Field & laboratory calibration of impact plates to measure coarse bedload

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ABSTRACT: During 2008-2009, an array of impact plates instrumented with either accelerometers or geophones was installed over a channel spanning weir in the Elwha River in Washington, USA. The impact system is the first permanent installation of its kind in North America. The system was deployed to measure the coarse sediment transport evacuated from two reservoirs following the removal of the upstream Elwha and Glines Canyon dams. It has been estimated that, collectively, 21 million m^3 of sediment was accumulated in the reservoirs (Hilldale et al. 2015). The focus of this manuscript is to discuss recent studies to better understand signals generated by accelerometer plates. Calibrated accelerometer plates will provide additional means to obtain a surrogate measurement of the mass of coarse sediment load passing the weir and potentially measurements of particle sizes in transport. A basic description of recent in-situ and laboratory experiments including data processing methodology will be discussed.

1 INTRODUCTION

Measurement of the transport of accumulated sediments released after dam removal is essential to assess the effectiveness of the evacuation of stored sediment and subsequent downstream channel change. Coarse sediment is largely responsible for the Elwha River morphology and will persist in the system longer than finer particle fractions. Continuous bedload data can be used to improve the planning of future dam removal projects, particularly where stored sediment will not be excavated, but allowed to be eroded through natural processes. The Elwha River inflows from the north in the Olympic Mountain range in Washington and terminates at the Strait of Juan de Fuca. The Elwha River is supplied with a combination of snowmelt, rainfall, and groundwater discharge (Curran et al. 2009). See Figure 1. Annual precipitation in the basin ranges from 560 cm in the upper basin (elevation 1350 m) to 140 cm near the mouth (elevation 0 m) (Munn et al. 1998). Additional details regarding the Elwha River impact plate system can be found in Hilldale et al. (2015) and Hilldale (2015).

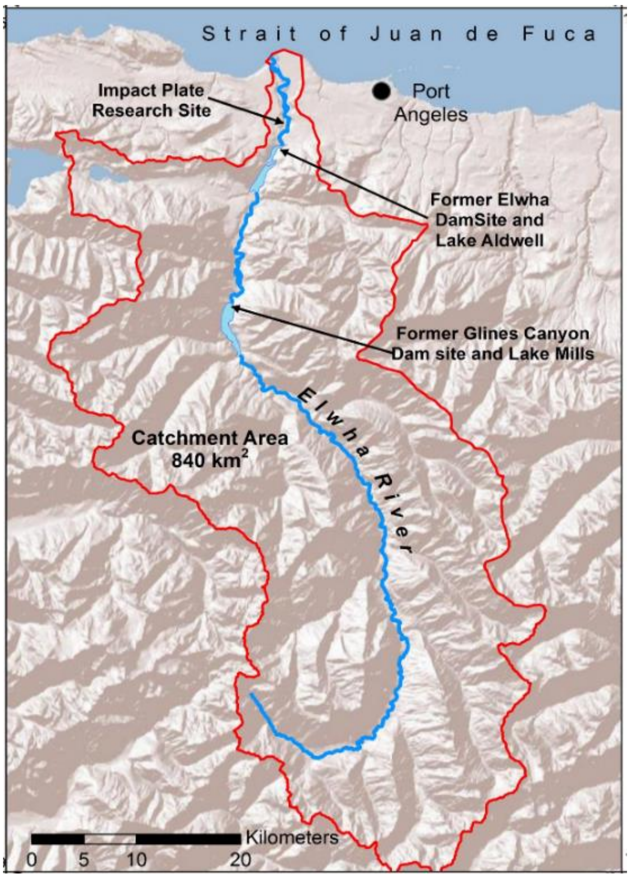

Figure 1. Map of the Elwha River.

Using the impact plate system, bed load transport is monitored at a location approximately 5 kilometers upstream from the mouth of the river. Locations of the former Elwha and Glines Canyon Dams are 2.9 km and 16.6 km upstream from the location of the impact plates, respectively. Gauged bedload on the lower Elwha River in year 2 of dam removal was 450,000 ± 360,000 tons using only the 46 geophone equipped plates (Magirl et al. 2015). Bedload was not quantified in year 1, but qualitative observations using bedload-surrogate instruments indicated detectable bedload starting just after full removal of the downstream dam (Magirl et al. 2015).

The testing and calibration of the accelerometer equipped impact plates installed on the Elwha River began in the spring and summer of 2015. Both laboratory and field testing studies of the accelerometer plates are ongoing to develop calibration which can supply additional information on bedload transport to supplement the data being collecting with the geophone plates. In addition to simple measurement of bedload with accelerometers, determination of particle size is also being pursued.

2 BACKGROUND

The impact plate system installed on a weir upon the Elwha River was modeled after the Swiss impact plate system (Bänzinger and Burch 1990; Rickenmann and McArdell 2007). This type of impact plate system has been installed in many locations in Switzerland, Austria, and Israel (Rickenmann et al. 2013). At the time of installation, it was thought that the accelerometers might provide more complete information on the transport of bedload on the Elwha River than simply the mass data, which would likely be available from the geophone equipped impact plates. Upon successful completion of the accelerometer testing and calibration, surrogate bedload measurements with the Elwha River impact plate system will likely consist of information on mass of bedload in transport as well as the sizes of bedload in transport on the Elwha River.

The manuscript provides details of in-situ testing for sensitivity and minimum particle size detection and laboratory experiments for correlation between accelerometer signals and measured bedload.

3 METHODOLGY

3.1 *Description of impact plate system installed on the Elwha River*

As discussed in Hilldale et al. (2015), the Elwha River impact plate system consists of 72 instrumented stainless steel plates spanning the entire 36 m wide channel. Each plate is 15.9 mm thick and measures 349 mm in the streamwise direction and 517 mm in the lateral dimension.

The plates are mounted to a steel channel that is affixed to the downstream side of the concrete weir. The steel channel houses wiring and provides physical support for each of the plates. The plates are acoustically isolated with a rubber membrane to inhibit structural vibration transmission between adjacent plates. In addition, the 6.4 mm gap between the adjacent plates and the longitudinal steel housing is filled with silicone to prevent infilling with sand and small gravel that could also transmit vibration between the plates. Downstream of the weir is an engineered riffle designed to facilitate fish passage. The engineered riffle is 200 m long with a 1.5% slope. Of the 72 plates, 46 are instrumented with a geophone (Geospace, 20DX) and 26 are instrumented with an accelerometer (STI, CMCP-1100). Each sensor is mounted to the underside of the plates in the geometric center using threads cut into the plates (Figure 2).

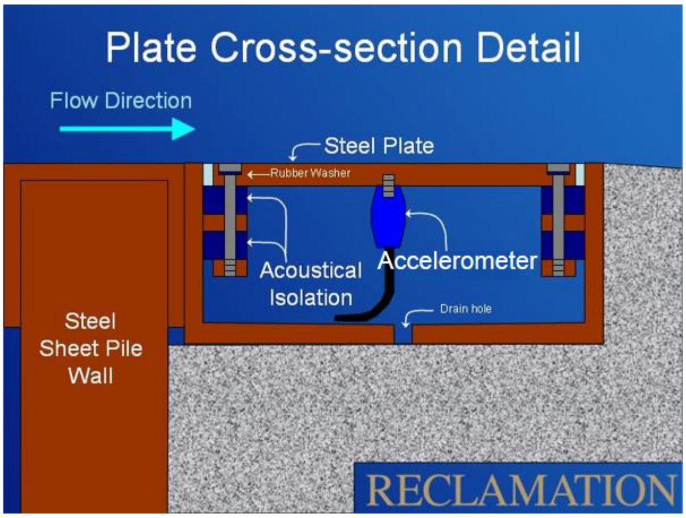

Figure 2. Illustration of the accelerometer mounted to the impact plate in the channel.

Wires are routed through the steel channel beneath the plates to the top of the surface diversion structure on river right. The wires terminate at an instrumented housing unit equipped with computers collecting and managing the data using National Instruments LabVIEW software and hardware. The data are routed to a series of National Instruments DAQ chassis with each chassis cross-referenced to a corresponding computer. The data on the computers and the selection of acquisition parameters can be accessed and managed remotely. The configuration of the impact plate data acquisition system is illustrated in Figure 3. The accelerometers are designated as “A” and the geophones are designated as “G”.

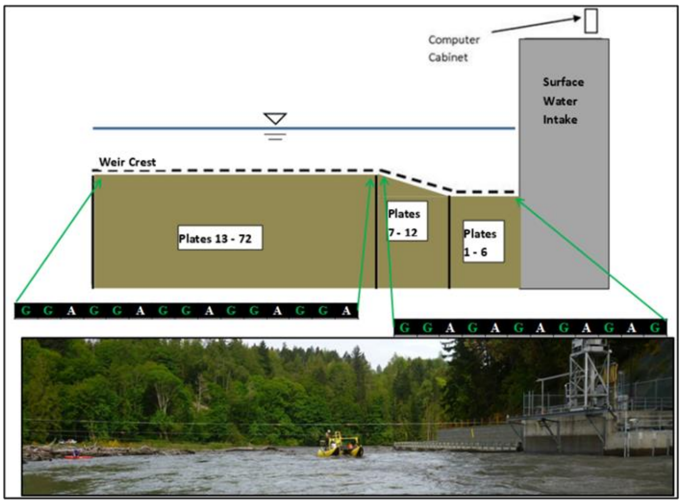

Figure 3. Diagram of the impact plate configuration and the weir looking downstream. Surface water intake structure on river right.

3.2 *Laboratory flume tests of the accelerometer plates*

Flume testing was performed at the USDA-ARS-National Sedimentation Laboratory located in Oxford, Mississippi. The work was performed to help establish a calibration technique, including data processing methodology, for relating accelerometer signals caused by impacts of gravel on the instrumented plates to the mass and potentially, the size of the transported material. Full scale replica impact plates were manufactured, configured, and mounted at the downstream end of the flume channel in a manner similar to the specifications of the Elwha River installation (Figure 4). Bedload flux was measured immediately downstream of the impact plates using a two automatic weigh pans designed by researchers from the Saint Anthony Falls Hydraulic Laboratory, University of Minnesota.

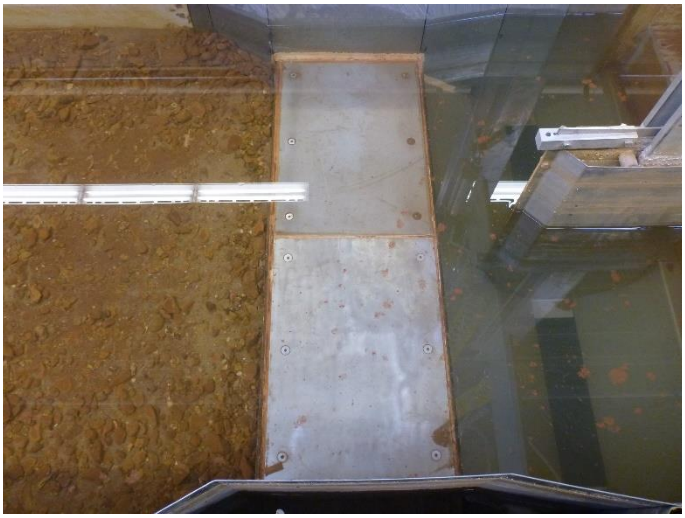

Figure 4. Instrumented impact plates installed in flume at USDA-ARS-NSL. Sediment sampling weigh pans are at the right of the photo with the 2-plate impact system in the center. Flow is from left to right.

The flume tests were conducted over a wide range of flow rates and entrained sand (D_{50}≈0.6 mm) and gravel (D_{50}≈16 mm) while accelerometer acoustic data was recorded. During measurement intervals, physical samples of transported gravel were collected in addition to the acoustic data. The physical samples were dried, sieved, and weighed to obtain a total mass > 4mm for each measure period. The bedload sediment and acoustic data were collected over periods ranging from 10 – 30 minutes depending on the transport rate of the sediment in the channel.

Figure 5. Gravel traps sampling particle size and mass. The sampling box shown is made from a metal screen material with 4 mm round holes.

The movement of the particles over the impact plates was found to range from single impacts to sequential signal data (i.e. rolling particles). Because the signals are discontinuous, non-linear, and non-stationary, it is necessary to employ a filtering technique to identify individual particle interactions. By selecting a moving average of the raw data and performing a Hilbert-transform, packets of data above a detection threshold can be analyzed over their respective time domains. The raw data can be segmented over these time domain packets to estimate individual impacts with corresponding instantaneous frequency and amplitude values. The sum of the peak heights can then be compared to the total mass.

3.3 *Elwha River calibration experiments*

During low flow conditions in September 2015, a negligible amount of bed material was mobile during the time of testing. Native bed material at the site was sieved and separated into the following classes: 4 – 8 mm, 8 – 16 mm, 16 – 32 mm, and large gravel less than 128 mm. The material was carried upstream of the impact plate array and released by hand allowing the current to carry the sediment across selected plates to simulate natural sediment transport. Signals from the corresponding plates were monitored in real-time for activity and files were recorded to the computer. From empirical tests, it was determined that the noise floor of the accelerometers is 10 mV_p (Figure 6).

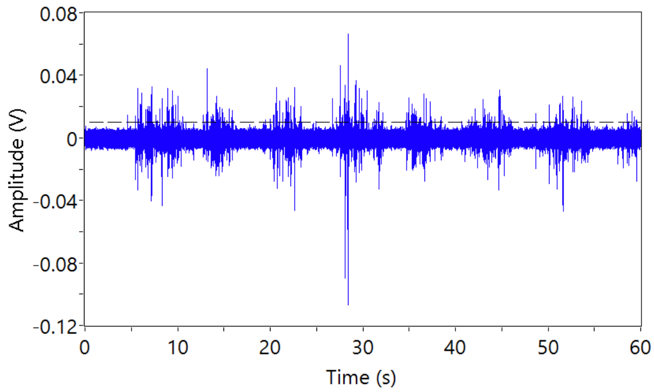

Figure 6. Raw signal from accelerometer in the 8 – 16 mm size range (Plate 40 in the Elwha River impact plate array).

The accelerometers can detect larger gravel particles as well without saturating the maximum voltage of the accelerometer. The peak voltage detection of the accelerometer plates is ± 1V, indicating that this result is well within the voltage range of the device (Figure 7).

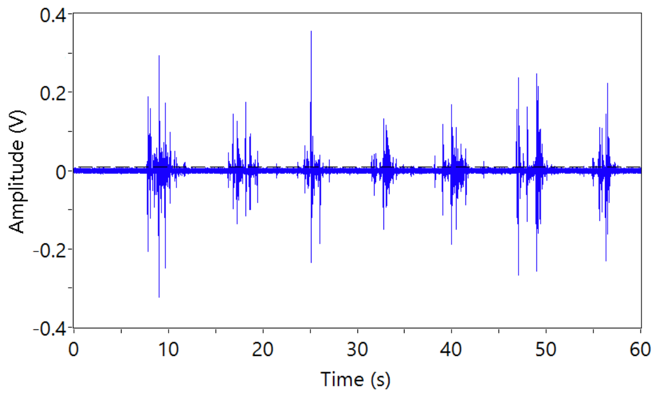

Figure 7. Raw signal from accelerometer in the 32 – 128 mm size range (Plate 40 in the Elwha River impact plate array).

In contrast to the accelerometer data, the geophone equipped plates show that the raw signals are much less sensitive and have a lower noise floor, allowing for the threshold to be decreased to 2 mV_p.

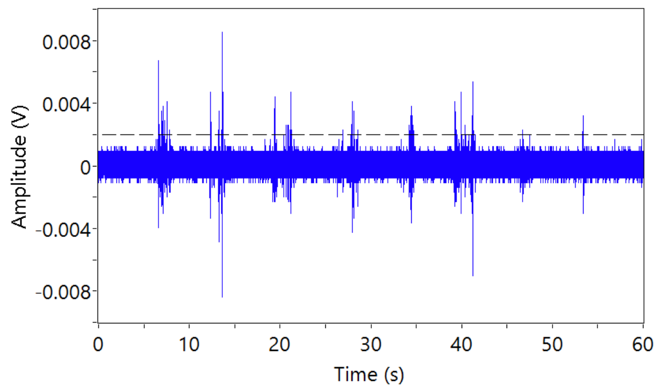

Figure 8. Raw signal from geophone in the 16 – 32 mm size range (Plate 50 in the Elwha River impact plate array).

The Hilbert Transform was applied to the accelerometer plate data, which was then smoothed using a 100 point moving average. By applying a threshold, packets of data were detected to represent the impact of gravel particles. Figure 9 shows the relationship over a 50 millisecond time window to illustrate individual packets.

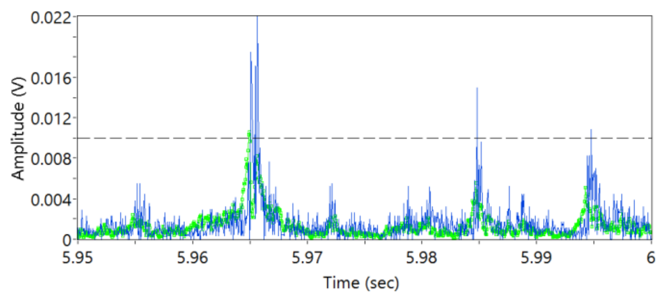

Figure 9. Raw data from accelerometer in the 8 – 16 mm size range overlaid with corresponding Hilbert transformation (Plate #40 in Elwha River impact plate array).

The maximum values of the raw signal within each Hilbert Transform packet were identified and summed over a time increment corresponding to the physical sample collection, which created a data set that could be used to related total transported mass of sediment to accelerometer data.

As shown in Figure 6, it was concluded that the accelerometer plates are capable of detecting particles in the 8 – 16 mm size range. It is highly probable that the accelerometers could also detect the upper end of the 4 – 8 mm size range. This is a significant improvement over the geophone instrumented impact plates, which cannot reliably detect particles < 16 mm.

4 RESULTS

Laboratory results show good correlation between the sum of the peak height voltages and the total mass of the coarse sediment transported over the impact plates. The Hilbert transform was used to establish an envelope of the data from the accelerometer, and data from gravel impacts was identified using an appropriate amplitude threshold. The sum of the peak heights related well to the total mass of transported material that was collected in a trap just downstream of the impact plate over the same time period (Figure 10).

The minimum detectable particle size may be less than 8 mm for lab-collected data. However, the increased noise in the Elwha River system may prevent detection of particles < 8 mm. This remains an ongoing issue to be resolved as more work is completed to obtain a field calibration of the accelerometer plates.

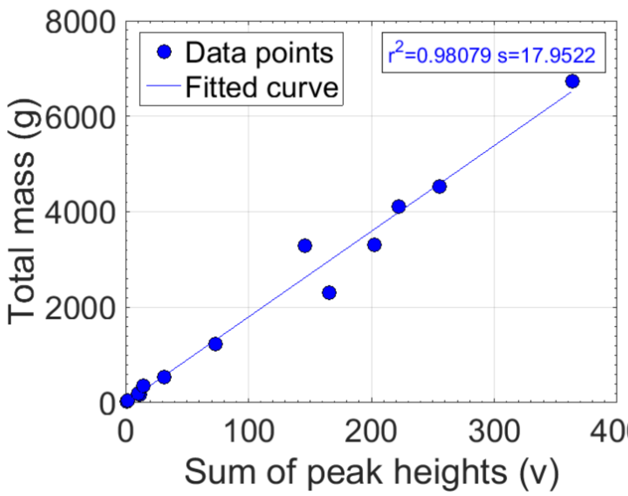

Figure 10. Linear correlation of total mass and the summation of peak height voltages resulting from the lab experiments

5 CONCLUSIONS AND FUTURE WORK

A preliminary calibration relation for the accelerometer equipped impact plates installed on the Elwha River was developed using data collected in the laboratory and the field. The calibration is based on relating the sum of the peak heights in the filtered signal to the mass of the transported gravel. The result showed a strong relationship between summed peak signal and total transported mass in a laboratory flume.

Noise floor in the laboratory was less than at the field site. While motor noise in the laboratory was evident, the accelerometer impact plates in the laboratory had a better overall signal to noise ratio than their accelerometers impact plate counterparts on the Elwha River in spite of low flow. Further investigation can compare signal to noise ratio on the Elwha River over the same impact plate during high flow and low flow conditions.

During the work on correlating particle mass and the sum of peaks from accelerometer impact plates in the flume, it was observed that there was a range of peak heights in the signal. One avenue that will be pursued in the future is relating the distribution of peak heights to the size distribution of particles in transport. Particles transported over the plates during the laboratory experiments were trapped and sieved, providing a data set that can be used to develop a relationship between accelerometer signal characteristics and particle size.

Future work will also focus on field calibration of the Elwha impact plates using physical samples of bedload related to coincidently collected impact data as described in Hilldale (2015). This data collection effort will provide the first field calibration of the accelerometers plates and additional data to strengthen the correlation between the plates and physical measurements developed using data collected in a laboratory flume.

6 REFERENCES

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