHEAR STRENGTH PARAMETERS OF TDA

Zahran, Khaled & El Naggar, Hany

*Dalhousie University, Halifax, Nova Scotia, Canada*

*Department of Civil and Resource Engineering – University of Dalhousie, Halifax, Nova Scotia, Canada*



## ABSTRACT

The increase in the number of discarded tires from vehicles every year is becoming a major issue all over the world. Tires stockpiles and landfills have become a critical issue as it is a rich environment for the breeding of rats and insects, and it is also a real fire hazard that may take up to months to extinguish. One of the safest effective ways of recycling tires is that it gets used as Tire Derived Aggregates (TDA) in the construction industry as lightweight backfilling material and for embankments fills. However, to use any material in the construction industry, several material properties must be evaluated including the shear strength parameters. The main focus of this research is to study the effect of the particle size on the shear strength parameters of TDA using the large-scale direct shear machine. This is a research in progress and more results on other TDA sizes will be provided at the time of the conference.

## RÉSUMÉ

L'augmentation annuelle du nombre de pneus mis au rebut par les véhicules devient un problème majeur dans le monde entier. Les stocks de pneus et les décharges sont devenus un problème critique car il s'agit d'un environnement riche pour l'élevage de rats et d'insectes. Il s'agit également d'un risque d'incendie pouvant prendre plusieurs mois à s'éteindre. L'un des moyens les plus sûrs de recycler les pneus est de les utiliser en tant qu'agrégats dérivés des pneus (TDA) dans l'industrie de la construction, en tant que matériau de remblayage léger et pour le remplissage de talus. Cependant, pour utiliser n'importe quel matériau dans l'industrie de la construction, plusieurs propriétés de matériau doivent être évaluées, y compris les paramètres de résistance au cisaillement. L'objectif principal de cette recherche est d'étudier l'effet de la taille des particules sur les paramètres de résistance au cisaillement du TDA à l'aide de la machine à cisaillement direct à grande échelle. Il s'agit d'une recherche en cours et d'autres résultats sur d'autres tailles d'TDA seront fournis au moment de la conférence.

## 1 INTRODUCTION

The number of scrap tires generated every year all over the world is rapidly increasing. The reason behind this increase is that the number of vehicles are increasing, and the current technology is not targeting new means for recycling of tires but it is more into the development of renewable fuels. In 2015, the Americans disposed around 250 million tires. In the same year, around 35 million scrap tires were discarded in Canada. Moreover, in Alberta, the number of scrap tires was around 5 million tires. Meanwhile, in Nova Scotia, the number of disposed tires is equal to the number of its residents and with the increase in the number of Canadians, the number of disposed tires will increase (Meles et al. 2015).

The number of scrap tires is becoming a great hazard for the environment as the main means of getting rid of scrap tires is either by stockpiling or disposing them in landfills. These solutions possess serious hazards and are not environmentally acceptable as they are considered a fertile environment for insects and mosquitoes to breed, and are prone to fire hazardous as tires could catch fire easily and it was noted that it's challenging to extinguish them (Cecich et al., 2016). Due to the environmental hazards related to stockpiling and landfilling of tires, some states and provinces banned the landfilling of scrap tires. (Edinçililer et al., 2010).

Fortunately, there are several methods of recycling of scrap tires such as using them as Tire Derived Fuel (TDF) due to their high heat value which is larger than the heat value of coal. Moreover, they could be used as ground rubbers for different applications as in children's playgrounds and gyms. Last but not least, they could be used in civil engineering projects as Tire Derived Aggregates (TDA) in which scrap tires are shredded into smaller pieces and used as a light backfill in road embankments, retaining walls and around culverts. TDA has two types; Type A and Type B. Type A has a maximum particle size of 200 mm or less. However, Type B has a maximum particle size of 400 mm or less.

However, for TDA to be utilized in Civil Engineering projects, its characterization and properties must first be evaluated to be used safely. One of the main characterizations which is essential for TDA adoption in such an industry is the Geotechnical characterization. However, The TDA geotechnical characterization is that its particles are considered large in size with respect to the available standard testing equipment and practitioners are hence forced to test smaller TDA particle sizes not representative of the real sizes that are used in construction projects. Hence, the main focus of this research is to study the particle size effect on the shear strength parameters of TDA using a large-scale direct shear machine. This is a research in progress and more results on other TDA sizes will be provided at the time of the conference.

## 2 BACKGROUND

Due to the high demand for using TDA in civil engineering projects, researchers have difficulty to keep up with this demand (Ashari, 2018). Several studies were done on granular and fine soils to study the effect of particle size on the shear strength parameters of soils. However, according to the author's knowledge, no studies were done to study the particle size effect on the shear strength parameters of TDA.

For the granular materials, one of the earliest studies for the particle size effect for coarse-grained soils was done by Kim et al, (2014). The authors in this research investigated the shear strength parameters of coarse-grained soils for three samples with three different maximum particle sizes; 4.75 mm, 7.9 mm and 15.9 mm. The samples were tested in a pure state, supported with a soft geogrid and a stiff geogrid. The testing was done using a shear box with dimensions of 300 mm \* 300 mm with a shear rate of 1 mm/min and the shear stress was calculated at 15% shear strain. Testing was done with three normal stresses; 98 kPa, 196, kPa and 294 kPa. The results showed that the angle of internal friction increases by increasing the particle size of the sample in its pure state. Moreover, the shear stress also increases by increasing the particle size of the sample.

Alias et al. (2014) studied the effect of the particle size on shear strength parameters of granular material in the direct shear test. The authors investigated the shear strength of two samples. One with a maximum particle size of 2.36 mm and a larger sample with a maximum particle size of 20 mm. The small sample was tested with a 60 mm \* 60 mm shear box with a shearing rate of 0.09 mm/min. The larger sample was tested in a 300 mm \* 300 mm shear box using the same shearing rate. The tests were performed under 3 normal stresses; 100 kPa, 200 kPa, and 300 kPa. The results showed that the peak effective internal friction increased from 35° to 40° by increasing the particle size. The residual internal friction effective internal friction also increases from 26° to 29° by increasing the sample particle size.

On the other hand, Islam et al. (2011) studied the effect of particle size on the shear strength behavior of sands. They conducted a series of direct shear tests on eight samples with uniform particle sizes (0.075, 0.15, 0.212, 0.300, 0.600, 1.18, 1.72 and 2.76 mm) and two samples with graded particle sizes (0.075-1.18 mm and 0.075-2.36 mm). Tests were performed with a shear box with a diameter of 50.8 mm. The tests were performed with a constant strain rate. The results showed the peak shear stress as well as the angle of internal friction increases as the particle size increase. It was also observed that as the gradation increases to a wider gradation, the peak shear stress and the angle of internal friction increases.

Furthermore, Vangla and Latha (2015) conducted a series of direct shear tests to investigate the Influence of Particle Size on the Friction and Interfacial Shear Strength of Sands. The tests were conducted on three sand samples; coarse, medium and fine sand. The coarse sand had a maximum particle size of 4.75 mm. The medium sand had a maximum particle size of 2 mm while the fine

sand had a maximum particle size of 0.425 mm. the tests were conducted using a large-scale direct shear test with a shear box of dimensions 300 mm \* 300 mm. The shearing rate was 1 mm/min under three normal stresses; 21 kPa, 37 kPa, 58 kPa. The results showed that the ultimate friction angle as well as the angle of repose increases as the maximum particle size of the sample increases.

As discussed earlier, detailed studies were conducted on coarse and fine-grained soils and it is noted that the shear strength of the sample increase as the particle size increase. However, according to the author's knowledge, no studies were performed on TDA to study the effect of the particle size on the shear strength of TDA.

## 3 EXPERIMENTAL SETUP AND MATERIAL

### 3.1 Direct Shear Test Apparatus

Figure 1 shows the large-scale direct shear test setup with a sample size of ( 305 mm length \* 305 mm width \* 230 mm height) that was used in this study. The lower movable part of the shear box was of height 90 mm, and the upper part was of dimension 130 mm. Height modification was done to the setup to account for the high compressibility of TDA as the initial height of the setup was 180 mm. So, a 50 mm height extension was added to the setup.

This setup can shear a sample up to 50 mm horizontal displacement with a shearing rate ranging between 0.02 - 2 mm/min. The setup has a load cell and two linear variable displacement transducers (LVDTs) which were used to measure the shear force (kN), horizontal displacement (mm) and vertical displacement (mm). The load cell and the 2 LVDTs were connected to a data acquisition system to record the data from the test. The direct shear apparatus could apply normal stresses ranging between 50.1 – 293.2 kPa with a deadweight loading mechanism.



Figure 1. Large-scale direct shear apparatus.

### 3.2 Material

The TDA used in this research was shredded at Halifax C&D Recycling Ltd. In this research, three different

samples were studied; random sample, 0.75 inches sample and 3 inches sample. The 3 inches sample was previously prepared and tested by Ali Iranikhah and El Naggar (2018) at Dalhousie University using the same source of TDA and the same Direct Shear apparatus.

The samples were named as so depending on the maximum particle size ( $D_{max}$ ) found in each of the samples, and the random sample is a random representative sample from the TDA brought from Halifax C&D Recycling Ltd with a maximum particle size of 2 inches as shown below in Figure 3.



Figure 2. TDA from Halifax C&D Recycling Ltd.

Any protruding steel in the 0.75 inches and the 3 inches sample was completely removed. However, the random sample was tested in its original state, having protruding steel. The samples were sieved following ASTM C136/C136M – 14. The 0.75 inches sample had TDA particle sizes ranging between 0.375 – 0.75 inches. the 3 inches sample had sizes ranging between 0.375 – 3 inches while the random sample had TDA particle sizes ranging between 0.375 – 2 inches, as shown below in Figure 3. Due to the particle size distribution of the three samples mentioned above, it was found that the three samples fall under type A TDA category.

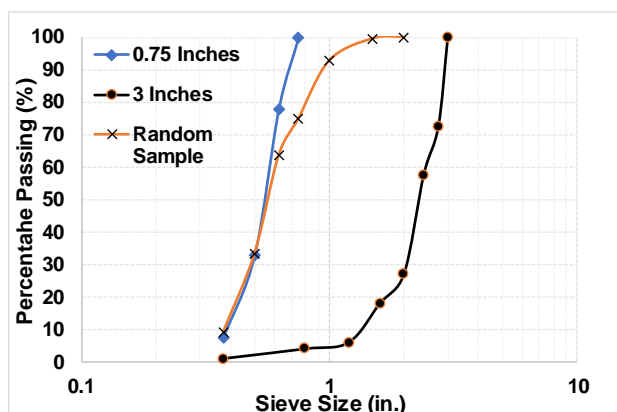


Figure 3. Particle size distribution of the tested samples.

The characteristics of the three samples are given below in Table 1. The average particle size ( $D_{50}$ ) of the samples ranged between 0.55 – 2.4 inches which qualify the samples for the study of the effect of the particle size effect on the shear strength parameters of TDA and more sample sizes will be presented at the conference time. The  $D_{50}$  for the 0.75 inches and the random samples was almost identical while the maximum particle size ( $D_{max}$ ) of the random sample was much higher than that of the 0.75 inches that will qualify the study of the effect of both the average and the maximum particle size on the shear strength parameters.

Table 1. Characteristics of The TDA used in the research

Characteristics	0.75 Inches	3 Inches	Random Sample
$D_{10}$	0.375	1.4	0.36
$D_{30}$	0.485	2.1	0.49
$D_{50}$	0.55	2.4	0.56
$D_{60}$	0.58	2.5	0.6
$D_{max}$	0.75	3	2
$C_u$	1.55	1.79	1.67
$C_c$	1.08	1.26	1.11

The coefficient of uniformity ( $C_u$ ) was calculated as follows:

$$C_u = D_{60} / D_{10} \quad [1]$$

While the coefficient of curvature ( $C_c$ ) was calculated as follows:

$$C_c = D_{30}^2 / (D_{60} * D_{10}) \quad [2]$$

## 4 SAMPLE PREPARATION AND TESTING SCHEME

### 4.1 Sample Preparation

Firstly, the sample was sieved with accordance to ASTM C136/C136M – 14. Then, any protruding steel was removed from the 0.75 and the 3 inches sample to result in a more conservative shear strength due to the absence of the extra cohesion from the interlocking between the protruding steel wires (Ashari, 2018). However, the random sample was tested in its original state with protruding steel to be able to compare the effect of the protruding steel on the shear parameters. After that, the retained particles on each sieve were mixed probably altogether to have less voids and to make sure that the failure plan inside the shear box is made of a representative portion of the sample not a uniform particle size.

Furthermore, a proper compaction was performed with a total compaction energy of 38,000 (Joules), to reach 60% of the modified proctor energy, was applied to the samples to be within the range suggested by ASTM D6270-08 which

stated that compaction of TDA is in the range of 60% of standard proctor energy up to 100% modified proctor energy and the compaction was done using a modified proctor hammer following the procedures of ASTM D1557. To reach the required compaction energy, TDA specimens were placed in five layers inside the shear box. Each layer was subjected to 75 blows with a total of 375 blows for the whole sample.

#### 4.2 Testing Scheme

A series of large-scale direct shear tests were performed with accordance to ASTM D3080/D3080M - 11 under strain-controlled conditions. The shear stress, horizontal displacement and vertical displacement were recorded at 10% horizontal strain according to ASTM D3080 as the TDA samples do not have peaks according to Strenk et al. (2007). The samples were subjected to three normal stresses; 50 kPa, 100 kPa and 200 kPa. Normal stresses were selected based on real site conditions and they were applied using a deadweight loading mechanism.

The TDA specimens were sheared at a constant shearing rate of 0.5 mm/min. A low shearing rate was chosen to avoid overestimating the calculated shear stresses. The chosen shearing rate was less than that used in the literature according to the author's knowledge (Kim et al. 2014; Alias et al. 2014; Eslam et al. 2011; Vangla and Latha. 2015; Xaio et al. 2015; Humphrey et al. 1993; Foose et al. 1996; Bernal et al. 1997).

The density of the specimens before shearing, after applying the normal stresses, was calculated to assure that the tests were done under similar conditions and it was summarized below in Table 2.

Table 2. Density before shearing (kg/m<sup>3</sup>).

Sample	Density Before Shearing (kg/m <sup>3</sup> )		
	50 (kPa)	100 (kPa)	200 (kPa)
0.75 Inches	638.1	674.2	725.2
3 Inches	650.4	679.3	760.5
Random Sample	667.2	690.4	780.1

### 5 EXPERIMENTAL RESULTS AND DISCUSSION

The results below were derived from a series of large scale direct shear tests with a shear box of dimensions 300 mm \* 300 mm \* 230 mm for three TDA samples. The shear stress was defined at 10% horizontal strain, as the TDA is a ductile material with no peak in the shear stress-strain curve, under three normal stresses; 50 kPa, 100 kPa and 200 kPa.

#### 5.1 Shear Stress – Strain Curves

Figure 4 shows the stress-strain curves for the three samples combined under three normal stresses. Shear stress at 10% horizontal strain was used in calculating the

shear strength parameters for TDA. In general, the 0.75 inches and the random samples, showed an almost identical stress-strain curves under the three normal stresses while the 3 inches sample showed a much higher stress-strain curve.

Under 50 kPa normal stress, the 0.75 inches sample and the random sample showed a similar shear stresses up to 14% horizontal strain, the maximum horizontal strain the machine could reach. However, the 3 inches sample showed shear stresses around 1.3 times higher than that of the 0.75 inches and the random samples.

Moreover, at 100 kPa normal stress, a slight difference in the shear stresses with about 4 kPa maximum difference between the 0.75 inches and the random samples was observed. However, the 3 inches sample showed shear stresses around 1.25 times higher than that of the 0.75 inches and the random samples.

Furthermore, at 200 kPa normal stress, both samples showed an almost identical behaviour up to 11% horizontal strain, and after that, the random sample came to a plateau while the 0.75 inches sample showed an increase in shear stresses. On the other hand, the 3 inches sample showed shear stresses around 1.3 times higher than that of the 0.75 inches and the random samples.

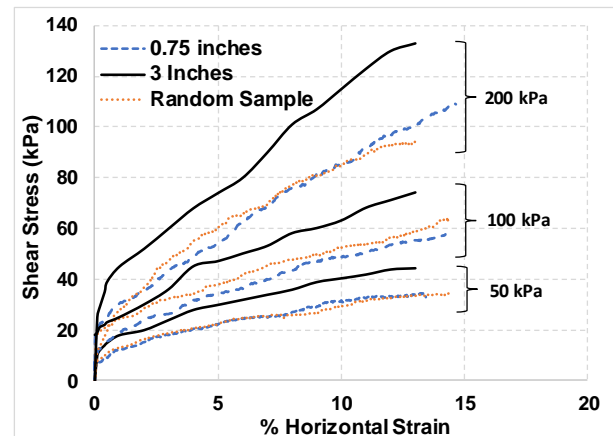


Figure 4. Shear Stress (kPa) Vs. Horizontal Strain (%)

#### 5.2 Angle of Internal Friction and Cohesion

Figure 5 and Table 3 indicate the shear strength parameters, such as angle of internal friction and cohesion, for the three TDA samples. It was observed that the shear strength of the 0.75 inches sample and the random sample is almost identical. While the 3 inches sample exhibited a higher shear strength.

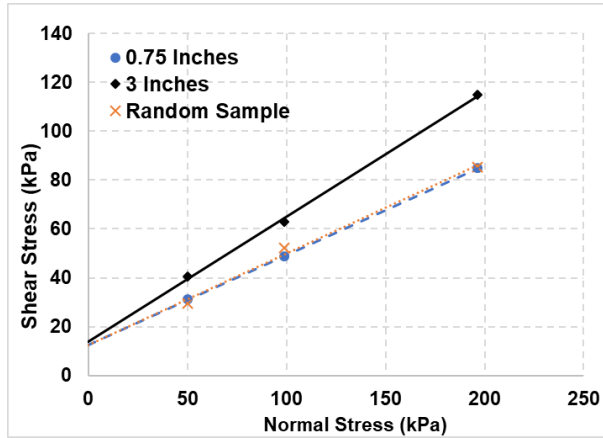


Figure 5. Shear Stress (kPa) Vs. Normal Stress (kPa)

As shown above, the fit line for the 0.75 inches and the random sample is almost identical, having the same slope and y-axis intercept, as the shear stress calculated at 10% horizontal strain was almost the same. However, the 3 inches sample showed a higher angle of internal friction and cohesion, which resulted in higher shear strength of the sample. Angle of internal friction and cohesion were summarized in Table 3.

Table 3. Angle of internal friction and cohesion

Sample Size	Angle of Internal Friction (°)	Cohesion (C)
0.75 Inches	20.23	12.56
Random Sample	20.59	12.45
3 inches	23.9	18.2

### 5.3 Strain behavior

Table 4 shows the maximum vertical deformation occurred for each sample under the three normal stresses. The 0.75 inches and the random sample experienced a contractive strain behavior under the different applied normal stresses in contrast to the 3 inches sample which exhibited a contractive–dilative strain behavior. The three samples showed an increase in the vertical deformation as the normal stress increases. Moreover, the 0.75 inches sample showed the highest vertical deformation followed by the random sample with a slight decrease in the vertical deformation while the 3 inches sample exhibited the least vertical deformation as shown in Table 4.

Table 4. Maximum Vertical Deformation (mm) for the TDA samples

Sample	Maximum Vertical Deformation (mm)		
	50 (kPa)	100 (kPa)	200 (kPa)
0.75 Inches	4	4.75	5.5
Random Sample	3.9	4	4.2
3 Inches	1.25	2.2	2.3

## 6 CONCLUSION

To study the particle size effect on the shear parameters of TDA, a series of direct shear tests were conducted on three TDA samples using a shear box of dimensions; 305 mm \* 305 mm \* 225 mm. From the tests results, it could be observed that:

- (1) The angle of internal friction of TDA increases by increasing the maximum particle size ( $D_{max}$ ).
- (2) The average particle size ( $D_{50}$ ) has a direct proportion with the angle of internal friction of TDA and this could be observed by comparing the results of the 3 inches sample with the results of either the 0.75 inches or the random sample as they have an almost identical average particle size ( $D_{50}$ ).
- (3) The cohesion resulted from the interlocking between the TDA particles is not affected by the particle size as the cohesion exhibited a decrease followed by an increase by increasing the particle size as shown in Table 3.
- (4) The contractive strain behavior that the 3 inches sample exhibited is due to the presence of larger voids between the sample particles while the 0.75 inches and the random samples exhibited a contractive–dilative strain behavior due to the presence of less voids within the samples.
- (5) The vertical deformation for TDA samples decreases as the maximum particle size ( $D_{max}$ ) increases as shown in Table 4.
- (6) The presence of protruding steel results in a less vertical deformation due to the excess interlocking between the sample particles as shown in Table 4.

This is a research in progress and more results on other TDA sizes will be provided at the time of the conference to validate the particle size effect on the shear strength parameters of TDA.

## 7 REFERENCES

Ashari Ghomi, M. (2018). Large-scale triaxial testing of sustainable TDA backfilling alternatives.

- ASTM D1557-12e1, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft<sup>3</sup> (2,700 kN-m/m<sup>3</sup>)), *ASTM International*, West Conshohocken, PA, 2012, [www.astm.org](http://www.astm.org)
- ASTM D3080 / D3080M-11, Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions, *ASTM International*, West Conshohocken, PA, 2011, [www.astm.org](http://www.astm.org)
- ASTM D6270-08(2012), Standard Practice for Use of Scrap Tires in Civil Engineering Applications, *ASTM International*, West Conshohocken, PA, 2012, [www.astm.org](http://www.astm.org)
- ASTM D6913-04, Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis, *ASTM International*, West Conshohocken, PA, 2004, [www.astm.org](http://www.astm.org)
- Bernal, A., Salgado, R., Swan, R., and Lovell, C. (1997). "Interaction between tire shreds, rubber-sand, and geosynthetics." *Geosynthetics Int.*, 4(6), 623-643.
- Cecich, V., Gonzales, L., Hoisaeter, A., Williams, J., & Krishna, R. (2016). Use of Shredded Tires as Lightweight Backfill Material for Retaining Structure. *Waste Management & Research*, 14, 433–451.
- Edincliiler, A., Cabalar, A. F., & Cevik, A. (2013). Modelling dynamic behaviour of sand–waste tires mixtures using neural networks and neuro-fuzzy. *European Journal of Environmental and Civil Engineering*, 17(8), 720-741. doi:10.1080/19648189.2013.814552
- Foose, Gary & Benson, Craig & J. Bosscher, P. (1996). Sand Reinforced with Shredded Waste Tires. *Journal of Geotechnical Engineering*. 122.10.1061/(ASCE)0733-9410(1996)122:9(760).
- Humphrey, D.N. & Sandford, T.C. & Cribbs, M.M. & Manion, W.P.. (1993). Shear strength and compressibility of tire chips for use as retaining wall backfill. *Shear Strength and Compressibility of Tire Chips for Use as Retaining Wall Backfill*. 29-35.
- Iranikhah, Ali. (2018) Experimental Investigation on the Shear Strength Parameters and Deformability Behavior of Various Soil Types Mixed with Tire-Derived Aggregate. (*Master's Thesis*). Dalhousie University.
- Islam, Mohammad & Siddika, A & Hossain, Md & Rahman, A & Asad, Md.A.. (2011). Effect of particle size on the shear strength behaviour of sands. *Australian Geomechanics Journal*. 46. 85-95.
- Kim, D., & Ha, S. (2014). Effects of Particle Size on the Shear Behavior of Coarse-Grained Soils Reinforced with Geogrid. *Materials* (Basel, Switzerland), 7(2), 963–979. doi:10.3390/ma7020963
- Meles, D., Chan, D., Yi, Y., & Bayat, A. (2015). Finite-element analysis of highway embankment made from tire-derived aggregate. *Journal of Materials in Civil Engineering*, 28(2), 04015100.
- Strenk, P. M., Wartman, J., Grubb, D. G., Humphrey, D. N., & Natale, M. F. (2007). Variability and Scale-Dependency of Tire-Derived Aggregate. *Journal of Materials in Civil Engineering*, 19(3), 233–241.]
- Vangla, P. & Latha, G.M. *Int. J. of Geosynth. and Ground Eng.* (2015) 1: 6. <https://doi.org/10.1007/s40891-014-0008-9>
- Xiao et al. (2103). Shear Resistance of Tire-Derived Aggregate Using Large-Scale Direct Shear Tests. *Journal of Materials in Civil Engineering. American Society of Civil Engineers*. 2014. doi: [https://doi.org/10.1061/\(ASCE\)MT.19435533.0001007](https://doi.org/10.1061/(ASCE)MT.19435533.0001007)