

Tanana River Hydrokinetic Energy Test Site Debris and Foundation Study



Jack Schmid

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SUMMARY REPORT

PROJECT TITLE: Tanana River Hydrokinetic Energy Test Site Debris and Foundation Study

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RECIPIENT: Institute of Northern Engineering
University of Alaska Fairbanks
451 Duckering Building
Fairbanks AK 99775-5880

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PROJECT LEAD: Jerome Johnson, Research Professor, Institute of Northern Engineering, UAF

OTHER PARTICIPANTS: Jack Schmid, Alaska Center for Energy and Power, UAF
Jon Holmgren, Jon's Machine Shop

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Introduction

One of the challenges of generating electrical energy with a hydrokinetic turbine in Alaska rivers is the detrimental effect of woody debris in the water column. In order to mitigate this problem the questions of describing what types of debris might be encountered, the frequency of occurrence, the force of impact, and location in the water column need to be answered. The University of Alaska Fairbanks (UAF) Alaska Hydrokinetic Energy Research Center (AHERC) designed, constructed, and tested a mechanical debris detection device (MDDD) for Ocean Renewable Power Company (ORPC). The MDDD was intended to be deployed in the Tanana River at Nenana, Alaska, to assess the debris conditions at the location and depth at which ORPC was planning to deploy a hydrokinetic turbine demonstration project. The MDD was mounted on ORPC's anchoring system that was designed to hold their turbine support structure in place during turbine operations. Due to difficulties in trying to deploy the anchoring system the MDDD was not deployed during the project period. This report summarizes the design, testing and operating instructions for the MDDD. Technical specifications and information are contained in the appendices.

1 MDDD overview

The design, construction and deployment of the MDDD were a preliminary effort to monitor debris in the water column. The system consisted of two vertical steel spines deployed under water that would register impacts, yield to excessive force, be self-clearing and automatically return to a normal configuration after self-cleaning. The spines were instrumented with strain gages, to evaluate forces, and inclinometers to monitor the position of the spines.

1.1 MDDD (design and mechanical apparatus)

The system design evolved from discussions in the AHERC group and Jon Holmgren and with ORPC engineers about the nature of debris in rivers. How debris might be detected and how to quantify the effects of debris impacts with the limited available funding. Some of the major criteria for a system were:

- Ability to survive large debris impacts
- Have some self-cleaning capability
- Record time and magnitude of impacts
- Maximize resolution in determining location of a debris impact on a detection device

Preliminary and finalized designs were socialized with ORPC personnel for feedback. The final plan was to construct a pair of devices to be mounted on ORPC's anchoring system designed to secure the ORPC RivGen bottom support frame. This anchor was modified to accommodate the pair of debris detection assemblies (figures 1 and 2)

The MDDD consisted of a pair of vertical steel spines approximately 2 meters long with a square cross section of 2.5 cm x 2.5 cm. Each spine was equipped with two strain gages along its length, a single axis inclinometer and a release device at the



Figure 1 Anchor with MDDD mount prior to mounting spines

base to allow the spine to hinge down if the force applied to it exceeded a given amount (Figure 3). The spine and release devices were mounted on a steel platform affixed to an anchor base resulting in the spine bases being approximately 2 meters above the river bottom when the assembly was placed in the river channel (Figures 1 and 2).



Figure 2 MDDD spines on anchor mounting platform

At the base of each spine was a cam and pivot shaft that rotated in pillow block bearings allowing the spine to rotate about a single axis. A cam follower comprised of a spring loaded shaft with a roller at the cam end applied a righting force on the cam that increased as the angle between the spine and the base plate decreased, approaching a horizontal position. This righting force was a function of having an increasing radius on the cam. This righting force was intended to bring the spine into an upright position after self-cleaning. The end of the cam had a detent where the cam follower would nest when the spine was in the upright position (Figure 4). This produced the large force required to initiate cam movement and a lesser force required to continue to force the spine towards a horizontal position. As the spine approached the horizontal position the probability of the

water current sweeping the spine clear increases. The force required to initiate cam movement was designed to be less than a force that might deform the spine. The scenarios envisioned that would result in spine movement were a strike by a large piece of debris or an accumulation of smaller debris.

2 Data Acquisition System and Sensors

The data acquisition system for the MDDD was a Campbell CR3000 Micrologger used to record the analog signals from the strain gages and inclinometers. The logger operated on power supplied by a 12 V battery. The logger supplied a 5 VDC bias for the strain gages; a pair of 12 V batteries in series provided 24 VDC excitation for the inclinometers. Each of the 12 V batteries was an Exide 100 amp hour lead acid marine battery. The data logging system current draw on the batteries was low enough that the data logger could operate for the planned period of monitoring of the deployment season without recharging the batteries.

Programming for the CR3000 used Campbell Scientific PC200W 4.1 PC support software to communicate with a PC laptop and the programs were created with the Campbell ShortCut program. The logger was programmed to sample at 1 Hz and to record at various intervals, typically 15 or 30 seconds. Programming instructions could specify recording the sample value at the end of the interval, the average of the samples in the interval, a maximum or minimum sample value in the interval and a time of maximum or minimum in the interval. Various programming regimes were used during the calibration and initial set up.

2.1 Strain Gages

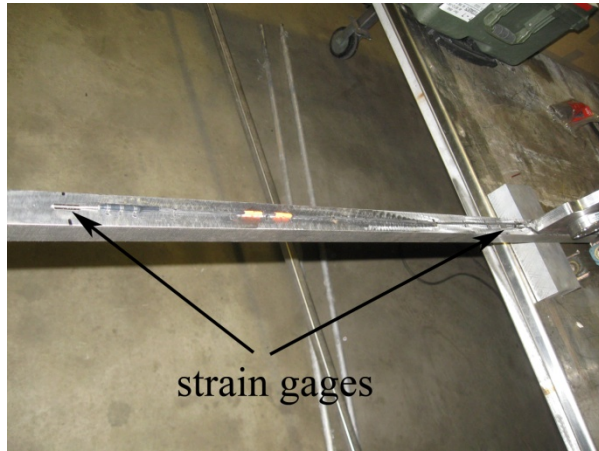


Figure 3 Strain gages mounted on steel spine

Strain gages were supplied by Kyowa Electronic Instruments. Kyowa was the only vendor found that could commit to supplying weldable strain gages and cable assemblies for long term underwater use. Unfortunately, Kyowa suppliers were affected by the March 11, 2011 Tohoku earthquake and tsunami in Japan. This resulted in an indeterminate lead time before the vendor could deliver strain gages. When the vendor indicated that they could supply their product, the order was placed in mid-June and the gages arrived in Fairbanks mid August. The strain gage installation consisted of affixing two strain gages to each spine (Figure 3). The gages were spot welded to the down current side of the spine with

one gage centered 10 cm above the spine support cam and the other centered 76 cm above the spine support cam. A special spot welding machine was provided on loan by Kyowa Electronic Instruments. The gage elements were encapsulated quarter bridge 3 wire systems with a bridge adapter installed in the signal cable approximately 2 meters from the gage. A 150 meter cable ran from each strain gauge to the data logger. The use of a strain gage bridge adapter was necessary because signal cable length was excessive for use with a quarter bridge gage. The adapter completed the bridge circuitry to make a 4-wire full bridge configuration. The gage, bridge and cable assembly were fabricated by Kyowa for use in an underwater application. Strain gage bridge 5 VDC excitation was provided by the Campbell CR3000 micrologger. The strain gage output was an analog voltage read by the CR3000.

Locating two strain gages on each detection spine provided coarse information about where on a spine a debris impact occurred.

2.2 Inclinometer



Figure 4 MDDD spine with inclinometer sensor on side of cam

The inclinometers (Figure 4) were supplied by ASM Automation. The devices and the supplied 150 meter cable were rated for underwater operation. The inclinometer output was a 4-20 ma signal and the sensor required a minimum excitation of 18 VDC. Excitation was provided by a pair of 12 V batteries in series. The purpose of the inclinometers was to indicate the attitude of a detection spine to make the strain information more meaningful. The output 4-20 ma signal was converted to a voltage signal at the CR3000 logger by means of precision 100 ohm shunt resistors supplied by Campbell Scientific. The inclinometers had a range of +/- 60 degrees on either side of the

midpoint of travel yielding a total range of 120 degrees. As deployed, the angle of a tripped spine in the horizontal position is reported as 0 degrees and the upright spine reported as 90 degrees. If the attitude of the spine tilts upstream the reported angle is greater than 90 degrees.

2.3 Signal cabling and shore side enclosure

The strain gages, inclinometers and their associated 150 meter long data cables were designed for extended underwater deployment. To transition the signal cables from the deployed MDDD to an on shore signal data logger for processing, the cables were bundled and fastened to a 3/8" chain for ballast and then the cable/chain assembly was fed through multiple 50-foot lengths of fire hose that provided abrasion resistance (Figure 5). The chain provided strain relief for the signal cable bundle and kept it on the river bottom. The signal cabling terminated on the river bank in a 2'x2'x4' steel job box housing the batteries and datalogger.



Figure 5 MDDD with signal cable shrouded in fire hose coiled on pallet

3 Strain Gage and Inclinometer Calibration

In order to render the MDDD strain gage data meaningful, a calibration process was performed immediately after the spine assembly fabrication was completed on August 23, 2011 at Jon's Machine Shop. Both spine assemblies were affixed to a table with the spines in a horizontal position. The spines were marked in 10 cm increments and a known weight was suspended from each mark for approximately 60 seconds while the datalogger was recording the output of the strain gages (Figure 6). The downward force of the weight plus the force due to the weight of the steel spine was reported as a moment of force about the strain gage. A plot of the moments vs. the output of the strain gage as recorded by the datalogger was used to generate a relationship between the forces applied and the reported strain gage output.



Figure 6 MDDD spines with calibration weights

The inclinometers were calibrated using a two-step process. A relationship between the angle of the spines with respect to the horizontal and the output current was established by measuring the output current with the spines set at four angles between approximately 15 degrees to 105 degrees. This established the values to be input in the data logger program to result in the data being reported in degrees.

4 Test Deployment and Analysis

In order to make the best use of the short time remaining in the field season, the detection spines were transported to Nenana on August 24, 2011, the day after the calibration to begin assembly of the spines to the anchor in the Crowley yard. Assembly took place on August 24, 25 and 26 in Nenana. The schedule was expedited so the MDDD would be ready whenever the deployment plan was finalized and Crowley equipment and crews would be ready to deploy the anchor and MDDD. When it became apparent that a full mid-channel deployment would not be possible it was decided to do a dockside deployment instead to test both the anchor pull resistance and MDDD performance (Figure 7).



Figure 7 MDDD being lowered into water

The MDDD was deployed in the Tanana River at Nenana from September 13 to September 20, 2011. The system was deployed off of the Crowley dock using the Crowley Manatowoc crane. Limited time and equipment precluded a mid-channel deployment. The location was approximately 3 meters from seawall in about 4 meters of water.

During the dockside deployment, handlers experienced difficulty keeping the anchor/MDDD assembly oriented with the current. This appeared to be the result of differences in the lifting center and the center of the drag forces on the system. The lifting bridle was secured on the four corners of the anchor and was centered over the middle of the anchor. The center of drag of the anchor and system was upstream of the center of lift and the anchor tended to spin about its center of lift.

MDDD in water deployment timeline

9/13/11 1600	Deploy MDDD off Crowley dock
9/13/11 2030	Initiate datalogger program
9/14/11 1040	Anchor Pull test
9/14/11 1150 -1300	Download data and load new logger program
9/16/11 1130	Download data and load new logger program
9/16/11 1300 -1600	Artificial debris impact tests. Water velocity at spines – approximately 1.2 m/sec one meter below surface*
9/20/11 1100	Retrieve MDDD – no logger data downloaded

*Water velocity measured with Marsh McBirney velocity meter with the sensor mounted on a 100 lb lead sounding weight suspended from the test boat.

After deployment (Figure 8) the data logger system was set up on the dock. A bug was discovered in the program that caused erroneous data to be reported in a real time monitoring function of the logger. When program instructions called for monitoring the time and magnitude of maximum values within each recording period, the bug produced an unrealistic time stamp and improbable strain gage readings. Attempts were made to configure a program to resolve the erroneous data problem. As a result of spending time dockside working with the logger, it was possible to observe the slow settling of the anchor into the silt as evidenced by the reduction in the portions of the spines above the water surface. By the next morning the anchor had settled approximately 40 cm (change in river stage over night was less than 5 cm). The logger was left running through the night and a conversation about the bug was initiated with Campbell Scientific on 9/14/11.



Figure 8 MDDD spines protruding above water surface after deployment

On the morning of 9/14/11 a pull test was performed on the anchor causing it to shift position as the pull set the anchor. The shift in attitude of the system was detected by the inclinometers on the debris detection spines. After the pull test, data was down loaded from the logger and the program was reset. When looking at the downloaded data on 9/15/11, the day after the pull test, it was determined that the program bug resulting in erroneous real time monitoring data did not affect the recorded data. Campbell Scientific had no solution for the problem of the real time monitoring function and since it did not affect recorded data, efforts to find a solution were suspended.

The behavior of the MDDD with objects intentionally placed in the water column, as debris surrogates, was tested on 9/16/11. Two scenarios were simulated. To simulate an accumulation of smaller debris a net was suspended from a 10' section of 4" ABS pipe acting as a float. The net used had a small mesh on the order of 1", and was approximately 4' x 24'. The net was folded over 3 times to yield a three layer net about 8' long. A 15' length of 3/8" steel chain was secured to the bottom of the net to provide weight. In essence this was a floating net curtain that hung down about 4' from the surface (Figure 9). The intention was to keep the net system above the level of the cam and follower to minimize the probability of fouling. The second type of simulated debris used two 15 gallon poly drums filled with water and a few links of steel chain making them a little less than neutral buoyancy. The poly drums were suspended from another 10' x 4" ABS pipe float.



Figure 9 Surrogate debris with net float and chain

The surrogate debris was placed in the river current 10's of meters upstream in order to have time position to the ABS pipe float perpendicular to the

current flow and have the float centered on the pair of spines. If the float impacted the spines and was centered, the probability was high that the float and net would remain on the spines and act like an accumulation of debris. The larger mass debris surrogate, the filled 15 gallon poly drums, was more difficult to have impact the spine. A number of attempts were required to have the poly drums impact the spines directly. When the net assembly was resting on the two spines, it was employed to catch the poly drums. A combination of the net and two poly drums was able to trip one of the spines (Figure 10). Multiple trials were performed until the net fouled on the dockside spine and could not be removed. The system was left with the net and float fouled until the removal from the water. In this configuration one spine remained vertical and the other was tripped enough so that there was no surface expression of the spine, float or net.



Figure 10 Surrogate debris on MDDD spines

The tips of the MDDD spines were just a few centimeters above the water surface. Being able to see the spines was helpful when directing the surrogate debris into the system. Having the system within a couple meters of the dock created difficulty maneuvering the surrogate debris in place because the boat could only operate on the channel side of the floating debris.

The difficulty of introducing surrogate debris onto the MDDD spines would increase greatly if the system was installed in mid-channel in faster, deeper water. The challenge would be twofold without being able to directly observe the debris; there would be the challenge of directing the surrogate debris so that the probability of direct impact is high and then having to make an assumption about the nature of the impact to be related to the data from strain gages.

The MDDD was removed from the water by the crane on 9/20/11. When the system came out of the water it appeared that the surrogate debris net had fouled on a hex head of a bolt securing the spine to the cam. There appeared to be no fouling in the cam or cam follower roller.

4.1 Strain Gage and Inclinometer Data

There are strain gage and inclinometer data sets for the periods 9/13 to 9/14/2011 and 9/14 to 9/16/2011. The period of these data sets was prior to the introduction of surrogate debris onto the detection system as an attempt at calibrations.

When the system was being set up for storage, the data acquisition system was taken apart for storage; the data logger was removed and transported to Fairbanks without downloading the data. During attempts to download the data for 9-16 to 9-20-11, the data were erased before successfully downloading it off of the Campbell data logger. This was the period when surrogate debris was used with the detection system. Data taken while the anchor was settling were saved and some of the strain gage and tilt sensor data are presented in the following plots with observations about the presented data.

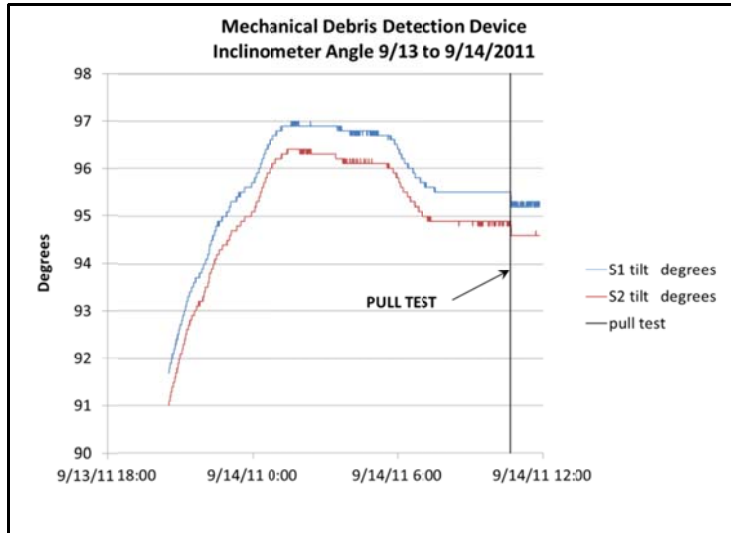


Figure 11 Inclinator 9/13 to 9/14/2011

Figure 11 displays the change in attitude of the MDDD after deployment. The offset between the reported angles of the two spines may be attributed to slight differences in mounting angle and this could be corrected in the future in adjusting the data logger program. The operation of the inclinometers was not checked after the system was assembled in Nenana prior to deployment and the angles reported are assumed to be within a few degrees. The close correlation of the data from both sensors suggests the reporting change in angle to be accurate to within a small fraction of

a degree. The change in angle is attributed to the settling of the anchor after deployment on 9/13/11. An increasing angle represents a greater settling of the upstream or fluke end of the anchor. During the pull test on 9/14/11 visual observations of the exposed spine tips indicated that the anchor shifted many centimeters. A shift in attitude of less than a degree is indicated by the tilt sensors at the time of the pull test.

Figure 12 indicates that after the pull test the attitude of the anchor remained stable.

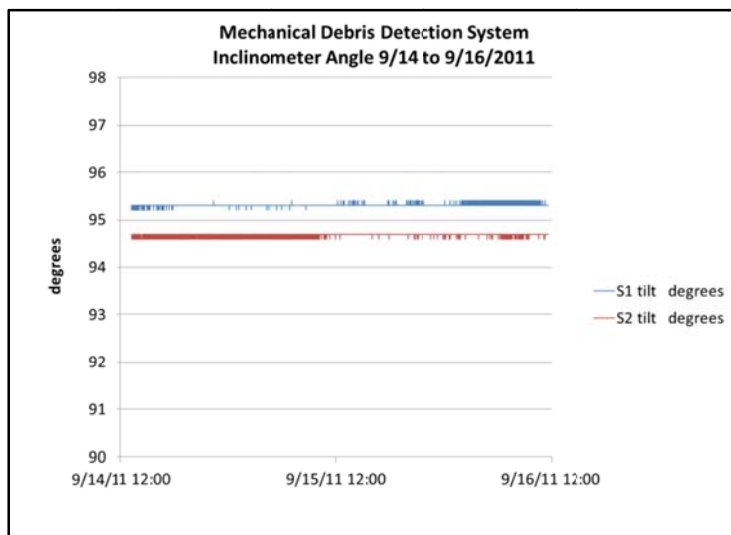


Figure 12 Inclinator 9/14 to 9/16/2011

Figures 13 and 14 indicate the response of the strain gages to the forces on the spine between 9/13 and 9/14/2011. Figure 13 presents the maximum force recorded in each 30 second sampling interval of 30 one second samples and Figure 14 presents the average for the 30 samples in each interval. The forces on the spine changed a small amount at the time of the pull test at approximately 10:29. About ½ hour prior to the pull test, an event occurred that registered on the all of strain gages. The change indicated by the S2 top gage seemed to be anomalous because of the large change and that it did not go back to its original condition as did the others. An additional force that remained on the upper part of the spine should have been registered by both the top and bottom gages and this does not seem to be evident.

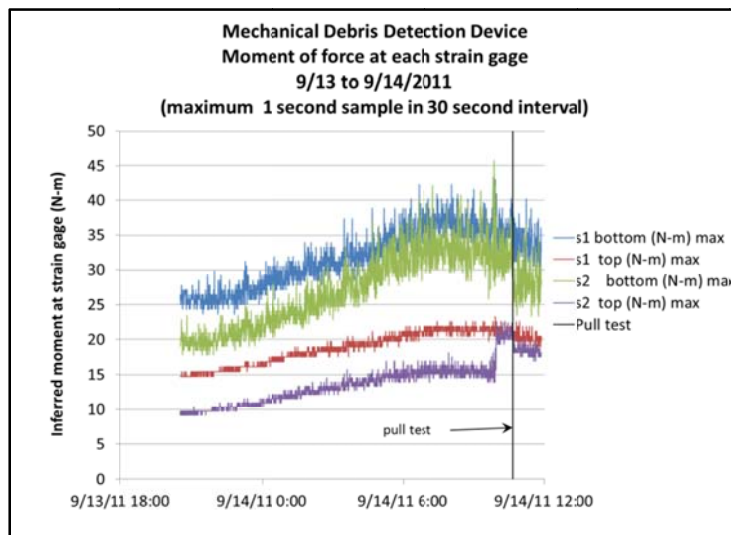


Figure 13 Strain gage maximum samples 9/13 to 9/14/2011

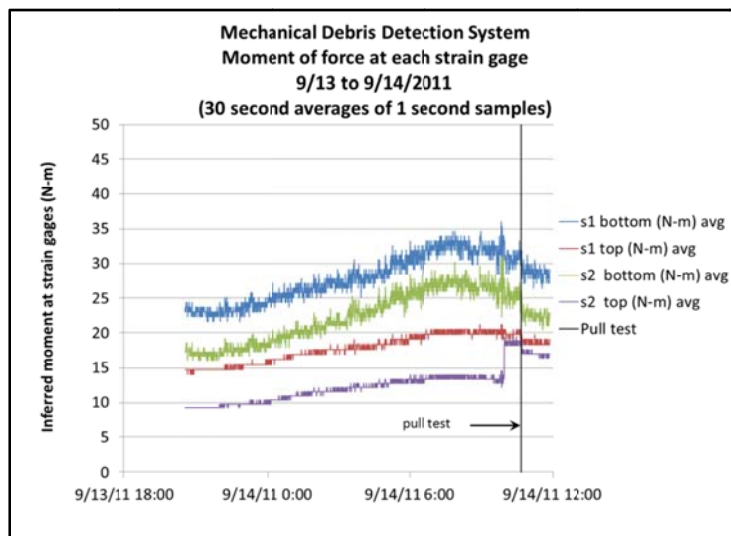


Figure 14 Strain gage sample averages 9/13 to 9/14/2011

Figures 15 and 16 present the data from 9/14 to 9/16/2011. During this period the data logger was programmed to record at 15 second intervals and with minimum resolution. The signal resolution set in the program was relatively low and resulted in a resolution of approximately 10 N-m. Even so, the data for the two day period indicated the MDDD operated well. The values reported during this period were higher than in the previous period. A physical change in the surroundings occurred between Tuesday, 9/13 and Friday, 9/16. A tug and barge was moored less than 100 meters upstream from the deployed MDDD on Tuesday and by Friday afternoon it had moved to a downriver location. The time of this move was not noted and the evidence of this is in photographs of the Crowley dock taken on Tuesday and Friday. The system recorded what appears to be an impact event on the afternoon of 9/14/2011.

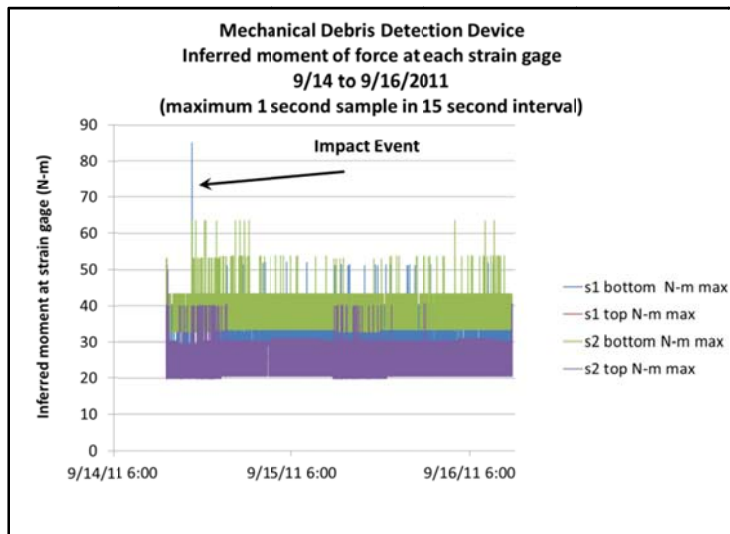


Figure 15 Strain gage maximum 9/14 to 9/16/2011

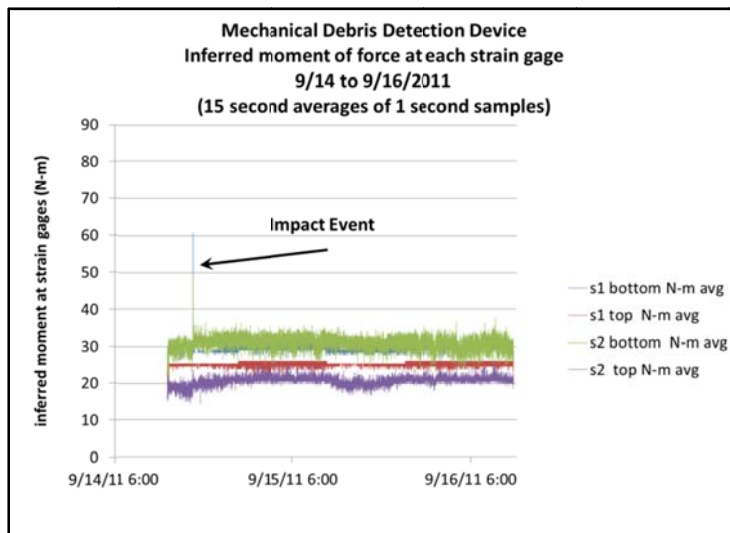


Figure 16 Strain gage sample averages 9/14 to 9/16/2011

Figures 17 and 18 report the data for a one hour and fifteen minute period during which an apparent impact event occurred. The impact was noted on the three strain gages, S2 bottom and top and S1 bottom.

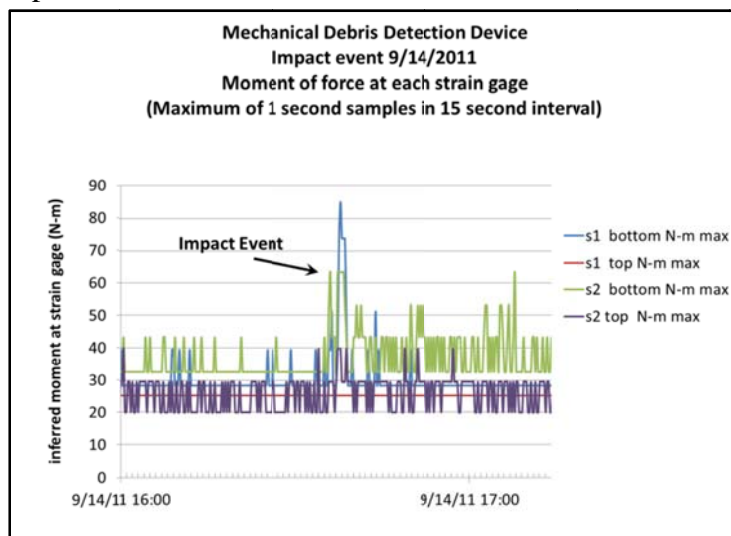


Figure 17 Strain gage maximum, impact event 9/14/2011

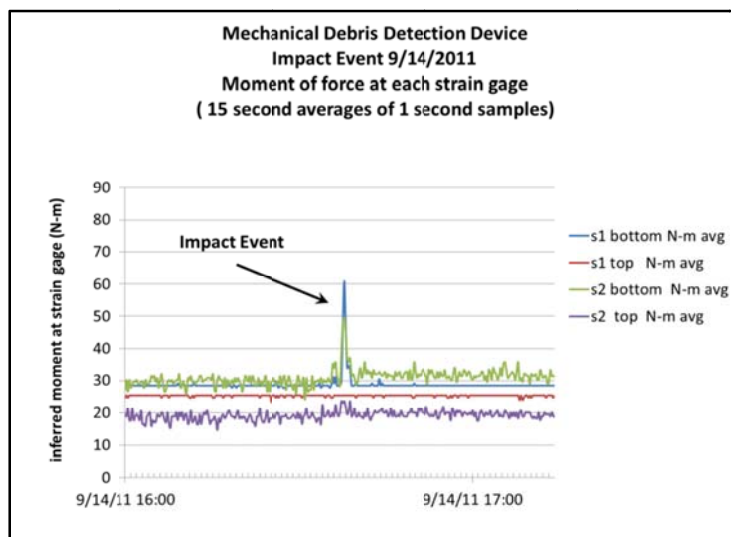


Figure 18 Strain gage sample averages, impact event 9/14/2011

5 Conclusions

The MDDD system demonstrated the possibility of recording the force of debris impacts and the time of occurrence. The self-cleaning capability appeared to be work when surrogate debris was introduced. The protrusions on the spines responsible for fouling the surrogate debris net can be remedied. Additional calibration and experience with the system is necessary to improve the quality of the information derived from the system. With respect to future deployments, in water calibrations with the DDS completely submerged will pose a much greater challenge than experienced in this deployment. Maneuvering a large piece of surrogate debris to hit a small target with no visual reference will be a difficult task.