BENDER ELEMENT
TEST ANALYSIS
SOFTWARE DEVELOPMENT
FOR LABORATORIES

*Writing for **theGeotechnica** this month are Karl Snelling and Dr Sean Rees, Managing Director and Geotechnical Specialist at GDS Instruments. In this in-depth article Karl and Sean discuss the test analysis software development for laboratories that has been developed to interpret the data from bender element test analysis.*

Bender element testing has become increasingly common-place in soil laboratories since its introduction in the late 1970s by Shirley and Hampton (1978). The test allows straightforward small-strain stiffness measurements to be made in soil specimens, and can be performed in a wide variety of test systems.

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To this day however there is still no recognised standard for interpreting the data obtained from bender element tests. This fact provided motivation for GDS Instruments, who specialise in providing soil and rock laboratory test systems, to help address the main aspect of subjectivity of the test interpretation – the determination of the shear wave propagation time. This resulted in the development of a user-friendly piece of software to automate the propagation time analysis.

How does the bender element test work?

Bender elements are made from piezoelectric ceramic bimorphs, and are used in pairs to measure the shear wave velocity in a soil specimen. This involves inserting each element a small distance into the top and base of a specimen, then applying an excitation voltage to one element to generate a shear wave in the soil, as illustrated in Figure 1.

The other element is used to pick up the shear wave that has propagated through the specimen, with its displacement due to the wave inducing a voltage, which is then read by a data acquisition unit. Through knowing the distance between the two elements, and observing the time required for the shear wave to propagate, a value of the shear wave velocity can be obtained. From this point only the specimen dimensions and soil bulk density are required to produce a shear stiffness estimate.

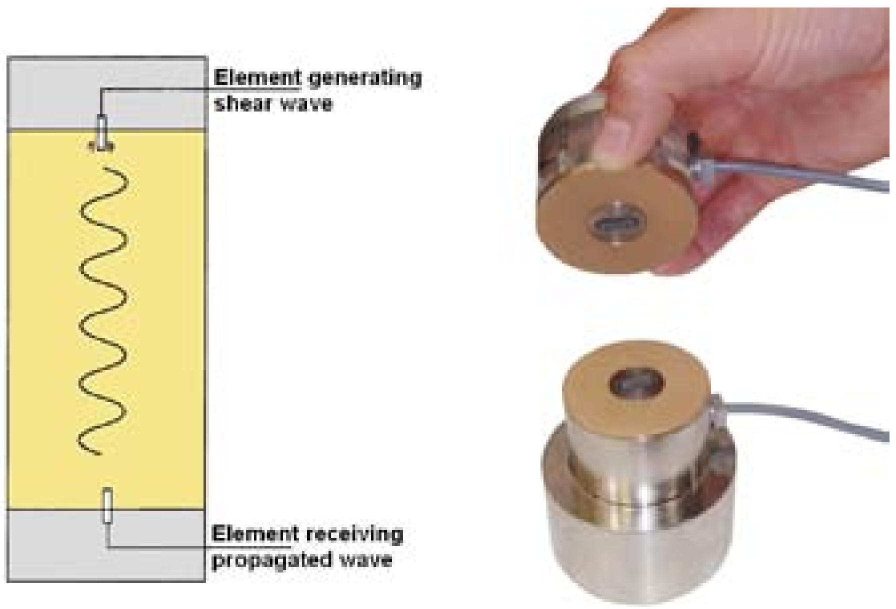

Figure 1 – Illustration of the bender element test (left); GDS bender elements inserted into a triaxial top-cap and pedestal (right).

What complicates the interpretation of bender element test data?

Although the bulk density and distance between elements can be measured accurately in the lab, the time taken for a shear wave to propagate through the soil is somewhat subjective. Consider the idealised received waveform shown in Figure 2 – which point would you say defines the time of shear wave arrival? Further to this, if two engineers agree on using the same point to define the arrival, would they necessarily record the exact same time purely through visual observation of the wave?

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These considerations are of course not recent, with many numerical methods already proposed in the geotechnical literature to objectively determine the propagation time of a shear wave. Such methods typically analyse the test data in either the time or frequency domain, and tend to vary in their complexity.

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However implementing such methods on a routine basis can often be difficult and time-consuming for labs without strong software coding skills, or knowledge of which analysis methods have previously been suggested. The task presented to the GDS team was therefore clear: review the literature, determine the analysis methods available, and develop a simple-to-use software tool that objectively finds the shear wave propagation time in bender element tests.

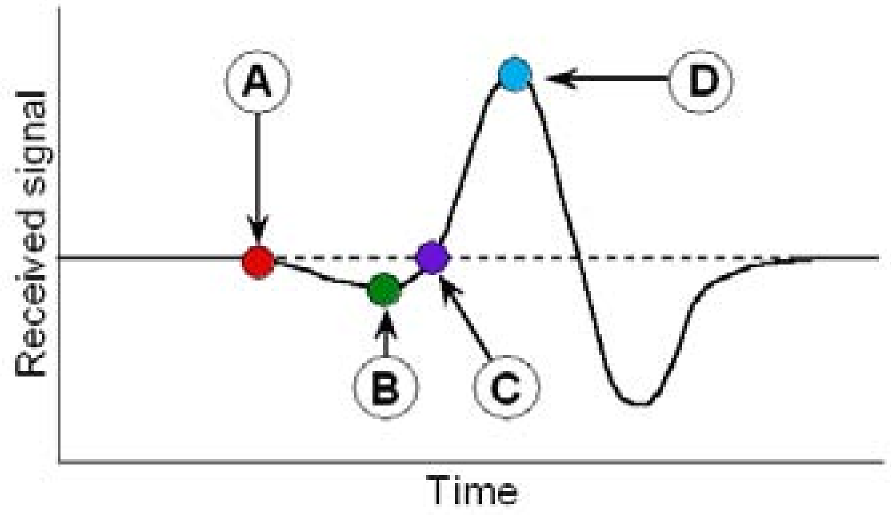

Figure 2 – Idealised shear wave recorded by a receiver bender element.

Development of the GDS Bender Element Analysis Tool

The development process led GDS to create the Bender Element Analysis Tool, or GDS BEAT for short. The tool is unique in that it does not simply settle on one specific numerical analysis method, but instead implements three: objective determination of Point A, B, C, and D via software algorithm, cross-correlation of the generating and receiving element signals, and a cross-power spectrum calculation of the signals to estimate propagation time in the frequency domain. This decision provides distinct advantages to the user, as the hard-work required to process the test data is removed, and a number of propagation time estimates are provided.

Given the tool was developed with the larger geotechnical community in mind, there were two other important specifications: be simple-to-use, and be flexible enough to analyse data taken from any bender element test system, not just the GDS system. Both of these specifications were achieved by using Microsoft Excel as the platform, a piece of software familiar to most practicing engineers. The tool was split into two Excel Add-Ins, each having a specific use – the first allows the user to load one data set into an Excel sheet, then select the various parameter values required to run the analysis, whilst the second permits multiple GDS data files to be simply

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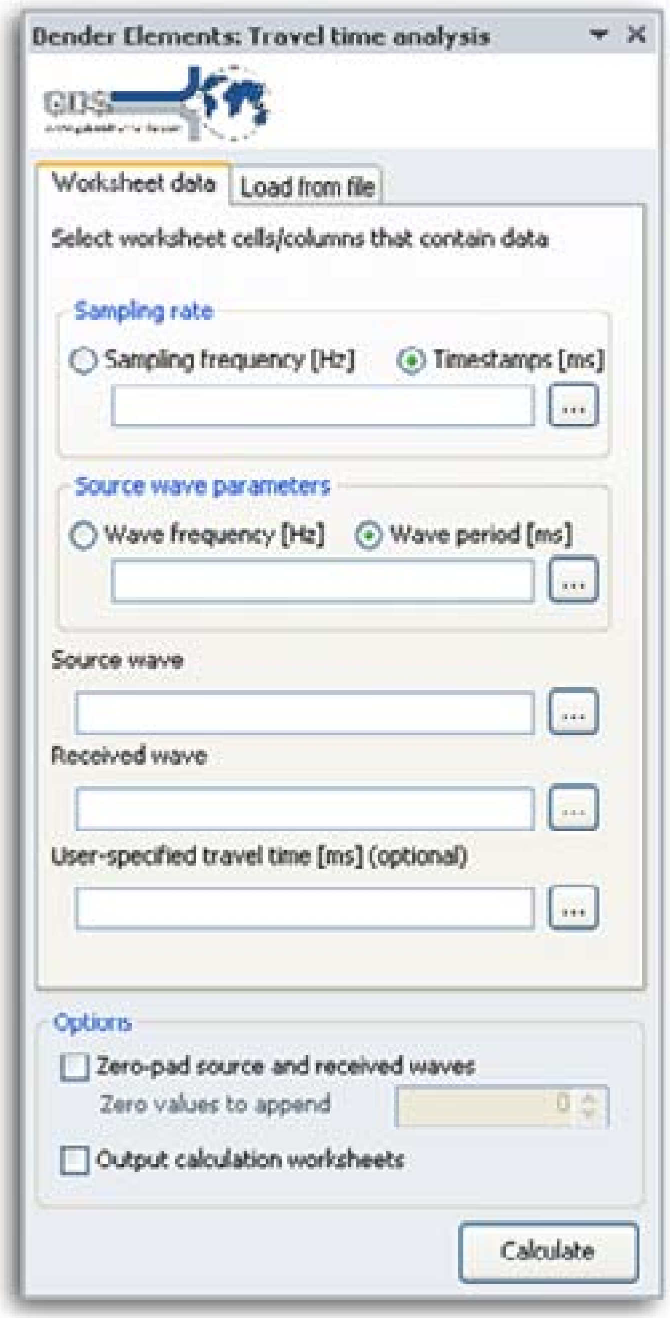

Figure 3 – Screenshots of the GDS BEAT Add-Ins created for Microsoft Excel.

dropped into the tool and batch analysed. Screenshots of each are displayed in Figure 3.

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It was also important to ensure the analysed data was presented in a clear format, both numerically and visually. With this in mind the tool produces two tabs in Excel following the analysis – one listing numerical values of the wave propagation time estimates and analysis metrics, and the other giving visual plots of the recorded element signals relative to the estimated propagation times. Presented in Figure 4, this combination of reporting allows the user to rapidly validate the analysis data, and to further process the information as required.

How well does GDS BEAT perform?

Developing BEAT was the first step for the GDS team, but it was also necessary to verify the software performed as

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specified during testing. A triaxial specimen of Leighton Buzzard sand was therefore prepared in a GDS Dynamic Triaxial Test System (DYNTTS), with bender element tests conducted using a GDS Bender Element System (BES) after saturation and consolidation

Figure 4 – Numerical (top) and visual (base) representations of a GDS BEAT analysis.

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were complete. This quickly showed how useful BEAT may be in laboratories – immediately after saving the bender element data, files were dropped into the tool, with rapid analysis providing on-the-spot estimates for the shear wave propagation time.

While this demonstrated the user-friendly nature of GDS BEAT, further review was conducted post-test to check how accurate the propagation time estimates really were when compared with traditional observation. To do this, the raw test data was sent to an

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academic familiar with bender element analysis, and asked to provide his own estimates by viewing the generated

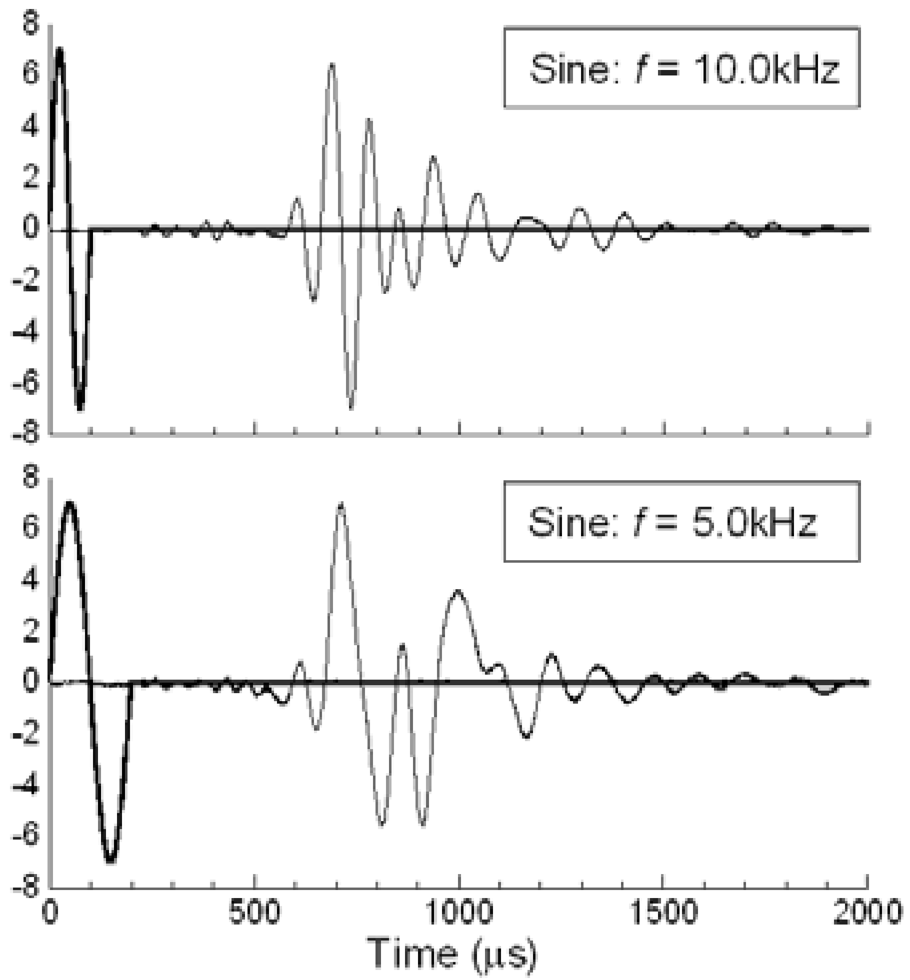

Figure 5 – Leighton Buzzard triaxial test specimen used to verify the performance of GDS BEAT (left); bender element signals obtained from the specimen (above).

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and received waveforms. The agreement between BEAT and the academic was highly encouraging: all but the cross-spectrum analysis method led to shear wave velocities being calculated within a 5 m/s band, which is just 2.2 % of the estimated 225 m/s shear wave velocity, when comparing across a sensible range of shear wave frequencies.

Ultimately GDS hope their new software tool, GDS BEAT, will not only be useful for engineers interpreting bender element data, but will also generate discussion within the geotechnical community and contribute in the move towards recognised test standards. For all those interested, further details and video demonstration can be found by visiting www.gdsinstruments.com, along with free download of the software for a limited time only.

References

Shirley D. J. and Hampton L. D. (1978). Shear-wave measurements in laboratory sediments. Journal of the Acoustical Society of America 63 (2), 607-613.