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Field deployment and response of a shaped DAS fibre loop

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Summary

Multicomponent seismic DAS sensing is possible in principle, assuming one has the freedom to deploy shaped cables in a trench or borehole environment, and assuming both high SNR and low gauge lengths are available. In 2018 a prototype shaped DAS loop/array was deployed by CREWES at the CaMI site in Alberta, to examine whether such sensing is practical in the field with current technology. A shaped loop of fibre (the prototype sensor) was buried and illuminated with a Vibroseis source, and its response was compared to synthetics built from a previously published DAS geometrical response model. Initial conclusions are cautiously positive and are suggestive that DAS fibre, if deployed in regular and well-characterized loops, will be able to produce data in the form of a trace for each of multiple components of seismic strain. Additional validation is required, but further development, including deployment of smaller loops, and less restrictive shapes, is certainly indicated.

Introduction

The potential of Distributed Acoustic Sensing (DAS) technology to support low-cost seismic monitoring has drawn a great deal of interest in recent years (e.g., Daley et al., 2013; Mateeva et al., 2014; Chalenski, 2016). Amongst the issues causing DAS data to differ from standard geophone data is the strong directional response of the fibre, which acts as a 1C sensor measuring strain or strain-rate along its axial direction (e.g., Kuvshinov, 2016). As the angle of intersection of the ray path of a seismic wave and the axis of a DAS fibre varies, the directionality response plays a strong role in explaining amplitude variations. If in addition the fibre is curved, and so has a continuously changing axial (tangent) direction, the amplitude response along an interval of DAS fibre may become quite complex. In 2016/17 a DAS fibre geometry model was introduced to keep track of these geometrical issues (Innanen, 2016). It has been used to discuss distinct fibre responses to body- versus surface waves and microseismic focal mechanisms (Eaid and Innanen, 2018), and it has been coupled to a 3D elastic finite difference model (Eaid et al., 2018) to permit very general forward modeling. The geometrical model also permits the design of shaped DAS fibres for multicomponent sensing to be formulated and appraised (Innanen, 2017). Analysis suggested that this should indeed be possible, given freedom to deploy DAS cables with relatively complex, and well-characterized, shapes, and interrogate them with low gauge lengths. After this theoretical analysis, several largely practical questions regarding the practical possibility of 6C DAS sensing naturally remained. To address these, in 2018 a prototype multicomponent DAS fibre loop was designed and deployed by CREWES researchers at the Containment and Monitoring Institute (CaMI) Field Research Station in Newell County Alberta. In November 2018 CREWES partnered with Halliburton to illuminate the buried loop. The purpose of this paper is to report on the design, deployment, and first shooting into the loop, and our initial data analysis.

Multicomponent DAS fibre loop design and deployment

A double-square pattern was excavated at the CaMI-FRS, with 10m sides and at a depth of approximately 2m (Figure 1). This permitted loops of fibre to be buried such that they occupied continuous 10m intervals with fixed axial directions. Each new direction occupied by the loop supplies a projection of the seismic strain tensor. Imagining such a tensor resolved into two lateral coordinates and one depth coordinate, our design covers the former but not the latter, so we can expect it to shed light on only 3 of the 6 independent strain components of an incident wave. The corners of the buried loop were carefully surveyed, as the precise geometry of the loop intervals is needed to interpret any measured seismic amplitudes (Figure 2).

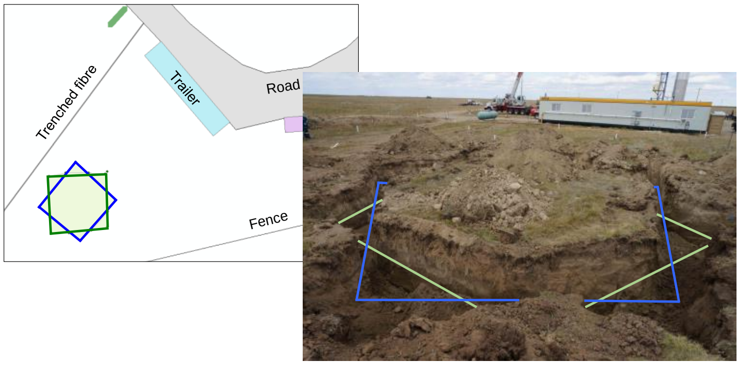

Figure 1. *A double-square pattern was excavated to a depth of 2m and two loops of straight and helical DAS fibre were buried, providing good lateral (though incomplete vertical) directional coverage.*

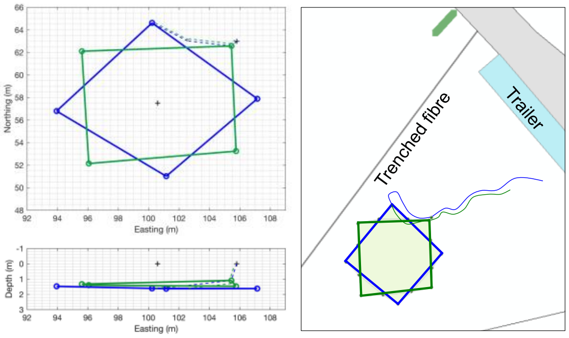

Figure 2. *The corners and crossover points of the buried DAS fibre were carefully surveyed to permit the amplitude response to be modeled. Top left: plan view; bottom left: profile view; right: deployment sketch. For reference the squares are indicated with blue and green.*

Acquisition

The DAS loop was illuminated by 10-150Hz Vibroseis sweeps from each of four vibe points between 0-60m from the centre of the array. Ten sweeps were stacked at each vibe point. A vibe point 30m to the north of the centre of the array was selected for detailed initial analysis. To supplement the fibre response, 3C geophones were deployed on the surface above each of the 8 corner points and at the centre. The DAS data were acquired with a 5m gauge length.

Initial results

The data were processed to a channel spacing of 1.02m, after which direct elastic arrivals were clearly visible in the shot record (Figure 3), including the first-arriving P-wave. The size of the array (chosen to accommodate gauge lengths of up to 10m) meant that it would not act as a point sensor, and indeed arrival time differences across the loop are noted. A synthetic record made using the CREWES DAS fibre geometry model (Figure 4) provides some context for the other features of the signal. The bright versus dim regions of the response (e.g., at fibre arc length positions 170m and 190m respectively) are evident in the synthetic and field records, and are clear indicators of the directionality response of a P-wave interacting with distinct intervals of the prototype sensor loop. The geometrical model also keeps track of the sense of the fibre, predicting positive and negative polarities for the strains sensed away from and towards the interrogator; these generally do not appear in the actual data, and must be corrected for. What we seek in the comparison between the synthetic and the field data is evidence that the amplitudes arriving at any given moment match those predicted by the geometrical model; thus when they are inverted (Innanen, 2017) reliable estimates of the strain tensor components in a field coordinate system may be determined. First analysis is suggestive that this has been achieved.

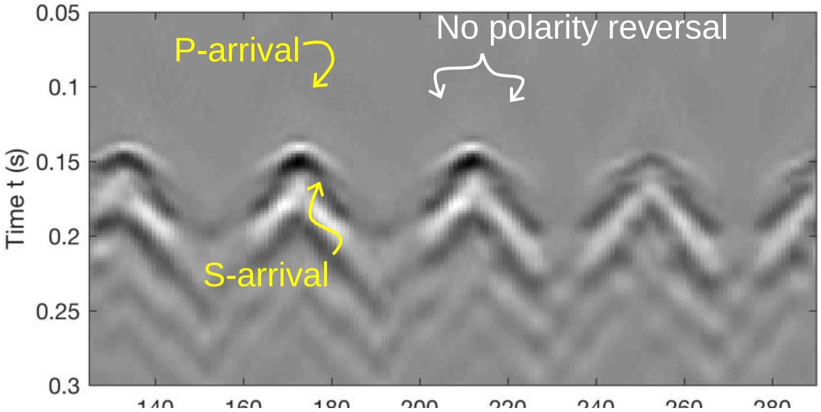

Figure 3. *Raw shot record acquired from the prototype DAS fibre loop. Moveout across the straight segments of the squares is visible, with the early arriving peaks occurring where the fibre loop makes its closest approach to the source. P-wave energy arrives first, followed by S-wave and surface wave energy.*

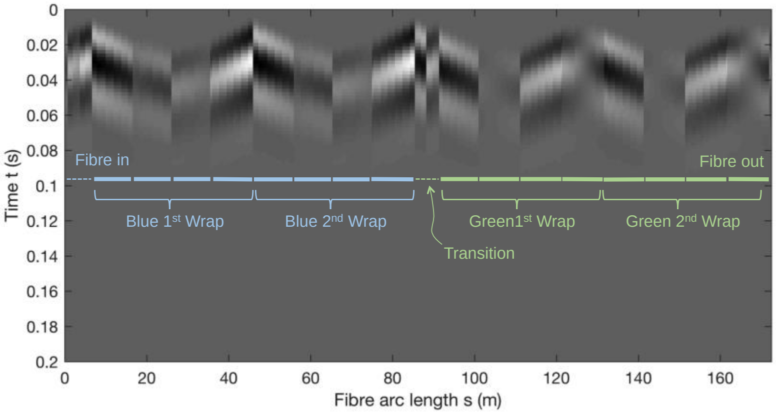

Figure 4. *Synthetic shot record computed using CREWES DAS geometric response model. Superimposed are the "unwrapped" segments of the prototype fibre loop (blue versus green). Amplitude variations based on fibre directionality match closely with those measured in the field (Figure 3). Both arrival times and arc-lengths differ from the field response by constant shifts; also note absence of polarity reversals in the field data.*

Conclusions

Our initial conclusions are cautiously positive. The results are suggestive of the ability to use the amplitudes produced by the fibre loop to back out a set of traces corresponding to 3 of the 6 independent components of strain arriving at the loop from the seismic source. Several processing steps must be undertaken to further establish and implement this. The strain arriving at the fibre loop must be processed to correct for moveout, so that amplitudes at each point in the buried loop arriving at a given instant are attributable to a single strain tensor. The 6C estimation scheme must be reduced to the corresponding 3C lateral subset, as depth components are not resolved by the loop. To complete the validation of the loop, the geophone data should be processed to provide independent confirmation of the amplitudes arriving at the loop.

Beyond this continued analysis of the response of the prototype loop in its current form, several avenues for future research are identifiable. Several vendors are able to provide gauge lengths at and below 2m, which opens the possibility of deploying smaller versions of shaped loops. This in turn means that they will be more straightforwardly treatable as point sensors (depending on dominant wavelengths within the seismic waves), and that fibre intervals oriented in depth can also be included, doubling the number of available strain / strain-rate tensor components to the full six.

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