ASTM INTERNATIONAL

Geotechnical
Testing Journal

Andrea Ventola[1] and Roman D. Hryciw[2]

DOI: 10.1520/GTJ20220032

The Sed360 Test for Rapid Sand Particle Size Distribution Determination

Geotechnical Testing Journal

doi:10.1520/GTJ20220032 available online at www.astm.org

TECHNICAL NOTE

Andrea Ventola[1] and Roman D. Hryciw[2]

The Sed360 Test for Rapid Sand Particle Size Distribution Determination

Reference

A. Ventola and R. D. Hryciw, "The Sed360 Test for Rapid Sand Particle Size Distribution Determination," *Geotechnical Testing Journal* https://doi.org/10.1520/GTJ20220032

Manuscript received February 17, 2022; accepted for publication October 31, 2022; published online January 6, 2023.

[1] Department of Civil and Environmental Engineering, University of Michigan, 2350 Hayward St., Ann Arbor, MI 48109-2125, USA (Corresponding author), e-mail: acvent@umich.edu, https://orcid.org/0000-0001-6603-9707

[2] Department of Civil and Environmental Engineering, University of Michigan, 2350 Hayward St., Ann Arbor, MI 48109-2125, USA

ABSTRACT

Sed360 is a largely automated system for determining image-based particle size distributions (PSDs) of sands. A sedimented soil specimen contained in a 25.4-mm (1-in)-diameter circular acrylic tube sits atop a rotating stage. While the tube rotates, a camera captures an image of the specimen every 4° of rotation. Narrow vertical strips from each image are automatically stitched together to form a complete, unwrapped 360° view of the soil specimen. Image analysis based on a mathematical Haar wavelet transform generates the soil specimen's PSD. Three sands were tested with the Sed360 and the image-based PSDs are compared to traditional sieving results. As in earlier studies, very good agreement was observed. The Sed360 affords the same benefits of the system's predecessors (LabSed and FieldSed) over sieving but adds automatic image capture and stitching to create large 360° unwrapped cylinder images of the specimen that are better suited for PSD determination by image analysis. The Sed360 also paves the way for testing a larger range of particle sizes by SedImaging.

Keywords

particle size distribution, soil classification, sand, SedImaging, image analysis, Sed360

Introduction

Many applications in geotechnical engineering, engineering geology, and related fields require numerous characterizations of sand particle size distributions (PSDs). While sieving is the industry standard for determining PSDs, the many shortcomings of sieving, including high equipment costs and long test times, are tipping the scales toward more advanced methods for PSD determination. Because of rapid advances in camera technology and analysis methods, image-based methods are leading the way among the alternatives to sieving.

One such image-based method, called SedImaging, was developed by Ohm and Hryciw (2014). This article describes a much more advanced and automated version of the SedImaging test. The new system is called the Sed360 because it produces PSDs from 360° optical scans of soil specimens.

SEDIMAGING AND THE PREDECESSORS OF SED360

SedImaging (short for sediment imaging) includes: hardware to sort particles by size using sedimentation through a tall column of water, a camera for capturing images of the soil after it has settled, and software for analyzing the settled soil assembly. SedImaging does not require oven-drying specimens, uses less energy, produces less noise, and can be performed in much less time than sieving (Ohm and Hryciw 2014, Ventola and Hryciw 2019, Ventola et al. 2020). Although the image analysis has remained largely unchanged since Ohm and Hryciw's (2014), the hardware, which is the focus of this article, has changed entirely.

Ohm and Hryciw's original system is referred to as LabSed. Its centerpiece was a 5 cm by 5 cm by 2.1 m (2 in by 2 in by 7 ft) tall aluminum sedimentation column. The soil particles settled through the water-filled column into a square-sectioned cartridge below. The cartridge had a single glass window through which the sorted particle assembly was photographed. The relatively large size and heavy system components of LabSed were not practical for field implementation. In response, a "FieldSed" was developed by Ventola and Hryciw (2019). The sedimentation column for the FieldSed was lightweight, clear, square cross-sectioned acrylic tubing. All four sides of the settled soil assembly could now be photographed. This increased the available surface area of the specimen for image analysis. The FieldSed sedimentation column was also of smaller size at 2.5 cm by 2.5 cm by 1.8 m (1 in by 1 in by 6 ft). Its portability allowed FieldSed to be the centerpiece of a large study to characterize Kalamazoo River bed sediments (Ventola et al. 2020). In this study, a prewashing method was also developed to account for soil particles that fell outside of the testable soil particle size range for SedImaging, which at that time was from 0.075 to 2.0 mm.

FieldSed had a lower throughput time than LabSed, but it still required users to manually rotate the sedimentation column to photograph each of its four sides. The PSDs determined for each side had to be combined to produce a single PSD representative of the entire specimen. This piece-wise analysis along with optical distortions at the corners of the column were additional drawbacks of the FieldSed.

THE SED360

The new Sed360 system replaces the square tubing of the FieldSed with a clear acrylic circular sedimentation column. The image capture of the cylindrical soil specimen utilizes a rotating stage. Instead of taking four images, the Sed360 is automated to take many images as it rotates. Narrow vertical strips from the images are extracted and stitched into one large seamless "unwrapped cylinder" image of the specimen surface. This single stitched image is analyzed to determine the specimen's PSD. This automation increases the testing efficiency of SedImaging by reducing the amount of required user intervention during a test. It will also lead to the expansion of the soil particle size range eligible for image analysis by more than a factor of two.

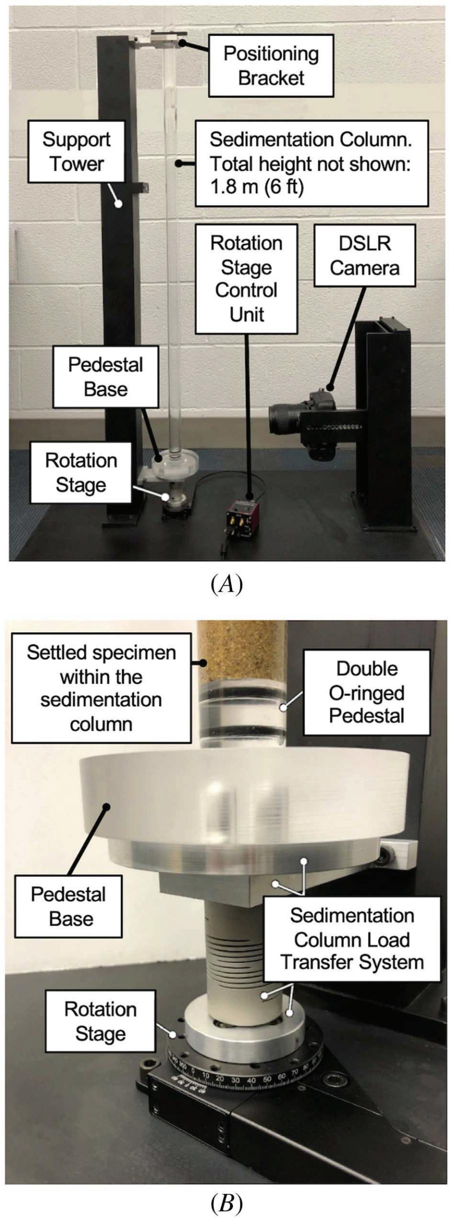
Sed360 Hardware

The Sed360 system, shown in **figure 1*A***, consists of a 1.8-m (6-ft)-long clear acrylic sedimentation column with an inside diameter of 25.4 mm (1 in) and a 3.2-mm (1/8-in) wall thickness. The column is held in place by a support tower. A positioning bracket mounted on the support tower (**fig. 1*A***) ensures perfect verticality while allowing the column to rotate. The sedimentation column is open at the top and fitted with a removable double O-ringed acrylic pedestal on the bottom (**fig. 1*B***). Removal of the pedestal allows for rapid clean up after testing. The sedimentation column sits atop a Thorlabs motorized precision rotation stage (**fig. 1*B***). Users can set the range and speed of rotation.

Figure 1*B* also shows the Sed360's load transfer system. The Thorlabs rotation stage has a load capacity of 15 N (1.5 kg, 3.4 lb). The weight of the Sed360 hardware plus soil and water in the column exceeds this capacity. Therefore, the system shown in **figure 2** was designed to transfer the weight of the sedimentation column and its contents from the stage to the support tower while still allowing the column to rotate freely. A drive block

FIG. 1

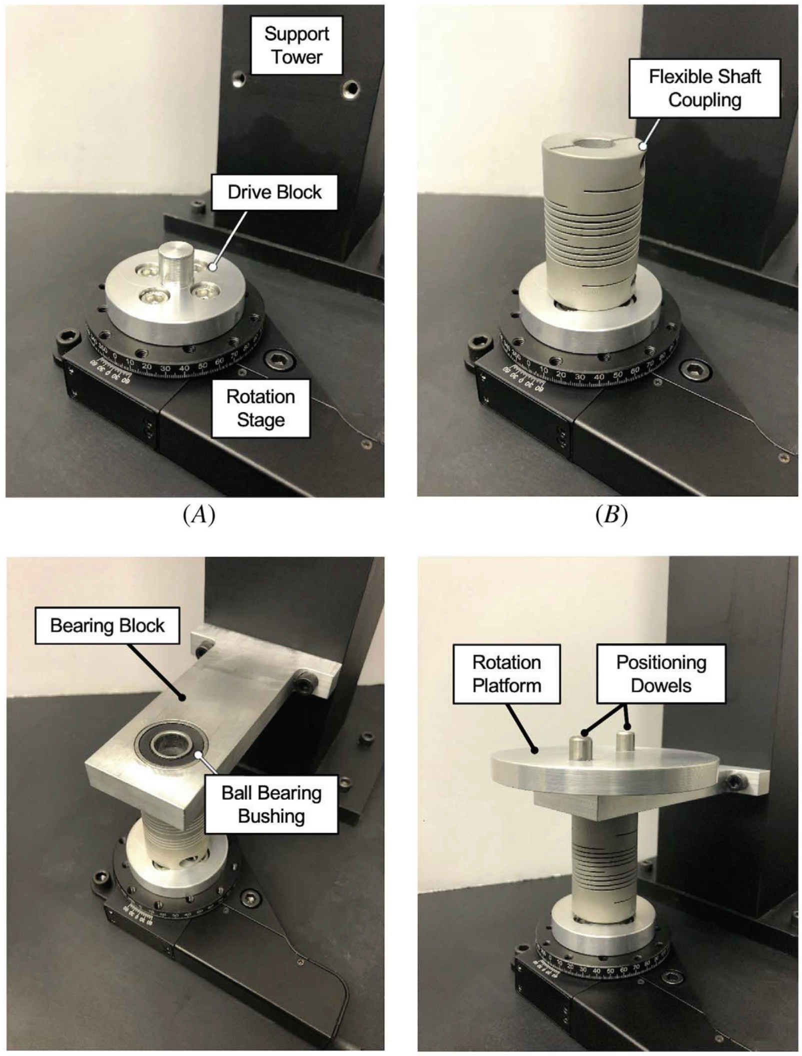
The Sed360: (*A*) full view, (*B*) pedestal, load transfer system, and rotation stage.



(**fig. 2*A***) is screwed into the rotation stage. A short central shaft protrudes up from the drive block where it is firmly locked into the lower section of a flexible shaft coupling (**fig. 2*B***). The coupling is used to adjust for any small longitudinal misalignments between the rotation stage and the parts of the load support system above it. The bearing block in **figure 2*C*** is secured to the system's support tower. A stainless steel ball bearing bushing is press-fitted into the bearing block (**fig. 2*C***). **Figure 2*D*** shows a rotation platform that sits on the bearing block. The rotation platform has a central aluminum shaft (not shown in **fig. 2**) permanently affixed to the underside of the platform. This shaft slips through the ball bearing bushing and is held tightly in the upper section of the flexible shaft coupling. Thus, the shaft and the platform rotate with the rotating stage, drive block, and flexible coupling. Lastly, the sedimentation column and its pedestal base sit on the rotation platform (**fig. 1*B***). Two rigid

FIG. 2

Load transfer system. (*A*) Drive block, (*B*) flexible shaft coupling, (*C*) bearing block, and (*D*) rotation platform.



positioning dowels project upward from the rotation platform (fig. 2*D*). They fit snugly into the removable pedestal base, ensuring accurate and consistent positioning of the sedimentation column for image capture.

The final piece of hardware of the Sed360 system is the presorter tube (not shown in fig. 1). The Sed360 presorter is identical in design and operation as the presorters used for LabSed and FieldSed, but with smaller dimensions. Ohm and Hryciw (2014) and Ventola et al. (2020) show the earlier presorters. As described by Ventola and Hryciw (2019) and Ventola et al. (2020), the presorter is used to instantaneously release a soil specimen into the top of the sedimentation column.

The Four Stages of the Sed360 Test

STAGE 1. INTRODUCING A SOIL SPECIMEN INTO THE SED360 SYSTEM

To begin the test, the sedimentation column is filled with water. Next, an 85 ± 15 g soil specimen is funneled into the open end of the presorter tube. Ventola et al. (2020) details the procedure used with the presorter to transfer and later release a soil specimen into the top of the sedimentation column. Once released, the specimen's soil particles begin to settle and sort by size.

The largest particles in the soil specimen naturally settle at the base of the sedimentation column first, followed by progressively finer grains. The time required for the entire soil specimen to settle will vary depending on the soil's gradation, but most well-graded sand specimens will settle in less than 10 min. Clean, poorly-graded medium sands will settle in under 5 min. Once all the specimen particles have settled, image capture using the rotation stage begins.

STAGE 2. SED360 IMAGE CAPTURE

The image capture is fully automated. For the current Sed360 test, the stage is programmed to rotate at a speed of 0.8°/s. A full 360° rotation takes 7.5 min. The rotation speed was conservatively selected to assure that there would be precise image stitching and no image blurring. While the stage is rotating, the camera is automatically capturing images. There is a 5-s pause between photographs; this corresponds to an image taken every 4°, totaling 90 images for the full rotation.

STAGE 3. IMAGE PROCESSING

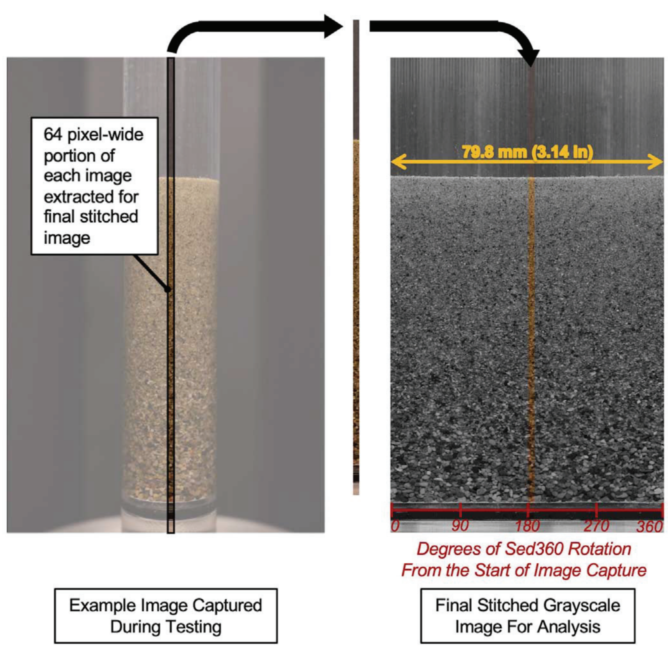
The 90 photographs collected during stage rotation are stitched to form an "unwrapped cylinder" of the settled soil. The image stitching is fully automated. For each of the 90 captured images, only a 64 pixel-wide portion from the center of the photographed sedimentation column is extracted, as seen in figure 3. This thin strip is taken from the portion of the sedimentation column that is perfectly normal to the axis of the camera to avoid distortion because of column curvature. To correct for any minor fluctuations in camera shutter speed or elapsed time between successive image captures, the slices are cropped to ensure perfect alignment of adjacent slices. The stitched image of the unwrapped cylinder is now ready for PSD analysis.

STAGE 4. PSD DETERMINATION USING HAAR WAVELET TRANSFORMATION

To determine the PSD in a Sed360 test, an image analysis method based on the mathematical Haar wavelet transform (HWT) (Haar 1910) is utilized. Hryciw, Ohm, and Zhou (2015) describe the HWT-based image analysis method. This article includes comparisons of the HWT-image based and sieve results for three soil specimens tested in the Sed360.

FIG. 3

Sed360 image stitching.



Results

Three sands of different colors and gradations were tested in the Sed360. The coarsest of the three sands (fig. 4*A*) is termed “2NS” by the Michigan Department of Transportation (MDOT 2010). This glacio-fluvial material

FIG. 4

Sed360 results. (*A*) 2NS specimen image, (*B*) 2NS PSDs, (*C*) Michigan dune specimen image, (*D*) Michigan dune PSDs, (*E*) Nesika Beach specimen image, and (*F*) Nesika Beach PSDs.

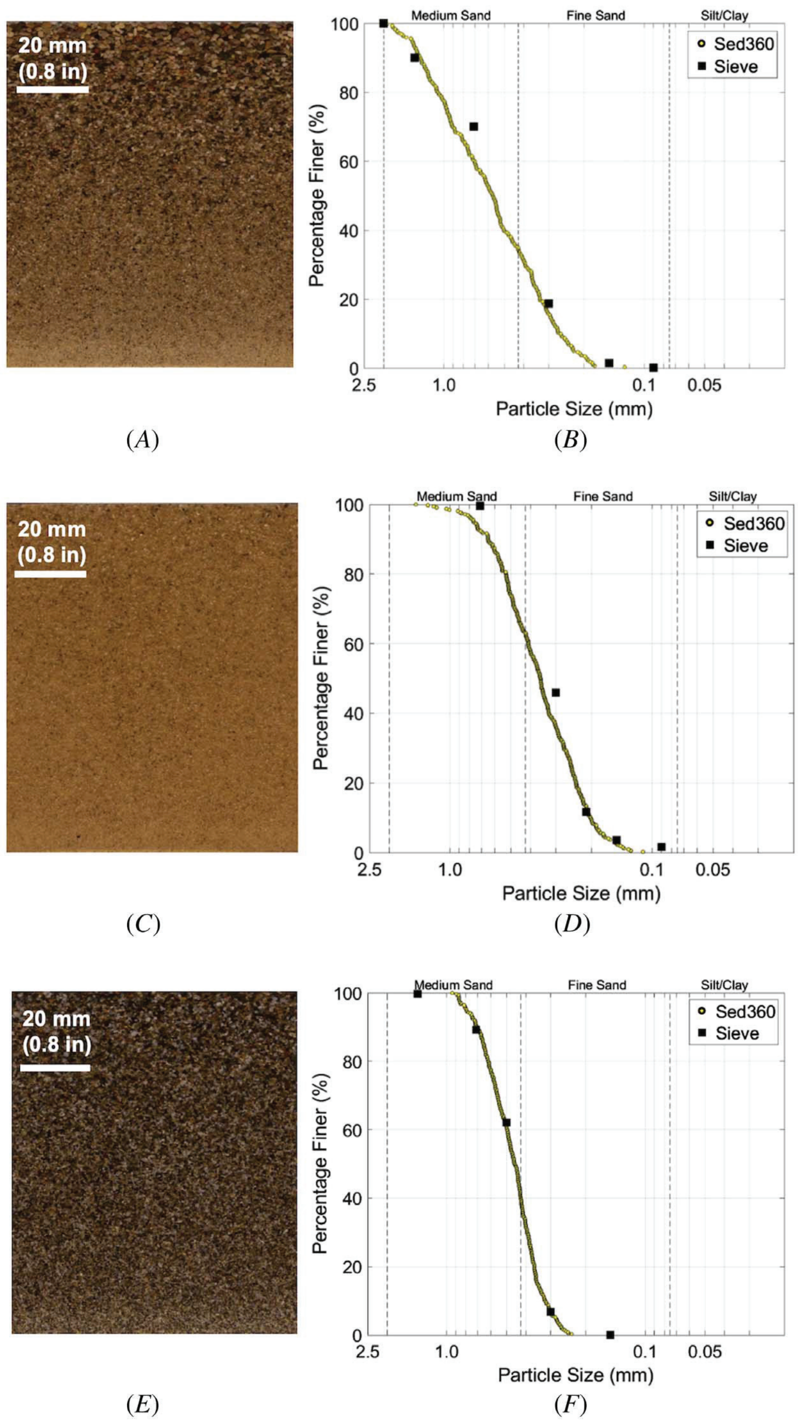


TABLE 1
Comparison of PSD parameters by Sed360 and sieving

	2NS		Michigan Dune		Nesika Beach	
Item	Sed360	Sieve	Sed360	Sieve	Sed360	Sieve
D_{60}, mm	0.70	0.60	0.41	0.39	0.50	0.49
D_{30}, mm	0.40	0.37	0.28	0.27	0.40	0.37
D_{10}, mm	0.28	0.24	0.21	0.21	0.31	0.31
C_u [a]	2.50	2.50	1.95	1.86	1.61	1.58
C_c [b]	0.82	0.95	0.91	0.89	1.03	0.90
Medium sand, %	66	60	38	36	60	57
Fine sand, %	34	40	62	64	40	43

Note: [a] Coefficient of uniformity, $C_u = D_{60}/D_{10}$. [b] Coefficient of curvature, $C_c = (D_{30})^2/(D_{60} \times D_{10})$.

contains a variety of particle colors. **Figure 4*C*** shows a more monocolored fine sand known as "Michigan Dune" from the eastern shore of Lake Michigan. Lastly, **figure 4*E*** shows the third specimen, a medium sand from Nesika Beach, Oregon, that contains a mix of black, white, and brown-colored particles. **Figure 4*B***, **4*D***, and **4*F*** show the HWT-based PSDs for the three specimens, respectively. The Sed360 images of each soil in **figure 4** are flipped vertically (i.e., the coarsest particles are now at the top of the figures) for visual alignment with the PSDs. By flipping these images, the actual particles are seen at the same height as their representation on the PSD. This is a nice visualization feature that sieving cannot provide.

The three sands were also sieved according to ASTM C136/C136M-19, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*, and the results are included in **figure 4*B***, **4*D***, and **4*F***. Overall, there is strong agreement between the Sed360 and the sieve PSDs as observed by comparison of various PSD parameters in **Table 1**.

Discussion

The advantages of FieldSed over sieving as described earlier and by Ventola et al. (2020) and Ventola and Hryciw (2019) also hold for the Sed360. However, the Sed360 has additional advantages. First, the new circular column atop a rotation stage allows for test automation. Secondly, the removable circular, double O-ringed pedestal of the Sed360 provides a better seal and facilitates rapid cleaning of the system.

The narrow widths of both the LabSed and FieldSed viewing windows limited the size of particles that could be analyzed by SedImaging to only medium and fine sands. Now, because of the "unwrapping" of the full surface area of the cylindrical specimen, coarse sand particles (2.00 to 4.75 mm) can be tested in the Sed360. Future research will focus on changes to the existing HWT-based analysis method needed to accurately size this expanded soil range.

Conclusions

SedImaging using the Sed360 system is a semi-automated method for rapidly generating image-based PSDs of sands. The system utilizes a circular sedimentation column that sits atop a precision rotating stage. The stage rotates at a preset speed while a camera captures images of the settled sand specimen every 4°. The collection of images are automatically stitched to form a seamless "unwrapped cylinder" image of the soil that is then analyzed using a HWT-based method to generate a PSD. Three sands of different gradations were tested using the Sed360 system. They showed very good agreement with sieving results.

ACKNOWLEDGMENTS
This material is based upon work supported by the US National Science Foundation under Grant CMMI 1825189. ConeTec Investigations Ltd. and the ConeTec Education Foundation are acknowledged for their support to the

Geotechnical Engineering Laboratories at the University of Michigan. The authors thank Steve Donajkowski for providing design suggestions and machining for the Sed360.

References

ASTM International. 2019. *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*. ASTM C136/C136M-19. West Conshohocken, PA: ASTM International, approved December 1, 2019. https://doi.org/10.1520/C0136_C0136M-19

Haar, A. 1910. "Zur Theorie der Orthogonalen Functionensysteme." *Mathematische Annalen* 69, no. 3 (September): 331–371.

Hryciw, R. D., H.-S. Ohm, and J. Zhou. 2015. "Theoretical Basis for Optical Granulometry by Wavelet Transformation." *Journal of Computing in Civil Engineering* 29, no. 3 (May): 04014050. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000345

Michigan Department of Transportation. 2010. *Materials Source Guide*. Lansing, MI: Michigan Department of Transportation.

Ohm, H.-S. and R. D. Hryciw. 2014. "Size Distribution of Coarse-Grained Soil by SedImaging." *Journal of Geotechnical and Geoenvironmental Engineering* 140, no. 4 (April): 04013053. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001075

Shin, S. and R. D. Hryciw. 2004. "Wavelet Analysis of Soil Mass Images for Particle Size Determination." *ASCE Journal of Computing in Civil Engineering* 18, no. 1 (January): 19–27. https://doi.org/10.1061/(ASCE)0887-3801(2004)18:1(19)

Ventola, A., G. Horstmeier, R. D. Hryciw, C. Kempf, and J. Eykholt. 2020. "Particle Size Distribution of Kalamazoo River Sediments by FieldSed." *Journal of Geotechnical and Geoenvironmental Engineering* 146, no. 12 (December): 05020012. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002421

Ventola, A. and R. D. Hryciw. 2019. "On-Site Particle Size Distribution by FieldSed." In *Geo-congress Engineering Geology, Site Characterization, and Geophysics*, edited by C. Meehan, S. Kumar, M. Pando, and J. Coe, 143–151. Reston, VA: American Society of Civil Engineers.