Advantages of wet work for near-surface seismic reflection

Summary
Benefits of shallow water settings (0.1 to 0.5 m) are pronounced on shallow, high-resolution seismic reflection images and, for examples discussed here, range from an order of magnitude increased signal-to-noise ratio to resolution potential elevated by more than 8 times. Overall data quality of high-resolution seismic reflection data at three sites notorious for poor near-surface reflection returns was improved by coupling the source and/or receivers to a well sorted and fully saturated surface. Half-period trace-to-trace static offsets evident in reflections from receivers planted into a creek bank were eliminated by moving the geophones to the base of a shallow creek at the toe of the bank. Reflections from a dipping bedrock were recorded with a dominant frequency approaching 1 KHz from hydrophones in 0.5 m of water at the toe of a dam using a hammer impact source. A tamper impacted by a dead blow hammer in a shallow (10-20 cm) deep creek produced reflections with a dominant frequency over 400 Hz at depths as shallow as 6 ms.

Introduction
It has long been known that increased saturation in a fine grained and well sorted near-surface setting greatly enhances the overall quality and therefore usefulness of both shallow and high-resolution seismic reflection data (Pullan and Hunter, 1990). Great success has been realized using high-resolution seismic reflection to map hydrostratigraphic units by coupling both source and receiver at the base of an irrigation channel or shallow body of water (Whitely et al., 1998; Good et al., 1999). In situations where interpretable and accurate high resolution data is absolutely essential and cost is no object, increasing saturation of the source and receiver coupling zone has been accomplished artificially by building and flooding a seismic trench (defined here as a trench constructed specifically for improving the quality of seismic reflection data) (Kim, 2001; Miller et al., 1994).

Improving source and receiver coupling has long been known to have a direct and positive affect on seismic reflection data characteristics (Miller et al., 1994; Hoover and O’Brien, 1980; Krohn, 1985). The degree to which data can be improved by optimizing the type of source or site preparations is limited for many sites. However, altering survey designs to less than optimal locations for achieving project goals, but dramatically improving the data quality should at least be considered for any shallow, high-resolution seismic reflection survey.

Natural changes in saturation have proven to affect the amplitude and bandwidth of shallow reflections (Jefferson et al., 1998). Seasonal changes in soil saturations of less than 50% increase the amplitude of higher frequency components of the seismic reflection wavelets by almost an order of magnitude. It is also noted that narrowing of the bandwidth can result from seasonal increases in soil moisture. A principal question that this work addresses is how much improvement can be actualized by acquiring seismic reflection data in fully saturated soil layers in comparison to equivalent dry near-surface soils. As well based on previous work it is imperative to ascertain if there are any adverse affects on data quality as a result of using ground contact impulsive and explosive sources and land geophones in water settings.

Figure 1. (a) 12-gauge Seisgun with some receivers fully submerged and others planted into the creek bank, less than 0.25 m for static water levels. (b) Hammer and tamper data with receivers all on creek bank highlight the extreme 180° phase mismatch in some locations due to static that at over 400 Hz is a problem on shallow reflection data where a 50 Hz conventional would represent less than 15° phase shift.
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Data Acquisition

Data for these studies were acquired along and within the shoreline of creeks and lakes. Investigations of geologic and hydrologic features at the toe of a dam and beneath a creek provided the opportunity to optimize data quality by slightly realigning pre-acquisition designed profiles. In one study, original survey designs called for seismic profiles to run along the down stream toe of a dam to characterize the potential of sediments to anchor the cutoff trench for a new dam. As well, at another site a planned seismic profile was to run between a creek and parking lot on a layer of rubble and other assorted fill materials ranging in depth from a meter to as much as 3 meters. Neither setting was optimal and both would likely have failed the pre-survey evaluation testing of technique feasibility. As it turns out moving the lines into saturated environments notably increased acquisition time but more dramatically and importantly improved data quality and therefore greatly benefited to overall project goals.

Hell Creek

Static problems in near-surface data can be debilitating and because of the higher frequency content of most these data the percentage of phase misalignment due to variation in near surface velocities can be in excess of 100% (Frei, 1995). A shot gather with a portion of the receivers planted under about 20 cm of water at the base of the bank line (due to surface obstacles) dramatically depict just one of the problems routinely encountered during CMP processing of high-resolution seismic reflection data (Figure 1a). With reflections posing dominant frequencies in excess of 400 Hz static of just an ms of variability in arrival time from trace to trace due to lateral changes in velocity can significantly reduce the quality and usefulness of a CMP stacked section (Figure 1b).

Shot gathers acquired from receivers beneath a few tens of centimeters of standing water retain a strong ground roll component, easily saturating close offset traces partly due to reduced attenuation in the saturated soils. With reflection from the shallowest interface possible as important as high amplitude coherent events from depth (30 m), two shot records were recorded at each station. One was recorded using a 12-gauge Seisgun pushed into the firm, saturated creek bottom and a second using a dead blow hammer impacting the top of a 1.2 m long soil tamper. The gun source generated high amplitude reflections with deeper penetration in this noisy setting (major street within 50 m) (Figure 2a). While the impact source was much less energetic and allowed reflections to be recorded in un clipped portions of the record as close as 2 m from the source (Figure 2b).

Reflections from a time-depth of around 6 ms are clearly and confidently interpretable on a high percentage of shot gathers recorded using the impact source (Figure 3). Recording, identifying, and enhancing reflections arriving at times less than 30 ms is extremely difficult and has been the reflection time window most commonly abused by inexperienced practitioners through over processing, inappropriate processing, and miss interpreting coherent source noise. Clear separation between first arrivals and reflections and unique ground roll energy provides a wedge shaped optimum window that includes about 5 traces (4 m) and 5 ms above 10 ms two way travel time on many shot gathers.

Spectral characteristics of the gun and hammer sources are very similar in spite of the more than 60 dB difference in reflection amplitudes and around 48 dB difference in ground roll (Figure 2). Increased source energy usually brings decreased dominant frequencies (Knapp and Steeples, 1986). Near offset traces are clearly clipped within the optimum window for reflections less than 15 ms two-way time on the gun data (Figure 2a). Processing this clipped portion of the record would result in coherent noise events that could be interpreted as reflections with these coherent events on CMP stacked sections having no relationship to real reflectors. Reflection bandwidths from these data span more than three octaves, with lowest useable around 30 Hz and upper corner more than 600 Hz. Considering receivers were 40 Hz geophones, some question remains as to how faithfully the signal was received by these sensors.
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Keechelus Dam

Sites with near-surface unsorted glacial outwash have been extremely difficult and at times impossible to image with high-resolution seismic reflection. Complicating the Keechelus Dam site were the physical presence of the dam itself and the dry near surface along the majority of the target transect. As part of the feasibility testing a hybrid land/marine spread was recorded from that incorporated active pressure transducers and a hammer impact source. Data recorded in 0.5 m or less of water on the upstream side of the dam toe possessed reflecting events with wavelet properties and therefore resolution potential and signal-to-noise ratio at the extreme limit of any data currently in the published literature (Figure 4).

An impact source in contact with boulders along the lake bottom resulted in highly irregular shot gathers along the spread, but clearly demonstrated extreme potential for this otherwise poor seismic reflection area. Low cut filtering provided clear separation between the groundroll and reflection wavelets (Figure 5). Vertical stacking improved the signal-to-noise ratio for stack counts up to about 8. Too much high frequency reflection energy in this setting can be a hindrance to CMP stacking. With the fractional millisecond accuracy necessary to get almost 1 KHz wavelets to stack coherently processing of these data to maintain this very high resolution potential would introduce a completely new set of challenges.

Observations

As is no surprise keeping the source and receivers in a fully saturated environment dramatically reduces problems with statics and boasts the dominant frequency and useable bandwidth. Improvement in spectral characteristics and signal-to-noise ratio was significantly beyond expectations when receivers were changed from magnet and coil geophones to active hydrophones. Using an impact source with low energy output was effective when coupling through the upper half meter was made using solid rock emplacements.

Dramatic increases in energy levels (>24 dB) generally comes at the price of reduced upper corner and dominant frequency. Clearly for the creek saturated setting an insignificant loose of reflection wavelet spectral properties was observed with this relatively massive increase in source energy between the Seisgun and hammer/tamper configuration. This increase in source energy equated to approximately an order of magnitude increase in recorded body wave energy. Signal from the receiver in the saturated portion of the seismogram yielded some of the shallowest time reflections documented in the literature.

Figure 3. Raw shot gathers from different locations along the profile. Clipping of groundroll observed on a few inside traces occurred at the receiver. Clipping of other energy is the result of elevated display gains. Reflections can be interpreted on these unprocessed shot records as shallow as 6 ms.

Figure 4. Raw shot gather acquired with hammer impacting steel rod and active pressure transducers.
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Figure 5. Vertically stacked shot gathers comparing two (a), eight (b), and thirty-two (c) impacts from 12-oz hammer on steel shaft in 0.5 m of water.

Figure 6. Four-shot vertical stacked shot gathers south to north (a) and north to south (b) with trace 1 the same station for both gathers. Source was a 12-oz hammer impacting a steel rod in 0.5 m of water with active hydrophones as sensors.

Conclusions

High-resolution shallow seismic reflection surveys have met with mixed results in settings with dry, unconsolidated, unsorted near-surface settings. Here examples are presented where seismic reflection holds substantial potential to resolve key issues when line locations and deployment schemes are modified slightly and take advantage of shallow (< 0.5 m) water environments. Using land equipment and techniques in saturated settings minimizes cost while maximizing data potential.

Reflections with dominant frequencies over 500 Hz from time depths as shallow as 6 ms were recorded in locally saturated environments where just a few tens of meters away in the absence of standing water seismic reflections possessing dominant frequencies less than 80 Hz are not interpretable above 50 ms. Potential for studying dams and dikes along the base of the upstream slope yet over the toe is quite high, with only slight operational modifications away from routine high-resolution, shallow reflection surveying techniques.

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REFERENCES