June 2021 ABC-UTC Monthly Webinar: Bring Your A-GaME to ABC – Adding Project Value Using Newer Geotechnical Tools		
#	**Questions**	**Responses**
1	Can you discuss ABC bridge foundation types, notably reinforced soil abutments relative to keys to success, extended studies, and how A-GaME can help?	A-GaME techniques generally offer benefits of accuracy, repeatability, increased data density, and acquisition of multiple datasets (such as several sensors on a CPT (Cone Penetration Test) cone or several measured parameters in MWD (Measurement While Drilling)). A-GaME techniques also tend to be faster and, therefore, more data can be gathered in the field without considerable [or any] added time and cost when supplementing or replacing "traditional" methods. This additional spatial data and improved data quality provides benefits for design and analysis as well as understanding of variability and risk. For reinforced soil abutments (e.g., GRS-IBS (Geosynthetic Reinforced Soil Integrated Bridge System)), parameters of particular interest on compressibility, consolidation, strength, and variations within foundational soils can be assessed well with CPT, laboratory testing, and likely ER (Electrical Resistivity)/Seismic methods. The frequency and location of measures need to be planned based on project requirements and actual encountered site conditions. The techniques discussed can provide improved settlement predictions- possibly making shallow foundations more preferable. They can also help direct foundation selection- perhaps avoiding inappropriate pile types (e.g., if a site is highly variable, perhaps steel piling could replace precast concrete piles for ease of splicing and pile cut-off). MWD can provide valuable information for drilled shaft construction regarding production rates and changes in stratigraphy.
2	Can you discuss how the A-GaME affects construction claims/damages, schedule delay causes, and corrective actions?	Primarily, A-GaME techniques allow improved site characterization which reduces the risk of construction claims and damages. Better site characterization affords several types of advantage: 1) assisting initial foundation selection; 2) improving the geotechnical design by using more and better quality information- thus coming up with more reliable estimates and reducing the risk of material and time overruns and delays; 3) improving overall confidence by identifying potential problems more completely in the design phase- so that as-bid design plans and specifications contain appropriate language and specifications- reducing the likelihood for costly change-orders during construction. Additionally, corrective actions, when necessary, are also made easier when there is additional preliminary information with which to compare newer data- the need for speculation and assumption is reduced.

3	Regarding ABC, what are the criteria for using drilled caissons, micropiles, or steel H piles for foundation designs based on cost?	Note that foundation system selection frequently is influenced by more that cost: Constructability, anticipated site conditions, project requirements (loads, sequencing, performance expectations - i.e., deflections, scour, adjacent structures, deterioration with time, etc.). With that said, an effective way to evaluate various viable foundation options for cost is by summing up all costs associated with foundation installation (e.g., include temporary works, working platforms, etc. required) as a ratio of factored resistance. By using a "foundation support cost", one can compare different foundation options with respect to the required project loads. This can even be done with the same foundation type but changes in geometry (e.g., comparing fewer deep piles with respect to a larger number of shallow piles). Usually project constraints, geometry, stratigraphy, and the relative expense of different types of foundation systems in a given geographic market will influence the cost. With respect to criteria used for foundation design, methods like CPT (Cone Penetration Testing) and MWD (Measurement While Drilling) have been assessed and engineering parameters have been correlated to constructed works' performance by load testing. Efficient (cost effective or quickly installed) foundations can be designed by a variety of methods and the selection of piles, shafts, micropiles, etc., is often governed by lateral loading, space requirements (fitting between other elements, low headroom, etc.).
4	How are you incorporating these techniques into the design and construction process, including specifications?	Implementing the A-GaME techniques into routine practice at the organizational level commonly requires agencies (owners) to incorporate them into manuals, procedural documents, and project specifications. Fundamentally, constructability and design (performance) needs should be major considerations as part of the site characterization investigation program. In other words, we should not think that minimum requirements are adequate, and we should use them in a prescriptive manner (e.g., "1 boring per substructure, 1 boring every 400 feet along roadways, etc."). Specifications usually don't need significant language updates to allow additional investigation methods as alternate or equivalent. Progressive owners are evaluating project needs on a case-by-case basis and adapting guidance to include information which will be valuable to designers, contractors and project decision-making. Multi-phase investigations are becoming more common where exploration geophysics is used to "scope" a project geotechnically, and then other techniques are deployed at meaningful locations in a subsequent phase. In alternative delivery, further investigation may be conducted once final locations and structure types are known. A motion to adopt a new AASHTO Manual on Subsurface Investigation is anticipated at the next AASHTO Committee on Materials and Pavements [This will be an update to the

		1988 manual; refer also to NCHRP Web-Only Document 258]. FHWA GEC5 is essentially the companion document to the proposed "means and methods" AASHTO Manual on Subsurface Characterization.
5	How many states have adopted the use of this technology? What is the cost for a typical bridge site? What is the percent error using this technology?	There are 5 featured investigation methods being promoted within the A-GaME FHWA EDC-5 initiative. Additionally, the overall effort focuses more broadly on incorporating newer in-situ site characterization procedures which provide greater coverage area and data density, allowing for an improved consideration of geotechnical risk and site variation. As of now, only about 6 state/territory DOTs are NOT officially pursuing A-GaME implementation at some level. 34 transportation organizations are either institutionalized or working toward that goal with one or more of the featured A-GaME technologies. With that said, all states and territories, the USACE and several other federal organizations and a significant number of local agencies have participated in at least one of ten webinars last fall (http://www.dfi.org/update/A-Game_Webinars.pdf). A slide on costs is included in the webinar content. Costs vary depending on if the techniques are self-performed or contracted, and other aspects like access (over water, distance from office). Broadly speaking, for comparison purposes, for the equivalent time and cost at a site for 1 soil boring, multiple CPT (Cone Penetration Test) soundings can be performed. Similarly, a complete geophysical site survey with one or more survey lines, may have the equivalent cost to a boring, but be performed in less field time. A multi-method bridge site investigation where some borings are replaced/supplemented by geophysics or CPT may have the same project cost and a lesser duration of an "equivalent" number of borings alone- while providing superior spatial data coverage and quality. With respect to % error- COV (coefficient of variation) for measurements used for design parameters is a better way of evaluating reliability of parameter/method. COV will range depending on number of measurements. Reliability will depend on the design method and quality of measure. CPT is a far more reliable, repeatable method than SPT (Standard Penetration Test). However, if CPT measurements cannot be obtained, SPT may be a best option of measurement. At this point, there is not enough data to suggest reliability of MWD (Measurement While Drilling) in all conditions. However, Florida DOT's and University of Florida's work on MWD has shown excellent correlation to unconfined compressive strength within Florida Limestone for drilled shaft design parameters.

6	Can you provide a summary regarding the use of this technology?	FHWA conducted a series of 10 webinars featuring the technology methods and application of the techniques for transportation applications in the winter of 2020/2021. The "Winter Webinar Series" is archived at: http://www.dfi.org/update/A-Game_Webinars.pdf In general, use-cases are where owners supplement "traditional" soil borings and accompanying in-situ and laboratory testing with newer and underutilized, but proven, technologies. These technologies are gaining acceptance, but at a slower rate than anticipated, given the advantages of the systems. The strengths of the techniques are clear at highly variable sites and where fast site characterization is needed. The techniques, which generally have digital data acquisition, are well suited for immediate use in computational modeling software and data visualization programs.
7	Can these improvement trials be massively implemented in Peru?	Any agency or project owner can make effective use of these technologies and the rational process of executing well-developed site investigations, which today often includes multiple exploration tools or multiple phases. Look to references such as FHWA GEC5 and the upcoming AASHTO Manual on Subsurface Investigations. Many U.S. State DOTs also have geotechnical design guides (many are available as PDF copies on the web) which describe or support use of technologies such as CPT (Cone Penetration Test) and geophysics. For example (Minnesota DOT): http://www.dot.state.mn.us/materials/geotmanual.html.
8	Can you provide more design examples using this technology?	Design examples can take many forms. Sources may include technical papers, supporting appendices of geotechnical manuals of practice from DOTs and other sources, textbooks, and information provided by software companies who provide data processing packages. Generally, geophysical methods are used to help assess stratigraphy and site variability, although some methods do provide engineering parameters. CPT (Cone Penetration Test) design can be performed using spreadsheets or computer software similarly to the design process using traditional Mohr-Coulomb methods. Indiana DOT is currently developing a CPT design guide. The two resources below provide information on Florida's use of MWD (Measurement While Drilling) and a design manual developed for use by Minnesota DOT geotechnical engineers which describes design cases for both shallow and deep foundation design. https://fdotresearch.com/2021/02/02/measuring-while-drilling-mwd-data-enlightens-

		engineers/ http://www.dot.state.mn.us/research/reports/2018/201832.pdf
9	Can you provide examples of ABC challenges and the cost to overcome those challenges? Is a field decision matrix from the geotechnical perspective available?	NCHRP Synthesis 484 "Influence of Geotechnical Investigations and Subsurface Conditions on Claims, Change Orders, and Overruns" (2016) provides some useful background reading. Figure 1 on Page 9 depicts a tendency for project cost increases where site investigation costs are a small % of project award cost. Field decision matrices are available- but best developed on a site-specific basis as many project challenges are project and site specific. Decisions may need to be based on soil strength, compressibility, permeability, and other factors such as the needed speed of constructions (less expensive solutions may take longer to build- such as using soil preloading and surcharging). A general matrix could be developed and applied broadly, but would need refinement as there are often many solutions to the same problem- geotechnics is not as straightforward as other codified aspects of transportation engineering. The primary ABC challenge is addressing site variability, and providing accurate stratigraphy and material characteristics for appropriate design and construction method selection, design, bidding, and installation. Improved geotechnical information helps ensure that appropriate foundation types are selected and that the subsequent designs are functional and constructable. Significant changes in groundwater character, material strength, or material qualities in the field (different from design representation or assumptions) can result in improper means and methods being selected. Usually, delays and cost overruns are attributable to field execution which is significantly different than the contract documents- proposed foundations are difficult or impossible to install, lengths are wrong, or much different tooling or techniques become necessary. Where severe problems exist, a new site investigation and re-design may be needed, potentially involving new contractors and extensive delays for review, approval, and cost negotiations. Costs to make corrections and revisions in the field can occasionally cost much more than the original foundation estimates, with additional costs associated with administration and delay from other work.
10	Which geophysical methods do you recommend for preliminary investigations, and which do you	The methods used will depend on actual field conditions, environment (i.e., interferences, noise, etc.), and subsurface depths and types of variations (or features) being targeted. Fundamentally, seismic and electrical methods use two disparate physical principles that

	recommend for final siting or design?	generally make one or the other frequently viable. Very generally, electrical resistivity requires moisture to aid in the transmission of electric currents and is not appropriate in very dry, rocky, or arid environments. Seismic methods are more broadly applicable, but may not show enough contrast to be useful in soil layers- but would be appropriate for picking distinct interfaces (such as soil/rock boundaries). Some methods are more appropriate for very-near-surface applications, such as ground penetrating radar. There are also magnetic and gravity methods in the toolkit. Geophysics is generally useful for assessing variability as the methods typically collect measurements at multiple locations allowing planar or volumetric visualizations of soil and rock stratigraphy and character. Use for final design varies- many methods provide fairly reliable stratigraphy when referenced with a few CPT (Cone Penetration Test) soundings or soil borings (providing "ground truth"). Seismic designs may provide wave speed for AASHTO seismic site classification, used in design. While resistivity provides measured values of resistance (often in ohm-meters) this measure is not used directly in design, but it can be used to help identify similar soils and interpolate/extrapolate the extent of deposits and provide a rationale for assigning known engineering properties of soils with similar resistivity. Results are interpreted and approximate in nature, but valuable due to their ability to represent comparatively large spatial extent.
11	How does this tool manage to optimize ABC construction?	The goal of ABC is to accelerate the construction process, which usually has the follow-on benefits of reduced traffic delay and user inconvenience, and improved safety. The A-GaME is a series of technologies which can be used to reduce risk and improve the quality of foundation design. Construction is expedited in several ways: 1) appropriate foundation systems are selected; 2) with improved data quality, geotechnical designs are more likely to be accurate, improving the likelihood that the plans and specifications are accurate- in terms of quantities, means, methods, inspection, and related requirements. The contractor brings the correct equipment and an appropriate amount of material to the site; 3) the risk of overruns, delays, re-design, and re-work is reduced. Optimization comes through improved quality, improved overall process (providing additional information for informed decision making) and associated risk reduction.

12	What other geotechnical tools can add value to ABC projects?	The greatest geotechnical value to ABC projects is in support of efficient construction. The actual time to construct foundations is more-or-less fixed given "normal" site conditions, but could become time-consuming if the character of the site is different from assumptions and expectations. If the ground is harder, softer, wetter, or more unstable than expected then there may need to be changes made to the construction- different from the plans. The A-GaME techniques are a selection of immediately implementable methods that can provide additional value so that the likelihood that the site is different than expected is minimized. Added value can most simply be used by applying a variety of techniques for independent verification (similar to using two different measuring devices or techniques to measure any other parameter). Some techniques are more appropriate for characterizing clay soils- such as the Vane Shear Test (VST) or soft rock- such as the Pressuremeter Test (PMT). The Flat Plate Dilatometer Test (DMT) can provide additional information on soil stiffness, which helps optimize the design of shallow foundations or tunnel walls. Cone Penetration Tests (CPT) provide a collection of measured values which (applying research correlations) can be used to determine a variety of engineering parameters used in computational modeling. The data density and repeatability of CPT data makes it comparatively robust, adding confidence. These tools can be combined with other tools such as remote sensing to provide more complete pictures of future foundation locations and help assess what risk factors may exist (settlement, instability, etc.).
	Questions during Webinar	
13	Which of these methods are good for evaluating and getting dimensions of existing foundations where there are no existing plans to use, for example, when setting a new precast deck on an existing substructure?	Ground penetrating radar may be useful to help locate near-surface features and may be capable of determining the locations of the toe/heel of a foundation or a pile cap. Other methods such as downhole CPT (Cone Penetration Test) or bored seismic methods may be able to help detect the extent of unknown pile lengths. In all cases when using geophysical and NDE (nondestructive evaluation) methods, contrasts are necessary to distinguish the target of interest (i.e., foundation elements and characteristics) from the surrounding materials. If the difference in the measured value is not great enough to provide this contrast, the results will be ambiguous. For instance, detecting the tip of a concrete or steel deep foundation in very dense soil/rock using seismic methods where the seismic velocities between the element and surrounding material are small or not apparent will result with inconclusive results. Therefore, consider the way (downhole vs. surface method) and physical measure (geophysical/NDE method) that will provide the measurable contrast to the

		resolution required. As an example, perhaps measuring the change in current induced within metallic reinforcement of a deep foundation or a steel pile as a source travels past the tip (within an adjacent borehole) may provide a more distinctive measurable change. Characterization of existing foundations for foundation reuse or to evaluate their in-service condition is an evolving area of interest. Invasive methods (core-hole) with down-hole methods like televiewers can provide useful information on condition, as well. Load-testing, in some instances to specified loading conditions, can provide performance data also.
14	Has CPT (Cone Penetration Test) become more usable in mixed soils such as layered gravel and silt?	Determination of engineering properties of materials which are not predominantly sands or clays is challenging for most in-situ and even some laboratory methods. CPT (Cone Penetration Test) correlations are improving as more research into local/regional geomaterials is conducted. The CPT is an excellent stratigraphy tool, but some materials are not well identified by automated processes to assess the soil behavior type. Whenever there are questions as to the type of materials encountered, another CPT push using a soil sampler can be used to help characterize these soils. If the particles are too large for the sampler, a traditional soil boring would be needed. As gravels are relatively large as compared to either CPT or SPT (Standard Penetration Test) samplers, the measurements from these methods may not agree well with performance of large foundation elements installed through the same strata.
15	What does MWD (Measurement While Drilling) actually measure?	MWD (Measurement While Drilling) measures and records various real-time drilling parameters, including the depth of the tooling, crowd (down pressure), torque, rotation speed of the drill, drill-fluid pressure, and flow rates of the drilling-fluid to drill the borehole. Other derived "compound" parameters can also be calculated using these various measured drilling parameters within useful and meaningful relationships. Teale's Specific Drilling Energy and Somerton's Index are examples of "compound parameters." A-GaME Winter Webinar #7 "MWD: The Digital Drill Rig" (Feb 11) explains MWD, provides fundamental concepts and a case study from Montana DOT. http://www.dfi.org/update/A-Game_Webinars.pdf

16	Do iron deposits influence the ER (Electrical Resistivity) methods?	Electrical Resistivity (ER) measurements are definitely influenced by factors such as brackish/salt water and inclusions of metal elements in the ground (guardrail, culverts, piling, utilities, etc.). Conditions where stray currents or shorts can interfere with apparent resistivity measurements should be avoided. Any soils with unusual properties should be investigated with companion "ground truth" CPT soundings or soil borings to ensure that potential unexpected behavior can be compared and evaluated. With that said, iron ore, occurring naturally in some deposits and associated with other naturally occurring minerals and physical properties (porosity, fractures, moisture content, etc.) would not be expected to interfere with apparent resistivity measurements used in the inversion process for imaging.
17	Can these techniques be used for geotechnical exploration over water bodies as well?	Similar to borehole drilling, CPT (Cone Penetration Test) can be performed on tracked vehicles (in marshes) or with trucks on barges over bodies of water. Televiewers and MWD (Measurement While Drilling) are used in conjunction with drilling- so if you can get the drill equipment to the site and extend casing to the bottom of the water body, you are able to use these techniques. There are completely submersible CPT systems, but those are expensive to operate and are typically used for offshore (oceanic) site investigations for things like oil platforms, wind turbines, and other high-value assets founded in deep water. ER (Electrical Resistivity) is well suited to use over water; a waterproof cable is used and the cable (and electrodes) are typically suspended at the water surface with floats. Seismic shear waves do not travel through water, but you can place geophones at the bottom of a shallow body of water. Seismic reflection is often successfully used in embayments to decern deposition and faulting boundaries.
18	I am doing my thesis about the addition of rubber in clay soils, to improve the resistance and permeability on pavements. How useful do you think this will be for pavement improvement?	This question appears to be outside the scope of the webinar (not ABC or geotechnical exploration related).

19	Is there a depth limitation to the CPT (Cone Penetration Test)?	Generally, the depth of penetration is limited by two factors, the inclination of the rods and the ground resistance (from the cone on a hard bearing layer, the accrued resistance along the rods, or a combination of the two). As a practical matter, most CPT (Cone Penetration Test) systems use cables, so there is also a limitation of the length of the cable and the number of rods onboard. Similar limitations exist for borings in that at some point it may be difficult for a drill rig to continue to advance augers or casing or a hole would be limited by the amount of tooling brought to the site. CPT cones typically have an inclinometer so that operators can determine how far off of vertical the cone is. Excessive inclination can increase the likelihood of damage or breakage of the cone or rod string, particularly if the cone is advancing and encounters a comparatively hard layer resulting in lateral stresses (similar to column buckling). With friction reducers and heavy push equipment, in loose sands or relatively soft clays, pushes of over 100 feet are achievable and 200-300 feet are possible.
20	What would be an appropriate geotechnical investigation tool/technique in shallow waters (and shallow bedrock) where it is not practical or cost prohibitive to use a drill rig on wheels/track or on a barge to take soil and rock cores? What would be the cost range for such techniques?	Shallow water poses access difficulties for equipment and barges which require some depth for flotation, as well as for boats maneuvering them into position. Shallow bedrock also poses challenges for anchoring barges into place. Some sites are challenging and require temporary trestles or platforms placed by cranes or even helicopters. CPT (Cone Penetration Test) is not an appropriate tool to characterize rock. ER (Electrical Resistivity) geophysics could be used as it can be deployed from a very small vessel- such as a flat-bottom rowboat. Note that this method would help characterize stratigraphy and potentially reveal information on rock quality (weathering/continuity). Borings would still be necessary unless the rock could be adequately characterized by other methods (test pits or similar techniques).
21	The CPT (Cone Penetration Test) method looks very promising. Is there pushback from clients to utilize/adopt this technology? Are costs	CPT (Cone Penetration Test) is used widely internationally and by many agencies in the U.S., but it has not been as widely adopted in US practice, despite its utility and advantages. Appreciation and acceptance of the technique varies widely. Many consultants prefer the CPT as more high-quality information is provided and it is very useful for computational modeling and assessment of variability. Engineers, practitioners, and contractors who prefer

	comparable to traditional borings? Are geotechs willing enough to adopt it? Are there any significant drawbacks?	"traditional" information of blow-count and soil types or are accustomed to historic practice tend to be late adopters. Today, with more colleges teaching the technique it is becoming more widely accepted, desired, and embraced by new engineers. Some larger consultants were happy to have cone data for large projects 20 years ago. Costs for the equipment and annual consumables are comparable to drilling- but during that same period a smaller crew is often used and more CPT soundings are advanced (3X to 10X more soundings) so there is a significant difference in cost per advance or cost/foot. An investigation program may cost $7k/week and provide 2-3 borings or between 10 and 30 soundings. Added modules for measuring soil resistivity and moisture, seismic parameters, etc. can add additional value. There are still learning gaps among geotechnical practitioners, structural engineers, contractors, construction engineers, and other members of transportation project delivery teams. Education and familiarity are improving. Today, impediments to adoption tend to be related to the need for purchasing new hardware/software, training, or changing specifications to allow more widespread use. It is anticipated that digital plans and digital twins, where information can appear electronically will encourage greater use as there will be less work required to import CPT soundings and the information will be easier to present using multiple colors or plan layers. The drawbacks include: 1) it is a more technical field, requiring computers, cables, and care and handling of equipment. Equipment is more fragile than traditional SPT (Standard Penetration Test) and requires beginning and end of test observations on sensor performance and software/hardware knowledge [compare modern cars with fuel injection compared to carburetors]. 2) the test results provide more information and therefore it is inherently somewhat more complex/confusing to those expecting a single value- like "3" over a 5-foot interval, a CPT test can have several traces with 10's of values each foot. 3) the information is used to express how a soil behaves as opposed to a more traditional grain-sized classification such as clay, silt, or sand (although this isn't much different from reporting a friction angle or cohesion). 4) Some engineers prefer a sample with each measurement afforded by the SPT test, rather than specific targeted sampling with the CPT soil sampler 5) The computers and probes are more sensitive to weather, water, temperature and the elements; procedures and care are more similar to lab tests than field tests in some respects- but this is also indicative of the more lab-like benefits afforded, such as accuracy, precision, repeatability, etc.

22	Besides the seismic word, which are the main differences between CPT (Cone Penetration Test) and a Seismic CPT?	The Seismic CPT (Cone Penetration Test) test uses a probe with a triaxial geophone (a true-interval seismic probe or frequent interval probe has 2, or 3 mounted at distances 1-m, or 0.45 m) apart to provide increased precision in measurements). The typical interval between seismic measurements is 1-m, but they can be conducted more frequently (continuously or "frequent interval" of 0.2m). In addition to the probe, a seismic source is needed and is usually used in conjunction with a wave guide (beam) and automated system to generate the shot/strike. In addition to the standard measurements of tip, sleeve, and pore water pressure, at regular intervals, the operator generates a compression wave or a shear wave and the time is measured from when the system is triggered to when the energy is measured at the geophone locations. The process is repeated at regular increments of depth. With processing, the wave speed- and changes in wave speed are plotted to aid in the interpretation of the stratigraphy and material properties. This additional information is useful for estimating settlement of embankments and shallow foundations, determining seismic site classification, and in providing ground-truth for seismic geophysical site characterization methods.
23	ER (Electrical Resistivity) has been heavily used in the oil industry for decades. Why has it taken so long to bring it to the bridge/transportation practice?	Most geophysical methods require specialized equipment and are somewhat computationally intensive. Oil and gas industries could afford to invest comparatively large amounts of money into both site investigation and processing using geophysical techniques as it was important for their deep-exploration needs. The advantages of near-surface geophysics were somewhat muted by the complexity and limitations of analog equipment. Technology advanced. With the development of digital field systems and with increases in computing power from consumer-grade computers, the utility, ease, and cost of geophysics improved to a degree where the technique is more marketable and cost competitive in transportation geotechnics. Today, many DOTs self-perform and many others have contracts with geology professionals who regularly provide services. The evolution of the technology has made it possible for the technology to be more widely applied- and as more owners are having success, and through technology transfer, these techniques are gaining additional acceptance and owners are starting to allow and/or encourage their use, particularly through alternative delivery projects (proposers demonstrating added value).