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Prototype Barge Impact Experiments, Allegheny Lock and Dam 2, Pittsburgh, Pennsylvania

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Contents

Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE). The experiments were conducted for the U.S. Army Engineer District (USAED), Louisville, in support of the Ohio River Mainstem Systems Study, and for the USAED, Pittsburgh, as part of the Monongahela Locks and Dams 2 and 3 Replacement Project. Publication of the report was accomplished under the Innovations for Navigation Projects (INP) Research Program, Work Unit (WU) 33143, "Design of Innovative Lock Walls for Barge Impact." This research was initiated by Mr. Robert C. Patev, former Principal Investigator of WU 33143. Current Principal Investigator is Dr. Robert M. Ebeling of the U.S. Army Engineer Research and Development Center (ERDC) Information Technology Laboratory (ITL).

Dr. Tony C. Liu was the INP Coordinator at the Directorate of Research and Development, HQUSACE; Research Area Manager was Mr. Barry Holliday, HQUSACE; and Program Monitors were Mr. Mike Kidby and Ms. Anjana Chudgar, HQUSACE. Mr. William H. McAnally of the ERDC Coastal and Hydraulics Laboratory was the Lead Technical Director for Navigation Systems; Dr. Stanley C. Woodson, ERDC Geotechnical and Structures Laboratory (GSL), was the INP Program Manager.

This report was prepared by Mr. Patev, U.S. Army Engineer District, New England, and Messrs. Bruce C. Barker and Leo V. Koestler III, Instrumentation Systems Development Division (ISDD), ITL. The authors acknowledge the dedicated efforts and support for these prototype full-scale experiments demonstrated by Ms. Chudgar, formerly of the USAED, Louisville, and Messrs. Thomas Churilla (retired) and Al Remaly of the USAED, Pittsburgh.

The research was monitored by Dr. Ebeling, under the supervision of Mr. H. Wayne Jones, Chief, Computer-Aided Engineering Division, ITL; Dr. Charles R. Welch, Chief, ISDD; Dr. Jeffery P. Holland, Director, ITL; and Dr. David W. Pittman, Acting Director, GSL.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

1 Introduction

Background

This report describes the details of the “prototype” full-scale barge impact experiments conducted at Old Lock and Dam 2 on the Allegheny River in Pittsburgh, PA. The prototype experiments were performed to assist in examining and quantifying the behavior of a barge system during impacts to a rigid lock wall. Since these types of full-scale impact experiments have never been attempted before, instrumentation and data collection equipment required detailed research and development so as to properly capture the behavior of an inland waterway tow. The state-of-the-art instrumentation program used for these experiments was also developed with the idea that a similar instrumentation program (albeit to a larger scale) could be applied to a larger full-scale impact experiment using a fully ballasted 15-barge tow.

The prototype experiments were conducted during the week beginning August 24, 1997, at Old Lock and Dam 2 just north of Pittsburgh. The experiments were conducted using a four-barge tow system that was composed of standard open-hopper barges. The tow was ballasted to 8.5 ft (2.4 m) of draft with an approximate mass of 4,000 short tons (3.6 million kg). Thirty-six prototype experiments into the old lock wall were successfully conducted. Twenty-five of the experiments were on the rigid concrete lock wall, and nine experiments were on the ultra-high molecular weight (UHMW) bumpers. The experiments yielded velocities ranging from 0.5 to 3.2 fps (0.1 to 0.9 m/sec) with angles of impact that ranged from 5 to 27 deg.

Some of the key instrumentation used for the experiments consisted of accelerometers and strain gages at specified locations on the standard open-hopper barges. Other innovative instrumentation was required to be developed for these experiments. One of these was clevis pin load cells, which were spliced into the lashings that “tie” the barges together. This instrument was used to measure the force in the lashing parts before, during, and after impact. These lashings become an important part in the multi-degree-of-freedom system for inland waterway barges. A more detailed explanation of the instrumentation used during the experiments is provided in the section “Instrumentation,” later in this chapter.

In addition, a differential global positioning system (DGPS) system was used to record and document impact velocities and angles during each experiment.

The DGPS locations, data processing, and data plots are also discussed in the section titled Instrumentation. The image trailing plots of the barges during each experiment taken from the DGPS data are shown in Appendix A.

The concept and installation of UHMW bumpers is discussed in a separate section of this chapter. Chapter 2 discusses observations from the data (unprocessed) that were collected during the experiments. The experiment data, presented with full raw data plots from all the experiments, are provided in Appendix B. Finally, conclusions and recommendations are presented in Chapter 3 to assist with the layout and instrumentation decisions for the next set of full-scale experiments currently being planned under the Innovations for Navigation Projects Research and Development Program.

Experiment Site—Old Lock and Dam 2, Allegheny River

Site selection

The location of the site for the prototype experiments was selected based on the location of the available towing companies that were willing to participate in these experiments. Site visits were made to various locations along the Ohio River to ensure that the experiment location met certain site requirements. Safety was the primary issue of these impact experiments, since they have never been attempted before in this level of scale.

The primary requirements for the experiment site were

a. Easy access for the instrumentation equipment and research staff from the U.S. Army Engineer Research and Development Center (ERDC).

b. A safe approach and landing area for the towboat.

c. Working space on landside to install equipment.

d. Access to a skiff or small vessel to assist with instrumentation installation.

e. Slow currents or relatively flat water.

f. Location on land owned or leased by the Government.

g. Out of the way of navigable areas in case of accidental sinking.

h. Distance from access to the public.

After visiting many sites up and down the Ohio River, Old Lock and Dam 2 on the Allegheny River met all the above requirements. In addition, the contractor selected for the experiments, River Salvage, Inc., made available a staging facility that was a short distance downstream from the experiment site.

The River Salvage docking facility was located within the City of Pittsburgh and was conveniently situated 5 miles (8 km) south of Lock and Dam 2 on the Allegheny River. Since River Salvage, Inc., owns the site, it permitted easy access to the site from the riverbank or adjacent mooring facilities for use as the first-stage assembly area for the barge instrumentation. In addition, access to electric power and welding equipment was made available on the site. This was crucial for installation of all the instrumentation on the barges. This location also permitted use of the equipment by the Corps of Engineers without paying any mobilization fee until the experiments were ready to commence.

Old Allegheny Lock 2

The site used for the experiments, Old Allegheny Lock 2, is just upstream from the existing Lock and Dam 2 on the Allegheny River, as shown in Figure 1. The Old Lock 2 was built in 1908 and was taken out of service in 1933 when the existing Lock and Dam 2 replaced it. The original chamber was 250 by 56 ft (76 by 17 m). The fixed-crest dam is from the upper guard wall to the right side of Figure 1. The old lock is approximately 1,500 ft (460 m) from the new Lock 2.

Figure 1. Looking downstream from Old Lock 2 to Lock and Dam 2

The only sections that were left intact at the old lock are the upper guide wall, landside chamber wall, and lower guide wall. The two guide walls are founded on timber crib structures that have earthen fill behind them. The foundation for the lock chamber wall is not known but is suspected to be rock founded. The foundation and dimensions of the chamber wall were confirmed with soundings before the testing was commenced. Figure 2 shows the layout of the walls from the parking lot for Old Lock and Dam 2.

Figure 2. Old Lock and Dam 2, Allegheny River

In the past few years, the old wall has been impacted numerous times by tows pushed by crosswinds across the approach into the existing Lock and Dam 2. Tows also currently use the wall to moor on while waiting for a locking vessel at Lock and Dam 2. In addition, the wall and esplanade have a very compact and solid backfill behind them, which seemed to be quite stable. The other parts of the lock were completely removed by blasting prior to the opening of the existing Lock and Dam 2. The gate sills for the Old Lock 2 are approximately 16 ft (5 m) under the water surface, according to recent sounding records. Schematic plan views of the existing and Old Lock 2 are shown in Figure 3 (note that the figure is not drawn to scale).

Figure 4 shows an elevation view of Old Lock 2 from the end of the lower guide wall to the lock chamber wall. The approach to the old lock wall has no obstructions from the railroad bridge (in foreground) to the old lock, since this is currently used as the approach for tows into the existing Lock and Dam 2. This wide clearance will permit enough room to safely approach the wall at various angles and speeds. In addition, the water at this point in the river is very slack, which allows for good maneuverability in this area.

Figure 4 also shows a view of the old chamber lock wall. This wall was the prime candidate on which to perform the impact experiment. The distance from the top of lock wall to the water surface was about 13 to 14 ft (4 m). The surface concrete on the wall is in relatively good shape, as well. This area is currently used as a fishing wharf by local residents, but is still owned and maintained by the Corps of Engineers.

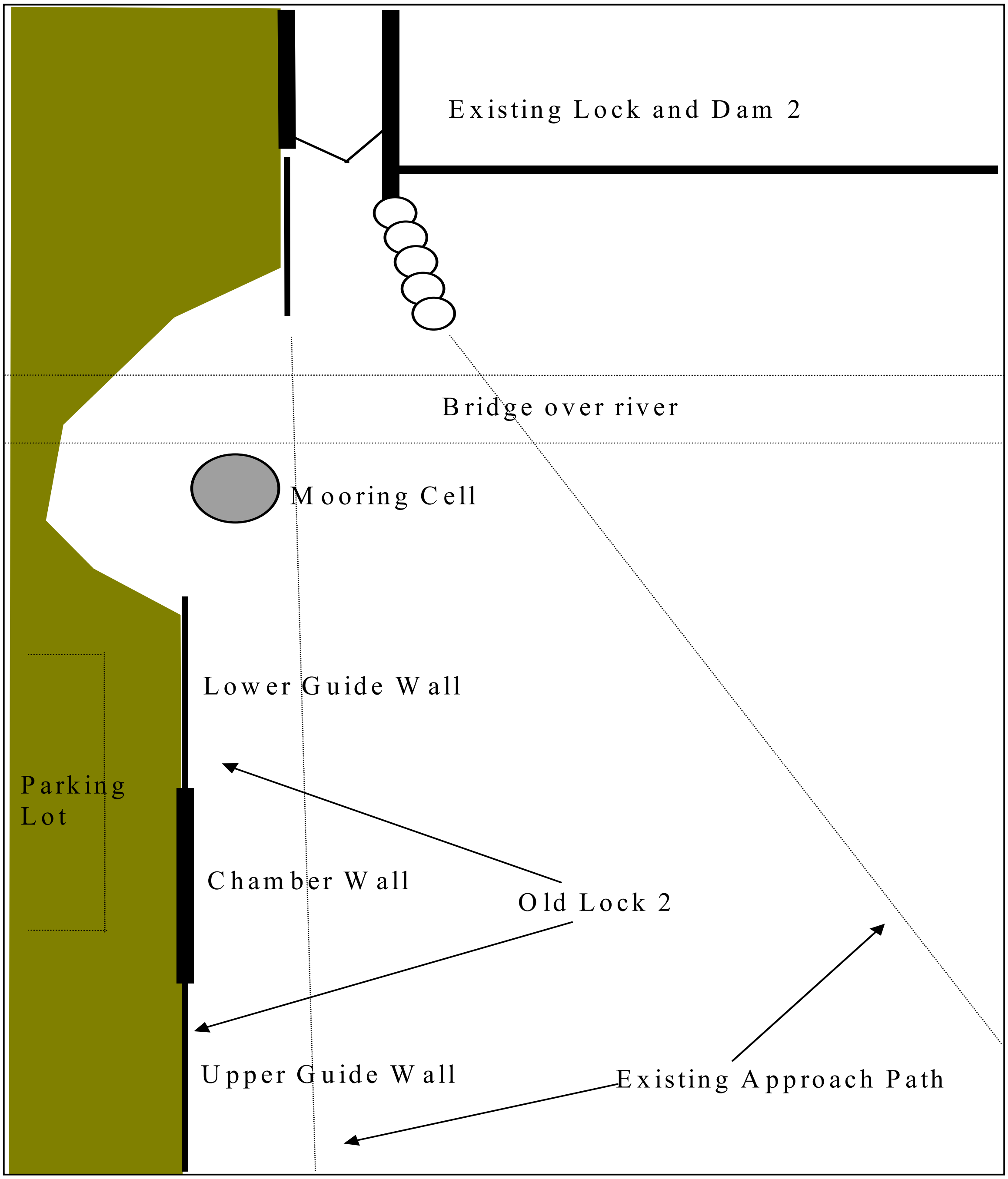


Figure 3. Schematic of old and existing Locks 2 (not to scale)

Figure 4. Old Lock 2 guide wall and portion of lock chamber wall, looking upstream

Prototype Experiment Schedule

As stated, the prototype experiments were held during the week of August 24, 1997. It was anticipated that this time of year was the best, to permit longer workdays (10-12 hr of daylight), drier conditions (generally very little rain with the exception of local thunderstorms), and flat pools and low flows in the Allegheny River. The schedule for the experiments was rather hectic for a full week, but was manageable given the number of instruments that were installed and the experiment impact matrix that was developed. The work plan developed for the experiments was to mobilize the crew, towboat, and barges for 2 days, to conduct 3 days of impact testing at Old Lock 2, and to demobilize for 2 days.

Based on this plan for the week's activities, the schedule shown in Table 1 was developed and used during the experiments.

Towboat and Barges

River Salvage, Inc., of Pittsburgh/Glenwillard, PA, supplied the barges and towboat for the prototype experiments under an open-ended maintenance contract with the U.S. Army Engineer District, Pittsburgh. The barges supplied for the experiments were standard open-hopper rake barges built by Dravo, Inc., of Pittsburgh, PA. The barges were 26 ft (8 m) wide by 175 ft (53 m) long and were ballasted to 8.5 ft (2.6 m) of draft with suitable dredged material from a downstream river location.

The four standard barges used for the experiments had a very sound structure but were missing some coamings and other external deck structure. The age of the barges was estimated at around 35 to 40 years. The towboat M/V *Anna S.* was a 1,200-hp vessel that was the location for the onboard instrumentation setup. The four standard open-hopper barges used for the experiments are shown in Figure 5. Figure 6 shows the M/V *Anna S.*, the towboat used during the experiments.

Table 1
Schedule for Experiments

Sunday (afternoon)	Arrive for tour of site and facilities, briefing on test schedule, instrumentation plan, and safety plan
Monday **Tuesday**	Installation of instrumentation on barges and lock walls at River Salvage, Inc.
Wednesday *Morning* *Morning/afternoon*	Initial test of equipment (low speed/ moderate angle) Review instrumentation results Frequency test *Start barge impact testing:* Low speeds (0.5-1 fps) - increase angle (0-20 deg) (5 impacts) Moderate speeds (1-2 fps) - increase angle (0-20 deg) (10 impacts)
Thursday *Morning* *Afternoon*	*Continue impact testing:* High speeds (2-3 fps) - increase angle (0-20 deg) (10 impacts) Install UHMW bumpers *Barge impact testing:* Low speeds (0.5-1 fps) - increase angle (0-20 deg) (5 impacts) Moderate speeds (1-2 fps) - increase angle (0-20 deg) (5 impacts)
Friday *Morning* *Afternoon*	*Complete impact testing on UHMW:* High speeds (2-3 fps) - increase angle (0-20 deg) (3 impacts) Start demobilization
Saturday	Complete demobilization of instrumentation and equipment

Figure 5. Standard barges used for the experiments (view from upper deck of towboat)

Figure 6. Motor vessel *Anna S.* used for the experiments

Instrumentation

Data acquisition systems

The instrumentation systems used for the prototype barge impact experiments consisted of two computer-based data acquisition systems: one located on the towboat and the other in a trailer on shore adjacent to the impact zone. A total of 22 channels of acceleration, strain, force, and pressure measurements were made on the towboat and 6 channels on the lock wall. Listings of the barge and wall active instrumentation and measurements included in the plan are presented in Table 2.

Micro Measurements Model 2311 strain gage amplifiers were buffered though a 64-channel multiplex card, then interfaced to the PC through a 12-bit digitizer card. All software used for system control and presentation was developed in-house by ERDC personnel. The data acquisition system located below the pilothouse of the towboat is shown as Figure 7. The GPS locations of the instrumentation on the wall and on the barges are shown in Figures 8 and 9, respectively.

All transducers, with the exception of the clevis pin load cells, were calibrated using ERDC calibration practices for resistive shunt calibration. The clevis pins were fielded using the manufacturer sensitivity calibration, as they were not delivered in time to allow pre-experiment calibration at ERDC.

Table 2
Barge and Lock Wall Instrumentation

Measurement Number	Channel Number	Location (GPS location from corner)	Description	Model	Range
Barge Instrumentation					
B-AX1	1 (barge)	0.09,-3.65	Acceleration	2262-C	200 g
B-AY1	2 (barge)	0.09,-3.65	Acceleration	2262-C	200 g
B-AZ1	3 (barge)	0.09,-3.65	Acceleration	2262-C	200 g
B-AX2	4 (barge)	0.09,-3.85	Acceleration	2262-C	200 g
B-AY2	5 (barge)	0.09,-3.85	Acceleration	2262-C	200 g
B-AZ2	6 (barge)	0.09,-3.85	Acceleration	2262-C	200 g
B-AX3	7 (barge)	0.03,-3.85	Acceleration	2262-C	200 g
B-AY3	8 (barge)	0.03,-3.85	Acceleration	2262-C	200 g
B-AZ3	9 (barge)	0.03,-3.85	Acceleration	2262-C	200 g
B-SX1	9 (barge)	0.57,-3.17	Strain	EA-06-125UR	20,000 µ
B-SXY1	9 (barge)	0.57,-3.17	Strain	EA-06-125UR	20,000 µ
B-SY1	9 (barge)	0.57,-3.17	Strain	EA-06-125UR	20,000 µ
B-SX2	9 (barge)	-0.21,-3.35	Strain	EA-06-125UR	20,000 µ
B-SXY2	9 (barge)	-0.21,-3.35	Strain	EA-06-125UR	20,000 µ
B-SY2	9 (barge)	-0.21,-3.35	Strain	EA-06-125UR	20,000 µ
B-F1	9 (barge)	-2.99, 3.20	Lashing load	SPA-50	50,000 lb
B-F2	9 (barge)	-52.70,11.37	Lashing load	SPA-50	50,000 lb
B-F3	9 (barge)	-53.60, 4.25	Lashing load	SPA-50	50,000 lb
B-F4	9 (barge)	-52.05, -3.39	Lashing load	SPA-50	50,000 lb
B-F5	9 (barge)	-104.05, 5.35	Lashing load	SPA-50	50,000 lb
B-P1	9 (barge)	-4.20, -3.94	Pressure	XTM-190	10 psi
B-P2	9 (barge)	-6.86, 3.97	Pressure	XTM-190	10 psi
Lock Wall Instrumentation					
L-AX1	1 (lock)		Acceleration	2262-C	25 g
L-AY1	2 (lock)		Acceleration	2262-C	25 g
L-AX2	3 (lock)		Acceleration	2262-C	25 g
L-AY2	4 (lock)		Acceleration	2262-C	25 g
L-AX3	5 (lock)		Acceleration	2262-C	25 g
L-AY3	6 (lock)		Acceleration	2262-C	25 g

Figure 7. Data acquisition system located below the towboat's pilothouse

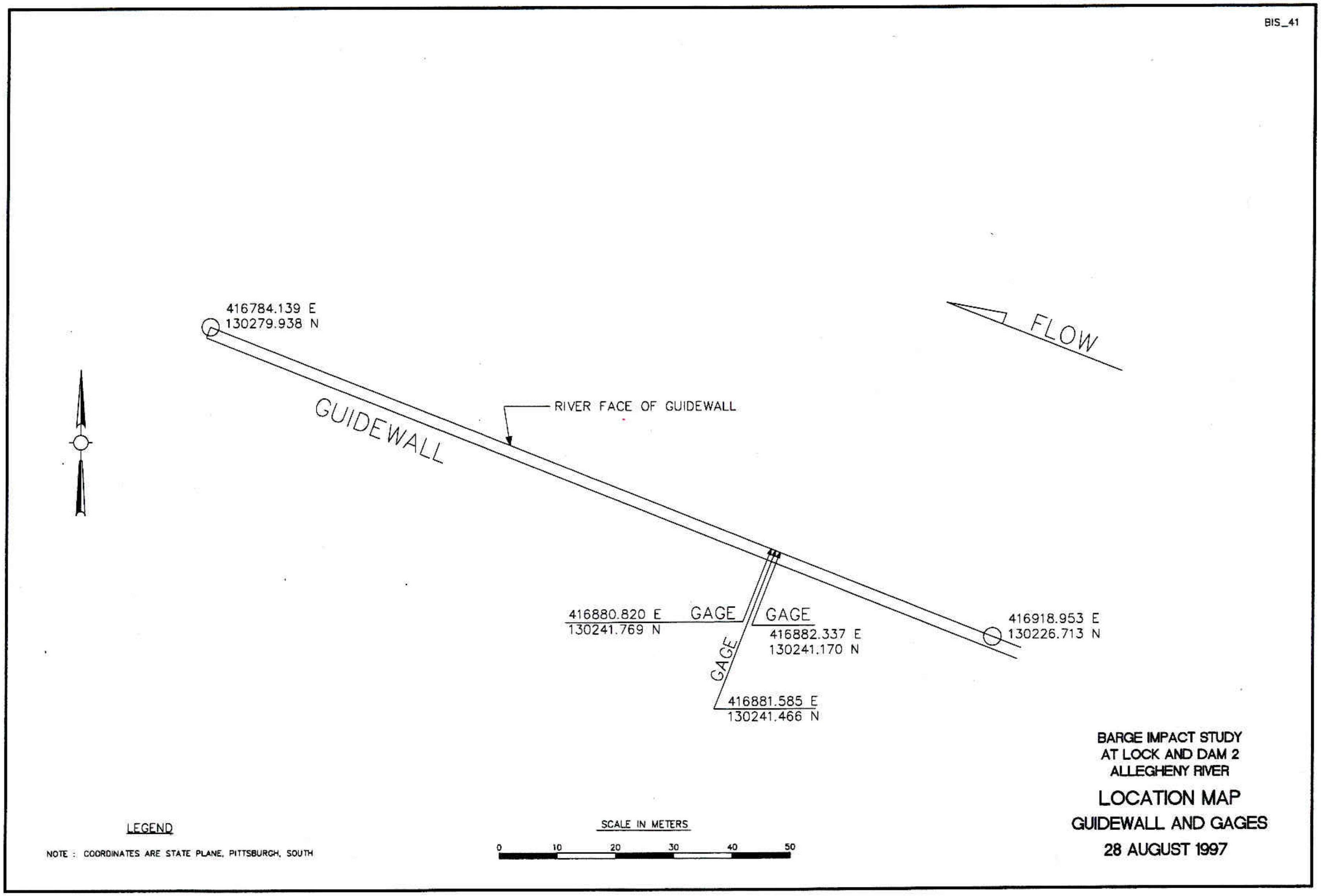


Figure 8. Diagram of page locations on the guide wall

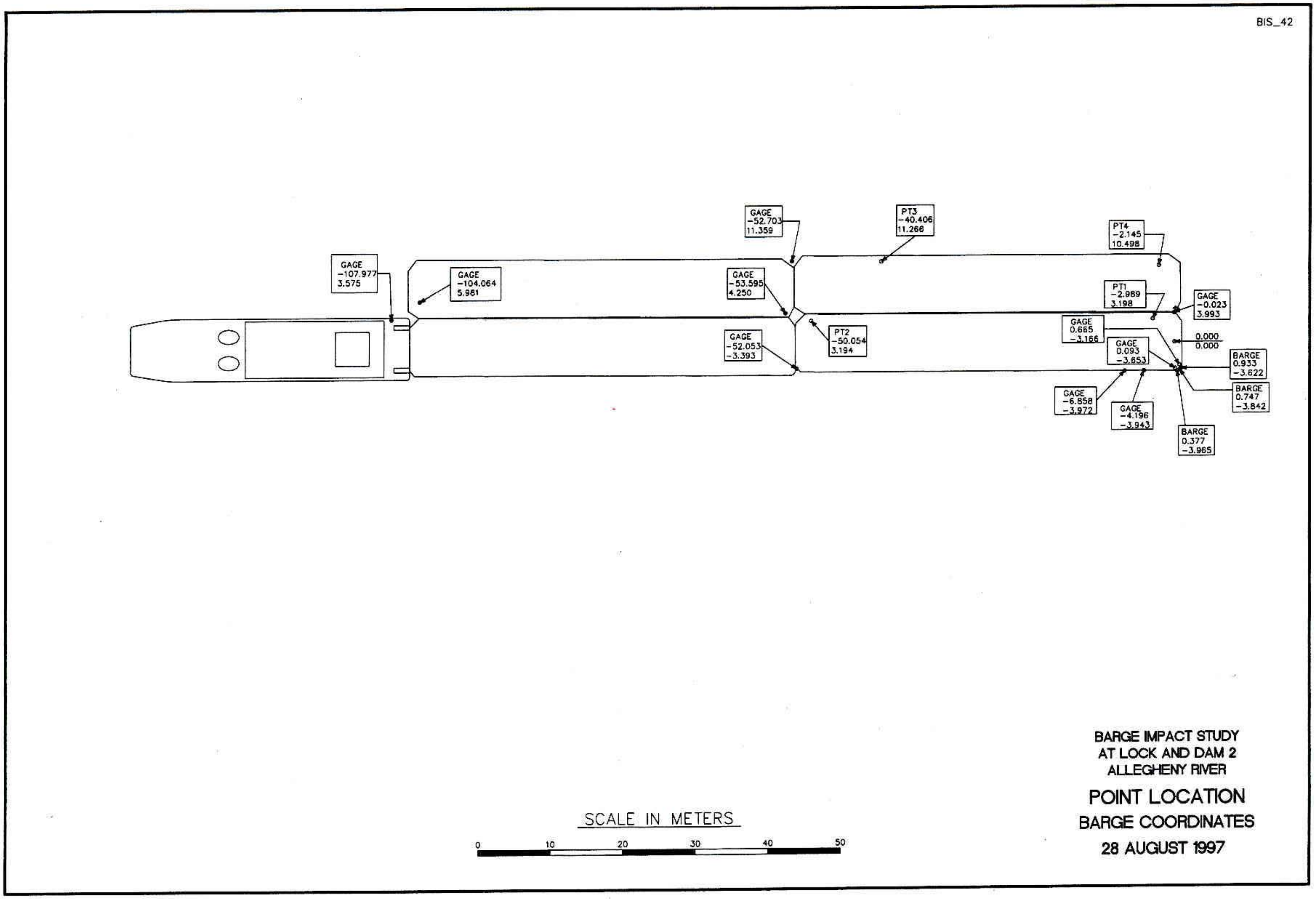


Figure 9. Diagram of gage locations on the barge

Barge instrumentation

Tri-axial accelerometer configurations were placed at three locations in the impact zone. It was intended that all three packages be mounted on a vertical center line at a 1-ft radius from the corner—one package on the top deck and the other two on gussets below the decking. However, the subject corner barge construction was inconsistent with typical hopper barges. The deck mount was located as planned, but the other packages had to be located on the interior hull, essentially on the impacted surface. This may have affected direct comparisons between accelerometer responses since the hull-mounted gages will receive the full shock of the impact that could induce undesirable resonance of the system. The locations of accelerometers are shown in Figure 10. Figure 11 shows the two under-deck accelerometers, and Figure 12 shows the accelerometer on the top deck.

All acceleration measurements for these tests were made using Model 2262-C piezoelectric accelerometers manufactured by the Endevco Corporation. For the first day of the experiments (Experiments 1-9) accelerometers with a full-scale range of 1,000 g were installed. After review of the data gathered for these tests, the barge accelerometers were replaced with 200-g full-scale instruments.

Strain gage rosettes were installed at two locations on the barge decking near the impact corner. These gages were located to either side of the welded joint to measure strain components in the X- and Y-axes, and 45 deg between X and Y. The general locations of the strain gages are indicated in Figure 10, and a photograph of their location on the top decking is shown as Figure 12. The gages were bonded to the decking using Measurements Group's AE-10 epoxy, as shown in Figure 13. Bridge completion networks, consisting of three mechanically isolated strain gages wired in a standard Wheatstone bridge configuration, were used adjacent to each strain gage to provide temperature compensation.

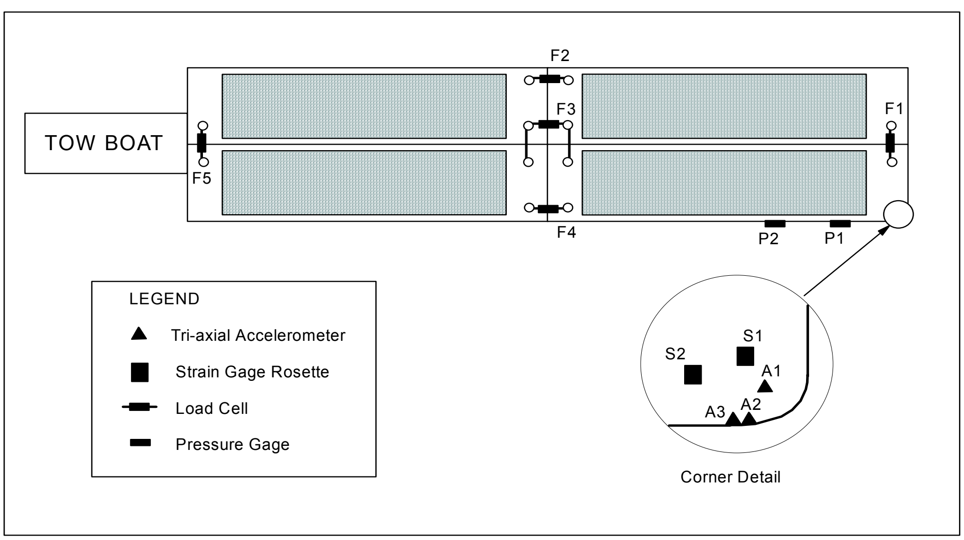


Figure 10. Layout of instrumentation on barges

Figure 11. Accelerometers installed under deck

Figure 12. Accelerometer installed on top deck, located on the left side near edge of barge (gages are located at the two rusty spots on the barge deck, to the right of the accelerometer)

Figure 13. Installation of strain gages on top of deck

Load-sensing clevis pins were used to measure tensile forces in the barge lashing parts (i.e., linear section of cable between timberheads). A clevis pin installed in the lashing is shown as Figure 14. These clevis pins were Strainsert Corporation Model SPA-50 units, with a maximum load capacity of 50,000 lb with a factor of safety of 2.5. Due to the varying lengths of the lashing cable, several clevis pins were placed in a configuration with multiple tension members. Locations of all clevis pin load cells are shown in Figure 10. Measurements F1, F2, and F4 effected this manner of multiple tension parts. Friction between the dead-men and lashings was observed to cause substantial binding of the cable sections.

Two piezo-resistive pressure gages, Model XTM-190 manufactured by Kulite Semiconductor Products, Inc., were mounted to the right side of the lead barge. These gages were mounted in an aluminum disk, which was attached magnetically to barge hull. The pressure gages, designated as P1 and P2 were located at a depth of 32.5 in. (830 mm) below the waterline and 15 and 23 ft (4.5 and 7 m) back from the impact corner. The purpose of these devices was to capture a rise/fall in water pressure due to the confinement effects of the wall on the side hull of the barge before, during, and after the impact. Figure 10 shows the locations of the two pressure gages. These gages were protected from impacts to the lock wall using rubber tires mounted to the barge side.

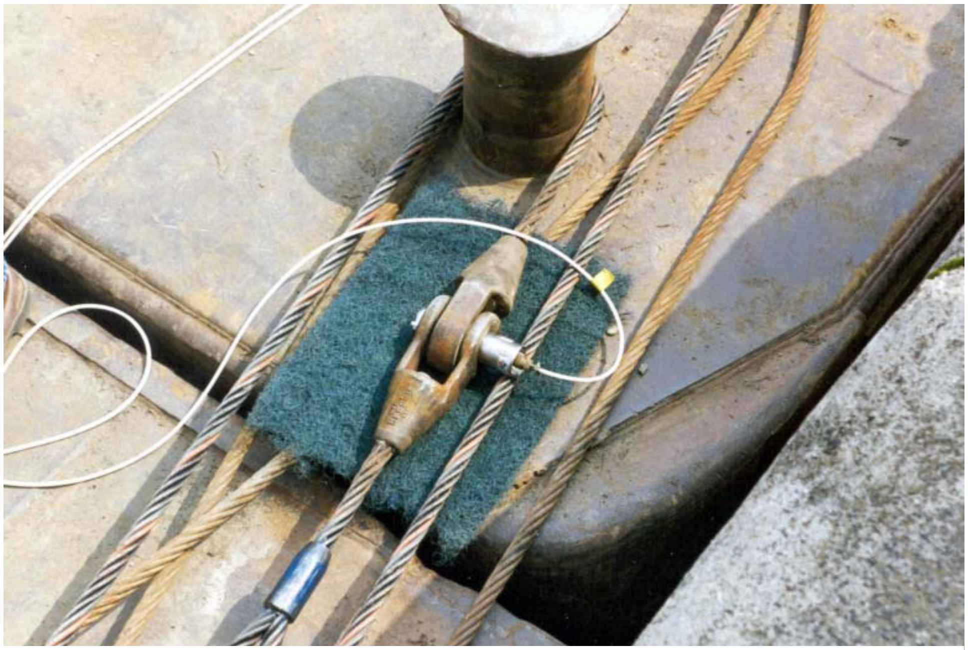


Figure 14. Clevis pin load cells in lashings

Lock wall instrumentation

Biaxial accelerometer mounts were attached to the lock wall at three locations, as shown in Figure 15. As with the barge measurements, these instruments were also Endevco Corporation 2262-C accelerometers with a full range of 25 g. A close-up of the biaxial accelerometer setup on the lock wall is shown as Figure 16. The mounts were located approximately 1 ft (0.3 m) above the impact zone, with spacing of 2.5 ft (0.7 m) between locations up the lock wall. The gage mounts were bolted to a 0.25-in. (6-mm)-thick mounting plate, which was glued to the lock wall with 5-Minute Epoxy. This mounting technique proved highly effective under the circumstances. For future tests, it is recommended that the lock wall be cored and that the gage mounts be recessed in the zone of interest.

Differential global positioning system

The DGPS equipment included four Trimble 4000SSI dual-frequency receivers that were mounted to the tow to measure the angle, speed, and point of impact on the guide wall. The DGPS antennas were mounted on the barges using magnetic mounts, as shown in Figure 17. The antennas were positioned to minimize interference and provide the best possible satellite reception. The locations of the receivers are shown in Figure 9 as PT1, PT2, PT3, and PT4. A 4,000SSI receiver was placed on the riverside lock wall of Lock and Dam 2, Allegheny River, to record raw data for postprocessing. A static survey was conducted and postprocessed against the Continuous Operating Reference Station at Pittsburgh, PA (Pit1) to obtain an accurate position for the base unit and the lock wall.

Figure 15. Lock wall accelerometers

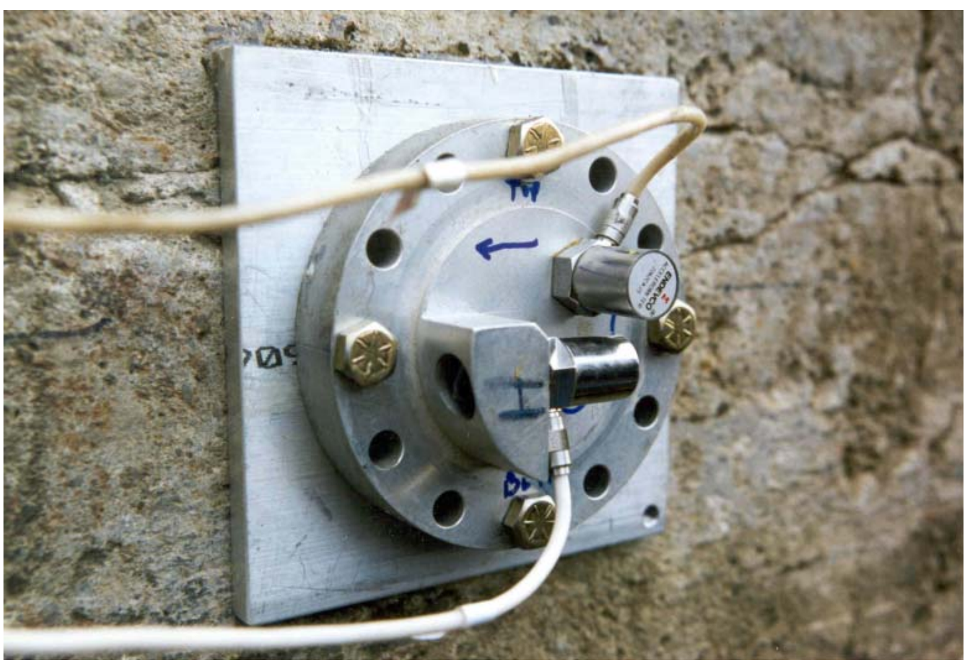


Figure 16. Biaxial accelerometers on lock wall

Figure 17. DGPS antennas and recorders on barges

The DGPS units recorded raw data at intervals of 0.5 sec. The data from the mobile DGPS units were postprocessed to obtain accurate differential positions of the units during the experiments. Location of the mobile DGPS units, instrumentation gages, and geometry of the barges were measured using a Topcon Total Station with tilt compensation. The Total Station was set up on the barges, and all points were measured relative to the tow. Due to some movement of the barges during the measuring period, major points were checked to determine the accuracy of the measurements, and this was found to be within 0.05-ft (15-mm) tolerance.

During the first series of experiments on August 27 and 28, the mobile DGPS units' data logging was stopped between tow runs. Therefore, the data files were shorter than is recommended for postprocessing (about 4 min, compared with the recommended 10 to 15 min). Data shown in Appendix A (Plates A1-A7) illustrate that the short measuring time produced erroneous data points. The positions appear to be offset from the correct positions, but the relationship between the points may be correct. Therefore, the data may be usable for speed and angle of the tow but not for the impact point along the lock wall. After it was recognized that the data files were shorter than recommended, the DGPS units were set to continuously record data over several runs, producing data files of 15 to 20 min in duration. These data plots (shown in Appendix A as Plates A8-A36) show that the longer recording times corrected the offset problem and produced accurate positions.

These experiments were designed to provide an array of tow speeds and angles of impact. During the experiments, an attempt was made to measure the speed and angle of the tow to provide immediate information for planning the next series of impacts. The mobile DGPS unit provided the speed and bearing of the antenna. However, the unit is not differentially corrected and can be in error. During the initial runs it was recognized that the angle reported by the DGPS unit was not acceptable. Therefore, the Total Station was set up on the lock wall near the point of impact, and the angle of the tow approaching the wall was measured and recorded. The DGPS unit provided the only measurement of speed. Comparing the data recorded in the field with the postprocessed data shows that the method of measuring the angle provided satisfactorily for a rough measurement. However, the speed recorded in the field from the mobile DGPS units was not satisfactory.

High-speed cameras and videotape equipment

A high-speed camera and two video cameras were used to further document each impact event. The video and high-speed cameras were very valuable in capturing the barge/wall interaction during impact. The high-speed camera used for the experiments shot at 100 frames per second to capture any deformation of the barge into the lock wall. This high-speed camera and one video camera (used for redundancy of image) were mounted on a stand that was 6 ft (1.8 m) off the top of the lock wall. This stand permitted the cameras to overhang the lock wall by about 1 ft (0.3 m) such that it would have a full “unwarped” view of the impact zone set below on the lock wall. Figure 18 shows the mount with the high-speed and video cameras that overhung the lock walls. The second video camera was set up to look directly down the lock wall as the barge approached and impacted the wall. This camera was mounted 3 ft (1 m) off the top of the lock walls, on the top of the handrail.

Figure 18. High-speed camera and video camera overlooking impact point

Ultra High Molecular Weight Bumpers

The experiments used two 5-ft (1.5-m)-long ultra high molecular weight (UHMW) bumpers that were donated by UltraPoly Corporation of Los Angeles, CA. The UHMW is a very dense material, and the surface is considered to be nearly frictionless. It is currently being used at some Corps of Engineers locks to replace old miter gate timbers. The purpose of trying the UHMW bumpers was to see the effects of this type of frictionless material on barge motion (i.e., speed and angle before and after impact) versus impacts on normal lock wall concrete.

The UHMW bumpers were composed of a 2-in. (50-mm)-thick UHMW material with two 1-in. rubber backing pads. Each bumper was installed using five 1-in. anchor bolts. The holes for each anchor bolt were drilled into the concrete lock wall using qualified installation staff, as shown in Figure 19. Each bumper was installed separately to cover the impact zone. The final setup of the UHMW bumpers is shown in Figure 20.

Figure 19. Installation of bumpers on lock wall

Figure 20. Final setup of UHMW bumpers

2 Observations from Prototype Impact Experiments

Thirty-six prototype impact experiments were successfully performed at Old Lock 2 during the period August 25-29, 1997. Of these experiments, 29 were on the concrete lock wall, and 7 were on the UHMW bumpers. The experiments used the ballasted four-barge configuration and instrumentation program, as described in previous sections. The time between impacts on the lock wall (i.e., stopping and backing the flotilla about 300 yd (275 m) away from the wall and starting again) was about 7 to 10 min.

The impact zone on the lock wall was established within a range of 5 ft (1.5 m) based on the spacing of the accelerometers on the lock wall. Surprisingly, nearly 95 percent of all the impacts were within that 5-ft zone. A majority of those impacts were very near the center mark. The velocities at impact ranged from about 1 to 3 fps, and the angles of impact ranged from 5 to 27 deg. The barge velocities and angles of impact are summarized in Table 3. Figure 21 presents a plot of the velocity versus angle matrix for the impact on the lock wall; Figure 22 plots the matrix for impact on the UHMW bumpers. The survey time plots of the barges approaching and impacting the wall are shown in Appendix A.

Since no direct impact loads or forces were measured during these experiments, it is difficult to directly quantify the data that were collected. All the data have been reviewed qualitatively to get a better understanding of how well or effectively the instrumentation performed during these experiments. The valuable information collected here will greatly assist with the planning of any future full-scale barge impact experiments. In addition, possibly some of the data recorded (after postprocessing and filtering) might be used for numerical model calibration in the future. Listed below are some of the observations that can be made regarding the instrumentation for the experiments:

- Of the greatest interest, the clevis pin load cells that measured the forces in the lashing parts performed extremely well. They gave a good feel as to what happens to the lashing systems before, during, and after impact. It was interesting to note both the positive and slack responses (i.e., tension and quasi-compression in lashings) of the various locations on the flotilla during the impact sequence.

- The strain gages indicated elastic performance of the barge corner. This meant that the top deck plate never went into a plastic mode. That was not expected to occur during the experiments but was confirmed by these strain gages. These data were also reinforced by information from the high-speed camera, which showed that no deformation was present in the barge corner. In addition, the strain data might also be used as possible calibration data for a new numerical model.

- The accelerometers collected excellent data, especially after replacing and decreasing their g-level before Experiment 4. It is hoped that these data will be very useful in future calibration of new numerical models.

- UHMW bumpers showed that the speed of a barge can be directed dramatically downstream while absorbing some energy. This type of material holds a lot of promise for use in the barge impact arena for locks. However, the attachment of the UHMW material to the concrete is important, as witnessed during Experiment 29 when the top UHMW bumper was impacted at the end and the entire bumper fell into the river. This result from Experiment 29 is shown in Figure 23.

The data that were collected during these experiments can be used for calibration purposes after a new numerical model has been developed for barge impact. However, since the data trends are important in understanding how and if the instrumentation worked, Appendix B is included in this document to show the raw data plots for the instrumentation. [***Caveat to the reader:*** The data in Appendix B have not been processed *in any way*. Any further interpretation of the data may be left to possible misinterpretation by those unfamiliar with how the data were recorded and the type of instrumentation that was used to collect the data.]

Table 3
Barge Impact Angles and Velocities

Date Performed	Experiment Number	Velocity at Impact (fps)	Angle at Impact (deg)
27 Aug 97	1	n/a	n/a
	2	n/a	n/a
	3	n/a	n/a
	4	n/a	n/a
28 Aug 97	5	n/a	n/a
	6	n/a	n/a
	7	n/a	n/a
	8	2.91	8.3
	9	2.46	9.5
	10	2.88	5.5
	11	1.98	11
	12	n/a	n/a
	13	1.12	19.25
	14	1.22	27.3
	15	1.66	11.1
	16	1.79	13.2
	17	1.42	27.5
	18	2.02	14.75
	19	2.31	11.5
	20	2.68	10.25
	21	2.47	15.5
	22	2.38	21.5
	23	2.52	16.25
	24	2.72	11.75
	25	3.20	10.5
29 Aug 97	26[1]	1.63	9
	27	2.60	10.25
	28	3.02	12.75
	29	2.41	18.5
	30	2.92	10.5
	31	3.16	14.5
	32	3.32	15
	33[2]	1.77	25.25
	34	3.02	11.5
	35	2.78	13.75
	36	2.44	3.5

Note: “n/a” means that GPS data were not properly recorded in field, and impact data were lost.
[1] Experiments 26-32 were on ultra high molecular weight bumpers.
[2] Experiments 33-36 were performed to test accelerometer ranges.

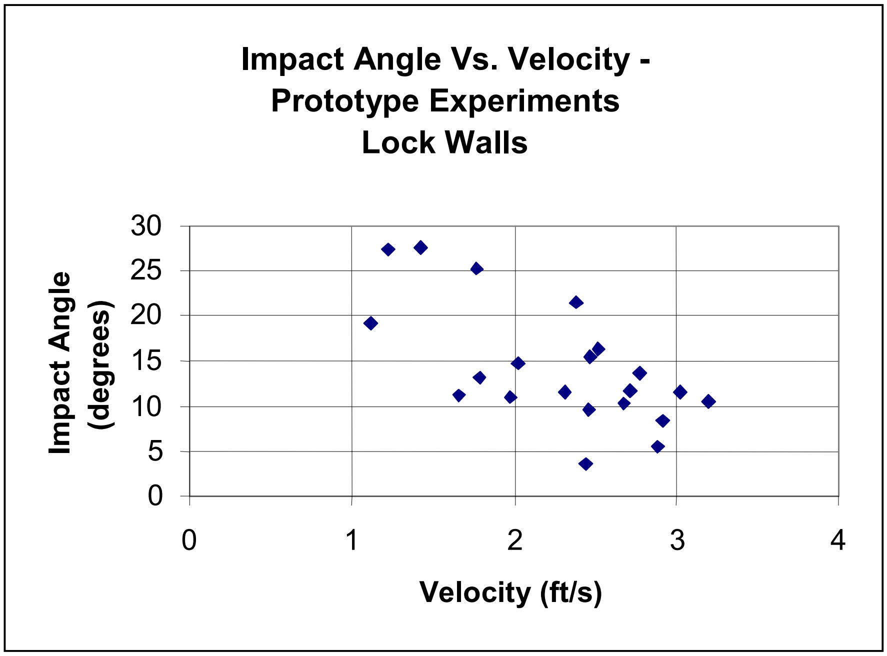


Figure 21. Impact versus velocity for impacts on lock wall

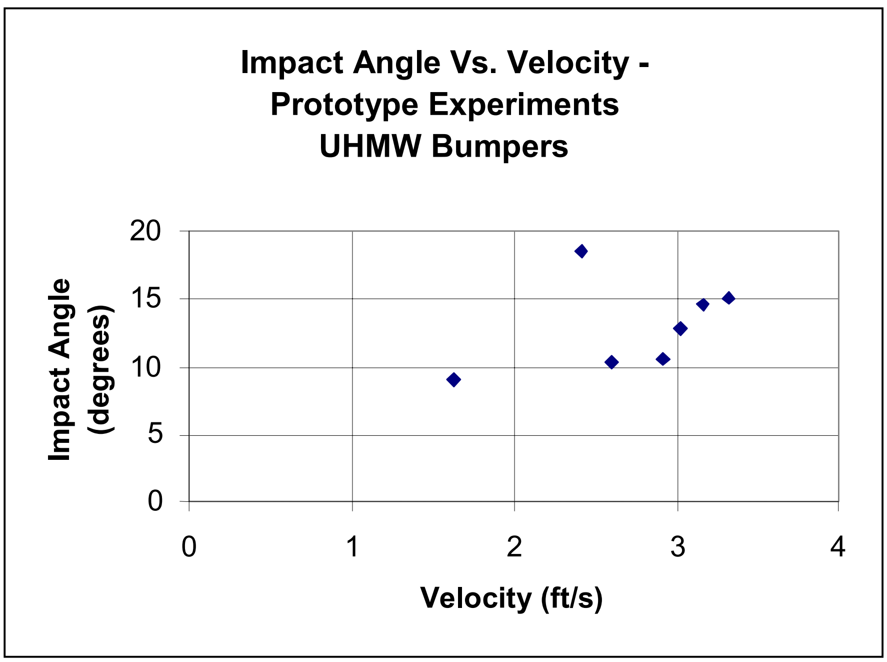


Figure 22. Impact versus velocity for impacts on UHMW bumpers

Figure 23. UHMW bumpers after Experiment 29

3 Conclusions and Recommendations

Overall, the prototype experiments were very valuable in providing a better understanding of the complex dynamics involved during the barge-wall collision. While actual barge impact loads were not quantified during these experiments, these efforts assisted greatly with defining the instrumentation that was required in the follow-up full-scale experiments also conducted under the Innovations for Navigation Projects Research Program. In addition, the use of UHMW plastic material indicated a positive translation of velocity to a downstream component that may cause lower impact forces.

The recommendations from these prototype experiments for the full-scale experiments are as follows:

a. Re-range accelerometer and add accelerometer locations to capture a wider scope of expected movements of the entire barge system.

b. Use larger load clevis pins among the landing (port) string of barges, and use the smaller pins for interior lashed connections.

c. Build an actual load-measurement device that measures the normal impact load between the barge and wall.

d. Perform experiments using both a baseline barge and a load-measurement barge using similar instrumentation.

e. Build and test a prototype fendering system using UHMW plastics to absorb and redirect the energy of the barge system.

f. Use real-time GPS to determine impact velocities and angles to fulfill a complete matrix of controlled impact events.

Appendix A
DGPS Survey Plots

The processed and corrected survey plots from the Trimble DGPS (differential global positioning system) are shown in Appendix A. The tracking plots show the approach to the wall and location of the impact on the lock wall. The plots show the movement of the barge to the wall over 3 sec before impact to the wall. All measurements in the plots are in meters. If “squiggly” lines are present in the plots, this indicates that the processed DGPS data were in error, and no speed or angle could be calculated from the recorded data.

Plates A1-A36 are plots of barge impact angle and velocity for prototype Experiments 1-36.

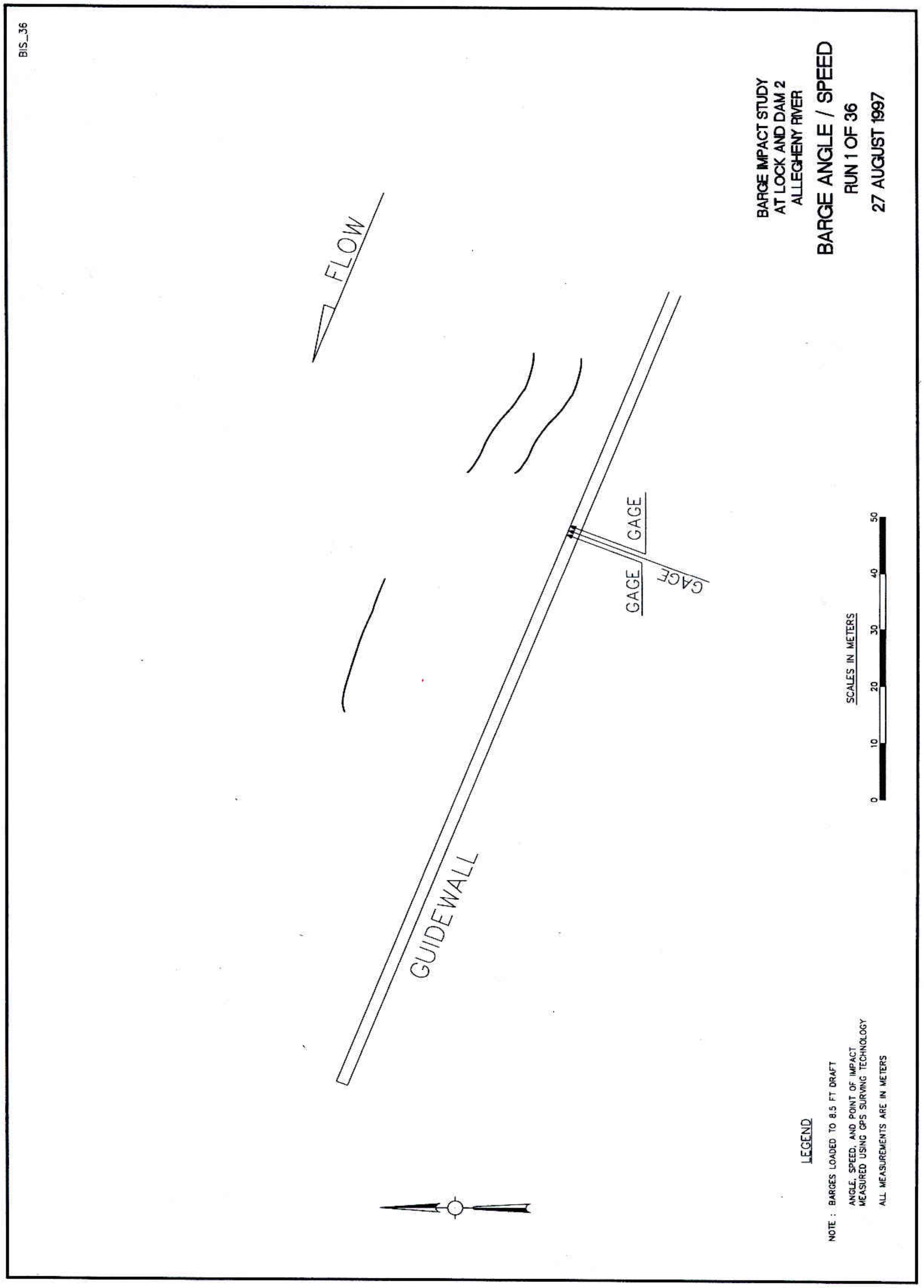

BIS_36
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 1 OF 36
27 AUGUST 1997
FLOW
GUIDEWALL
GAGE
GAGE
GAGE
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A1

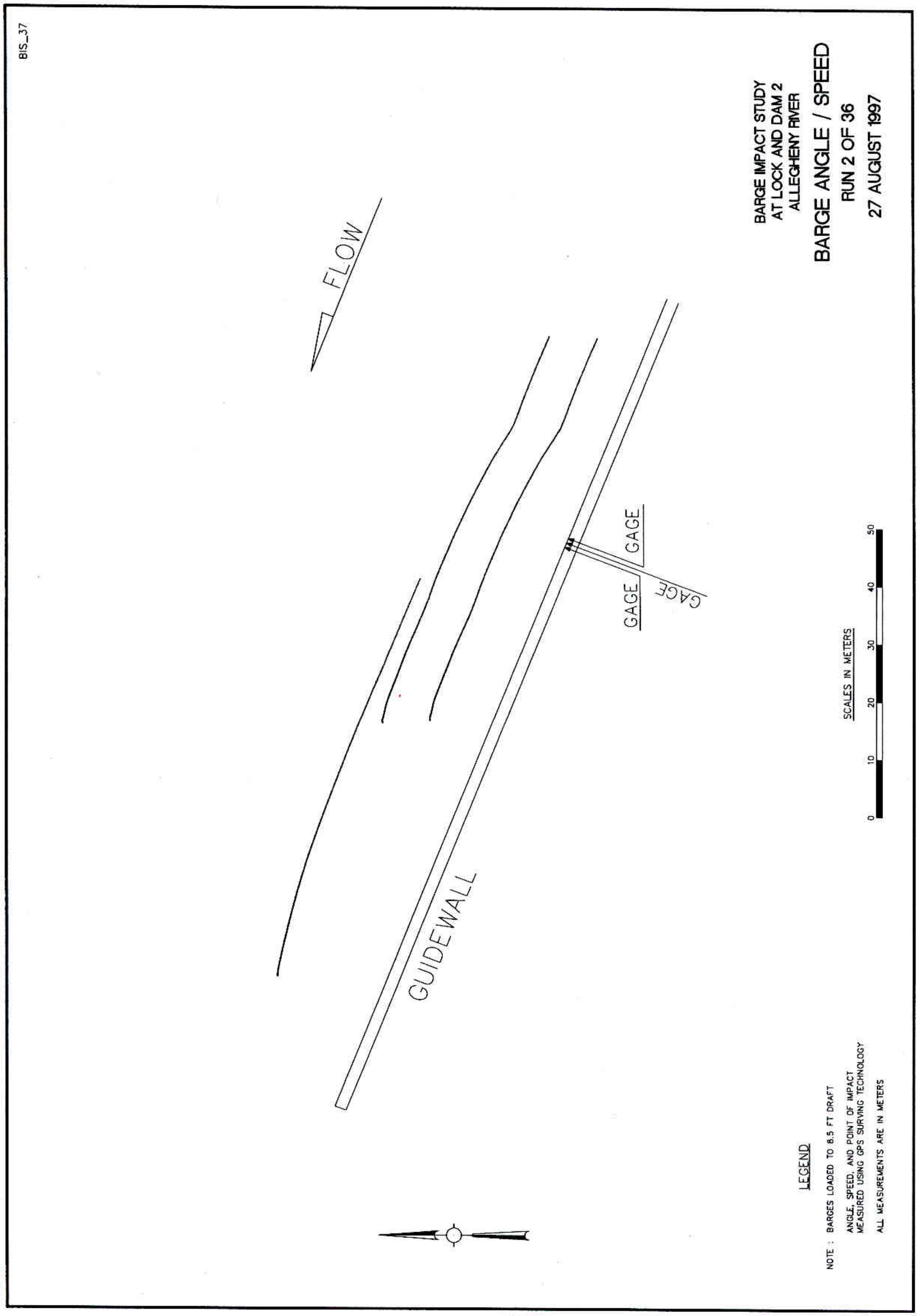

BIS_37
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 2 OF 36
27 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A2

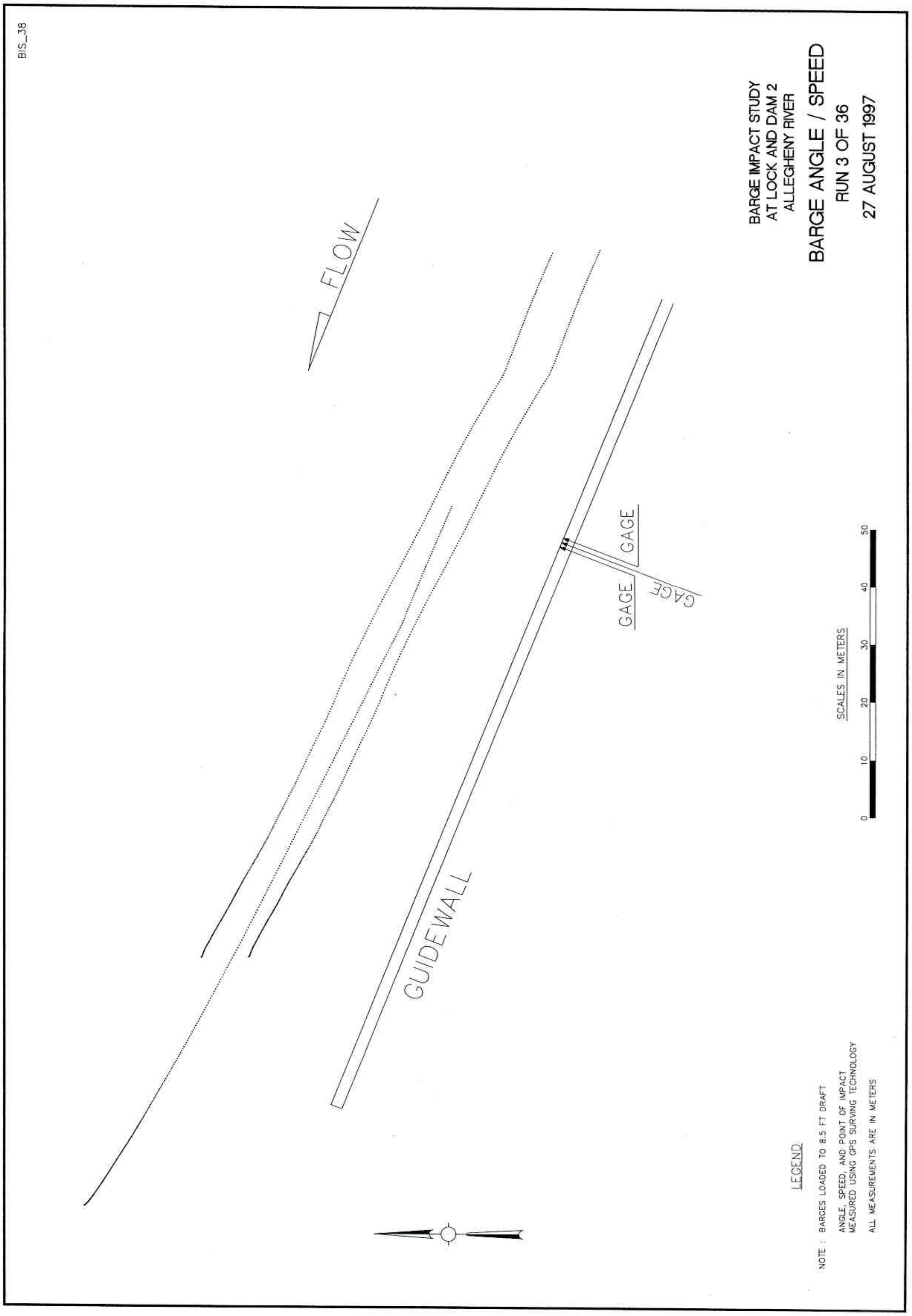

BIS_38
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 3 OF 36
27 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
GUIDEWALL
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A3

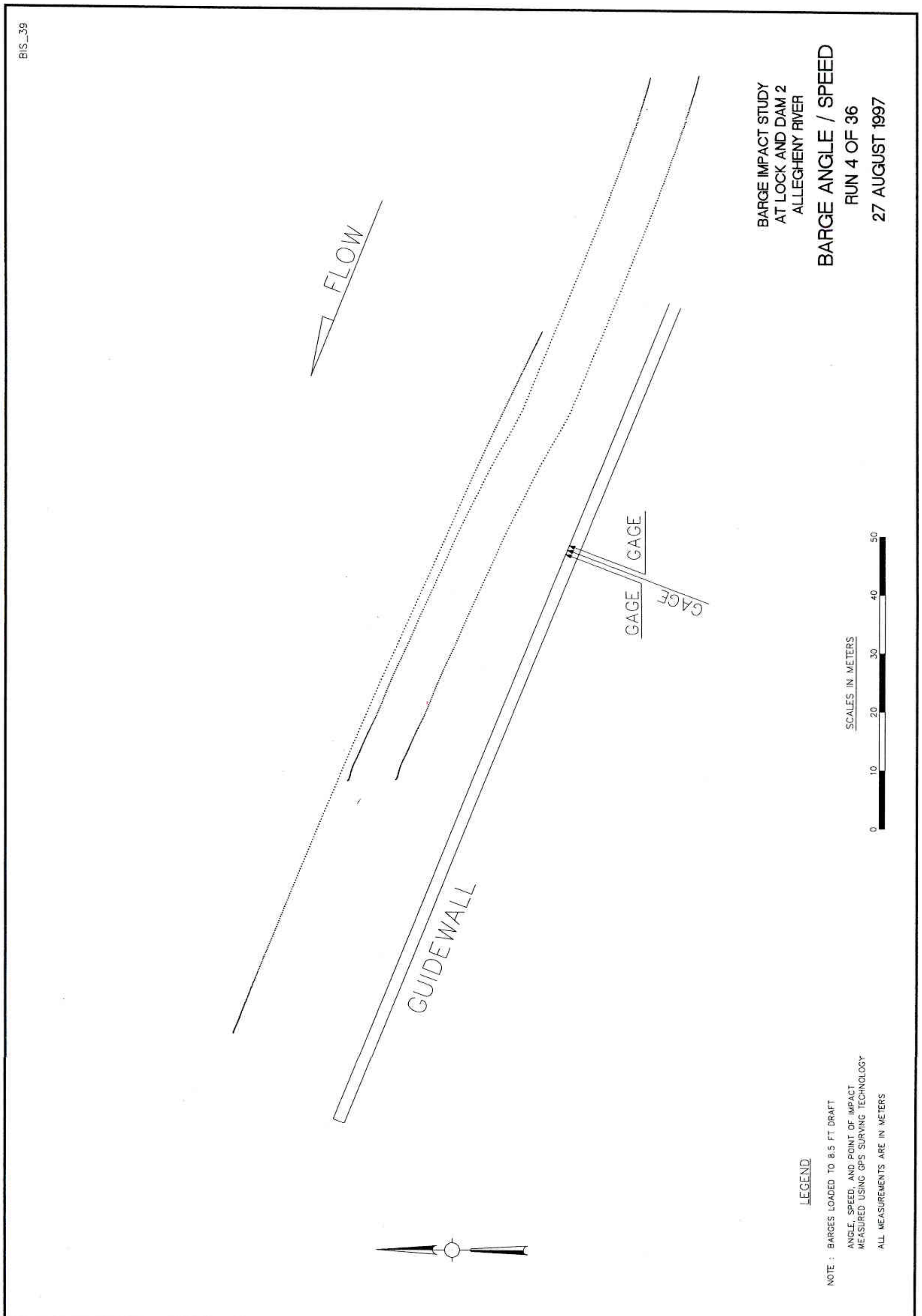

BIS_39
FLOW
GUIDEWALL
GAGE
GAGE
GAGE
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 4 OF 36
27 AUGUST 1997
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A4

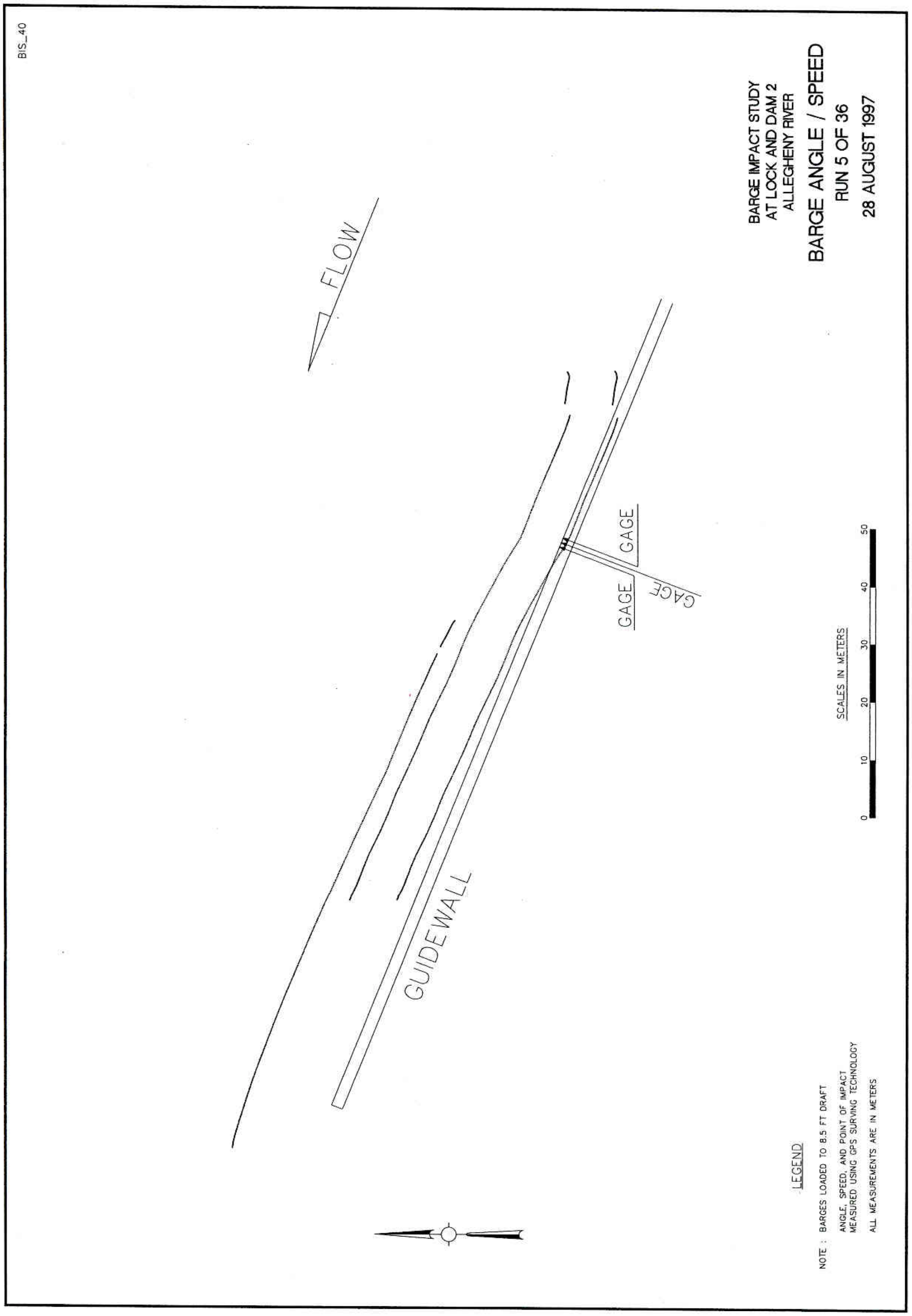

BIS_40
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 5 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
GUIDEWALL
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A5

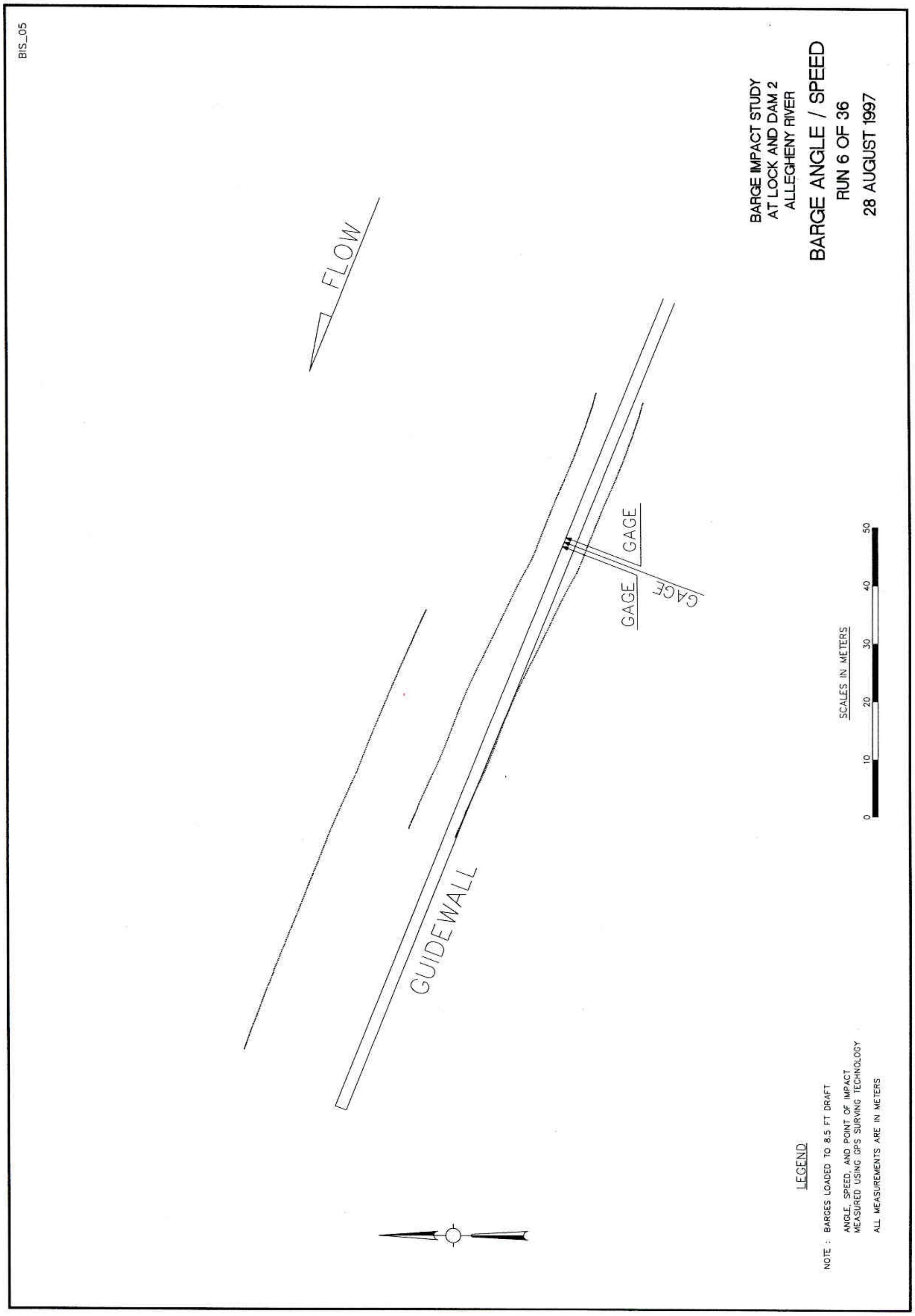

BIS_05
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 6 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
GUIDEWALL
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A6

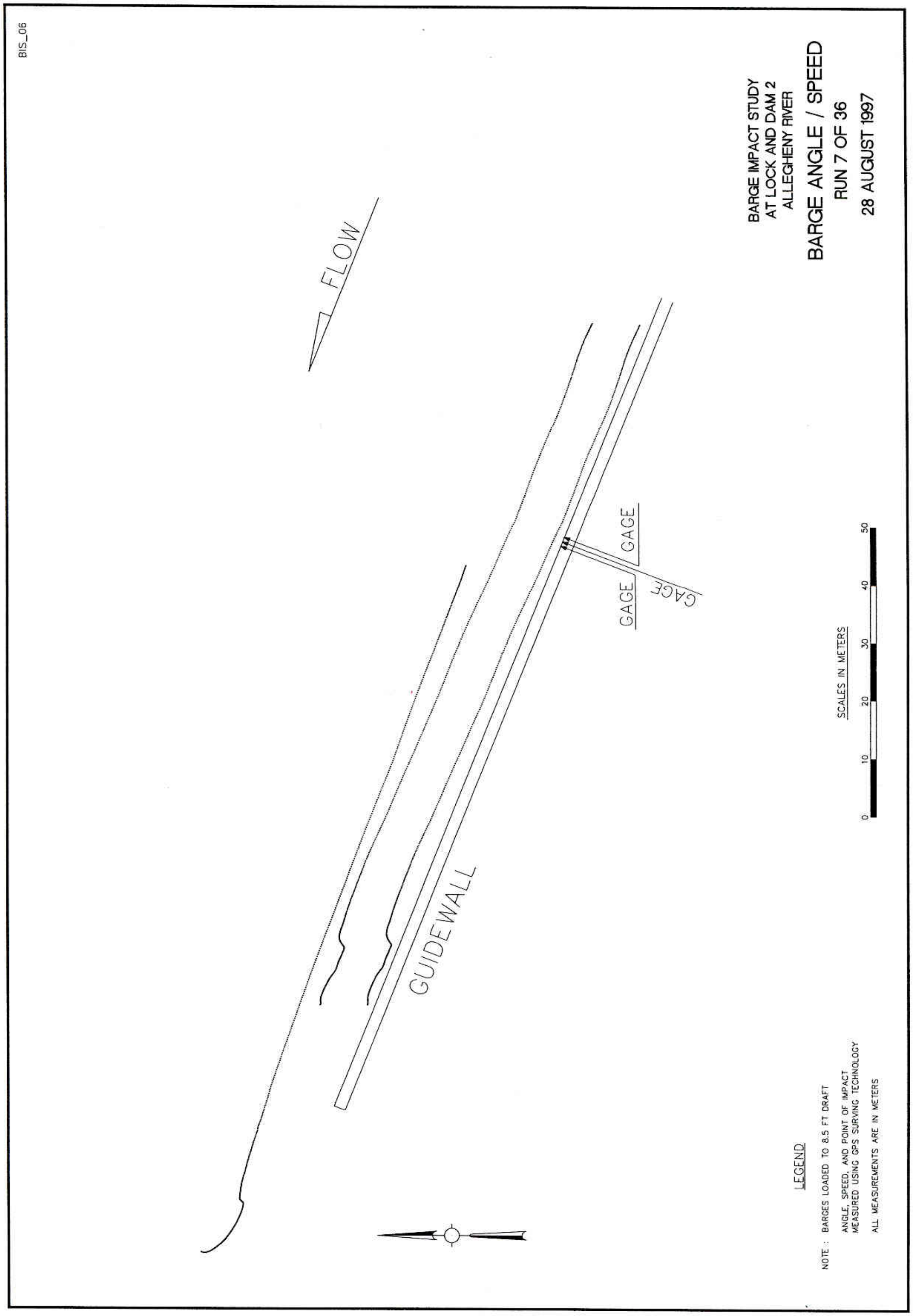

BIS_06
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 7 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A7

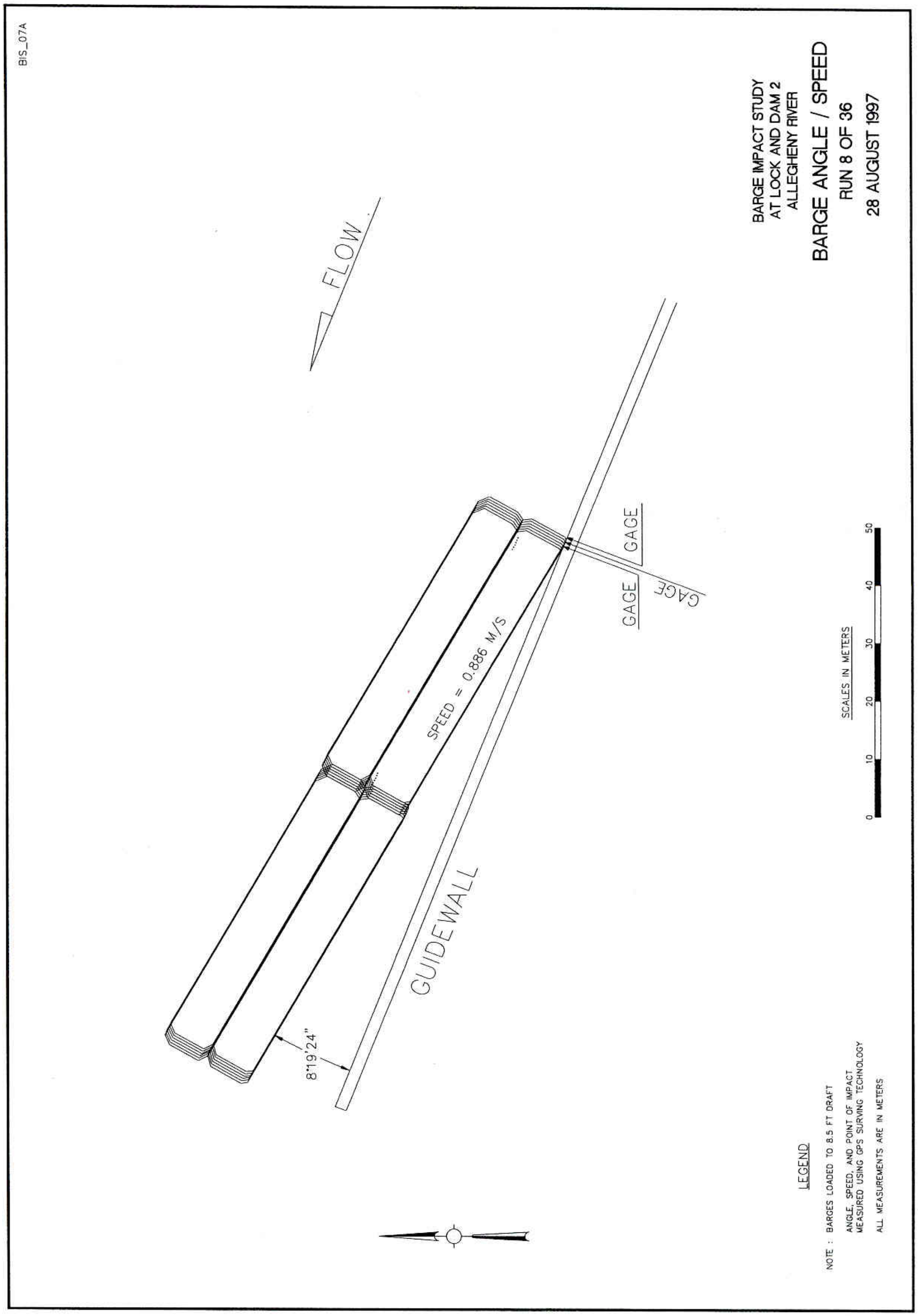

BIS_07A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 8 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.886 M/S
GUIDEWALL
8°19'24"
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A8

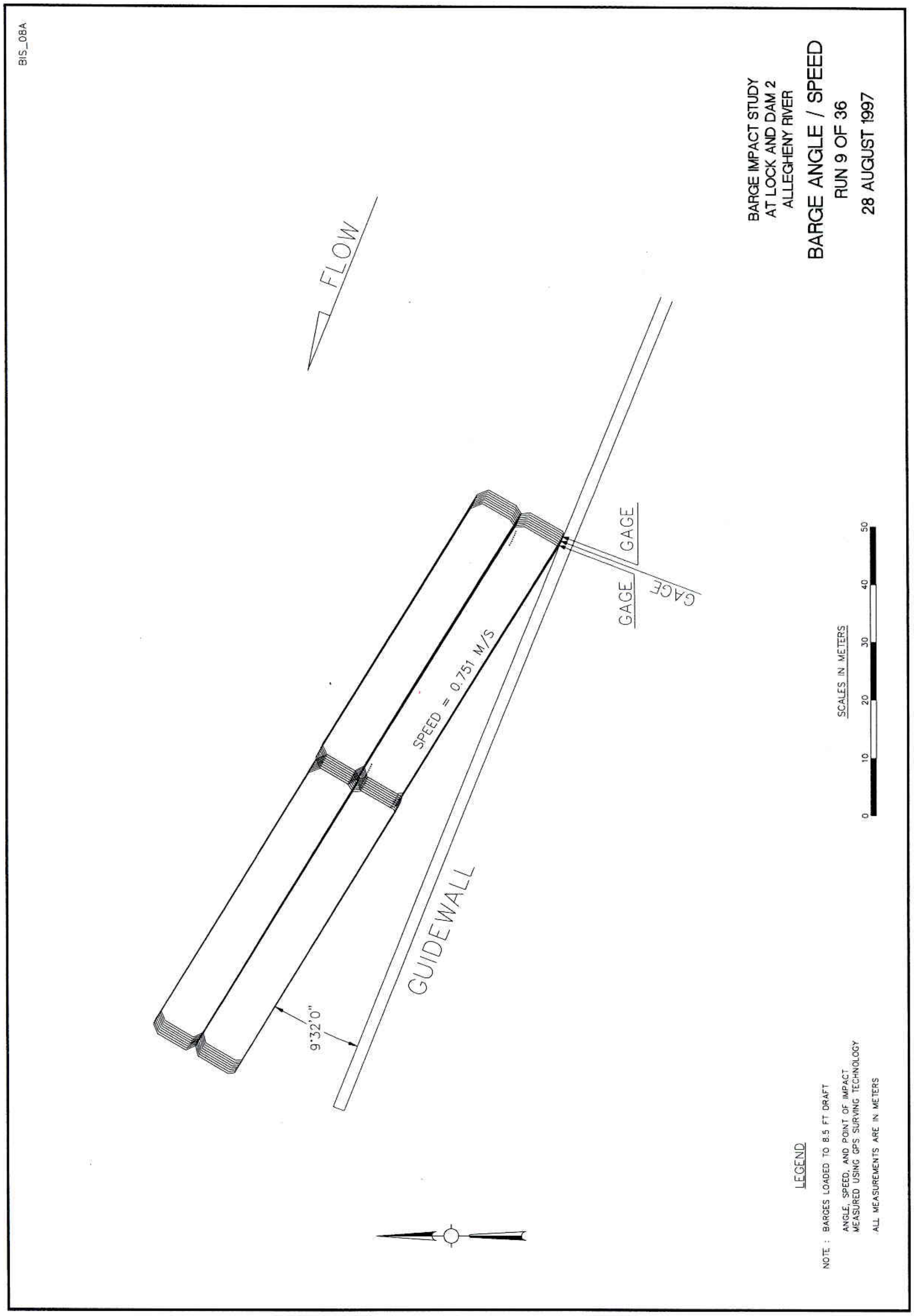

BIS_08A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 9 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.751 M/S
GUIDEWALL
9°32'0"
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A9

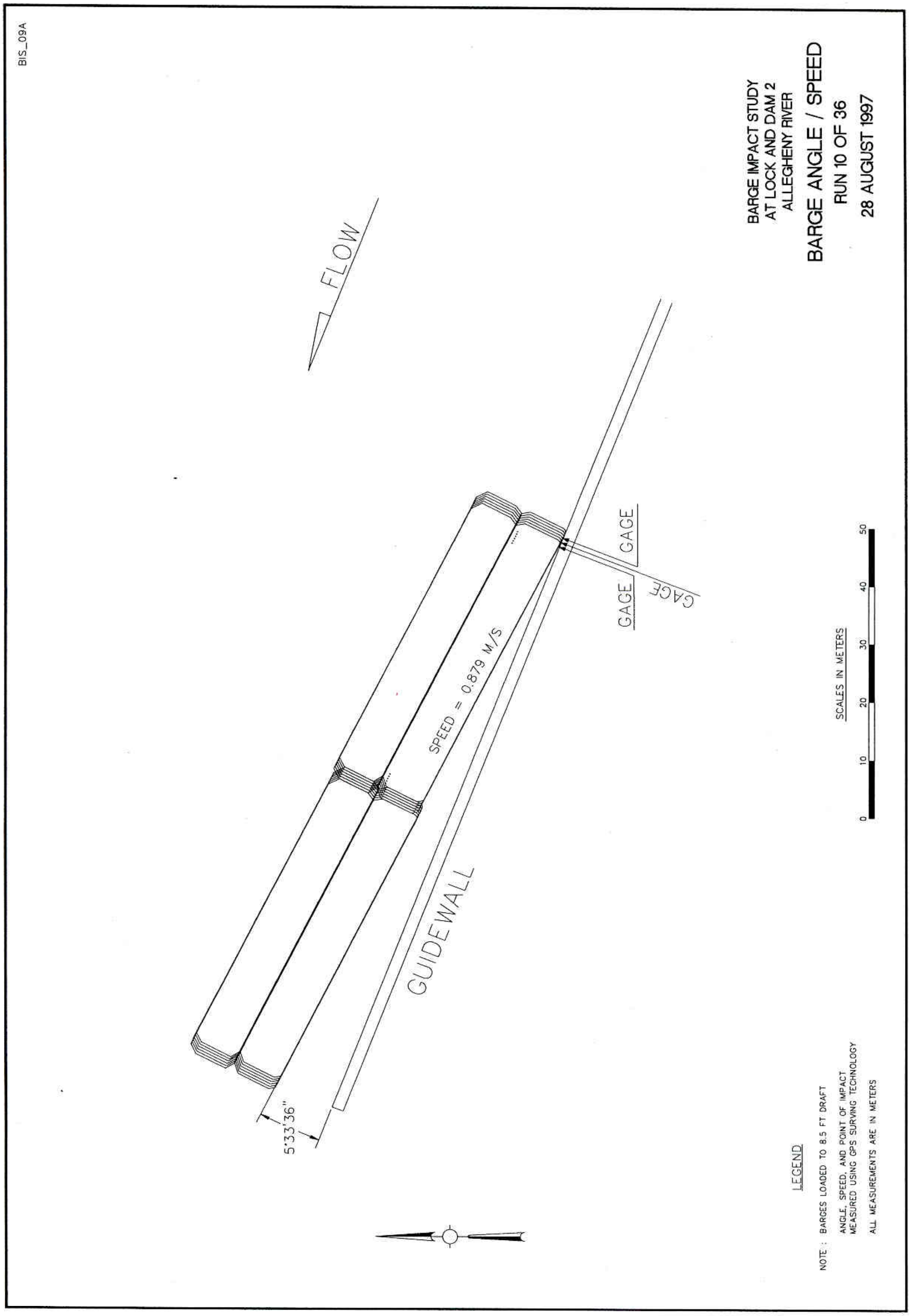

BIS_09A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 10 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.879 M/S
GUIDEWALL
5°33'36"
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A10

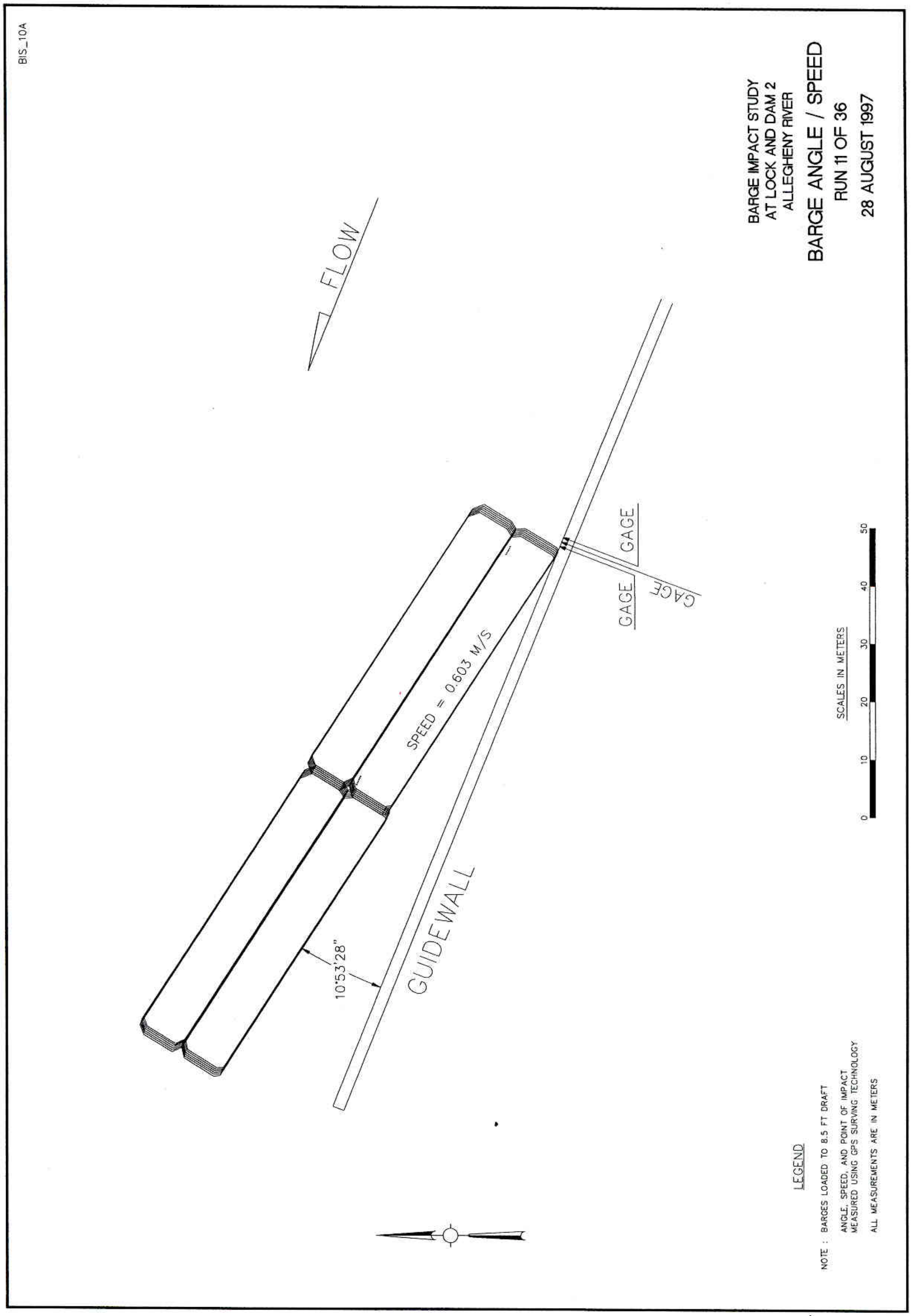
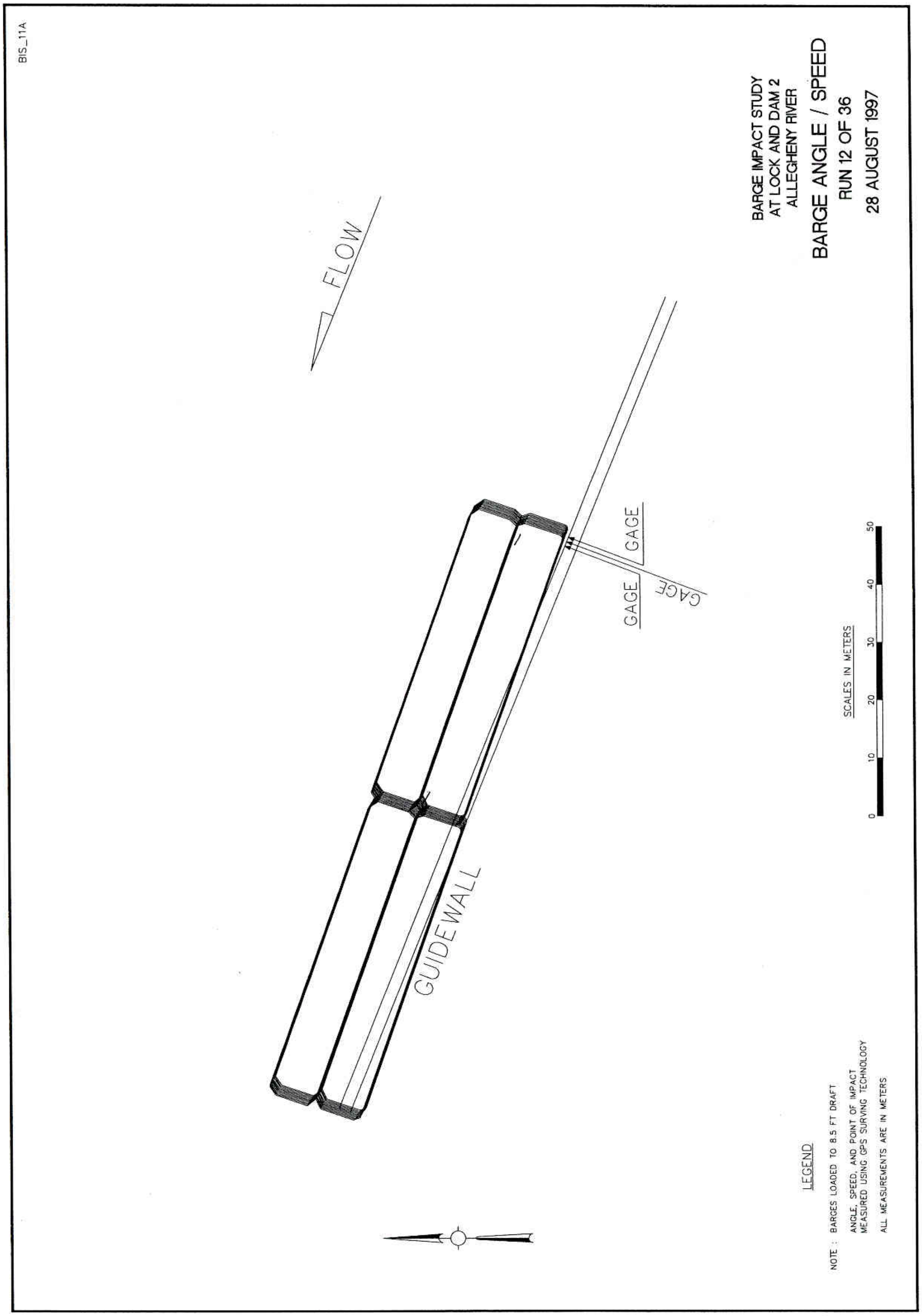

BIS_10A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 11 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.603 M/S
GUIDEWALL
10°53'28"
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A11



BIS_11A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 12 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A12

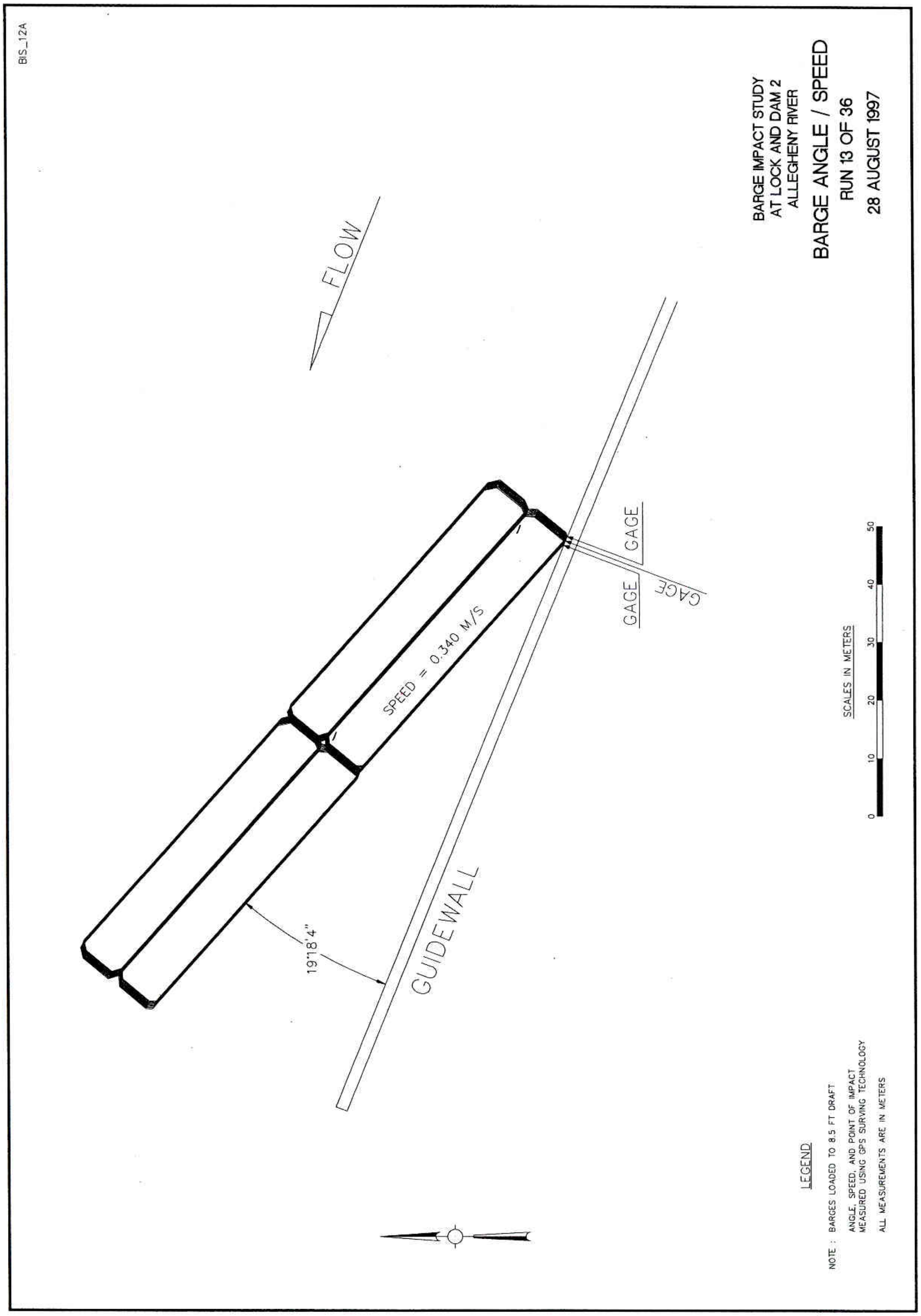

BIS_12A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 13 OF 36
28 AUGUST 1997
FLOW
SPEED = 0.340 M/S
19°18'4"
GUIDEWALL
GAGE
GAGE
GAGE
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A13

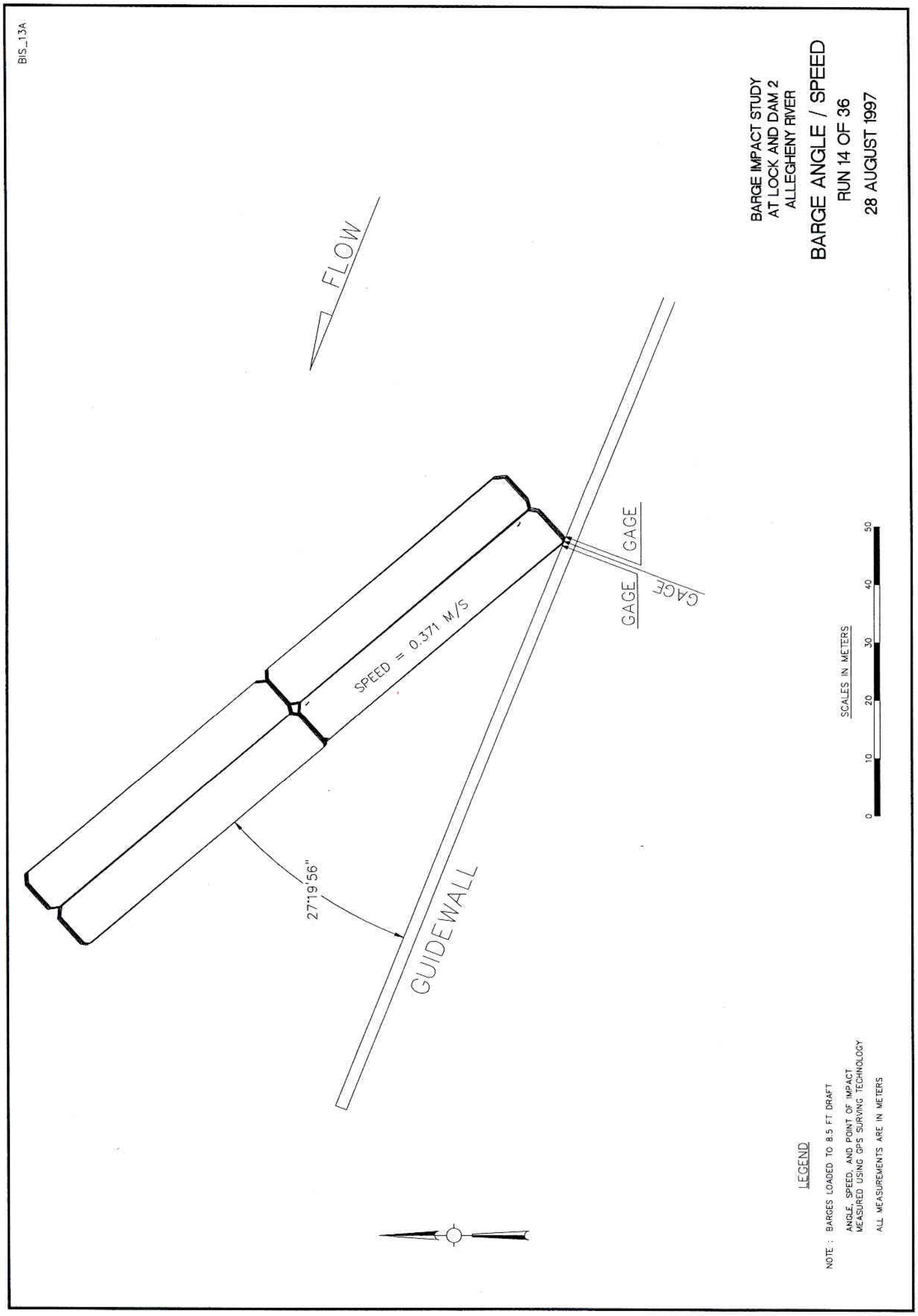
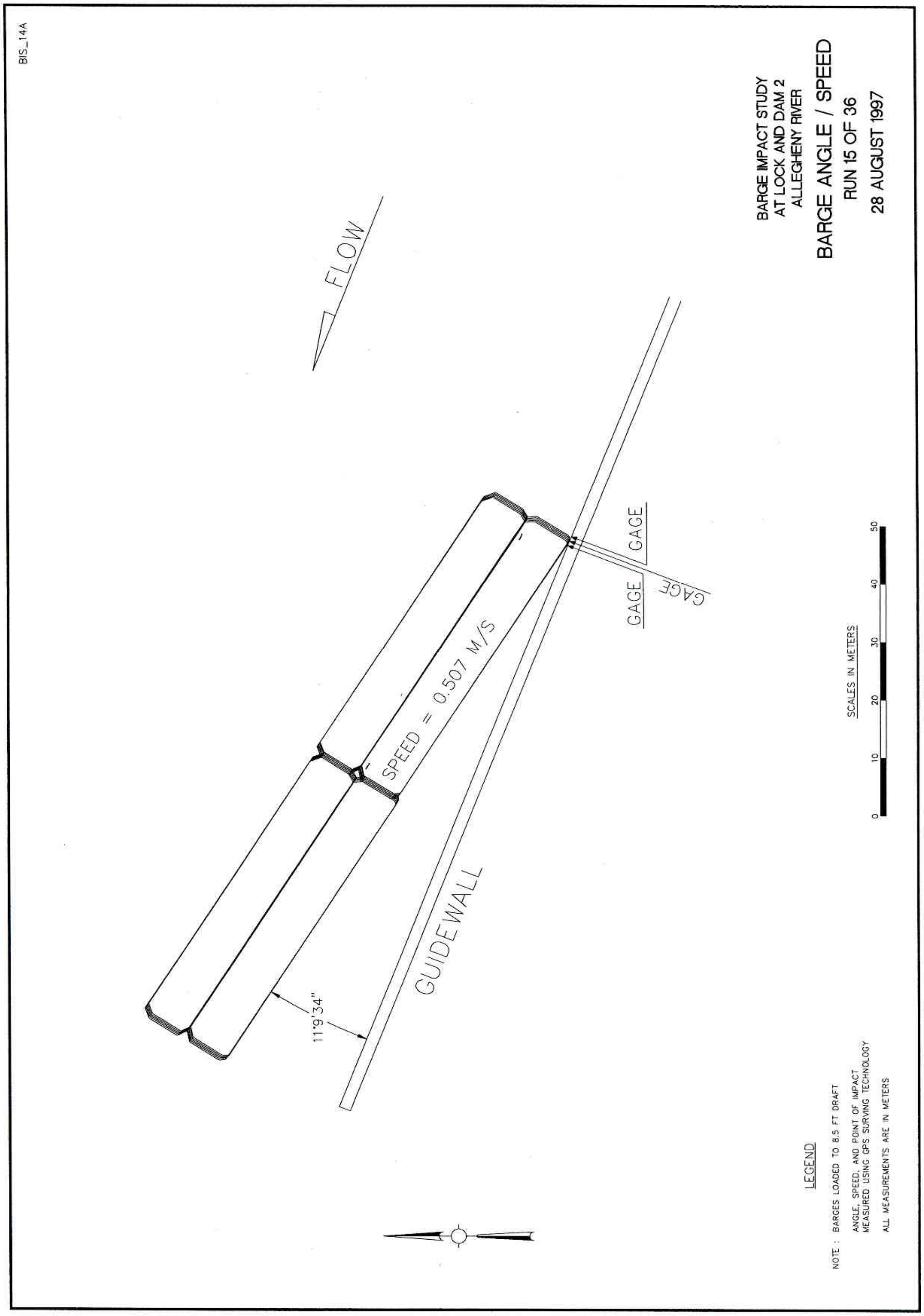

BIS_13A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 14 OF 36
28 AUGUST 1997
FLOW
SPEED = 0.371 M/S
GAGE
GAGE
GAGE
GAGE
27°19'56"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A14


BIS_14A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 15 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.507 M/S
GUIDEWALL
11°9'34"
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS
Plate A15

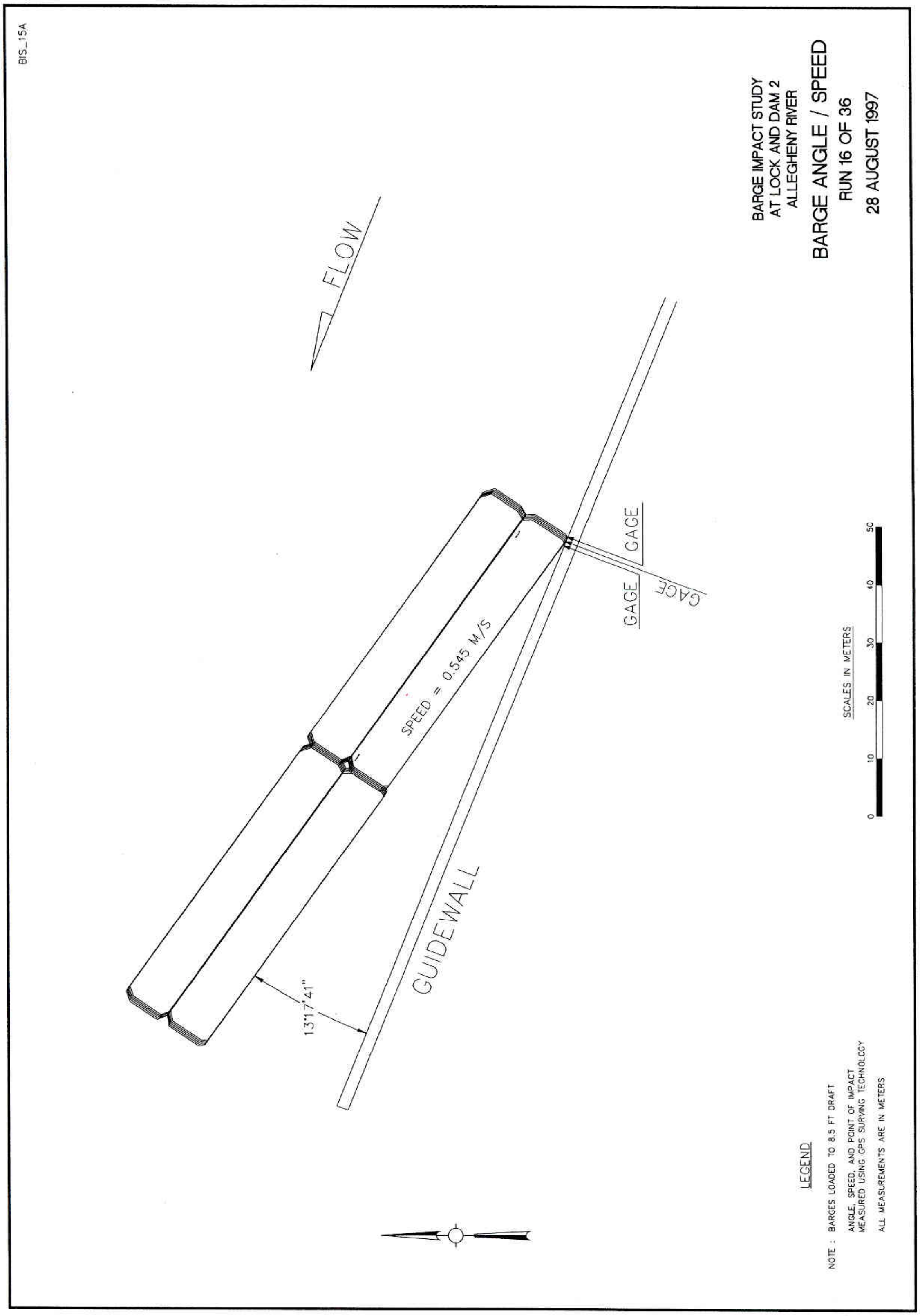
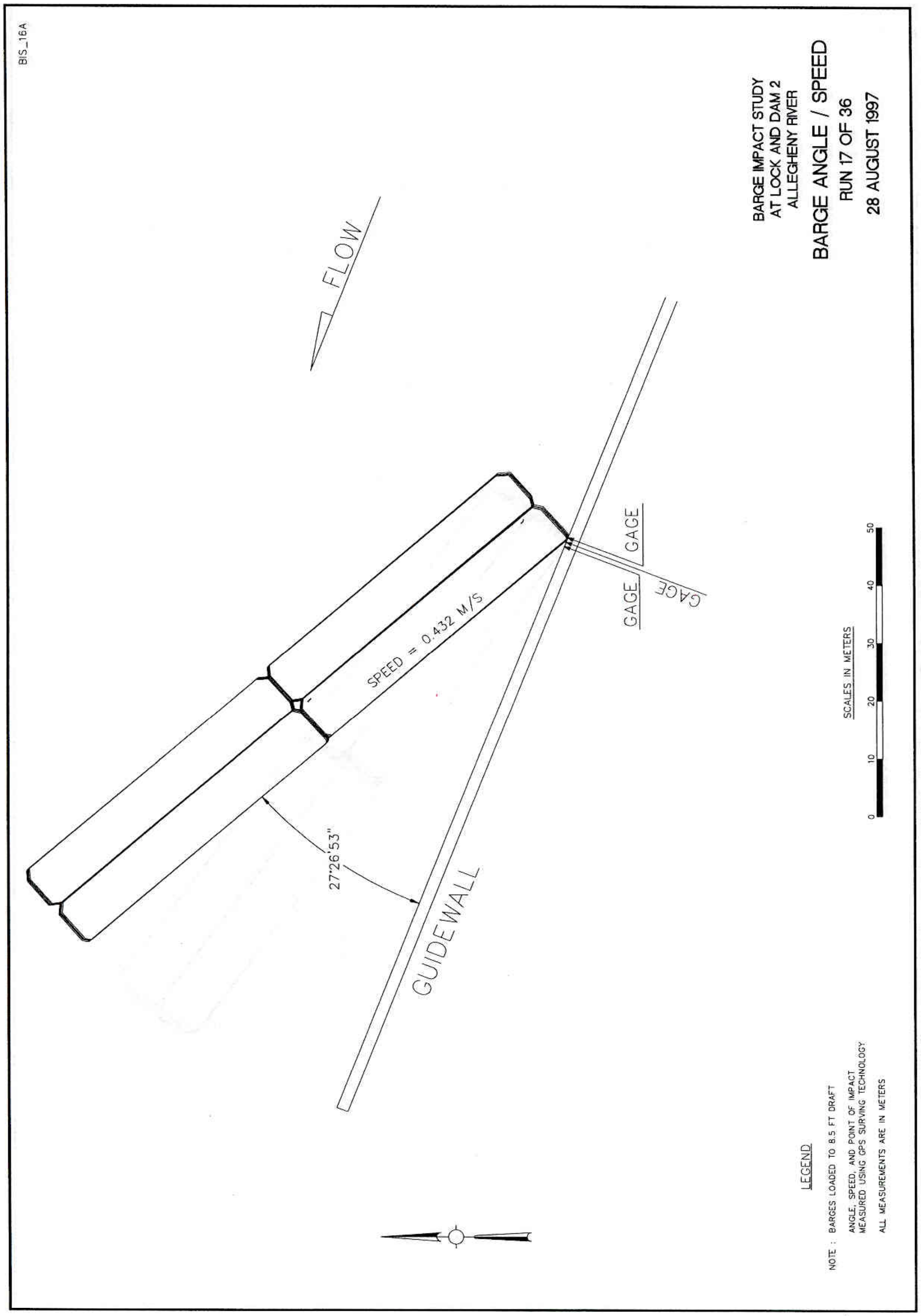

BIS_15A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 16 OF 36
28 AUGUST 1997
FLOW
SPEED = 0.545 M/S
GAGE
GAGE
GAGE
GUIDEWALL
13°17'41"
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A16



BIS_16A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 17 OF 36
28 AUGUST 1997
FLOW
SPEED = 0.432 M/S
GAGE
GAGE
GAGE
27°26'53"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A17

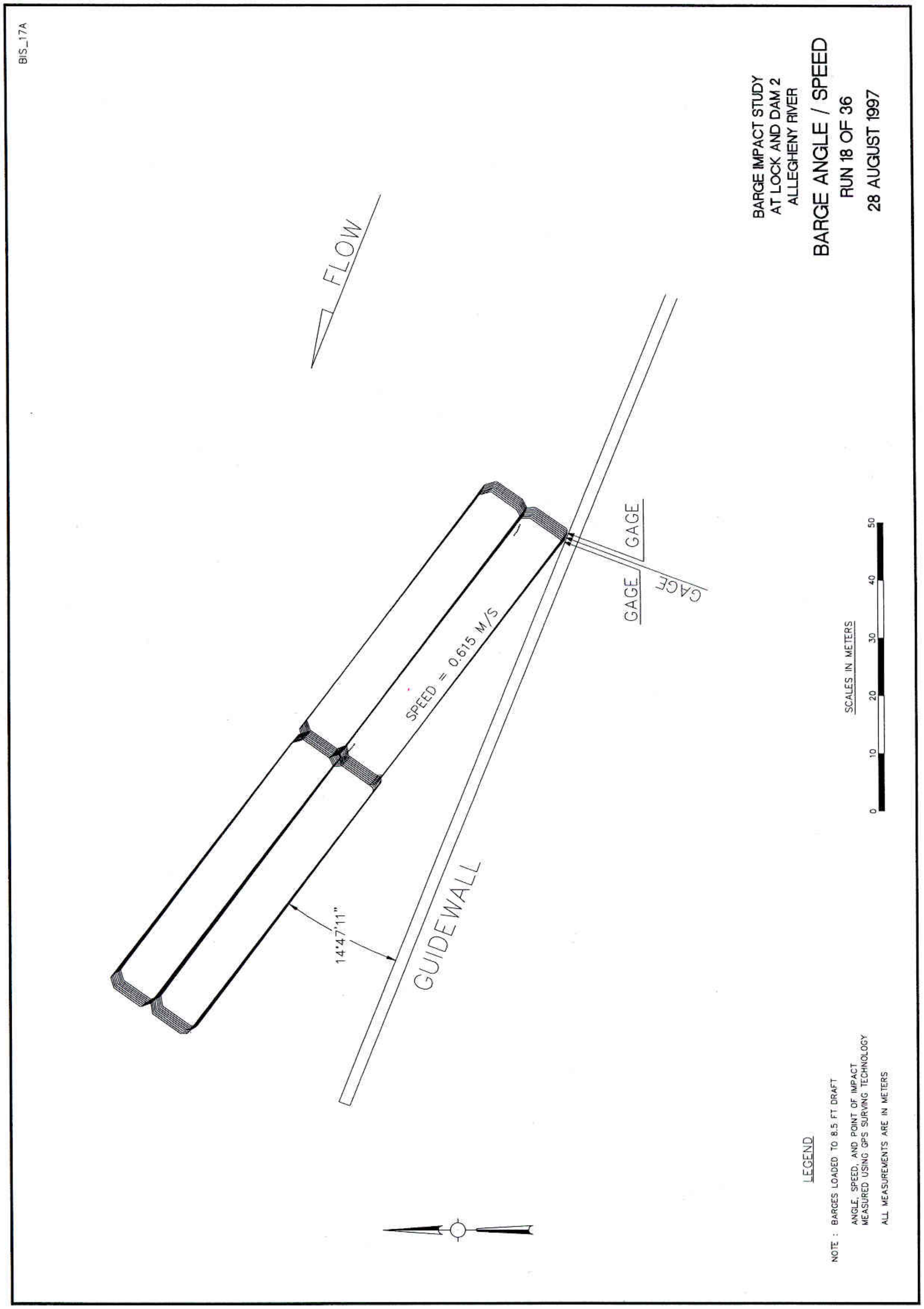

BIS_17A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 18 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.615 M/S
14°47'11"
GUIDEWALL
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A18

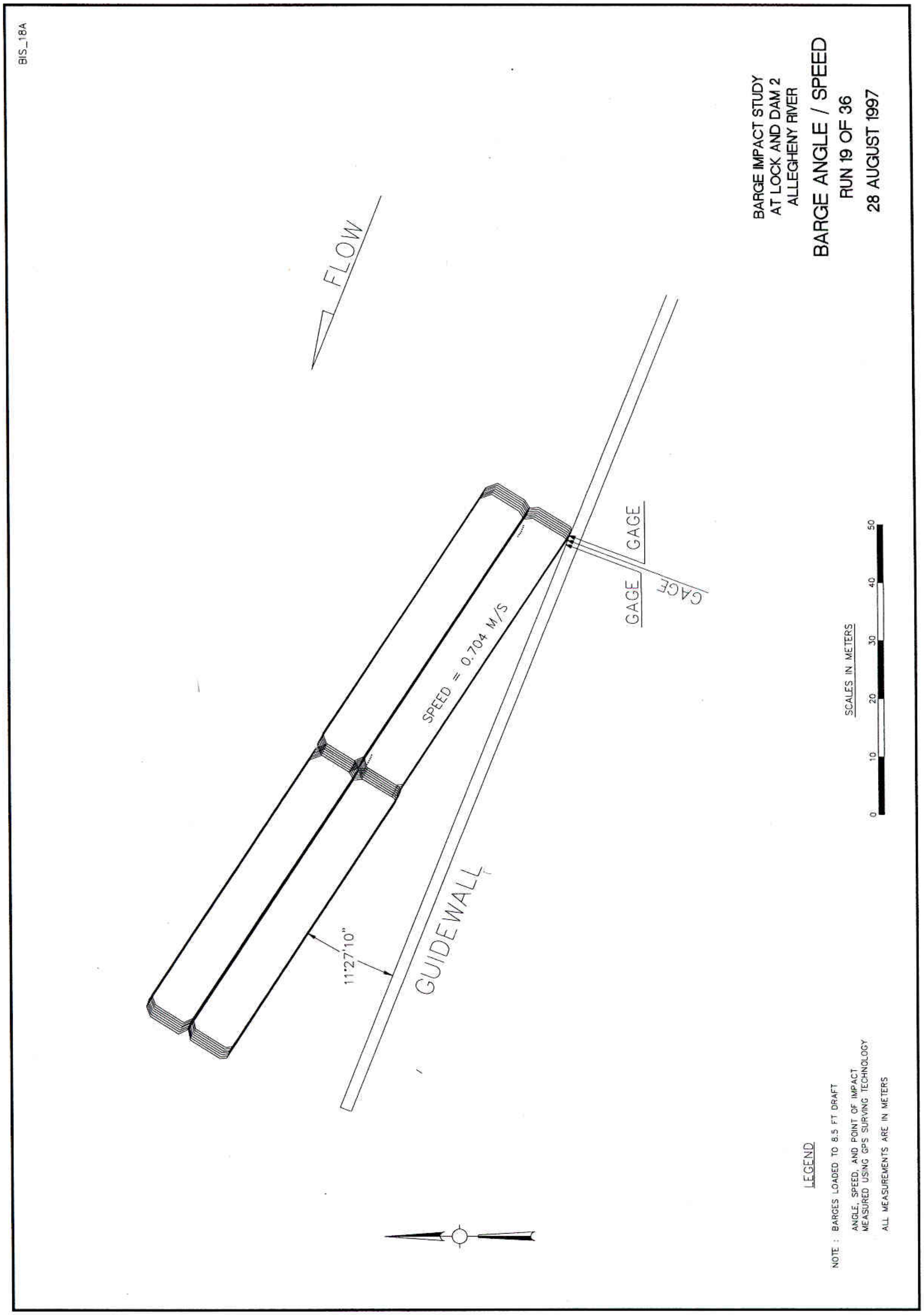

BIS_18A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 19 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.704 M/S
11°27'10"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A19

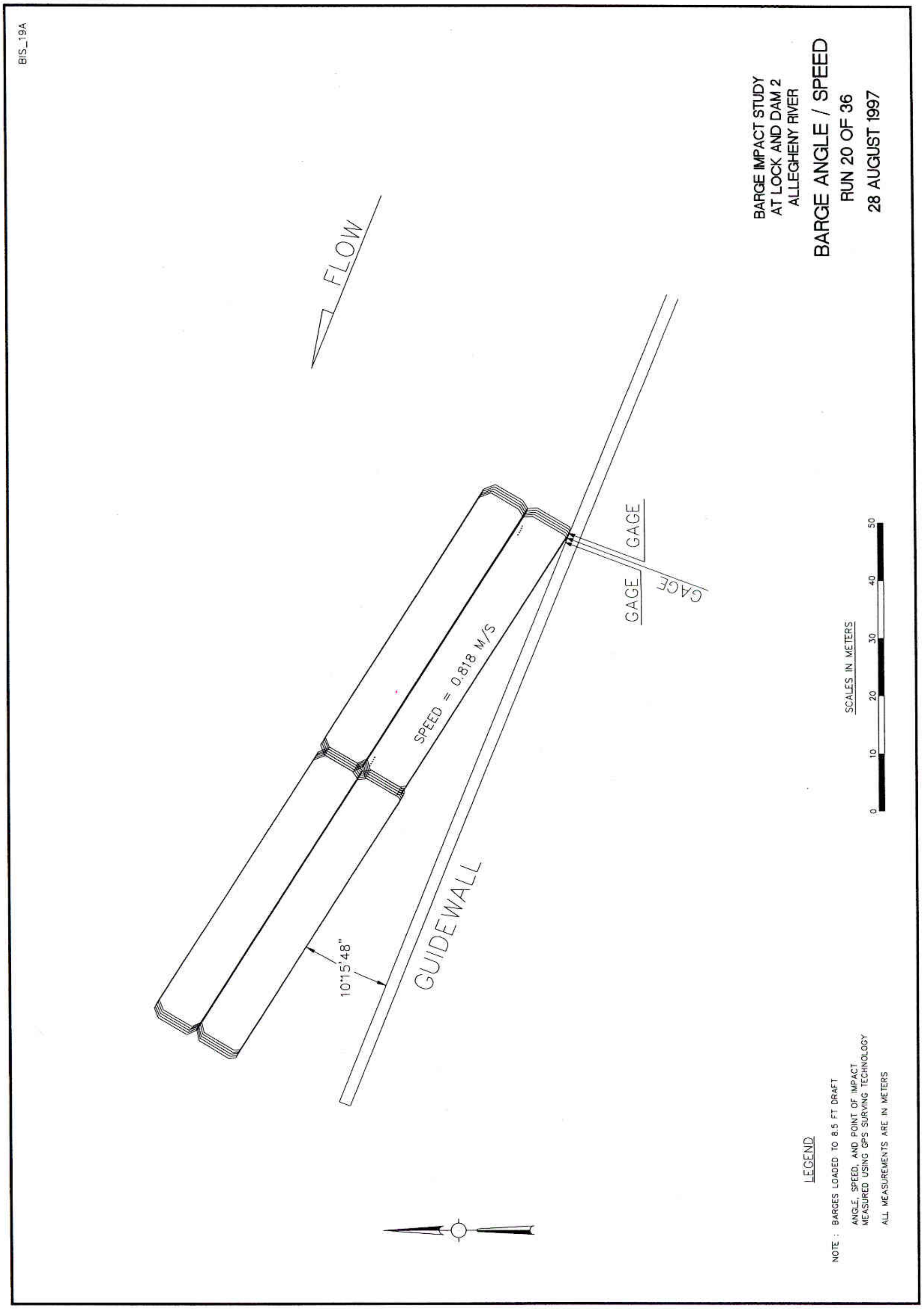

BIS_19A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 20 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.818 M/S
GUIDEWALL
10°15'48"
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A20

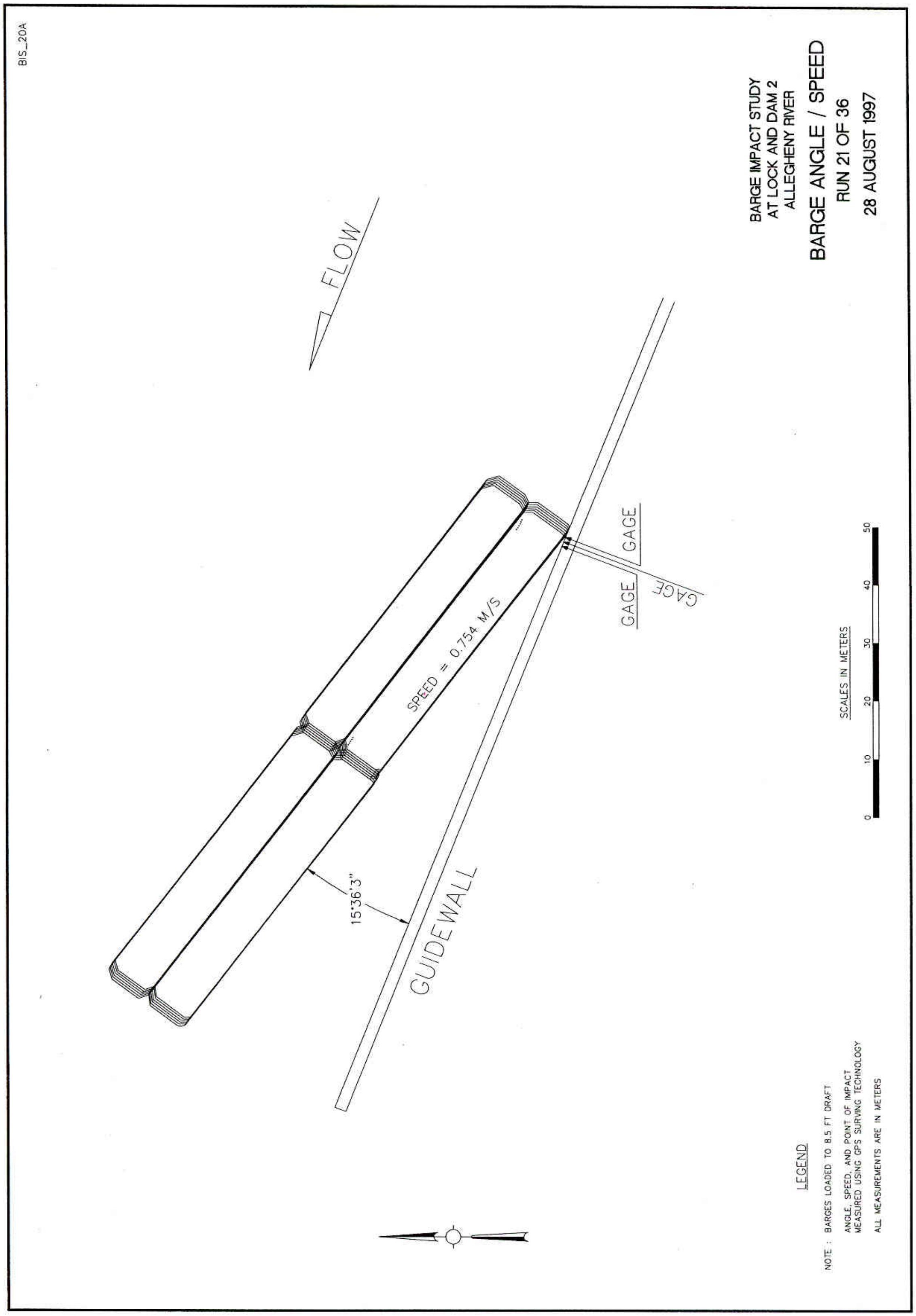

BIS_20A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 21 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.754 M/S
15°36'3"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A21

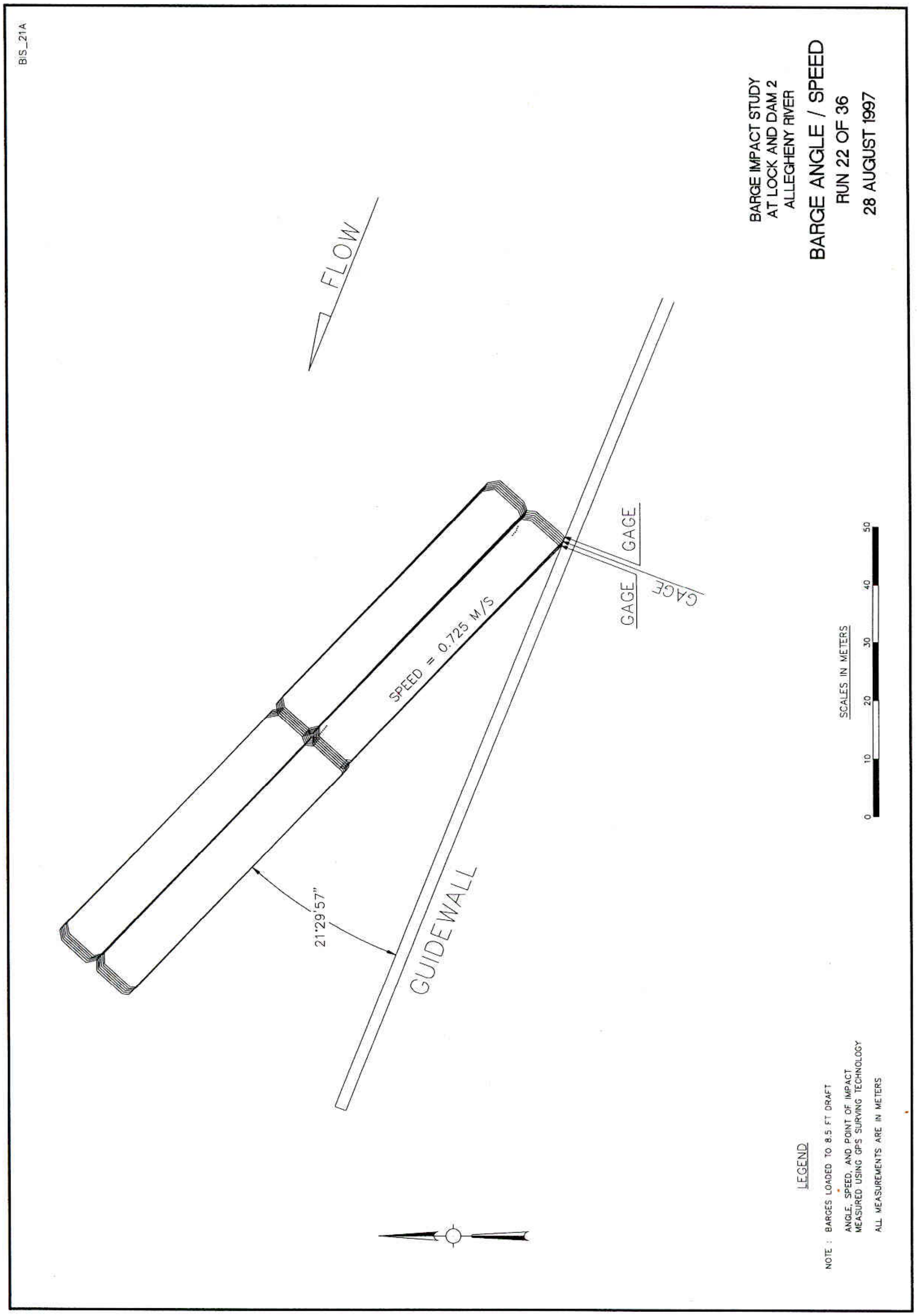

BIS_21A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 22 OF 36
28 AUGUST 1997
FLOW
SPEED = 0.725 M/S
GAGE
GAGE
GAGE
GUIDEWALL
21°29'57"
SCALES IN METERS
0 10 20 30 40 50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A22

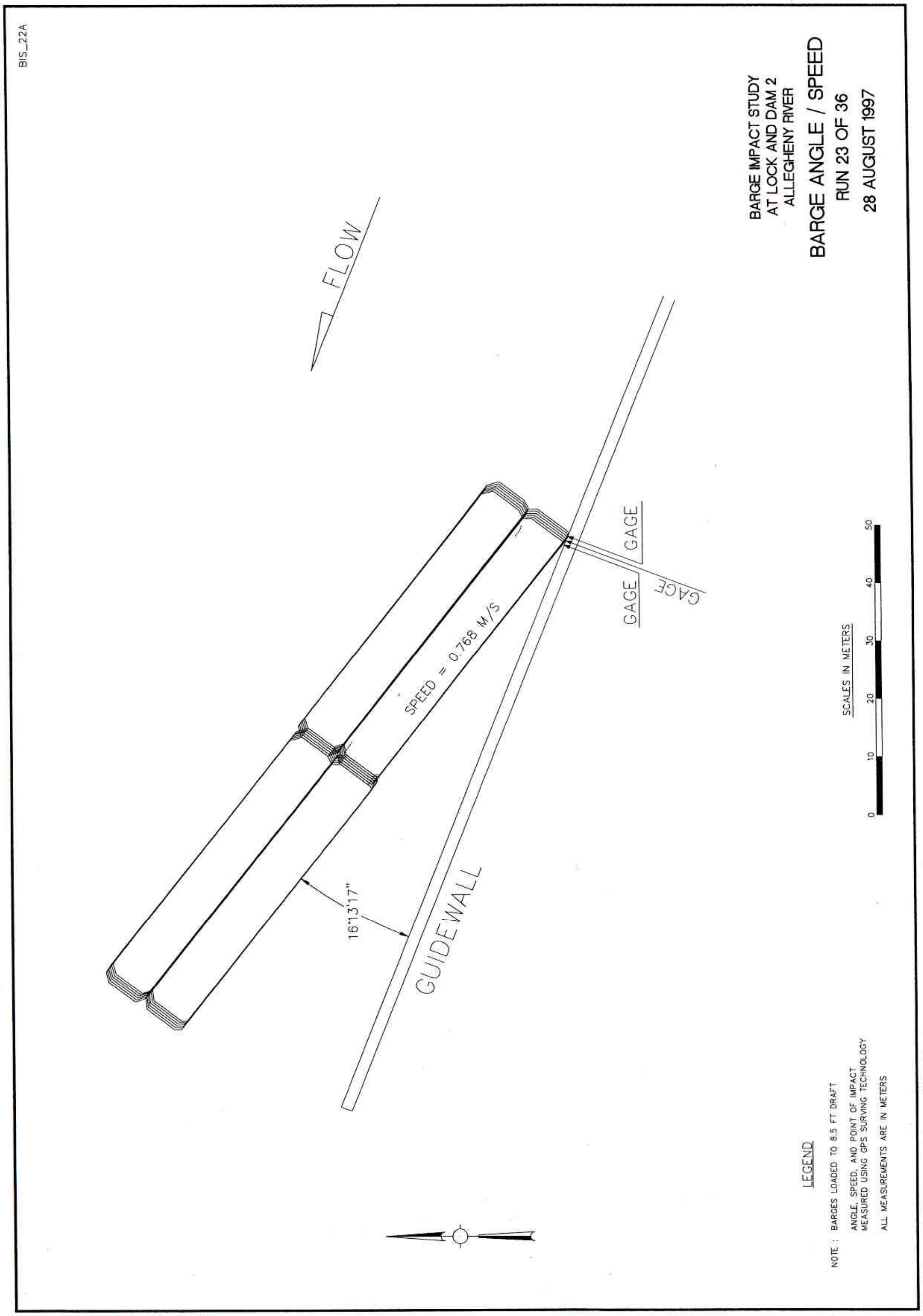

BIS_22A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 23 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.768 M/S
16°13'17"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A23

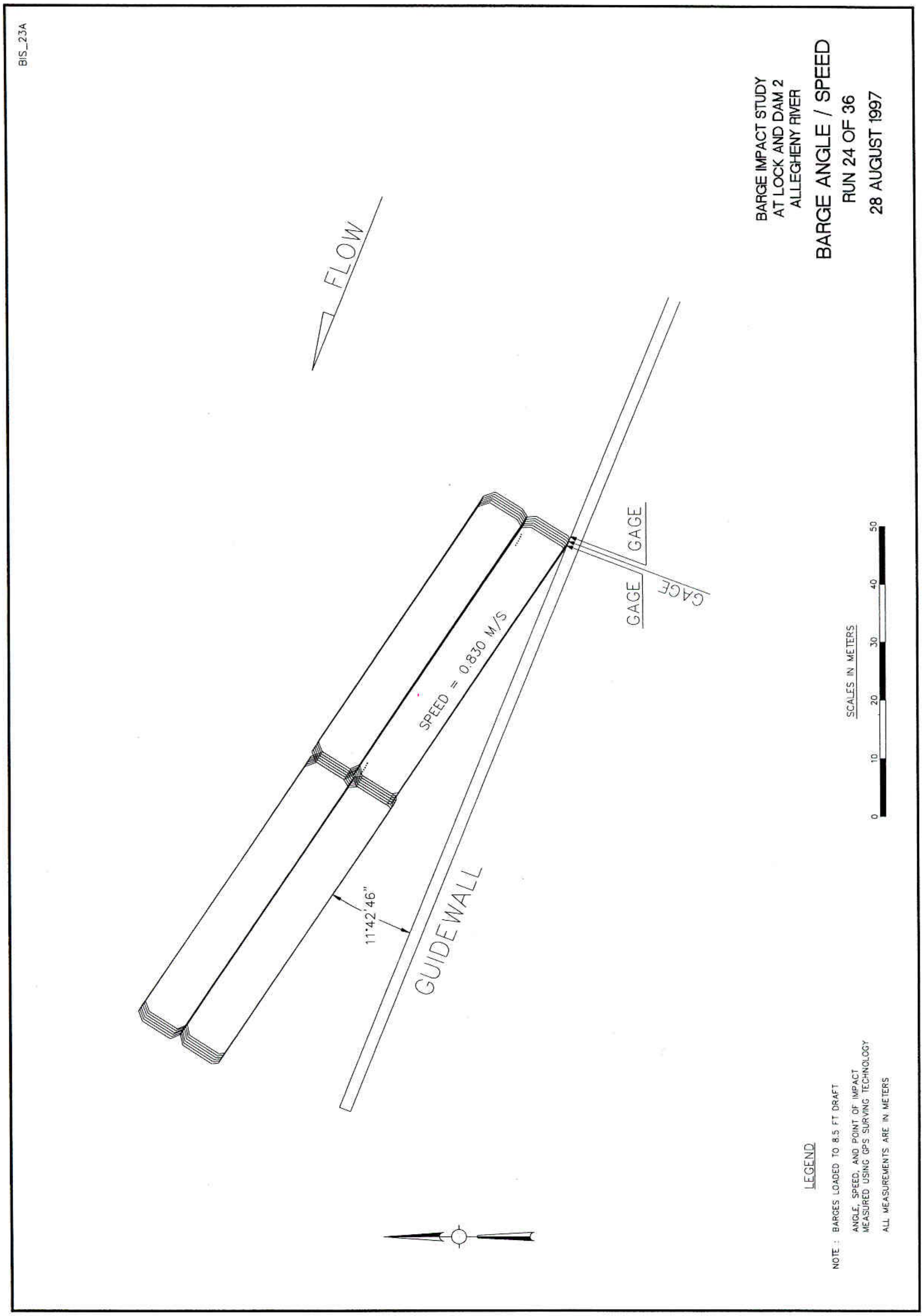

BIS_23A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 24 OF 36
28 AUGUST 1997
FLOW
SPEED = 0.830 M/S
GAGE
GAGE
GAGE
11°42'46"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A24

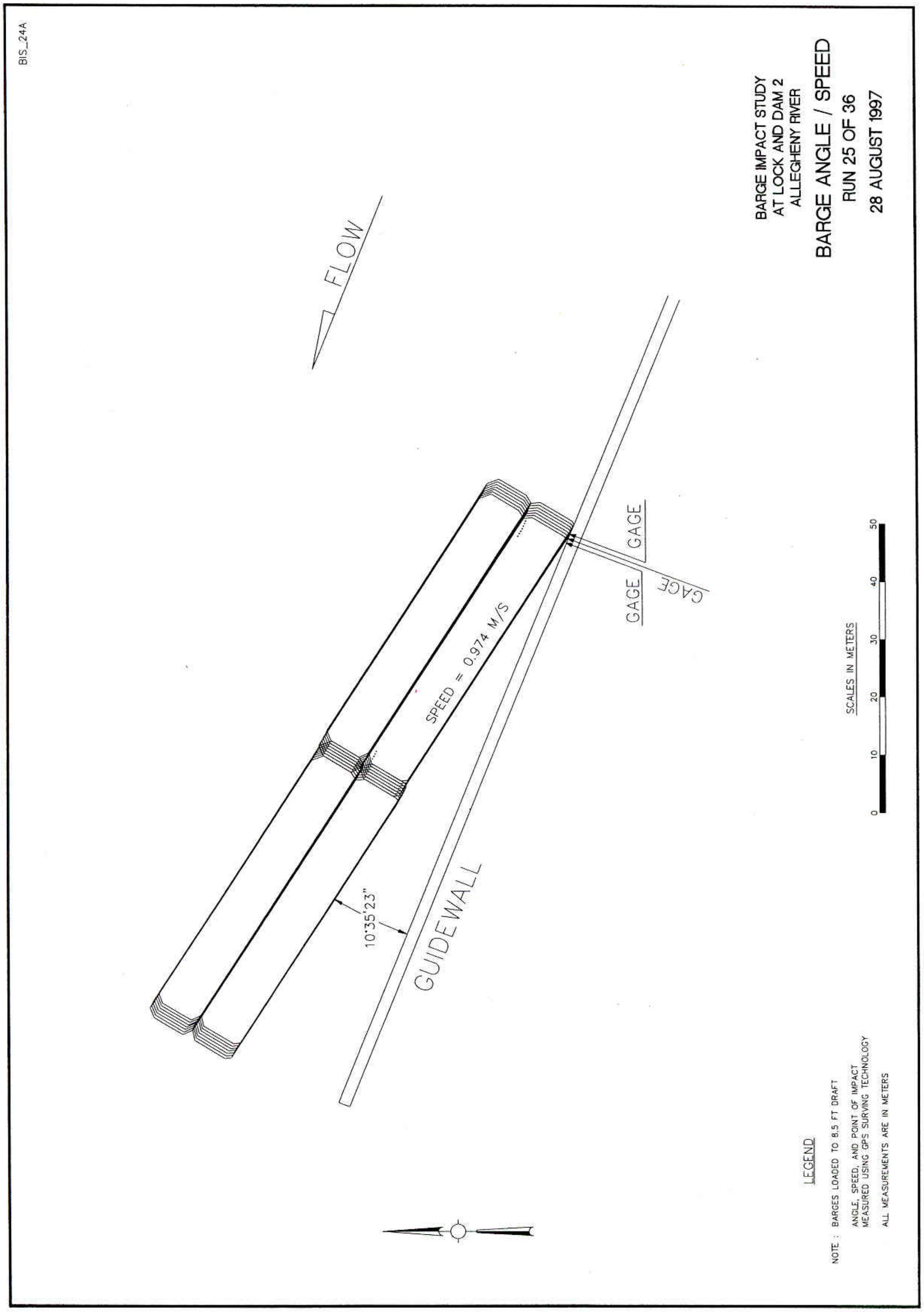

BIS_24A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 25 OF 36
28 AUGUST 1997
FLOW
GAGE
GAGE
GAGE
SPEED = 0.974 M/S
10°35'23"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A25

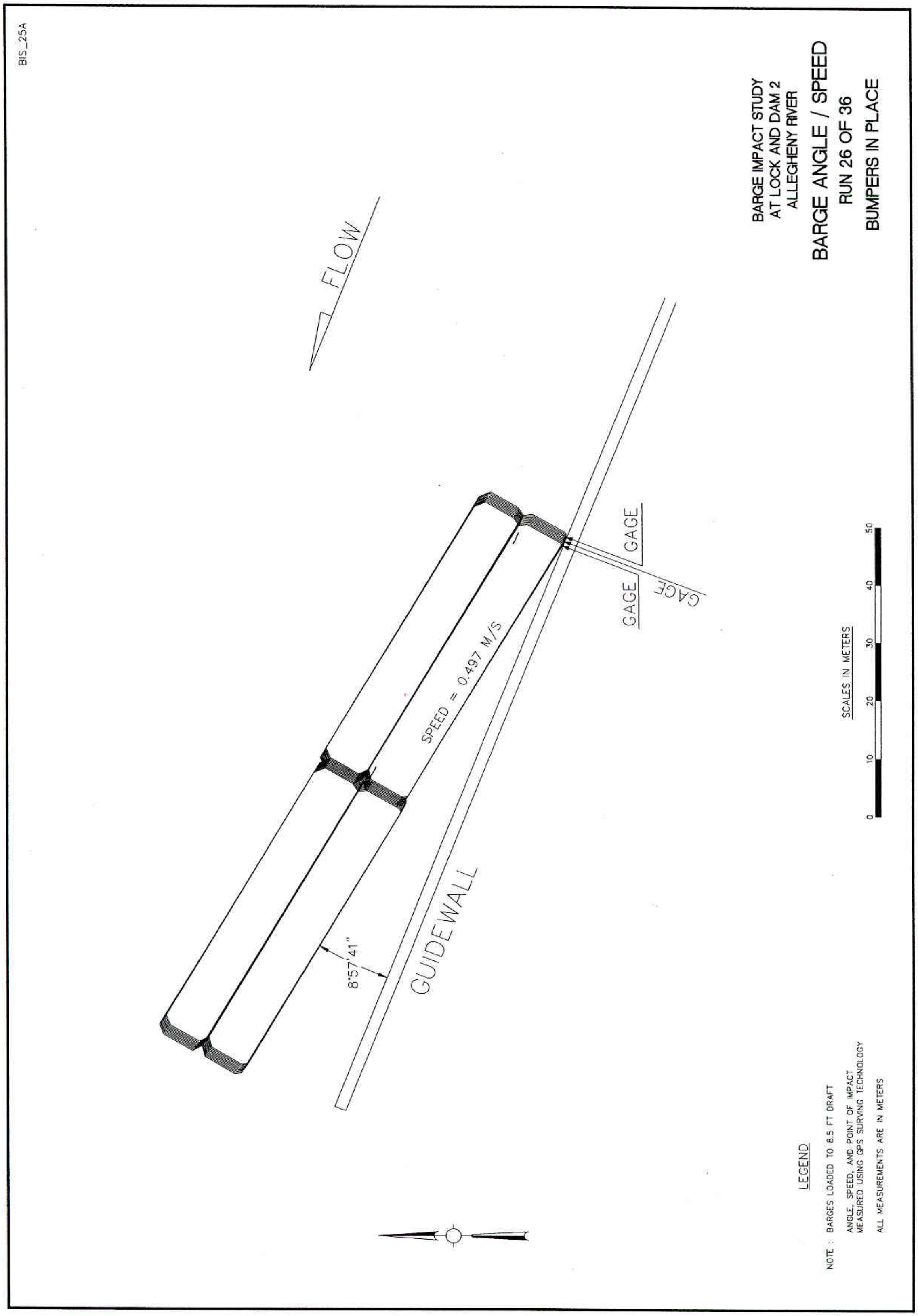

BIS_25A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 26 OF 36
BUMPERS IN PLACE
FLOW
GAGE
GAGE
GAGE
SPEED = 0.497 M/S
8°57'41"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A26

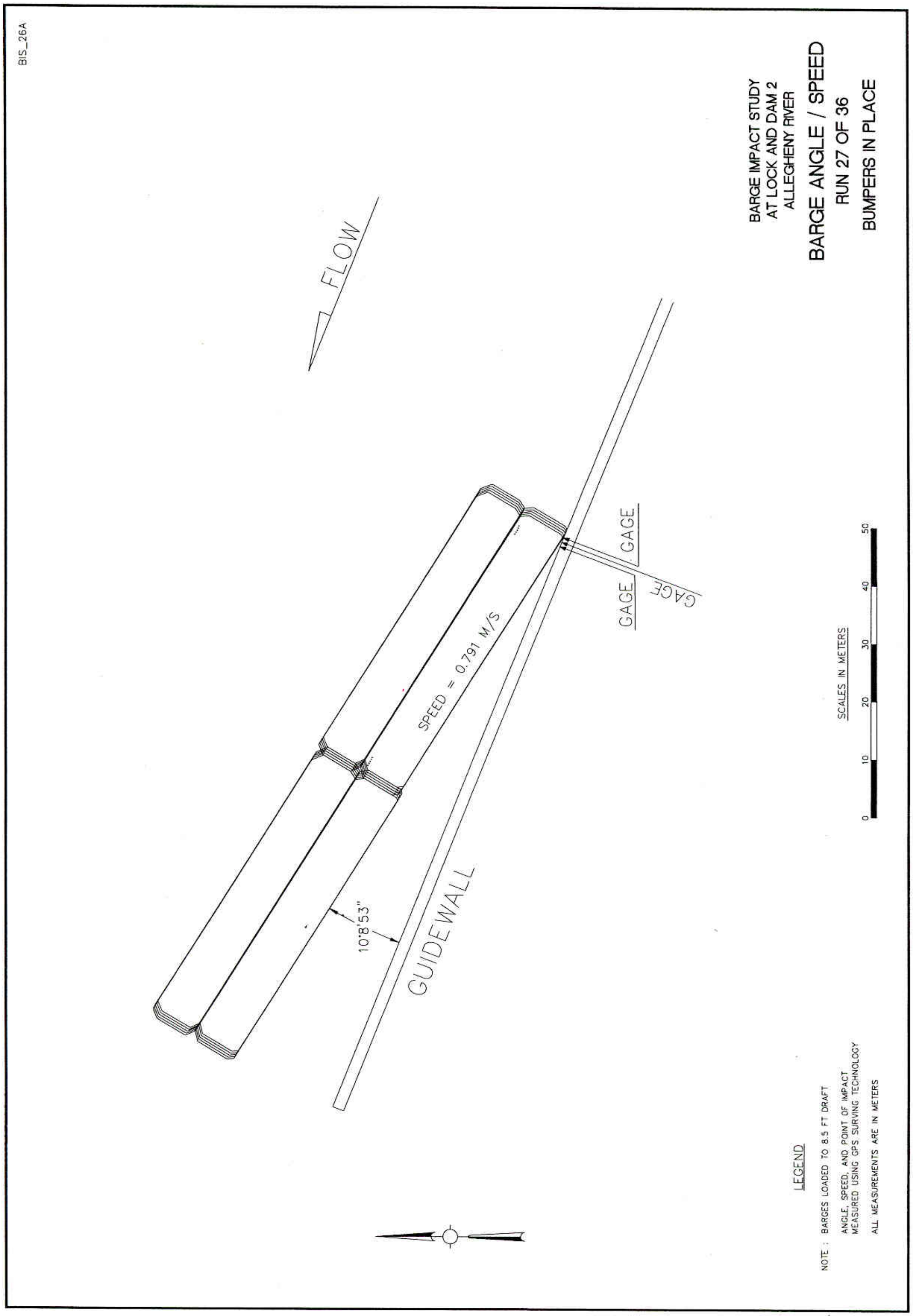

BIS_26A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 27 OF 36
BUMPERS IN PLACE
FLOW
GAGE
GAGE
GAGE
SPEED = 0.791 M/S
10°8'53"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A27

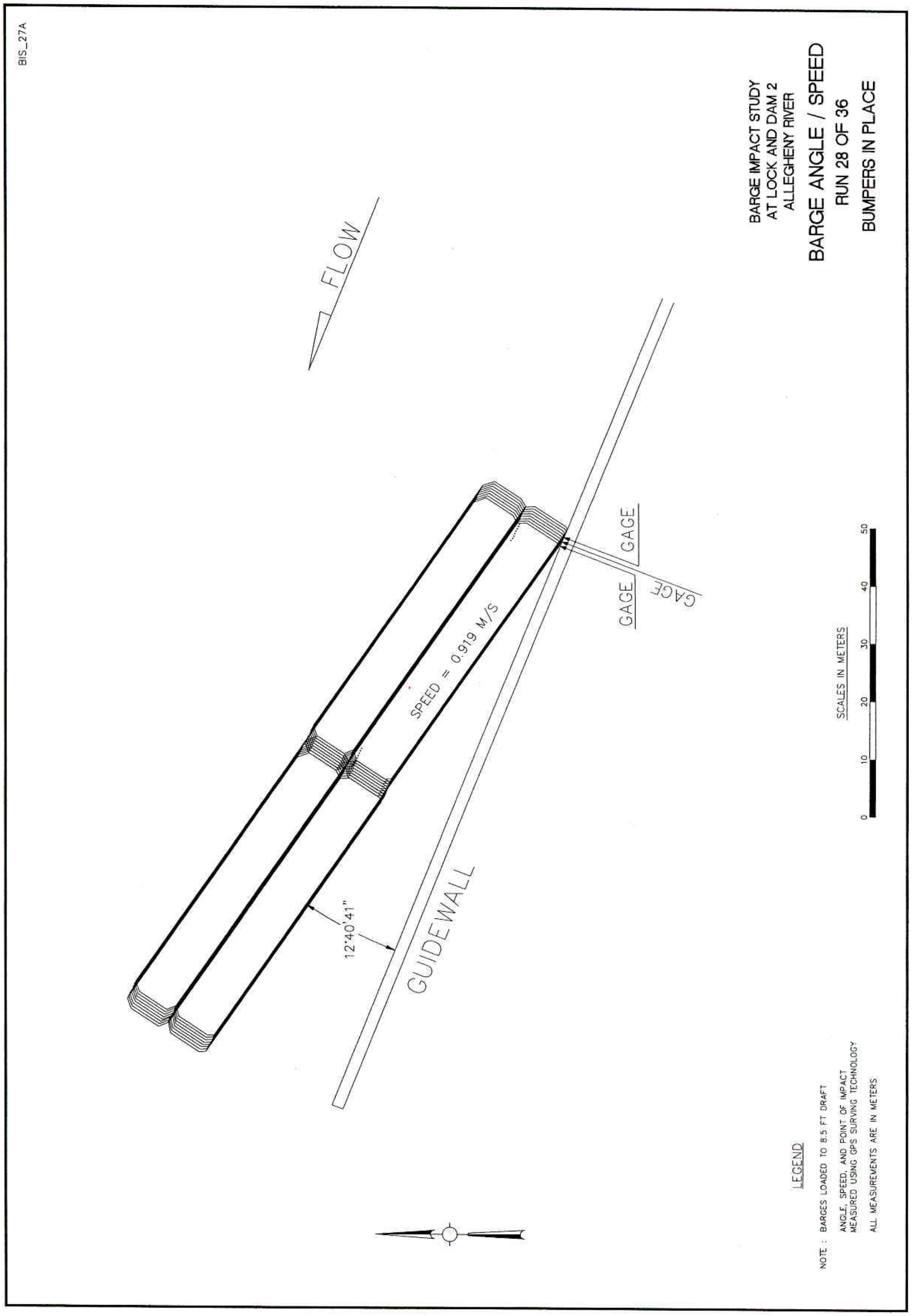

BIS_27A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 28 OF 36
BUMPERS IN PLACE
FLOW
SPEED = 0.919 M/S
GAGE
GAGE
GAGE
12°40'41"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A28

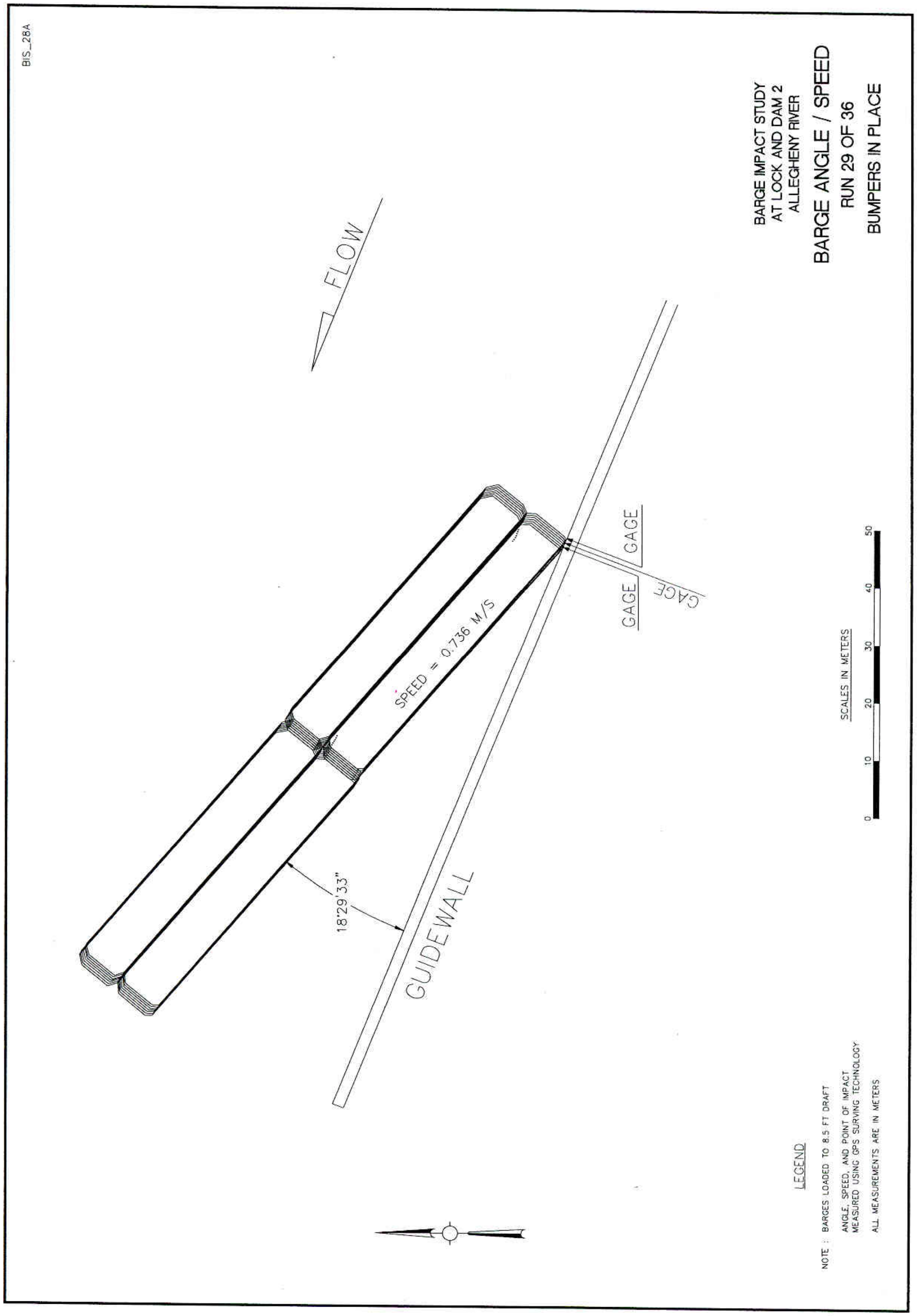

BIS_28A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 29 OF 36
BUMPERS IN PLACE
FLOW
SPEED = 0.736 M/S
GAGE
GAGE
GAGE
18°29'33"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A29

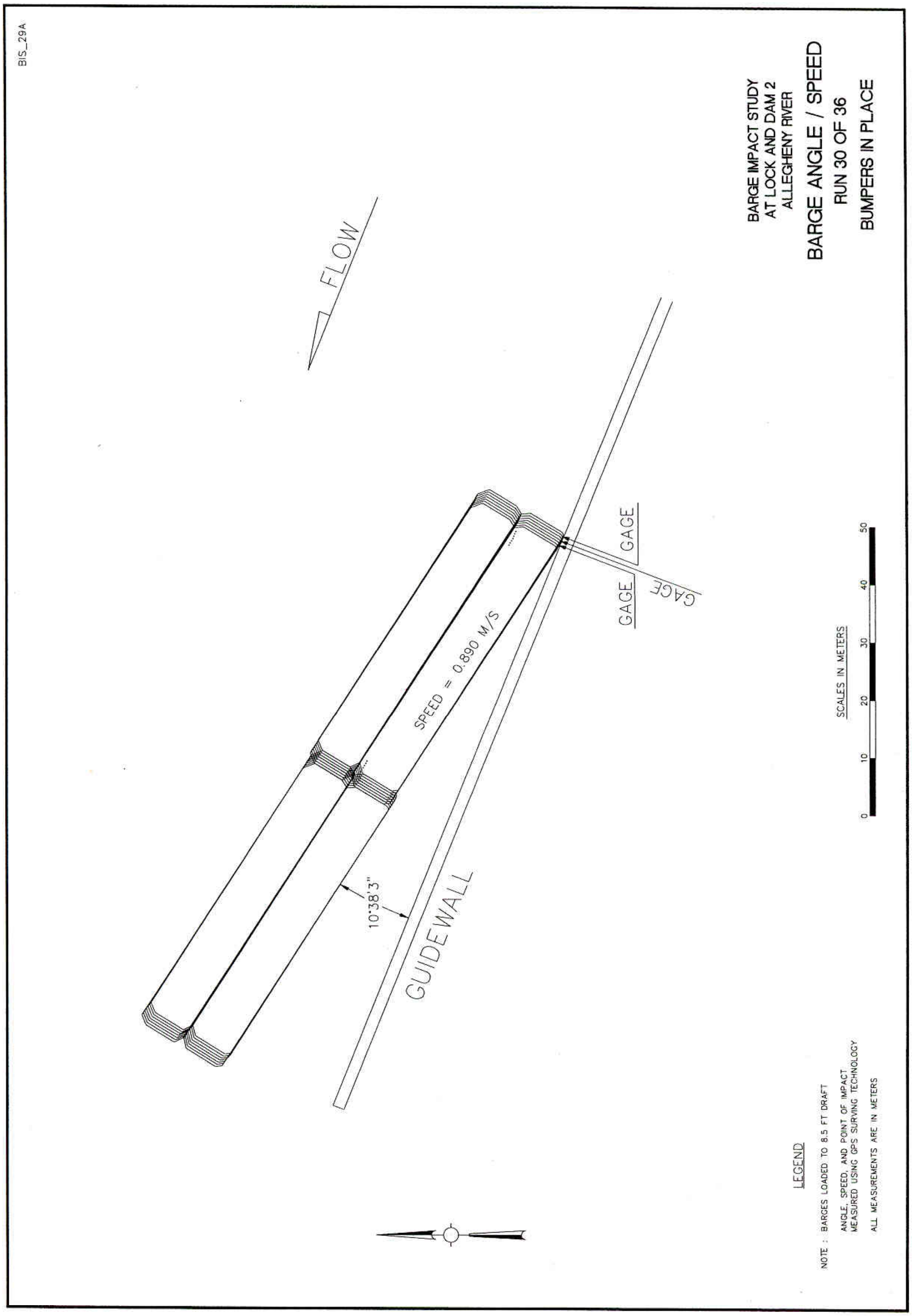

BIS_29A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 30 OF 36
BUMPERS IN PLACE
FLOW
GAGE
GAGE
GAGE
SPEED = 0.890 M/S
10°38'3"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A30

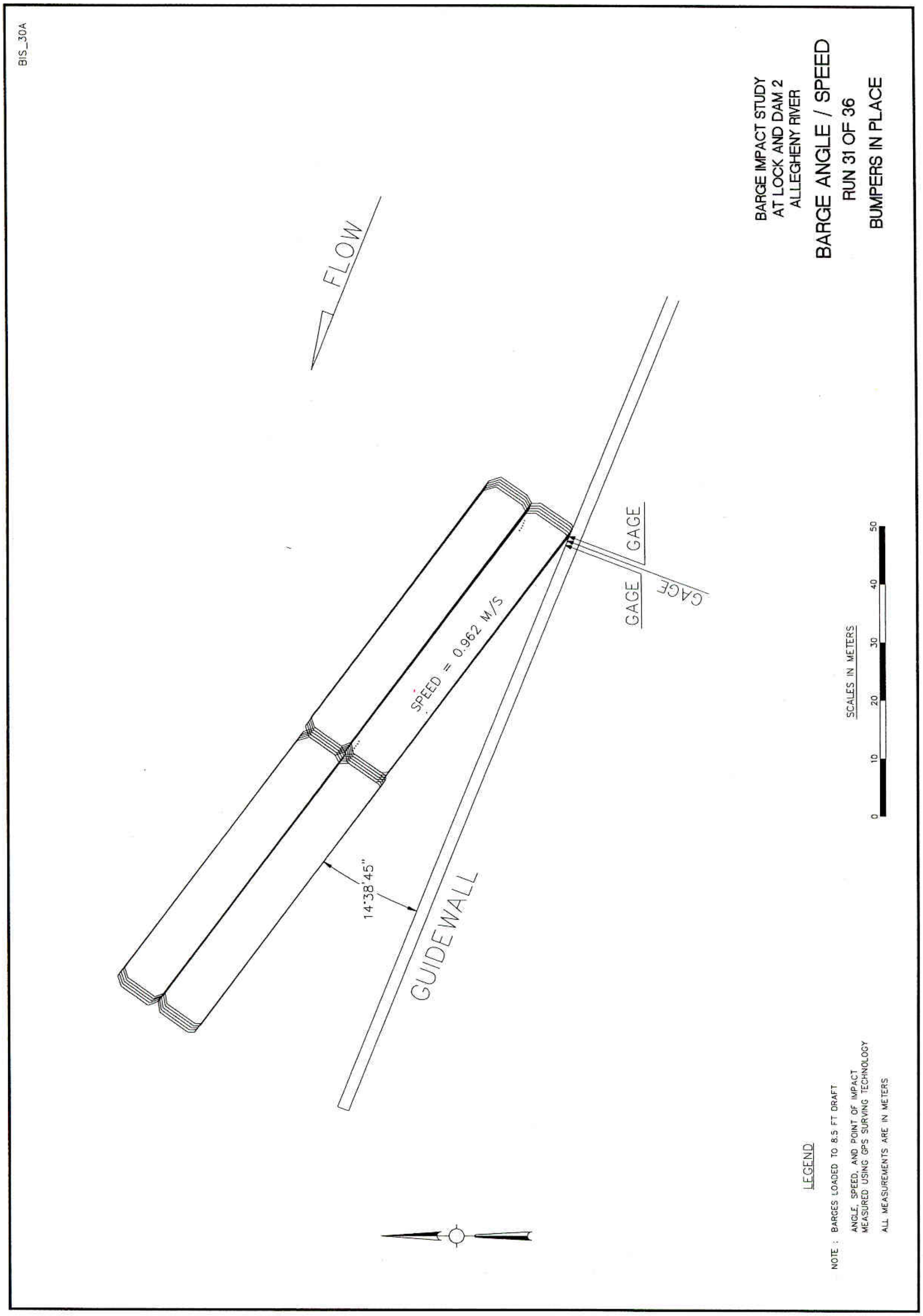

BIS_30A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 31 OF 36
BUMPERS IN PLACE
FLOW
GAGE
GAGE
GAGE
SPEED = 0.962 M/S
14°38'45"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A31

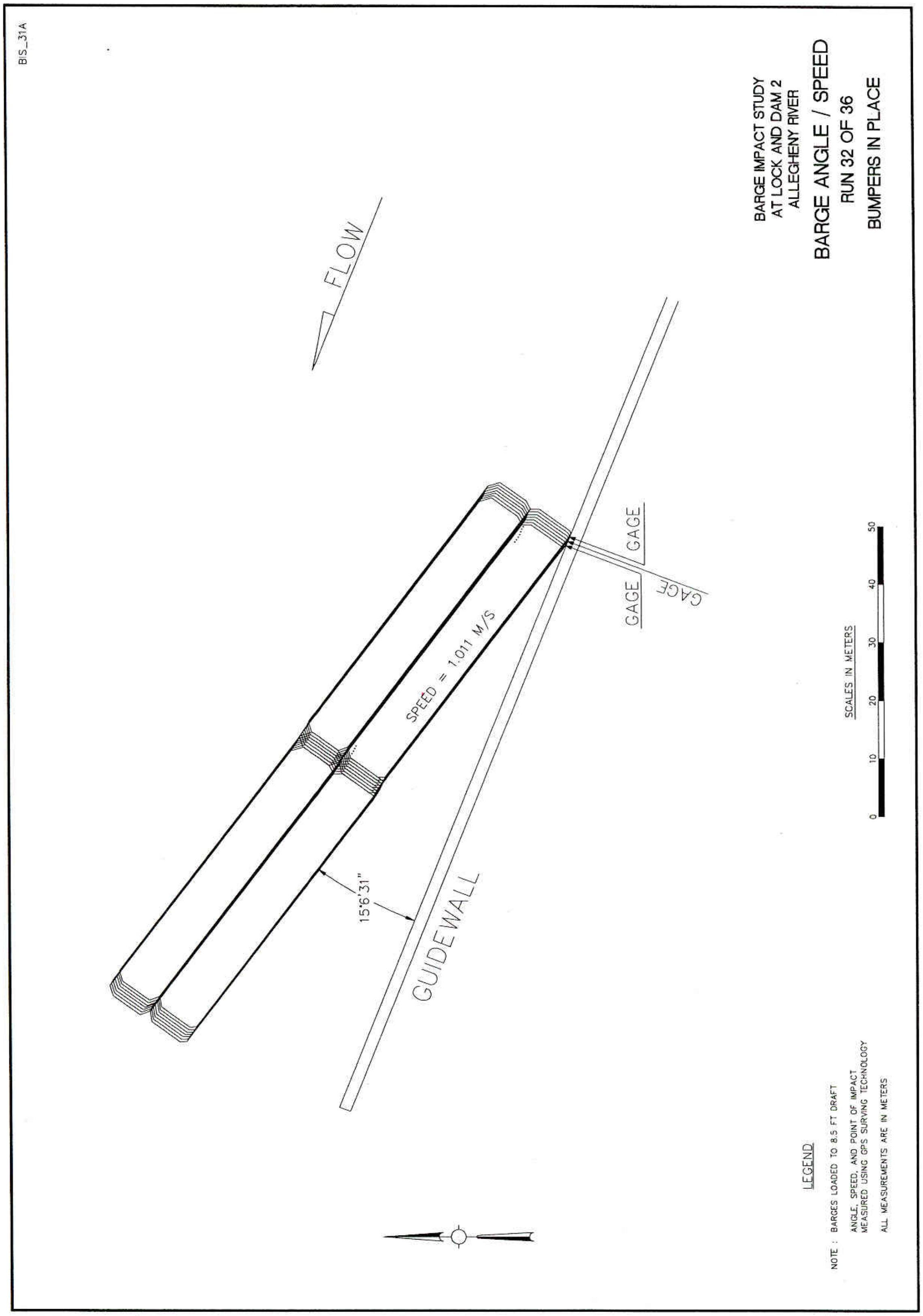

BIS_31A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 32 OF 36
BUMPERS IN PLACE
FLOW
GAGE
GAGE
GAGE
SPEED = 1.011 M/S
15°6'31"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A32

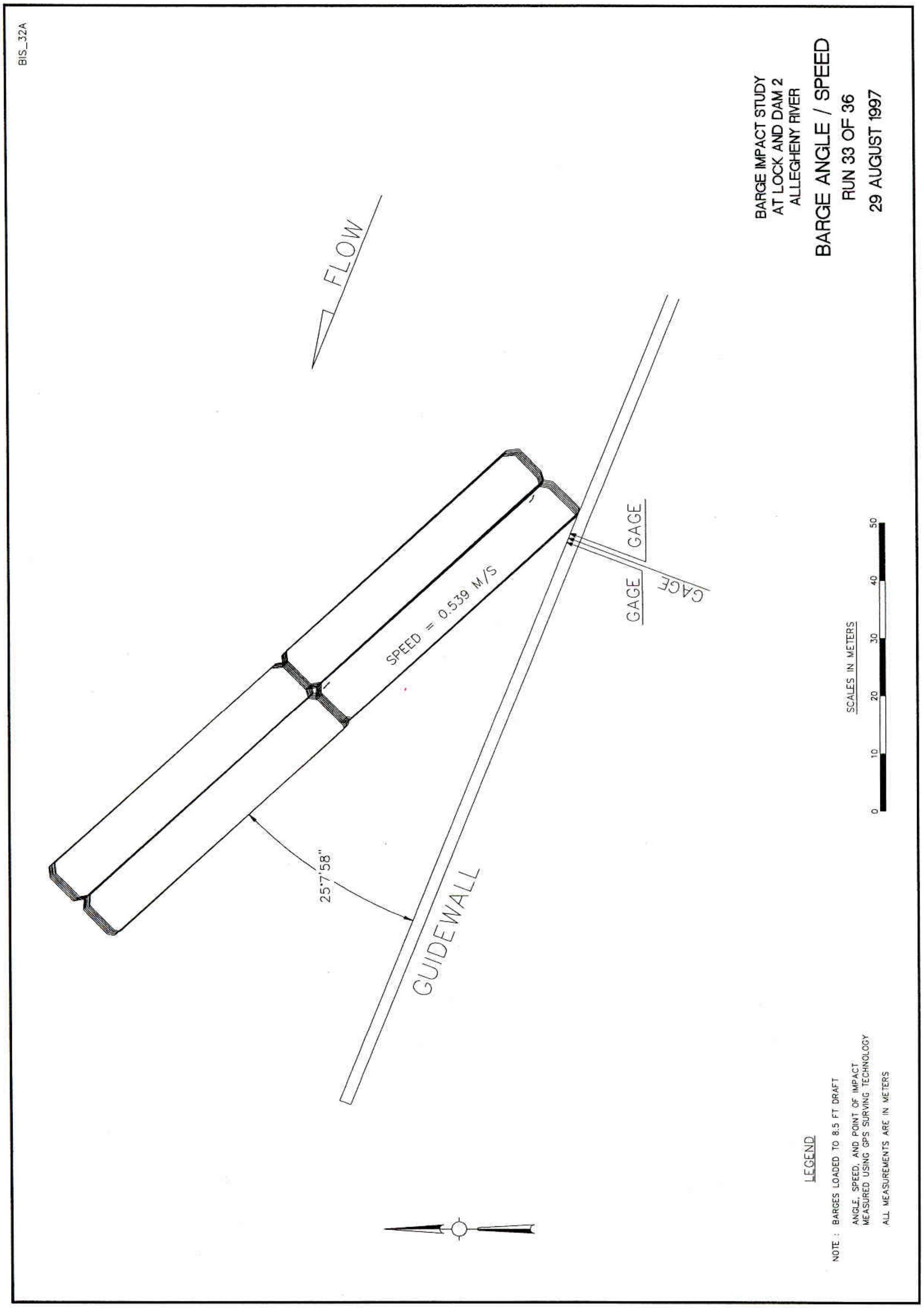

BIS_32A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 33 OF 36
29 AUGUST 1997
FLOW
SPEED = 0.539 M/S
GAGE
GAGE
GAGE
25°7'58"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A33

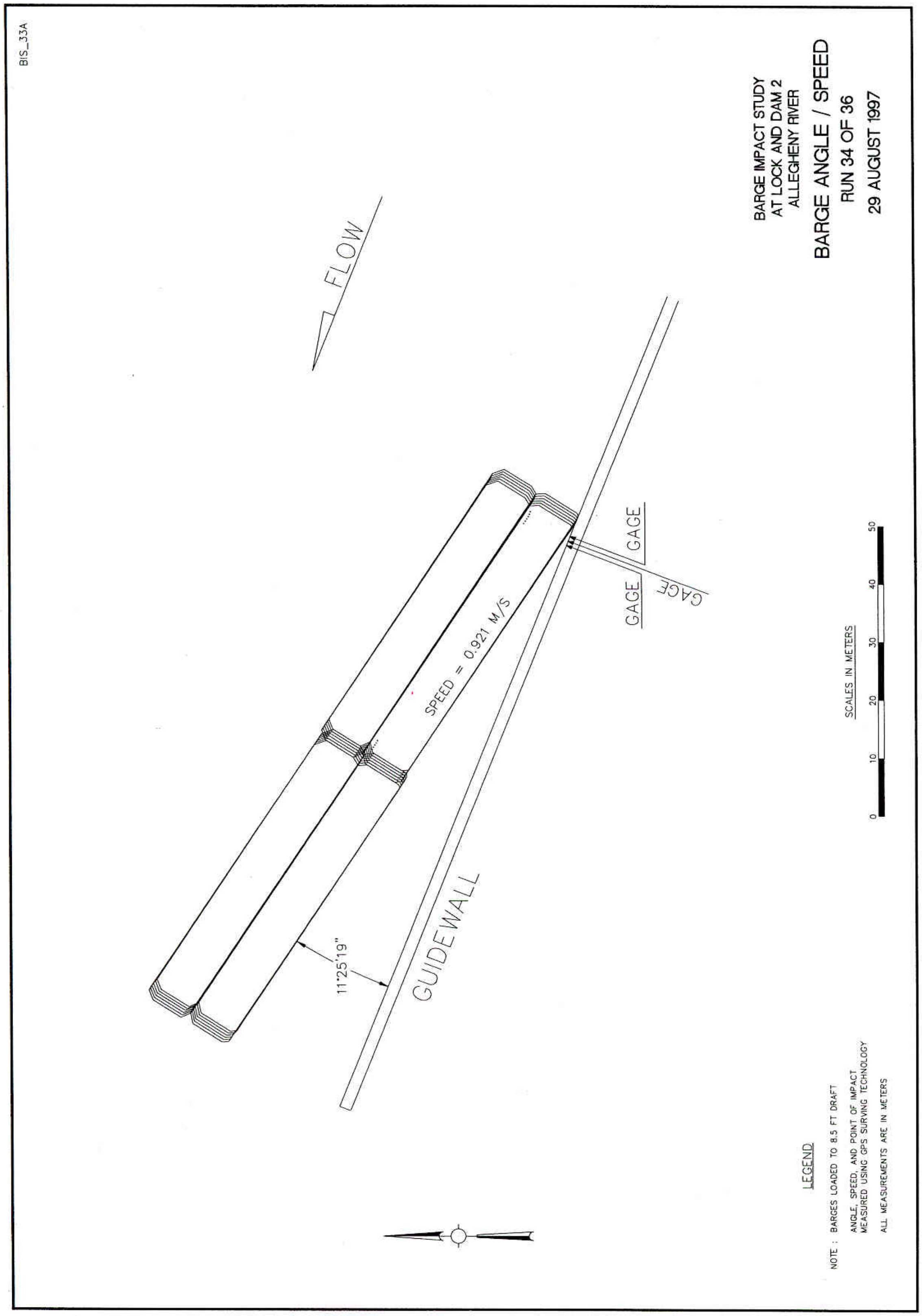

BIS_33A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 34 OF 36
29 AUGUST 1997
FLOW
SPEED = 0.921 M/S
GAGE
GAGE
GAGE
GUIDEWALL
11°25'19"
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A34

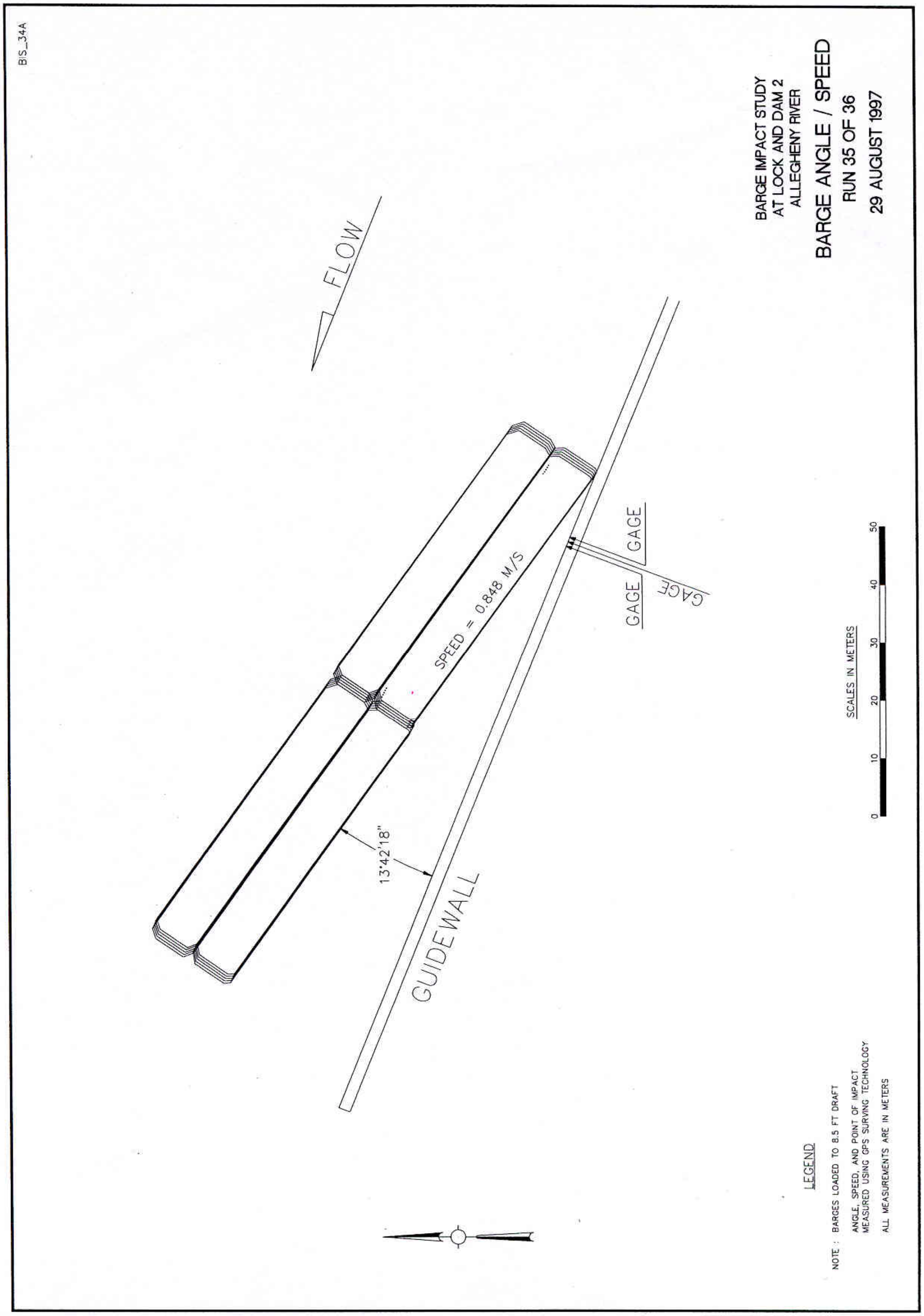

BIS_34A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 35 OF 36
29 AUGUST 1997
FLOW
SPEED = 0.848 M/S
GAGE
GAGE
GAGE
GAGE
13°42'18"
GUIDEWALL
SCALES IN METERS
0
10
20
30
40
50
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT
MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

Plate A35

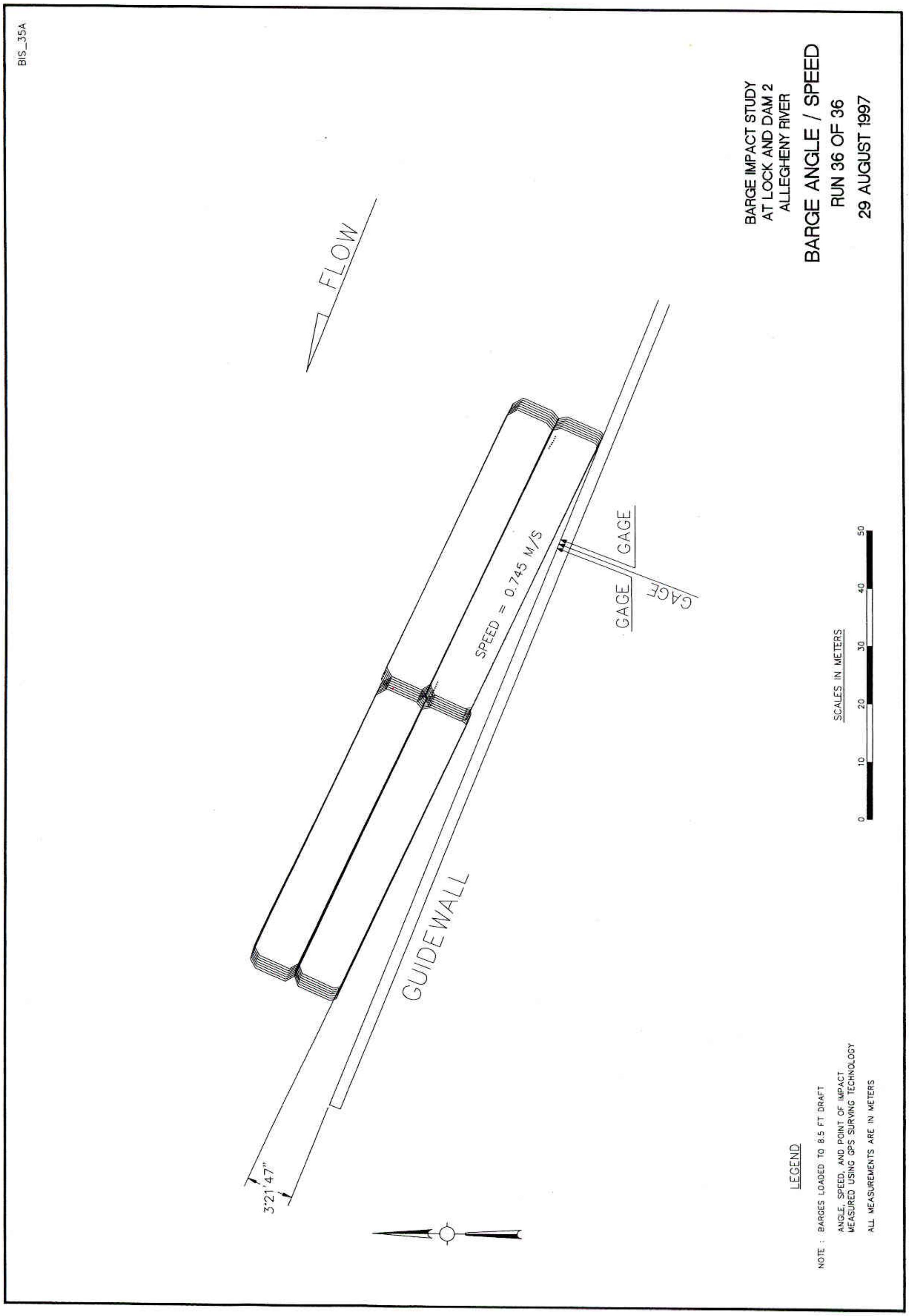
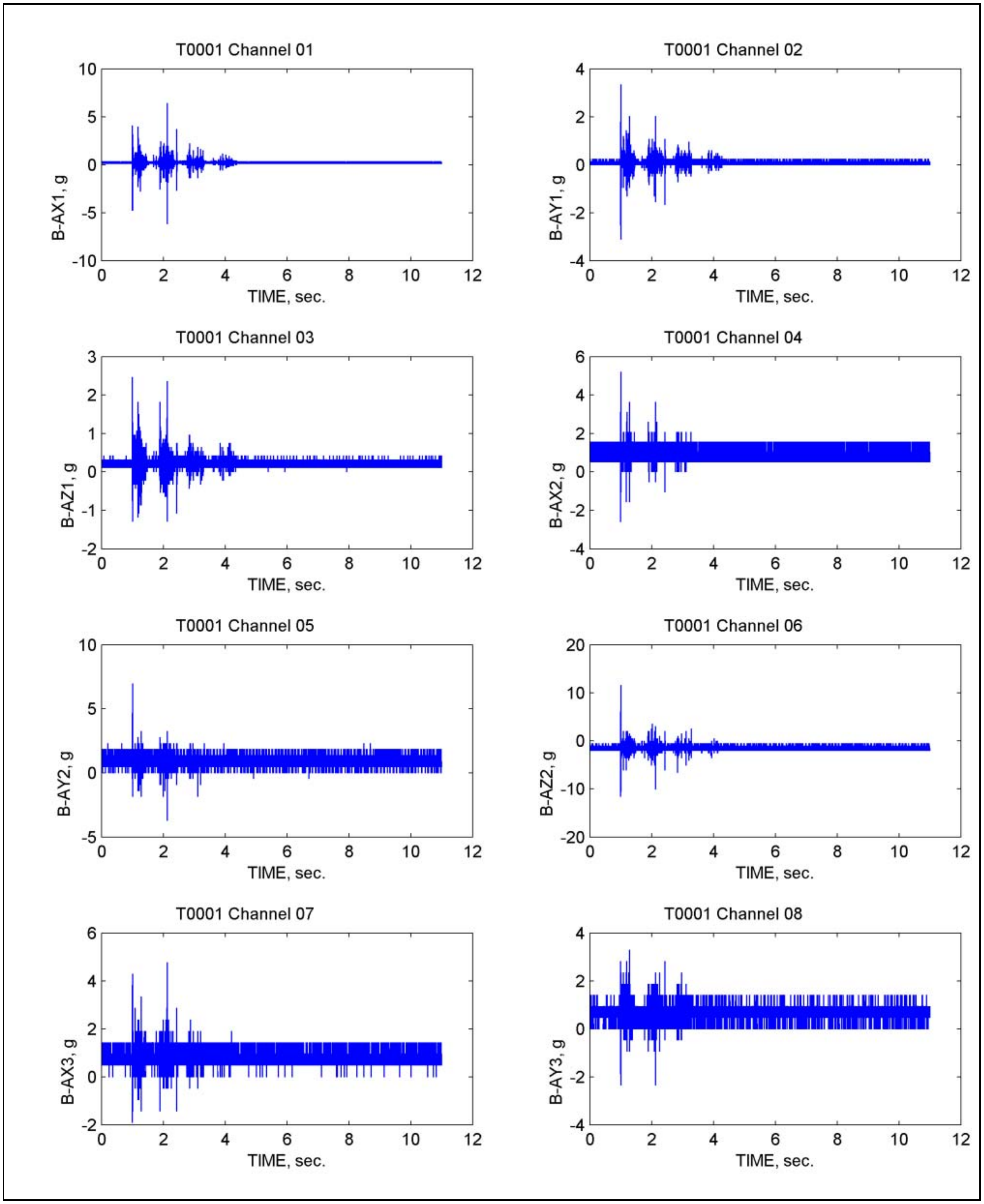

BIS_35A
BARGE IMPACT STUDY
AT LOCK AND DAM 2
ALLEGHENY RIVER
BARGE ANGLE / SPEED
RUN 36 OF 36
29 AUGUST 1997
FLOW
SPEED = 0.745 M/S
GAGE
GAGE
GAGE
GUIDEWALL
SCALES IN METERS
0 10 20 30 40 50
3°21'47"
LEGEND
NOTE : BARGES LOADED TO 8.5 FT DRAFT
ANGLE, SPEED, AND POINT OF IMPACT MEASURED USING GPS SURVING TECHNOLOGY
ALL MEASUREMENTS ARE IN METERS

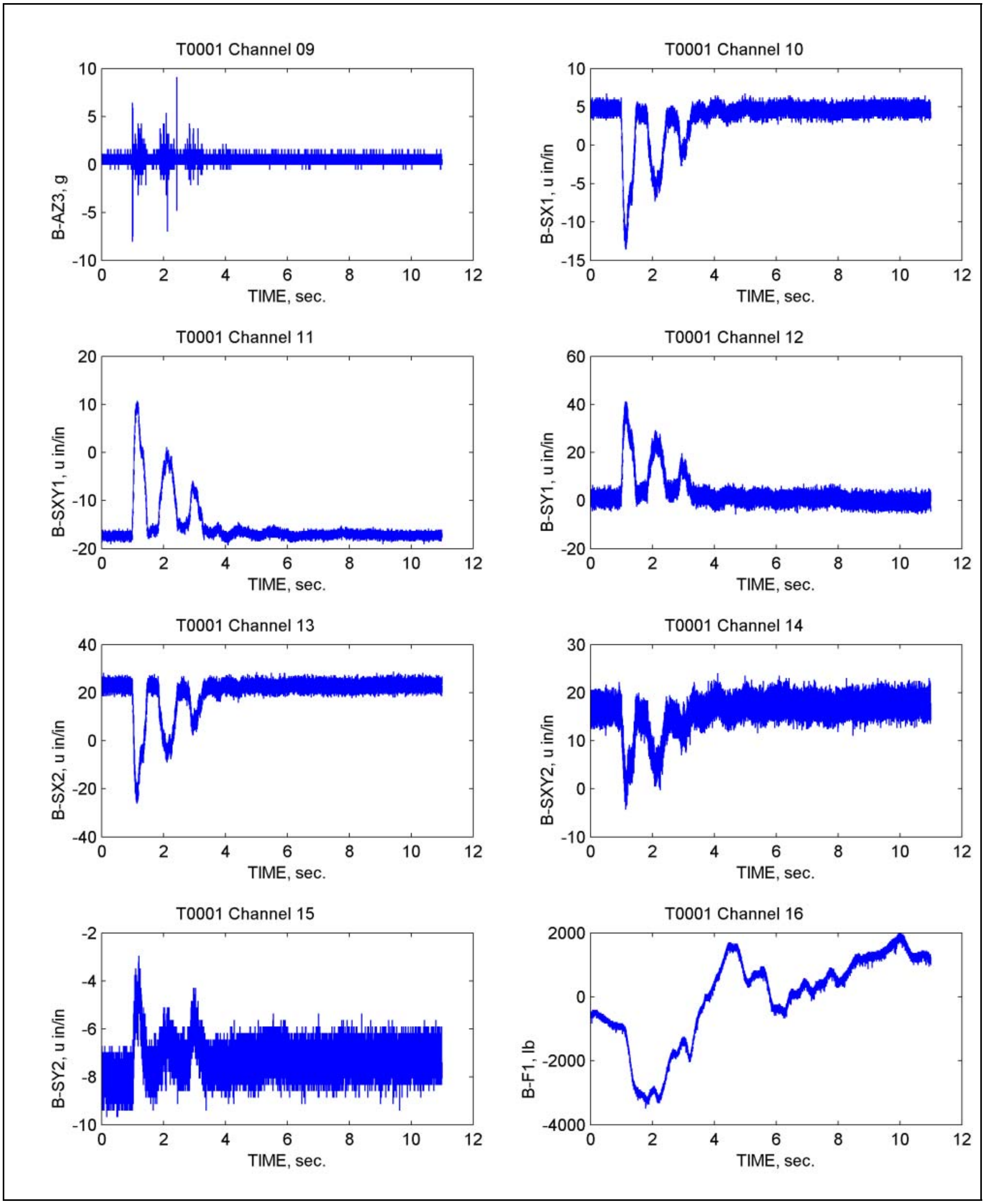
Plate A36

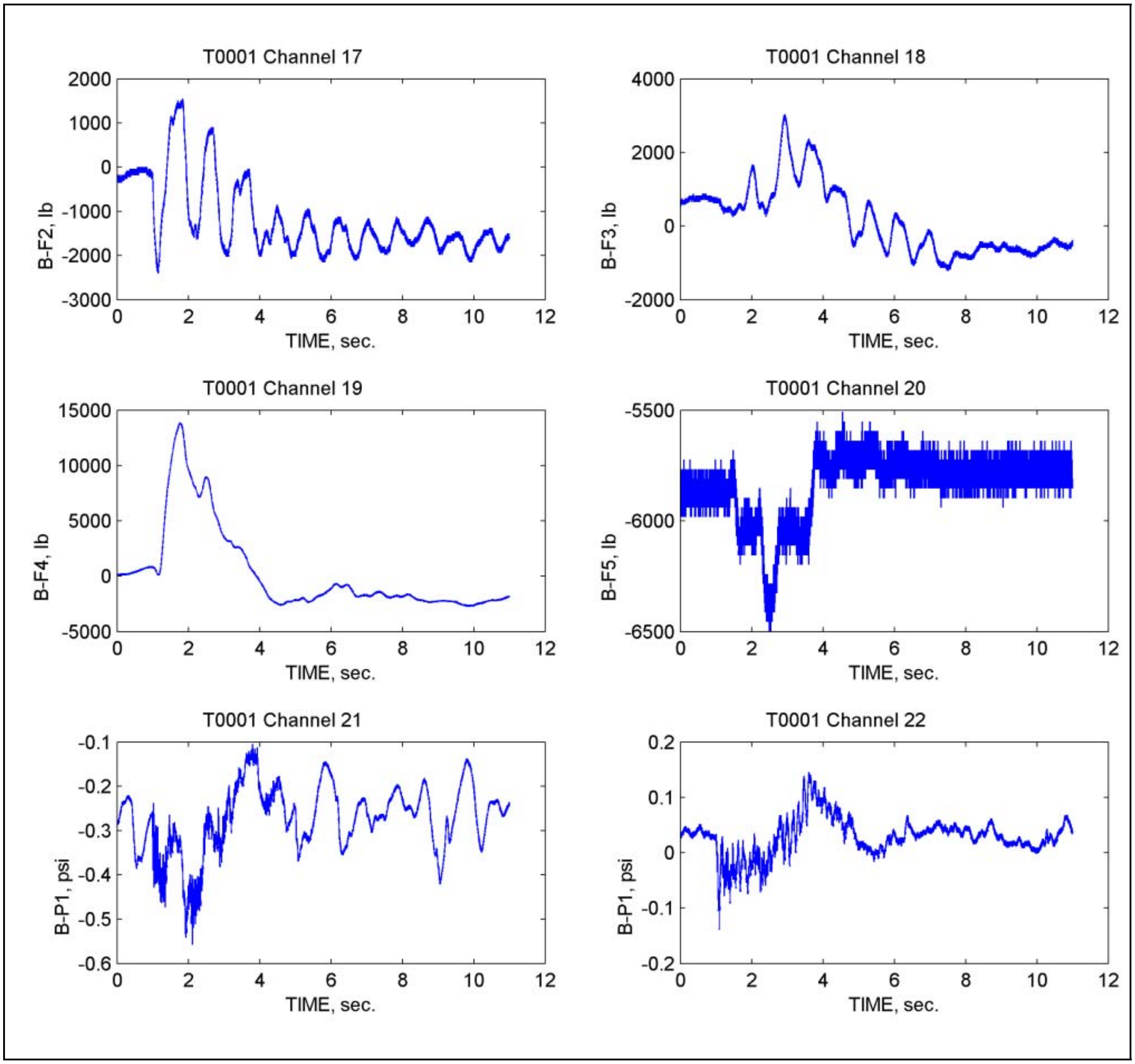
Appendix B
Raw Experiment Data Plots

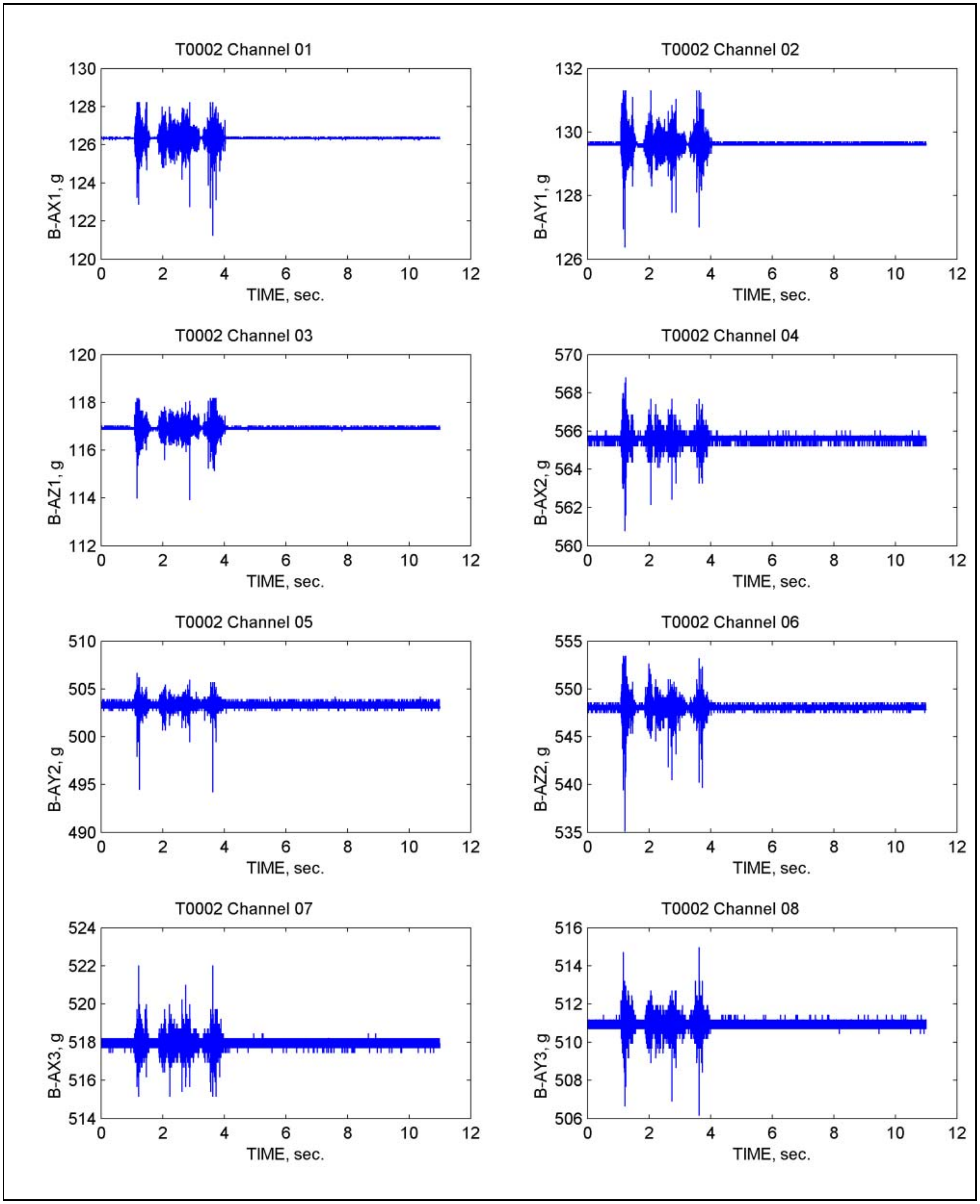
The plots of the raw data from the instrumentation are presented in this report appendix to show the general trends that were noted with the collected data. The data plots on the following pages are for Experiments 1-36, as the plots indicate. The reference for each instrument (e.g., B-F2) in each plot can be determined from Table 2 of the main text.

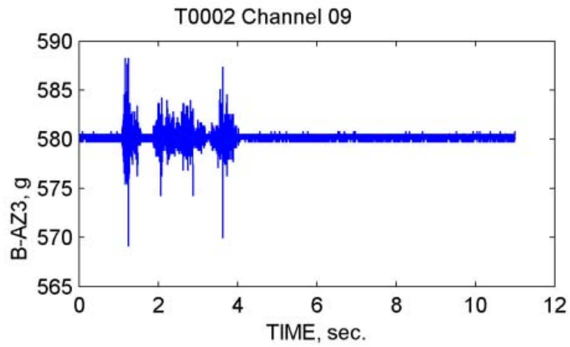
> ***Caveat to the reader:***
>
> These plots have not been processed in any way. They are purely raw data on scaled plots. Thus, interpretation and any further use of these data is left to possible misinterpretation by those unfamiliar with how the data were recorded and the type of instrumentation that was used to collect the data.

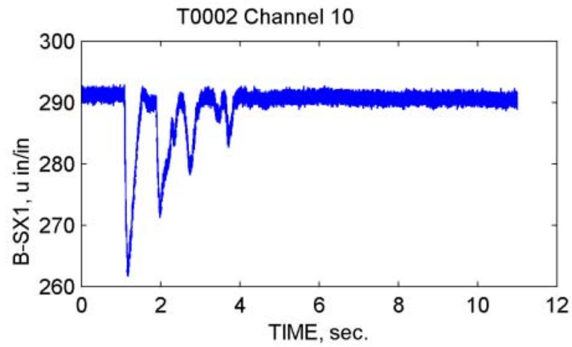

T0001 Channel 01
B-AX1, g
TIME, sec.
T0001 Channel 02
B-AY1, g
TIME, sec.
T0001 Channel 03
B-AZ1, g
TIME, sec.
T0001 Channel 04
B-AX2, g
TIME, sec.
T0001 Channel 05
B-AY2, g
TIME, sec.
T0001 Channel 06
B-AZ2, g
TIME, sec.
T0001 Channel 07
B-AX3, g
TIME, sec.
T0001 Channel 08
B-AY3, g
TIME, sec.

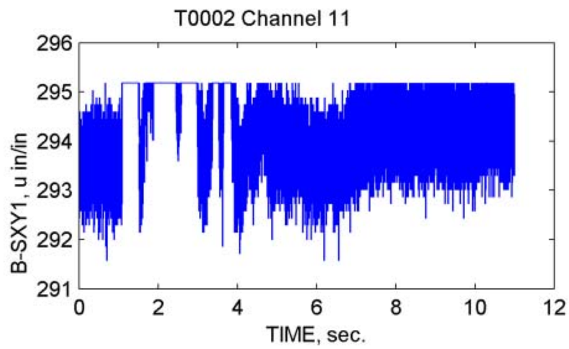

T0001 Channel 09
B-AZ3, g
TIME, sec.
T0001 Channel 10
B-SX1, u in/in
TIME, sec.
T0001 Channel 11
B-SXY1, u in/in
TIME, sec.
T0001 Channel 12
B-SY1, u in/in
TIME, sec.
T0001 Channel 13
B-SX2, u in/in
TIME, sec.
T0001 Channel 14
B-SXY2, u in/in
TIME, sec.
T0001 Channel 15
B-SY2, u in/in
TIME, sec.
T0001 Channel 16
B-F1, lb
TIME, sec.

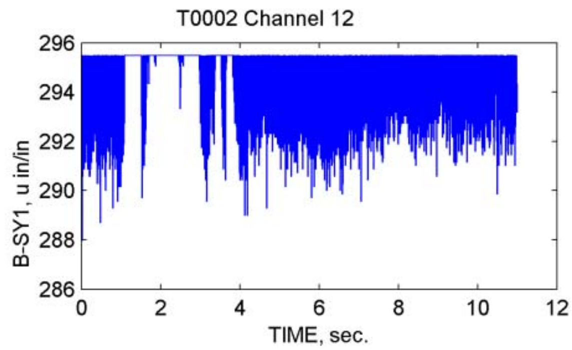

T0001 Channel 17
B-F2, lb
TIME, sec.
T0001 Channel 18
B-F3, lb
TIME, sec.
T0001 Channel 19
B-F4, lb
TIME, sec.
T0001 Channel 20
B-F5, lb
TIME, sec.
T0001 Channel 21
B-P1, psi
TIME, sec.
T0001 Channel 22
B-P1, psi
TIME, sec.

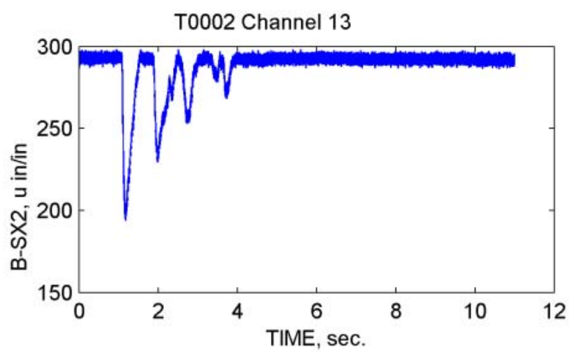

T0002 Channel 01
B-AX1, g
TIME, sec.
T0002 Channel 02
B-AY1, g
TIME, sec.
T0002 Channel 03
B-AZ1, g
TIME, sec.
T0002 Channel 04
B-AX2, g
TIME, sec.
T0002 Channel 05
B-AY2, g
TIME, sec.
T0002 Channel 06
B-AZ2, g
TIME, sec.
T0002 Channel 07
B-AX3, g
TIME, sec.
T0002 Channel 08
B-AY3, g
TIME, sec.

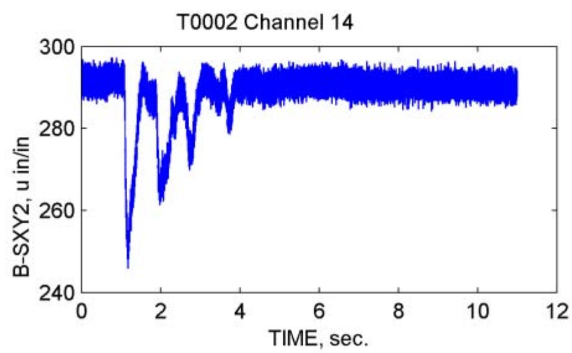

T0002 Channel 09
B-AZ3, g
TIME, sec.

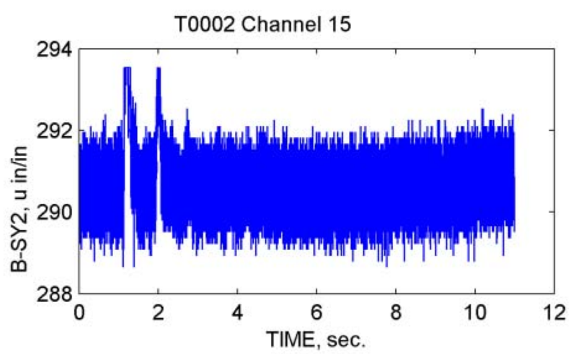

T0002 Channel 10
B-SX1, u in/in
TIME, sec.

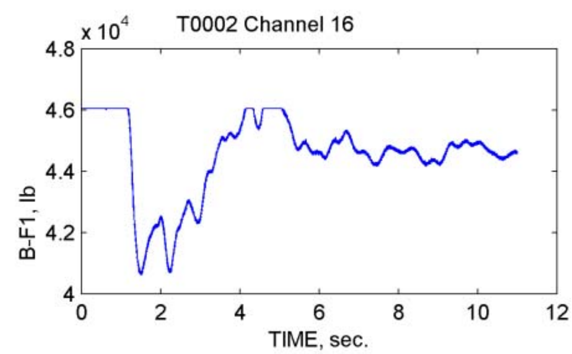

T0002 Channel 11
B-SXY1, u in/in
TIME, sec.

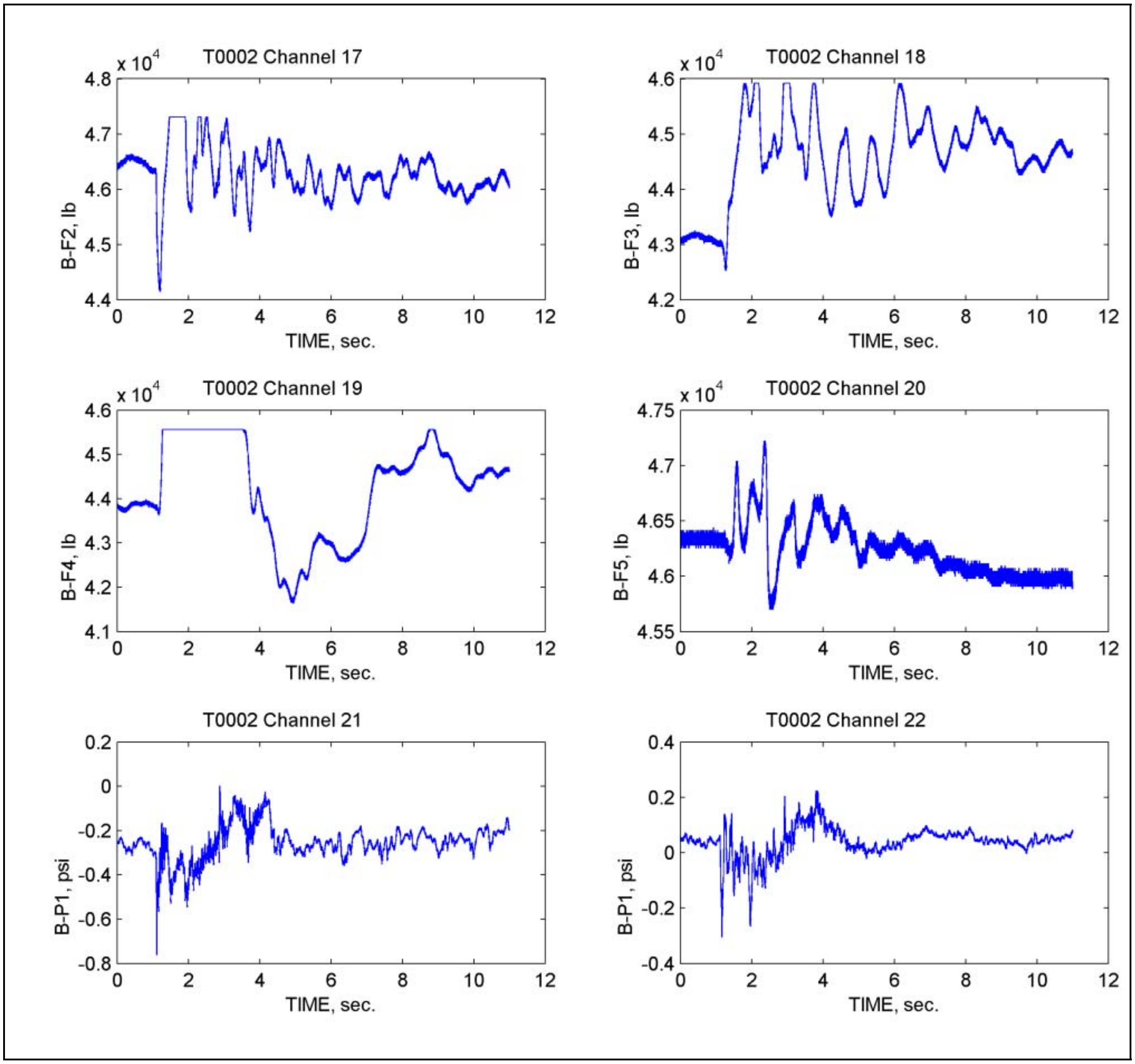

T0002 Channel 12
B-SY1, u in/in
TIME, sec.

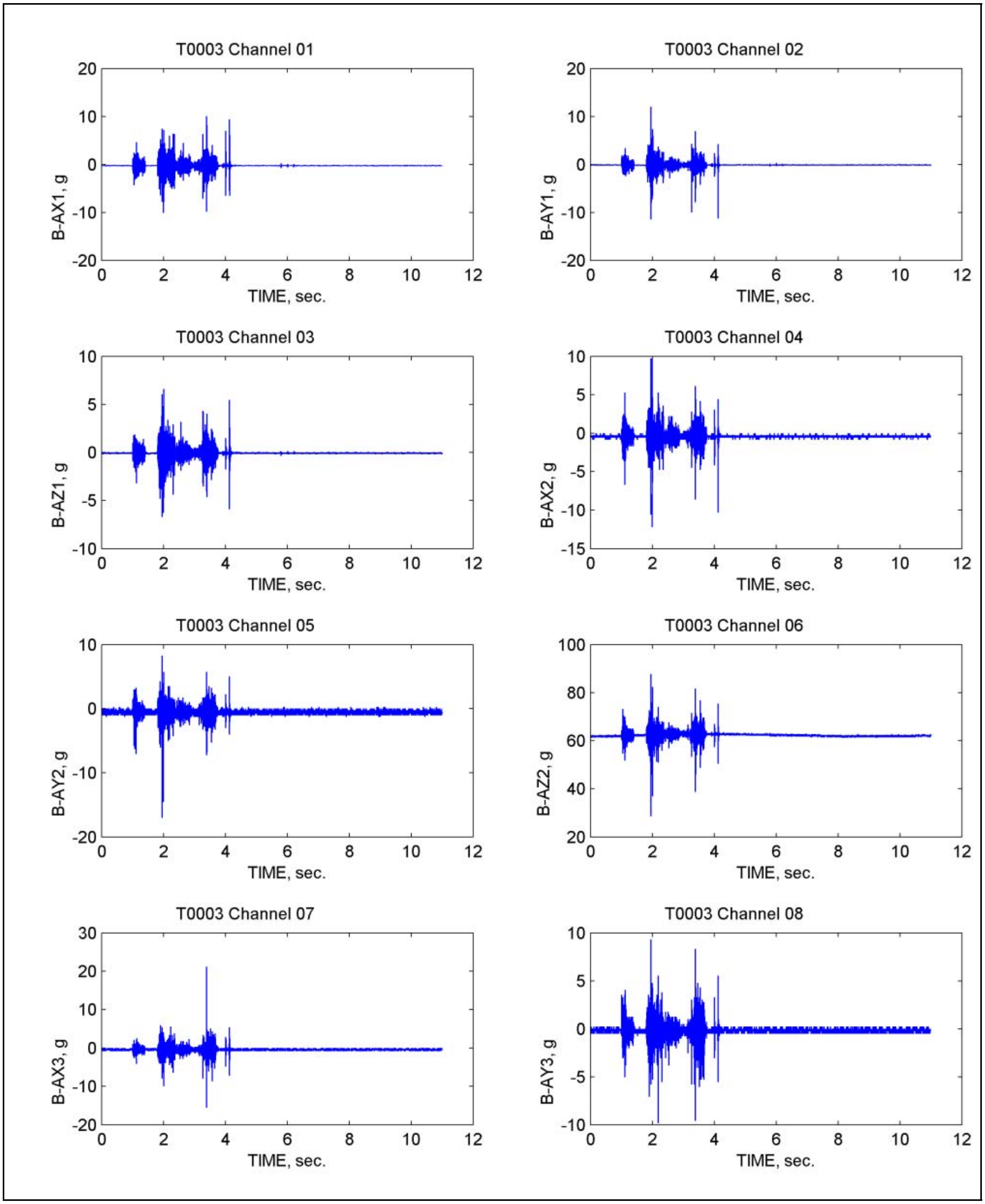

T0002 Channel 13
B-SX2, u in/in
TIME, sec.

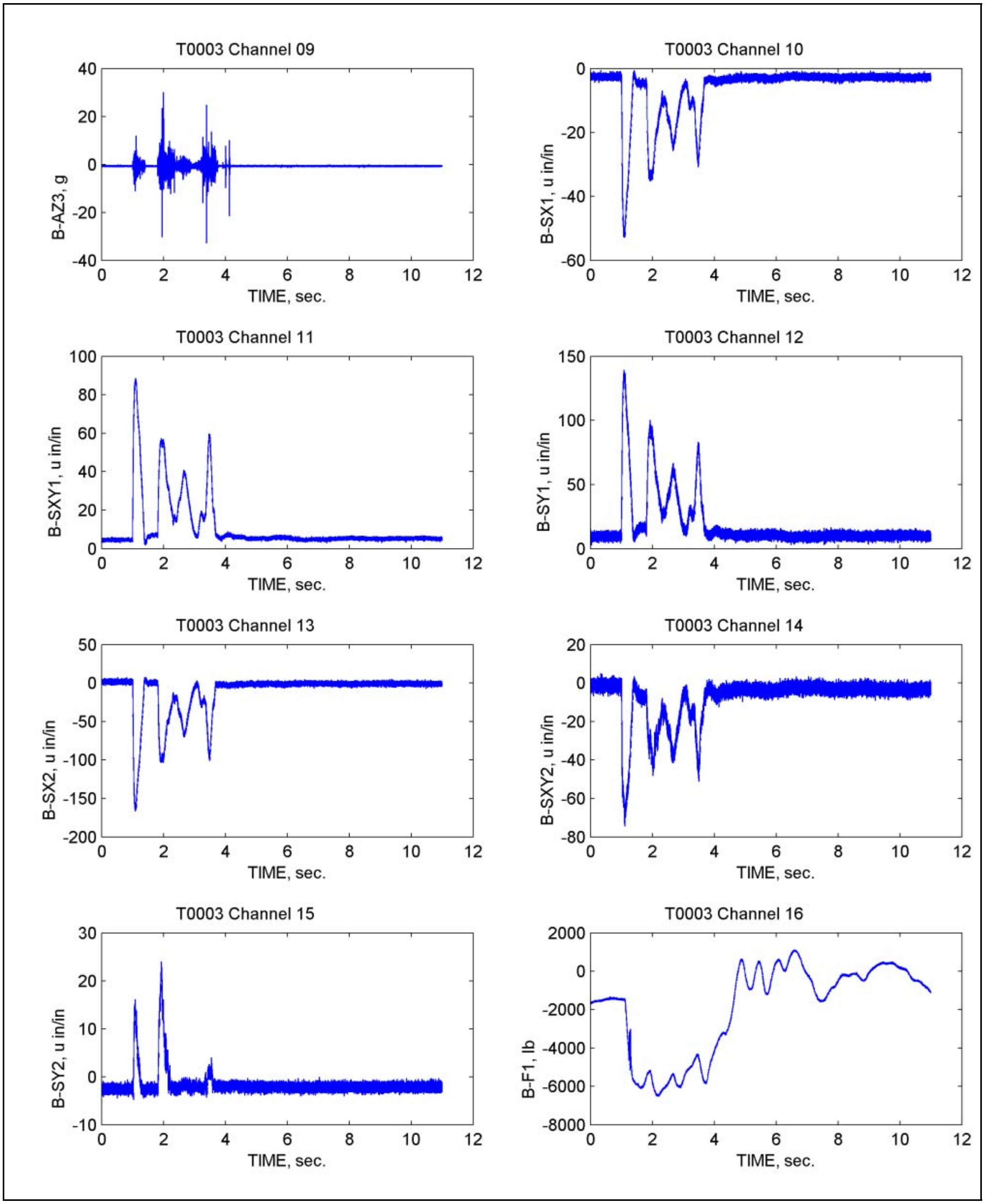

T0002 Channel 14
B-SXY2, u in/in
TIME, sec.

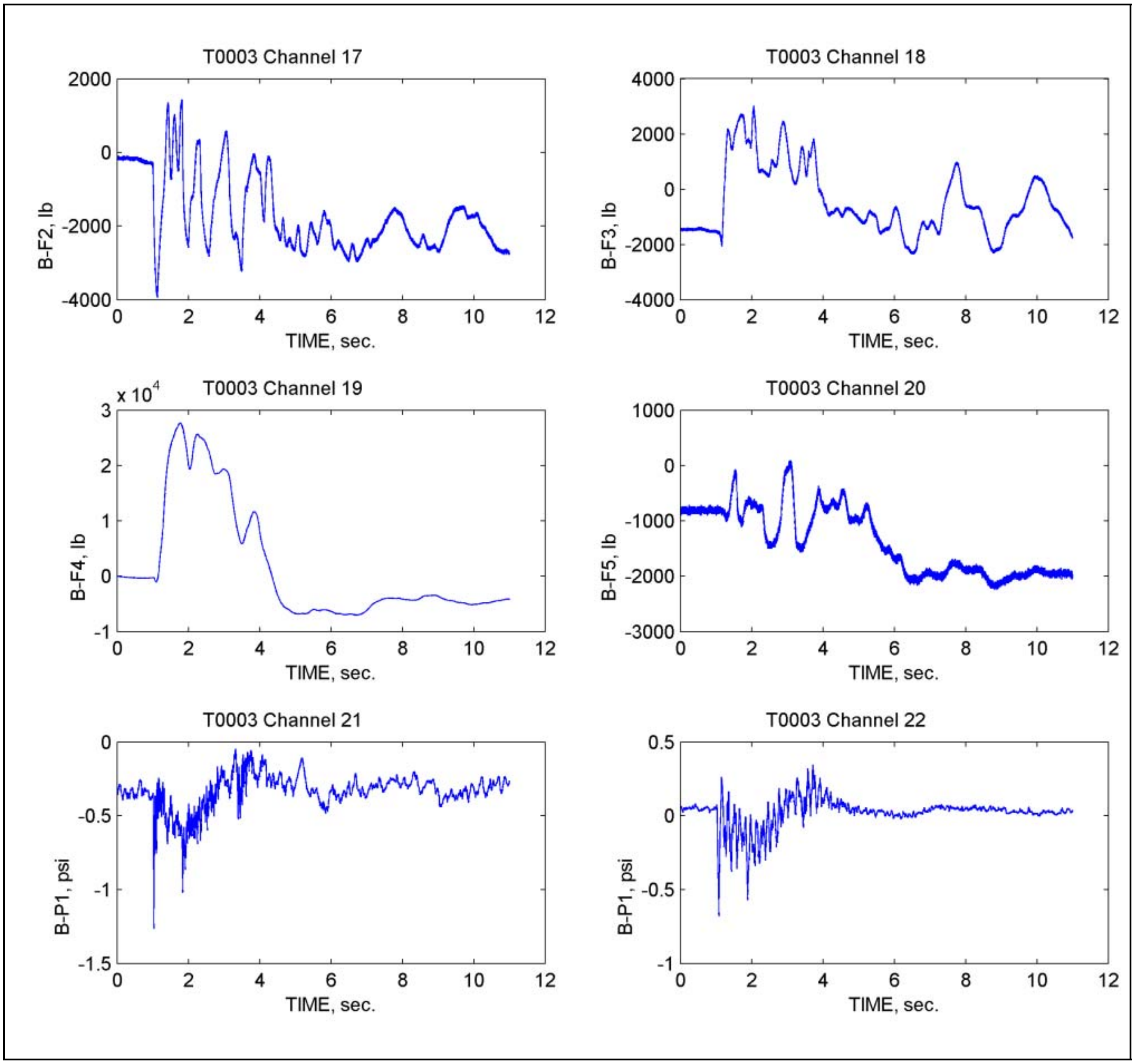

T0002 Channel 15
B-SY2, u in/in
TIME, sec.

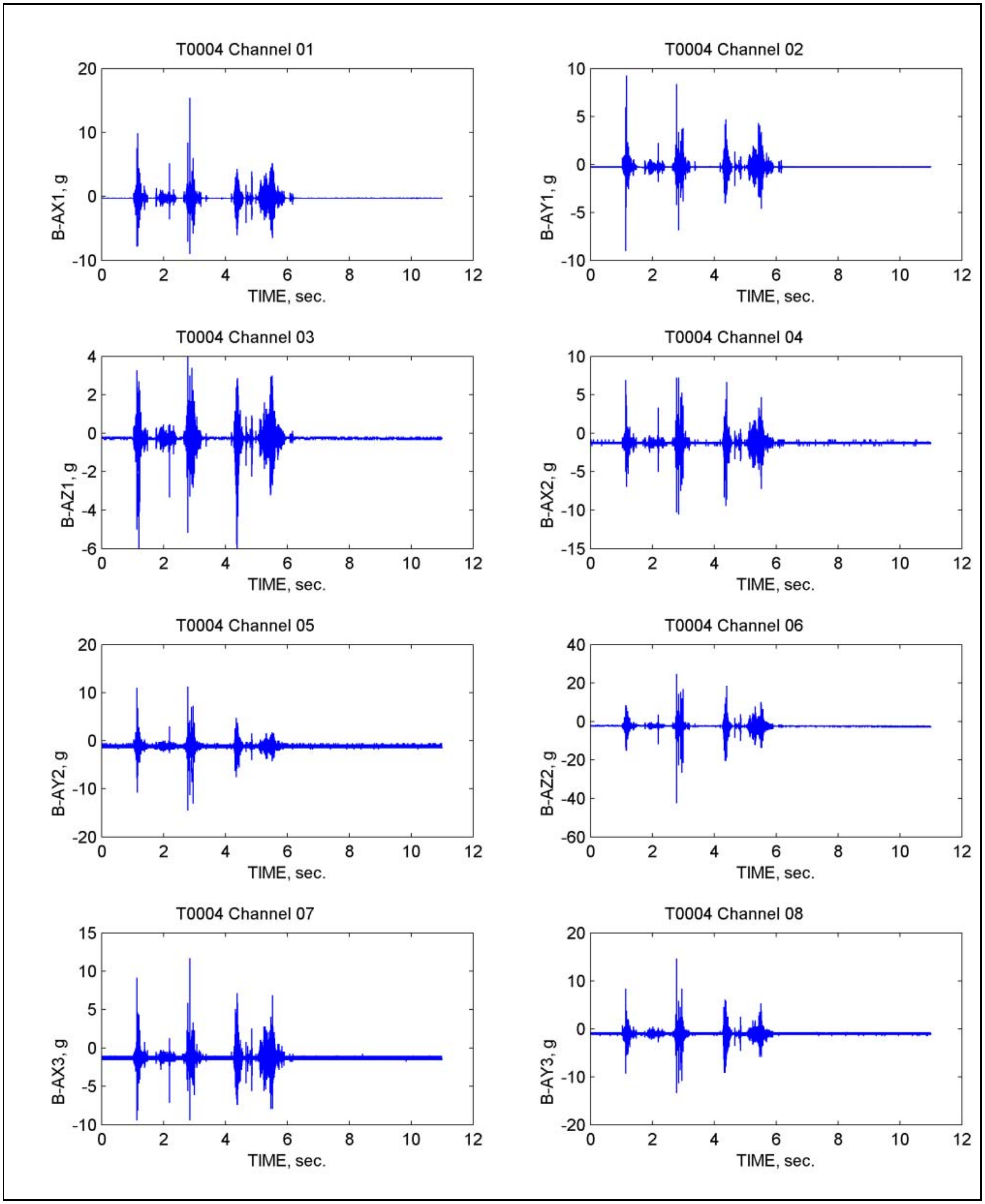

T0002 Channel 16
x 10^4
B-F1, lb
TIME, sec.


T0002 Channel 17
x 10^4
B-F2, lb
TIME, sec.
T0002 Channel 18
x 10^4
B-F3, lb
TIME, sec.
T0002 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0002 Channel 20
x 10^4
B-F5, lb
TIME, sec.
T0002 Channel 21
B-P1, psi
TIME, sec.
T0002 Channel 22
B-P1, psi
TIME, sec.

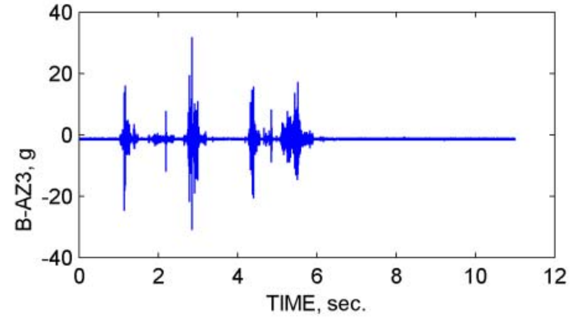

T0003 Channel 01
B-AX1, g
TIME, sec.
T0003 Channel 02
B-AY1, g
TIME, sec.
T0003 Channel 03
B-AZ1, g
TIME, sec.
T0003 Channel 04
B-AX2, g
TIME, sec.
T0003 Channel 05
B-AY2, g
TIME, sec.
T0003 Channel 06
B-AZ2, g
TIME, sec.
T0003 Channel 07
B-AX3, g
TIME, sec.
T0003 Channel 08
B-AY3, g
TIME, sec.


T0003 Channel 09
B-AZ3, g
TIME, sec.
T0003 Channel 10
B-SX1, u in/in
TIME, sec.
T0003 Channel 11
B-SXY1, u in/in
TIME, sec.
T0003 Channel 12
B-SY1, u in/in
TIME, sec.
T0003 Channel 13
B-SX2, u in/in
TIME, sec.
T0003 Channel 14
B-SXY2, u in/in
TIME, sec.
T0003 Channel 15
B-SY2, u in/in
TIME, sec.
T0003 Channel 16
B-F1, lb
TIME, sec.

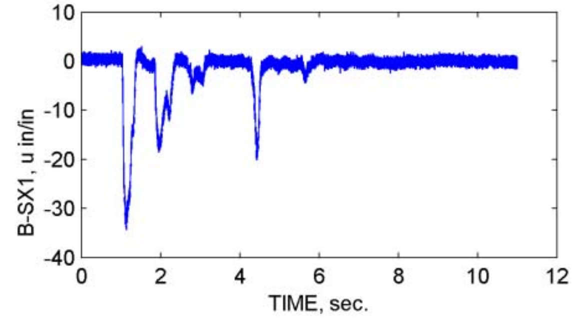

T0003 Channel 17
B-F2, lb
TIME, sec.
T0003 Channel 18
B-F3, lb
TIME, sec.
T0003 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0003 Channel 20
B-F5, lb
TIME, sec.
T0003 Channel 21
B-P1, psi
TIME, sec.
T0003 Channel 22
B-P1, psi
TIME, sec.


T0004 Channel 01
B-AX1, g
TIME, sec.
T0004 Channel 02
B-AY1, g
TIME, sec.
T0004 Channel 03
B-AZ1, g
TIME, sec.
T0004 Channel 04
B-AX2, g
TIME, sec.
T0004 Channel 05
B-AY2, g
TIME, sec.
T0004 Channel 06
B-AZ2, g
TIME, sec.
T0004 Channel 07
B-AX3, g
TIME, sec.
T0004 Channel 08
B-AY3, g
TIME, sec.

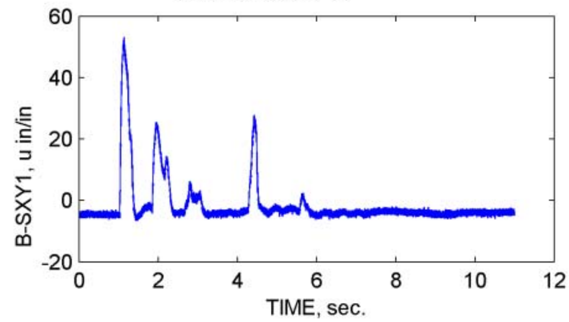
T0004 Channel 09



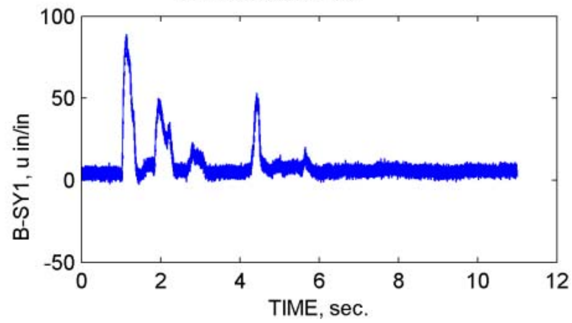
T0004 Channel 10



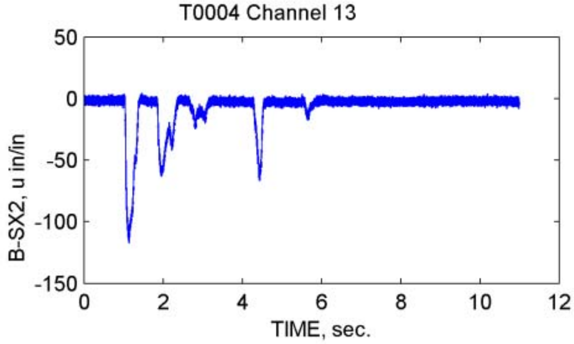
T0004 Channel 11



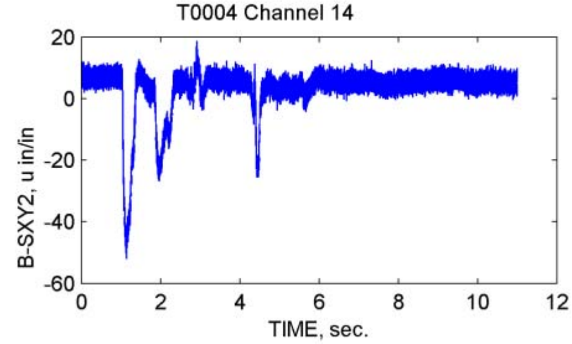
T0004 Channel 12



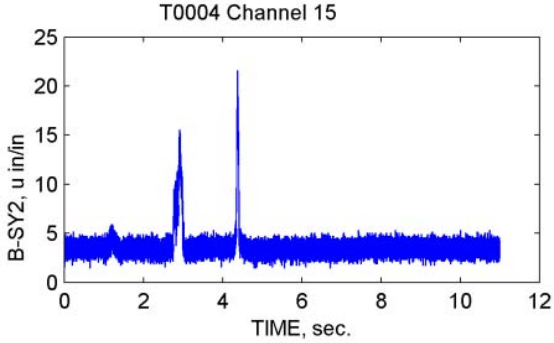
T0004 Channel 13



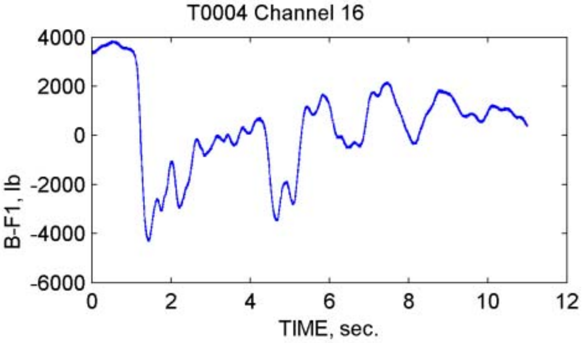
T0004 Channel 14

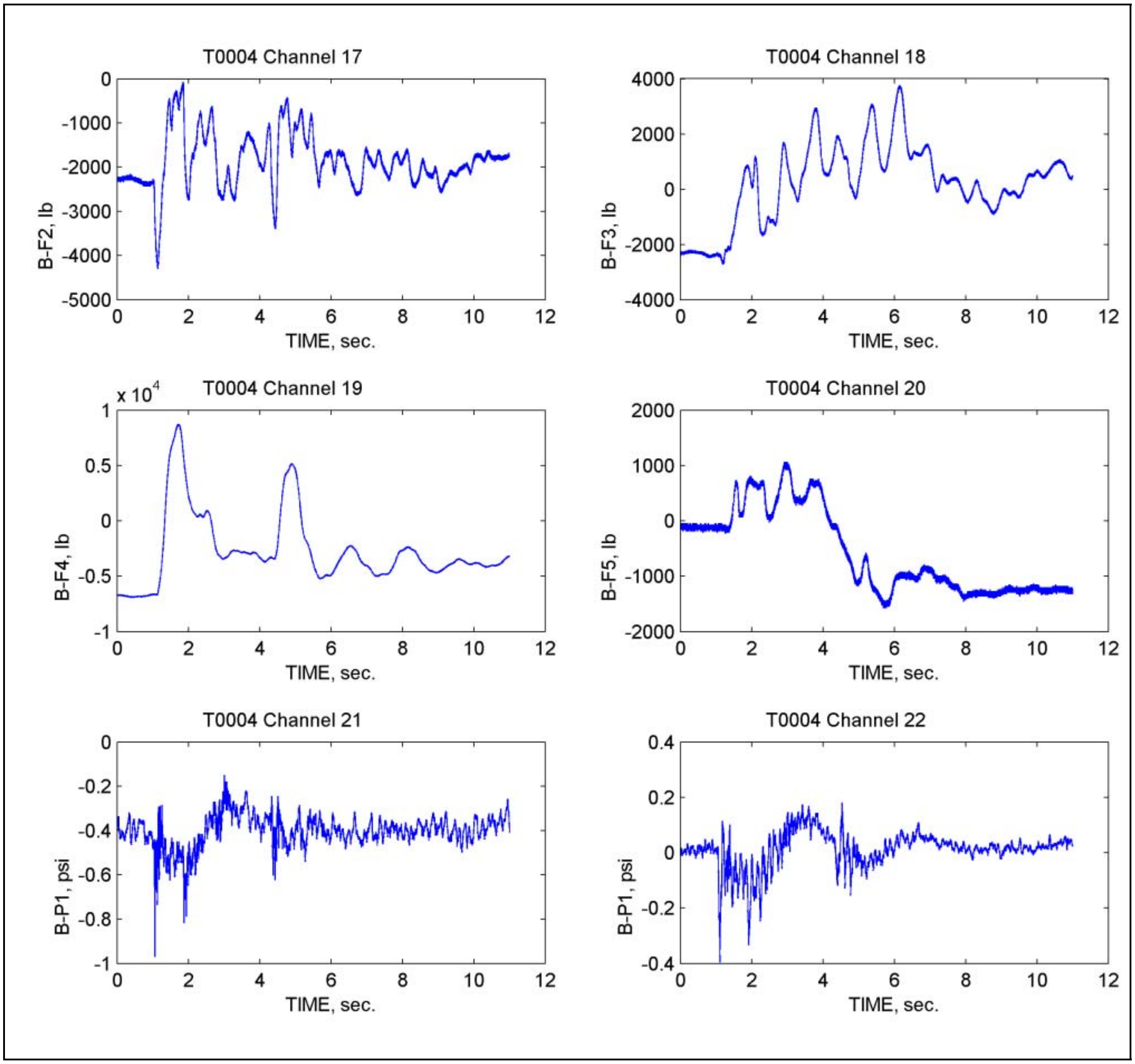


T0004 Channel 15



T0004 Channel 16

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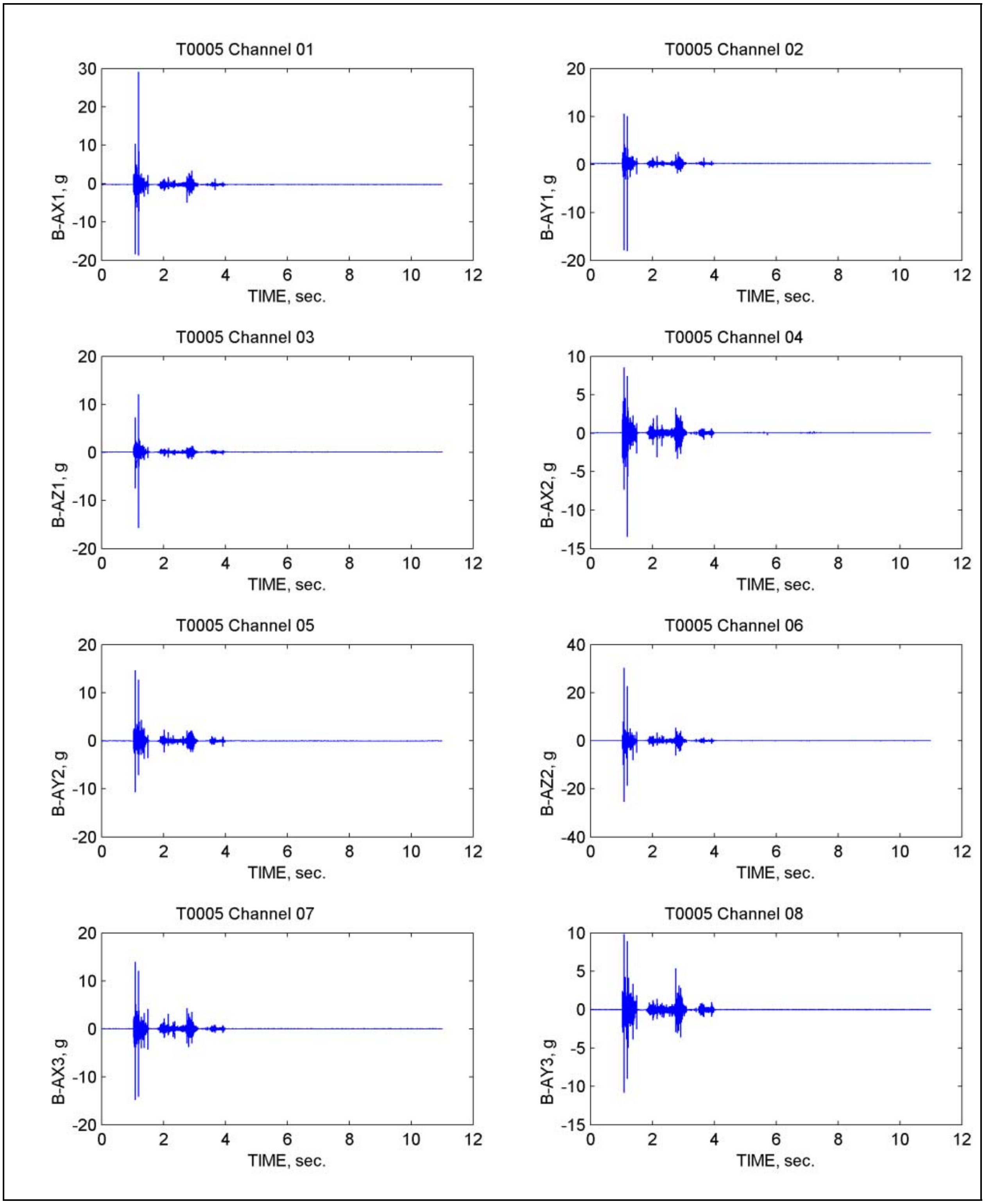
B-F2, lb
TIME, sec.
T0004 Channel 18
B-F3, lb
TIME, sec.
T0004 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0004 Channel 20
B-F5, lb
TIME, sec.
T0004 Channel 21
B-P1, psi
TIME, sec.
T0004 Channel 22
B-P1, psi
TIME, sec.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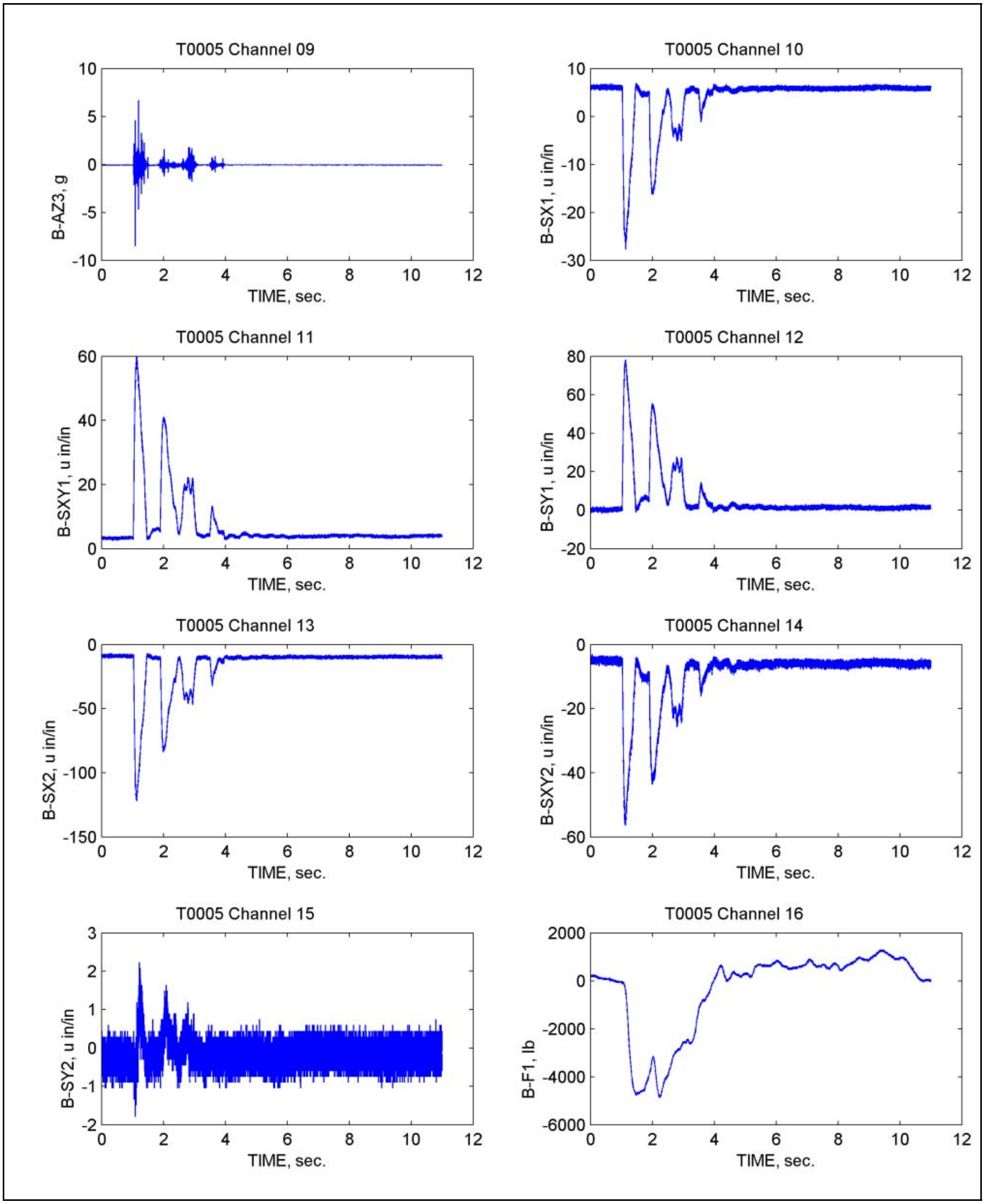
B-AX1, g
TIME, sec.
T0005 Channel 02
B-AY1, g
TIME, sec.
T0005 Channel 03
B-AZ1, g
TIME, sec.
T0005 Channel 04
B-AX2, g
TIME, sec.
T0005 Channel 05
B-AY2, g
TIME, sec.
T0005 Channel 06
B-AZ2, g
TIME, sec.
T0005 Channel 07
B-AX3, g
TIME, sec.
T0005 Channel 08
B-AY3, g
TIME, sec.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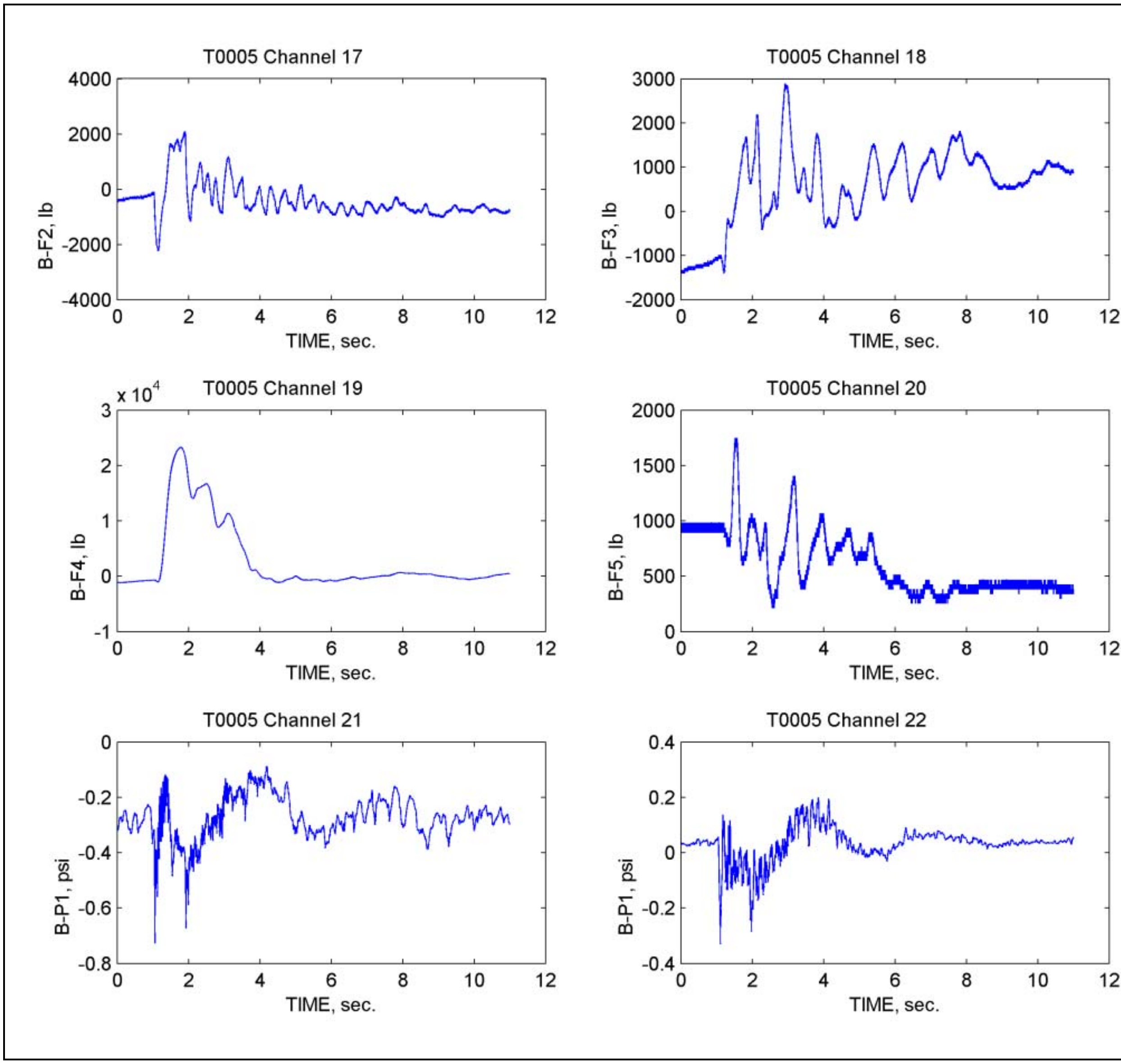
TIME, sec.
T0005 Channel 10
B-SX1, u in/in
TIME, sec.
T0005 Channel 11
B-SXY1, u in/in
TIME, sec.
T0005 Channel 12
B-SY1, u in/in
TIME, sec.
T0005 Channel 13
B-SX2, u in/in
TIME, sec.
T0005 Channel 14
B-SXY2, u in/in
TIME, sec.
T0005 Channel 15
B-SY2, u in/in
TIME, sec.
T0005 Channel 16
B-F1, lb
TIME, sec.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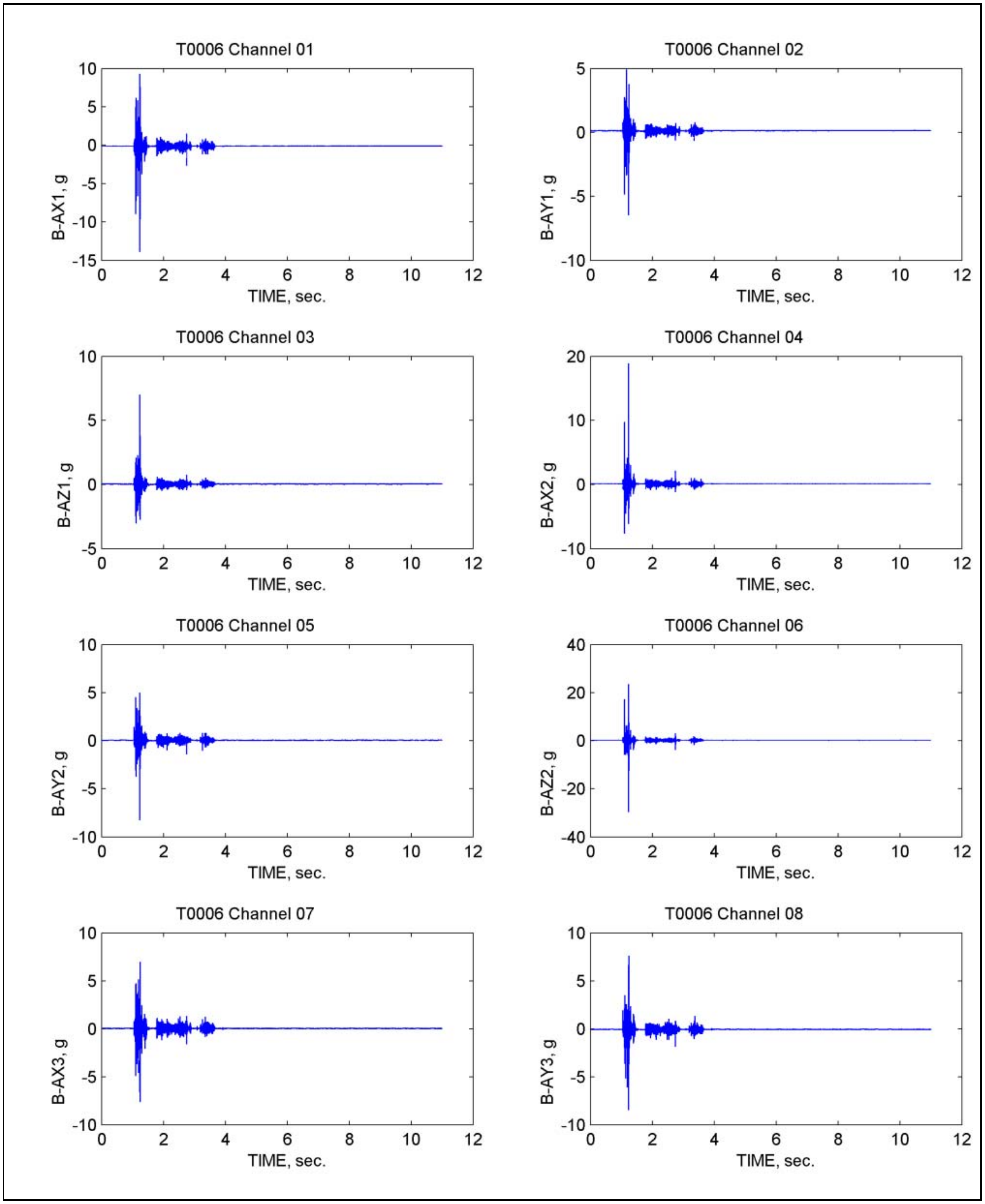
TIME, sec.
T0005 Channel 18
B-F3, lb
TIME, sec.
T0005 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0005 Channel 20
B-F5, lb
TIME, sec.
T0005 Channel 21
B-P1, psi
TIME, sec.
T0005 Channel 22
B-P1, psi
TIME, sec.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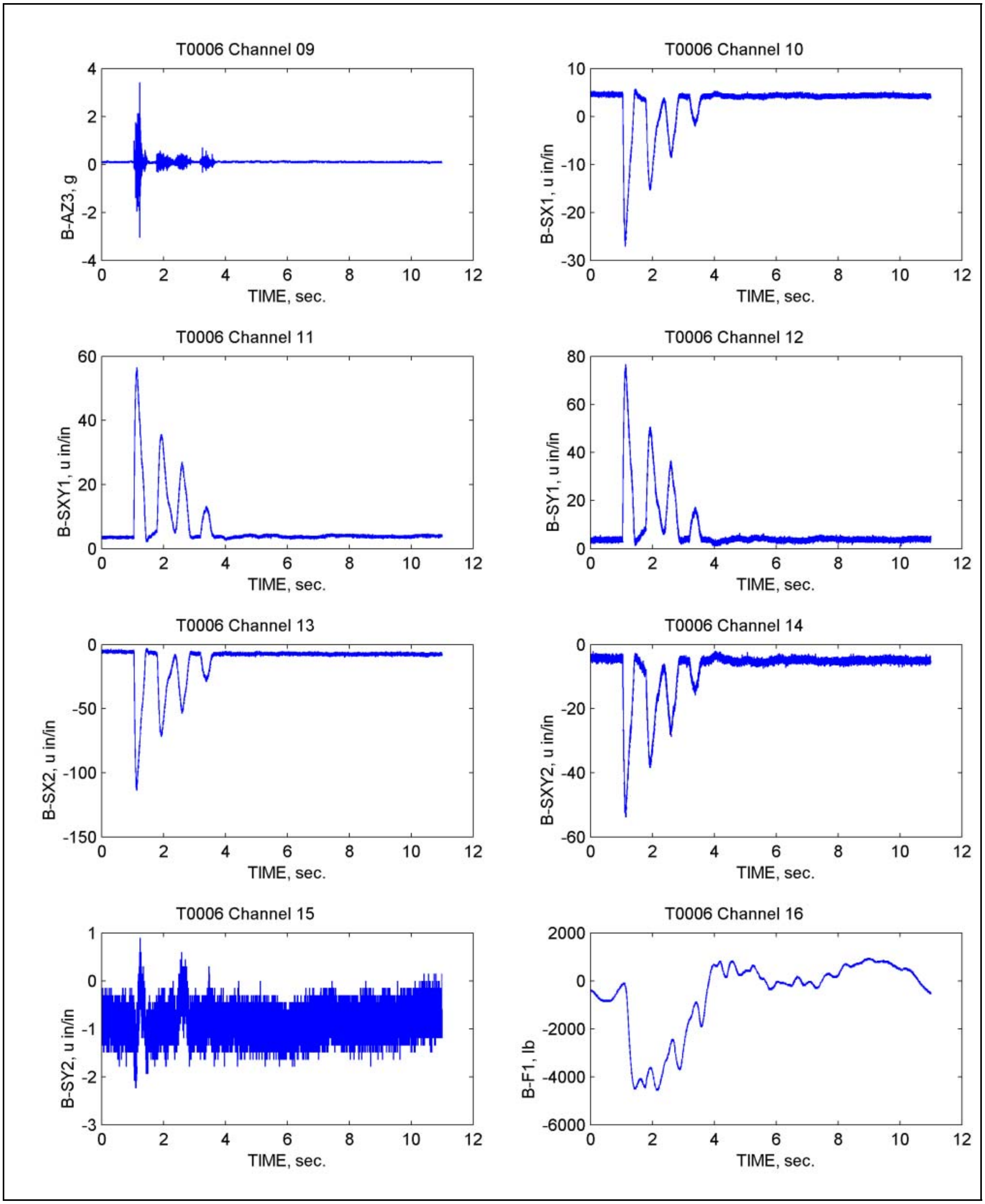
T0006 Channel 02
B-AY1, g
T0006 Channel 03
B-AZ1, g
T0006 Channel 04
B-AX2, g
T0006 Channel 05
B-AY2, g
T0006 Channel 06
B-AZ2, g
T0006 Channel 07
B-AX3, g
T0006 Channel 08
B-AY3, g
TIME, sec.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TIME, sec.
T0006 Channel 10
B-SX1, u in/in
TIME, sec.
T0006 Channel 11
B-SXY1, u in/in
TIME, sec.
T0006 Channel 12
B-SY1, u in/in
TIME, sec.
T0006 Channel 13
B-SX2, u in/in
TIME, sec.
T0006 Channel 14
B-SXY2, u in/in
TIME, sec.
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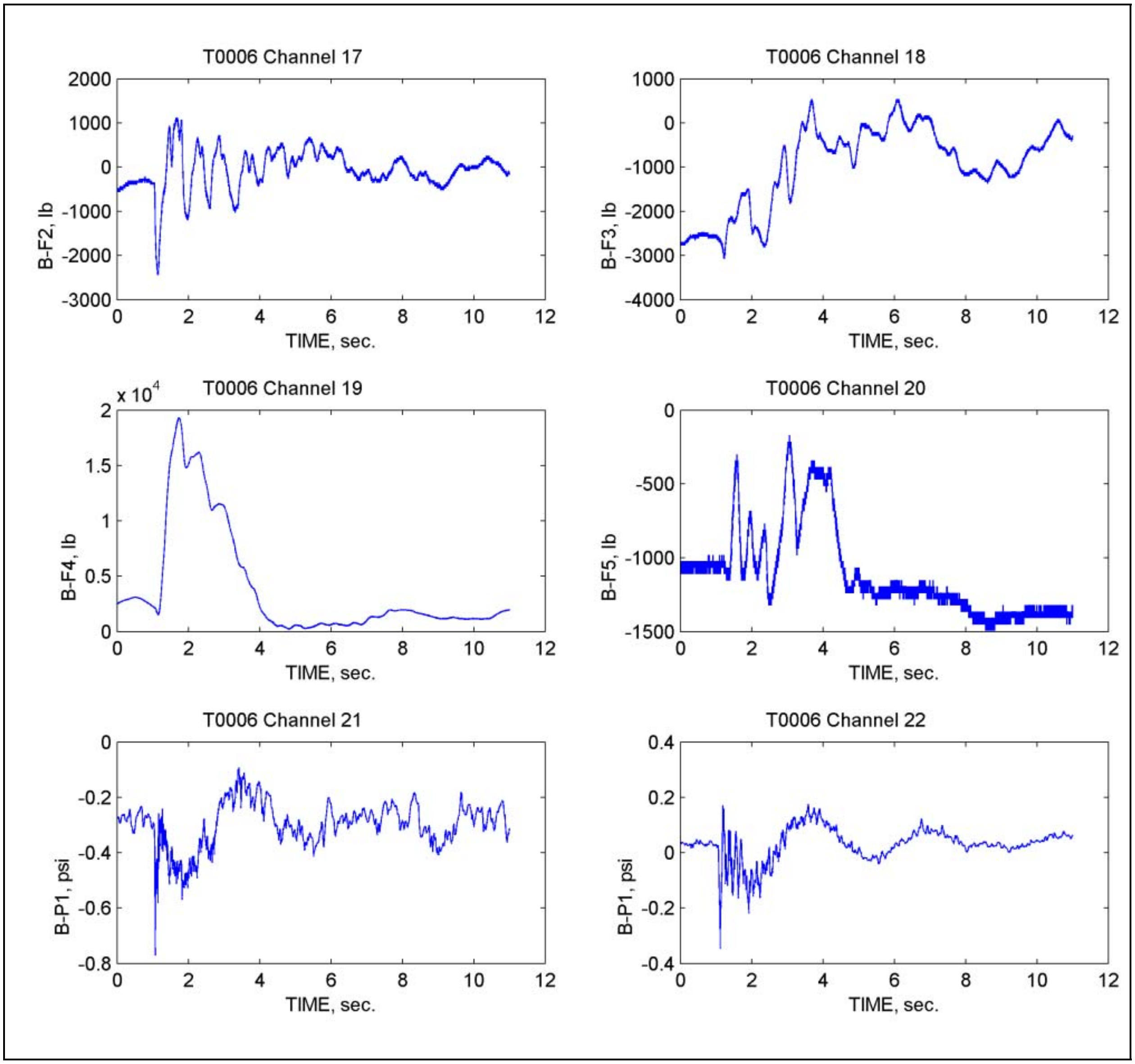
B-SY2, u in/in
TIME, sec.
T0006 Channel 16
B-F1, lb
TIME, sec.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B-F2, lb
TIME, sec.
T0006 Channel 18
B-F3, lb
TIME, sec.
T0006 Channel 19
x 10^4
B-F4, lb
TIME, sec.
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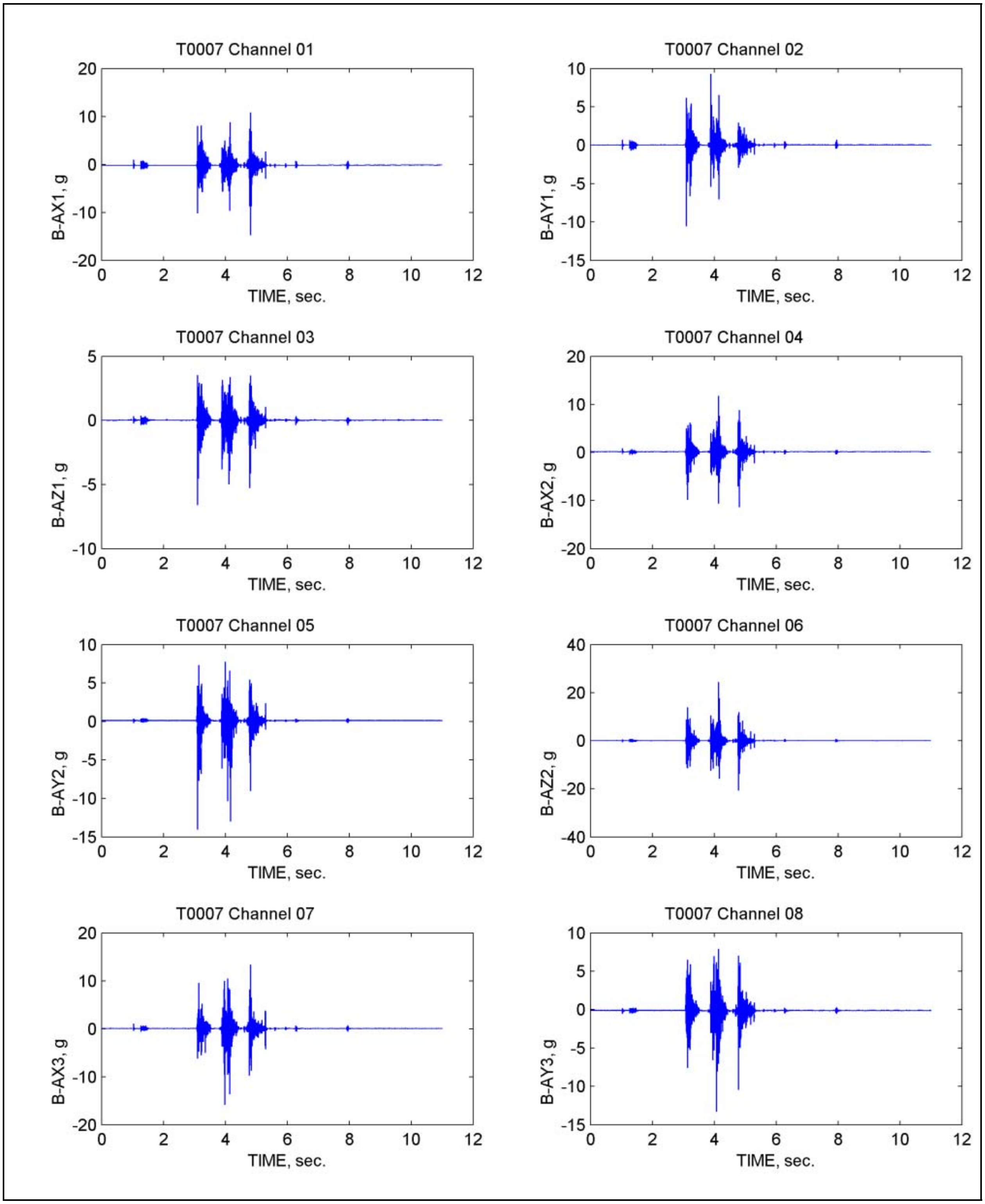
B-F5, lb
TIME, sec.
T0006 Channel 21
B-P1, psi
TIME, sec.
T0006 Channel 22
B-P1, psi
TIME, sec.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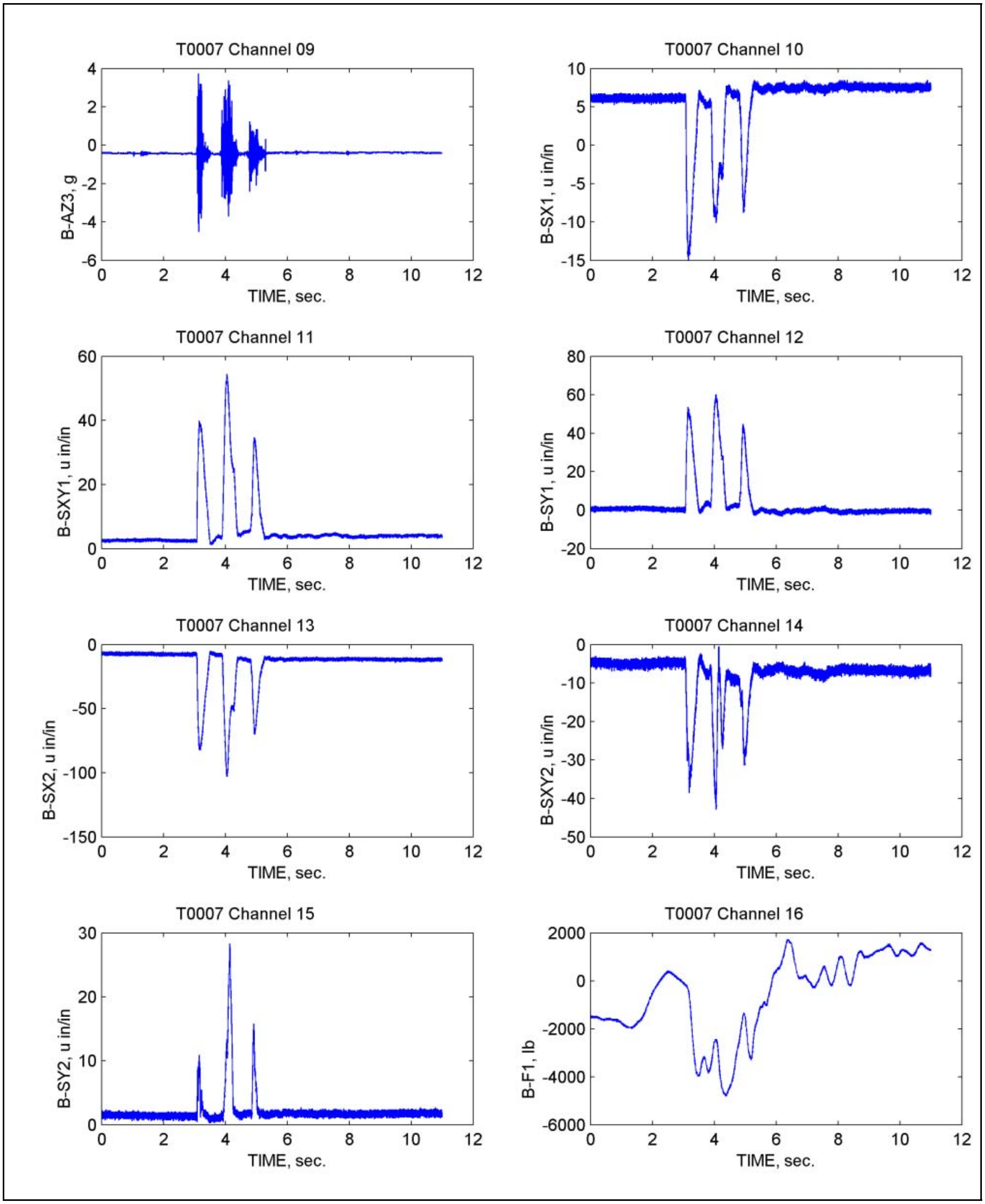
TIME, sec.
T0007 Channel 02
B-AY1, g
TIME, sec.
T0007 Channel 03
B-AZ1, g
TIME, sec.
T0007 Channel 04
B-AX2, g
TIME, sec.
T0007 Channel 05
B-AY2, g
TIME, sec.
T0007 Channel 06
B-AZ2, g
TIME, sec.
T0007 Channel 07
B-AX3, g
TIME, sec.
T0007 Channel 08
B-AY3, g
TIME, sec.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TIME, sec.
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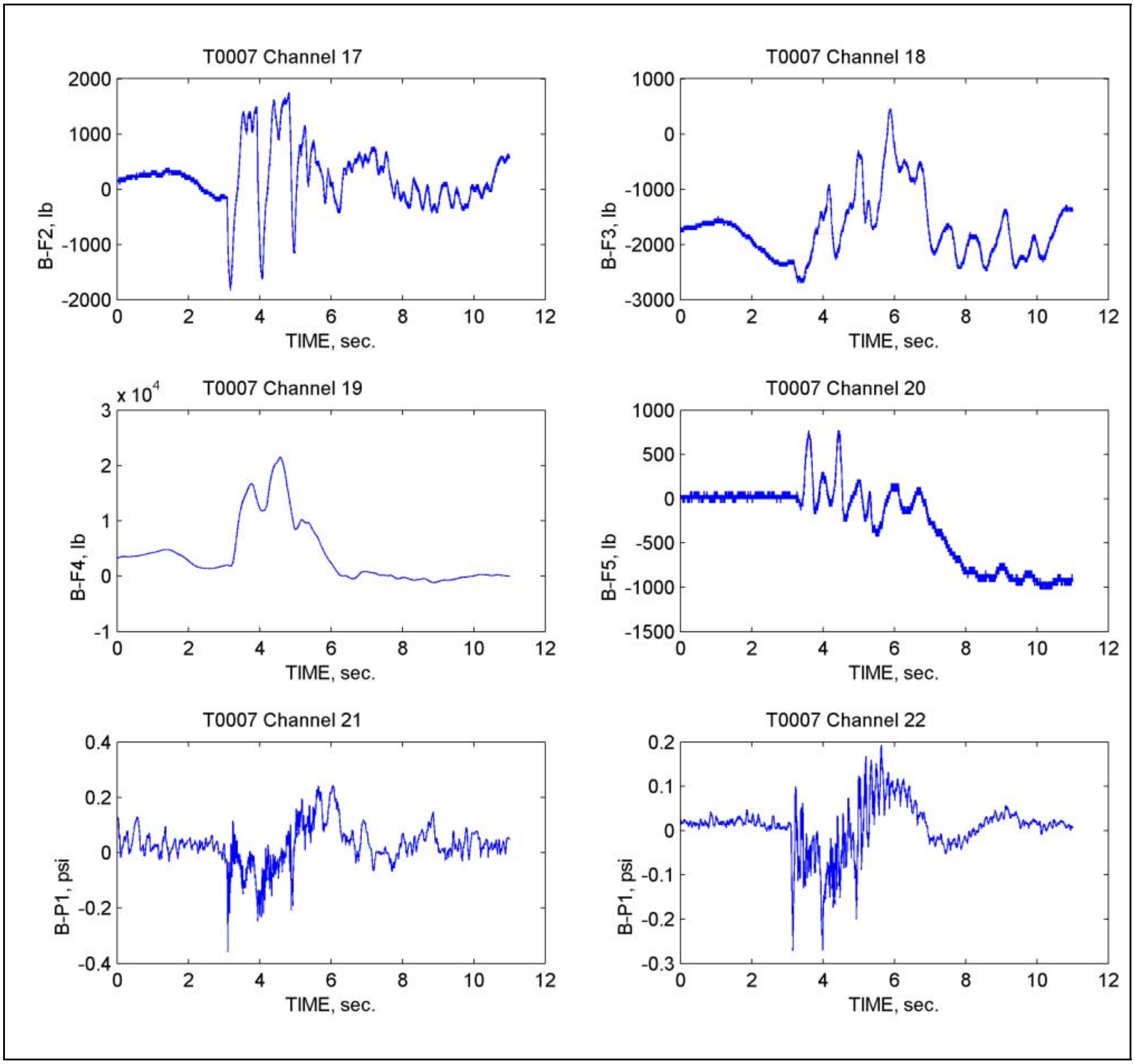
B-SX1, u in/in
TIME, sec.
T0007 Channel 11
B-SXY1, u in/in
TIME, sec.
T0007 Channel 12
B-SY1, u in/in
TIME, sec.
T0007 Channel 13
B-SX2, u in/in
TIME, sec.
T0007 Channel 14
B-SXY2, u in/in
TIME, sec.
T0007 Channel 15
B-SY2, u in/in
TIME, sec.
T0007 Channel 16
B-F1, lb
TIME, sec.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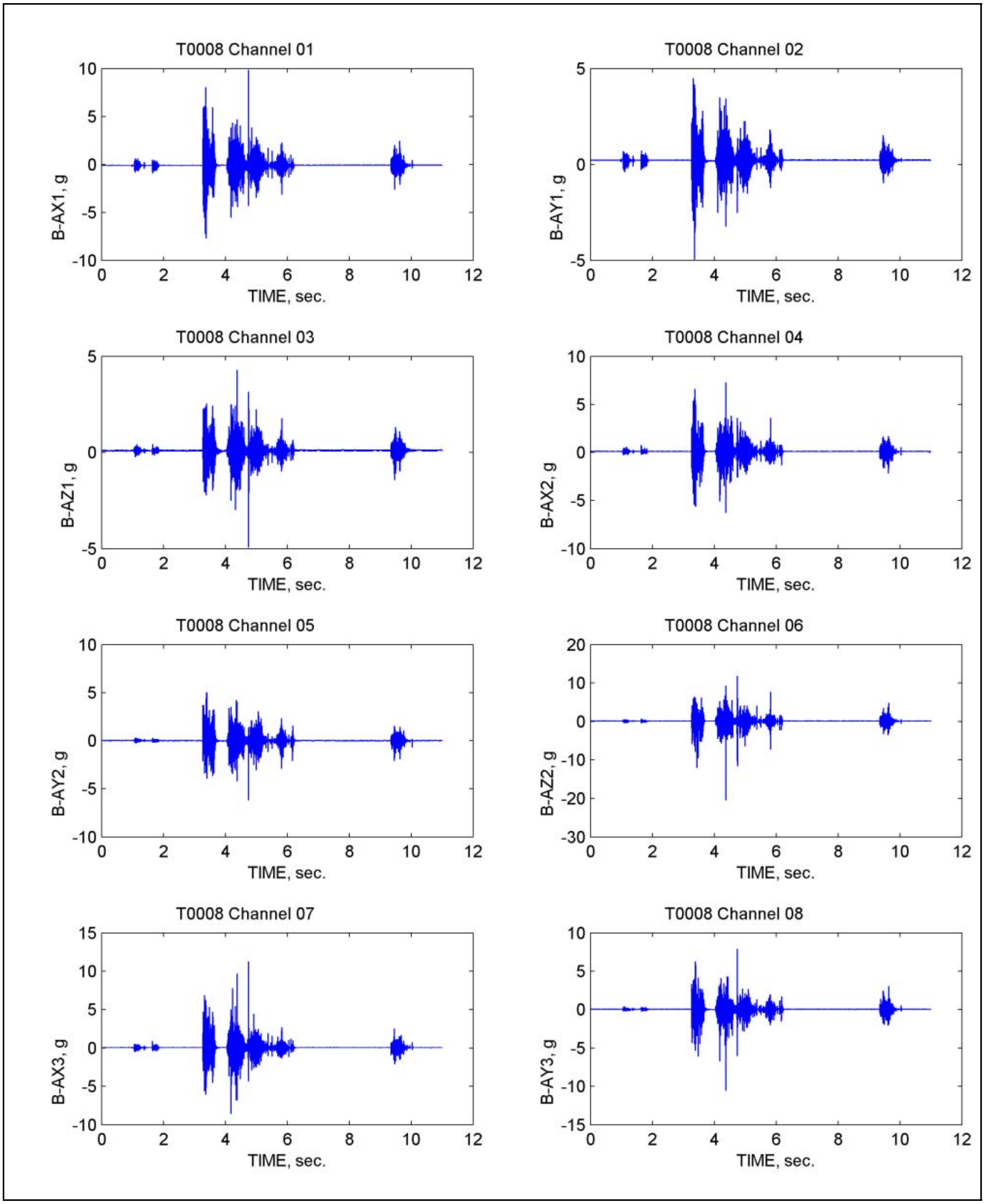
TIME, sec.
T0007 Channel 18
B-F3, lb
TIME, sec.
T0007 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0007 Channel 20
B-F5, lb
TIME, sec.
T0007 Channel 21
B-P1, psi
TIME, sec.
T0007 Channel 22
B-P1, psi
TIME, sec.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TIME, sec.
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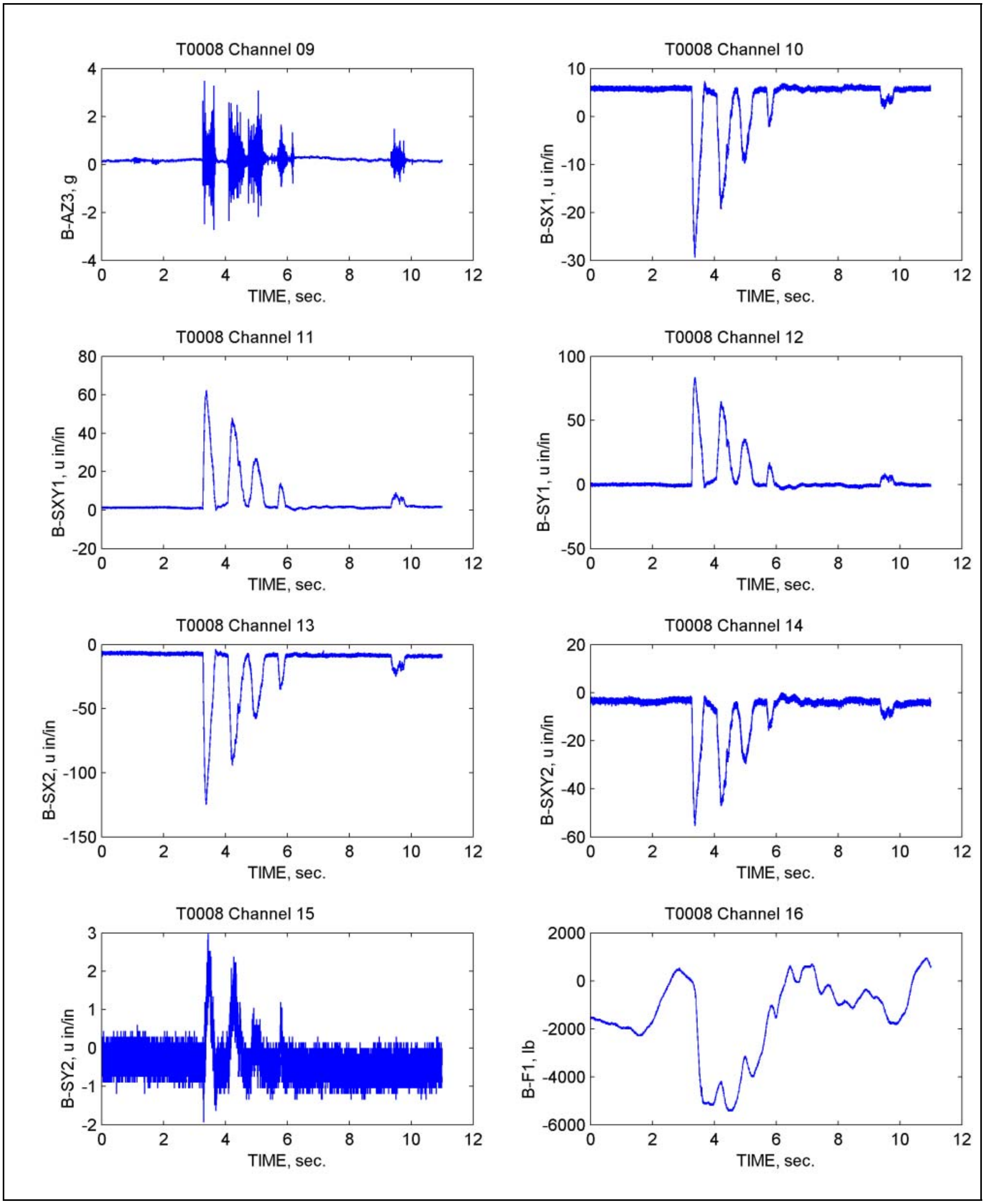
B-AY1, g
TIME, sec.
T0008 Channel 03
B-AZ1, g
TIME, sec.
T0008 Channel 04
B-AX2, g
TIME, sec.
T0008 Channel 05
B-AY2, g
TIME, sec.
T0008 Channel 06
B-AZ2, g
TIME, sec.
T0008 Channel 07
B-AX3, g
TIME, sec.
T0008 Channel 08
B-AY3, g
TIME, sec.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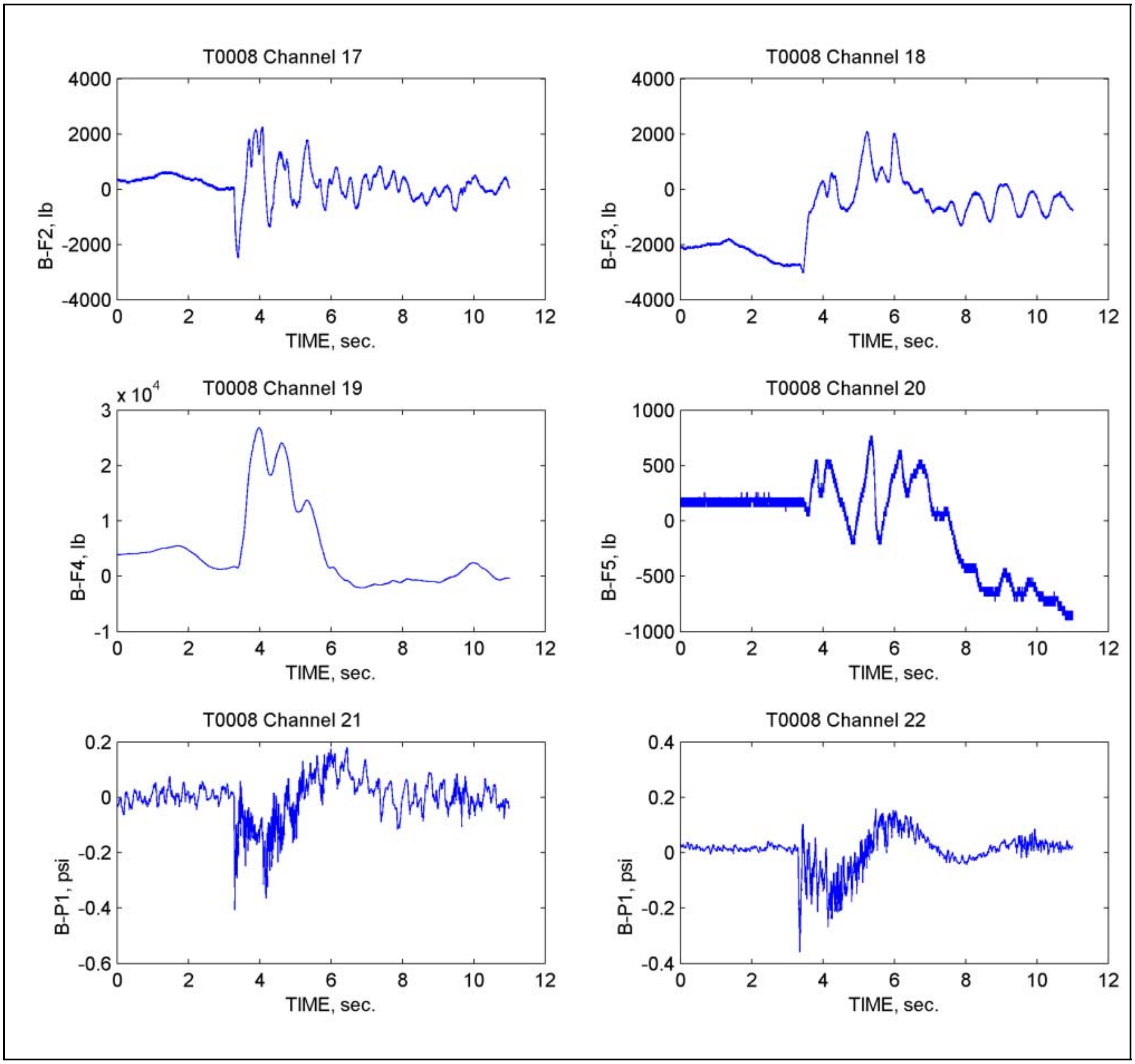
B-AZ3, g
TIME, sec.
T0008 Channel 10
B-SX1, u in/in
TIME, sec.
T0008 Channel 11
B-SXY1, u in/in
TIME, sec.
T0008 Channel 12
B-SY1, u in/in
TIME, sec.
T0008 Channel 13
B-SX2, u in/in
TIME, sec.
T0008 Channel 14
B-SXY2, u in/in
TIME, sec.
T0008 Channel 15
B-SY2, u in/in
TIME, sec.
T0008 Channel 16
B-F1, lb
TIME, sec.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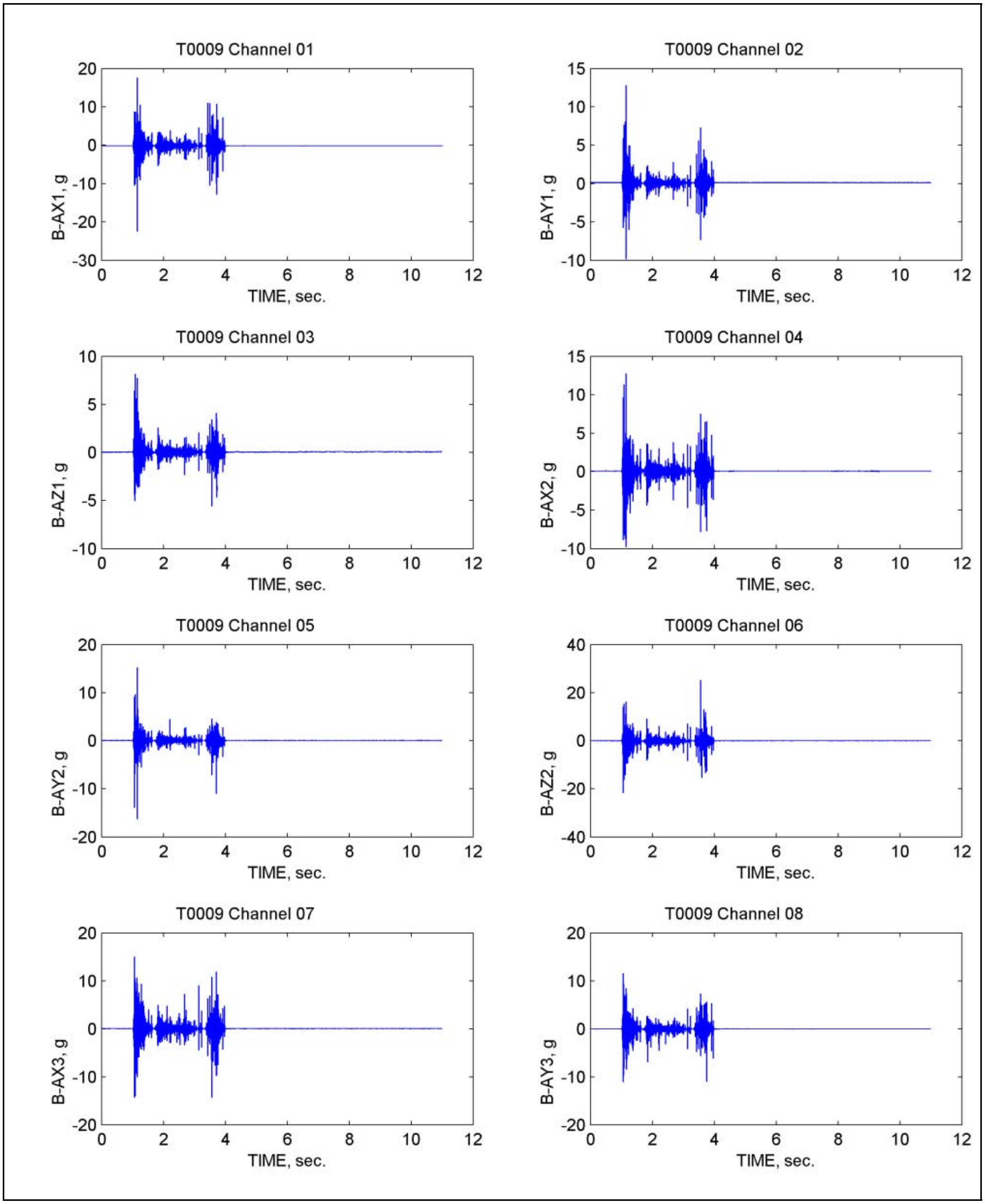
B-F2, lb
TIME, sec.
T0008 Channel 18
B-F3, lb
TIME, sec.
T0008 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0008 Channel 20
B-F5, lb
TIME, sec.
T0008 Channel 21
B-P1, psi
TIME, sec.
T0008 Channel 22
B-P1, psi
TIME, sec.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TIME, sec.
T0009 Channel 02
B-AY1, g
TIME, sec.
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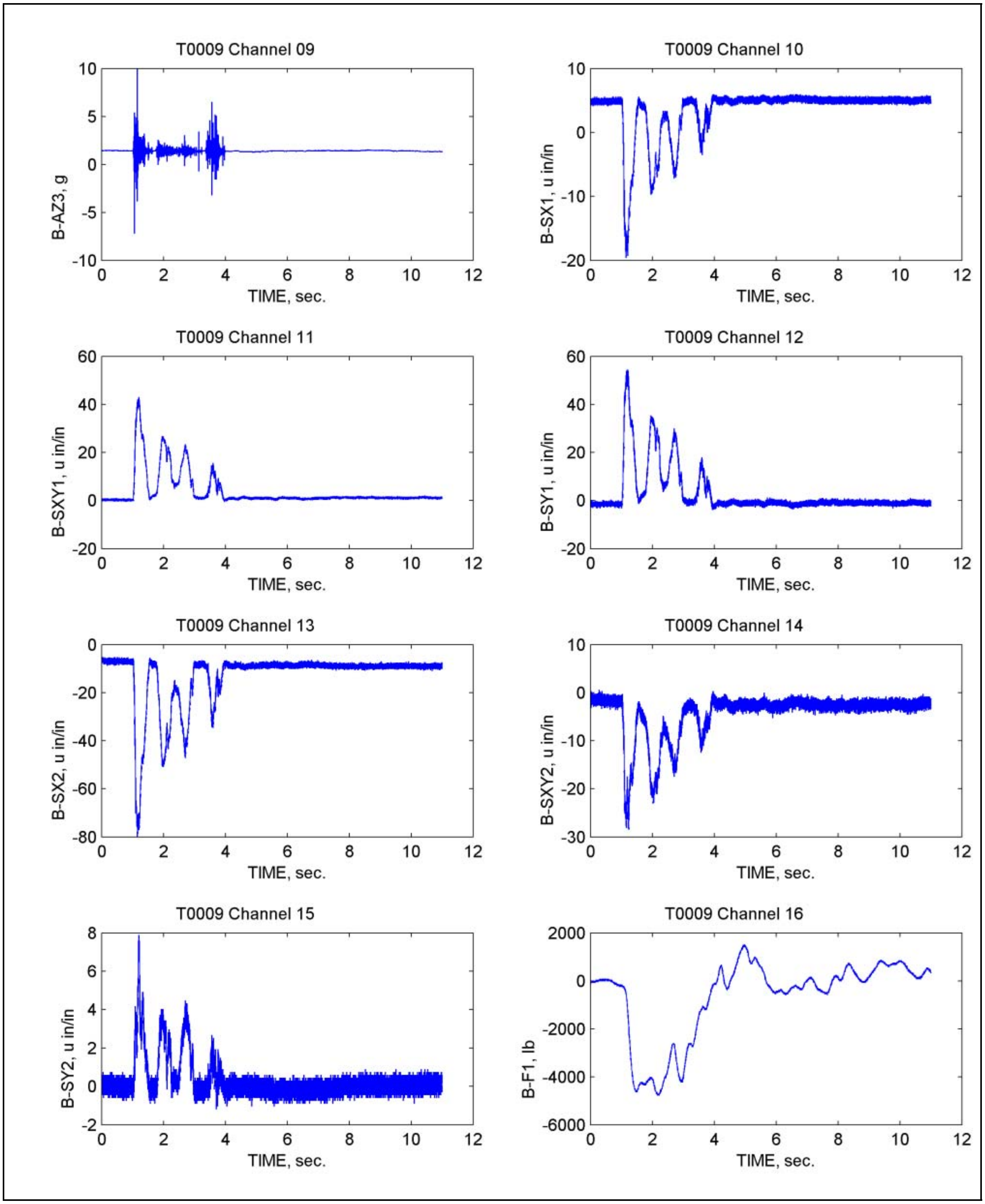
B-AZ1, g
TIME, sec.
T0009 Channel 04
B-AX2, g
TIME, sec.
T0009 Channel 05
B-AY2, g
TIME, sec.
T0009 Channel 06
B-AZ2, g
TIME, sec.
T0009 Channel 07
B-AX3, g
TIME, sec.
T0009 Channel 08
B-AY3, g
TIME, sec.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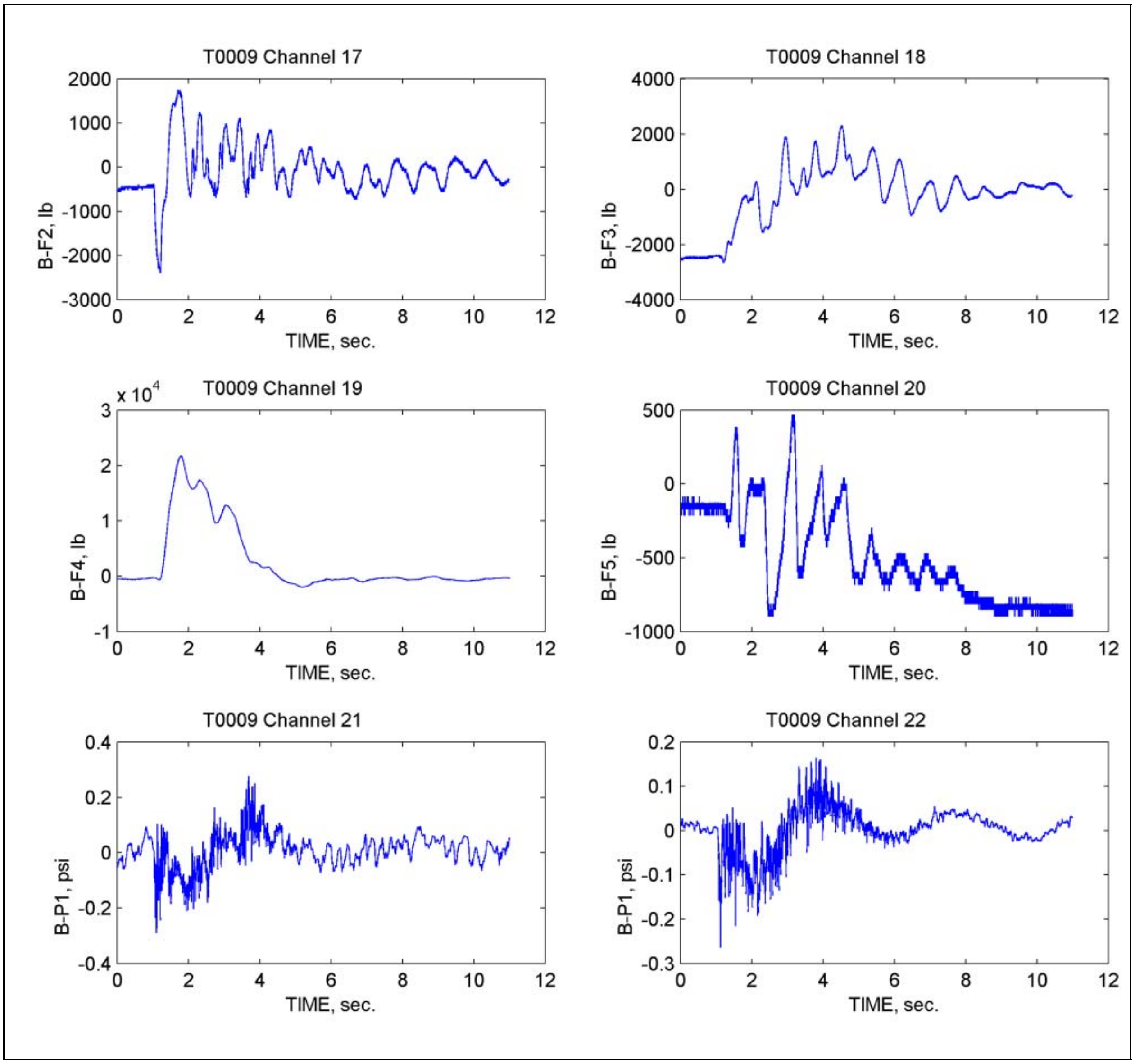
B-AZ3, g
TIME, sec.
T0009 Channel 10
B-SX1, u in/in
TIME, sec.
T0009 Channel 11
B-SXY1, u in/in
TIME, sec.
T0009 Channel 12
B-SY1, u in/in
TIME, sec.
T0009 Channel 13
B-SX2, u in/in
TIME, sec.
T0009 Channel 14
B-SXY2, u in/in
TIME, sec.
T0009 Channel 15
B-SY2, u in/in
TIME, sec.
T0009 Channel 16
B-F1, lb
TIME, sec.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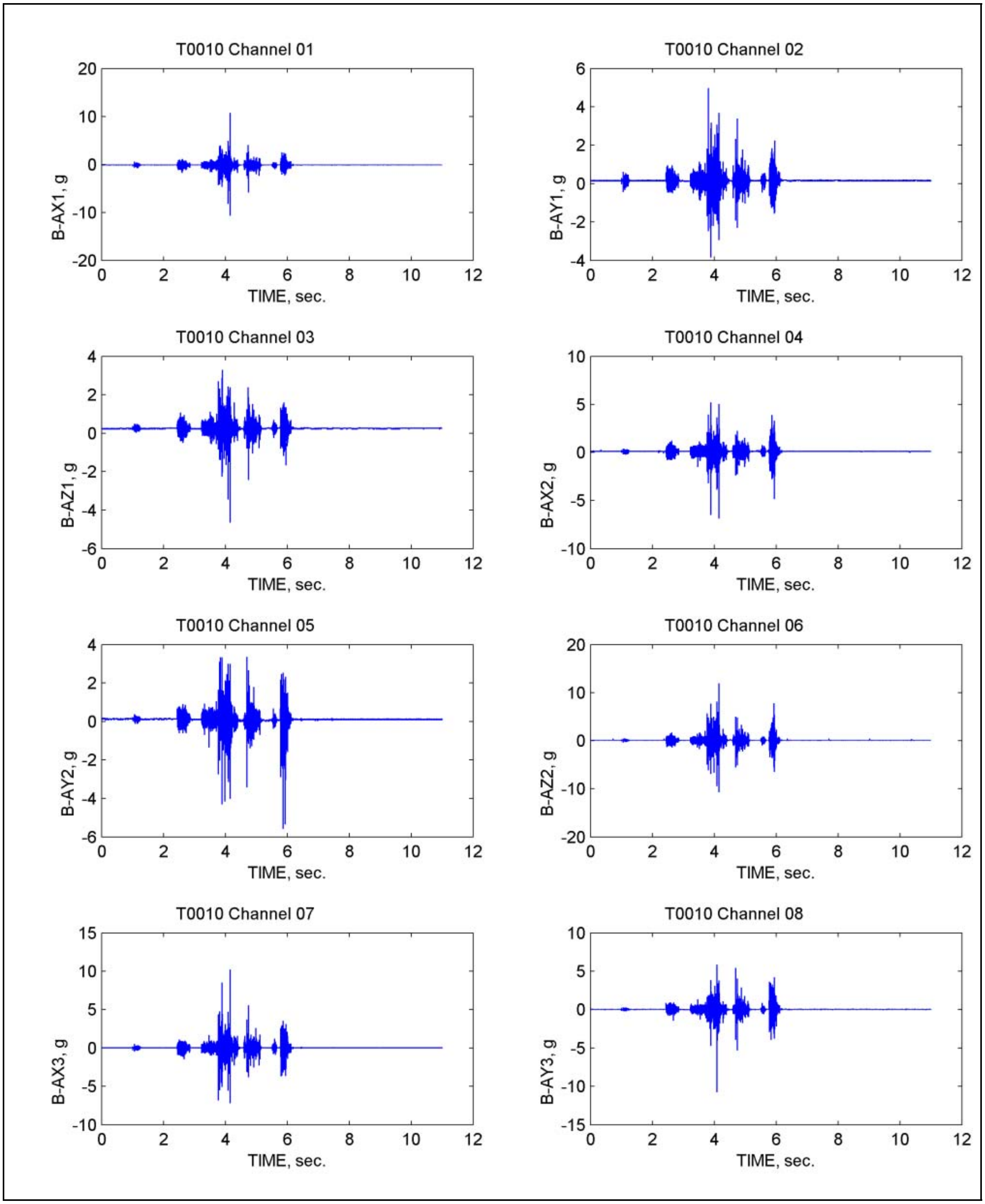
B-F2, lb
TIME, sec.
T0009 Channel 18
B-F3, lb
TIME, sec.
T0009 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0009 Channel 20
B-F5, lb
TIME, sec.
T0009 Channel 21
B-P1, psi
TIME, sec.
T0009 Channel 22
B-P1, psi
TIME, sec.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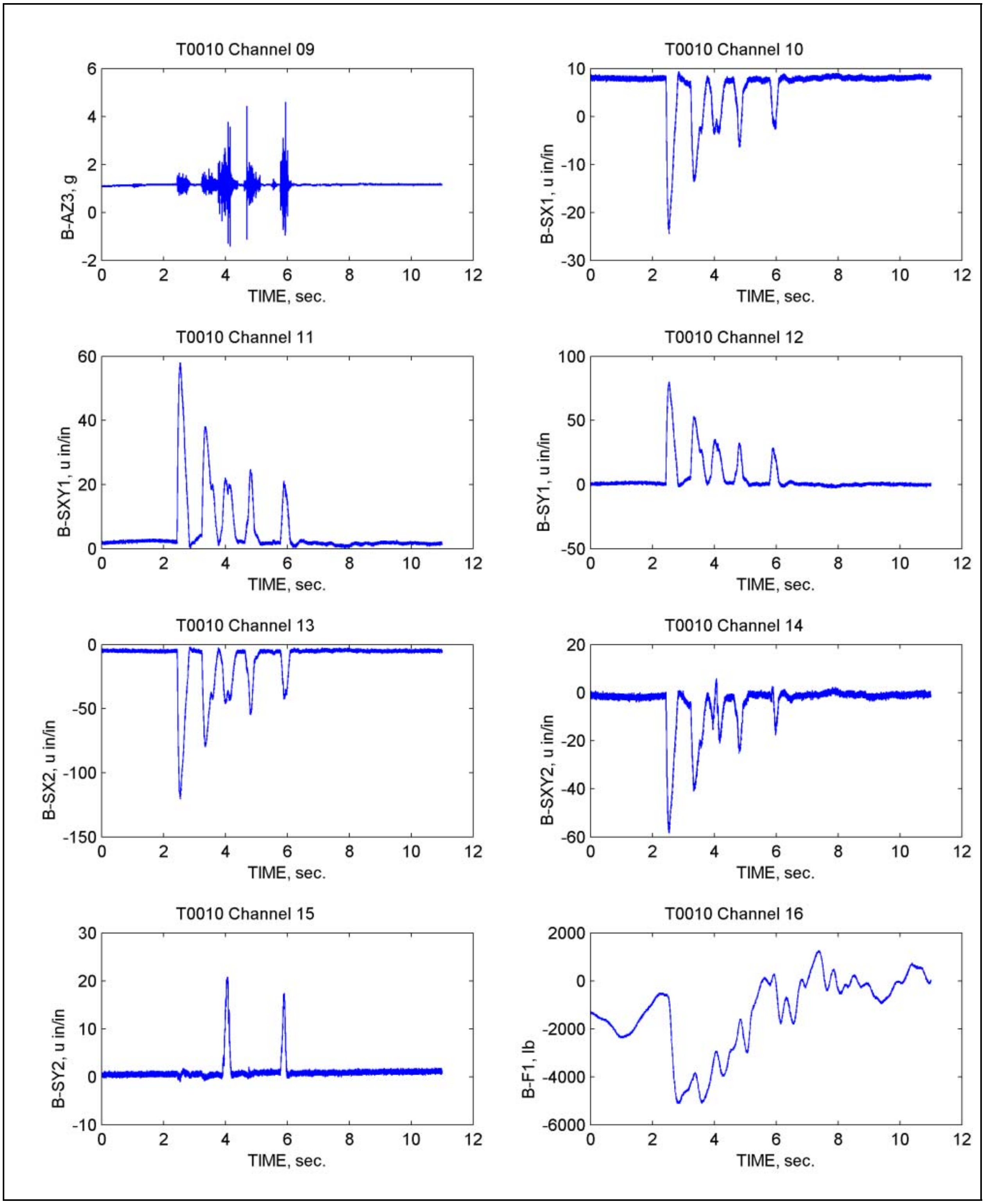
B-AX1, g
TIME, sec.
T0010 Channel 02
B-AY1, g
TIME, sec.
T0010 Channel 03
B-AZ1, g
TIME, sec.
T0010 Channel 04
B-AX2, g
TIME, sec.
T0010 Channel 05
B-AY2, g
TIME, sec.
T0010 Channel 06
B-AZ2, g
TIME, sec.
T0010 Channel 07
B-AX3, g
TIME, sec.
T0010 Channel 08
B-AY3, g
TIME, sec.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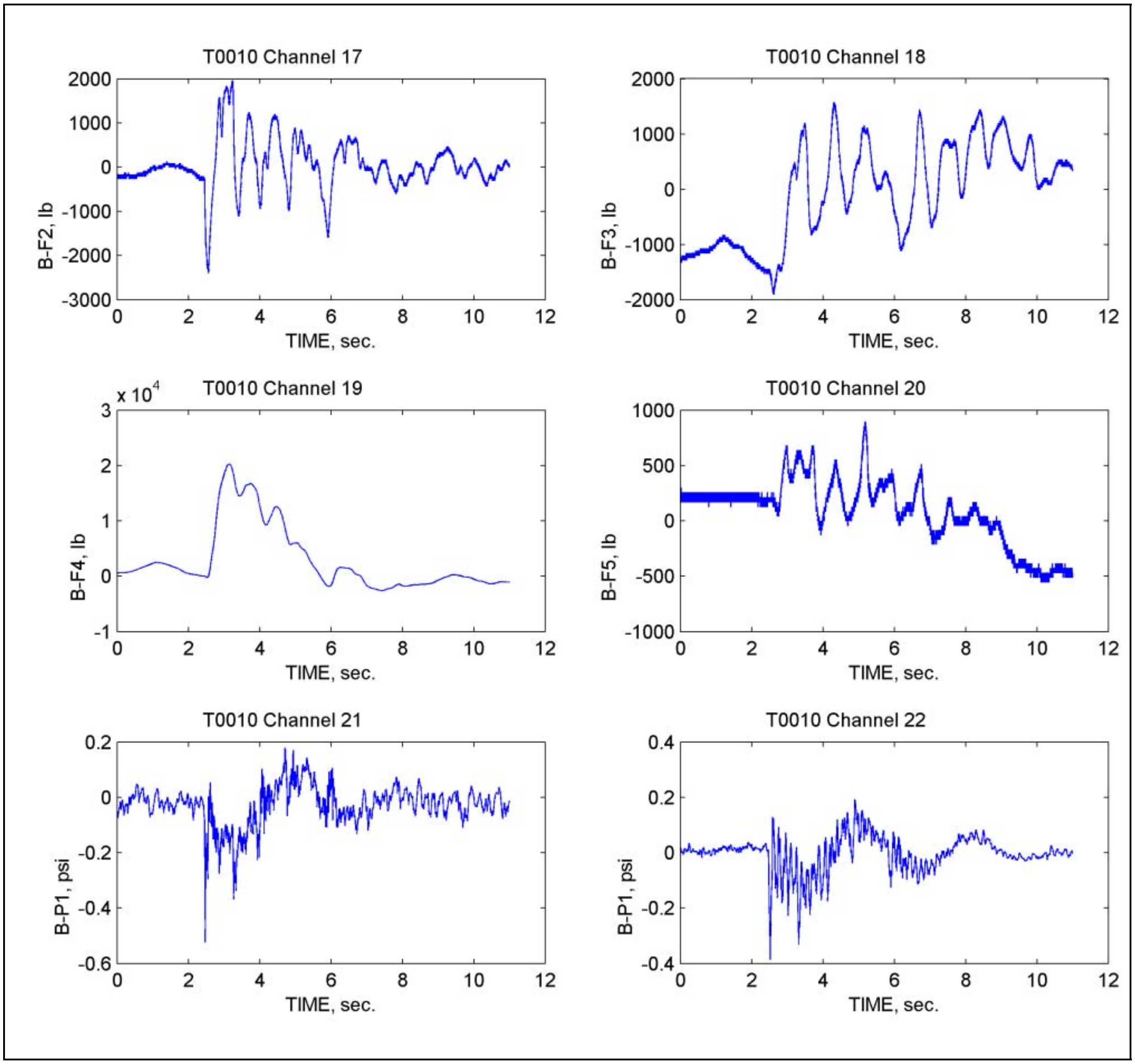
B-AZ3, g
TIME, sec.
T0010 Channel 10
B-SX1, u in/in
TIME, sec.
T0010 Channel 11
B-SXY1, u in/in
TIME, sec.
T0010 Channel 12
B-SY1, u in/in
TIME, sec.
T0010 Channel 13
B-SX2, u in/in
TIME, sec.
T0010 Channel 14
B-SXY2, u in/in
TIME, sec.
T0010 Channel 15
B-SY2, u in/in
TIME, sec.
T0010 Channel 16
B-F1, lb
TIME, sec.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B-F2, lb
TIME, sec.
T0010 Channel 18
B-F3, lb
TIME, sec.
T0010 Channel 19
x 10^4
B-F4, lb
TIME, sec.
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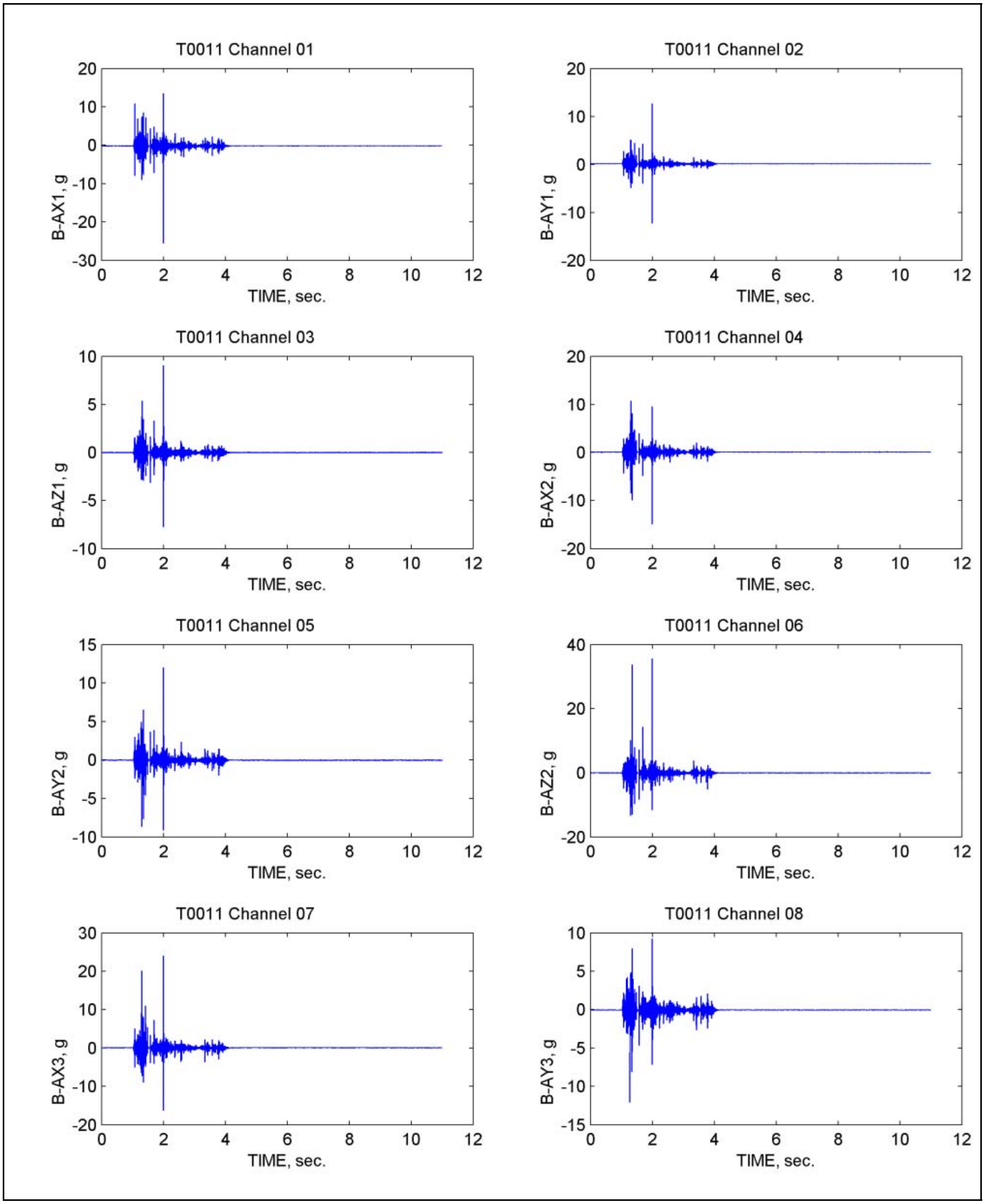
B-F5, lb
TIME, sec.
T0010 Channel 21
B-P1, psi
TIME, sec.
T0010 Channel 22
B-P1, psi
TIME, sec.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TIME, sec.
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TIME, sec.
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TIME, sec.
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TIME, sec.
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B-AY2, g
TIME, sec.
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TIME, sec.
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TIME, sec.
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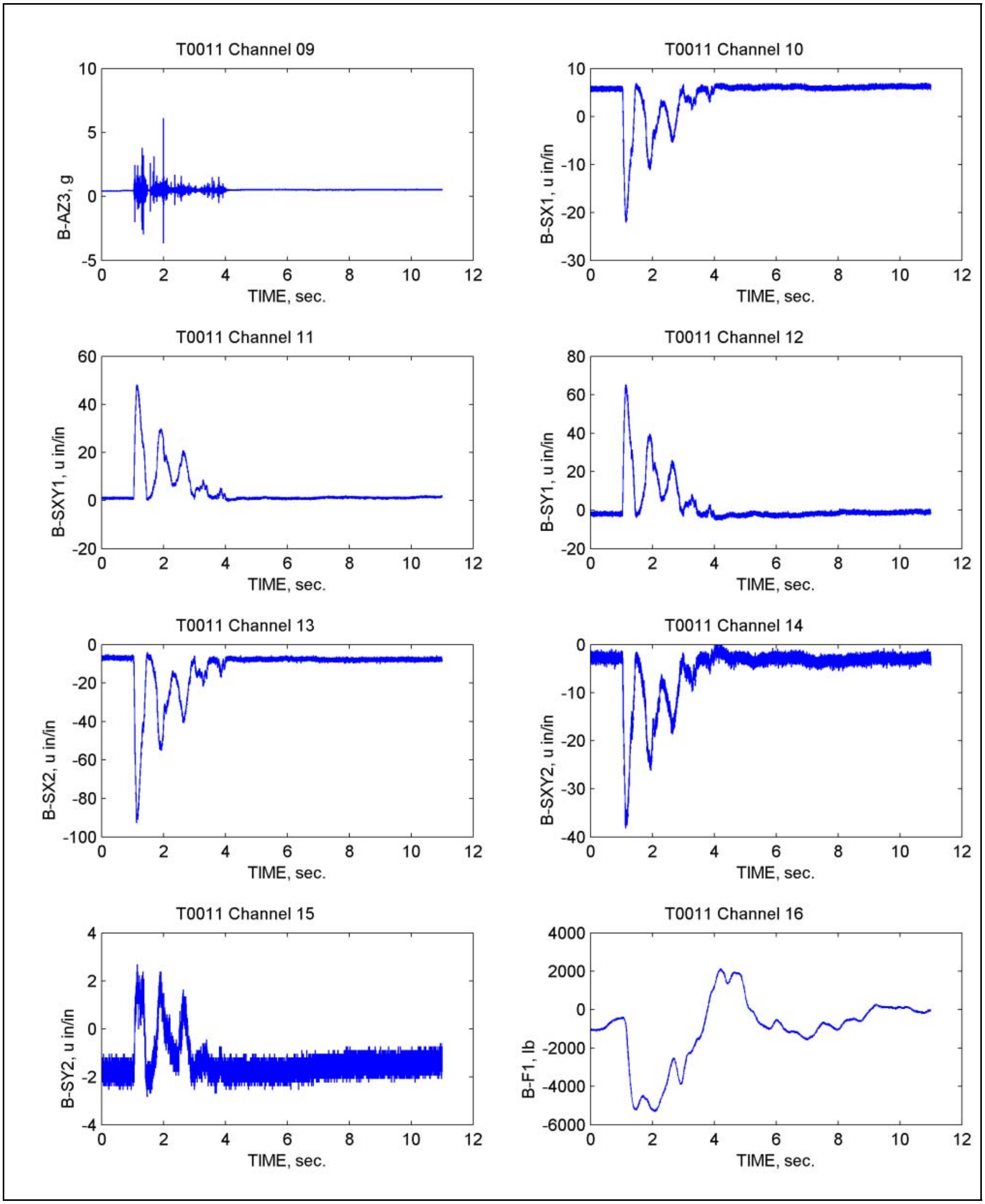
TIME, sec.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TIME, sec.
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TIME, sec.
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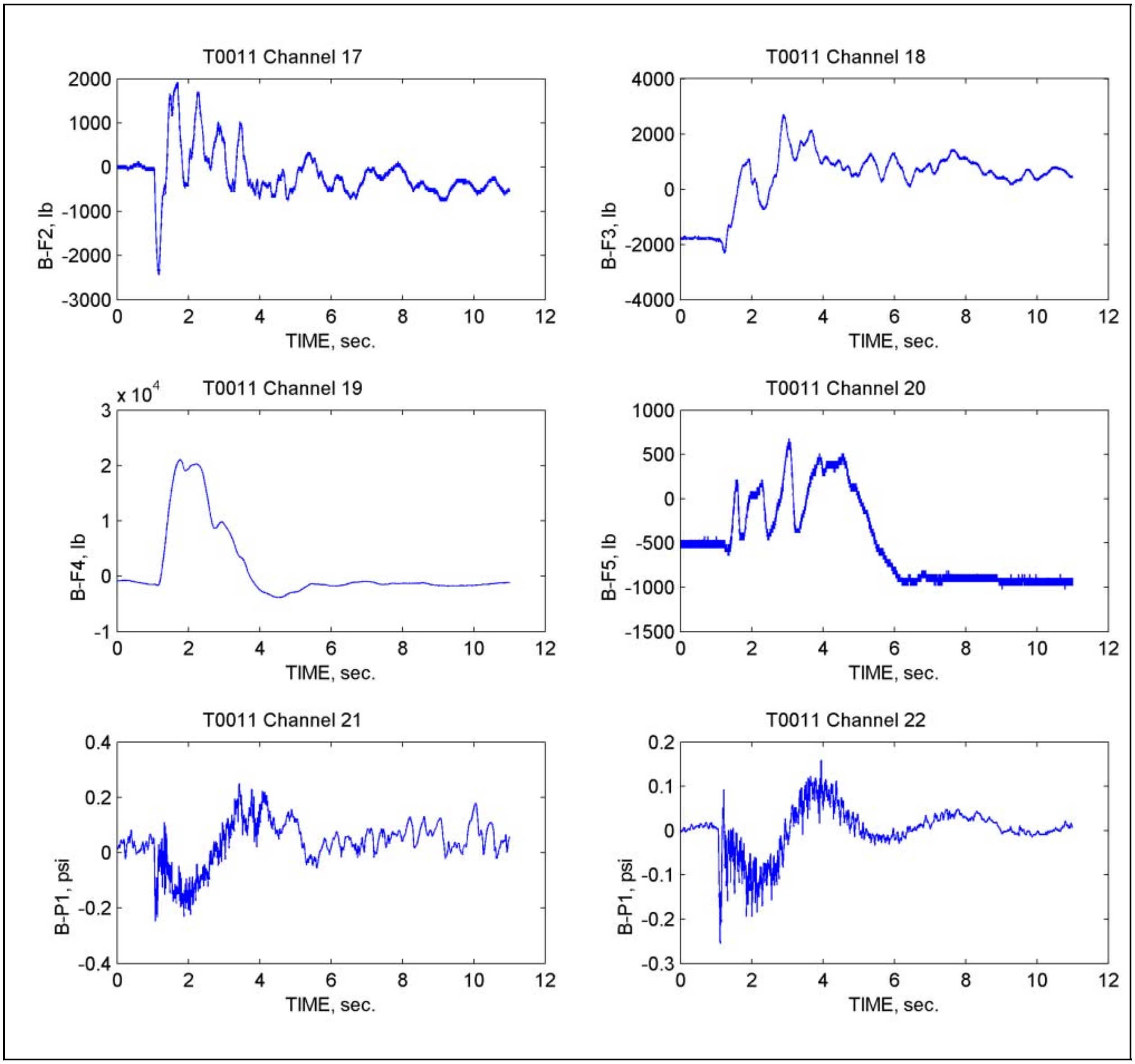
B-SXY1, u in/in
TIME, sec.
T0011 Channel 12
B-SY1, u in/in
TIME, sec.
T0011 Channel 13
B-SX2, u in/in
TIME, sec.
T0011 Channel 14
B-SXY2, u in/in
TIME, sec.
T0011 Channel 15
B-SY2, u in/in
TIME, sec.
T0011 Channel 16
B-F1, lb
TIME, sec.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TIME, sec.
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TIME, sec.
T0011 Channel 19
x 10^4
B-F4, lb
TIME, sec.
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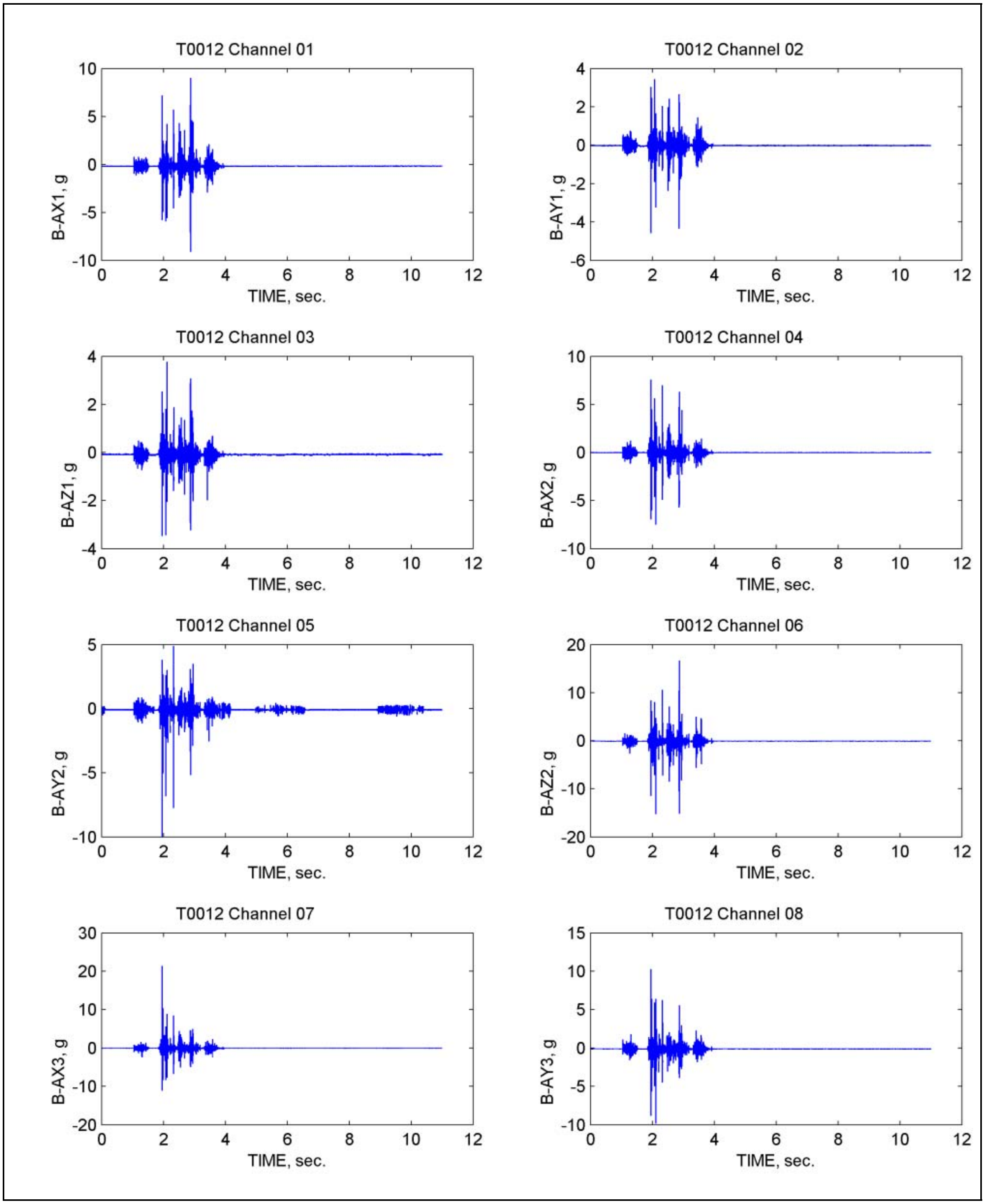
B-F5, lb
TIME, sec.
T0011 Channel 21
B-P1, psi
TIME, sec.
T0011 Channel 22
B-P1, psi
TIME, sec.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TIME, sec.
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TIME, sec.
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B-AX2, g
TIME, sec.
T0012 Channel 05
B-AY2, g
TIME, sec.
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B-AZ2, g
TIME, sec.
T0012 Channel 07
B-AX3, g
TIME, sec.
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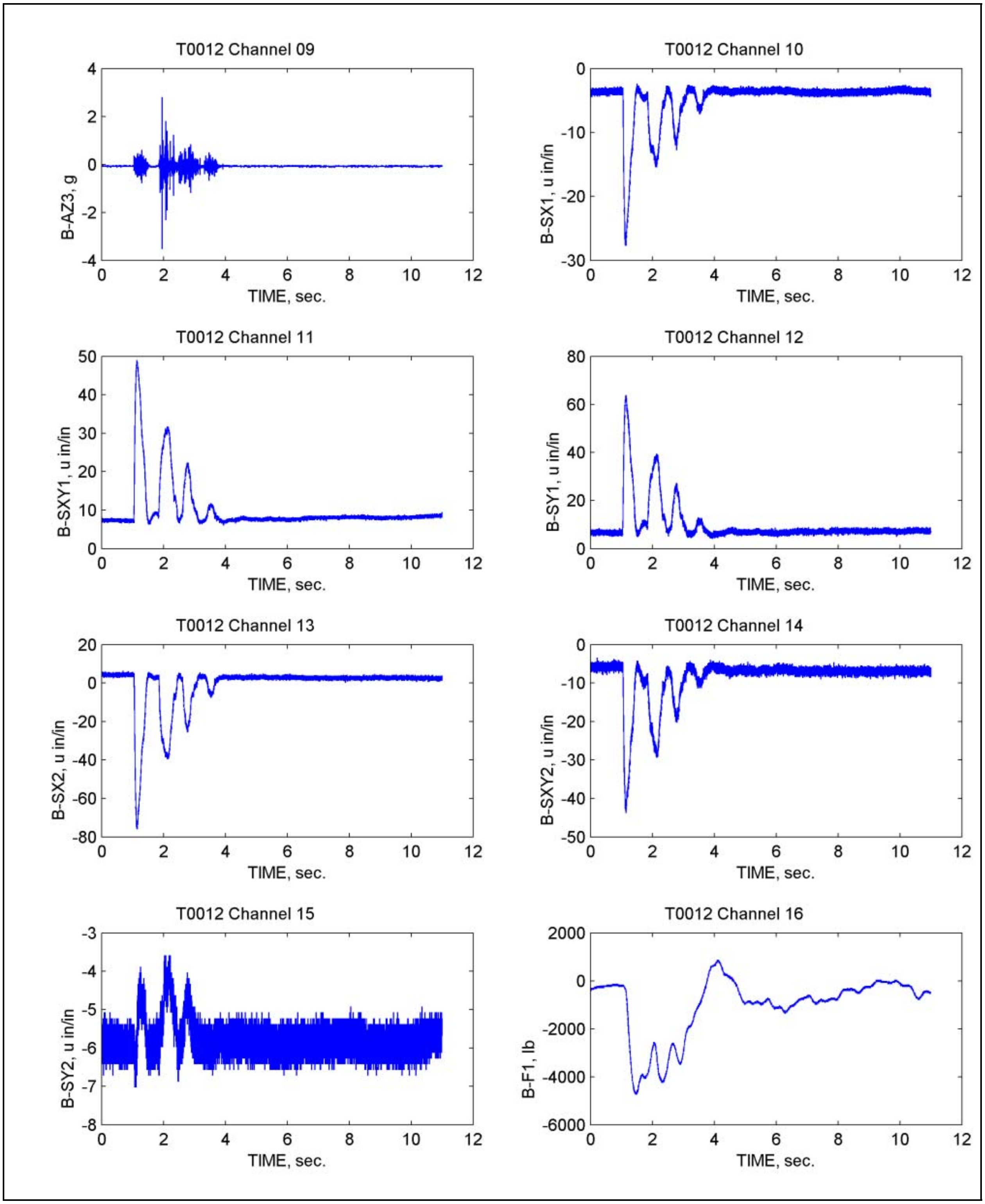
B-AY3, g
TIME, sec.


T0012 Channel 09
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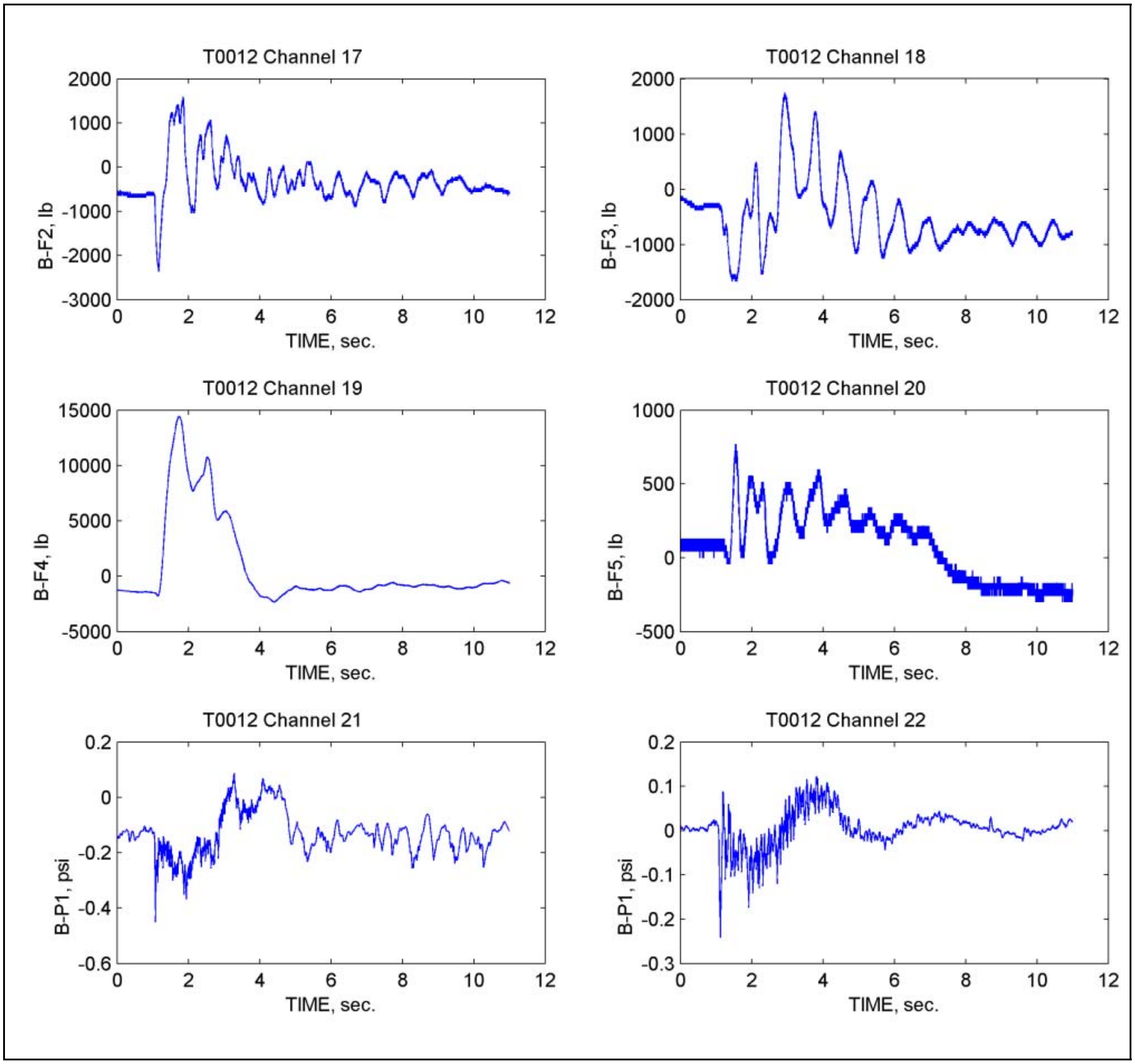
TIME, sec.
T0012 Channel 11
B-SXY1, u in/in
TIME, sec.
T0012 Channel 12
B-SY1, u in/in
TIME, sec.
T0012 Channel 13
B-SX2, u in/in
TIME, sec.
T0012 Channel 14
B-SXY2, u in/in
TIME, sec.
T0012 Channel 15
B-SY2, u in/in
TIME, sec.
T0012 Channel 16
B-F1, lb
TIME, sec.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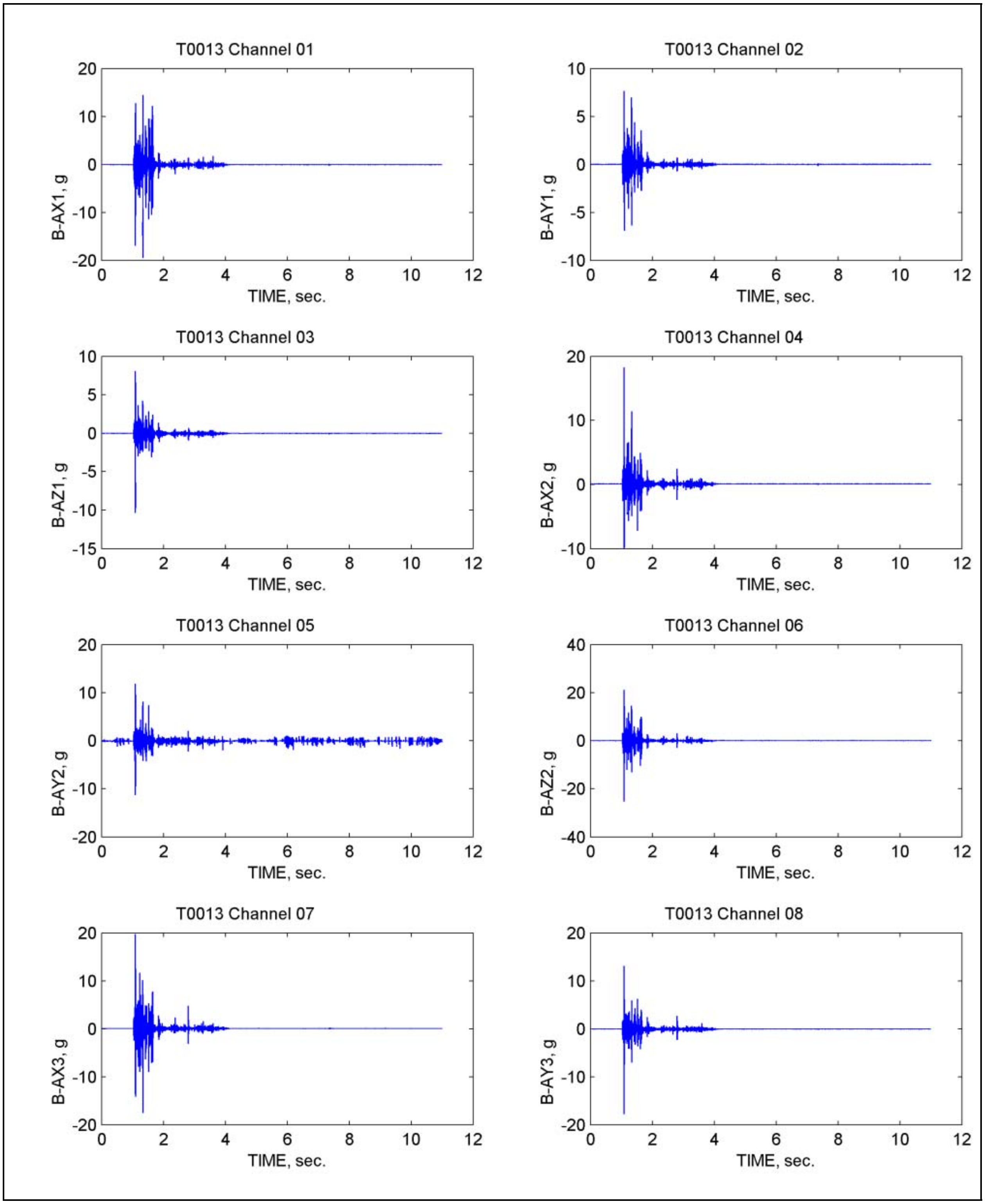
B-F2, lb
TIME, sec.
T0012 Channel 18
B-F3, lb
TIME, sec.
T0012 Channel 19
B-F4, lb
TIME, sec.
T0012 Channel 20
B-F5, lb
TIME, sec.
T0012 Channel 21
B-P1, psi
TIME, sec.
T0012 Channel 22
B-P1, psi
TIME, sec.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TIME, sec.
T0013 Channel 03
B-AZ1, g
TIME, sec.
T0013 Channel 04
B-AX2, g
TIME, sec.
T0013 Channel 05
B-AY2, g
TIME, sec.
T0013 Channel 06
B-AZ2, g
TIME, sec.
T0013 Channel 07
B-AX3, g
TIME, sec.
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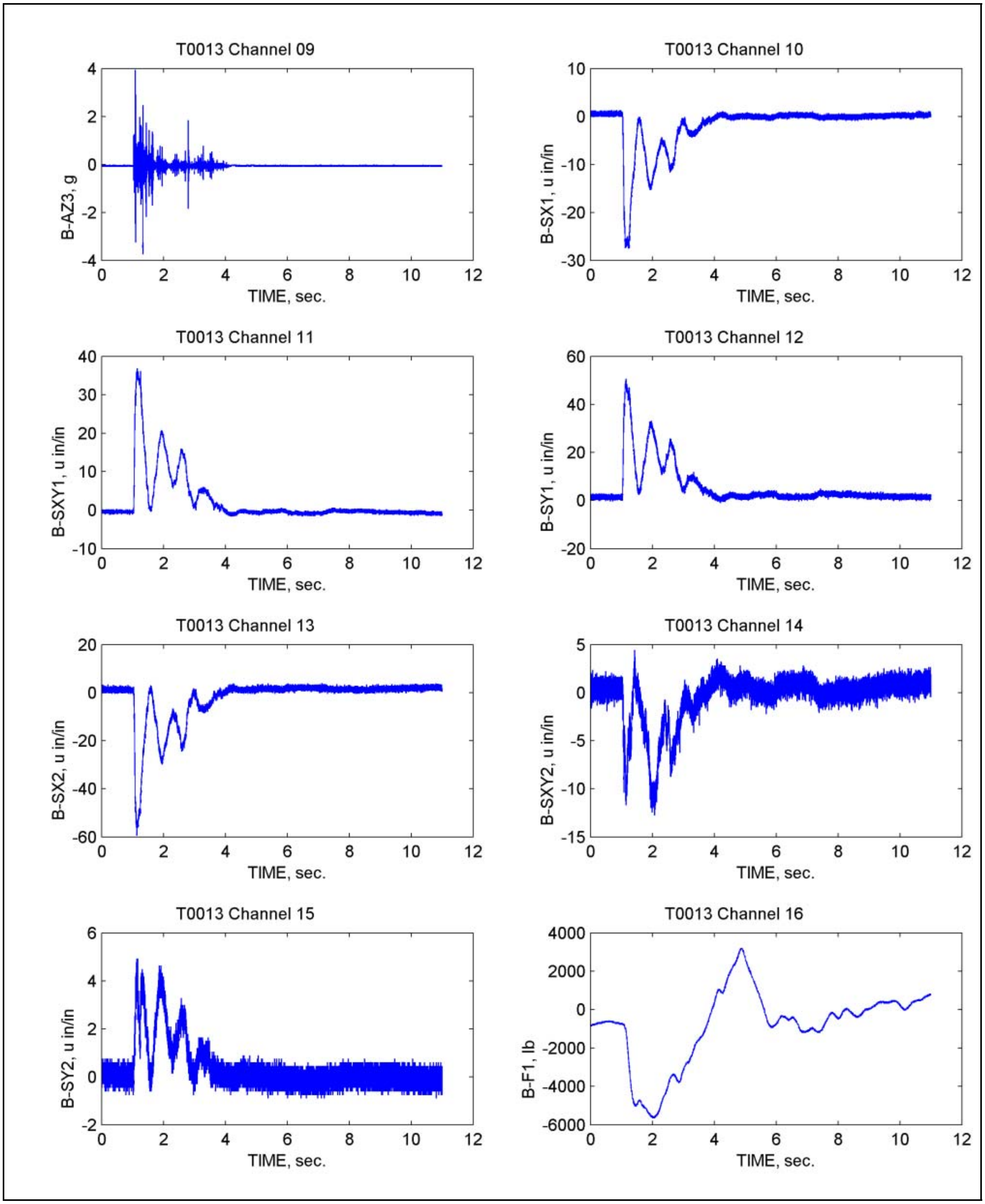
TIME, sec.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TIME, sec.
T0013 Channel 10
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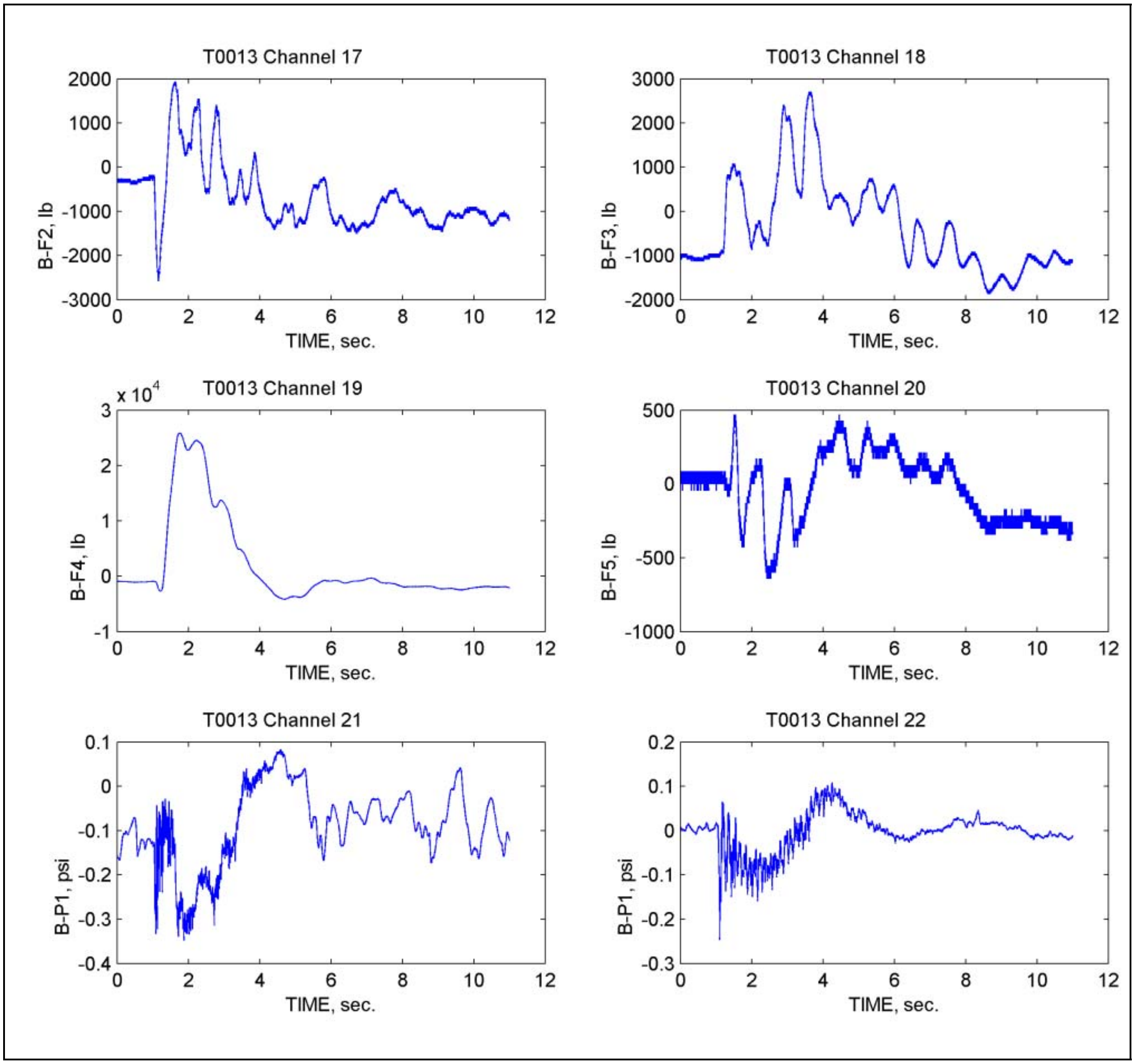
TIME, sec.
T0013 Channel 11
B-SXY1, u in/in
TIME, sec.
T0013 Channel 12
B-SY1, u in/in
TIME, sec.
T0013 Channel 13
B-SX2, u in/in
TIME, sec.
T0013 Channel 14
B-SXY2, u in/in
TIME, sec.
T0013 Channel 15
B-SY2, u in/in
TIME, sec.
T0013 Channel 16
B-F1, lb
TIME, sec.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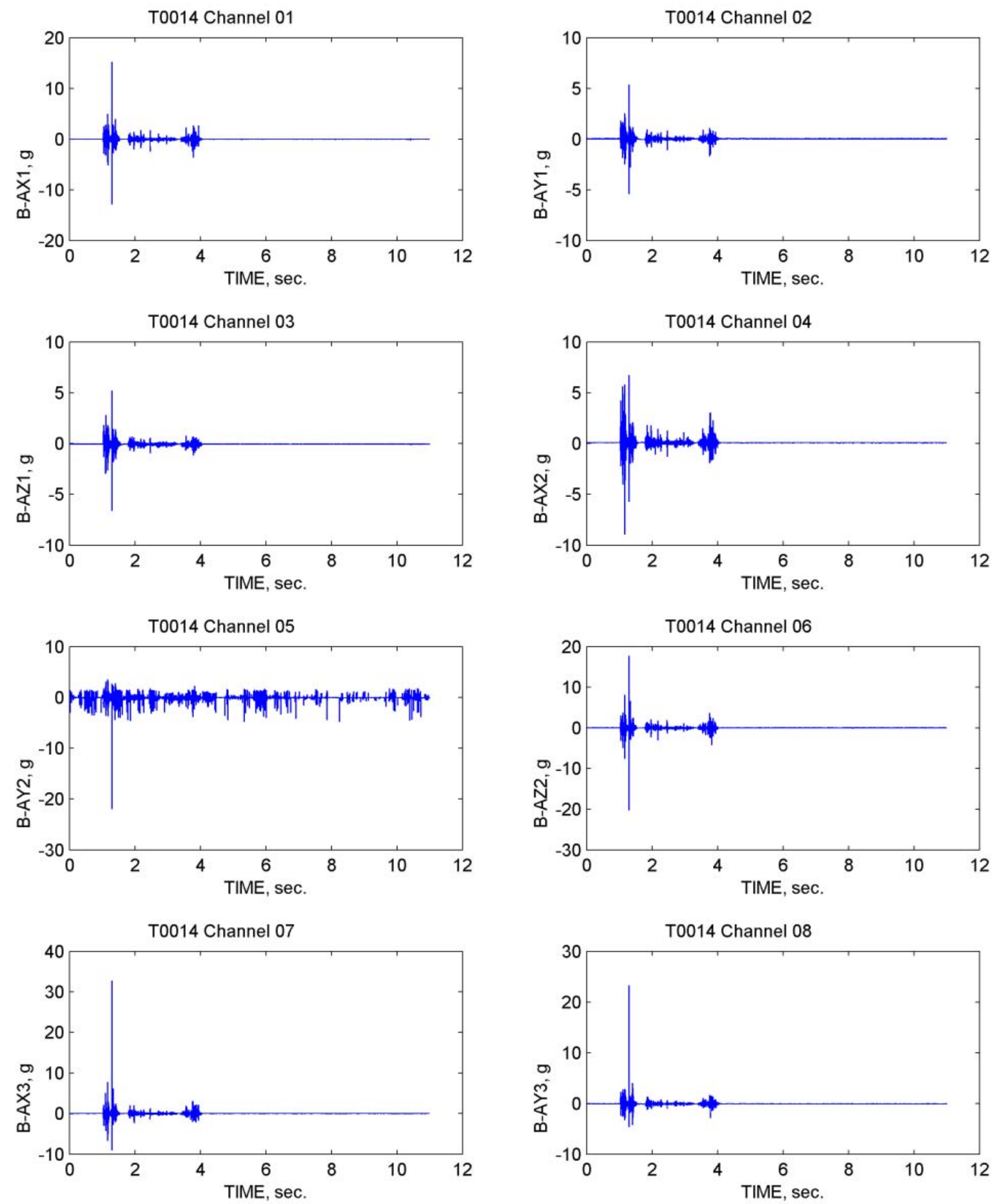
B-F2, lb
TIME, sec.
T0013 Channel 18
B-F3, lb
TIME, sec.
T0013 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0013 Channel 20
B-F5, lb
TIME, sec.
T0013 Channel 21
B-P1, psi
TIME, sec.
T0013 Channel 22
B-P1, psi
TIME, sec.



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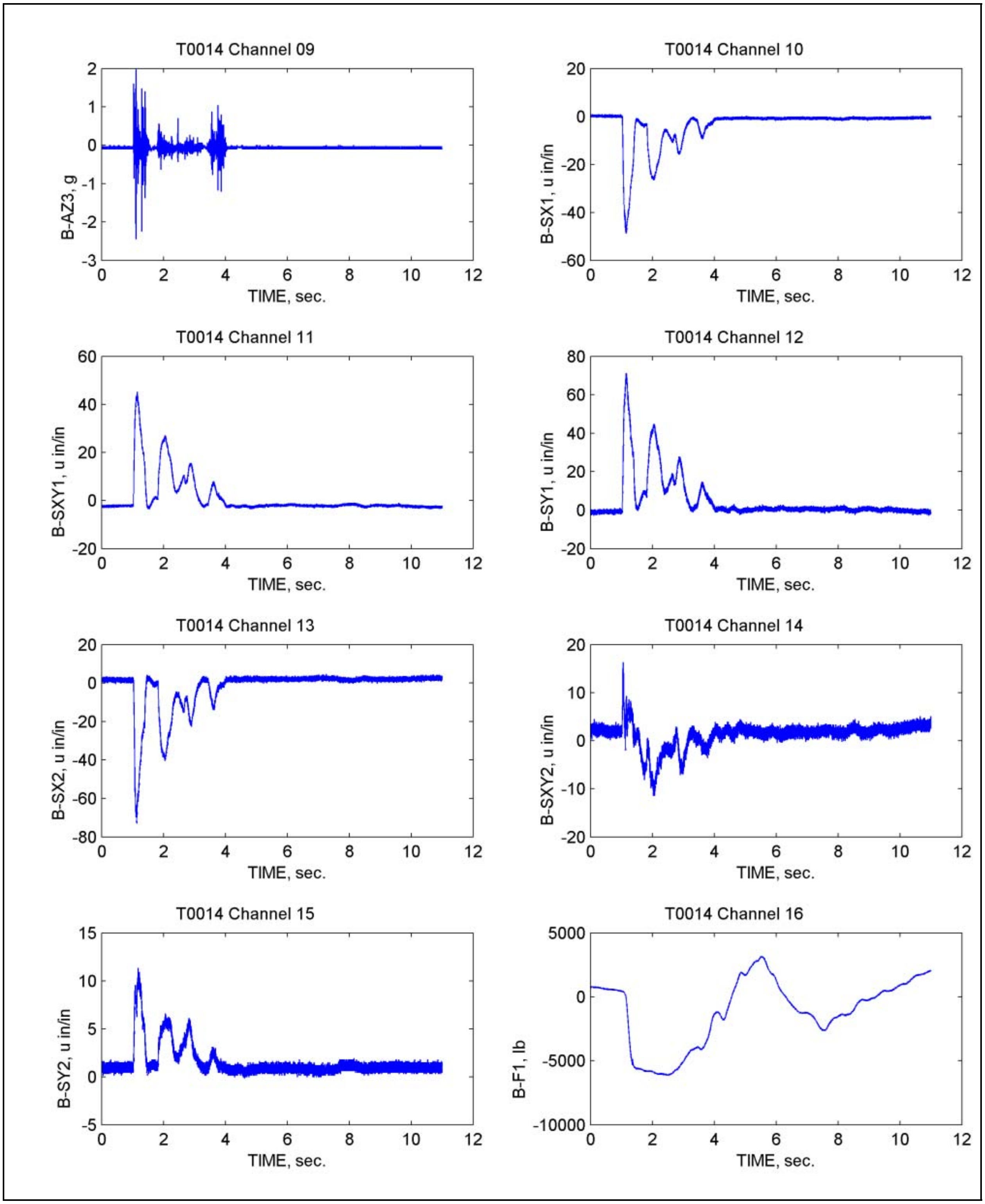
B-AX1, g
TIME, sec.
T0014 Channel 02
B-AY1, g
TIME, sec.
T0014 Channel 03
B-AZ1, g
TIME, sec.
T0014 Channel 04
B-AX2, g
TIME, sec.
T0014 Channel 05
B-AY2, g
TIME, sec.
T0014 Channel 06
B-AZ2, g
TIME, sec.
T0014 Channel 07
B-AX3, g
TIME, sec.
T0014 Channel 08
B-AY3, g
TIME, sec.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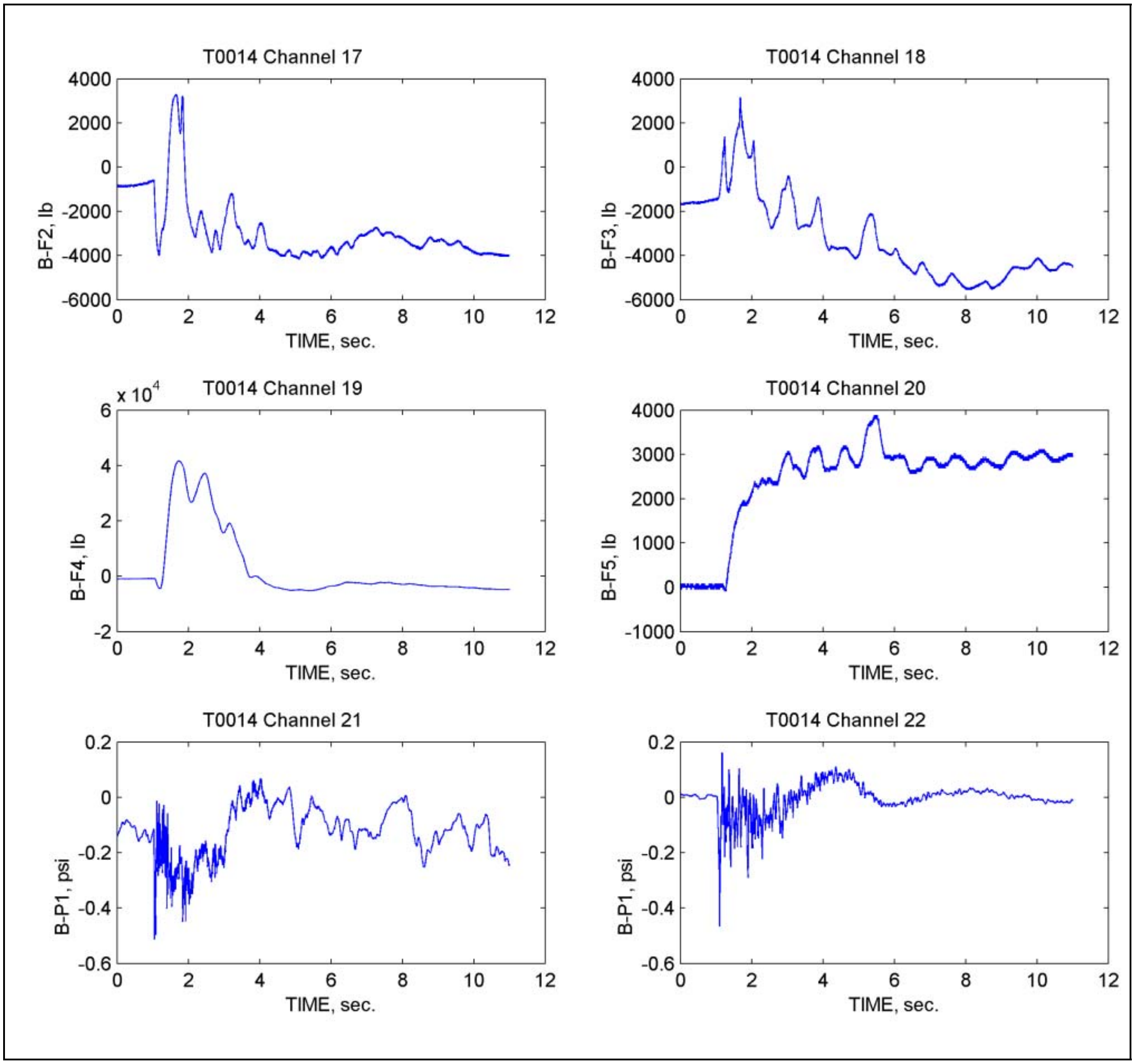
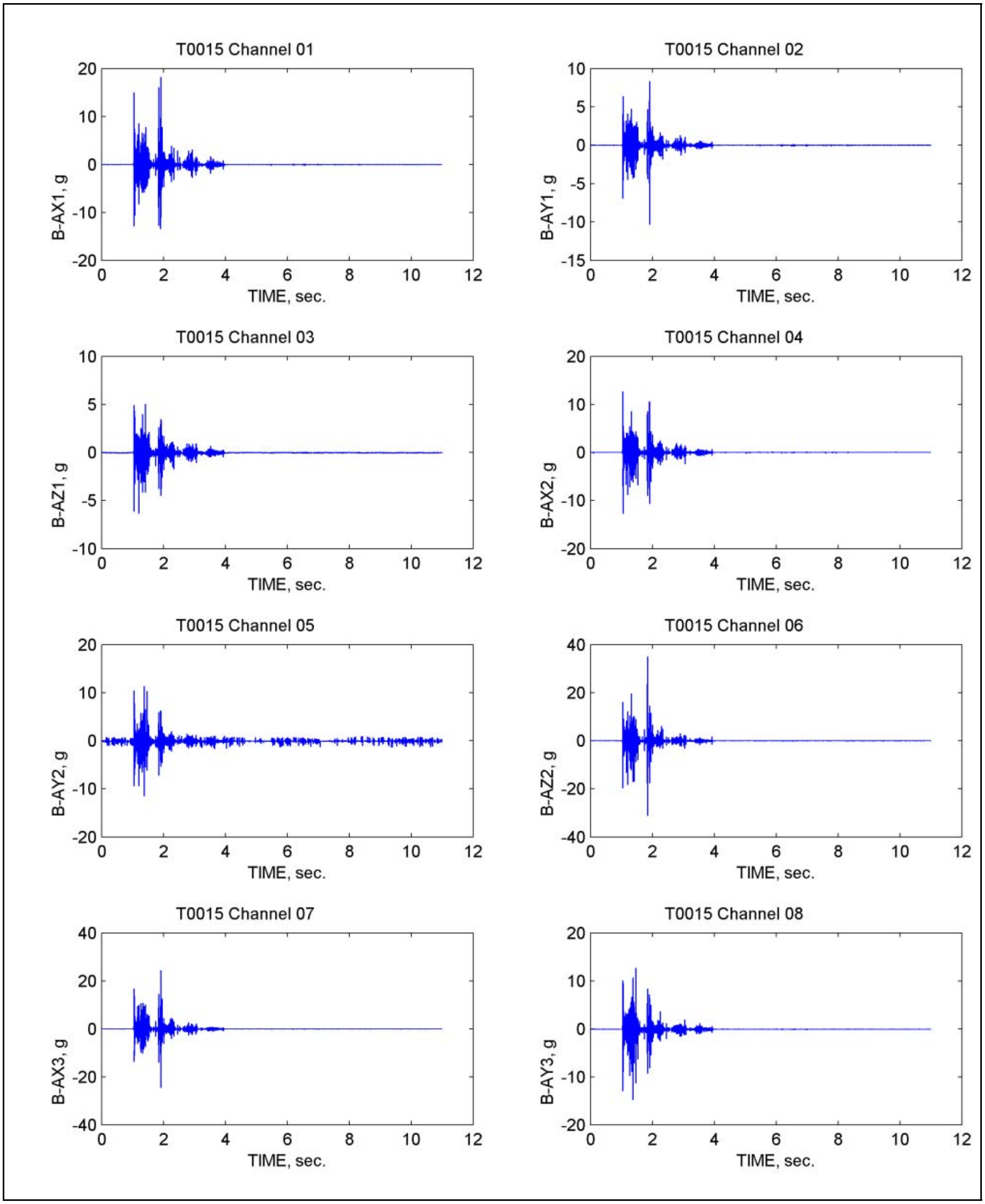
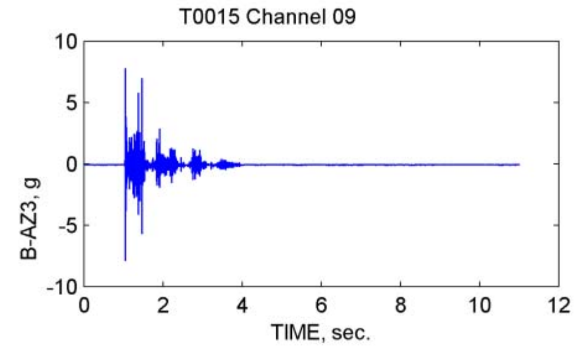
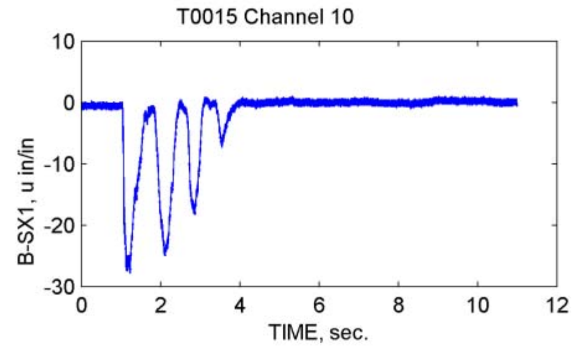
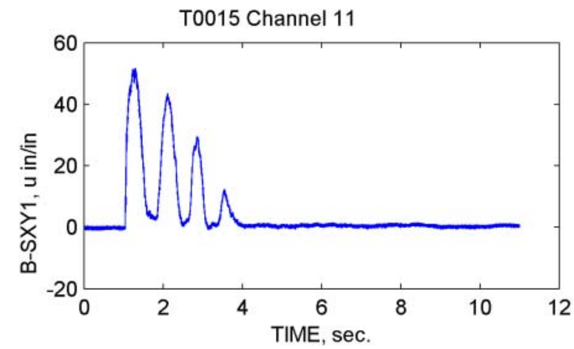
B-AZ3, g
TIME, sec.
T0014 Channel 10
B-SX1, u in/in
TIME, sec.
T0014 Channel 11
B-SXY1, u in/in
TIME, sec.
T0014 Channel 12
B-SY1, u in/in
TIME, sec.
T0014 Channel 13
B-SX2, u in/in
TIME, sec.
T0014 Channel 14
B-SXY2, u in/in
TIME, sec.
T0014 Channel 15
B-SY2, u in/in
TIME, sec.
T0014 Channel 16
B-F1, lb
TIME, sec.

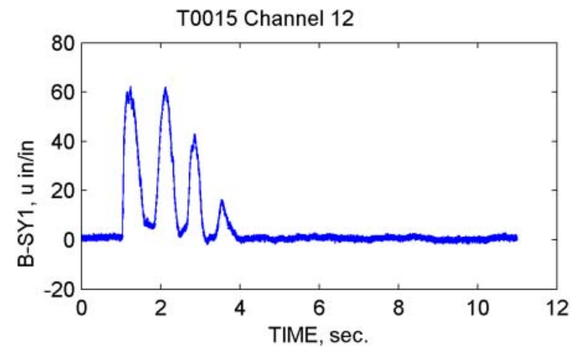

T0014 Channel 17
B-F2, lb
TIME, sec.
T0014 Channel 18
B-F3, lb
TIME, sec.
T0014 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0014 Channel 20
B-F5, lb
TIME, sec.
T0014 Channel 21
B-P1, psi
TIME, sec.
T0014 Channel 22
B-P1, psi
TIME, sec.

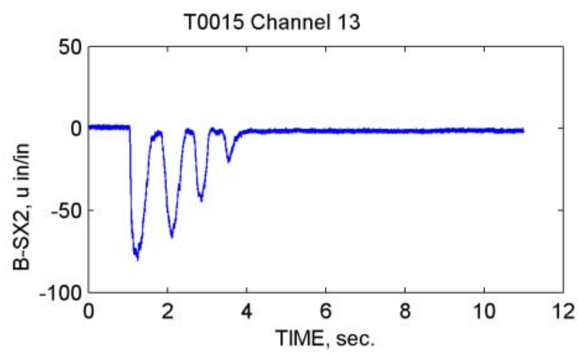

T0015 Channel 01
B-AX1, g
TIME, sec.
T0015 Channel 02
B-AY1, g
TIME, sec.
T0015 Channel 03
B-AZ1, g
TIME, sec.
T0015 Channel 04
B-AX2, g
TIME, sec.
T0015 Channel 05
B-AY2, g
TIME, sec.
T0015 Channel 06
B-AZ2, g
TIME, sec.
T0015 Channel 07
B-AX3, g
TIME, sec.
T0015 Channel 08
B-AY3, g
TIME, sec.

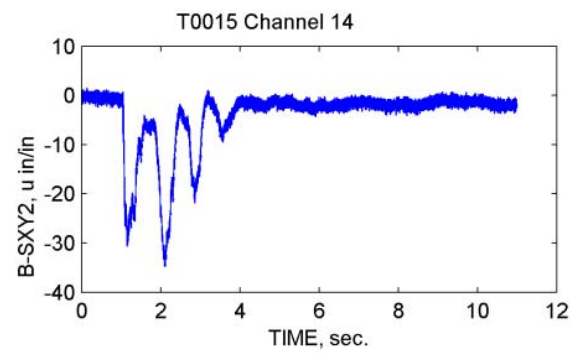

T0015 Channel 09
B-AZ3, g
TIME, sec.

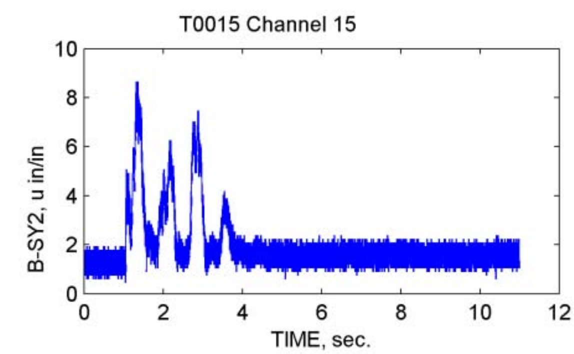

T0015 Channel 10
B-SX1, u in/in
TIME, sec.

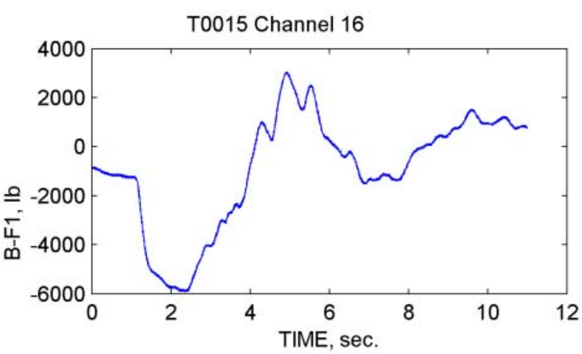

T0015 Channel 11
B-SXY1, u in/in
TIME, sec.

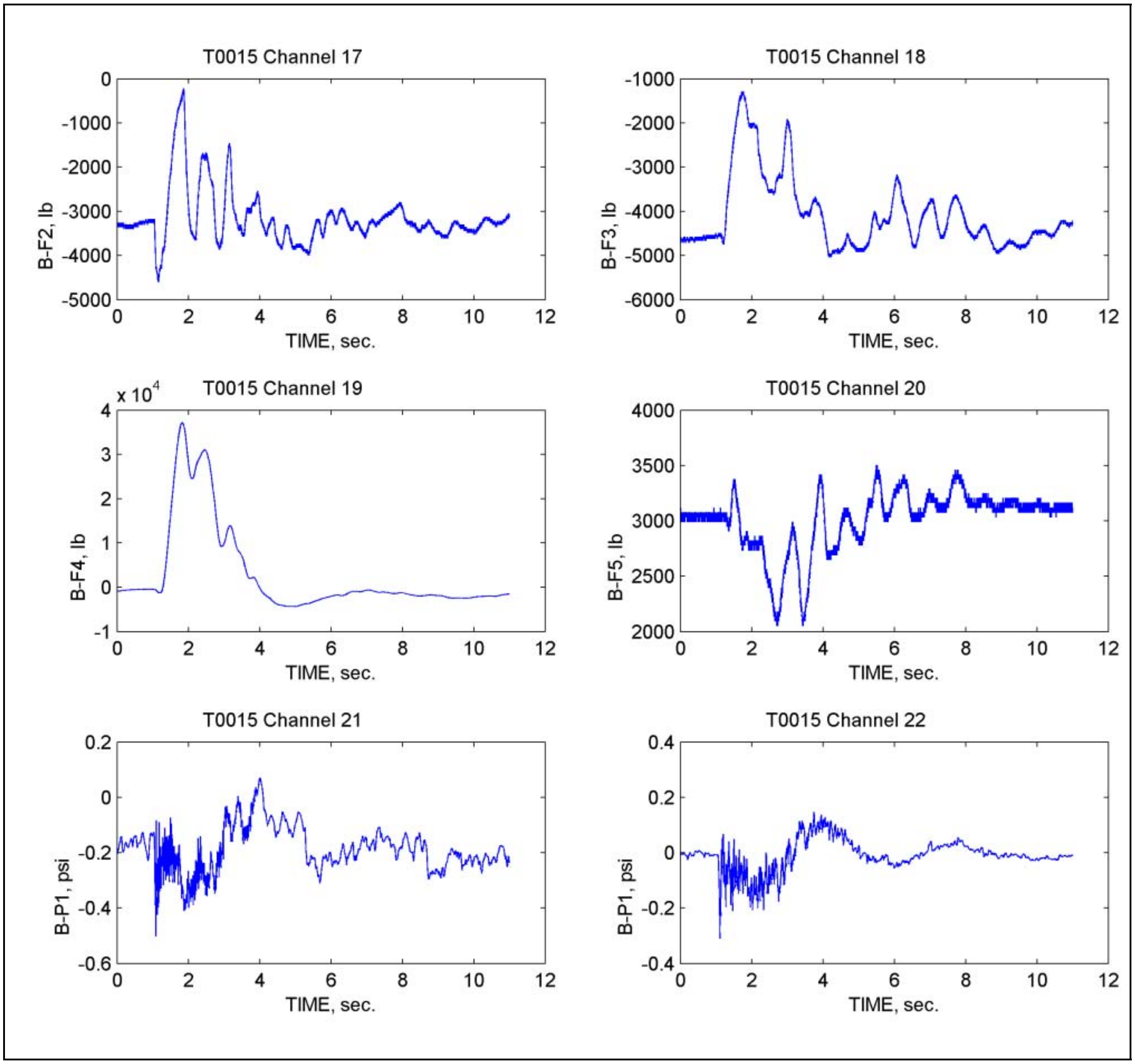

T0015 Channel 12
B-SY1, u in/in
TIME, sec.

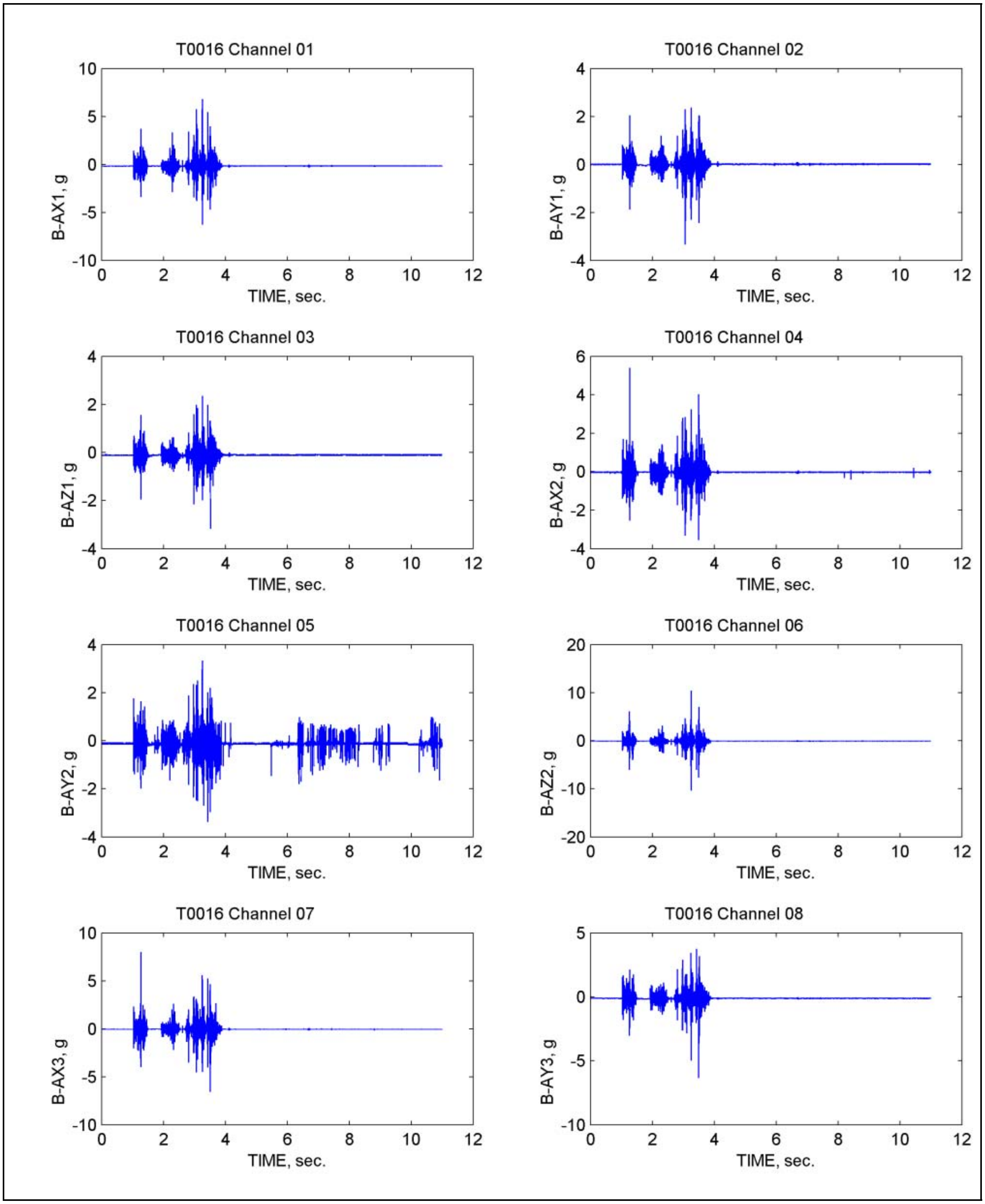

T0015 Channel 13
B-SX2, u in/in
TIME, sec.

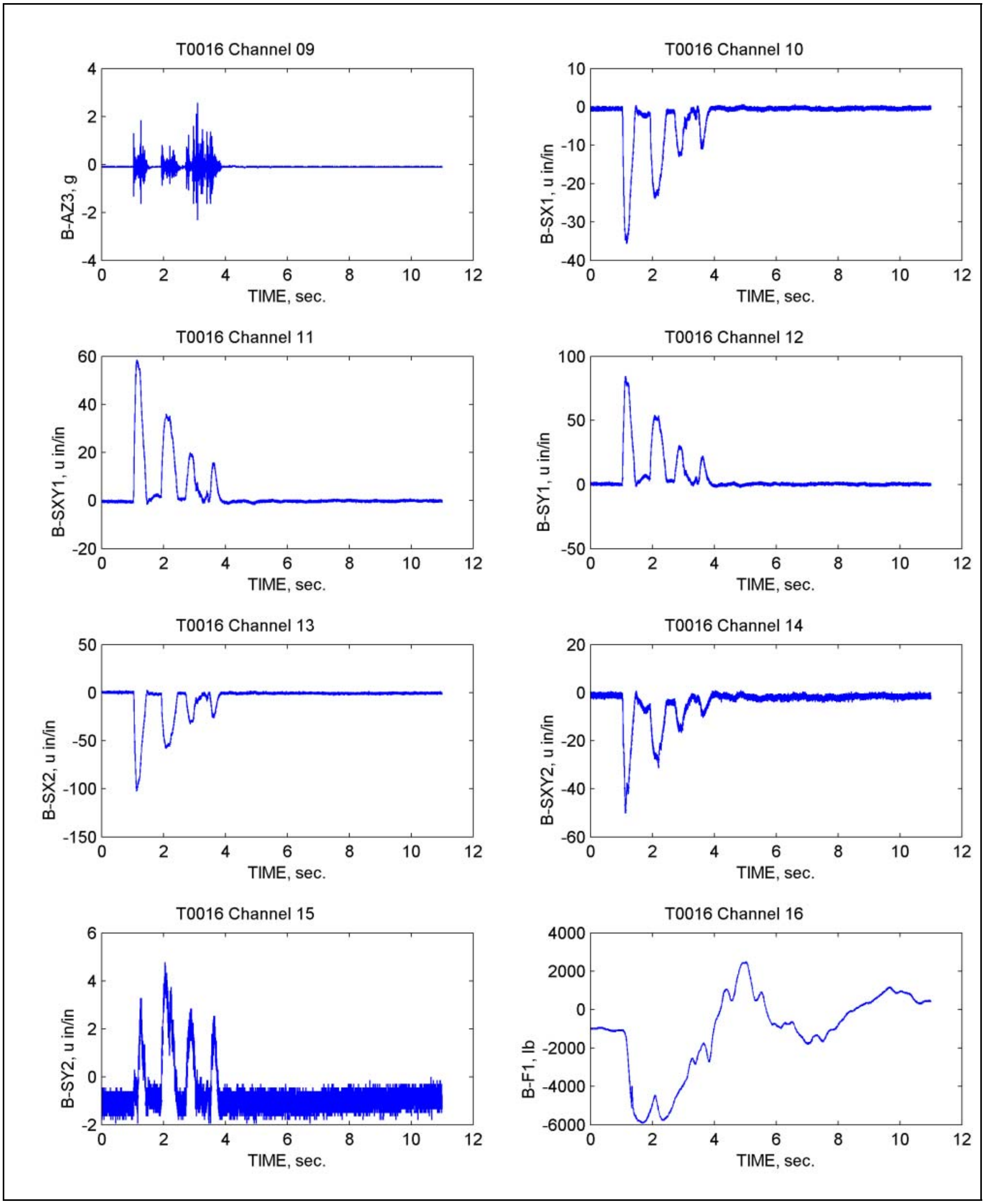

T0015 Channel 14
B-SXY2, u in/in
TIME, sec.

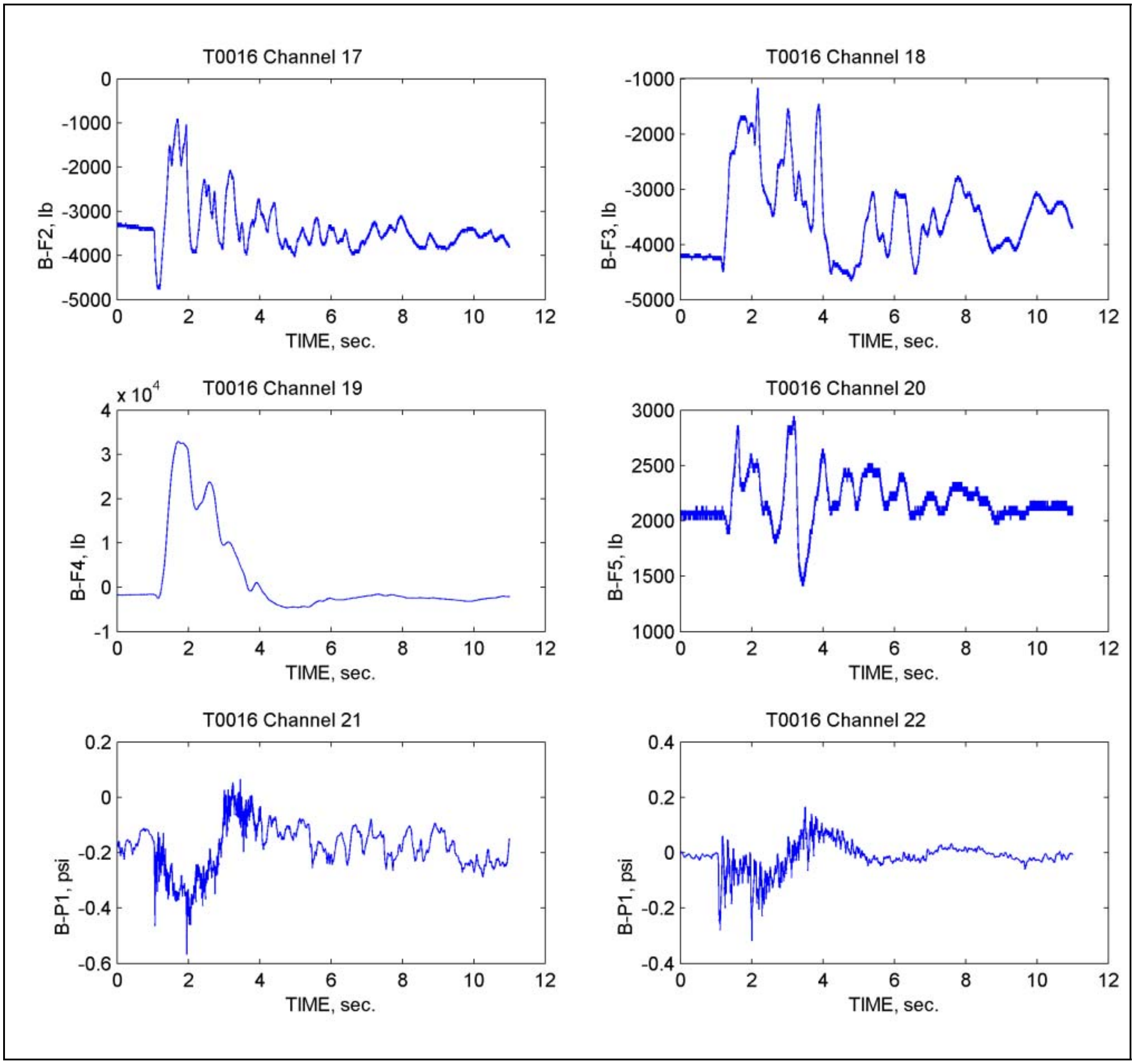

T0015 Channel 15
B-SY2, u in/in
TIME, sec.

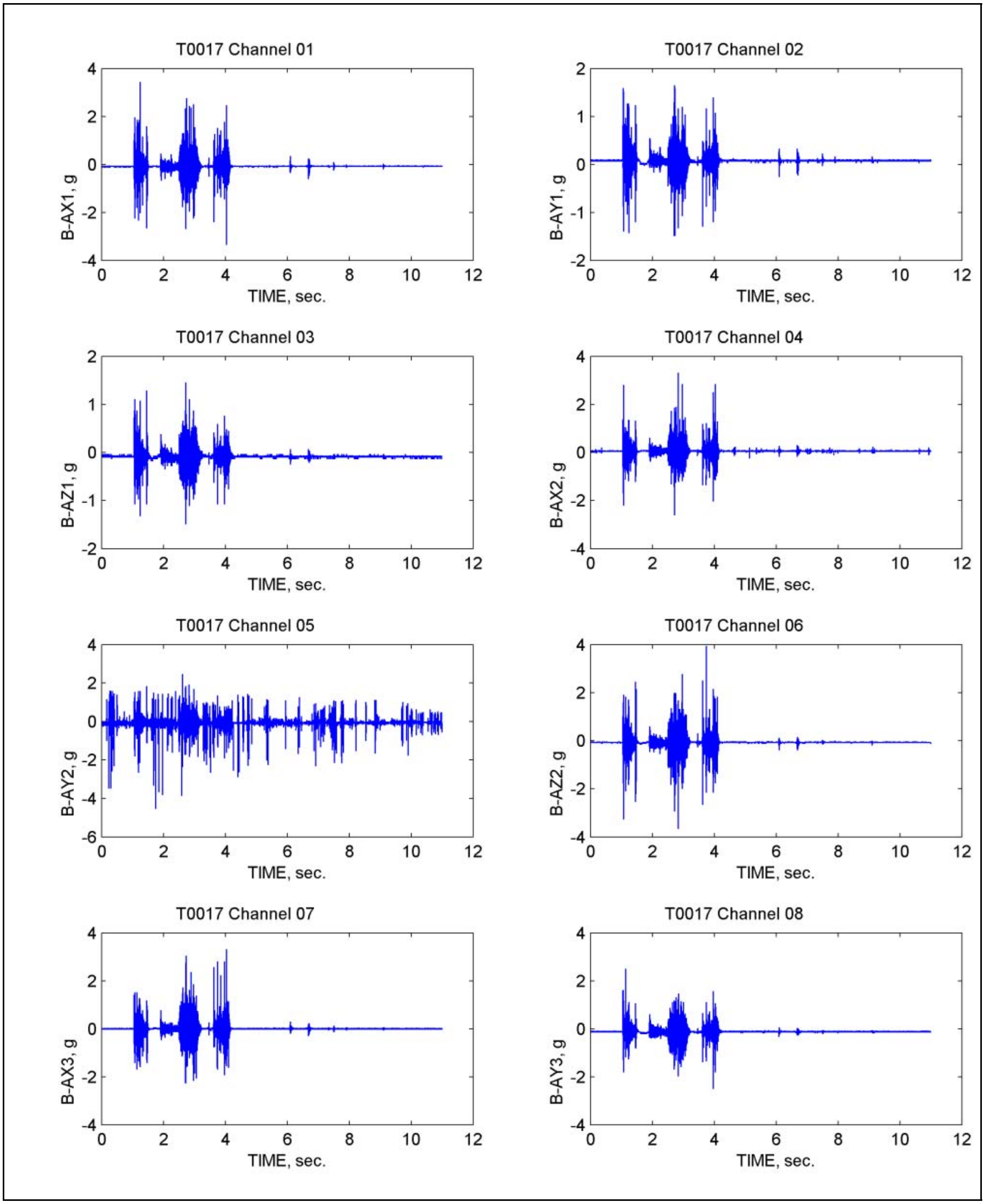

T0015 Channel 16
B-F1, lb
TIME, sec.

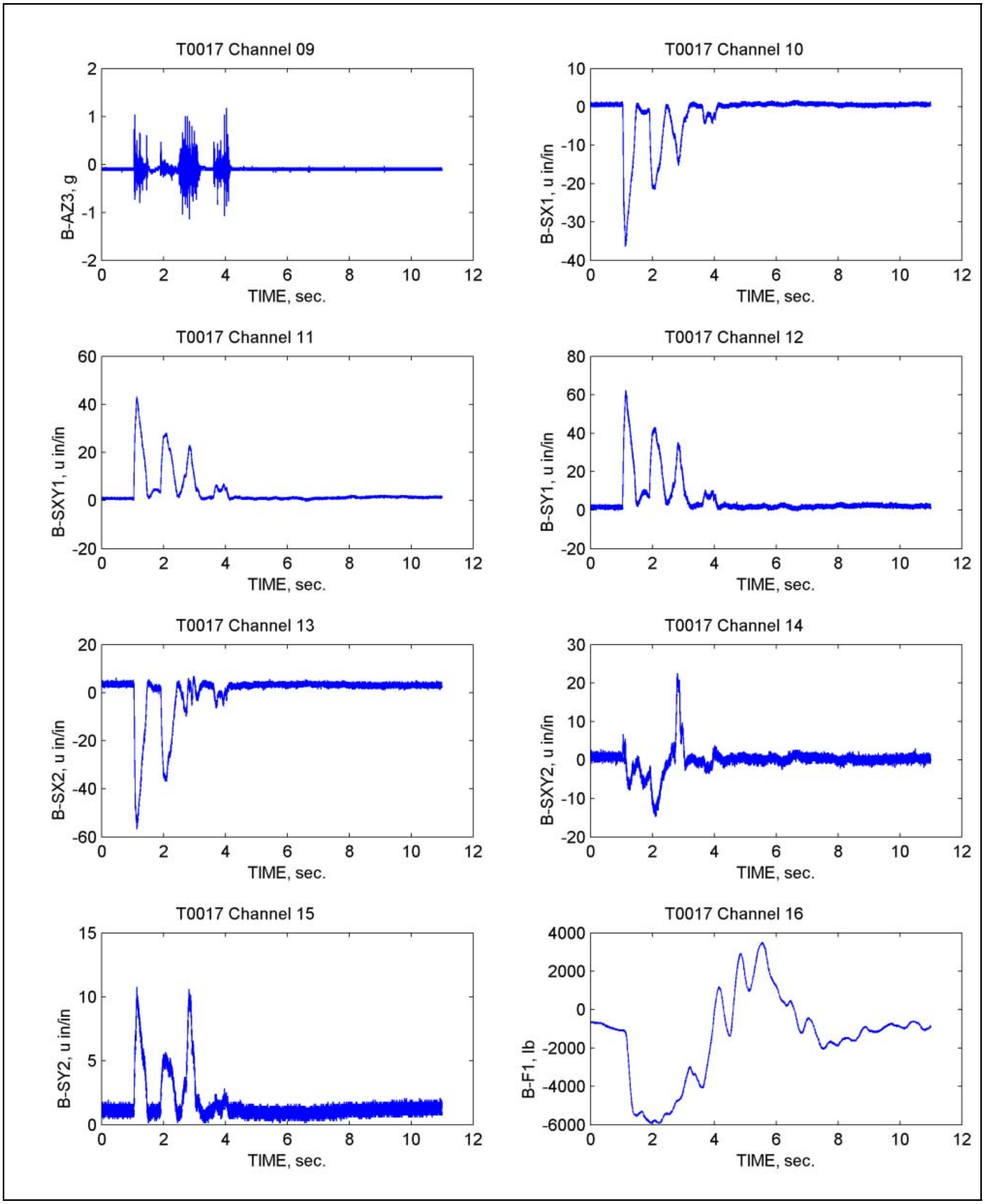

T0015 Channel 17
B-F2, lb
TIME, sec.
T0015 Channel 18
B-F3, lb
TIME, sec.
T0015 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0015 Channel 20
B-F5, lb
TIME, sec.
T0015 Channel 21
B-P1, psi
TIME, sec.
T0015 Channel 22
B-P1, psi
TIME, sec.

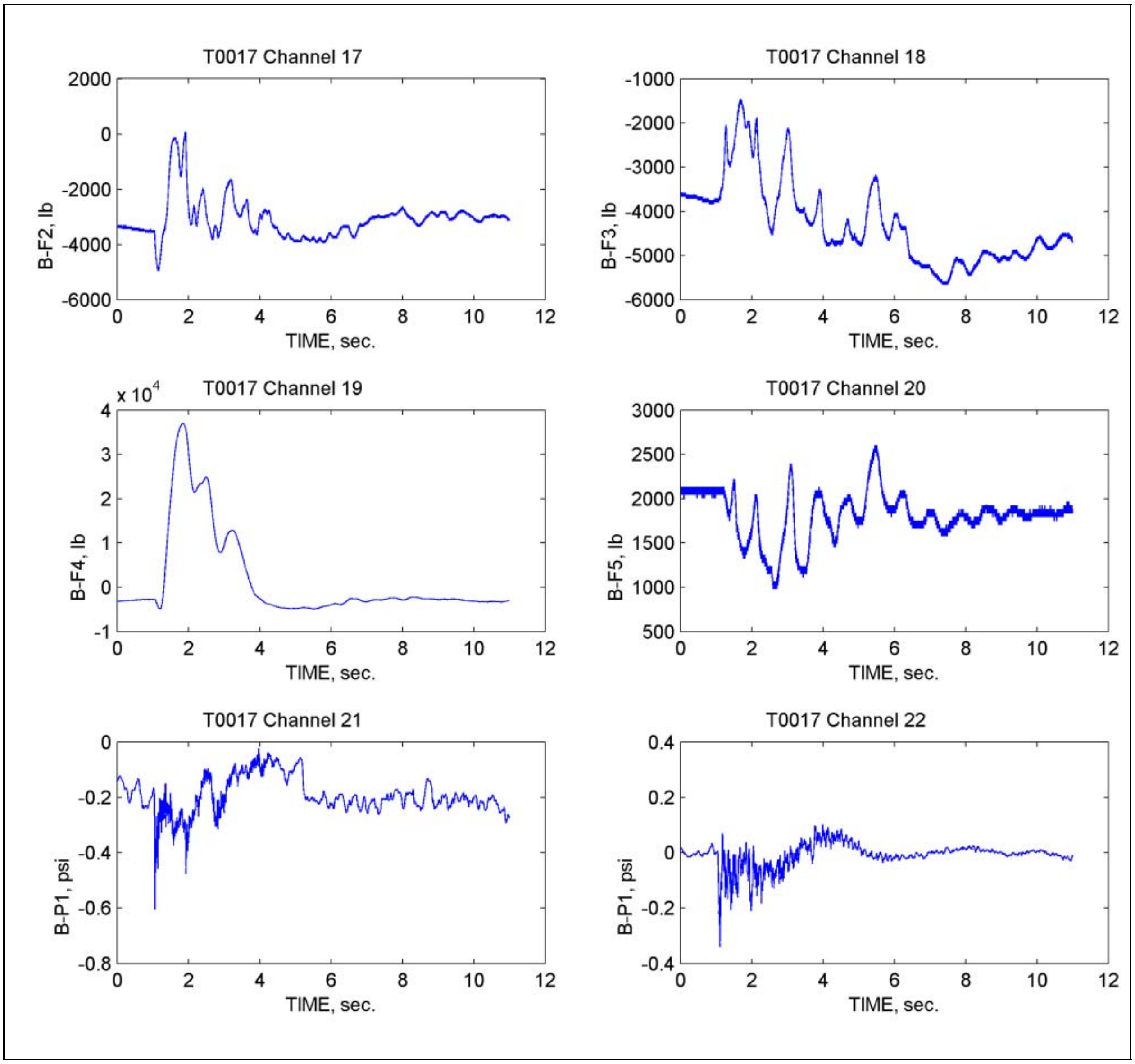

T0016 Channel 01
B-AX1, g
TIME, sec.
T0016 Channel 02
B-AY1, g
TIME, sec.
T0016 Channel 03
B-AZ1, g
TIME, sec.
T0016 Channel 04
B-AX2, g
TIME, sec.
T0016 Channel 05
B-AY2, g
TIME, sec.
T0016 Channel 06
B-AZ2, g
TIME, sec.
T0016 Channel 07
B-AX3, g
TIME, sec.
T0016 Channel 08
B-AY3, g
TIME, sec.

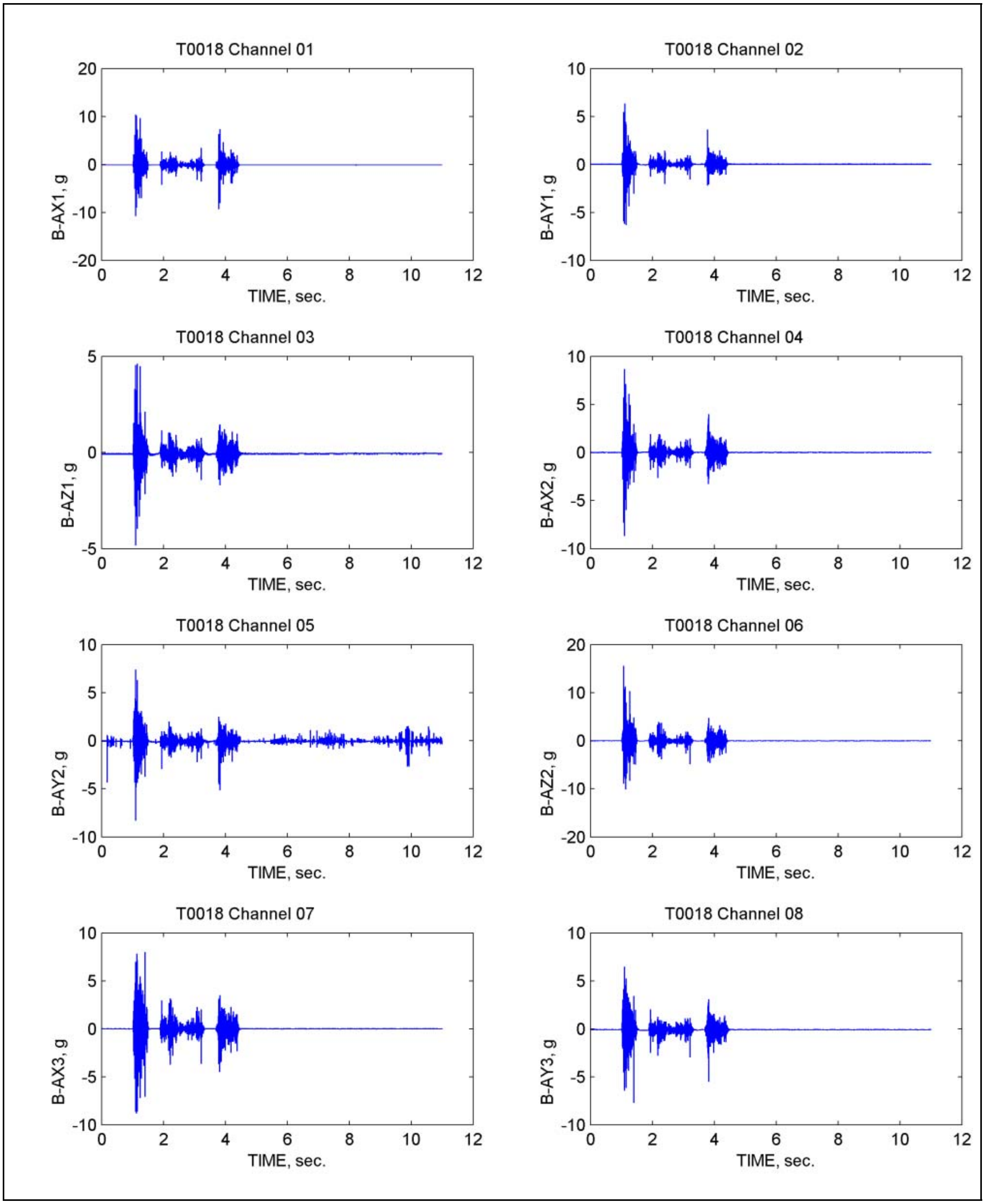

T0016 Channel 09
B-AZ3, g
TIME, sec.
T0016 Channel 10
B-SX1, u in/in
TIME, sec.
T0016 Channel 11
B-SXY1, u in/in
TIME, sec.
T0016 Channel 12
B-SY1, u in/in
TIME, sec.
T0016 Channel 13
B-SX2, u in/in
TIME, sec.
T0016 Channel 14
B-SXY2, u in/in
TIME, sec.
T0016 Channel 15
B-SY2, u in/in
TIME, sec.
T0016 Channel 16
B-F1, lb
TIME, sec.

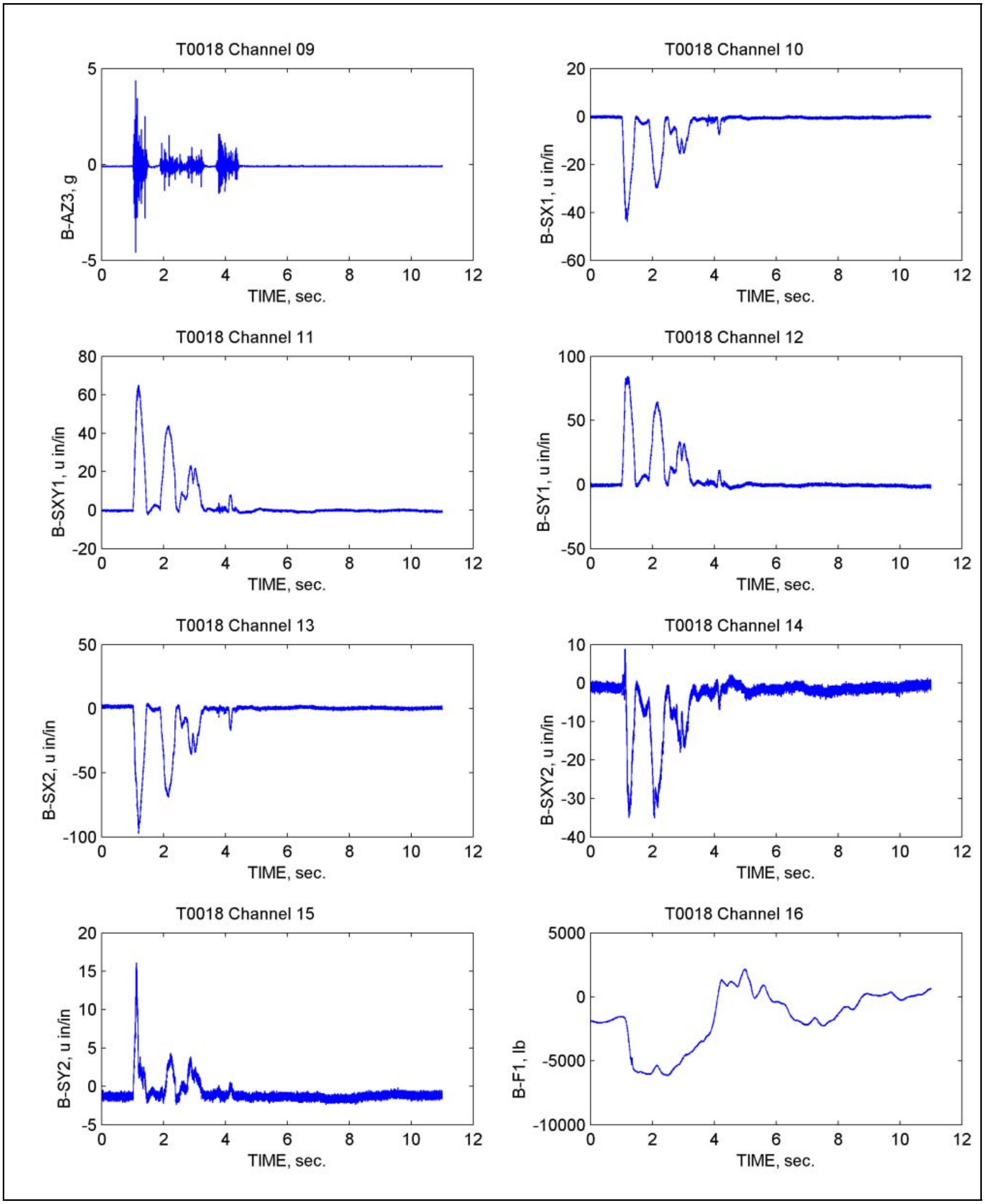

T0016 Channel 17
B-F2, lb
TIME, sec.
T0016 Channel 18
B-F3, lb
TIME, sec.
T0016 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0016 Channel 20
B-F5, lb
TIME, sec.
T0016 Channel 21
B-P1, psi
TIME, sec.
T0016 Channel 22
B-P1, psi
TIME, sec.

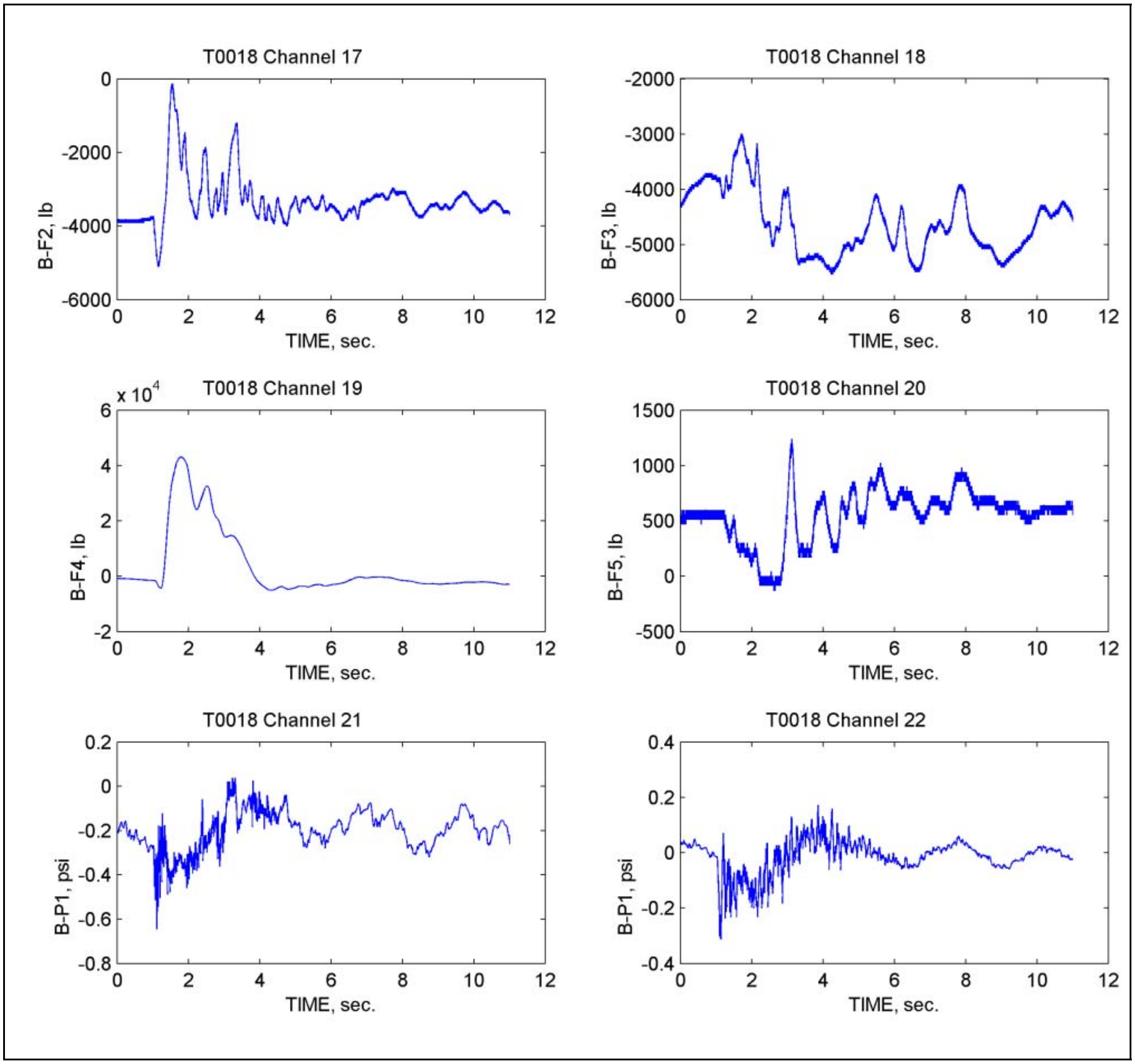

T0017 Channel 01
B-AX1, g
TIME, sec.
T0017 Channel 02
B-AY1, g
TIME, sec.
T0017 Channel 03
B-AZ1, g
TIME, sec.
T0017 Channel 04
B-AX2, g
TIME, sec.
T0017 Channel 05
B-AY2, g
TIME, sec.
T0017 Channel 06
B-AZ2, g
TIME, sec.
T0017 Channel 07
B-AX3, g
TIME, sec.
T0017 Channel 08
B-AY3, g
TIME, sec.

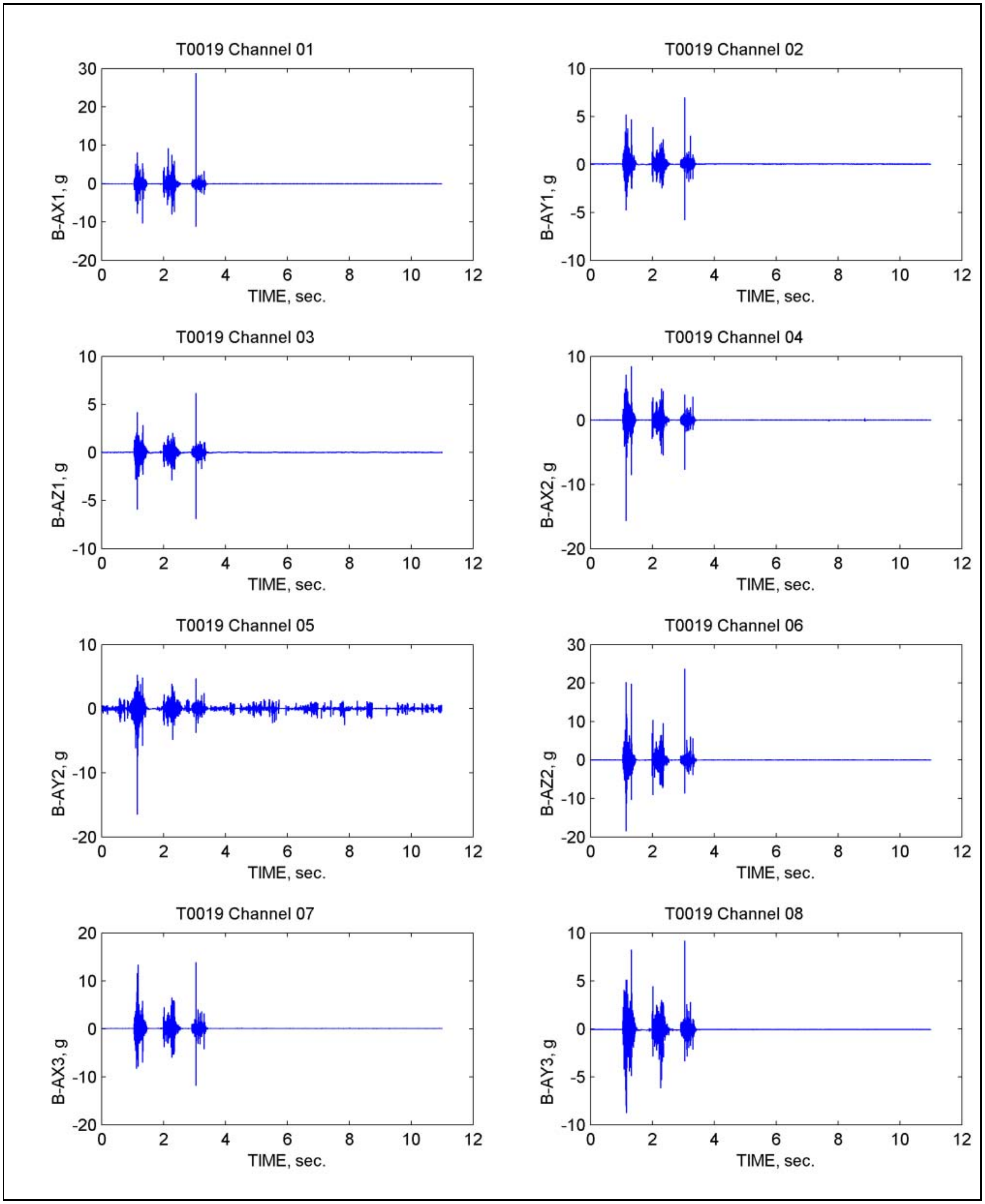

T0017 Channel 09
B-AZ3, g
TIME, sec.
T0017 Channel 10
B-SX1, u in/in
TIME, sec.
T0017 Channel 11
B-SXY1, u in/in
TIME, sec.
T0017 Channel 12
B-SY1, u in/in
TIME, sec.
T0017 Channel 13
B-SX2, u in/in
TIME, sec.
T0017 Channel 14
B-SXY2, u in/in
TIME, sec.
T0017 Channel 15
B-SY2, u in/in
TIME, sec.
T0017 Channel 16
B-F1, lb
TIME, sec.

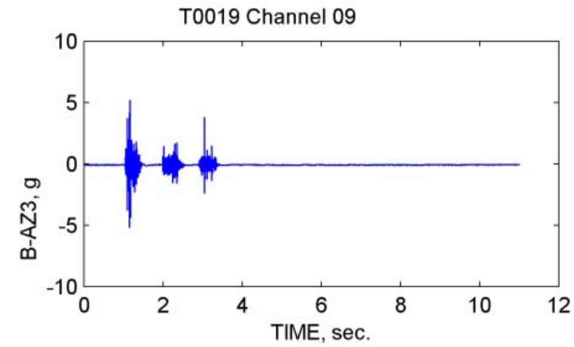

T0017 Channel 17
B-F2, lb
TIME, sec.
T0017 Channel 18
B-F3, lb
TIME, sec.
T0017 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0017 Channel 20
B-F5, lb
TIME, sec.
T0017 Channel 21
B-P1, psi
TIME, sec.
T0017 Channel 22
B-P1, psi
TIME, sec.

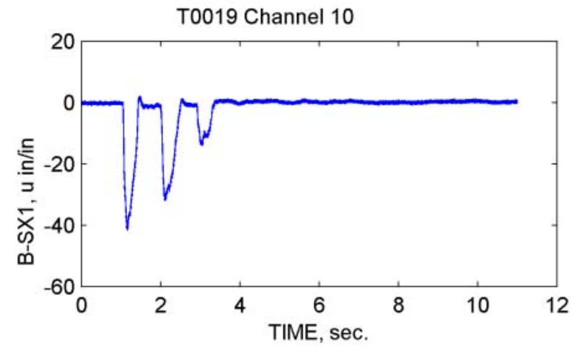

T0018 Channel 01
B-AX1, g
TIME, sec.
T0018 Channel 02
B-AY1, g
TIME, sec.
T0018 Channel 03
B-AZ1, g
TIME, sec.
T0018 Channel 04
B-AX2, g
TIME, sec.
T0018 Channel 05
B-AY2, g
TIME, sec.
T0018 Channel 06
B-AZ2, g
TIME, sec.
T0018 Channel 07
B-AX3, g
TIME, sec.
T0018 Channel 08
B-AY3, g
TIME, sec.

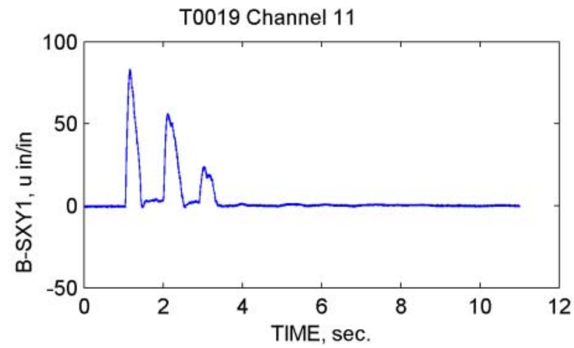

T0018 Channel 09
B-AZ3, g
TIME, sec.
T0018 Channel 10
B-SX1, u in/in
TIME, sec.
T0018 Channel 11
B-SXY1, u in/in
TIME, sec.
T0018 Channel 12
B-SY1, u in/in
TIME, sec.
T0018 Channel 13
B-SX2, u in/in
TIME, sec.
T0018 Channel 14
B-SXY2, u in/in
TIME, sec.
T0018 Channel 15
B-SY2, u in/in
TIME, sec.
T0018 Channel 16
B-F1, lb
TIME, sec.

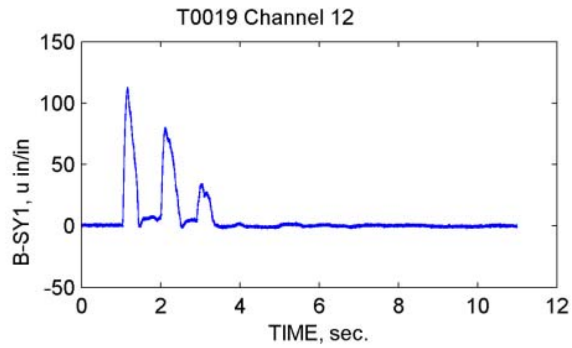

T0018 Channel 17
B-F2, lb
TIME, sec.
T0018 Channel 18
B-F3, lb
TIME, sec.
T0018 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0018 Channel 20
B-F5, lb
TIME, sec.
T0018 Channel 21
B-P1, psi
TIME, sec.
T0018 Channel 22
B-P1, psi
TIME, sec.

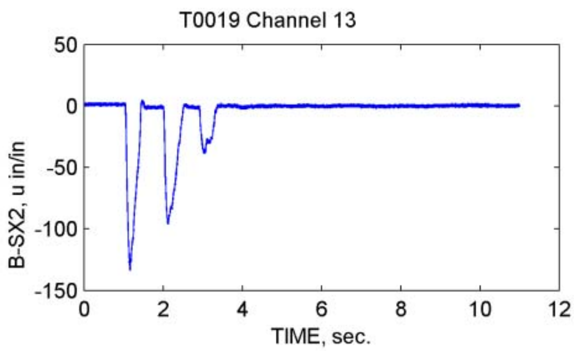

T0019 Channel 01
B-AX1, g
TIME, sec.
T0019 Channel 02
B-AY1, g
TIME, sec.
T0019 Channel 03
B-AZ1, g
TIME, sec.
T0019 Channel 04
B-AX2, g
TIME, sec.
T0019 Channel 05
B-AY2, g
TIME, sec.
T0019 Channel 06
B-AZ2, g
TIME, sec.
T0019 Channel 07
B-AX3, g
TIME, sec.
T0019 Channel 08
B-AY3, g
TIME, sec.

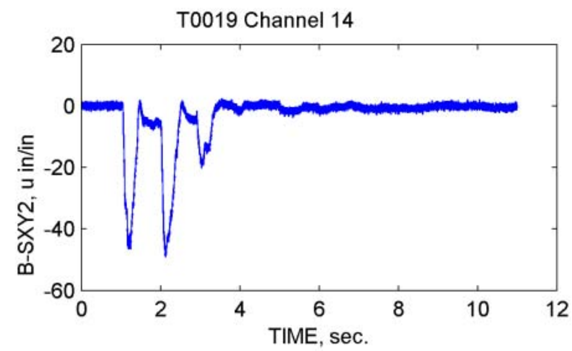

T0019 Channel 09
B-AZ3, g
TIME, sec.

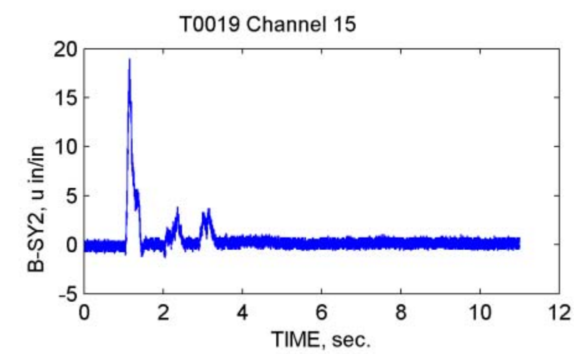

T0019 Channel 10
B-SX1, u in/in
TIME, sec.

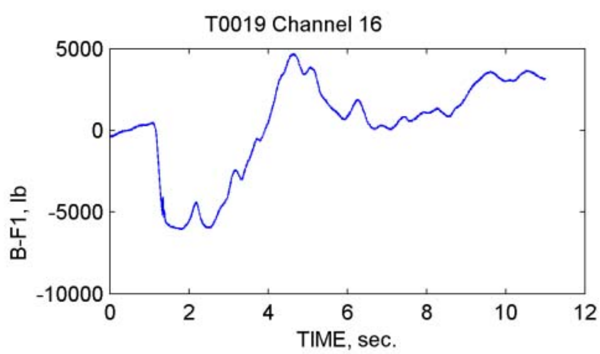

T0019 Channel 11
B-SXY1, u in/in
TIME, sec.

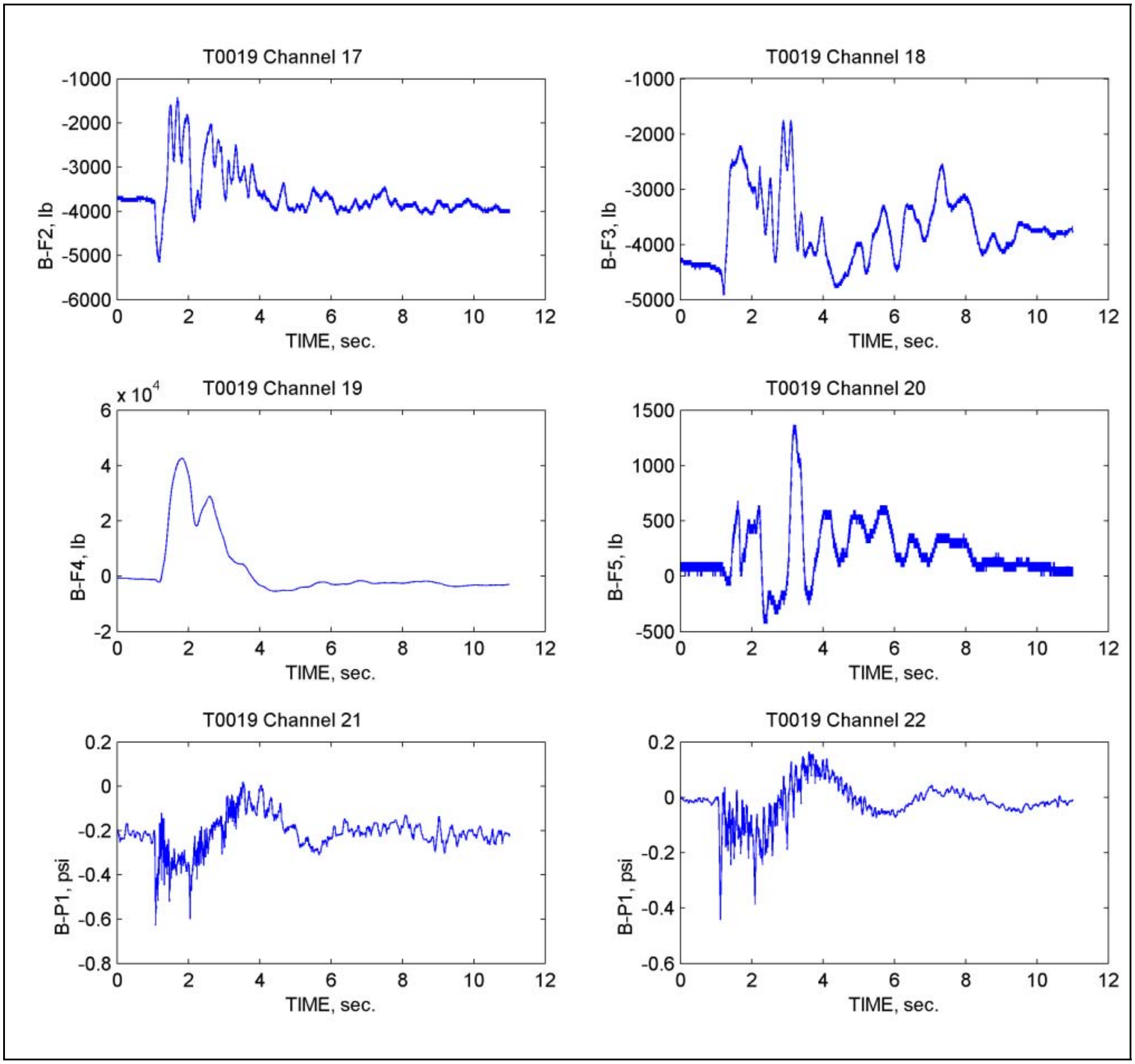

T0019 Channel 12
B-SY1, u in/in
TIME, sec.

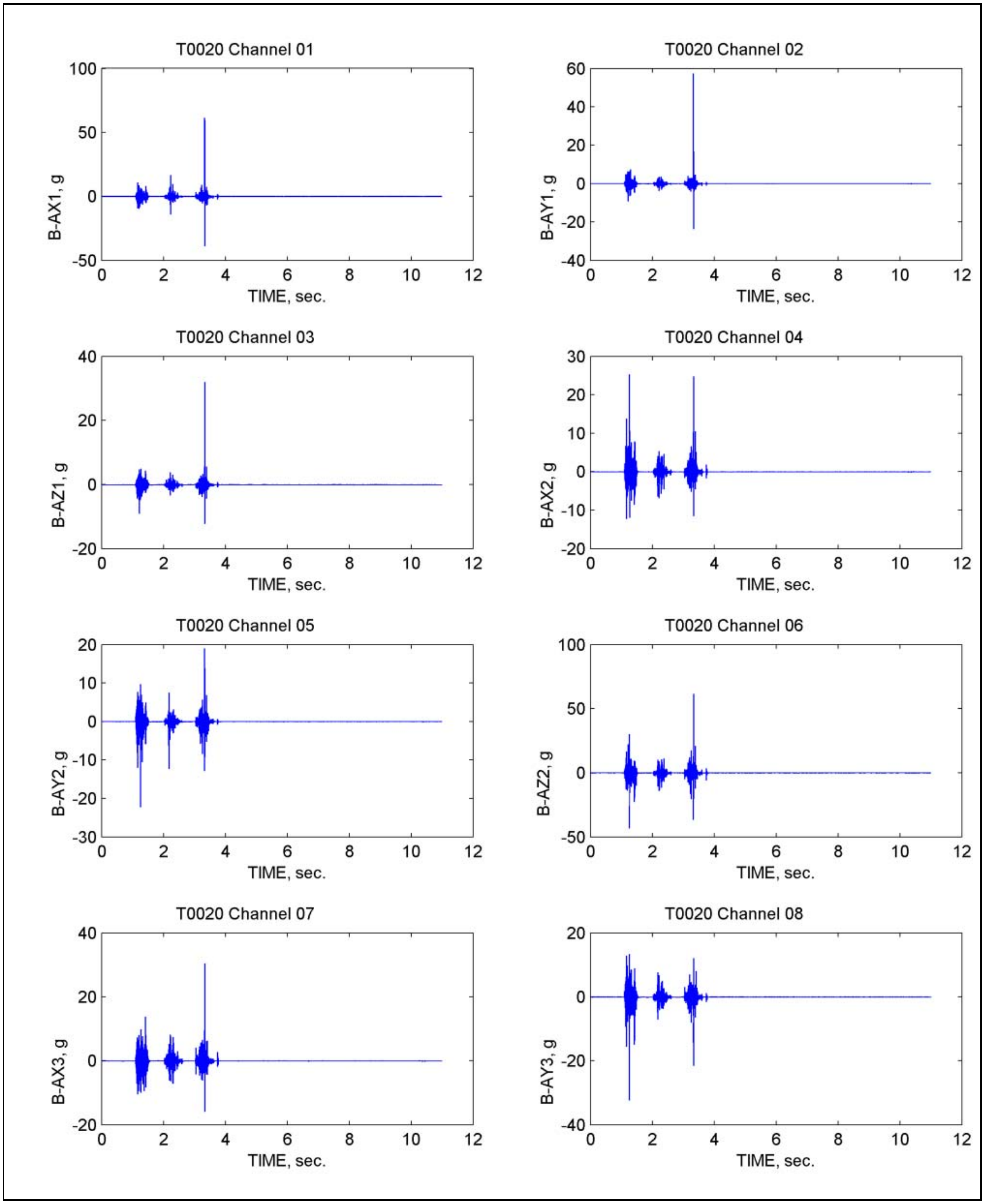

T0019 Channel 13
B-SX2, u in/in
TIME, sec.


T0019 Channel 14
B-SXY2, u in/in
TIME, sec.

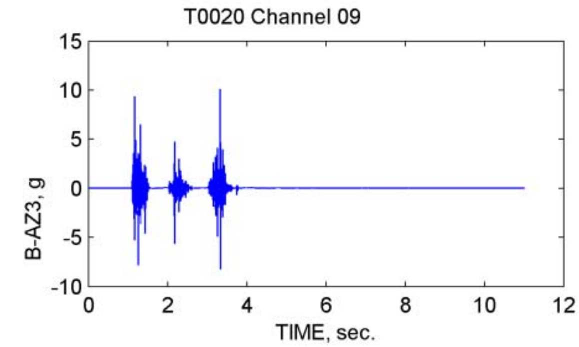

T0019 Channel 15
B-SY2, u in/in
TIME, sec.

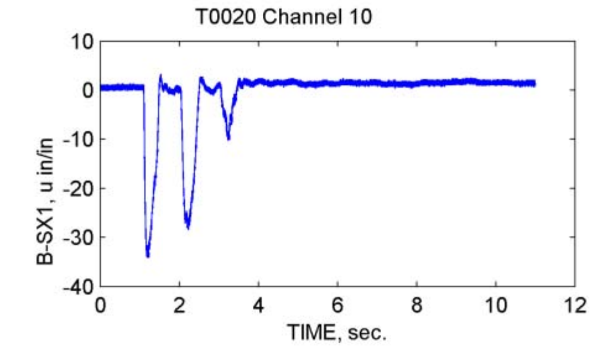

T0019 Channel 16
B-F1, lb
TIME, sec.

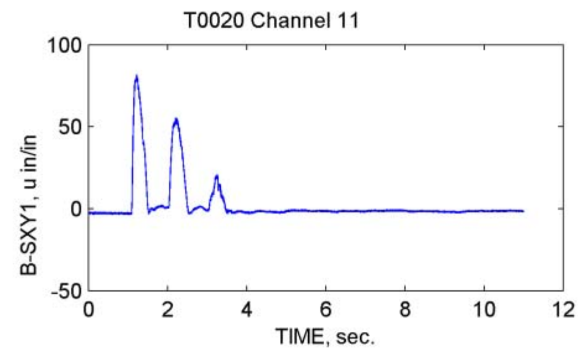

T0019 Channel 17
B-F2, lb
TIME, sec.
T0019 Channel 18
B-F3, lb
TIME, sec.
T0019 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0019 Channel 20
B-F5, lb
TIME, sec.
T0019 Channel 21
B-P1, psi
TIME, sec.
T0019 Channel 22
B-P1, psi
TIME, sec.

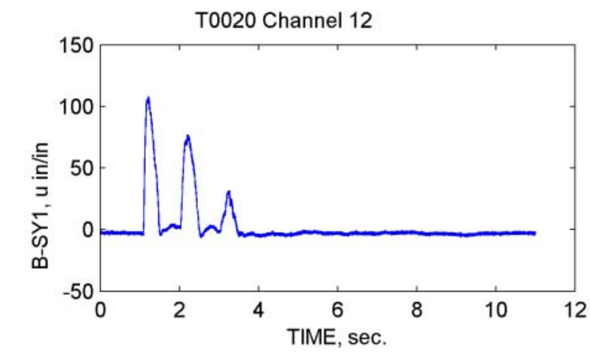


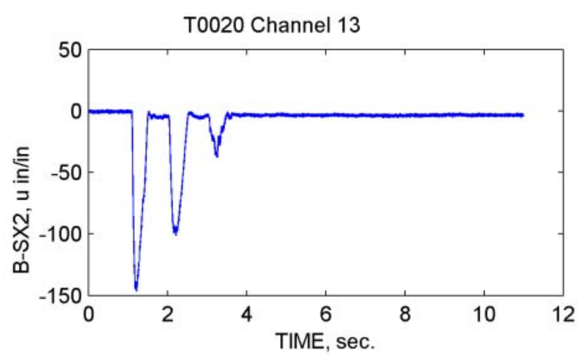
T0020 Channel 01
B-AX1, g
TIME, sec.
T0020 Channel 02
B-AY1, g
TIME, sec.
T0020 Channel 03
B-AZ1, g
TIME, sec.
T0020 Channel 04
B-AX2, g
TIME, sec.
T0020 Channel 05
B-AY2, g
TIME, sec.
T0020 Channel 06
B-AZ2, g
TIME, sec.
T0020 Channel 07
B-AX3, g
TIME, sec.
T0020 Channel 08
B-AY3, g
TIME, sec.

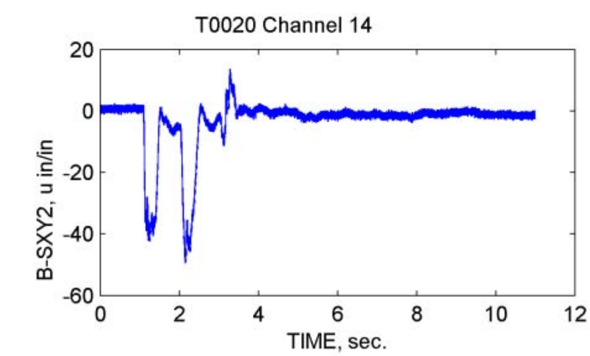

T0020 Channel 09
B-AZ3, g
TIME, sec.

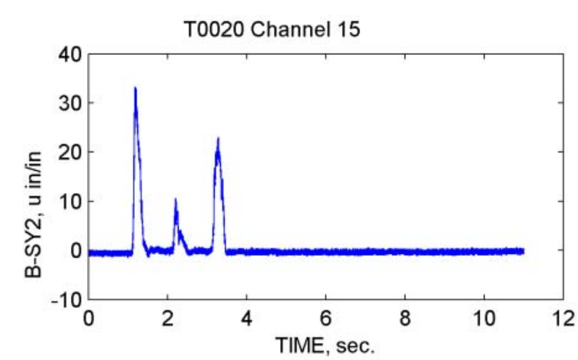

T0020 Channel 10
B-SX1, u in/in
TIME, sec.

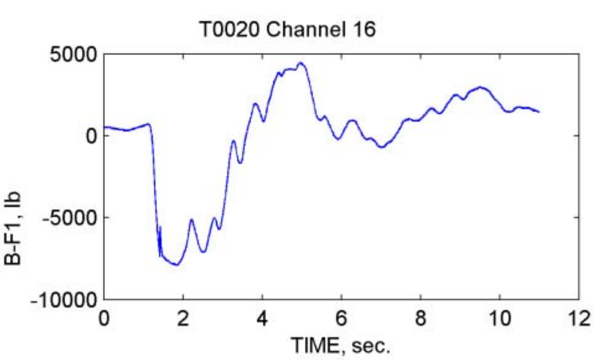

T0020 Channel 11
B-SXY1, u in/in
TIME, sec.

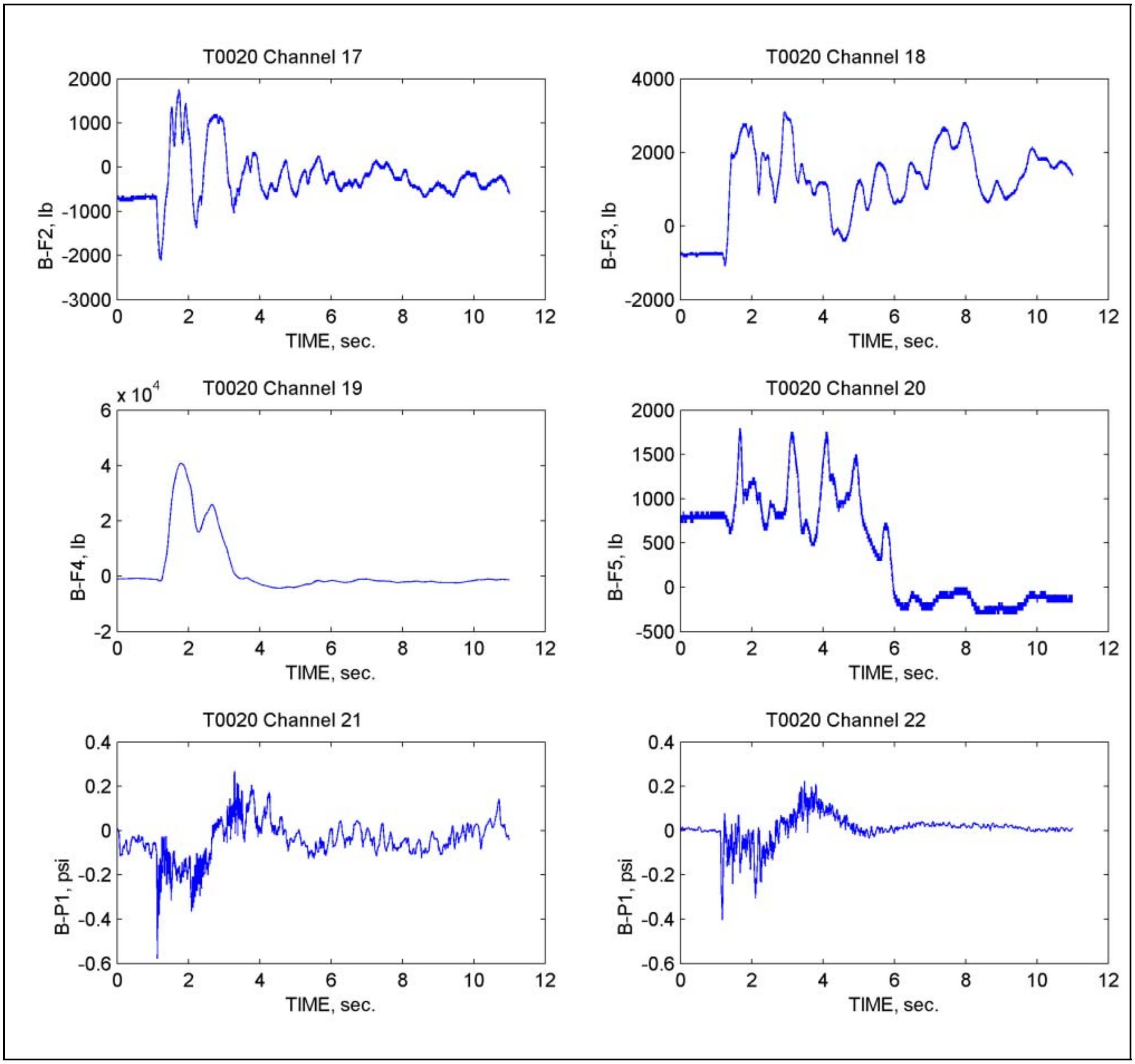

T0020 Channel 12
B-SY1, u in/in
TIME, sec.

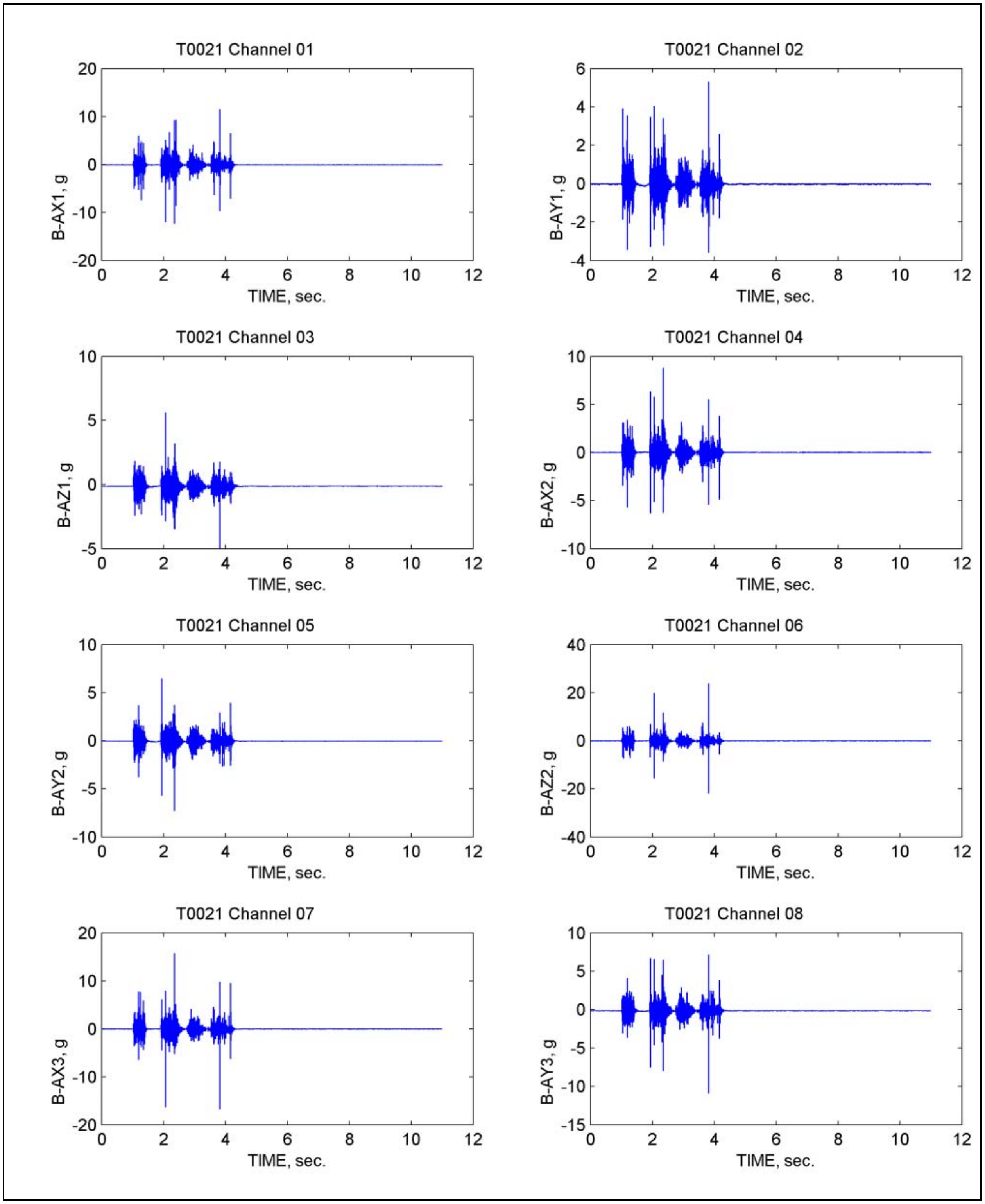

T0020 Channel 13
B-SX2, u in/in
TIME, sec.

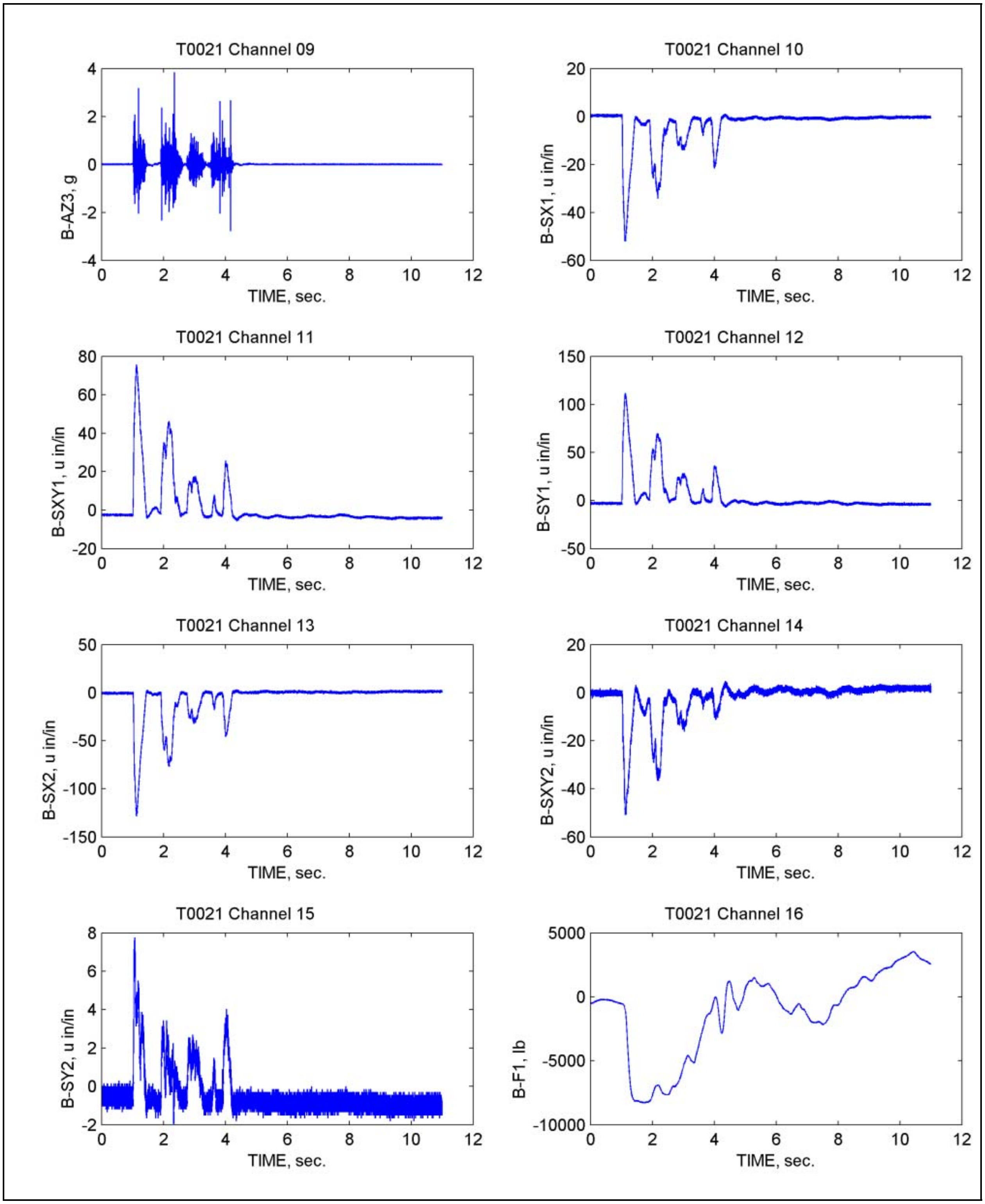

T0020 Channel 14
B-SXY2, u in/in
TIME, sec.

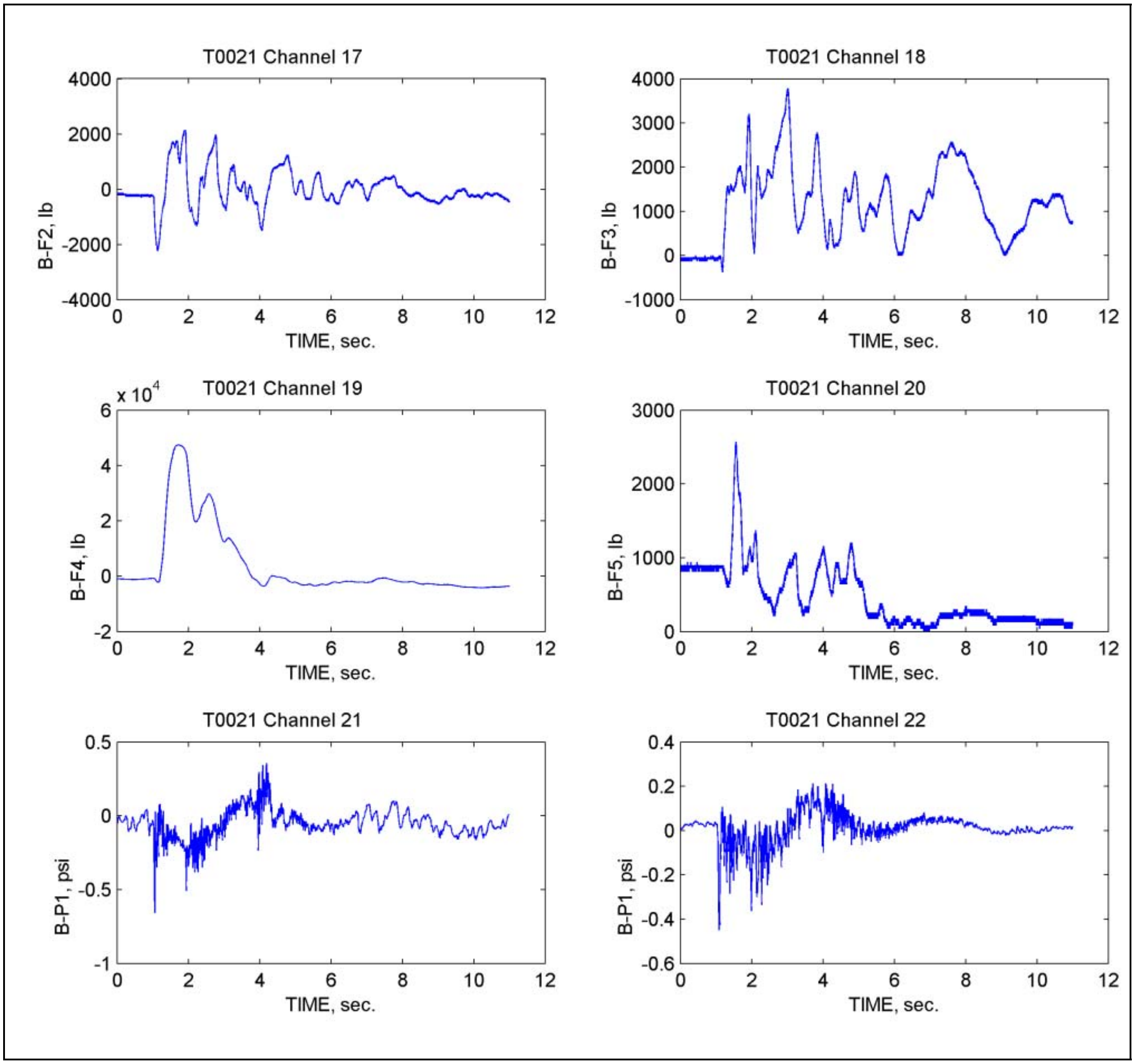

T0020 Channel 15
B-SY2, u in/in
TIME, sec.

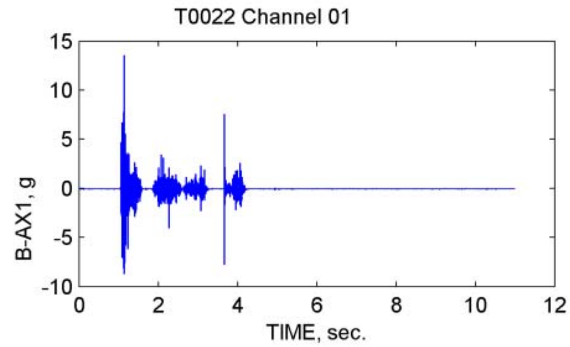

T0020 Channel 16
B-F1, lb
TIME, sec.

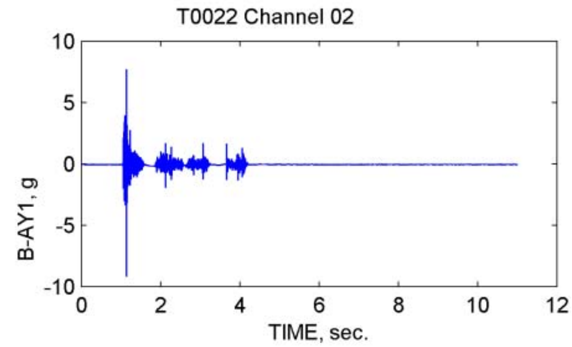

T0020 Channel 17
B-F2, lb
TIME, sec.
T0020 Channel 18
B-F3, lb
TIME, sec.
T0020 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0020 Channel 20
B-F5, lb
TIME, sec.
T0020 Channel 21
B-P1, psi
TIME, sec.
T0020 Channel 22
B-P1, psi
TIME, sec.

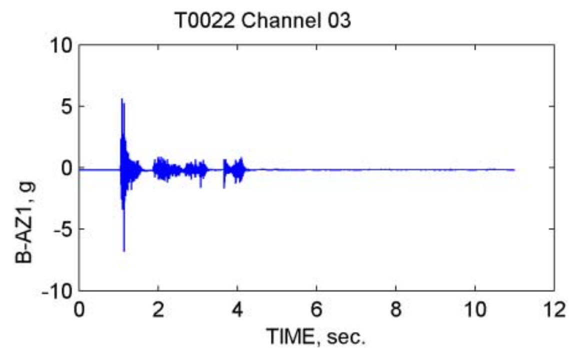

T0021 Channel 01
B-AX1, g
T0021 Channel 02
B-AY1, g
T0021 Channel 03
B-AZ1, g
T0021 Channel 04
B-AX2, g
T0021 Channel 05
B-AY2, g
T0021 Channel 06
B-AZ2, g
T0021 Channel 07
B-AX3, g
T0021 Channel 08
B-AY3, g
TIME, sec.

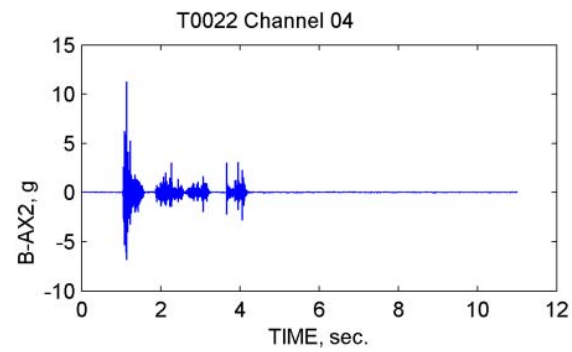

T0021 Channel 09
B-AZ3, g
TIME, sec.
T0021 Channel 10
B-SX1, u in/in
TIME, sec.
T0021 Channel 11
B-SXY1, u in/in
TIME, sec.
T0021 Channel 12
B-SY1, u in/in
TIME, sec.
T0021 Channel 13
B-SX2, u in/in
TIME, sec.
T0021 Channel 14
B-SXY2, u in/in
TIME, sec.
T0021 Channel 15
B-SY2, u in/in
TIME, sec.
T0021 Channel 16
B-F1, lb
TIME, sec.

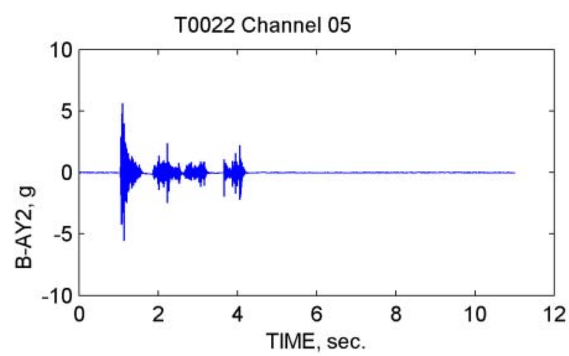

T0021 Channel 17
B-F2, lb
TIME, sec.
T0021 Channel 18
B-F3, lb
TIME, sec.
T0021 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0021 Channel 20
B-F5, lb
TIME, sec.
T0021 Channel 21
B-P1, psi
TIME, sec.
T0021 Channel 22
B-P1, psi
TIME, sec.

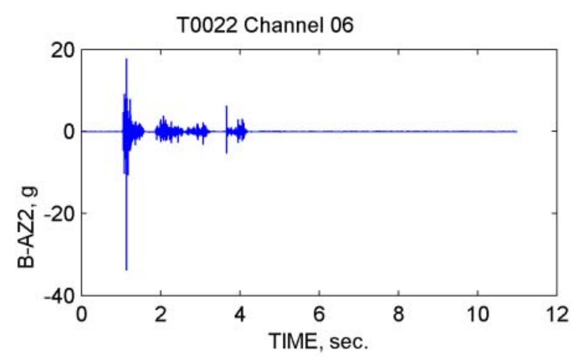

T0022 Channel 01
B-AX1, g
TIME, sec.

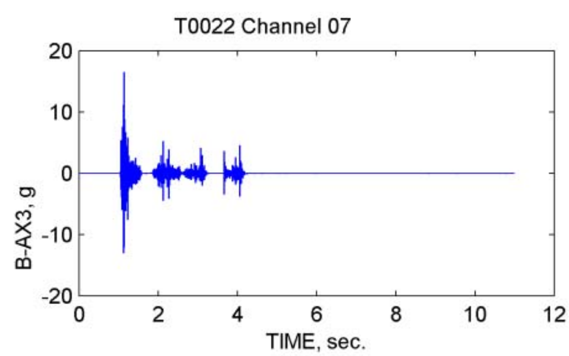

T0022 Channel 02
B-AY1, g
TIME, sec.

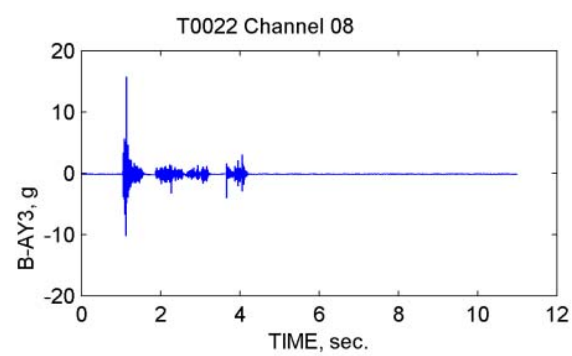

T0022 Channel 03
B-AZ1, g
TIME, sec.

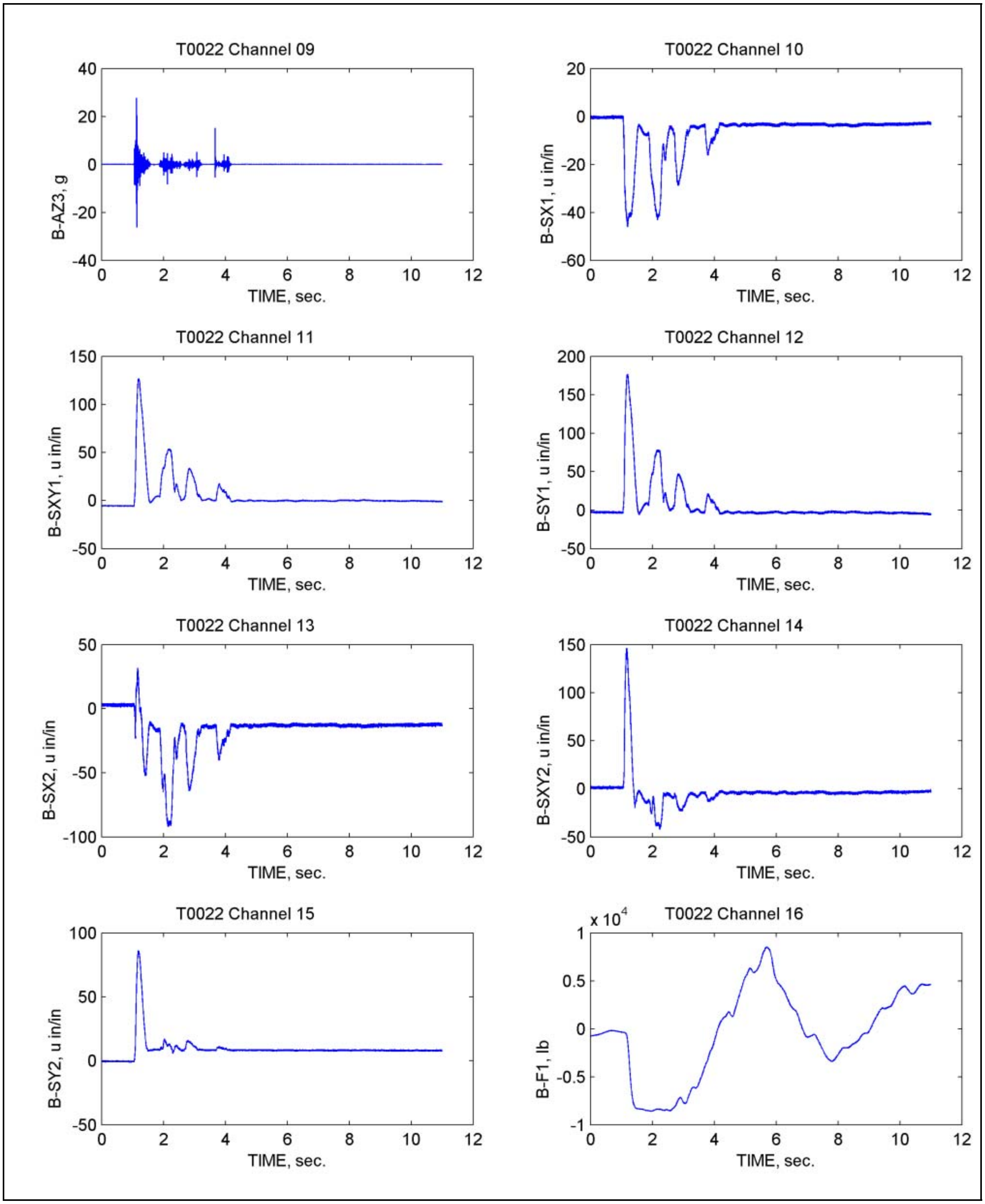

T0022 Channel 04
B-AX2, g
TIME, sec.

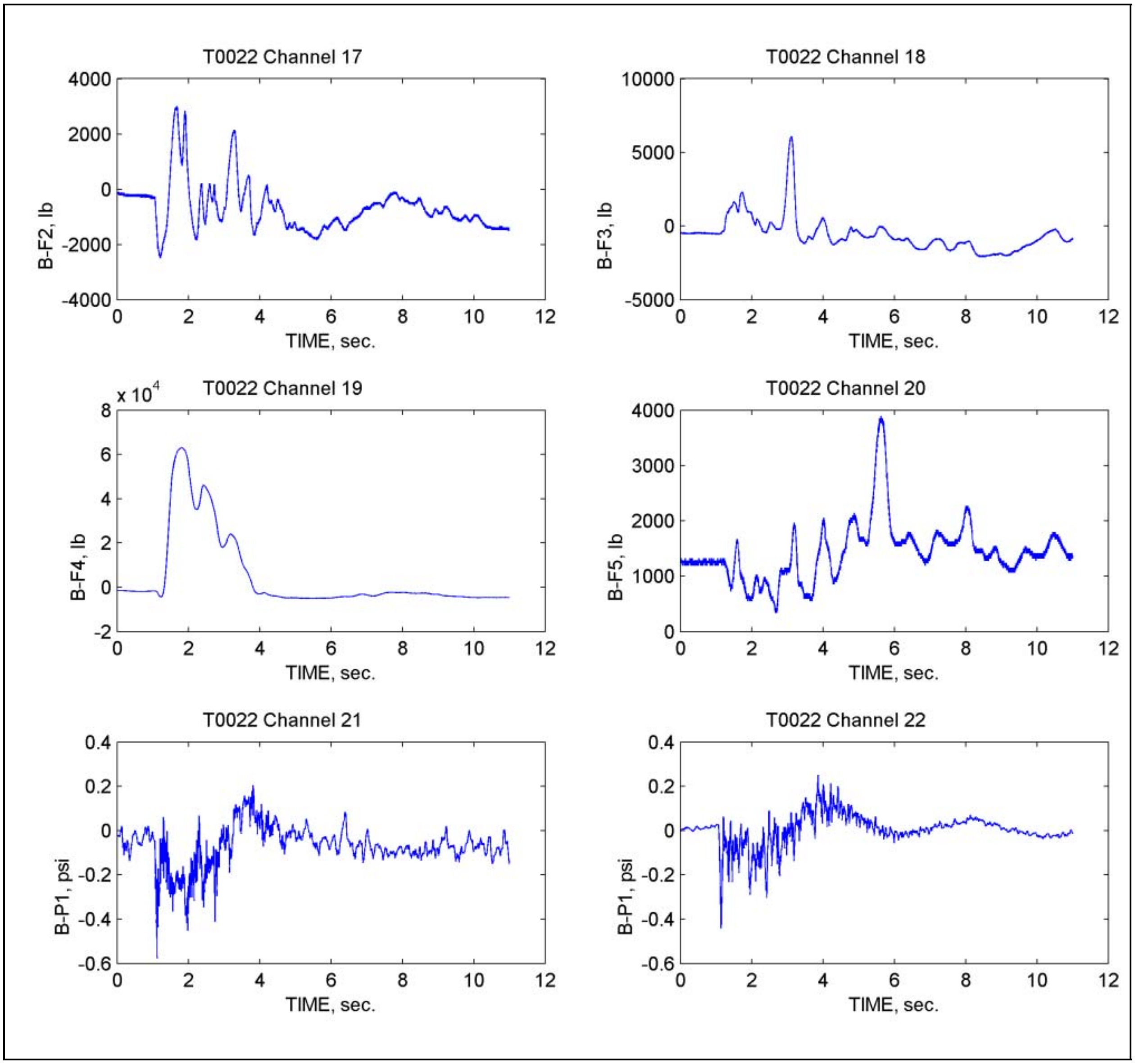

T0022 Channel 05
B-AY2, g
TIME, sec.

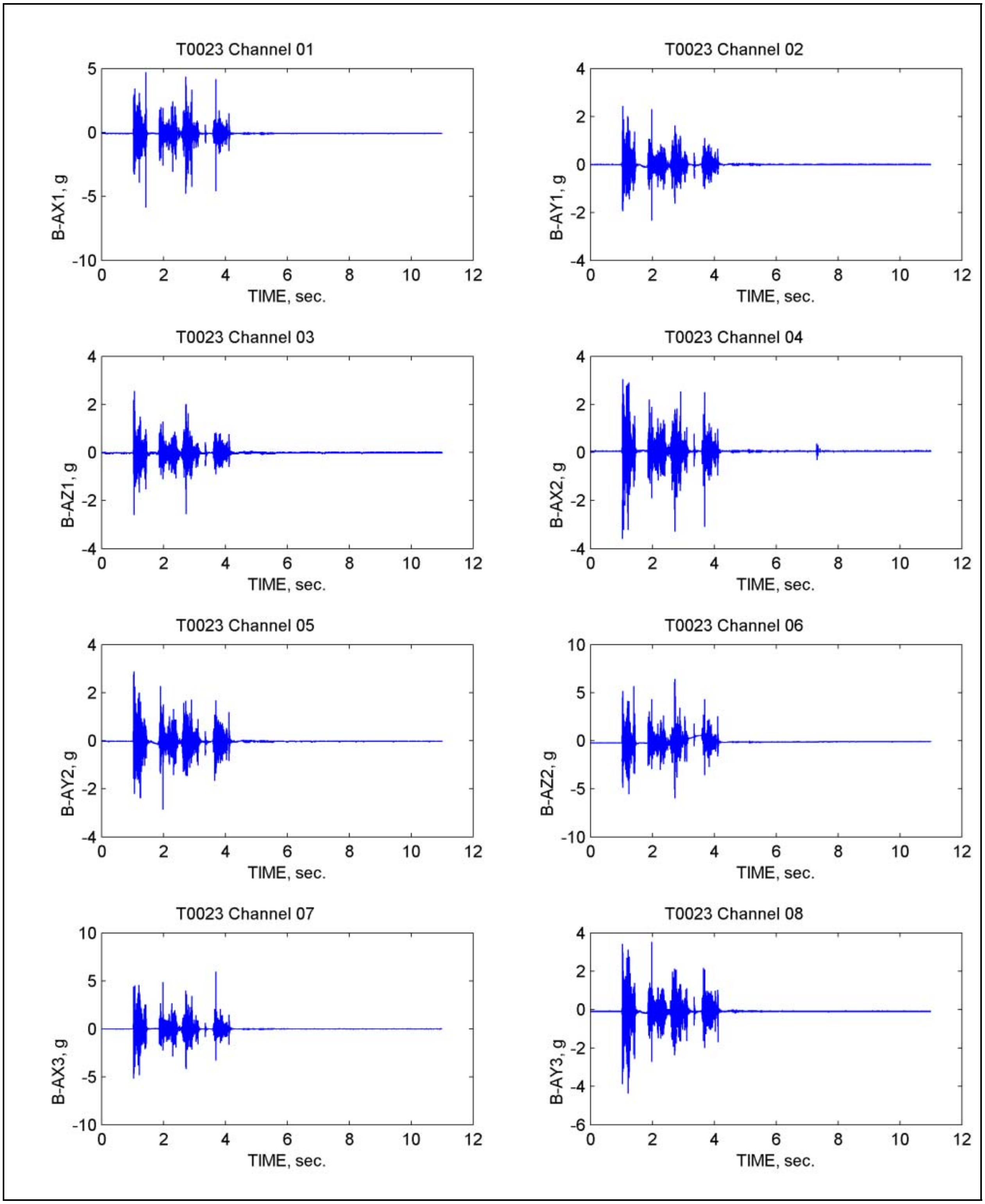

T0022 Channel 06
B-AZ2, g
TIME, sec.

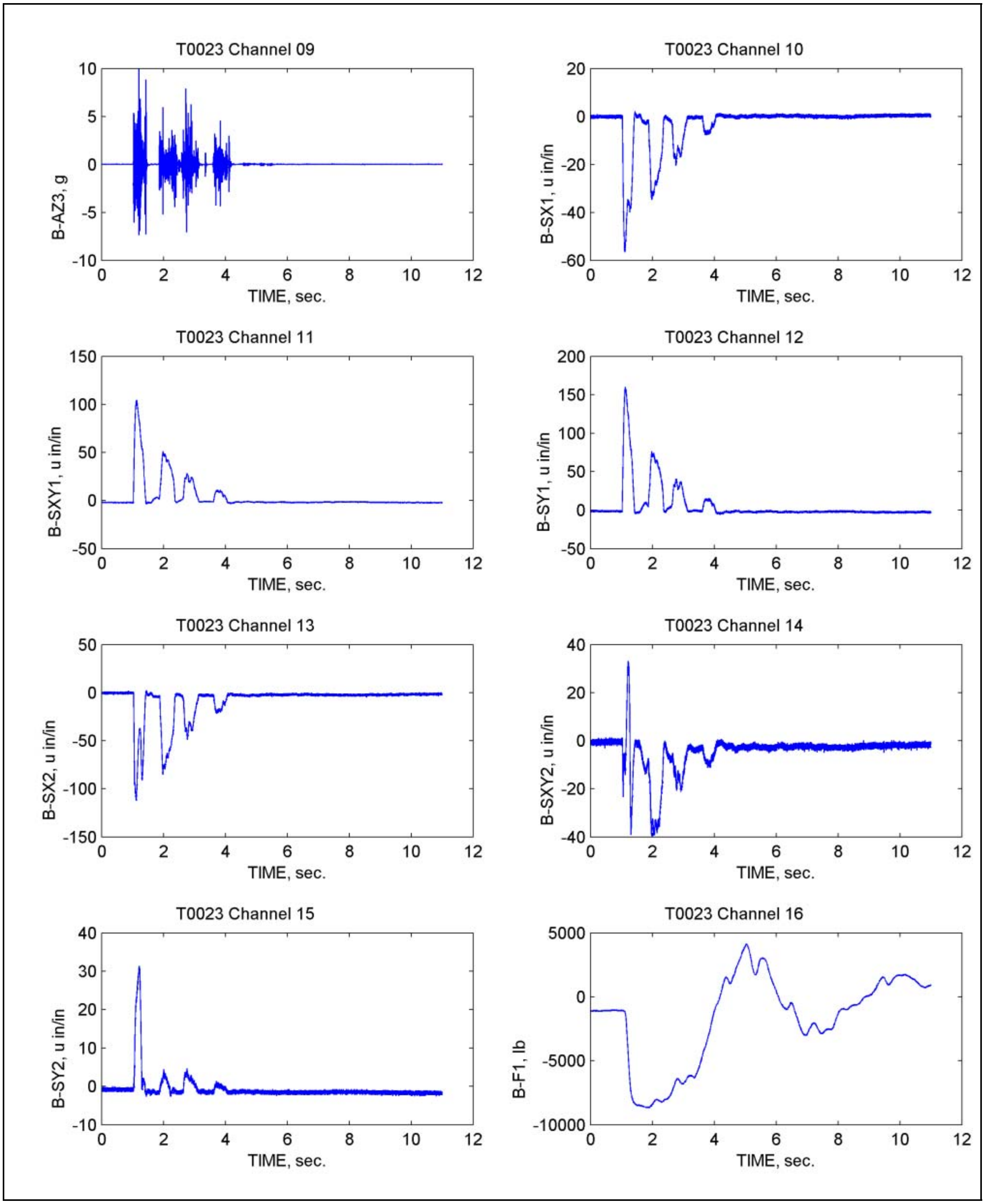

T0022 Channel 07
B-AX3, g
TIME, sec.

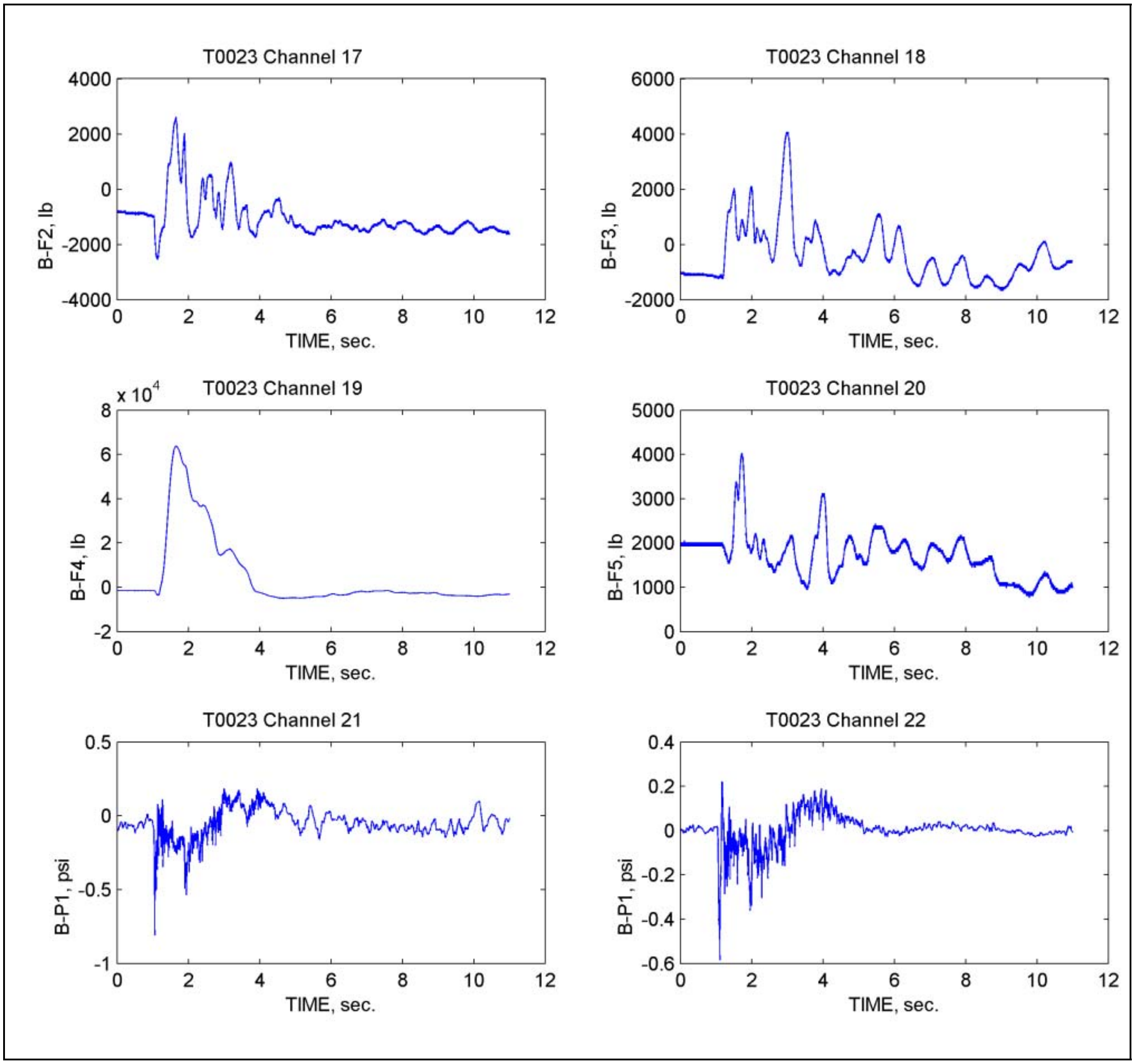

T0022 Channel 08
B-AY3, g
TIME, sec.

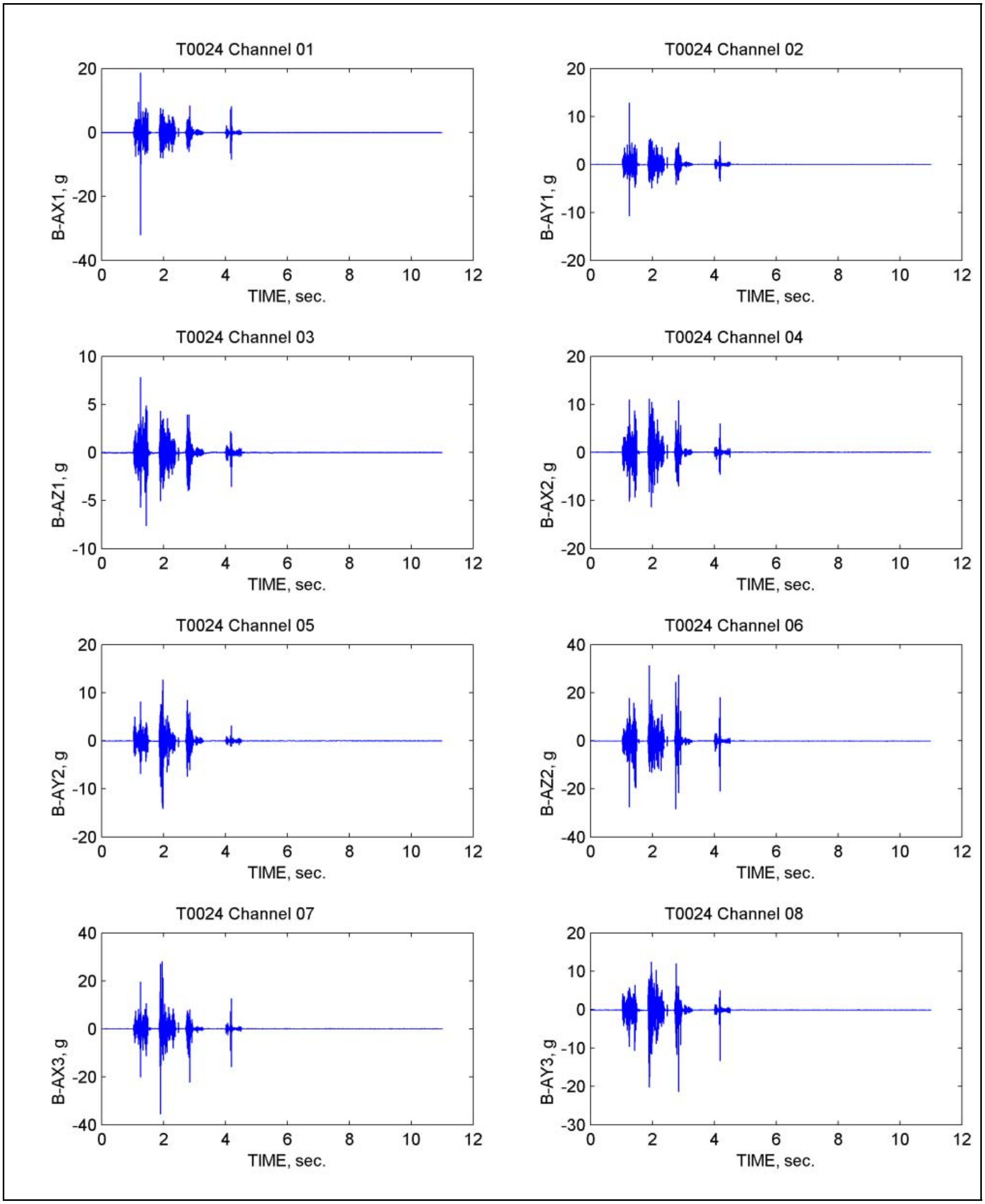

T0022 Channel 09
B-AZ3, g
TIME, sec.
T0022 Channel 10
B-SX1, u in/in
TIME, sec.
T0022 Channel 11
B-SXY1, u in/in
TIME, sec.
T0022 Channel 12
B-SY1, u in/in
TIME, sec.
T0022 Channel 13
B-SX2, u in/in
TIME, sec.
T0022 Channel 14
B-SXY2, u in/in
TIME, sec.
T0022 Channel 15
B-SY2, u in/in
TIME, sec.
T0022 Channel 16
x 10^4
B-F1, lb
TIME, sec.

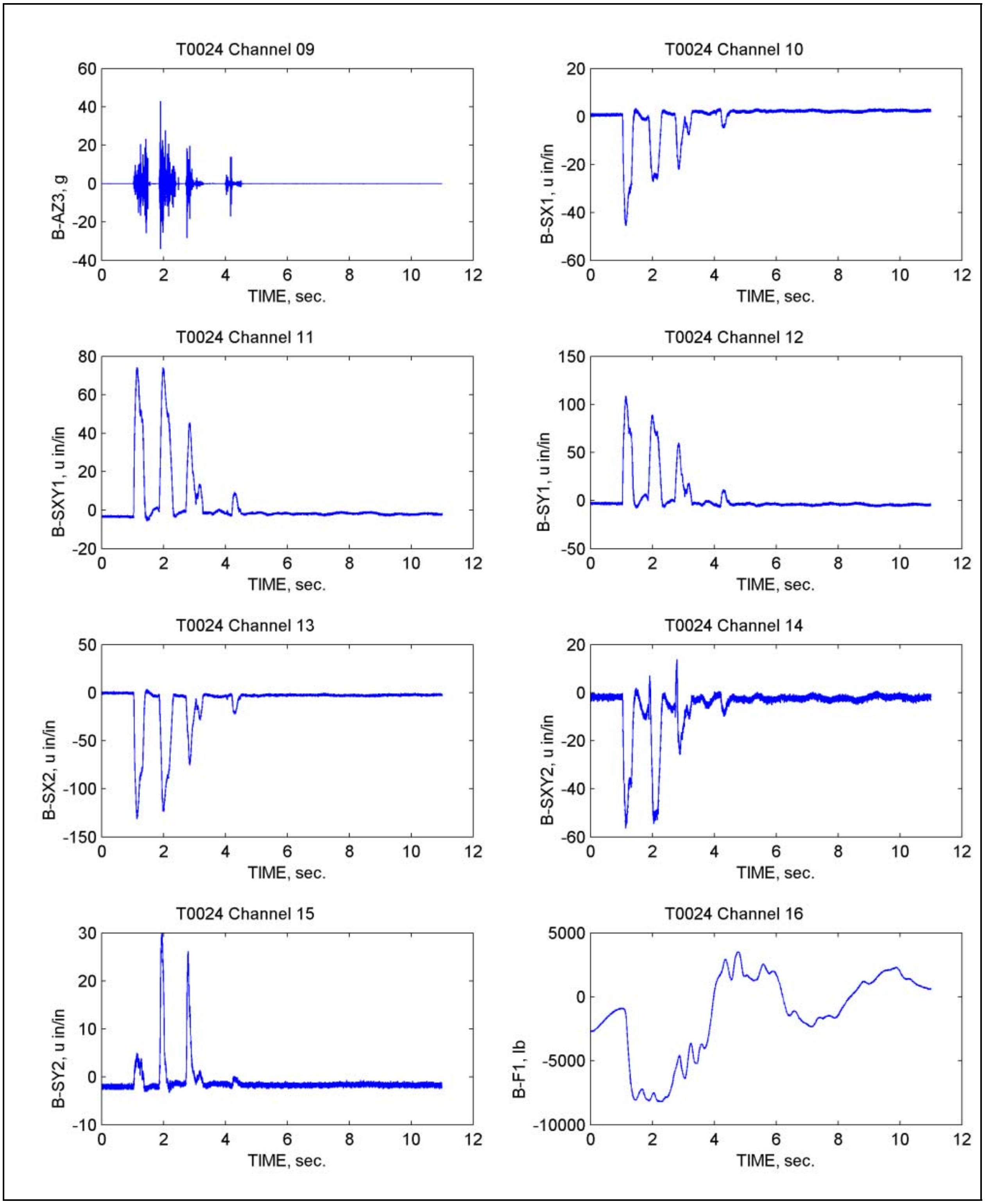

T0022 Channel 17
B-F2, lb
TIME, sec.
T0022 Channel 18
B-F3, lb
TIME, sec.
T0022 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0022 Channel 20
B-F5, lb
TIME, sec.
T0022 Channel 21
B-P1, psi
TIME, sec.
T0022 Channel 22
B-P1, psi
TIME, sec.

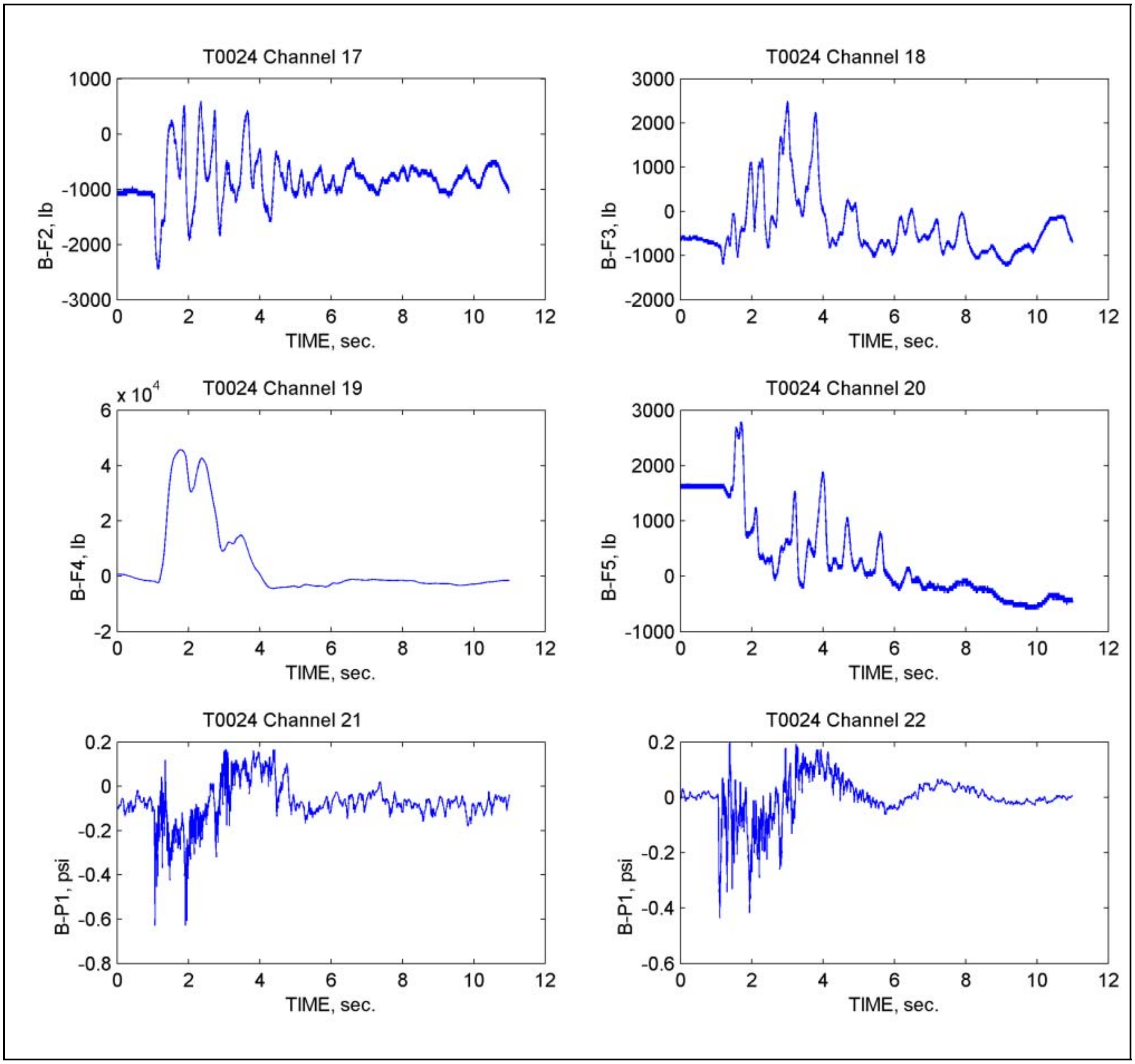

T0023 Channel 01
B-AX1, g
5
0
-5
-10
TIME, sec.
0
2
4
6
8
10
12
T0023 Channel 02
B-AY1, g
4
2
0
-2
-4
TIME, sec.
0
2
4
6
8
10
12
T0023 Channel 03
B-AZ1, g
4
2
0
-2
-4
TIME, sec.
0
2
4
6
8
10
12
T0023 Channel 04
B-AX2, g
4
2
0
-2
-4
TIME, sec.
0
2
4
6
8
10
12
T0023 Channel 05
B-AY2, g
4
2
0
-2
-4
TIME, sec.
0
2
4
6
8
10
12
T0023 Channel 06
B-AZ2, g
10
5
0
-5
-10
TIME, sec.
0
2
4
6
8
10
12
T0023 Channel 07
B-AX3, g
10
5
0
-5
-10
TIME, sec.
0
2
4
6
8
10
12
T0023 Channel 08
B-AY3, g
4
2
0
-2
-4
-6
TIME, sec.
0
2
4
6
8
10
12

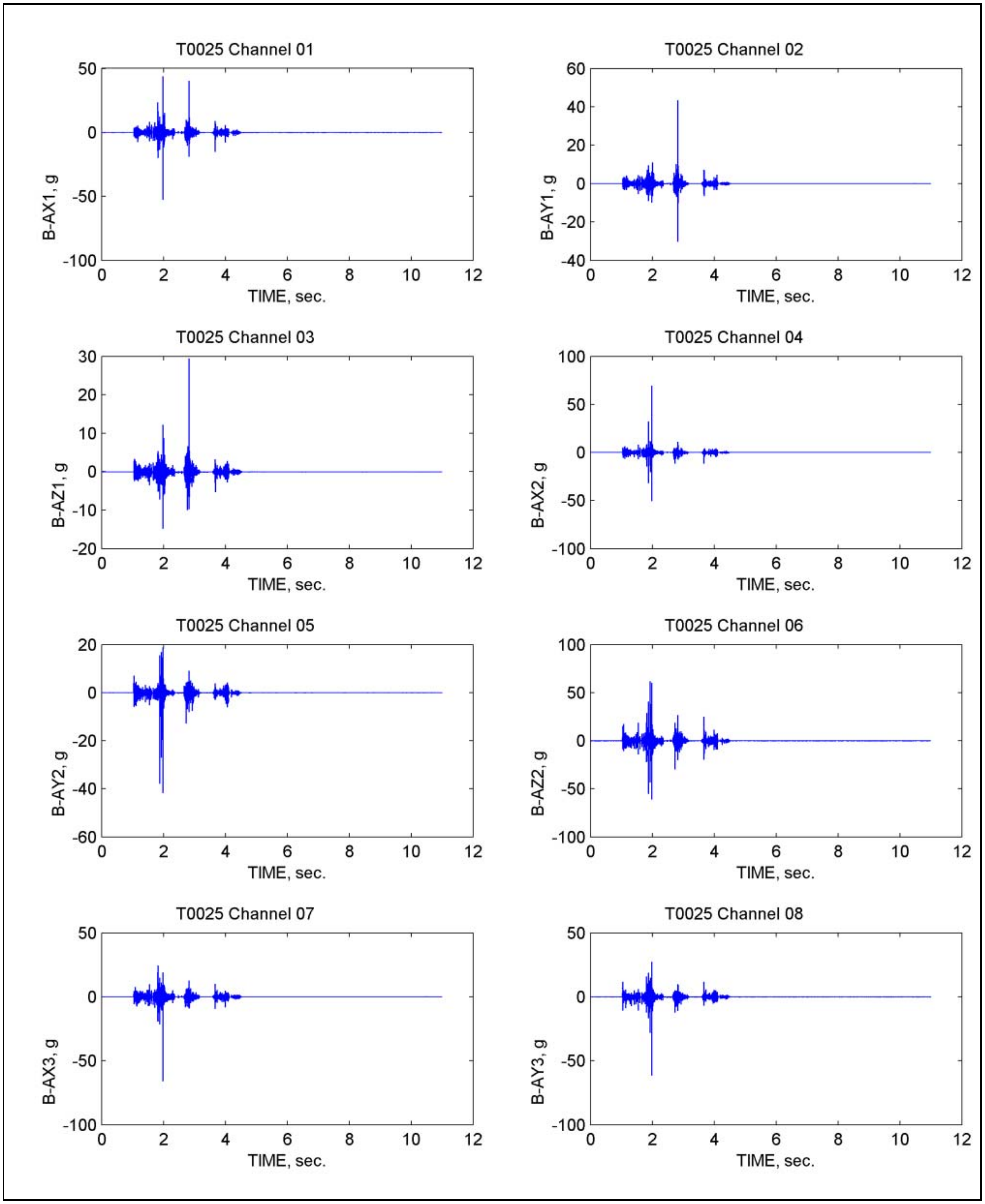

T0023 Channel 09
B-AZ3, g
TIME, sec.
T0023 Channel 10
B-SX1, u in/in
TIME, sec.
T0023 Channel 11
B-SXY1, u in/in
TIME, sec.
T0023 Channel 12
B-SY1, u in/in
TIME, sec.
T0023 Channel 13
B-SX2, u in/in
TIME, sec.
T0023 Channel 14
B-SXY2, u in/in
TIME, sec.
T0023 Channel 15
B-SY2, u in/in
TIME, sec.
T0023 Channel 16
B-F1, lb
TIME, sec.


T0023 Channel 17
B-F2, lb
TIME, sec.
T0023 Channel 18
B-F3, lb
TIME, sec.
T0023 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0023 Channel 20
B-F5, lb
TIME, sec.
T0023 Channel 21
B-P1, psi
TIME, sec.
T0023 Channel 22
B-P1, psi
TIME, sec.

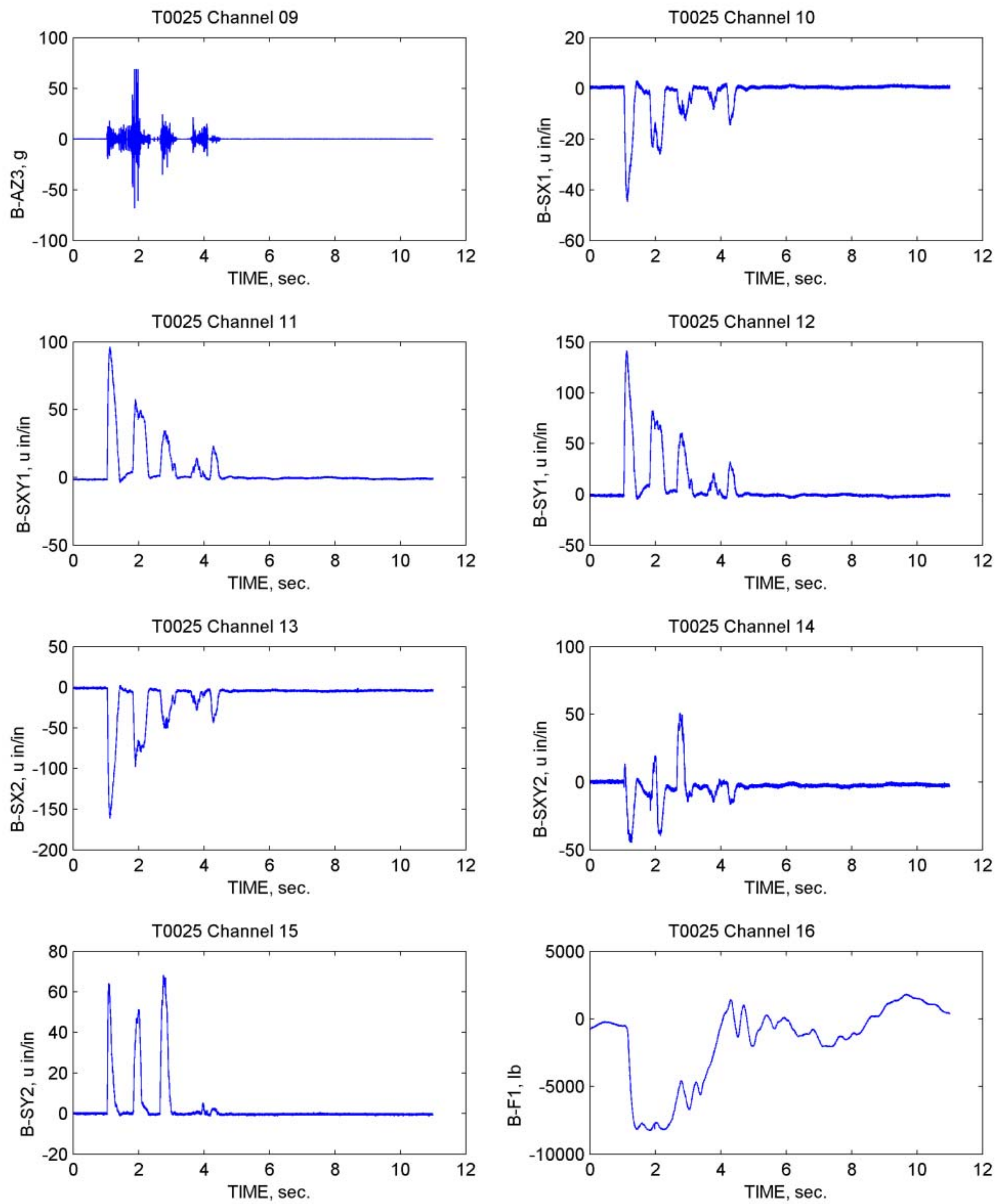

T0024 Channel 01
B-AX1, g
TIME, sec.
T0024 Channel 02
B-AY1, g
TIME, sec.
T0024 Channel 03
B-AZ1, g
TIME, sec.
T0024 Channel 04
B-AX2, g
TIME, sec.
T0024 Channel 05
B-AY2, g
TIME, sec.
T0024 Channel 06
B-AZ2, g
TIME, sec.
T0024 Channel 07
B-AX3, g
TIME, sec.
T0024 Channel 08
B-AY3, g
TIME, sec.

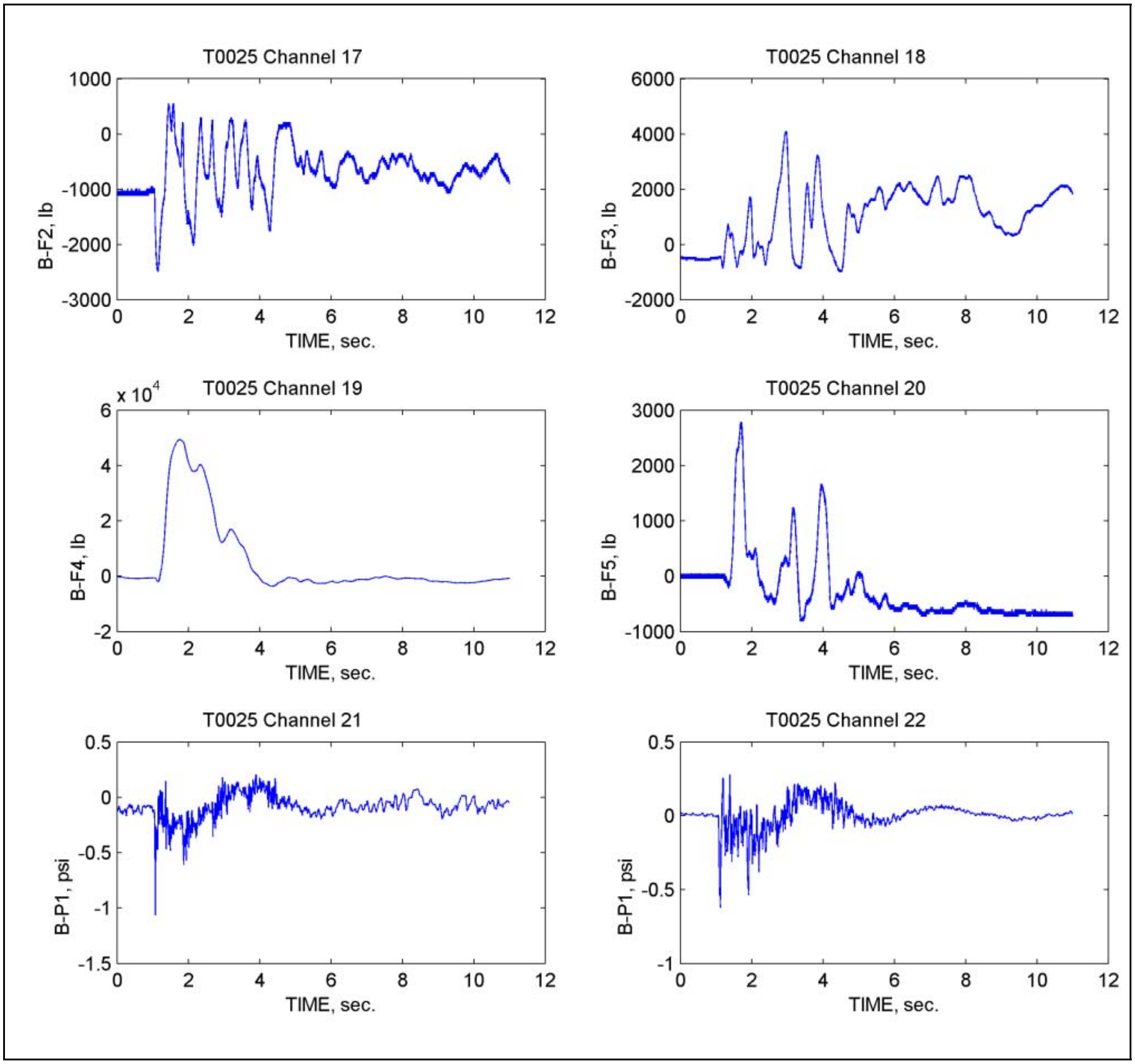

T0024 Channel 09
B-AZ3, g
TIME, sec.
T0024 Channel 10
B-SX1, u in/in
TIME, sec.
T0024 Channel 11
B-SXY1, u in/in
TIME, sec.
T0024 Channel 12
B-SY1, u in/in
TIME, sec.
T0024 Channel 13
B-SX2, u in/in
TIME, sec.
T0024 Channel 14
B-SXY2, u in/in
TIME, sec.
T0024 Channel 15
B-SY2, u in/in
TIME, sec.
T0024 Channel 16
B-F1, lb
TIME, sec.

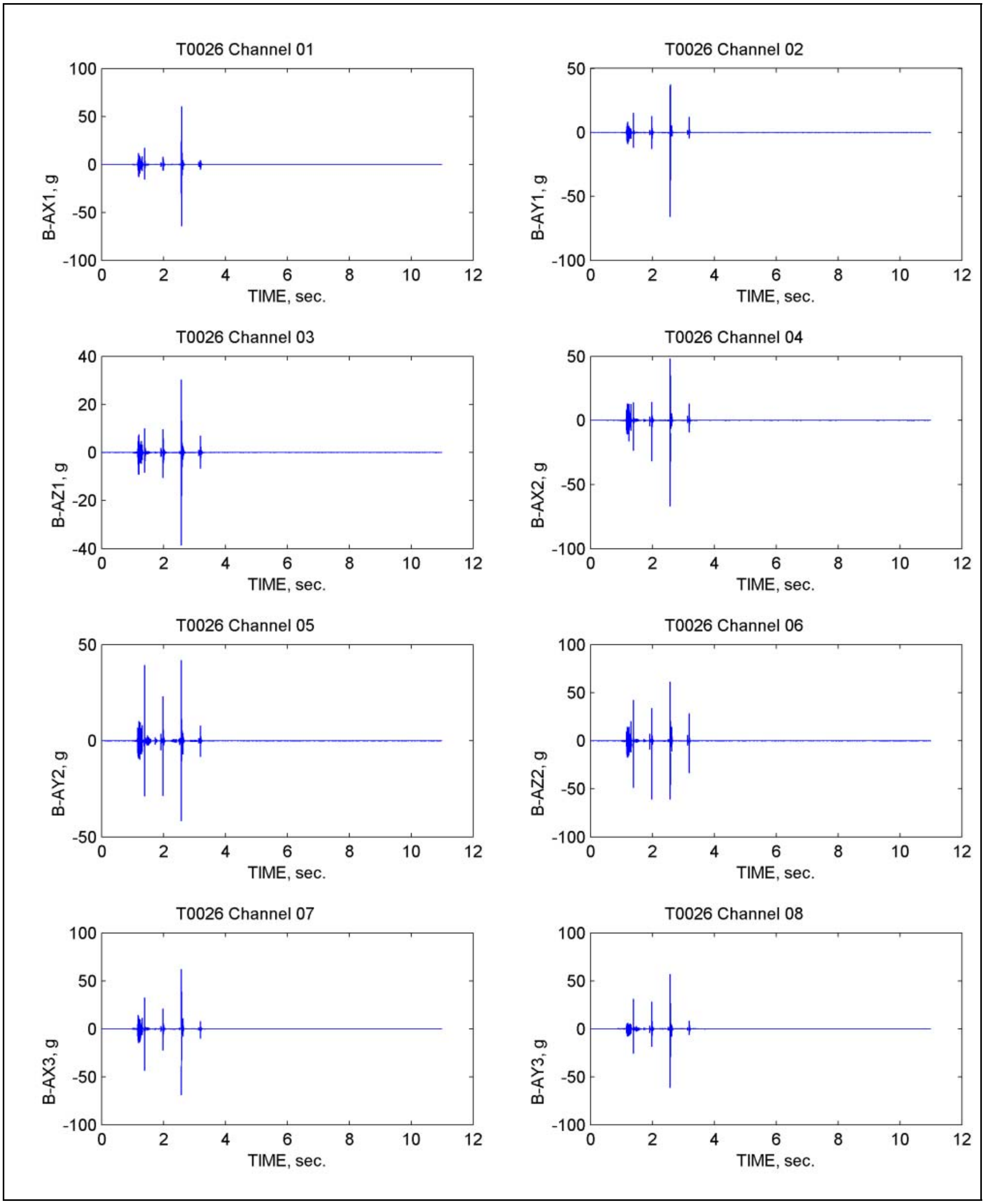

T0024 Channel 17
B-F2, lb
TIME, sec.
T0024 Channel 18
B-F3, lb
TIME, sec.
T0024 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0024 Channel 20
B-F5, lb
TIME, sec.
T0024 Channel 21
B-P1, psi
TIME, sec.
T0024 Channel 22
B-P1, psi
TIME, sec.

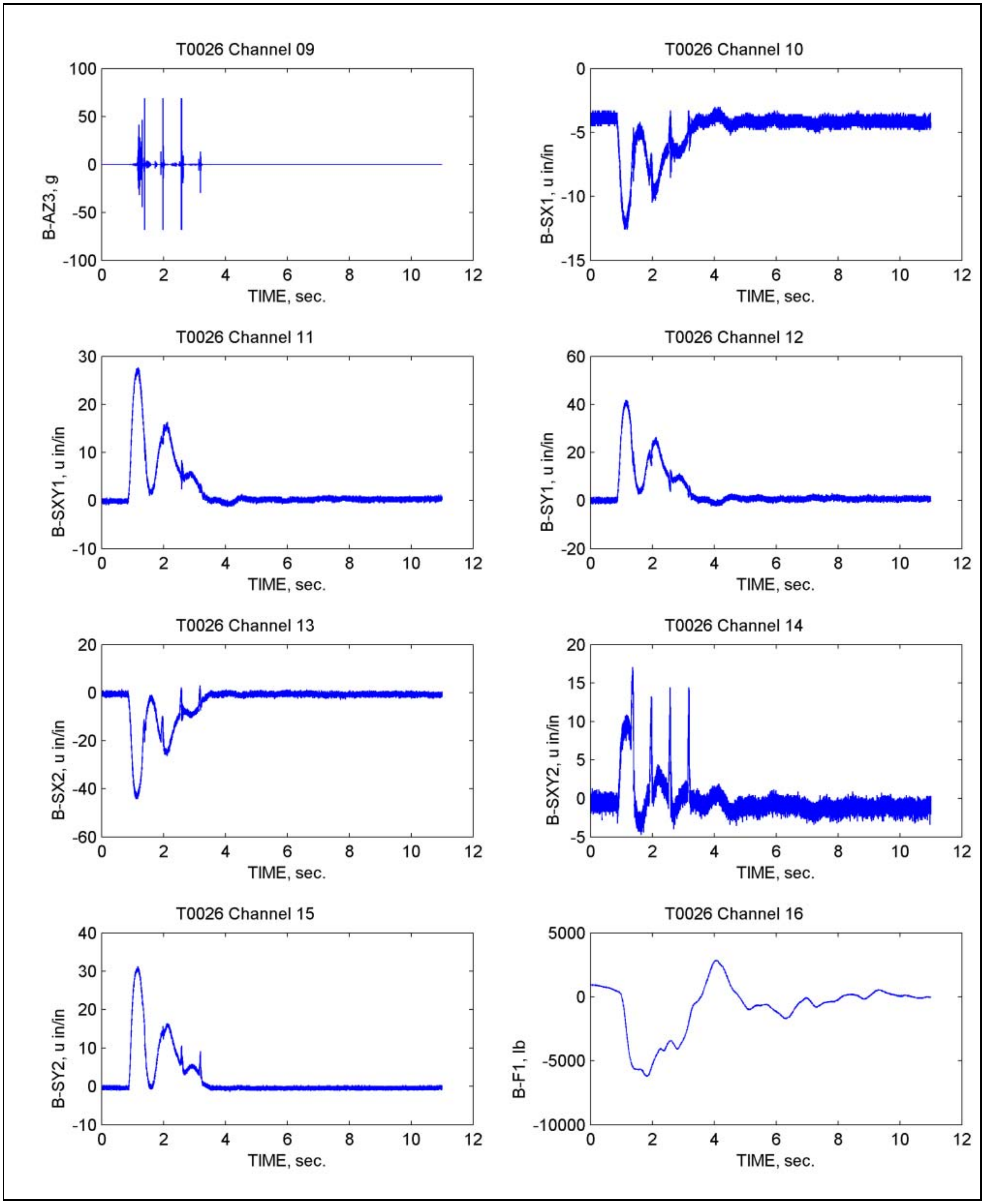


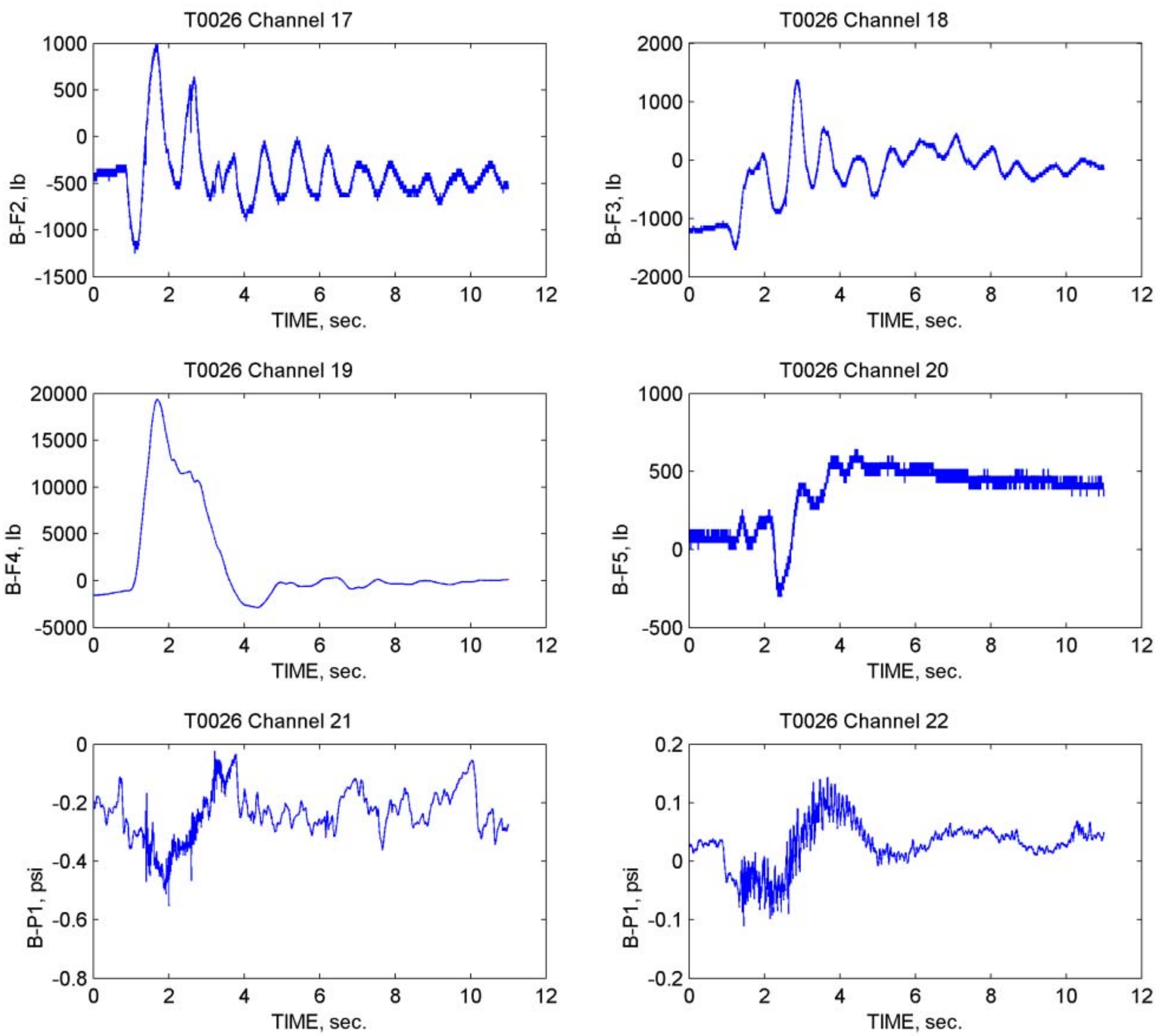
T0025 Channel 01
B-AX1, g
T0025 Channel 02
B-AY1, g
T0025 Channel 03
B-AZ1, g
T0025 Channel 04
B-AX2, g
T0025 Channel 05
B-AY2, g
T0025 Channel 06
B-AZ2, g
T0025 Channel 07
B-AX3, g
T0025 Channel 08
B-AY3, g
TIME, sec.

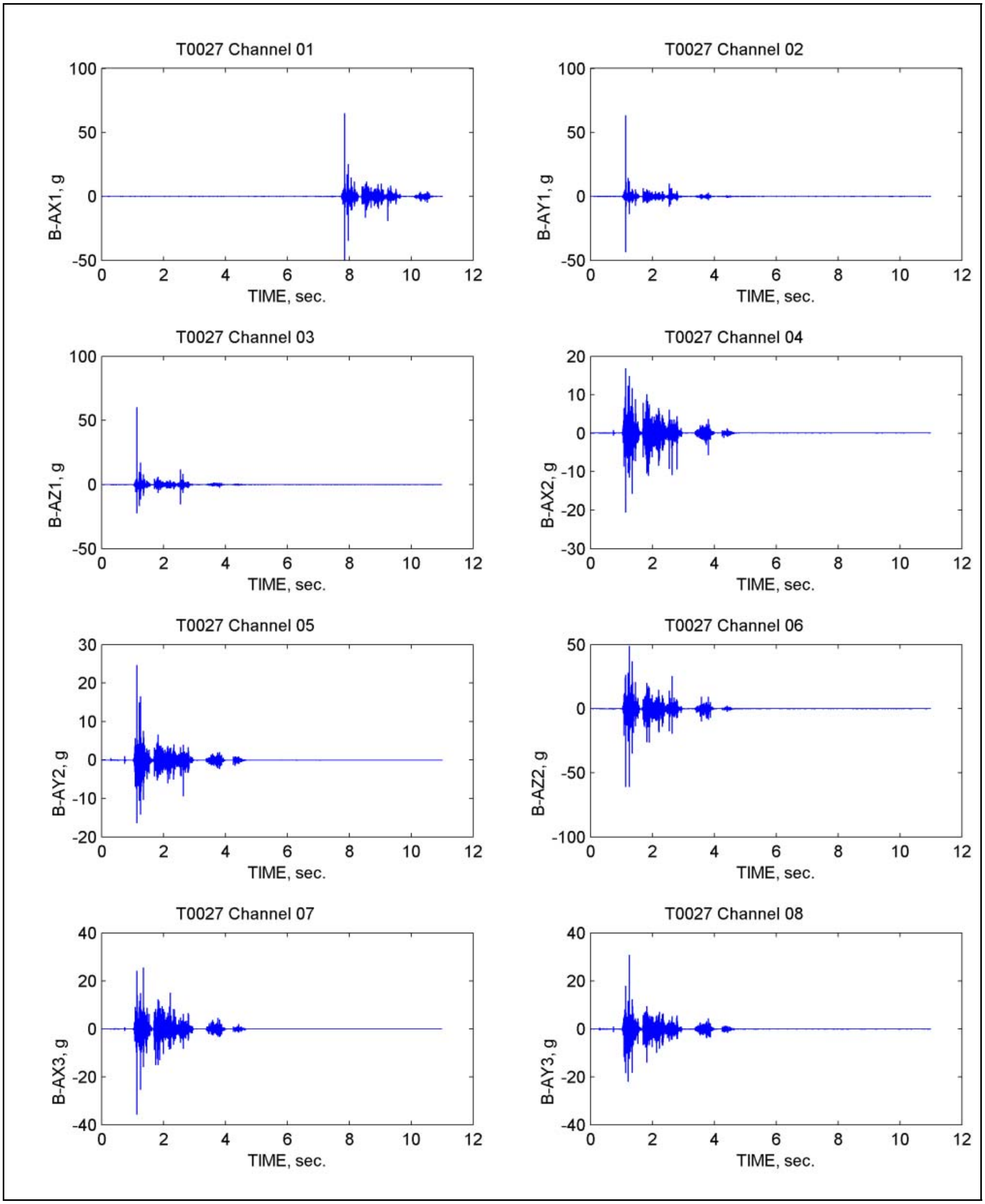

T0025 Channel 09
B-AZ3, g
TIME, sec.
T0025 Channel 10
B-SX1, u in/in
TIME, sec.
T0025 Channel 11
B-SXY1, u in/in
TIME, sec.
T0025 Channel 12
B-SY1, u in/in
TIME, sec.
T0025 Channel 13
B-SX2, u in/in
TIME, sec.
T0025 Channel 14
B-SXY2, u in/in
TIME, sec.
T0025 Channel 15
B-SY2, u in/in
TIME, sec.
T0025 Channel 16
B-F1, lb
TIME, sec.


T0025 Channel 17
B-F2, lb
TIME, sec.
T0025 Channel 18
B-F3, lb
TIME, sec.
T0025 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0025 Channel 20
B-F5, lb
TIME, sec.
T0025 Channel 21
B-P1, psi
TIME, sec.
T0025 Channel 22
B-P1, psi
TIME, sec.

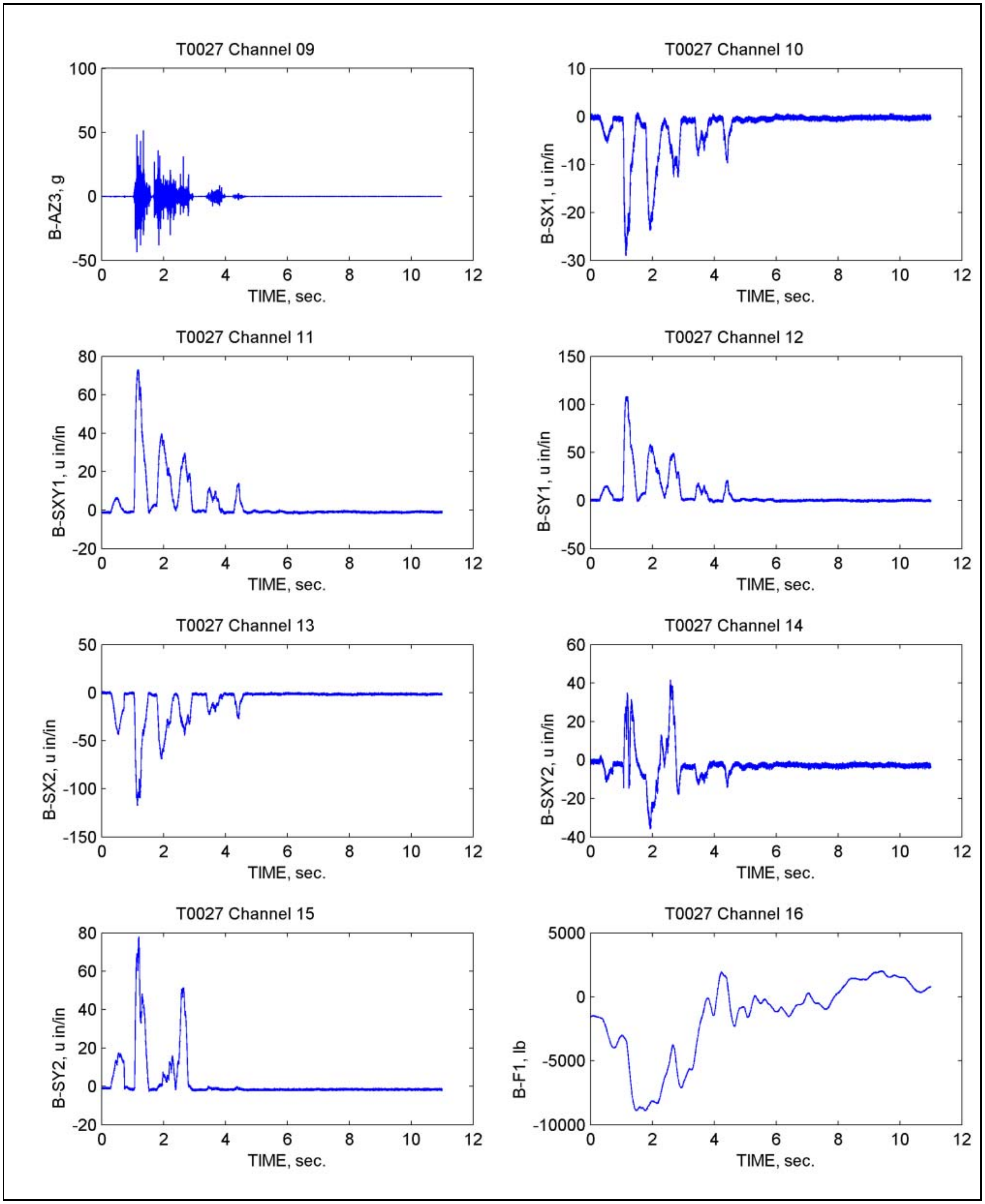

T0026 Channel 01
B-AX1, g
TIME, sec.
T0026 Channel 02
B-AY1, g
TIME, sec.
T0026 Channel 03
B-AZ1, g
TIME, sec.
T0026 Channel 04
B-AX2, g
TIME, sec.
T0026 Channel 05
B-AY2, g
TIME, sec.
T0026 Channel 06
B-AZ2, g
TIME, sec.
T0026 Channel 07
B-AX3, g
TIME, sec.
T0026 Channel 08
B-AY3, g
TIME, sec.

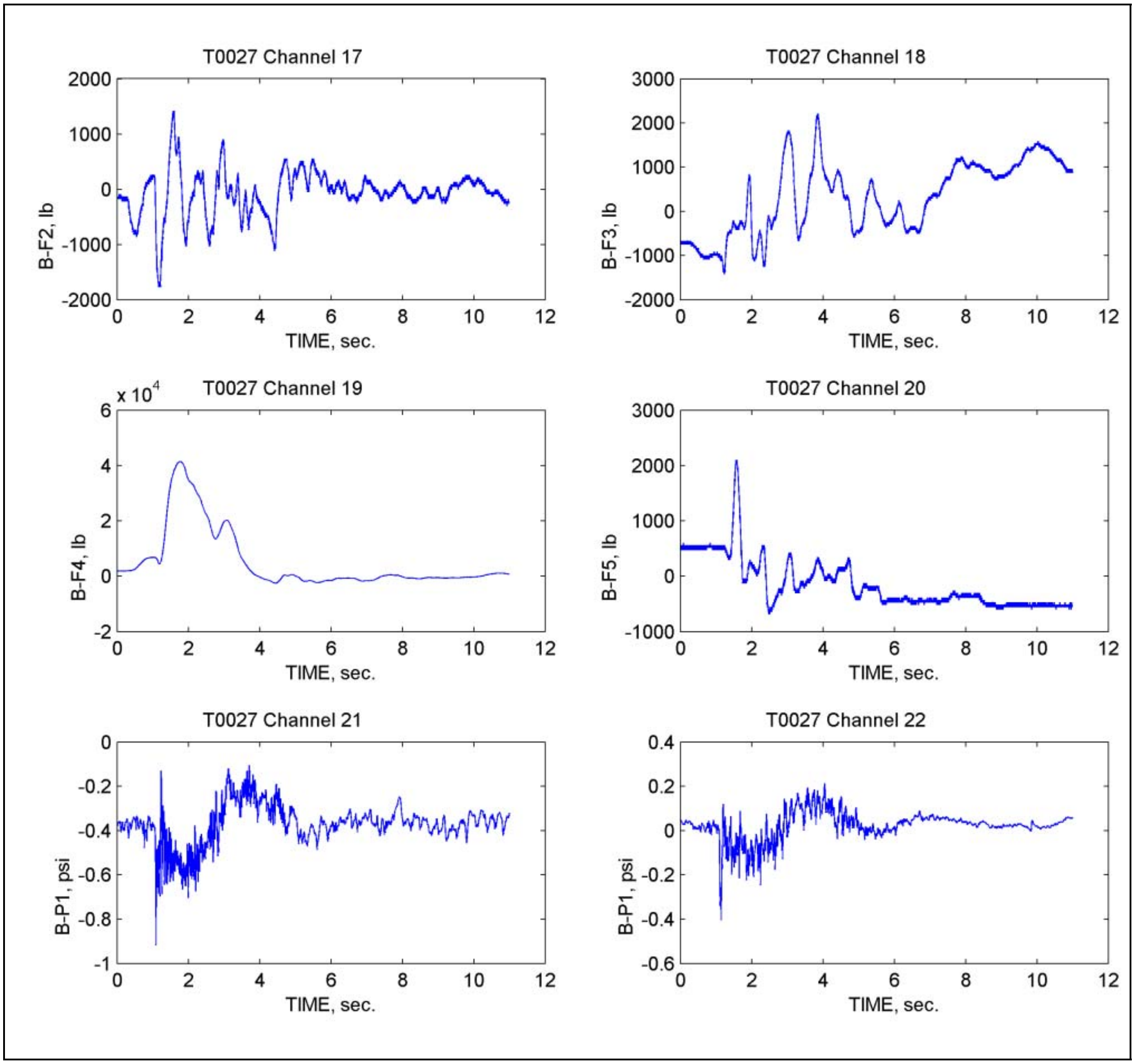

T0026 Channel 09
B-AZ3, g
TIME, sec.
T0026 Channel 10
B-SX1, u in/in
TIME, sec.
T0026 Channel 11
B-SXY1, u in/in
TIME, sec.
T0026 Channel 12
B-SY1, u in/in
TIME, sec.
T0026 Channel 13
B-SX2, u in/in
TIME, sec.
T0026 Channel 14
B-SXY2, u in/in
TIME, sec.
T0026 Channel 15
B-SY2, u in/in
TIME, sec.
T0026 Channel 16
B-F1, lb
TIME, sec.

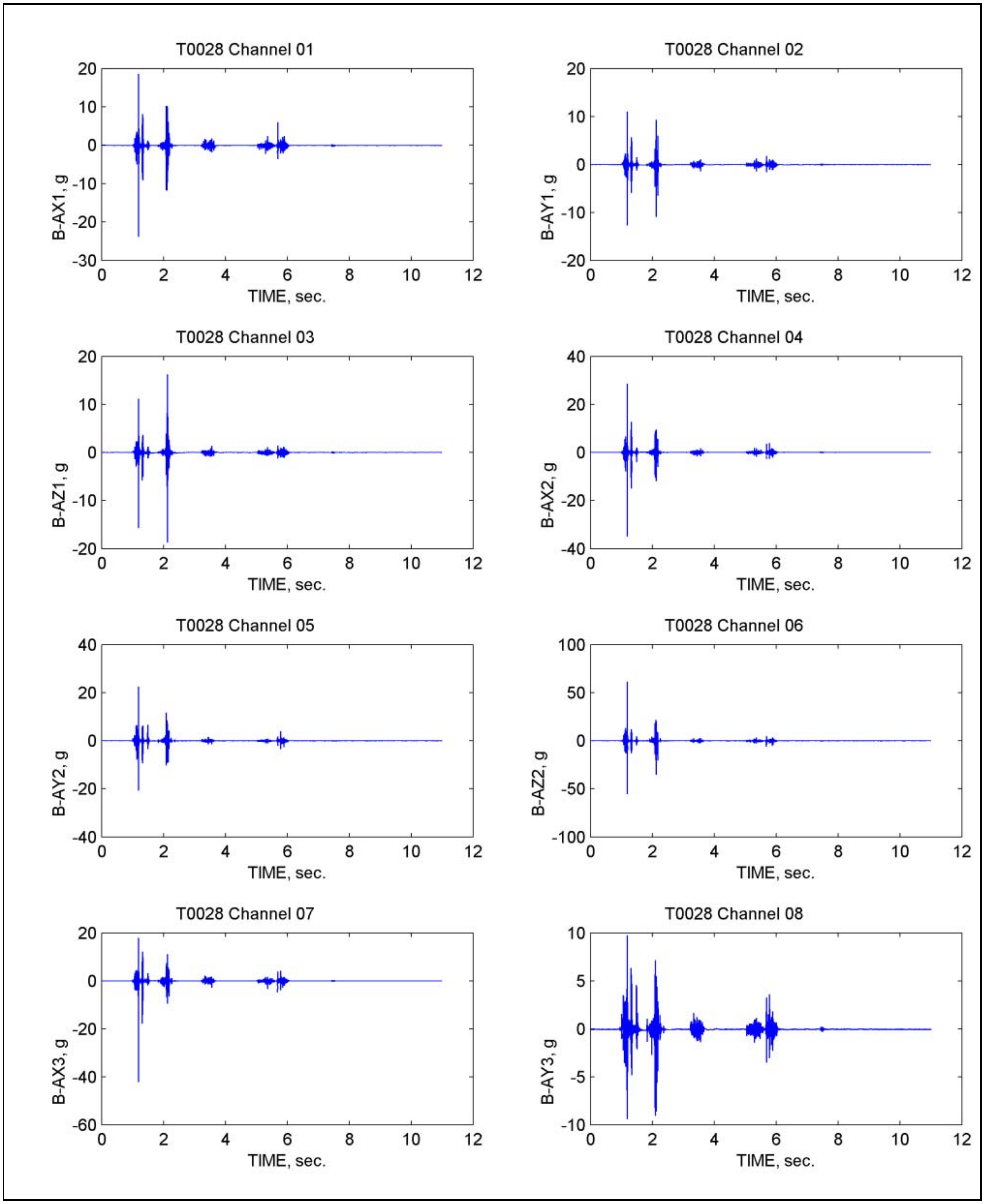

T0026 Channel 17
B-F2, lb
TIME, sec.
T0026 Channel 18
B-F3, lb
TIME, sec.
T0026 Channel 19
B-F4, lb
TIME, sec.
T0026 Channel 20
B-F5, lb
TIME, sec.
T0026 Channel 21
B-P1, psi
TIME, sec.
T0026 Channel 22
B-P1, psi
TIME, sec.

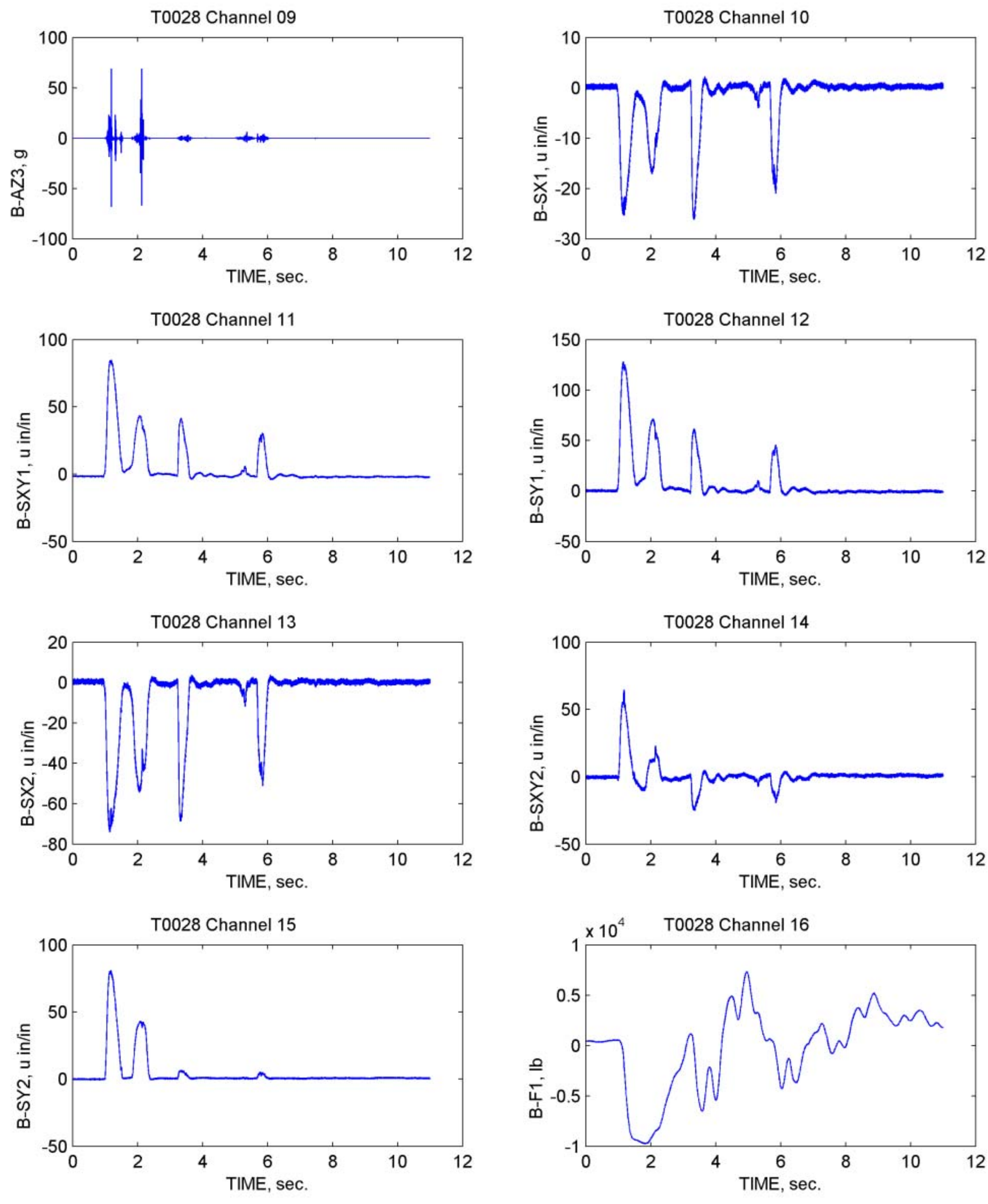


T0027 Channel 01
B-AX1, g
TIME, sec.
T0027 Channel 02
B-AY1, g
TIME, sec.
T0027 Channel 03
B-AZ1, g
TIME, sec.
T0027 Channel 04
B-AX2, g
TIME, sec.
T0027 Channel 05
B-AY2, g
TIME, sec.
T0027 Channel 06
B-AZ2, g
TIME, sec.
T0027 Channel 07
B-AX3, g
TIME, sec.
T0027 Channel 08
B-AY3, g
TIME, sec.

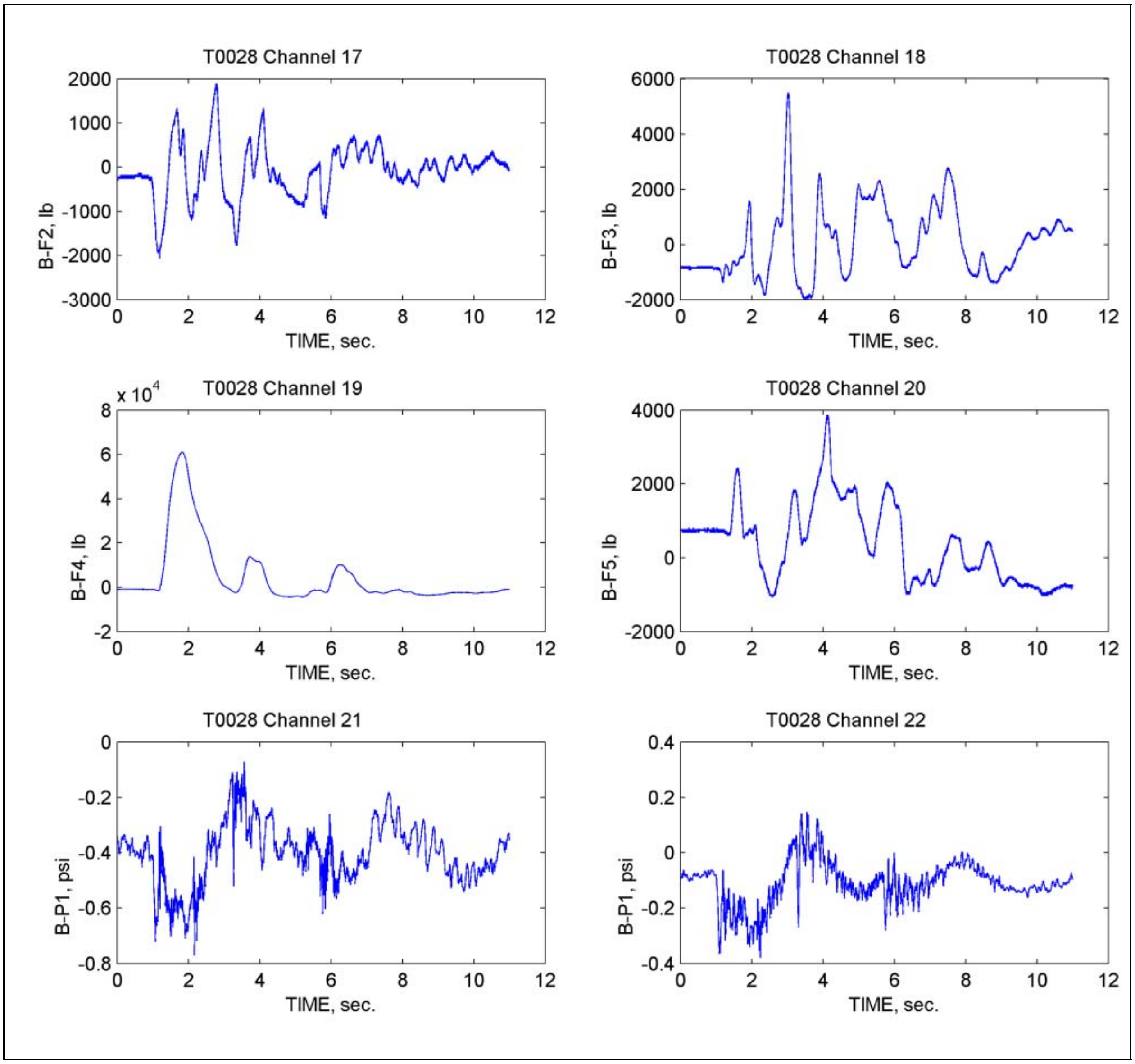

T0027 Channel 09
B-AZ3, g
TIME, sec.
T0027 Channel 10
B-SX1, u in/in
TIME, sec.
T0027 Channel 11
B-SXY1, u in/in
TIME, sec.
T0027 Channel 12
B-SY1, u in/in
TIME, sec.
T0027 Channel 13
B-SX2, u in/in
TIME, sec.
T0027 Channel 14
B-SXY2, u in/in
TIME, sec.
T0027 Channel 15
B-SY2, u in/in
TIME, sec.
T0027 Channel 16
B-F1, lb
TIME, sec.

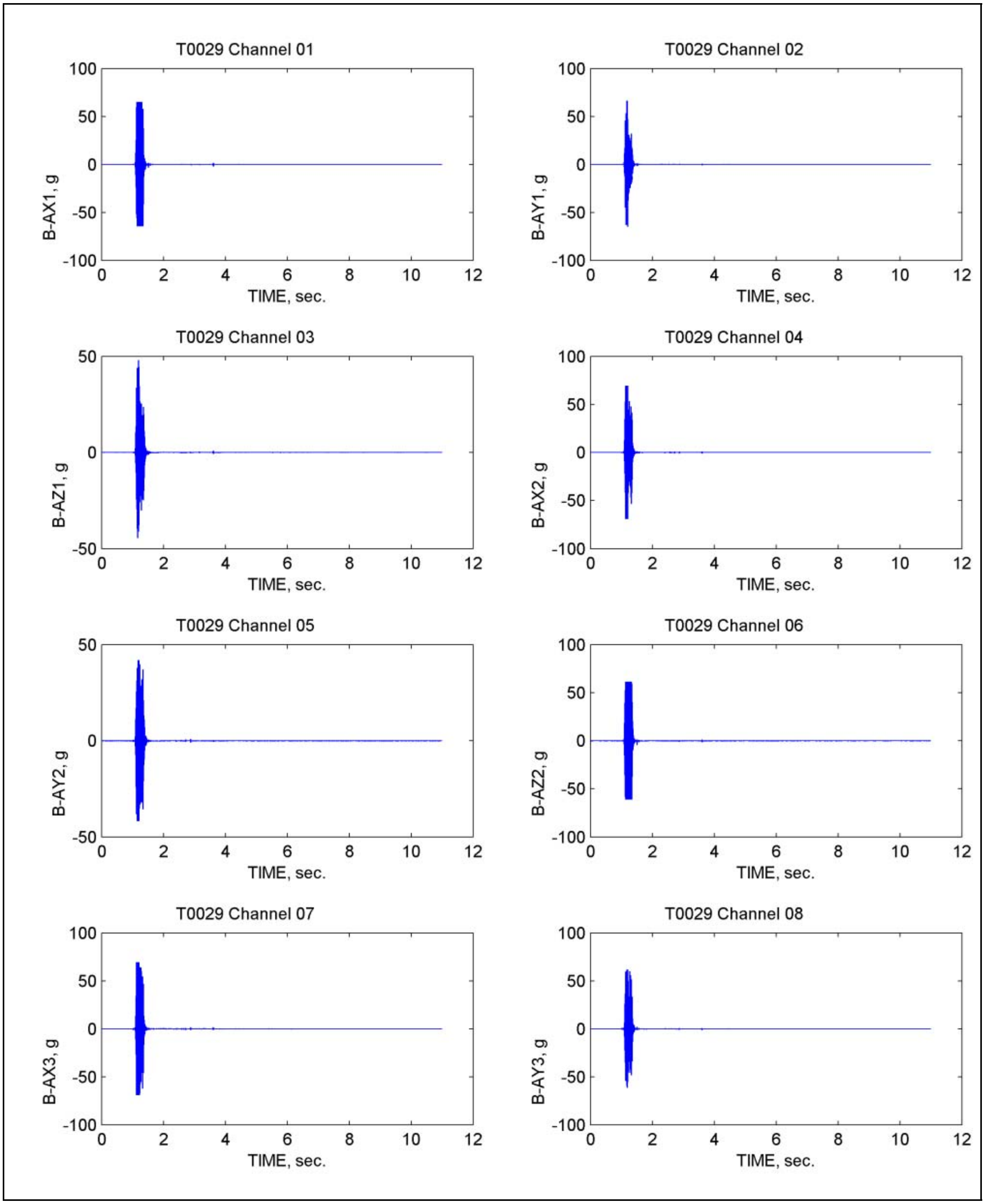

T0027 Channel 17
B-F2, lb
TIME, sec.
T0027 Channel 18
B-F3, lb
TIME, sec.
T0027 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0027 Channel 20
B-F5, lb
TIME, sec.
T0027 Channel 21
B-P1, psi
TIME, sec.
T0027 Channel 22
B-P1, psi
TIME, sec.

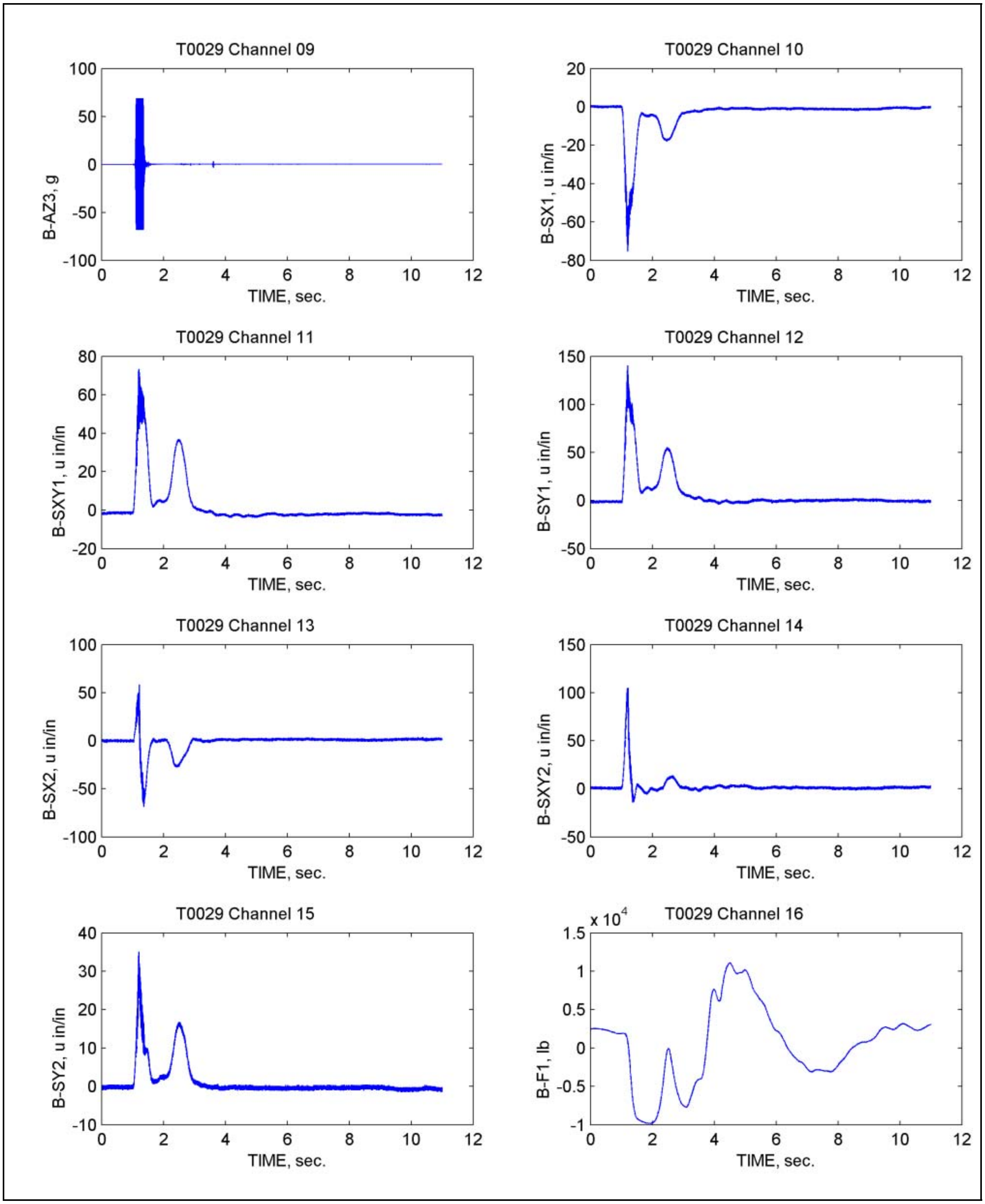

T0028 Channel 01
B-AX1, g
TIME, sec.
T0028 Channel 02
B-AY1, g
TIME, sec.
T0028 Channel 03
B-AZ1, g
TIME, sec.
T0028 Channel 04
B-AX2, g
TIME, sec.
T0028 Channel 05
B-AY2, g
TIME, sec.
T0028 Channel 06
B-AZ2, g
TIME, sec.
T0028 Channel 07
B-AX3, g
TIME, sec.
T0028 Channel 08
B-AY3, g
TIME, sec.

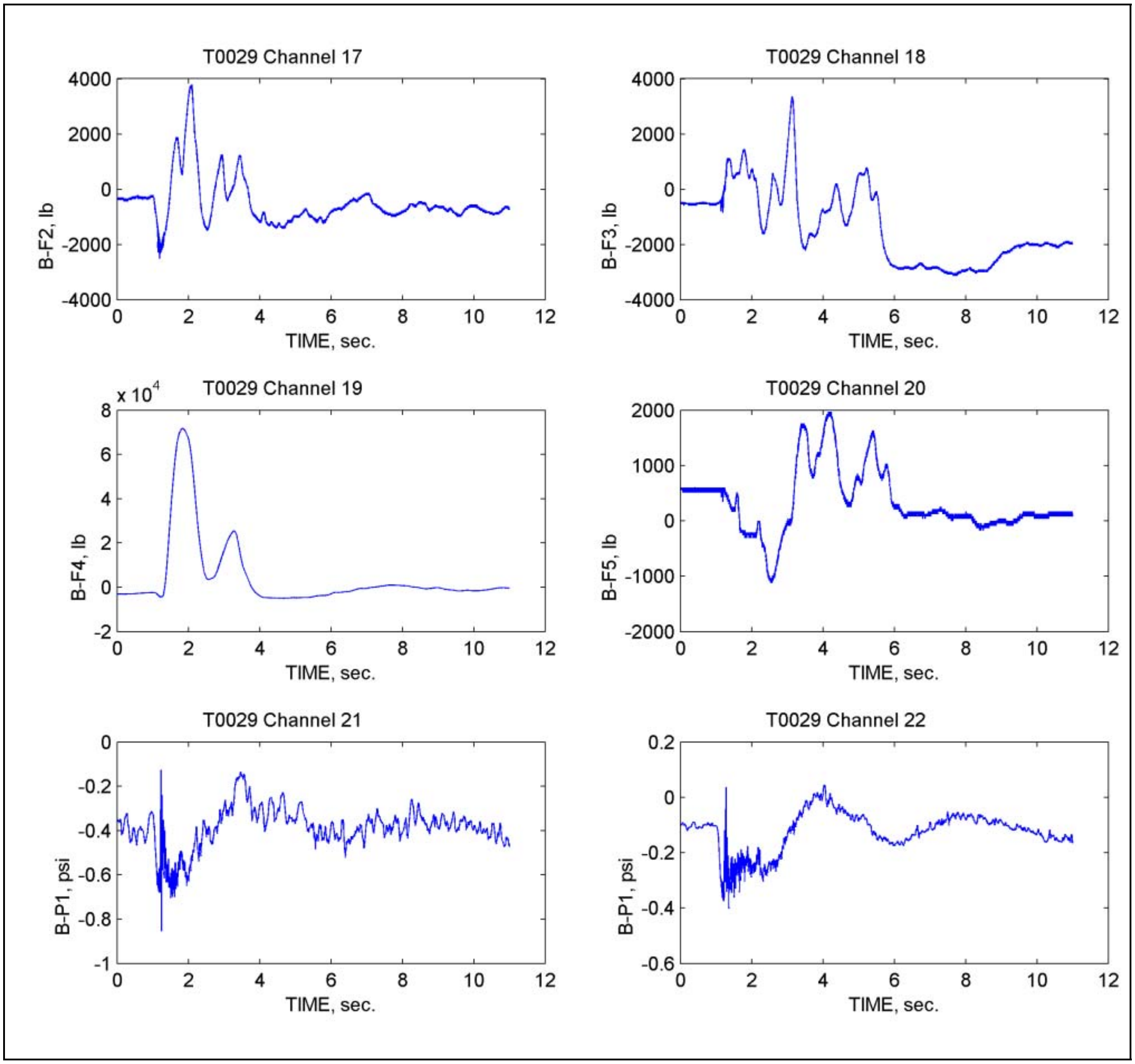


T0028 Channel 09
B-AZ3, g
TIME, sec.
T0028 Channel 10
B-SX1, u in/in
TIME, sec.
T0028 Channel 11
B-SXY1, u in/in
TIME, sec.
T0028 Channel 12
B-SY1, u in/in
TIME, sec.
T0028 Channel 13
B-SX2, u in/in
TIME, sec.
T0028 Channel 14
B-SXY2, u in/in
TIME, sec.
T0028 Channel 15
B-SY2, u in/in
TIME, sec.
T0028 Channel 16
x 10^4
B-F1, lb
TIME, sec.

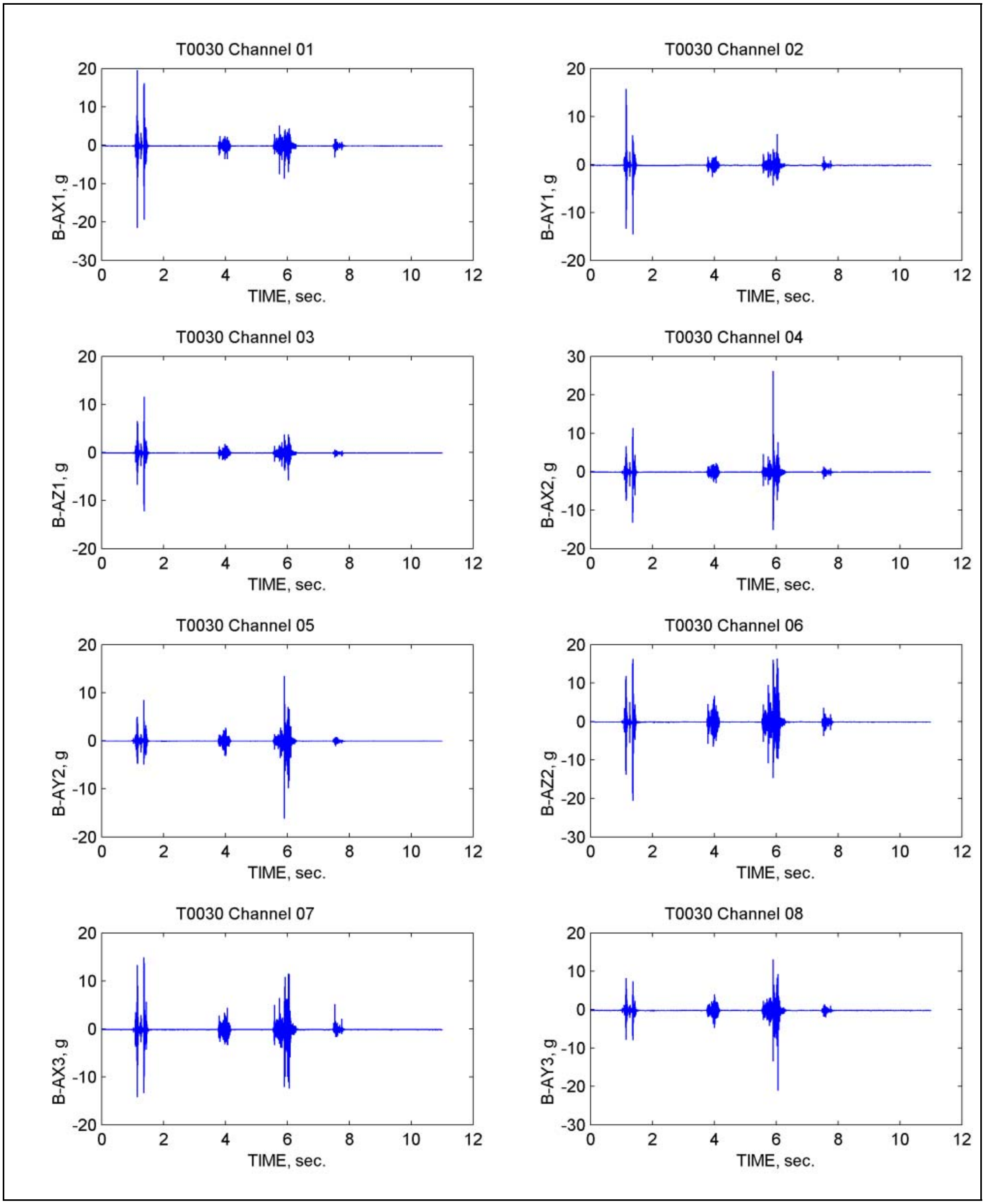

T0028 Channel 17
B-F2, lb
TIME, sec.
T0028 Channel 18
B-F3, lb
TIME, sec.
T0028 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0028 Channel 20
B-F5, lb
TIME, sec.
T0028 Channel 21
B-P1, psi
TIME, sec.
T0028 Channel 22
B-P1, psi
TIME, sec.

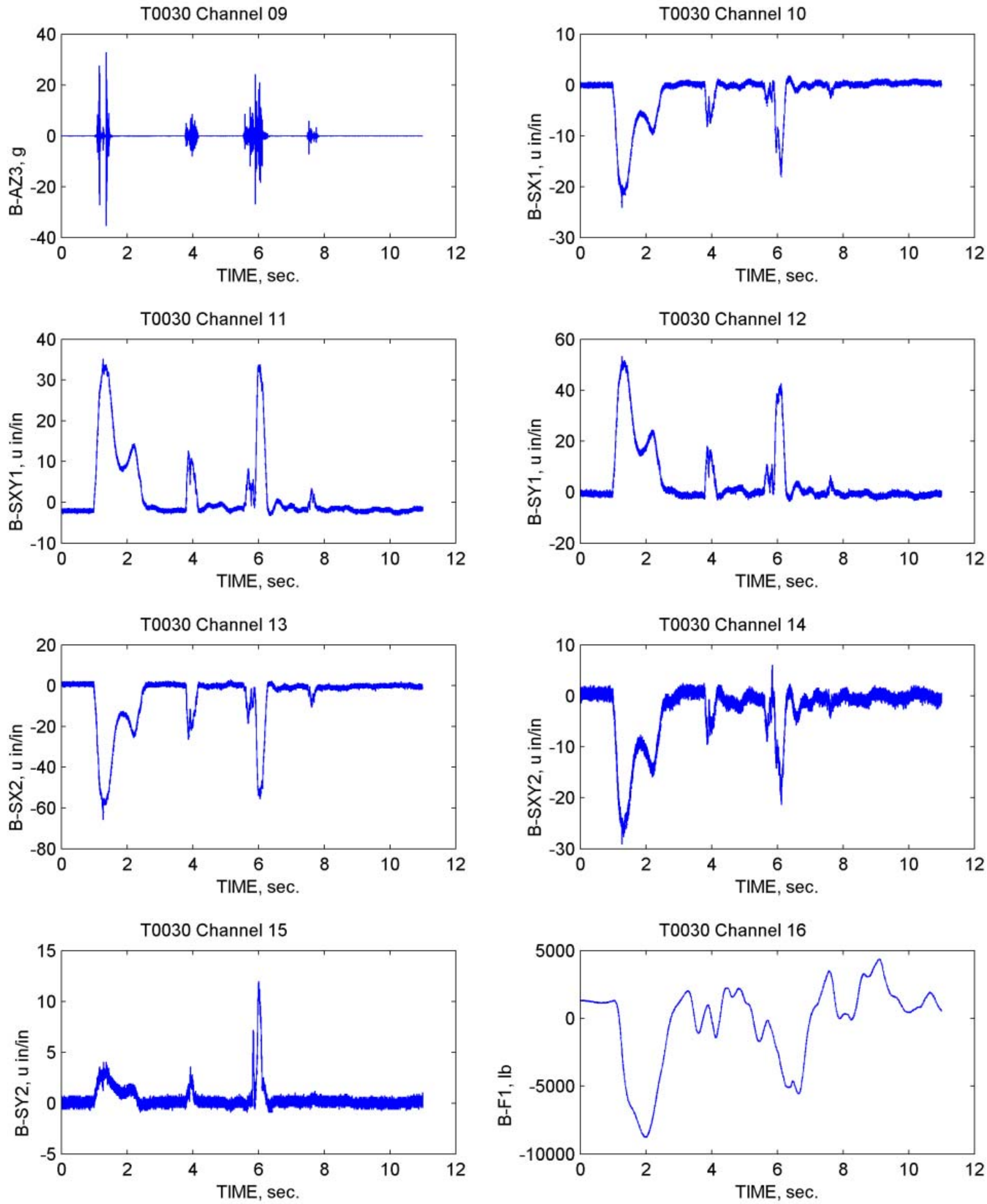

T0029 Channel 01
B-AX1, g
TIME, sec.
T0029 Channel 02
B-AY1, g
TIME, sec.
T0029 Channel 03
B-AZ1, g
TIME, sec.
T0029 Channel 04
B-AX2, g
TIME, sec.
T0029 Channel 05
B-AY2, g
TIME, sec.
T0029 Channel 06
B-AZ2, g
TIME, sec.
T0029 Channel 07
B-AX3, g
TIME, sec.
T0029 Channel 08
B-AY3, g
TIME, sec.


T0029 Channel 09
B-AZ3, g
TIME, sec.
T0029 Channel 10
B-SX1, u in/in
TIME, sec.
T0029 Channel 11
B-SXY1, u in/in
TIME, sec.
T0029 Channel 12
B-SY1, u in/in
TIME, sec.
T0029 Channel 13
B-SX2, u in/in
TIME, sec.
T0029 Channel 14
B-SXY2, u in/in
TIME, sec.
T0029 Channel 15
B-SY2, u in/in
TIME, sec.
x 10^4
T0029 Channel 16
B-F1, lb
TIME, sec.

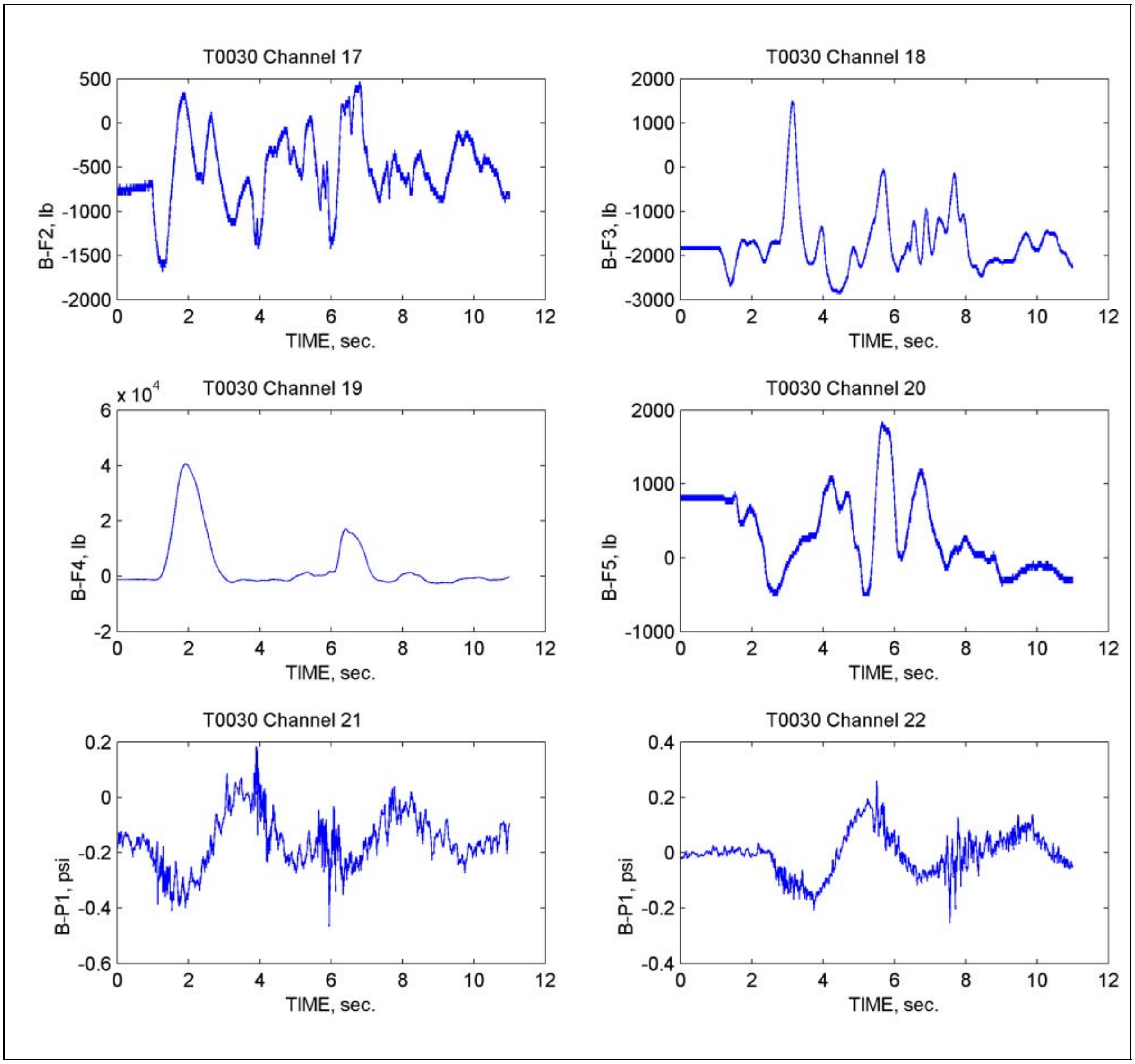


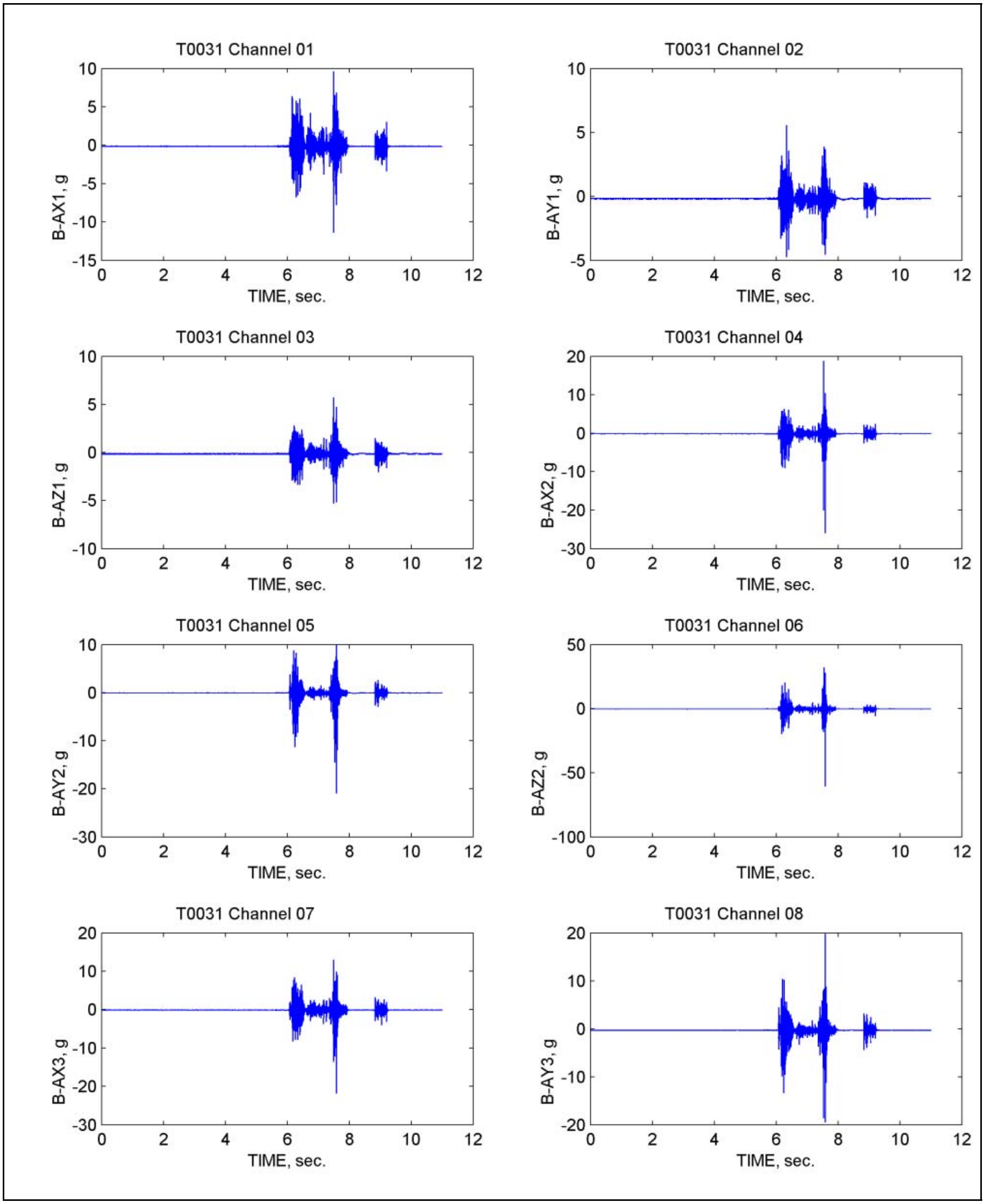
T0029 Channel 17
B-F2, lb
TIME, sec.
T0029 Channel 18
B-F3, lb
TIME, sec.
T0029 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0029 Channel 20
B-F5, lb
TIME, sec.
T0029 Channel 21
B-P1, psi
TIME, sec.
T0029 Channel 22
B-P1, psi
TIME, sec.

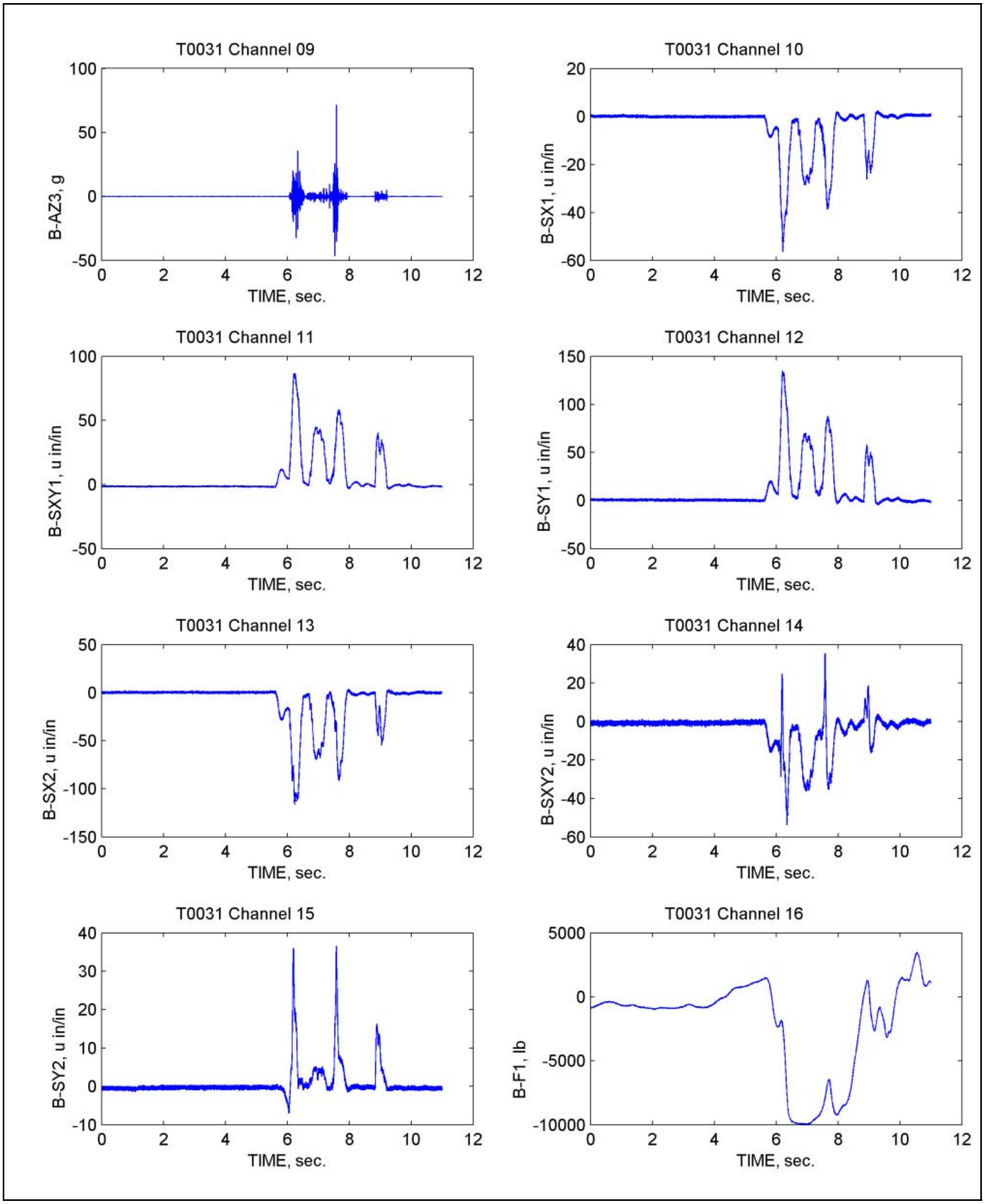

T0030 Channel 01
B-AX1, g
TIME, sec.
T0030 Channel 02
B-AY1, g
TIME, sec.
T0030 Channel 03
B-AZ1, g
TIME, sec.
T0030 Channel 04
B-AX2, g
TIME, sec.
T0030 Channel 05
B-AY2, g
TIME, sec.
T0030 Channel 06
B-AZ2, g
TIME, sec.
T0030 Channel 07
B-AX3, g
TIME, sec.
T0030 Channel 08
B-AY3, g
TIME, sec.

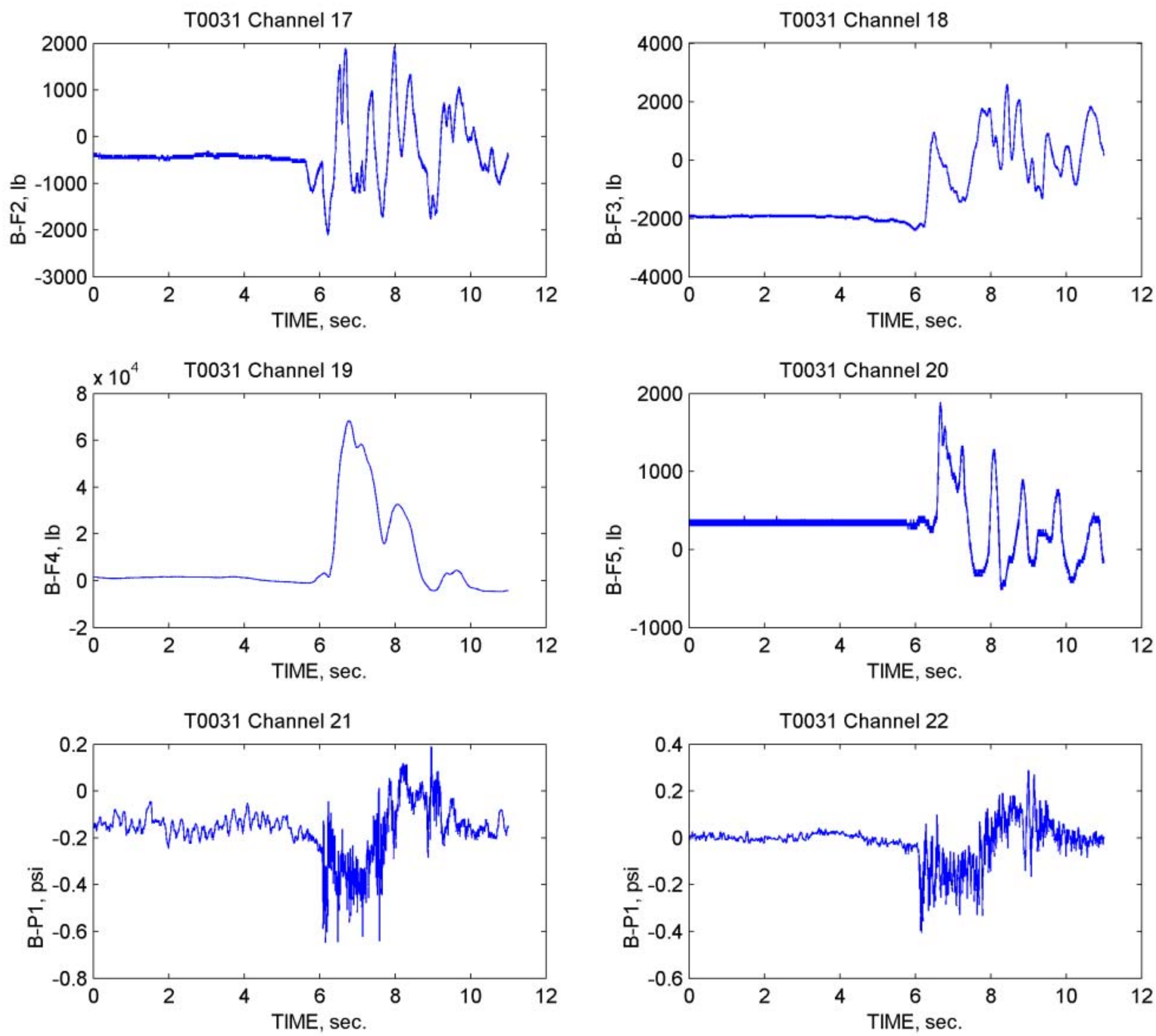


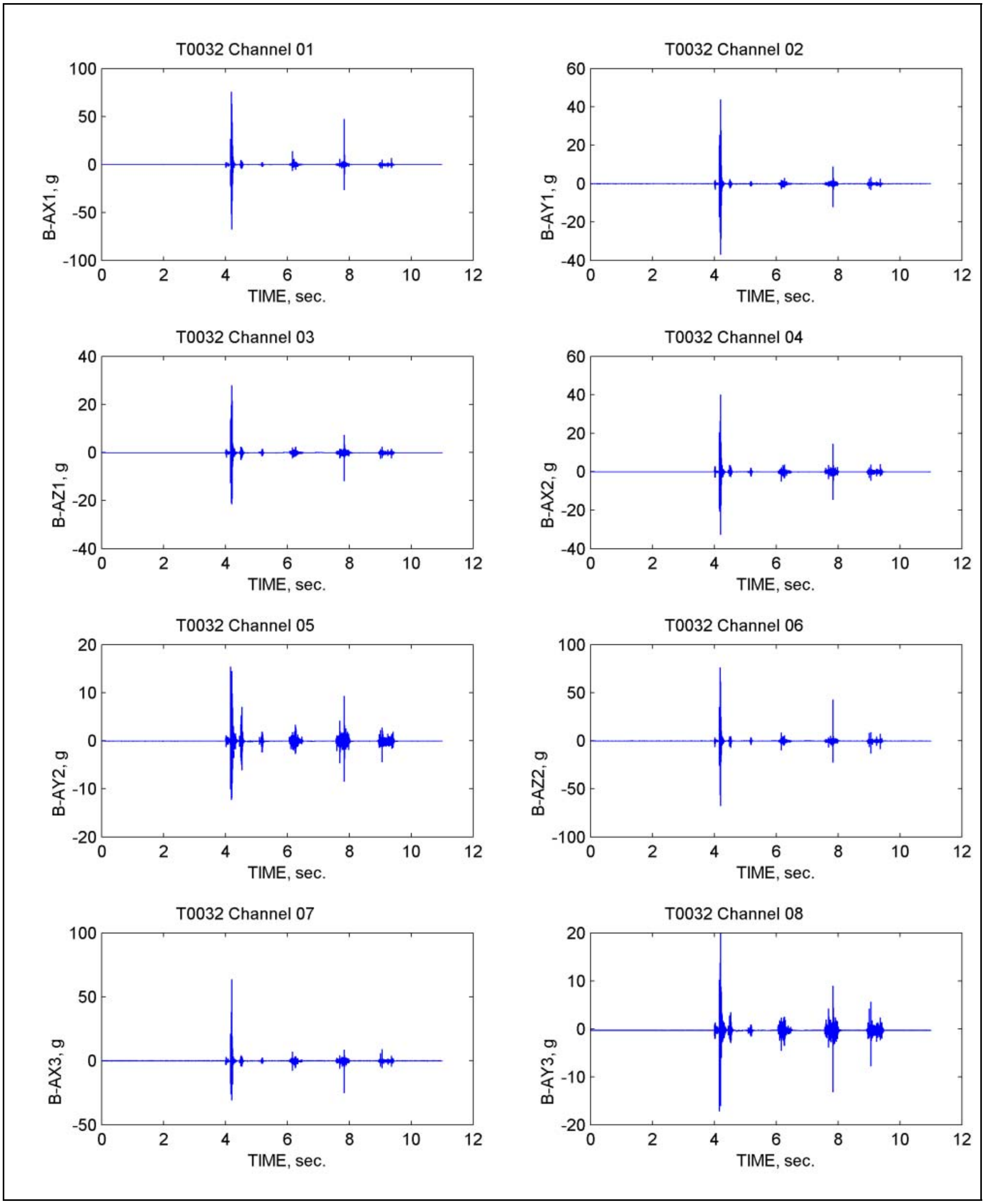
T0030 Channel 09
B-AZ3, g
TIME, sec.
T0030 Channel 10
B-SX1, u in/in
TIME, sec.
T0030 Channel 11
B-SXY1, u in/in
TIME, sec.
T0030 Channel 12
B-SY1, u in/in
TIME, sec.
T0030 Channel 13
B-SX2, u in/in
TIME, sec.
T0030 Channel 14
B-SXY2, u in/in
TIME, sec.
T0030 Channel 15
B-SY2, u in/in
TIME, sec.
T0030 Channel 16
B-F1, lb
TIME, sec.

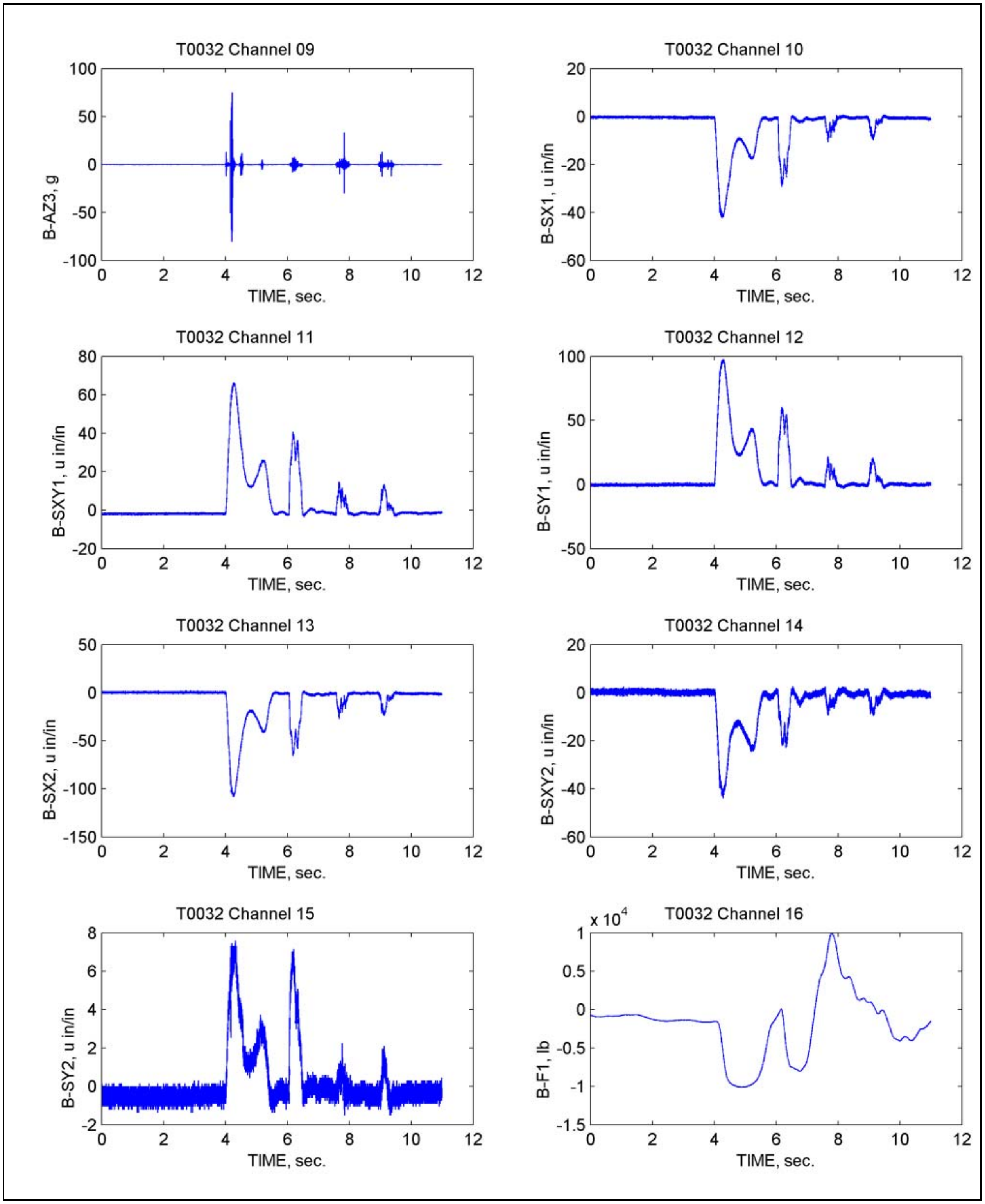

T0030 Channel 17
B-F2, lb
TIME, sec.
T0030 Channel 18
B-F3, lb
TIME, sec.
T0030 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0030 Channel 20
B-F5, lb
TIME, sec.
T0030 Channel 21
B-P1, psi
TIME, sec.
T0030 Channel 22
B-P1, psi
TIME, sec.

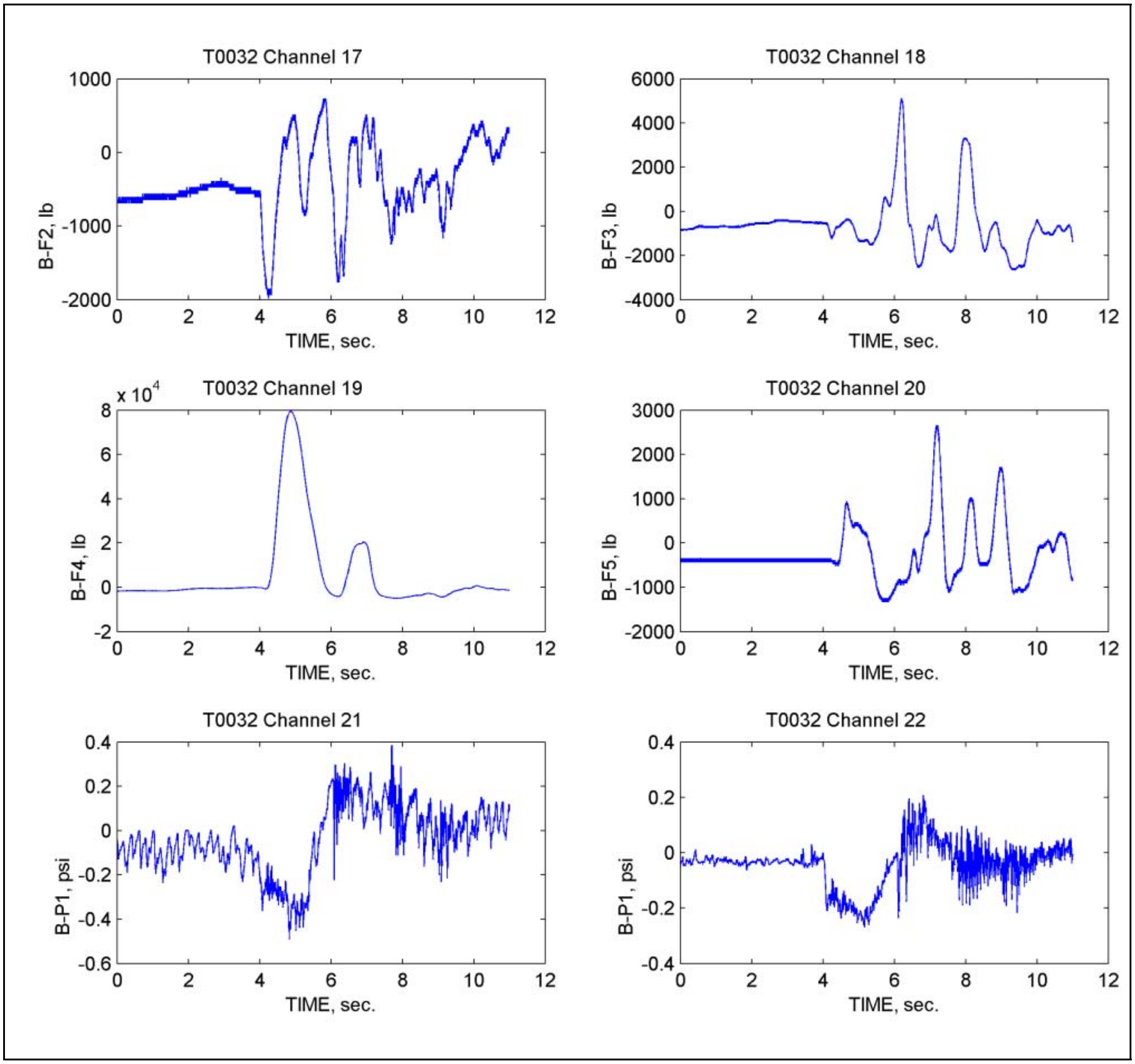

T0031 Channel 01
B-AX1, g
TIME, sec.
T0031 Channel 02
B-AY1, g
TIME, sec.
T0031 Channel 03
B-AZ1, g
TIME, sec.
T0031 Channel 04
B-AX2, g
TIME, sec.
T0031 Channel 05
B-AY2, g
TIME, sec.
T0031 Channel 06
B-AZ2, g
TIME, sec.
T0031 Channel 07
B-AX3, g
TIME, sec.
T0031 Channel 08
B-AY3, g
TIME, sec.

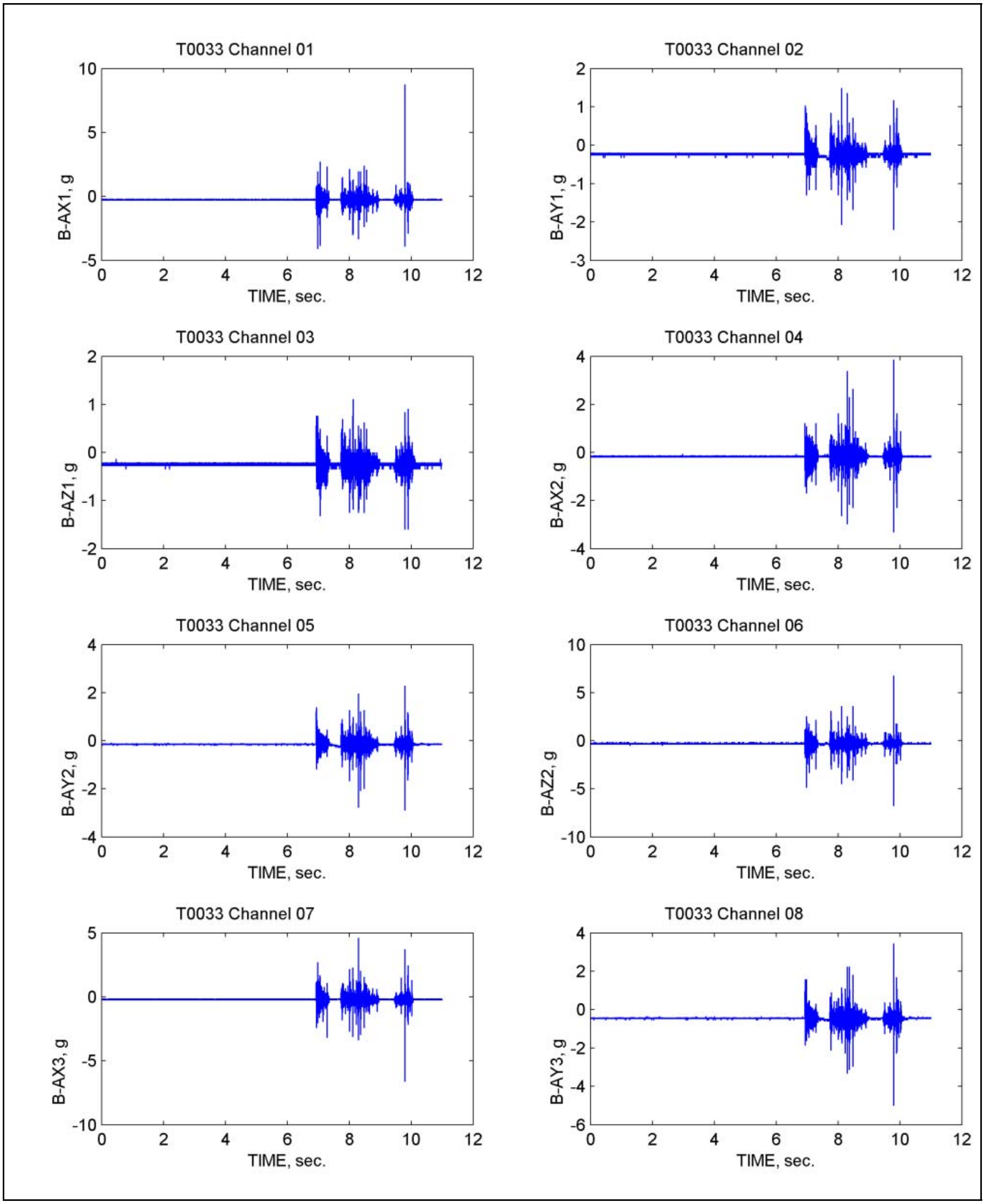

T0031 Channel 09
B-AZ3, g
TIME, sec.
T0031 Channel 10
B-SX1, u in/in
TIME, sec.
T0031 Channel 11
B-SXY1, u in/in
TIME, sec.
T0031 Channel 12
B-SY1, u in/in
TIME, sec.
T0031 Channel 13
B-SX2, u in/in
TIME, sec.
T0031 Channel 14
B-SXY2, u in/in
TIME, sec.
T0031 Channel 15
B-SY2, u in/in
TIME, sec.
T0031 Channel 16
B-F1, lb
TIME, sec.

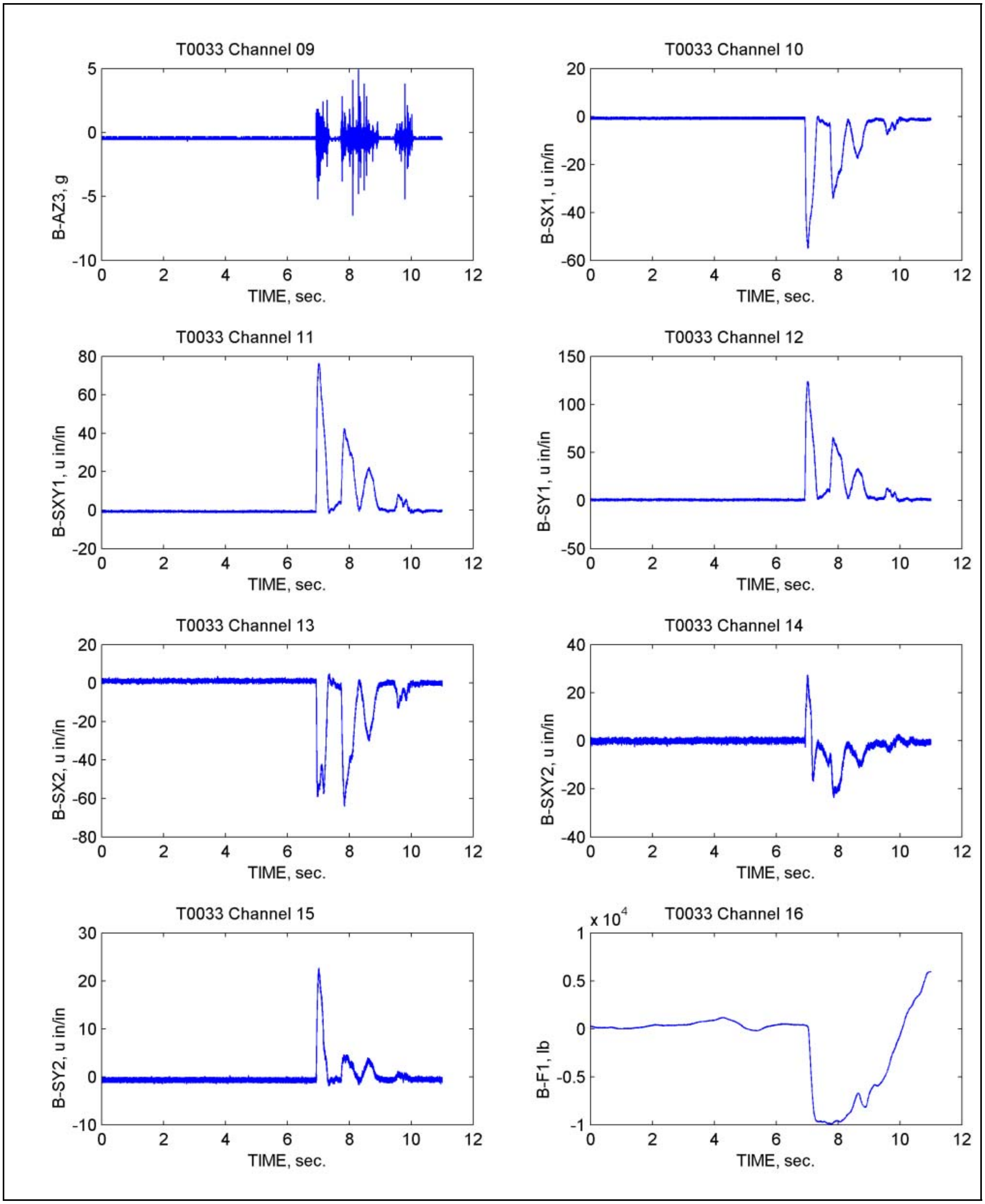

T0031 Channel 17
B-F2, lb
TIME, sec.
T0031 Channel 18
B-F3, lb
TIME, sec.
T0031 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0031 Channel 20
B-F5, lb
TIME, sec.
T0031 Channel 21
B-P1, psi
TIME, sec.
T0031 Channel 22
B-P1, psi
TIME, sec.


T0032 Channel 01
B-AX1, g
TIME, sec.
T0032 Channel 02
B-AY1, g
TIME, sec.
T0032 Channel 03
B-AZ1, g
TIME, sec.
T0032 Channel 04
B-AX2, g
TIME, sec.
T0032 Channel 05
B-AY2, g
TIME, sec.
T0032 Channel 06
B-AZ2, g
TIME, sec.
T0032 Channel 07
B-AX3, g
TIME, sec.
T0032 Channel 08
B-AY3, g
TIME, sec.

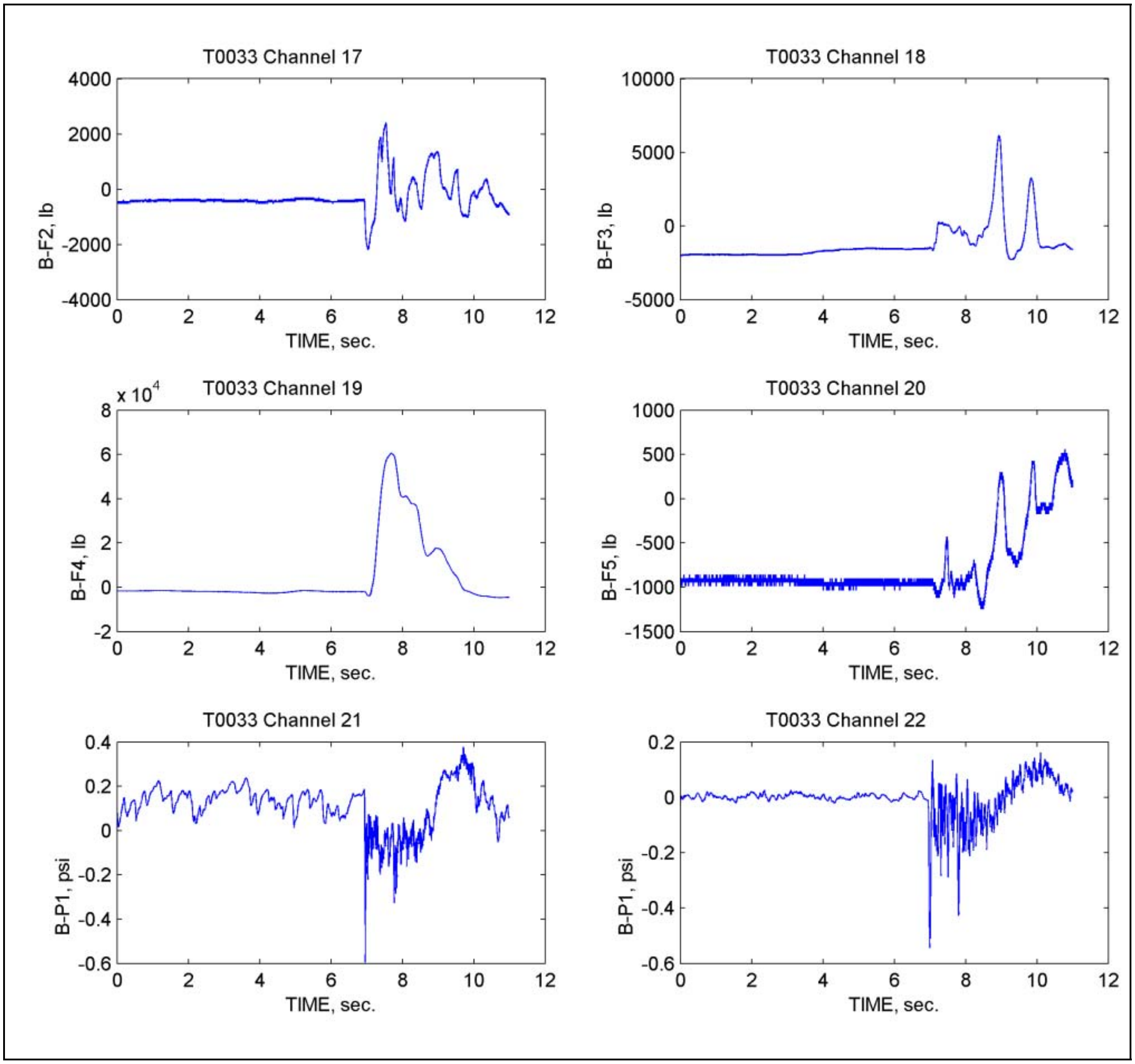

T0032 Channel 09
B-AZ3, g
TIME, sec.
T0032 Channel 10
B-SX1, u in/in
TIME, sec.
T0032 Channel 11
B-SXY1, u in/in
TIME, sec.
T0032 Channel 12
B-SY1, u in/in
TIME, sec.
T0032 Channel 13
B-SX2, u in/in
TIME, sec.
T0032 Channel 14
B-SXY2, u in/in
TIME, sec.
T0032 Channel 15
B-SY2, u in/in
TIME, sec.
T0032 Channel 16
x 10^4
B-F1, lb
TIME, sec.

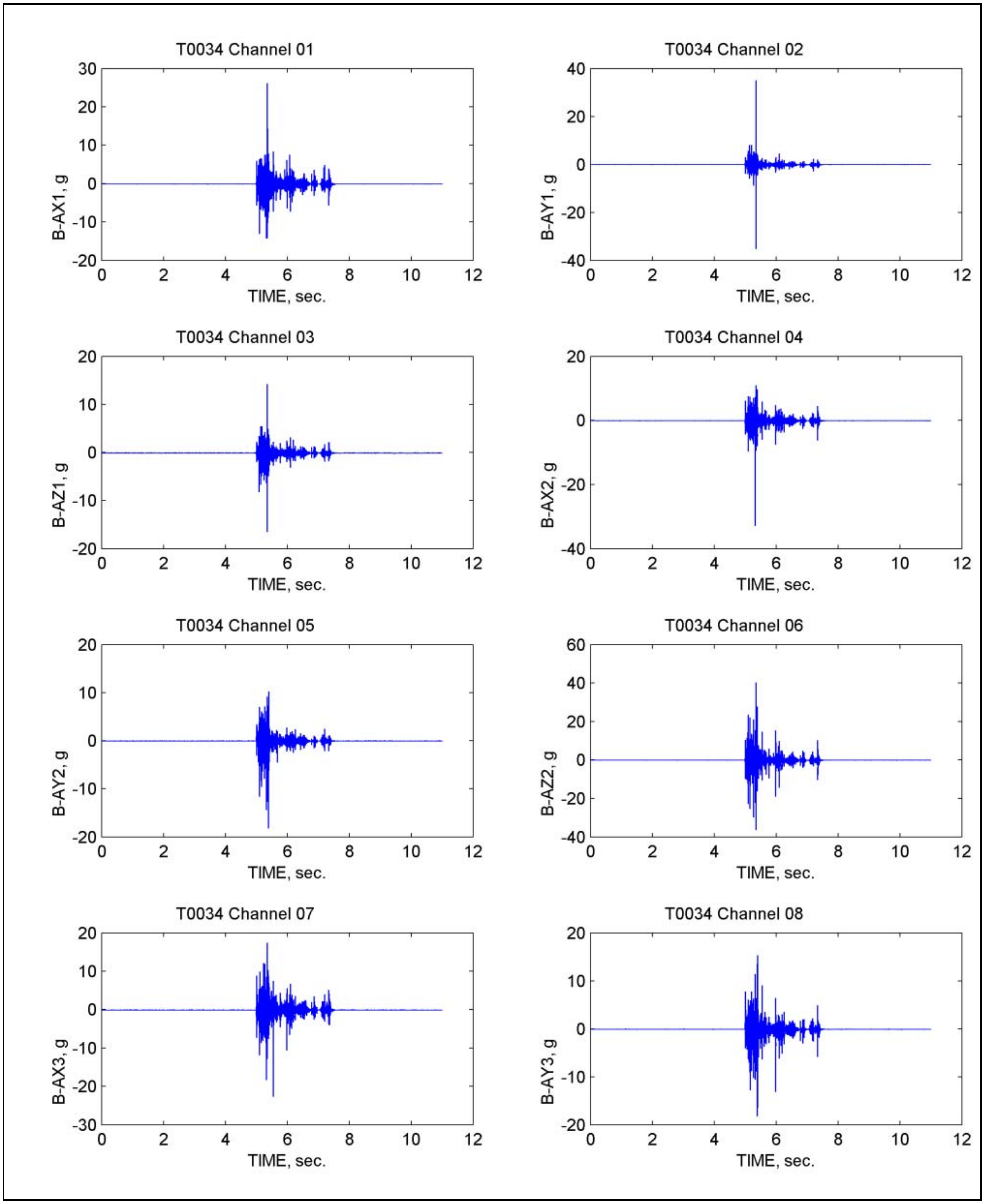

T0032 Channel 17
B-F2, lb
TIME, sec.
T0032 Channel 18
B-F3, lb
TIME, sec.
T0032 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0032 Channel 20
B-F5, lb
TIME, sec.
T0032 Channel 21
B-P1, psi
TIME, sec.
T0032 Channel 22
B-P1, psi
TIME, sec.

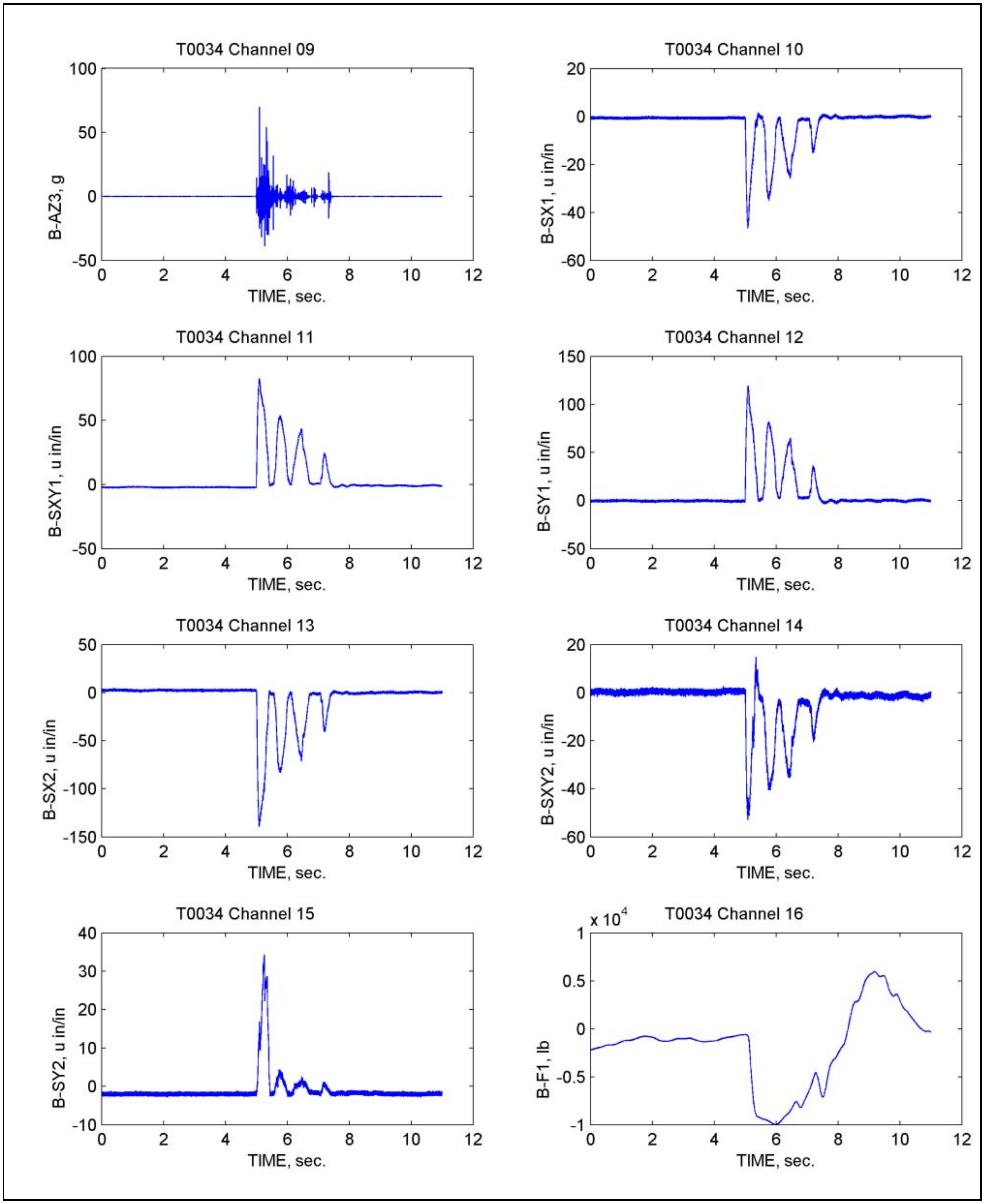

T0033 Channel 01
B-AX1, g
TIME, sec.
T0033 Channel 02
B-AY1, g
TIME, sec.
T0033 Channel 03
B-AZ1, g
TIME, sec.
T0033 Channel 04
B-AX2, g
TIME, sec.
T0033 Channel 05
B-AY2, g
TIME, sec.
T0033 Channel 06
B-AZ2, g
TIME, sec.
T0033 Channel 07
B-AX3, g
TIME, sec.
T0033 Channel 08
B-AY3, g
TIME, sec.

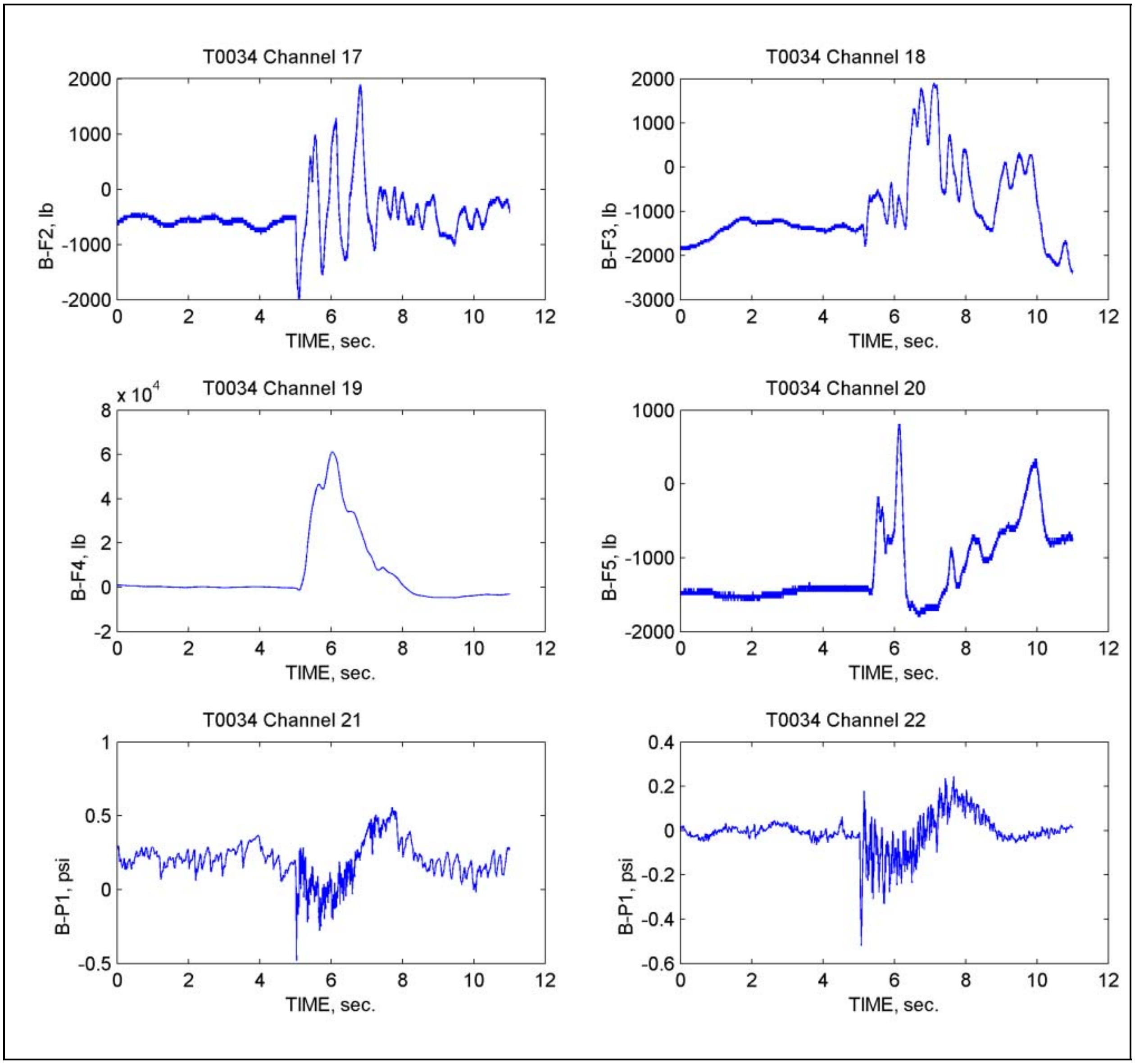


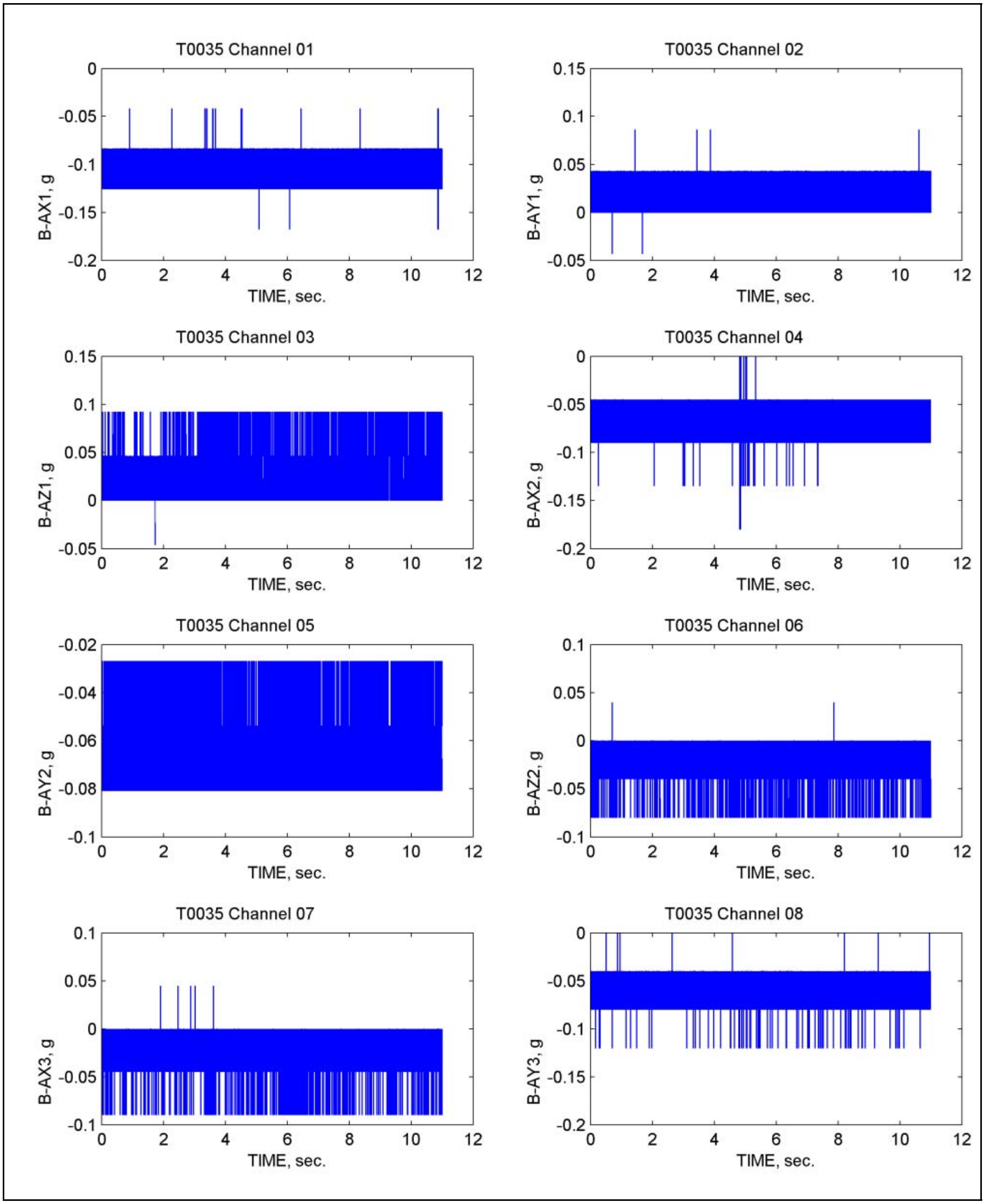
T0033 Channel 09
B-AZ3, g
TIME, sec.
T0033 Channel 10
B-SX1, u in/in
TIME, sec.
T0033 Channel 11
B-SXY1, u in/in
TIME, sec.
T0033 Channel 12
B-SY1, u in/in
TIME, sec.
T0033 Channel 13
B-SX2, u in/in
TIME, sec.
T0033 Channel 14
B-SXY2, u in/in
TIME, sec.
T0033 Channel 15
B-SY2, u in/in
TIME, sec.
T0033 Channel 16
x 10^4
B-F1, lb
TIME, sec.

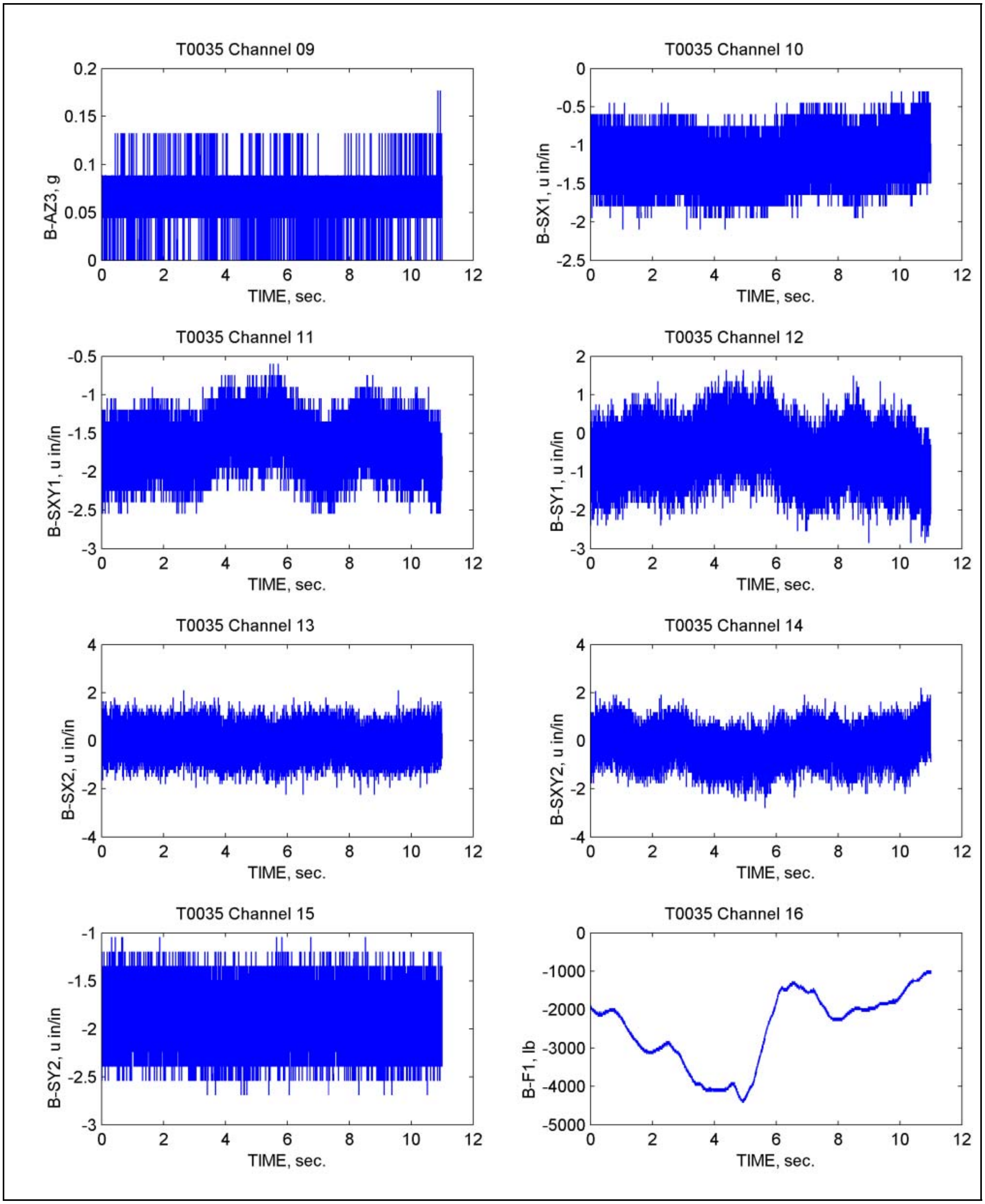

T0033 Channel 17
B-F2, lb
TIME, sec.
T0033 Channel 18
B-F3, lb
TIME, sec.
T0033 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0033 Channel 20
B-F5, lb
TIME, sec.
T0033 Channel 21
B-P1, psi
TIME, sec.
T0033 Channel 22
B-P1, psi
TIME, sec.

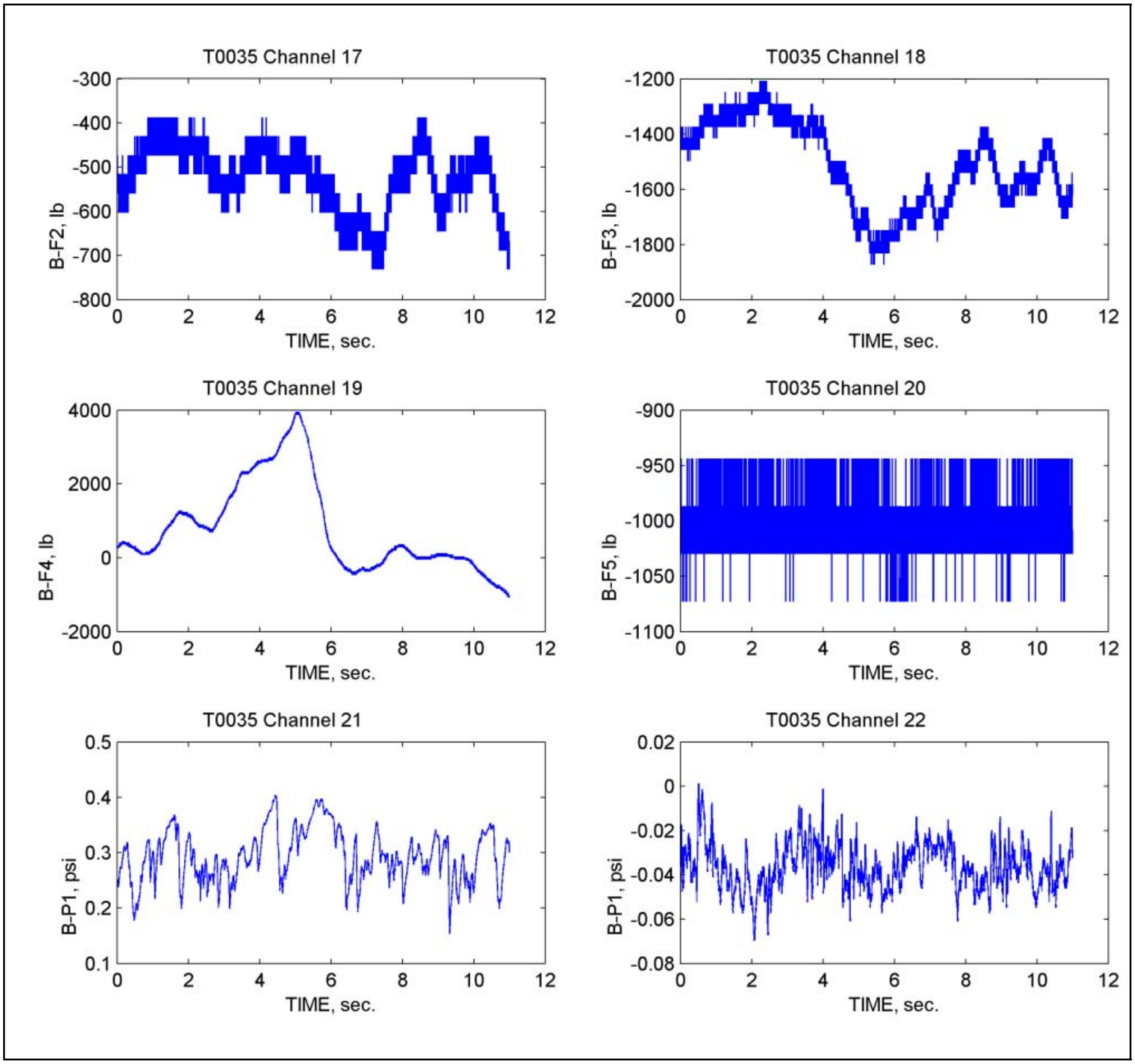

T0034 Channel 01
B-AX1, g
TIME, sec.
T0034 Channel 02
B-AY1, g
TIME, sec.
T0034 Channel 03
B-AZ1, g
TIME, sec.
T0034 Channel 04
B-AX2, g
TIME, sec.
T0034 Channel 05
B-AY2, g
TIME, sec.
T0034 Channel 06
B-AZ2, g
TIME, sec.
T0034 Channel 07
B-AX3, g
TIME, sec.
T0034 Channel 08
B-AY3, g
TIME, sec.

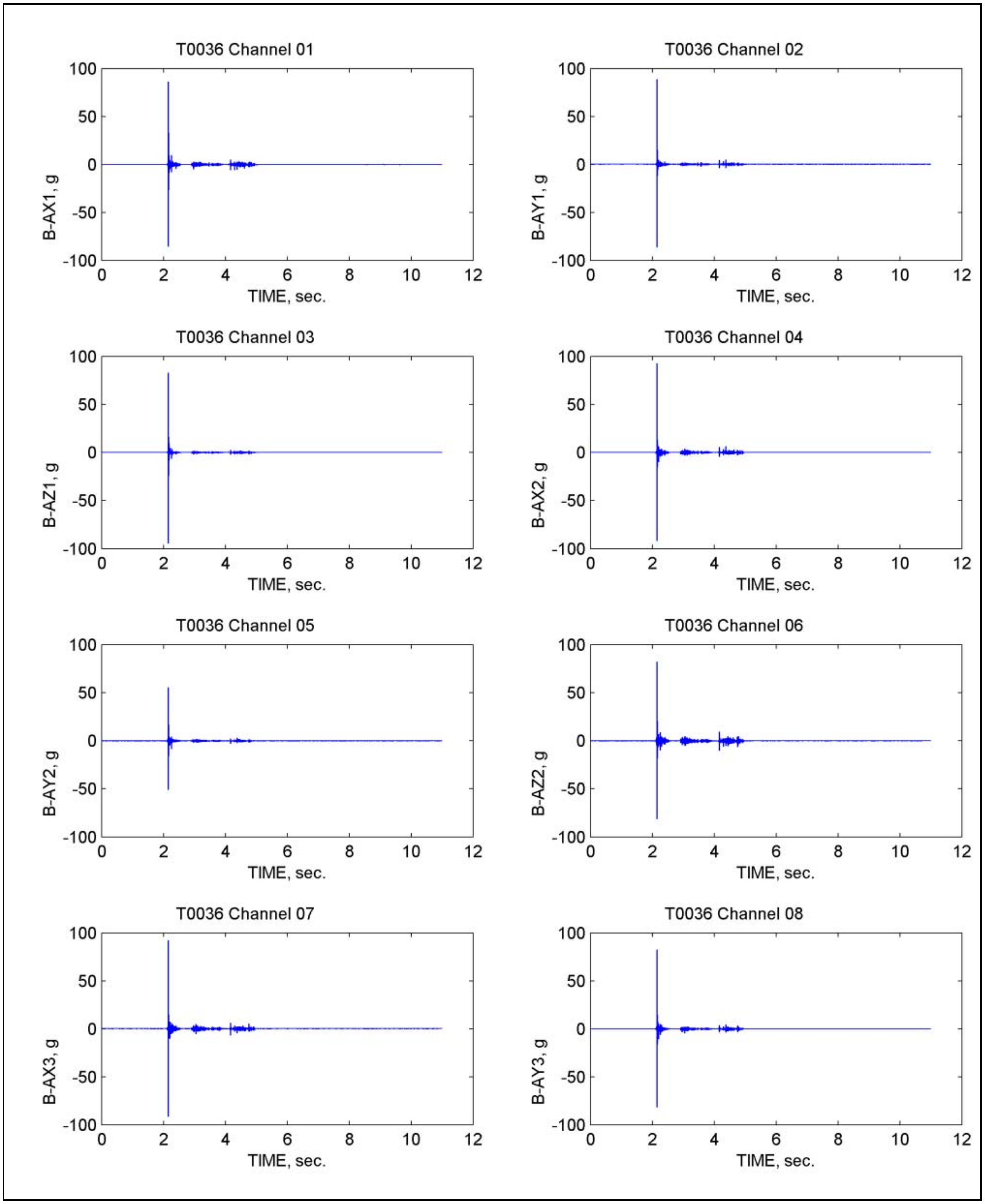

T0034 Channel 09
B-AZ3, g
TIME, sec.
T0034 Channel 10
B-SX1, u in/in
TIME, sec.
T0034 Channel 11
B-SXY1, u in/in
TIME, sec.
T0034 Channel 12
B-SY1, u in/in
TIME, sec.
T0034 Channel 13
B-SX2, u in/in
TIME, sec.
T0034 Channel 14
B-SXY2, u in/in
TIME, sec.
T0034 Channel 15
B-SY2, u in/in
TIME, sec.
T0034 Channel 16
x 10^4
B-F1, lb
TIME, sec.

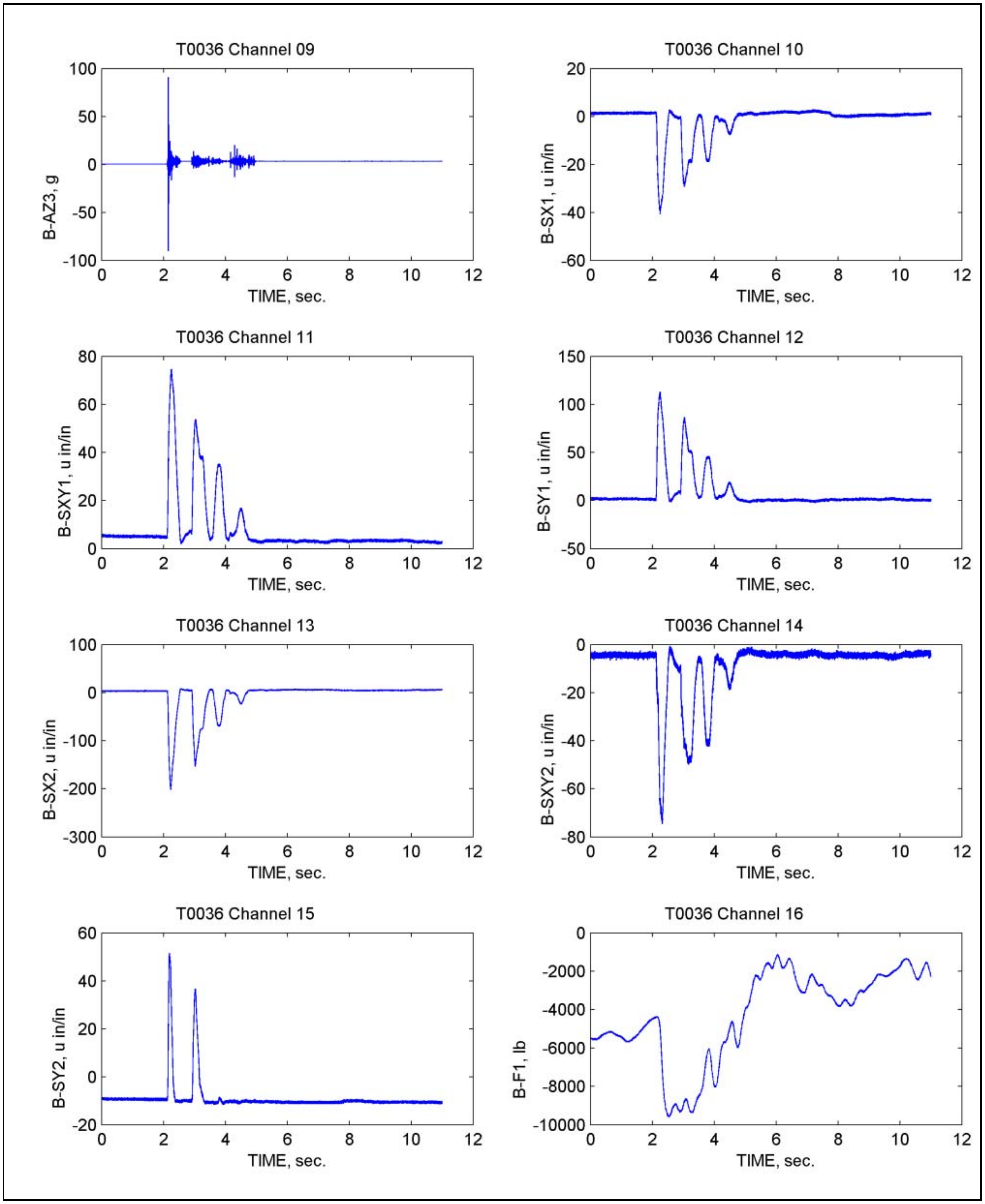

T0034 Channel 17
B-F2, lb
TIME, sec.
T0034 Channel 18
B-F3, lb
TIME, sec.
T0034 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0034 Channel 20
B-F5, lb
TIME, sec.
T0034 Channel 21
B-P1, psi
TIME, sec.
T0034 Channel 22
B-P1, psi
TIME, sec.

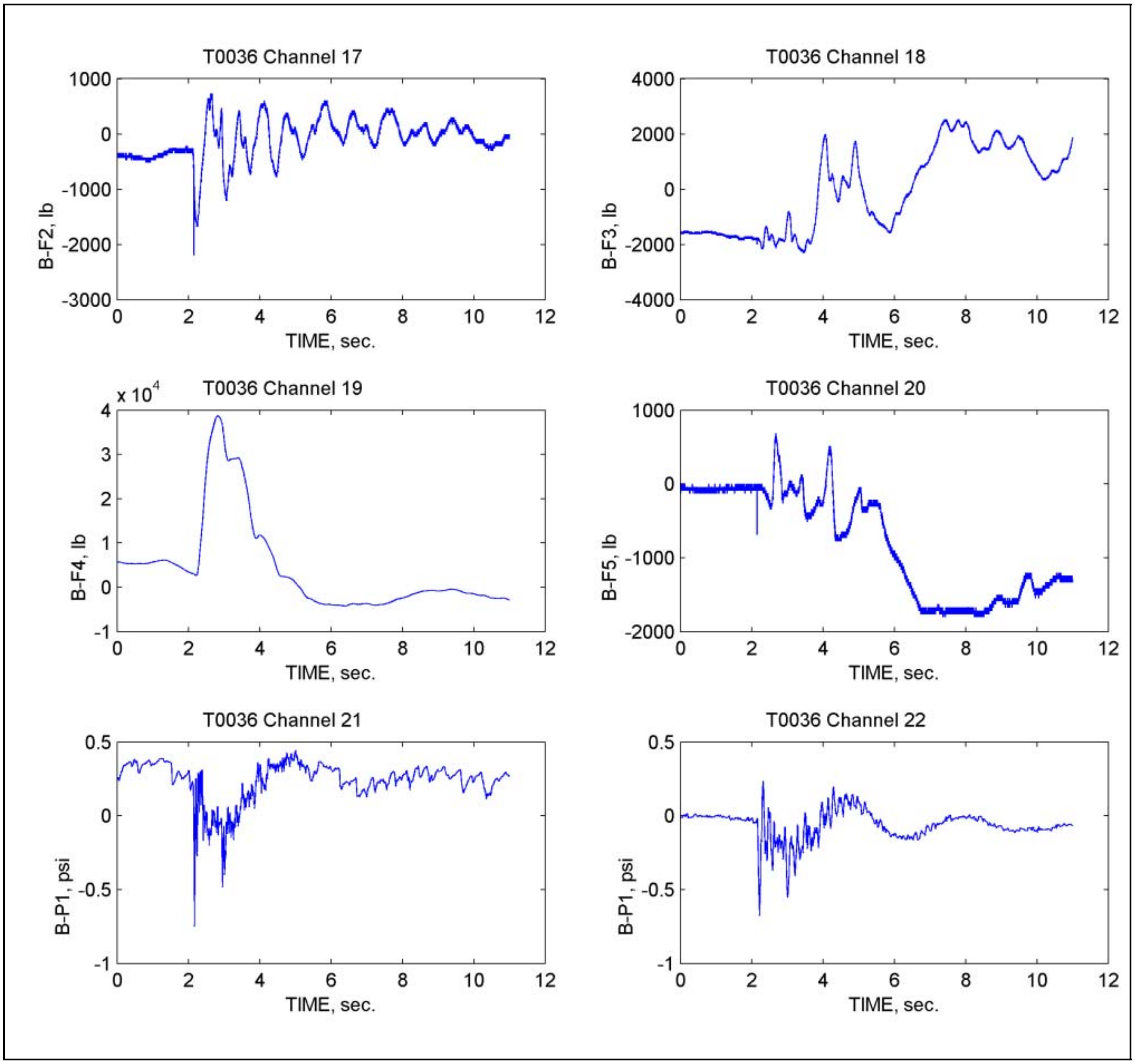

T0035 Channel 01
B-AX1, g
TIME, sec.
T0035 Channel 02
B-AY1, g
TIME, sec.
T0035 Channel 03
B-AZ1, g
TIME, sec.
T0035 Channel 04
B-AX2, g
TIME, sec.
T0035 Channel 05
B-AY2, g
TIME, sec.
T0035 Channel 06
B-AZ2, g
TIME, sec.
T0035 Channel 07
B-AX3, g
TIME, sec.
T0035 Channel 08
B-AY3, g
TIME, sec.


T0035 Channel 09
B-AZ3, g
TIME, sec.
T0035 Channel 10
B-SX1, u in/in
TIME, sec.
T0035 Channel 11
B-SXY1, u in/in
TIME, sec.
T0035 Channel 12
B-SY1, u in/in
TIME, sec.
T0035 Channel 13
B-SX2, u in/in
TIME, sec.
T0035 Channel 14
B-SXY2, u in/in
TIME, sec.
T0035 Channel 15
B-SY2, u in/in
TIME, sec.
T0035 Channel 16
B-F1, lb
TIME, sec.

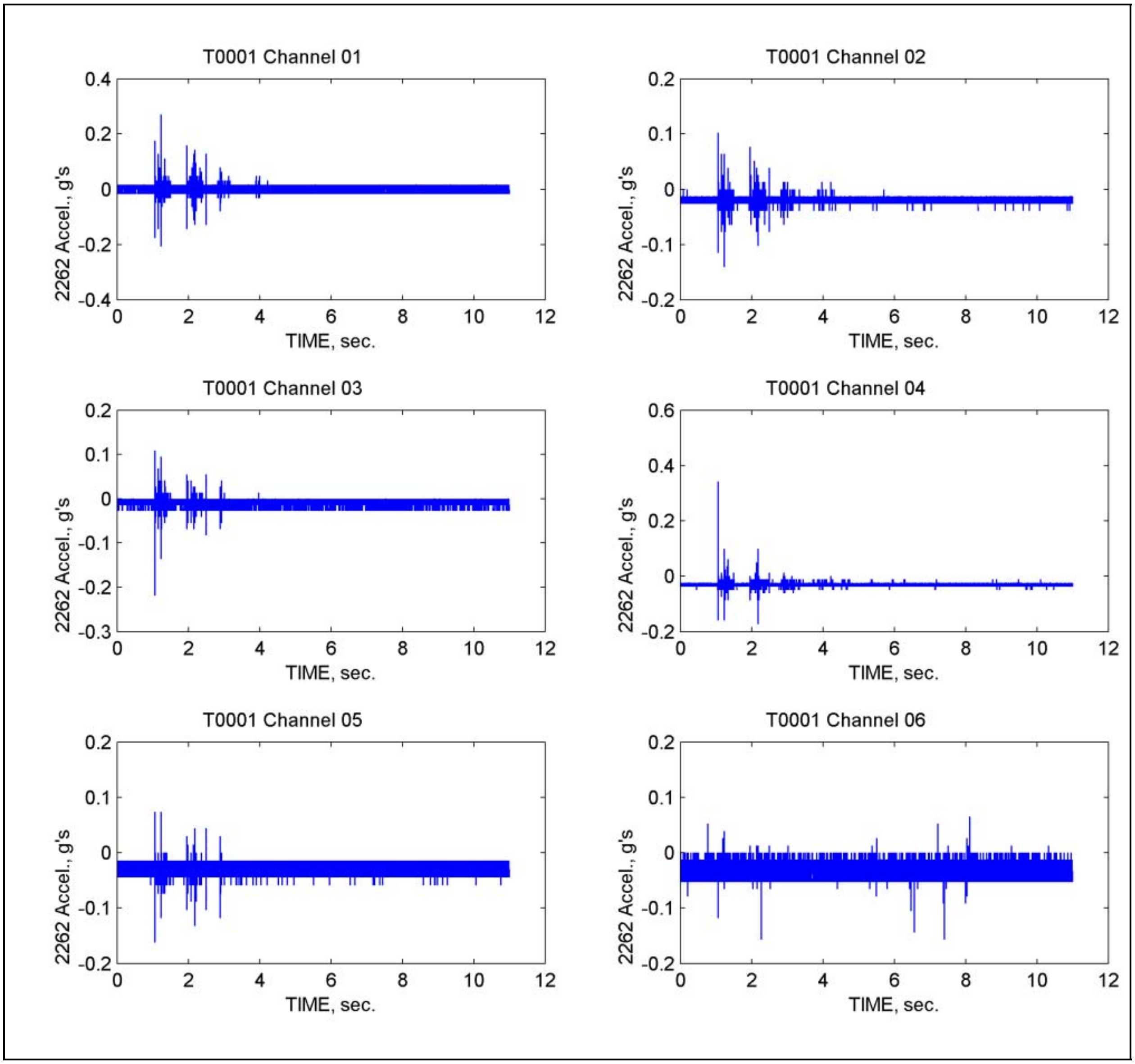

T0035 Channel 17
B-F2, lb
TIME, sec.
T0035 Channel 18
B-F3, lb
TIME, sec.
T0035 Channel 19
B-F4, lb
TIME, sec.
T0035 Channel 20
B-F5, lb
TIME, sec.
T0035 Channel 21
B-P1, psi
TIME, sec.
T0035 Channel 22
B-P1, psi
TIME, sec.

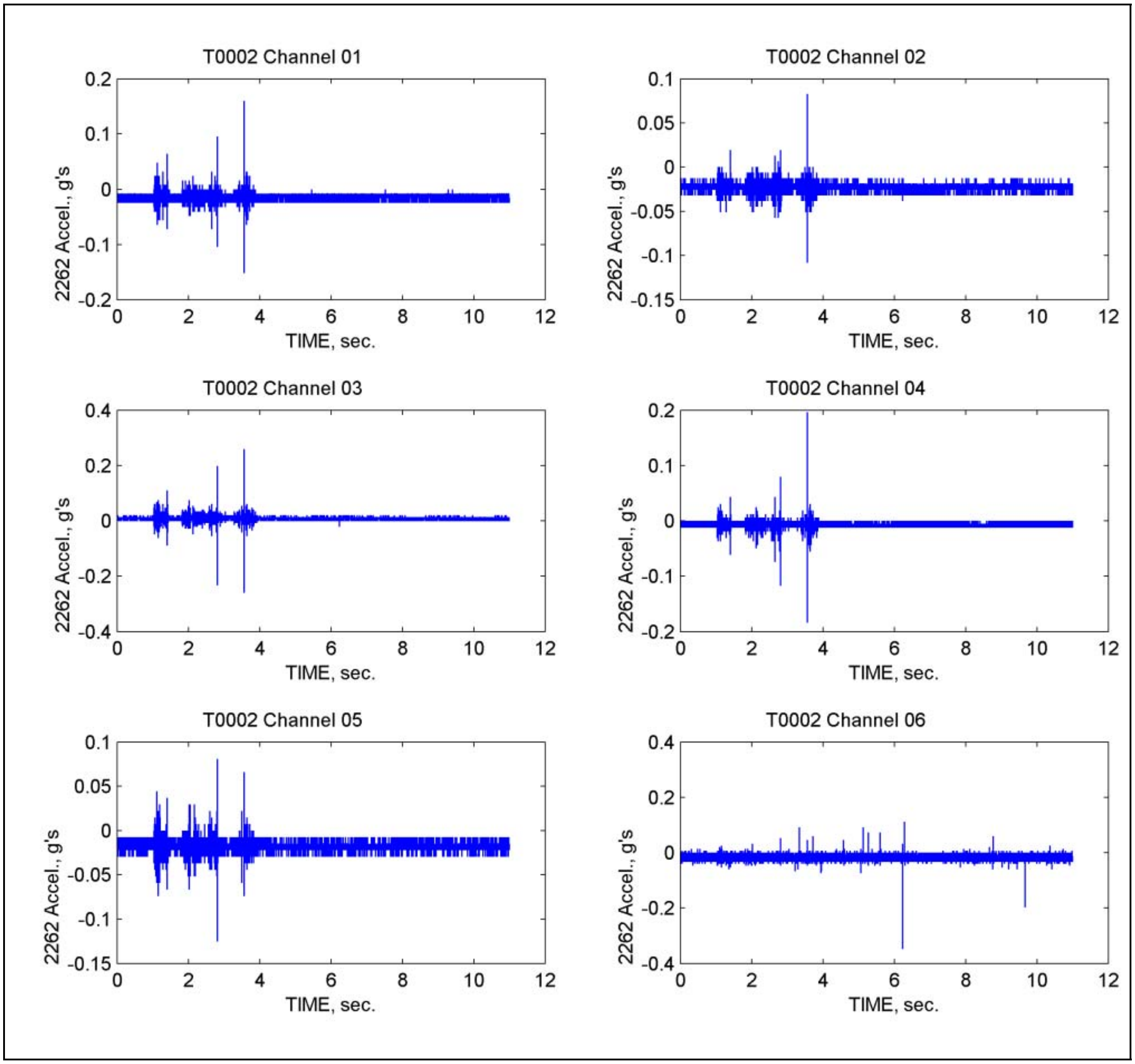

T0036 Channel 01
B-AX1, g
T0036 Channel 02
B-AY1, g
T0036 Channel 03
B-AZ1, g
T0036 Channel 04
B-AX2, g
T0036 Channel 05
B-AY2, g
T0036 Channel 06
B-AZ2, g
T0036 Channel 07
B-AX3, g
T0036 Channel 08
B-AY3, g
TIME, sec.

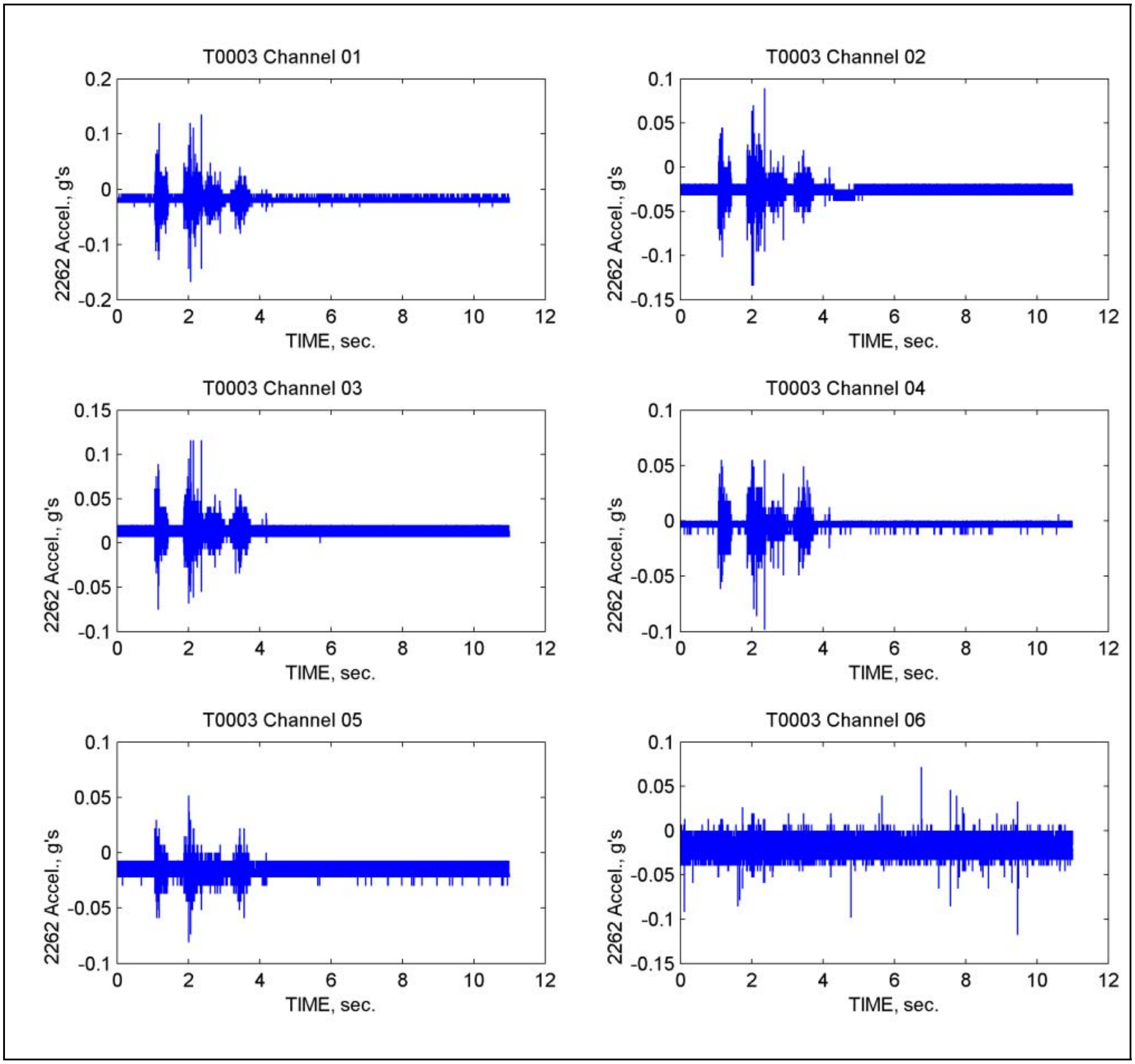

T0036 Channel 09
B-AZ3, g
TIME, sec.
T0036 Channel 10
B-SX1, u in/in
TIME, sec.
T0036 Channel 11
B-SXY1, u in/in
TIME, sec.
T0036 Channel 12
B-SY1, u in/in
TIME, sec.
T0036 Channel 13
B-SX2, u in/in
TIME, sec.
T0036 Channel 14
B-SXY2, u in/in
TIME, sec.
T0036 Channel 15
B-SY2, u in/in
TIME, sec.
T0036 Channel 16
B-F1, lb
TIME, sec.

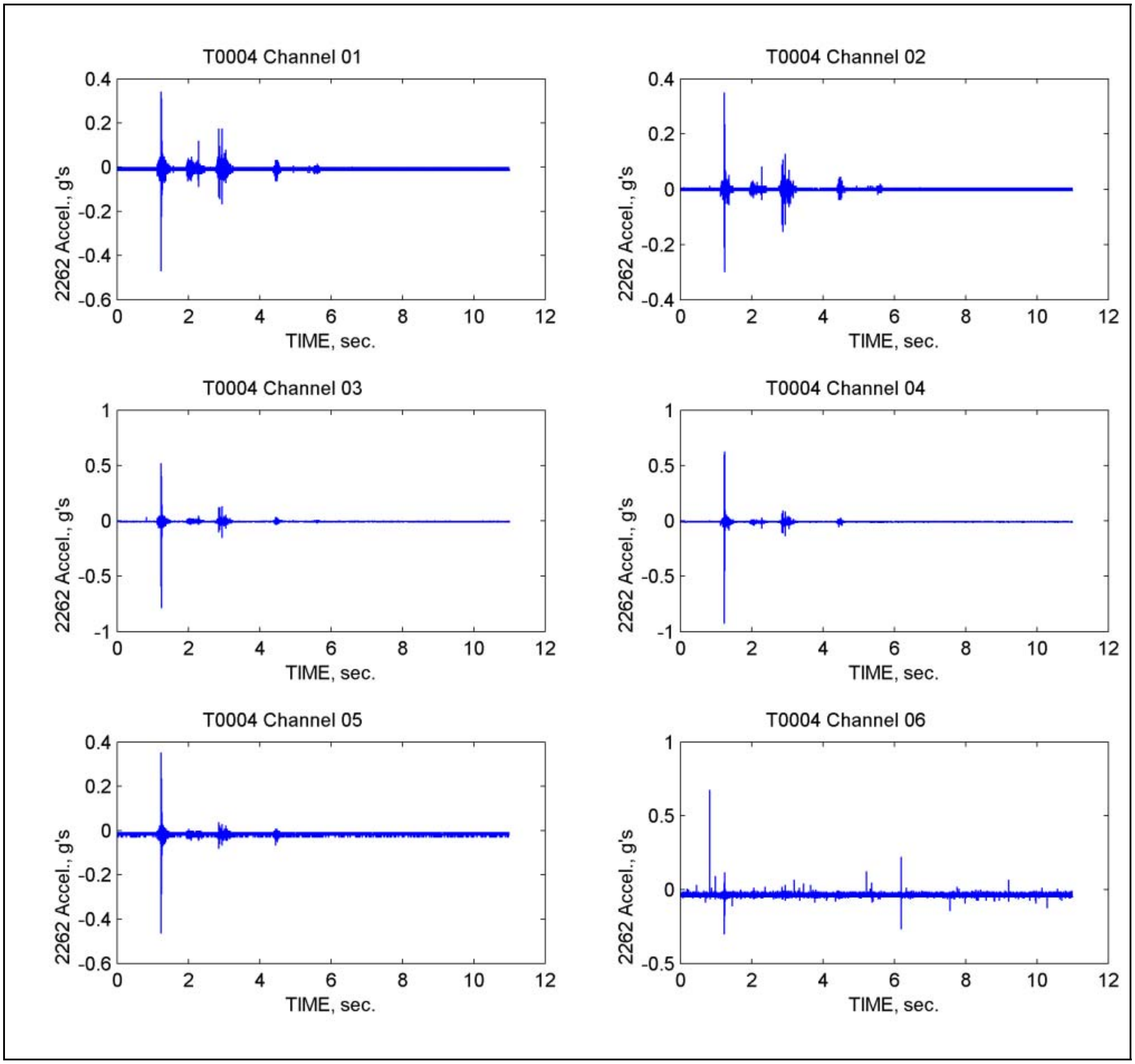


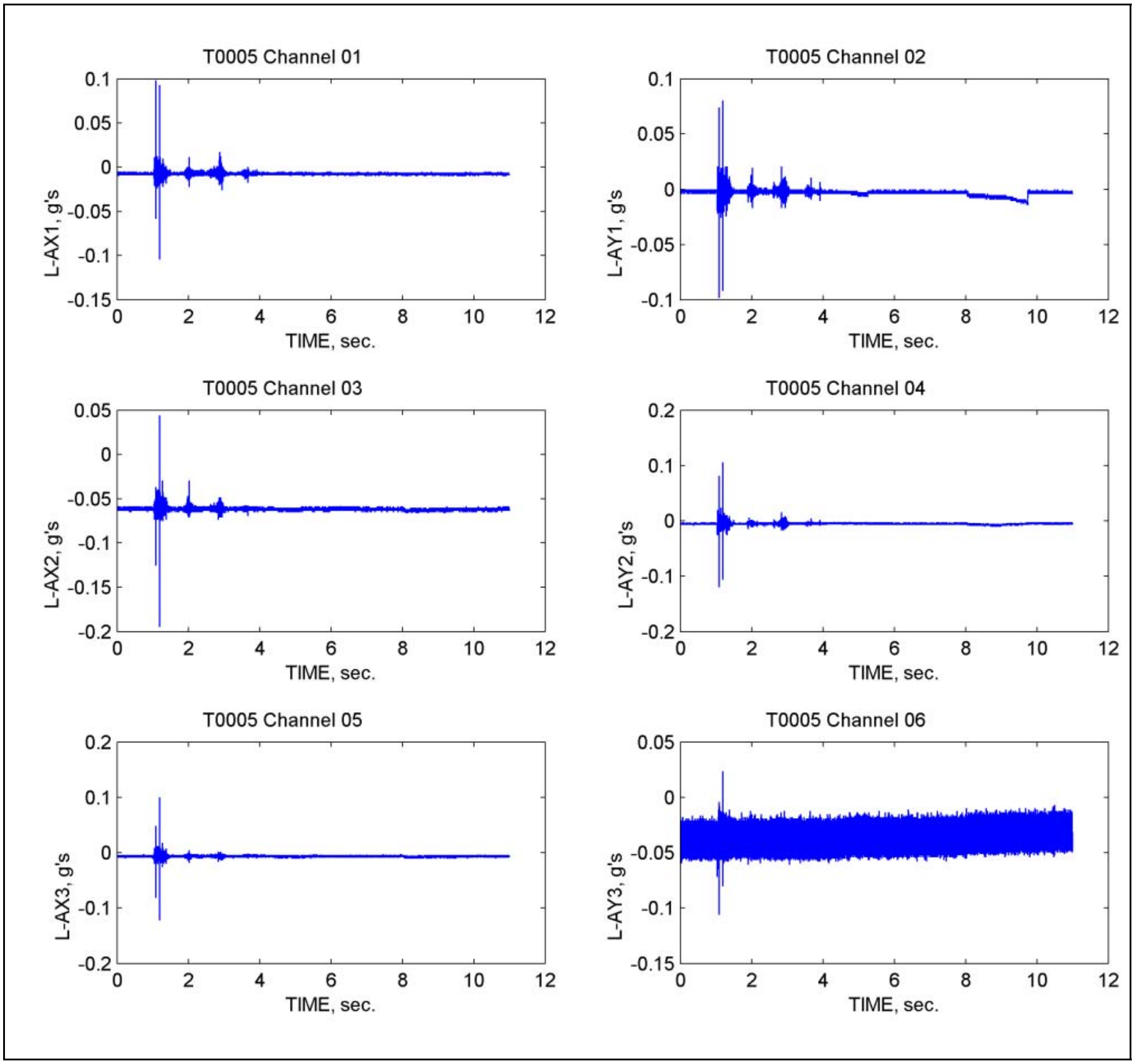
T0036 Channel 17
B-F2, lb
TIME, sec.
T0036 Channel 18
B-F3, lb
TIME, sec.
T0036 Channel 19
x 10^4
B-F4, lb
TIME, sec.
T0036 Channel 20
B-F5, lb
TIME, sec.
T0036 Channel 21
B-P1, psi
TIME, sec.
T0036 Channel 22
B-P1, psi
TIME, sec.

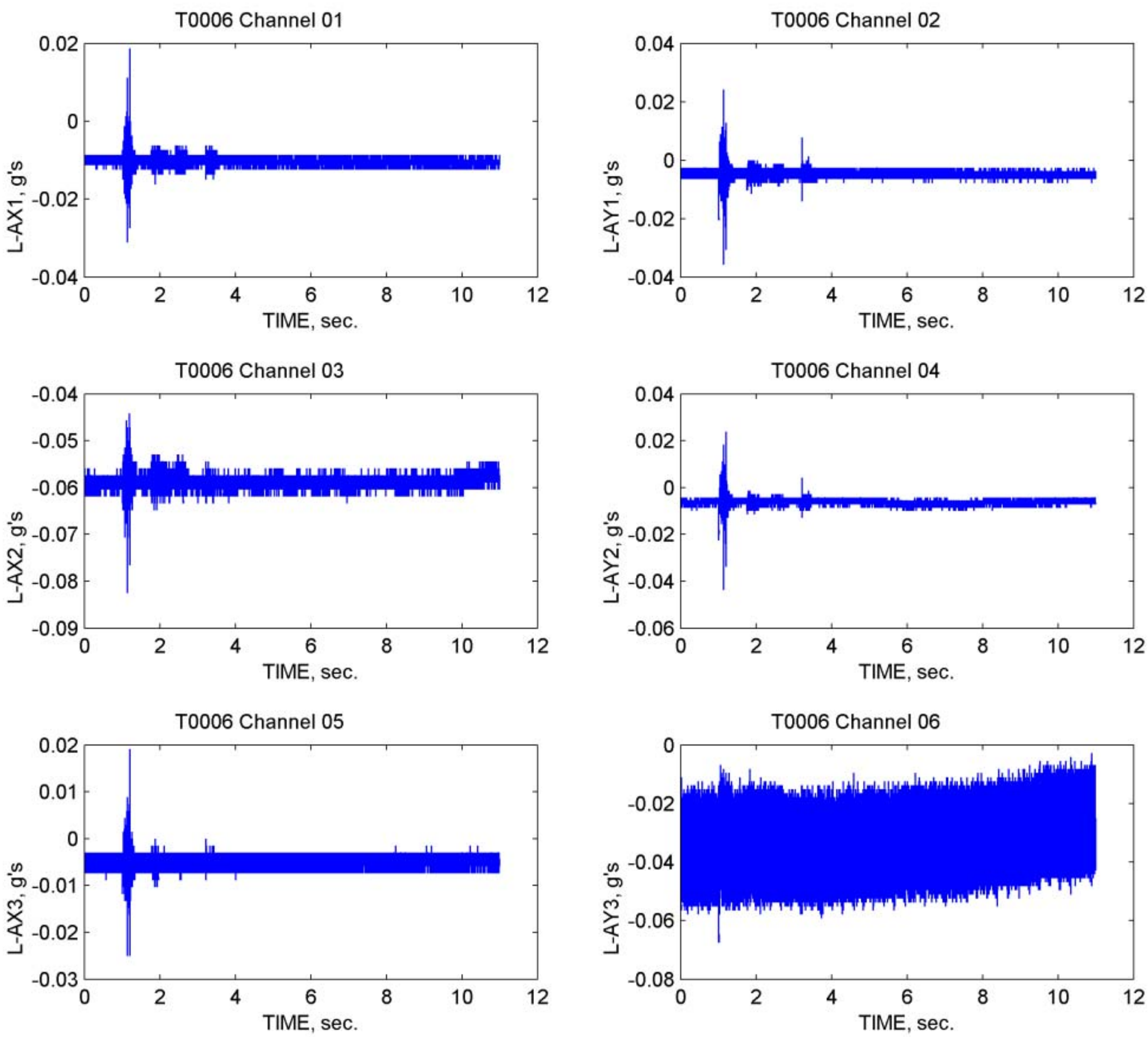

T0001 Channel 01
T0001 Channel 02
T0001 Channel 03
T0001 Channel 04
T0001 Channel 05
T0001 Channel 06
2262 Accel., g's
TIME, sec.

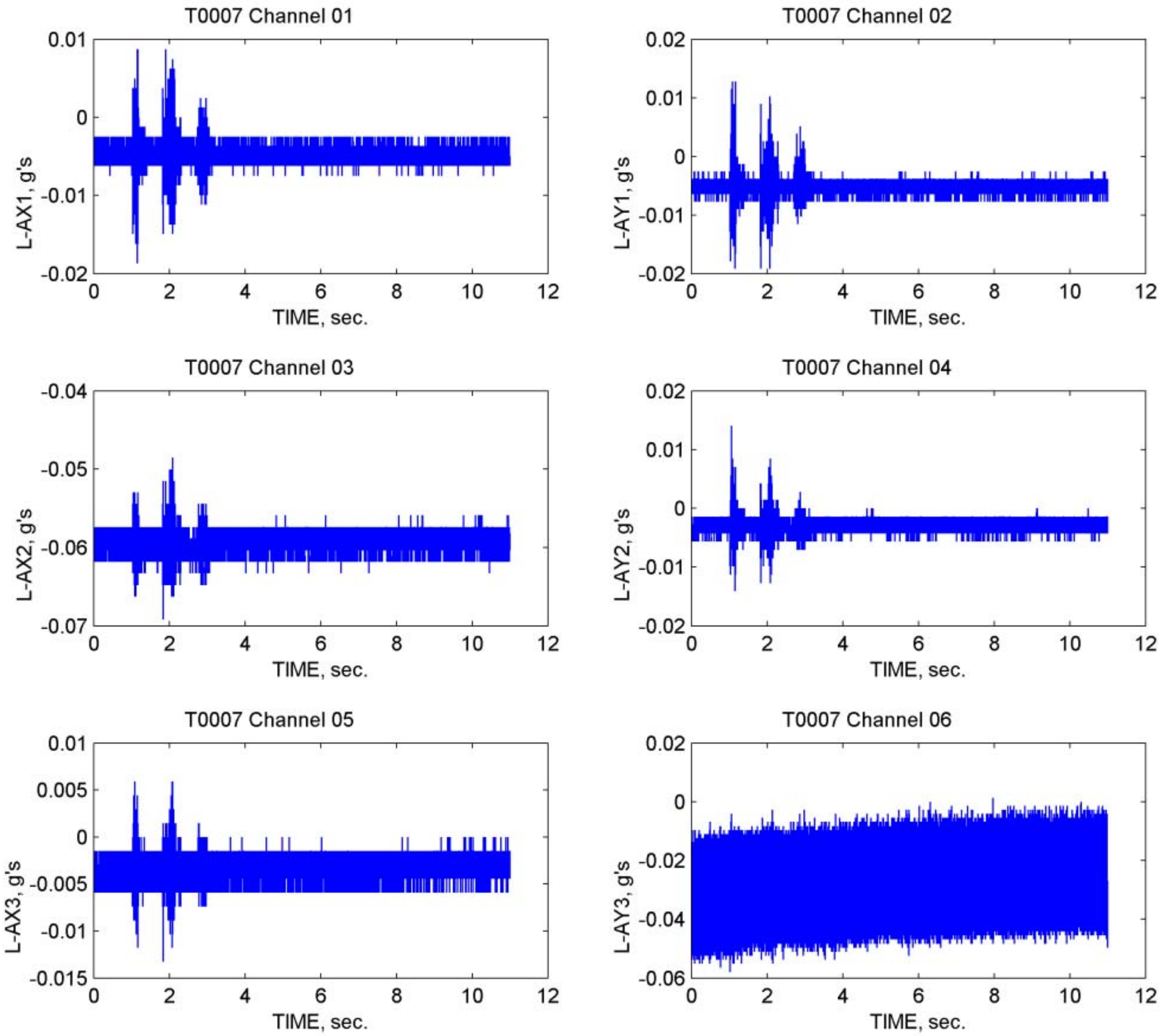

T0002 Channel 01
0.2
0.1
0
-0.1
-0.2
2262 Accel., g's
0
2
4
6
8
10
12
TIME, sec.
T0002 Channel 02
0.1
0.05
0
-0.05
-0.1
-0.15
2262 Accel., g's
TIME, sec.
T0002 Channel 03
0.4
0.2
0
-0.2
-0.4
2262 Accel., g's
TIME, sec.
T0002 Channel 04
0.2
0.1
0
-0.1
-0.2
2262 Accel., g's
TIME, sec.
T0002 Channel 05
0.1
0.05
0
-0.05
-0.1
-0.15
2262 Accel., g's
TIME, sec.
T0002 Channel 06
0.4
0.2
0
-0.2
-0.4
2262 Accel., g's
TIME, sec.

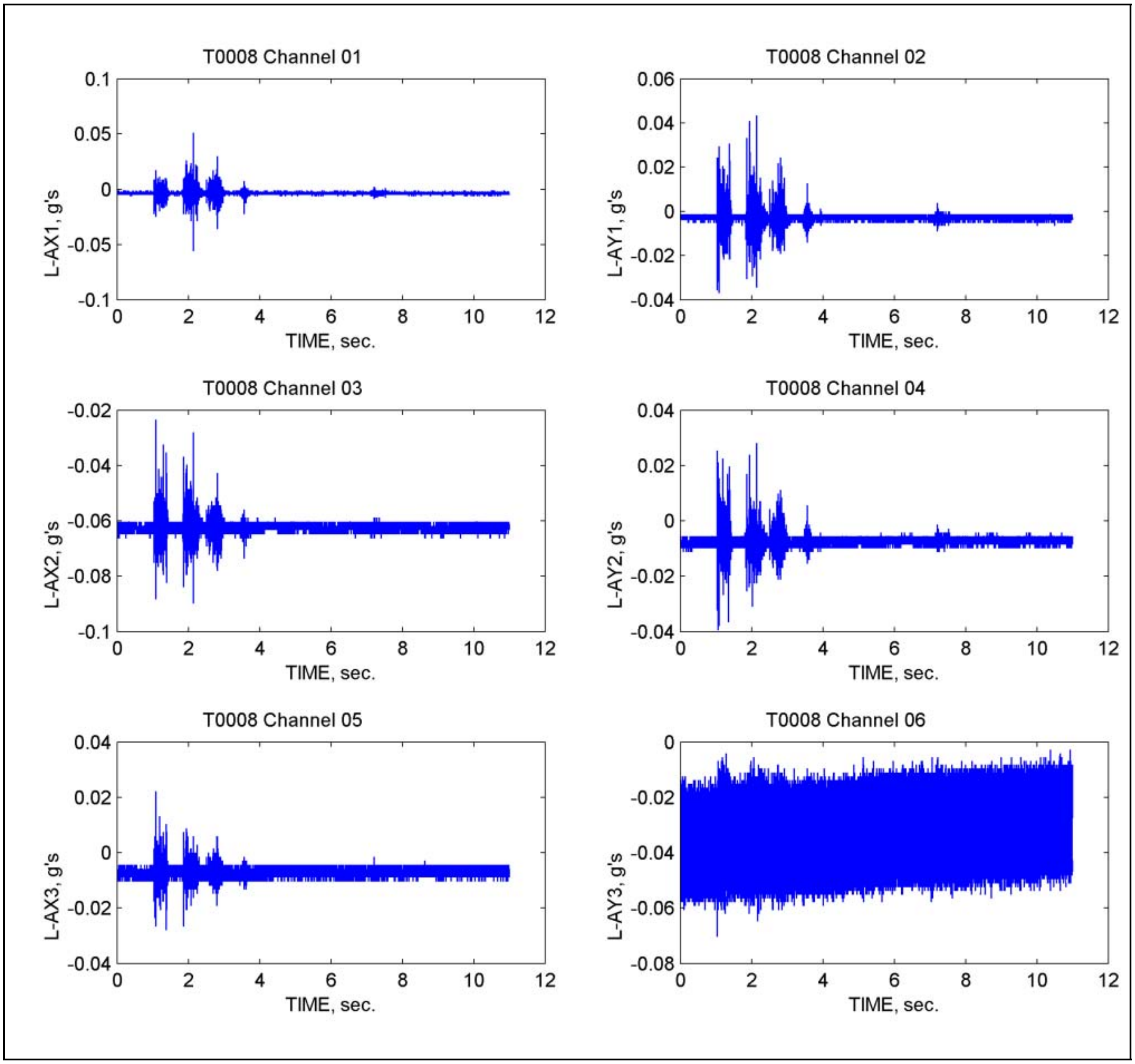

T0003 Channel 01
2262 Accel., g's
TIME, sec.
T0003 Channel 02
2262 Accel., g's
TIME, sec.
T0003 Channel 03
2262 Accel., g's
TIME, sec.
T0003 Channel 04
2262 Accel., g's
TIME, sec.
T0003 Channel 05
2262 Accel., g's
TIME, sec.
T0003 Channel 06
2262 Accel., g's
TIME, sec.

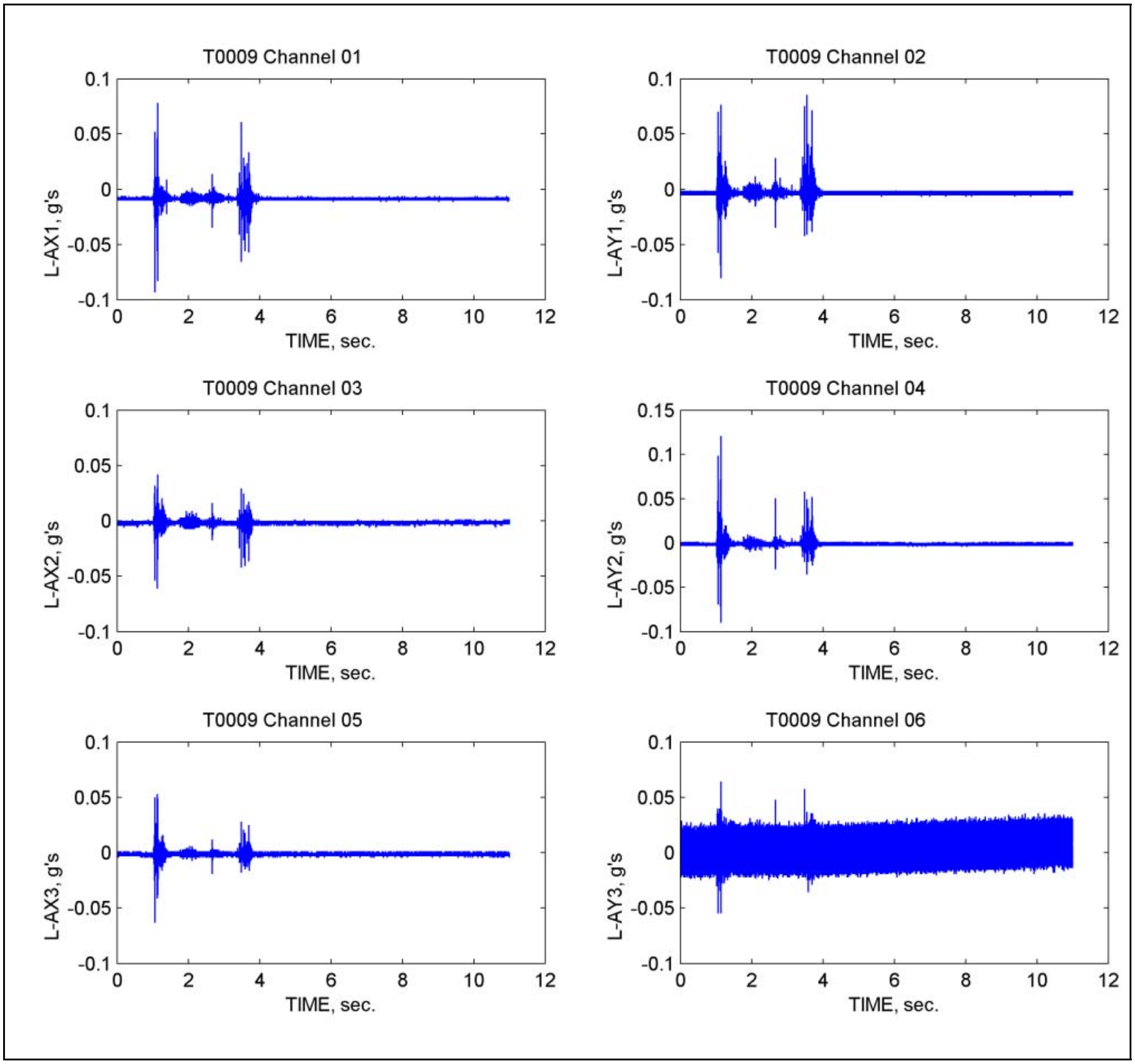

T0004 Channel 01
2262 Accel., g's
TIME, sec.
T0004 Channel 02
2262 Accel., g's
TIME, sec.
T0004 Channel 03
2262 Accel., g's
TIME, sec.
T0004 Channel 04
2262 Accel., g's
TIME, sec.
T0004 Channel 05
2262 Accel., g's
TIME, sec.
T0004 Channel 06
2262 Accel., g's
TIME, sec.

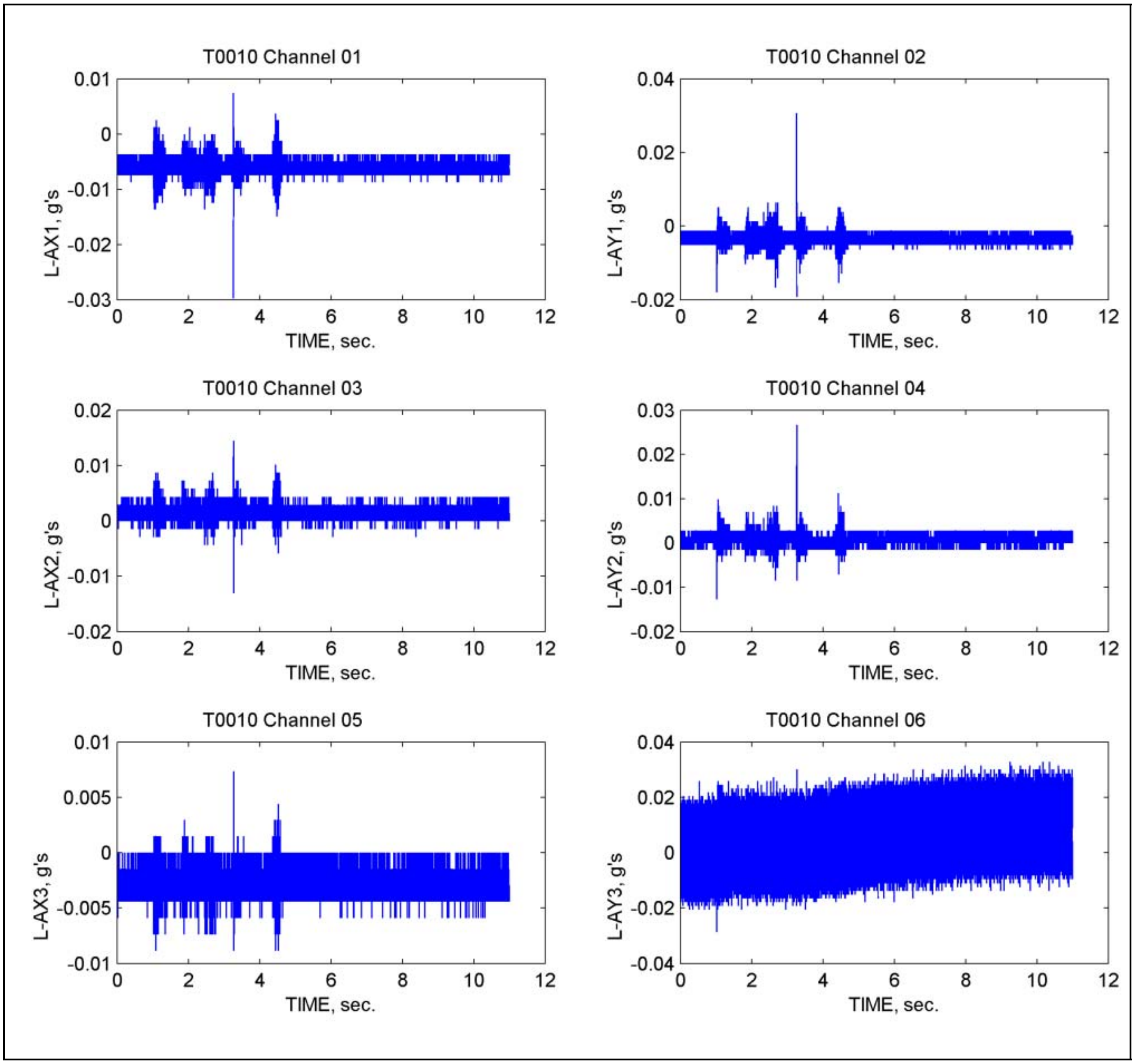

T0005 Channel 01
L-AX1, g's
TIME, sec.
T0005 Channel 02
L-AY1, g's
TIME, sec.
T0005 Channel 03
L-AX2, g's
TIME, sec.
T0005 Channel 04
L-AY2, g's
TIME, sec.
T0005 Channel 05
L-AX3, g's
TIME, sec.
T0005 Channel 06
L-AY3, g's
TIME, sec.

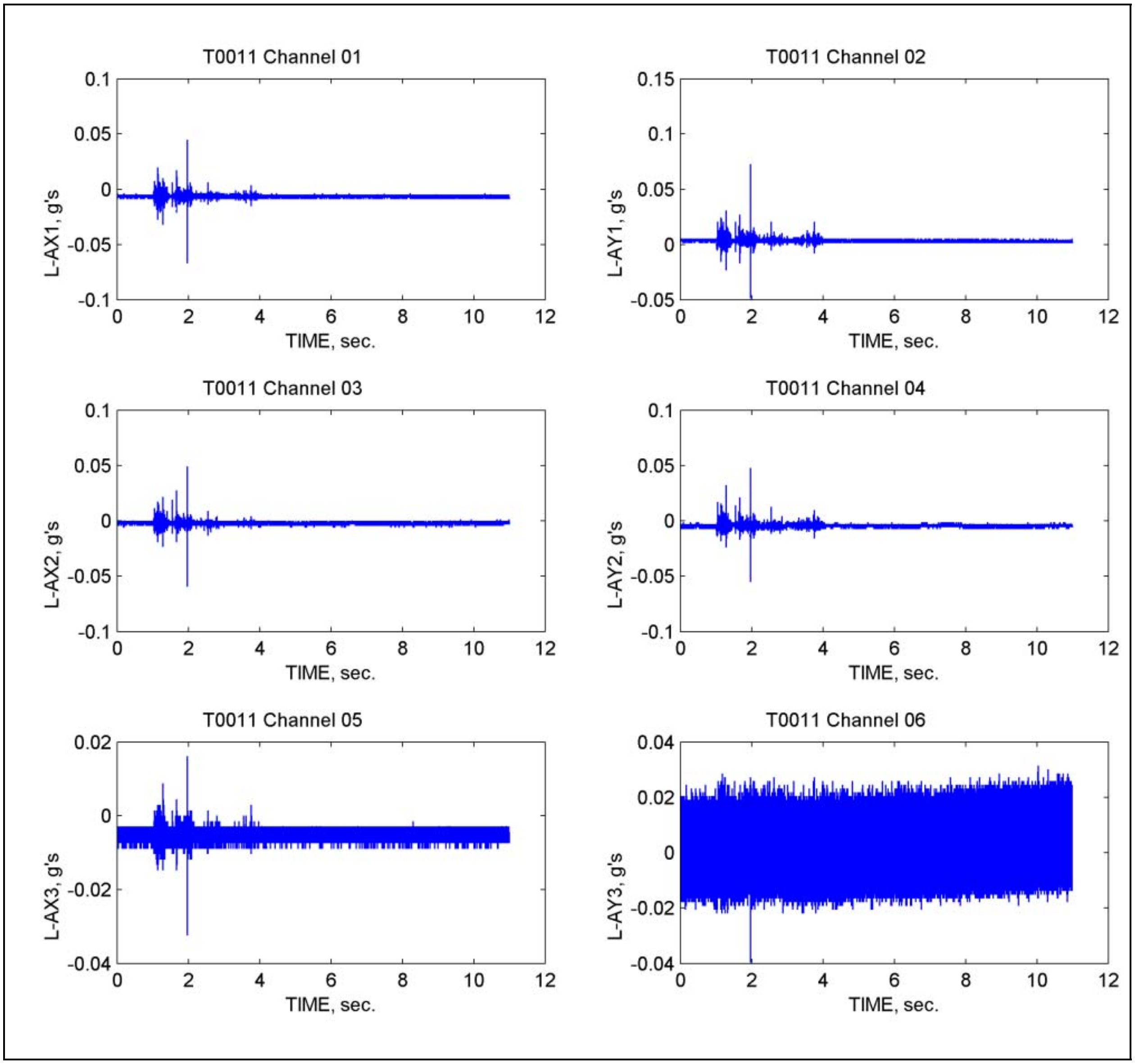

T0006 Channel 01
L-AX1, g's
TIME, sec.
T0006 Channel 02
L-AY1, g's
TIME, sec.
T0006 Channel 03
L-AX2, g's
TIME, sec.
T0006 Channel 04
L-AY2, g's
TIME, sec.
T0006 Channel 05
L-AX3, g's
TIME, sec.
T0006 Channel 06
L-AY3, g's
TIME, sec.

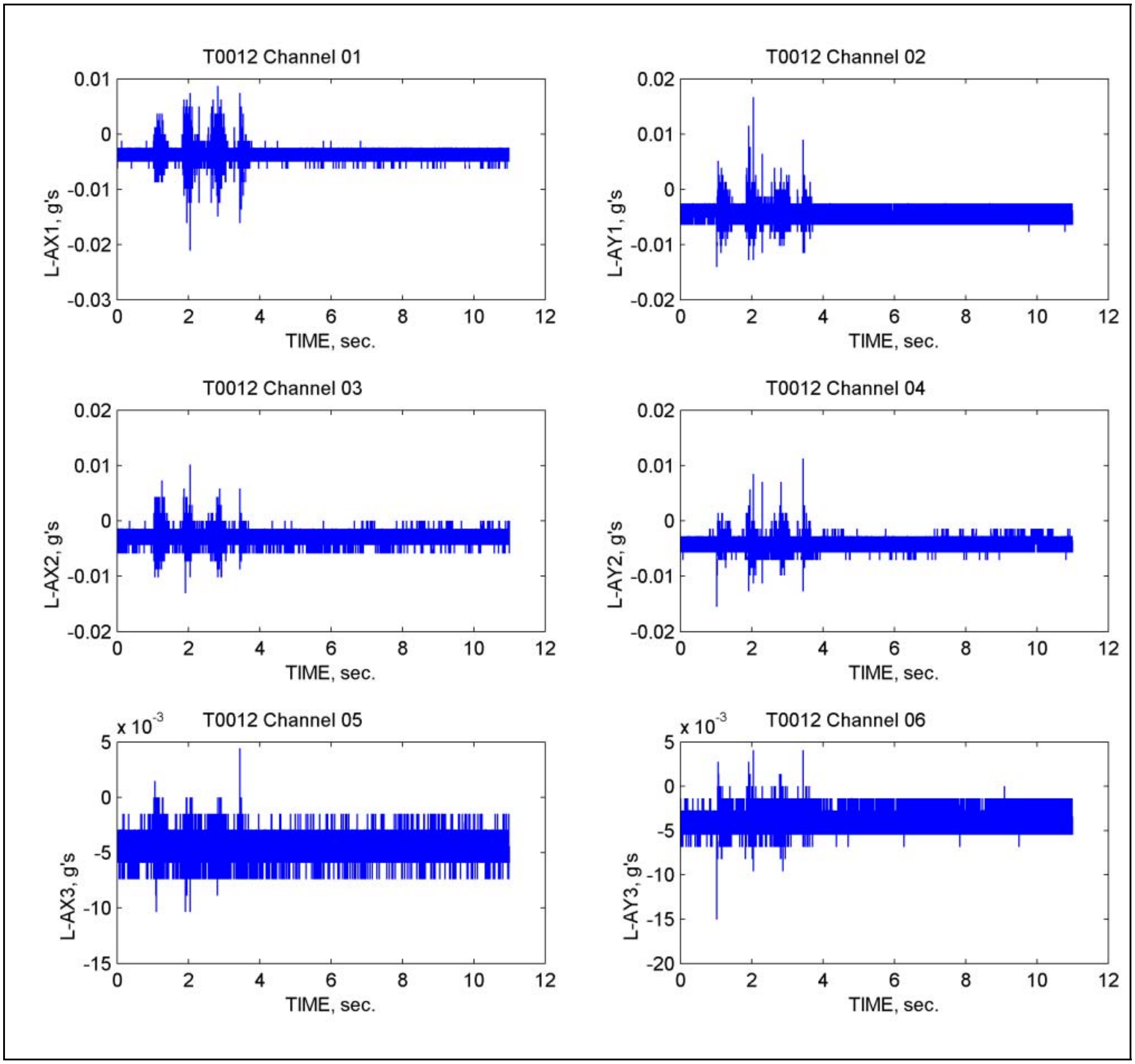

T0007 Channel 01
L-AX1, g's
TIME, sec.
T0007 Channel 02
L-AY1, g's
TIME, sec.
T0007 Channel 03
L-AX2, g's
TIME, sec.
T0007 Channel 04
L-AY2, g's
TIME, sec.
T0007 Channel 05
L-AX3, g's
TIME, sec.
T0007 Channel 06
L-AY3, g's
TIME, sec.

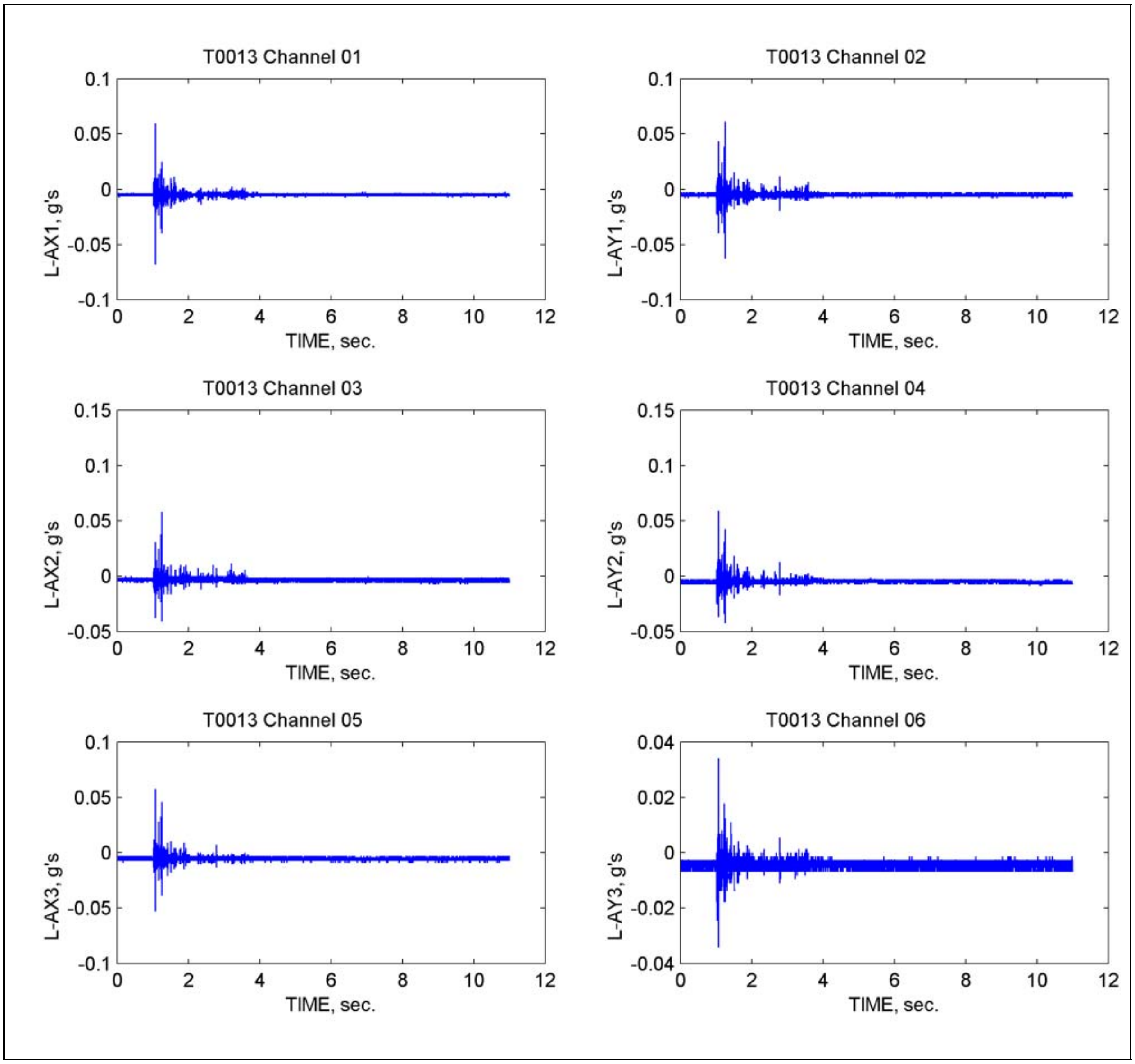

T0008 Channel 01
L-AX1, g's
TIME, sec.
T0008 Channel 02
L-AY1, g's
TIME, sec.
T0008 Channel 03
L-AX2, g's
TIME, sec.
T0008 Channel 04
L-AY2, g's
TIME, sec.
T0008 Channel 05
L-AX3, g's
TIME, sec.
T0008 Channel 06
L-AY3, g's
TIME, sec.

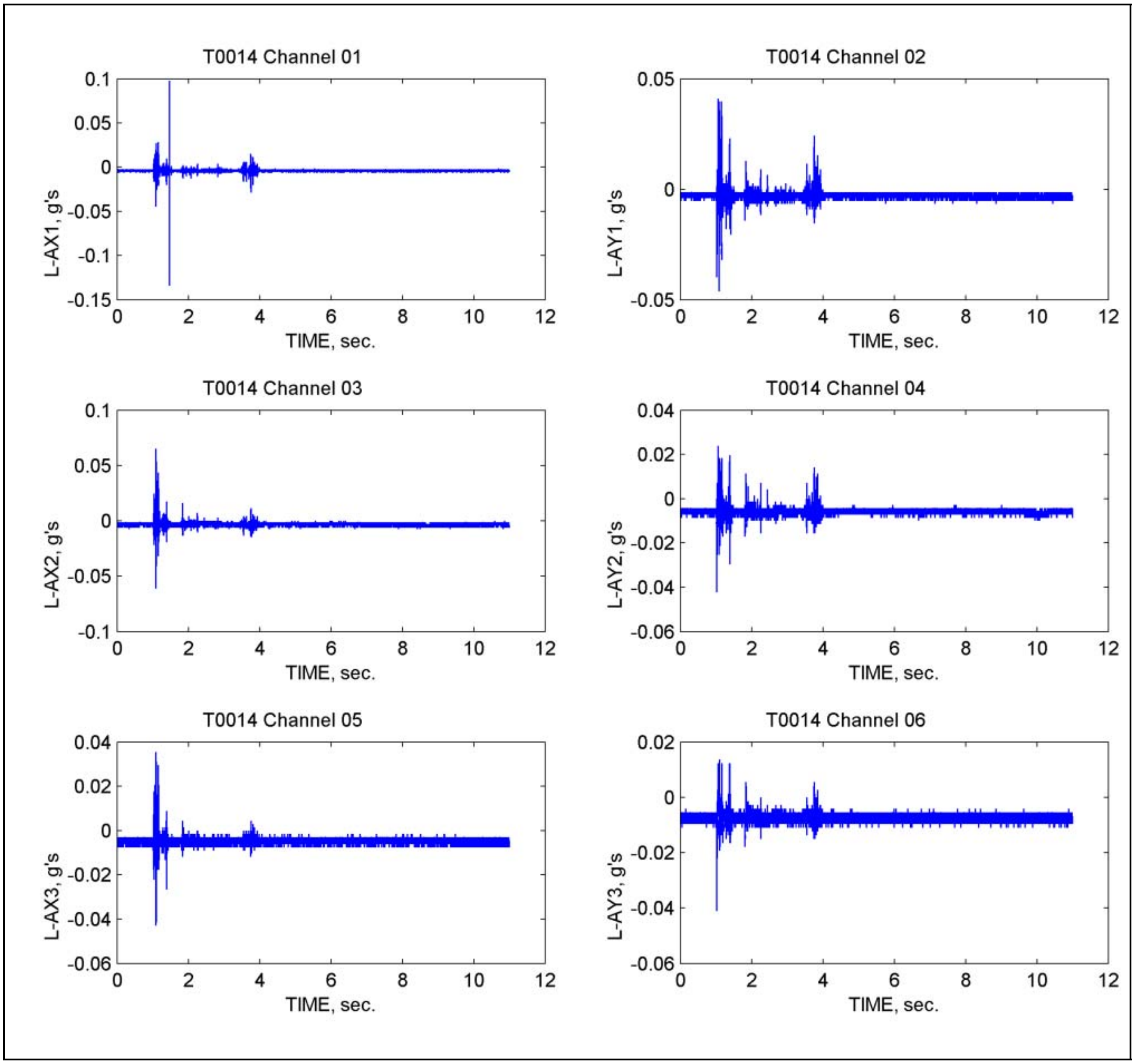

T0009 Channel 01
L-AX1, g's
TIME, sec.
T0009 Channel 02
L-AY1, g's
TIME, sec.
T0009 Channel 03
L-AX2, g's
TIME, sec.
T0009 Channel 04
L-AY2, g's
TIME, sec.
T0009 Channel 05
L-AX3, g's
TIME, sec.
T0009 Channel 06
L-AY3, g's
TIME, sec.

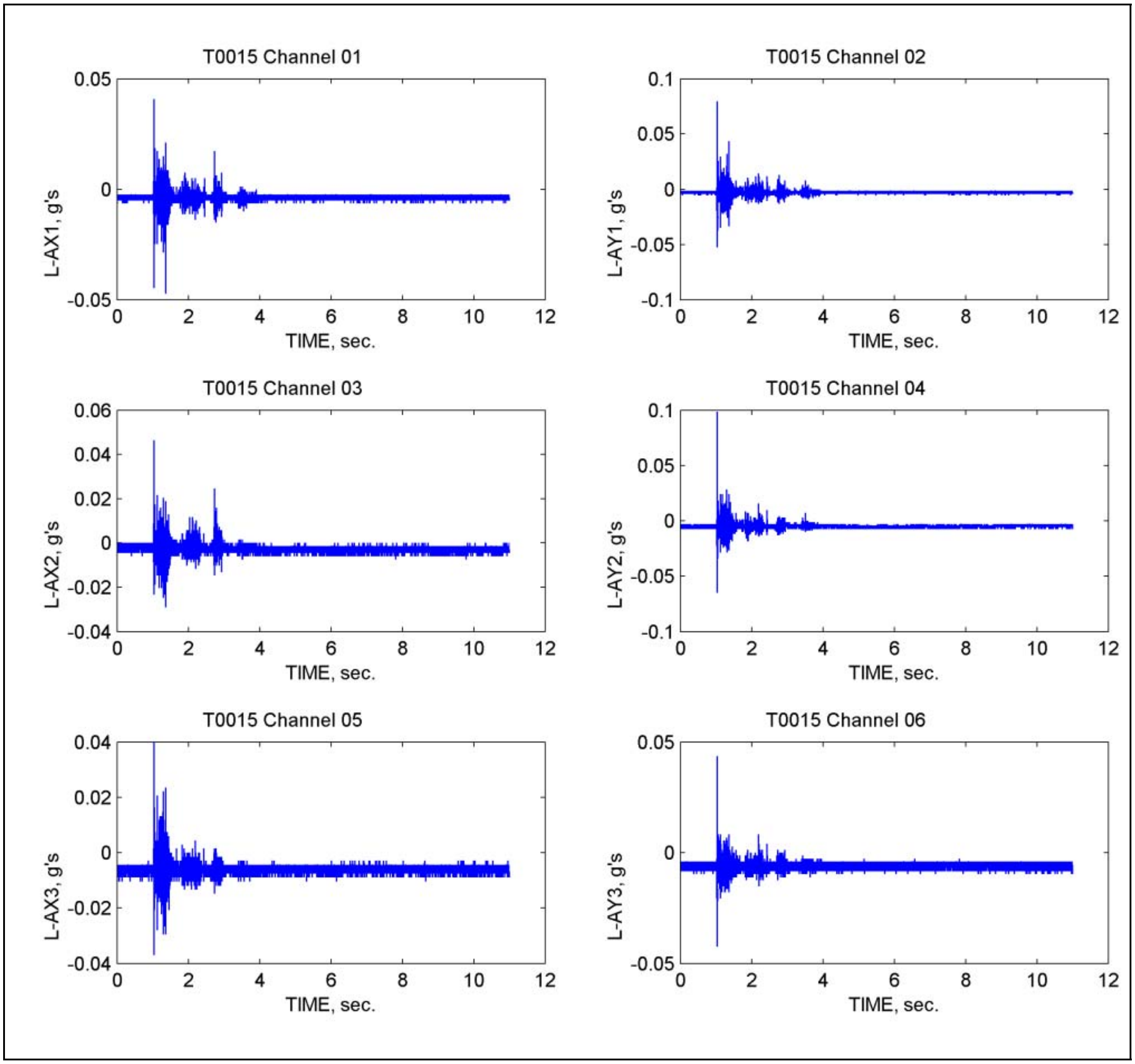

T0010 Channel 01
L-AX1, g's
TIME, sec.
T0010 Channel 02
L-AY1, g's
TIME, sec.
T0010 Channel 03
L-AX2, g's
TIME, sec.
T0010 Channel 04
L-AY2, g's
TIME, sec.
T0010 Channel 05
L-AX3, g's
TIME, sec.
T0010 Channel 06
L-AY3, g's
TIME, sec.

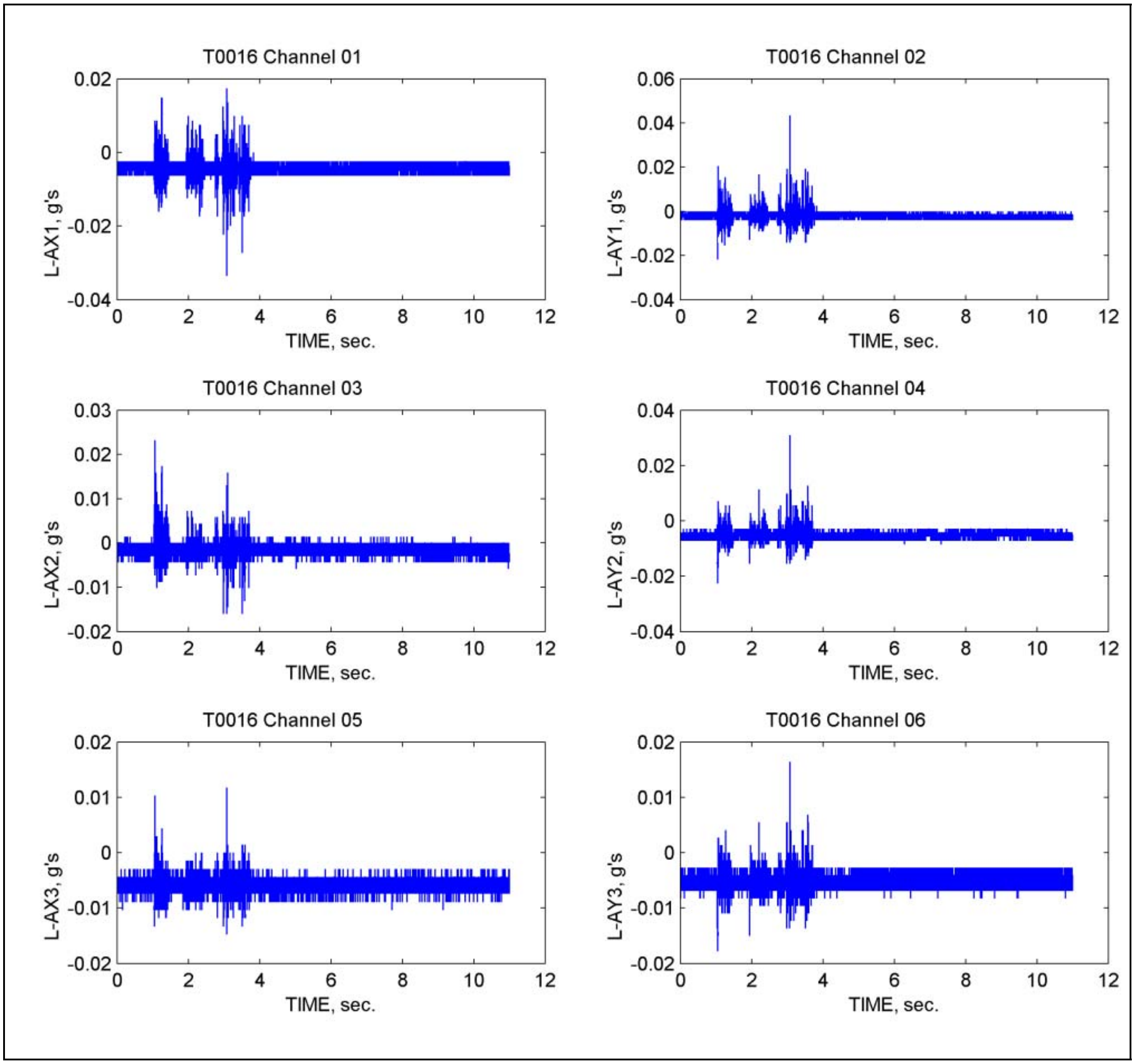

T0011 Channel 01
L-AX1, g's
TIME, sec.
T0011 Channel 02
L-AY1, g's
TIME, sec.
T0011 Channel 03
L-AX2, g's
TIME, sec.
T0011 Channel 04
L-AY2, g's
TIME, sec.
T0011 Channel 05
L-AX3, g's
TIME, sec.
T0011 Channel 06
L-AY3, g's
TIME, sec.

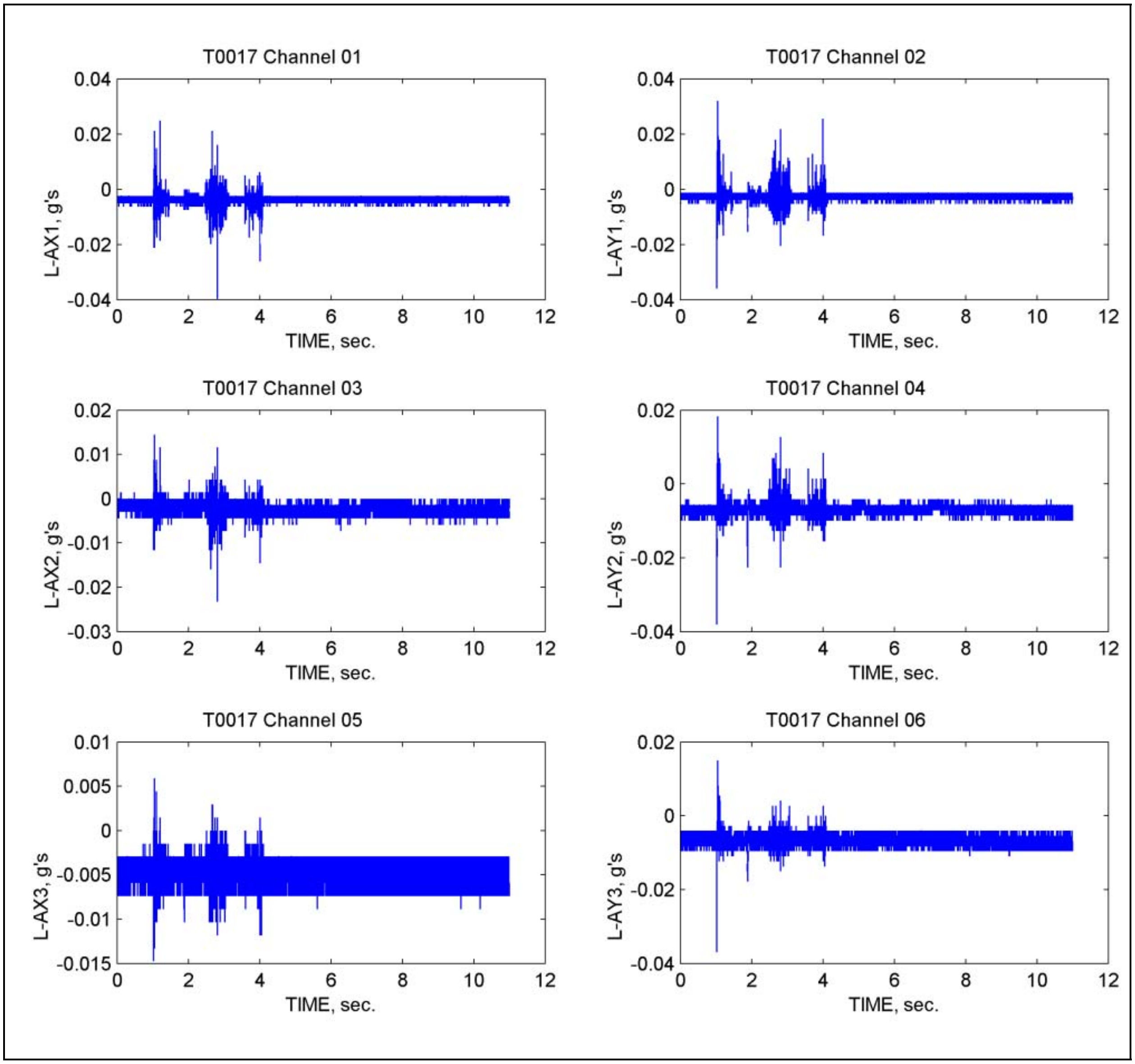

T0012 Channel 01
L-AX1, g's
TIME, sec.
T0012 Channel 02
L-AY1, g's
TIME, sec.
T0012 Channel 03
L-AX2, g's
TIME, sec.
T0012 Channel 04
L-AY2, g's
TIME, sec.
x 10^-3
T0012 Channel 05
L-AX3, g's
TIME, sec.
x 10^-3
T0012 Channel 06
L-AY3, g's
TIME, sec.

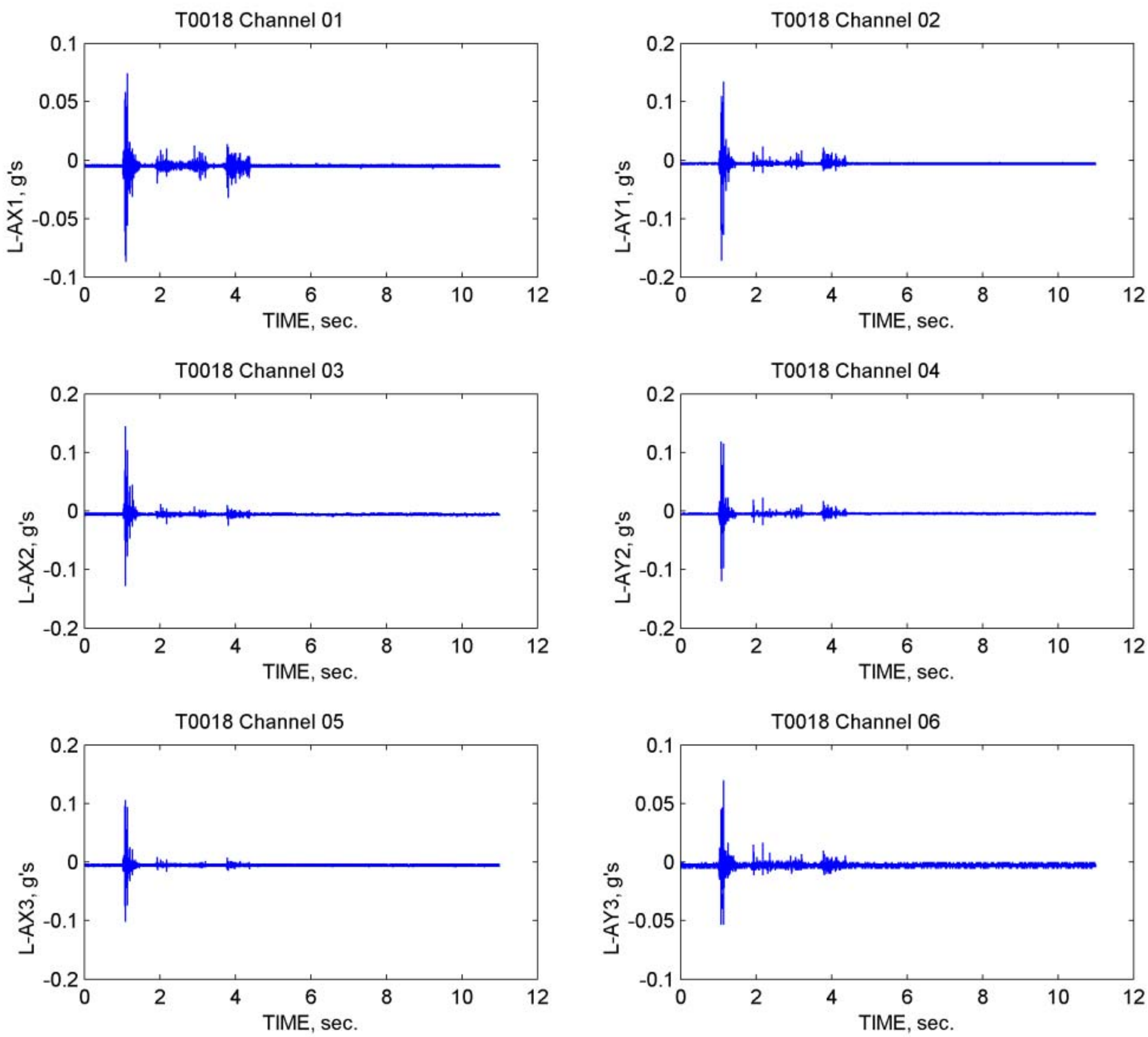

T0013 Channel 01
L-AX1, g's
TIME, sec.
T0013 Channel 02
L-AY1, g's
TIME, sec.
T0013 Channel 03
L-AX2, g's
TIME, sec.
T0013 Channel 04
L-AY2, g's
TIME, sec.
T0013 Channel 05
L-AX3, g's
TIME, sec.
T0013 Channel 06
L-AY3, g's
TIME, sec.


T0014 Channel 01
L-AX1, g's
TIME, sec.
T0014 Channel 02
L-AY1, g's
TIME, sec.
T0014 Channel 03
L-AX2, g's
TIME, sec.
T0014 Channel 04
L-AY2, g's
TIME, sec.
T0014 Channel 05
L-AX3, g's
TIME, sec.
T0014 Channel 06
L-AY3, g's
TIME, sec.


T0015 Channel 01
L-AX1, g's
TIME, sec.
T0015 Channel 02
L-AY1, g's
TIME, sec.
T0015 Channel 03
L-AX2, g's
TIME, sec.
T0015 Channel 04
L-AY2, g's
TIME, sec.
T0015 Channel 05
L-AX3, g's
TIME, sec.
T0015 Channel 06
L-AY3, g's
TIME, sec.


T0016 Channel 01
L-AX1, g's
TIME, sec.
T0016 Channel 02
L-AY1, g's
TIME, sec.
T0016 Channel 03
L-AX2, g's
TIME, sec.
T0016 Channel 04
L-AY2, g's
TIME, sec.
T0016 Channel 05
L-AX3, g's
TIME, sec.
T0016 Channel 06
L-AY3, g's
TIME, sec.


T0017 Channel 01
L-AX1, g's
TIME, sec.
T0017 Channel 02
L-AY1, g's
TIME, sec.
T0017 Channel 03
L-AX2, g's
TIME, sec.
T0017 Channel 04
L-AY2, g's
TIME, sec.
T0017 Channel 05
L-AX3, g's
TIME, sec.
T0017 Channel 06
L-AY3, g's
TIME, sec.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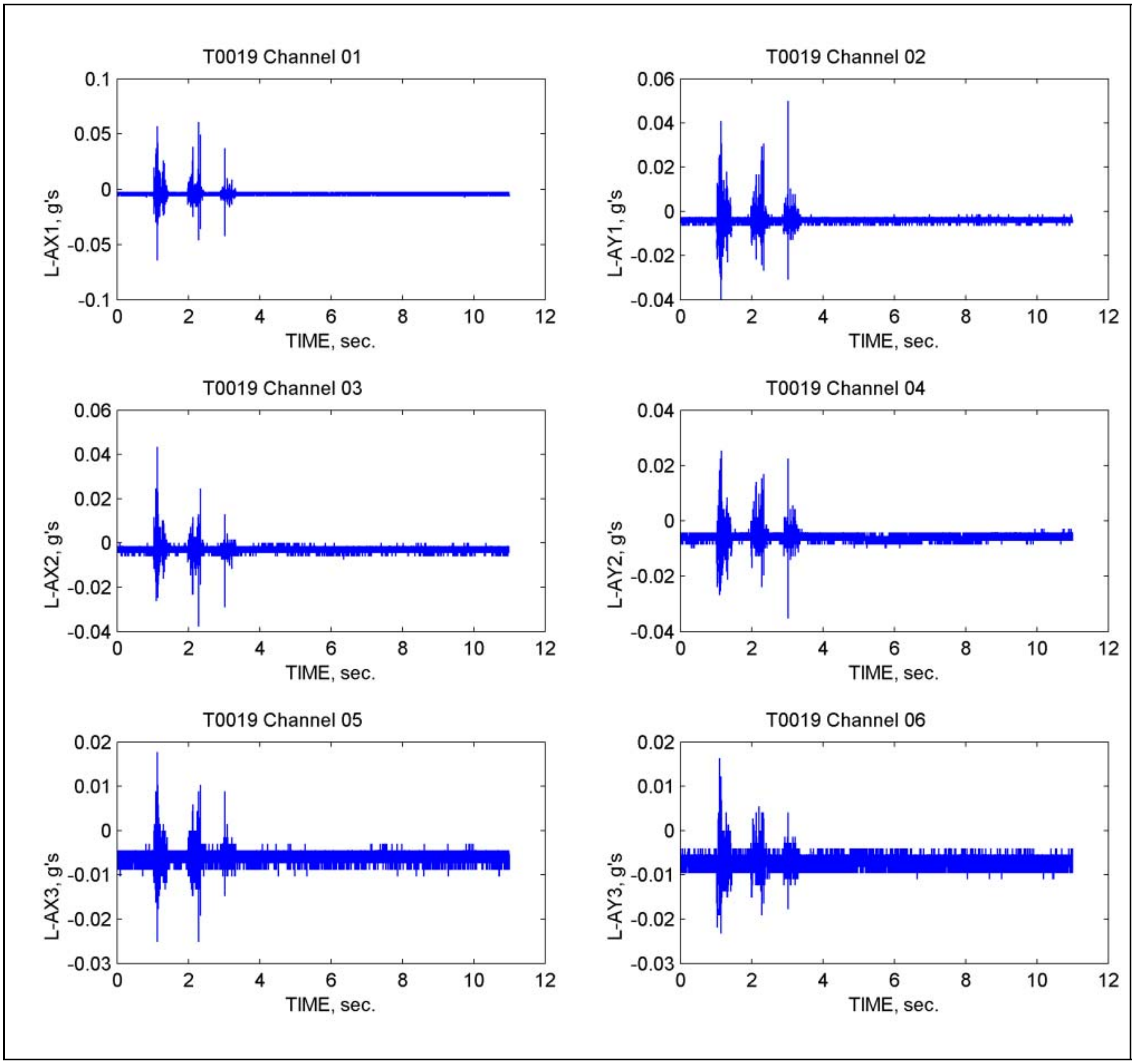
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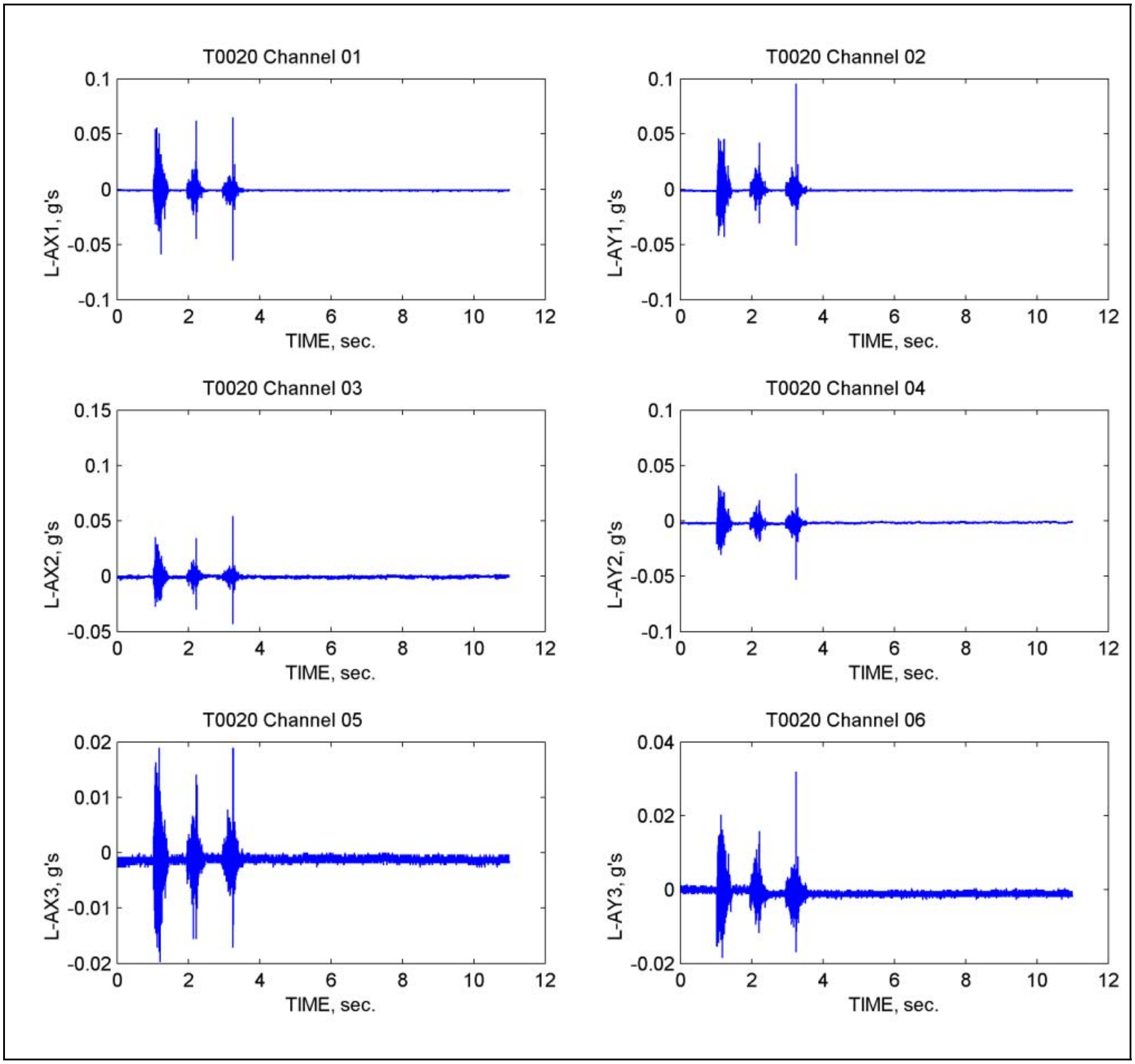
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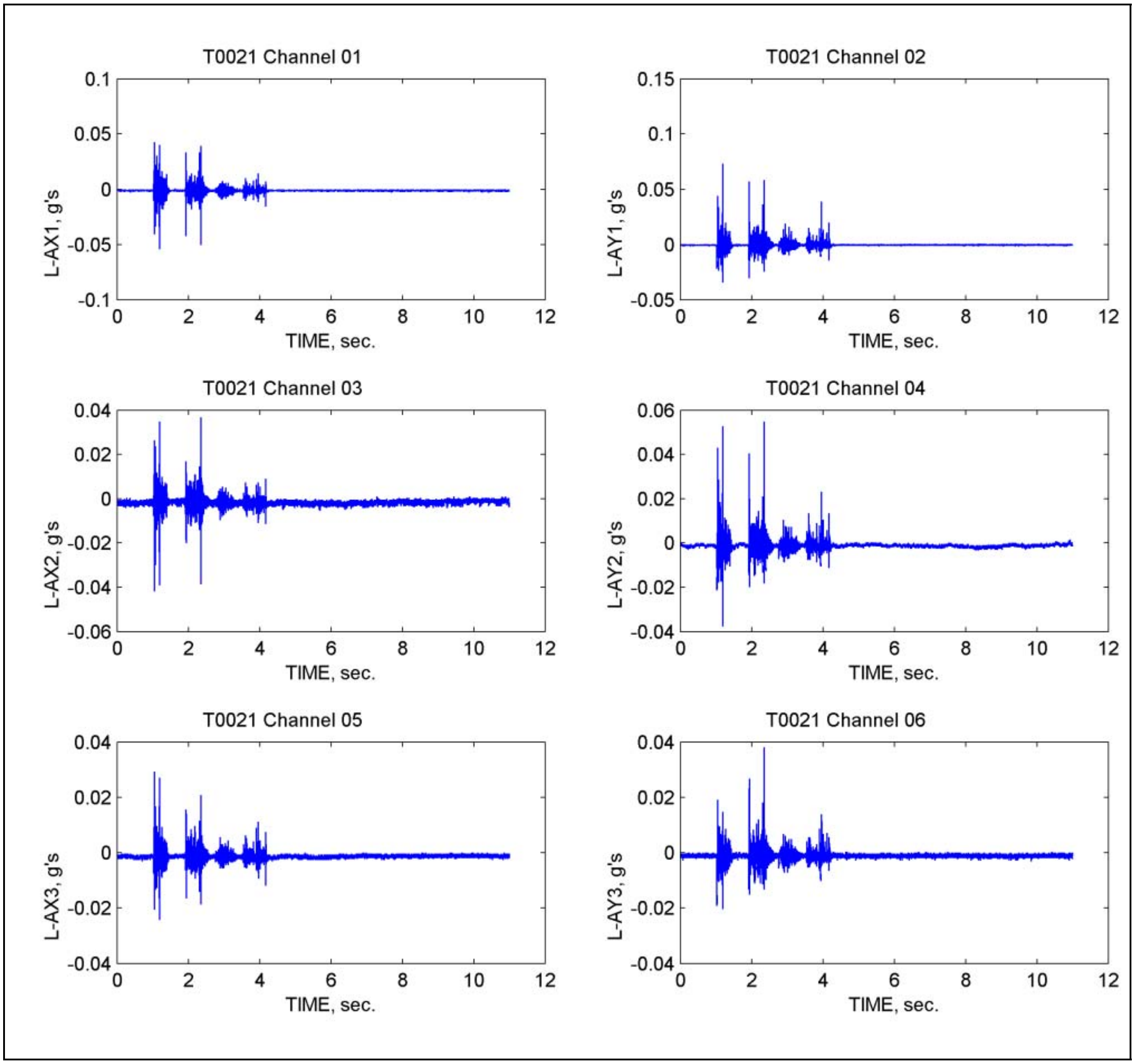
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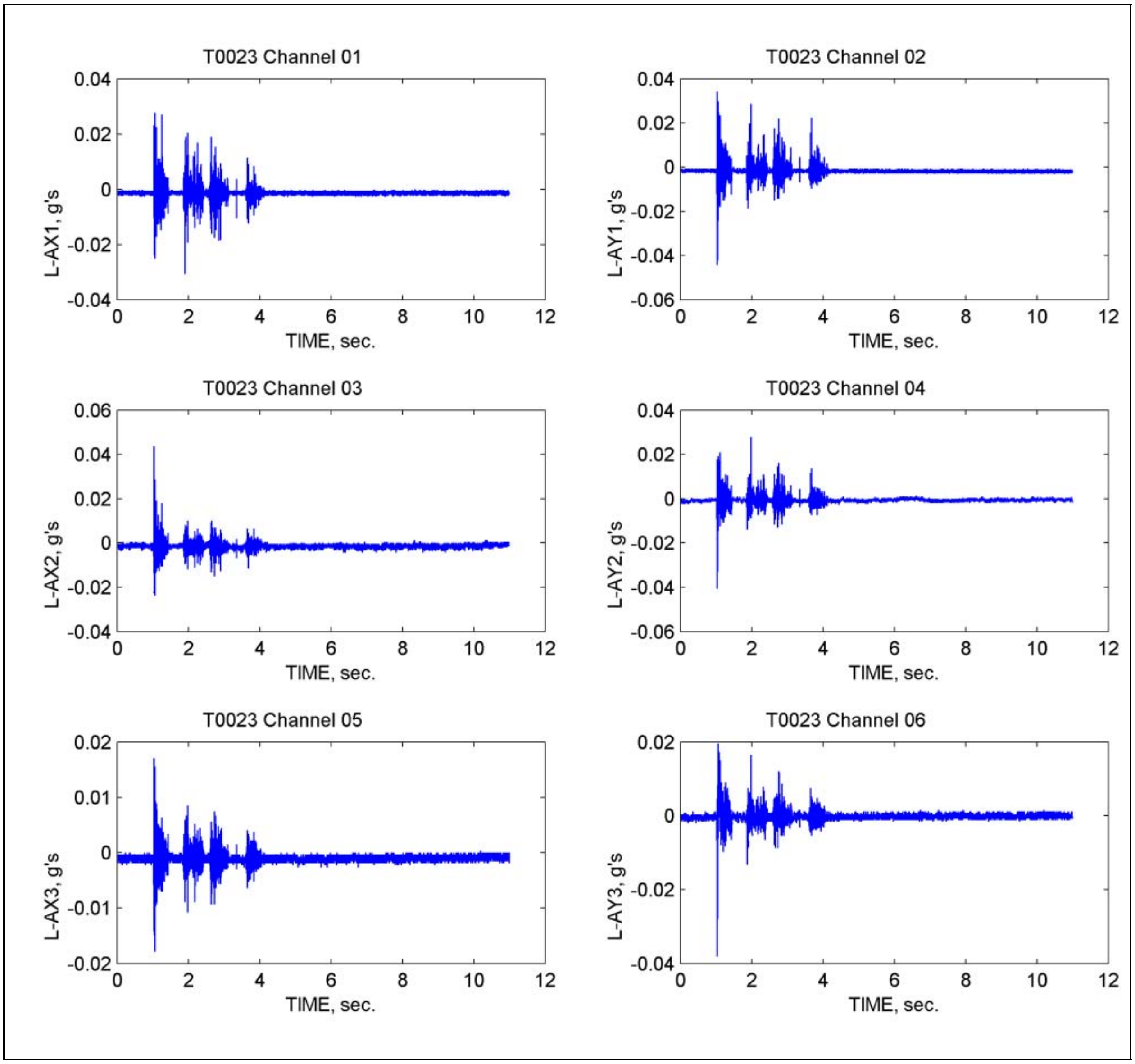
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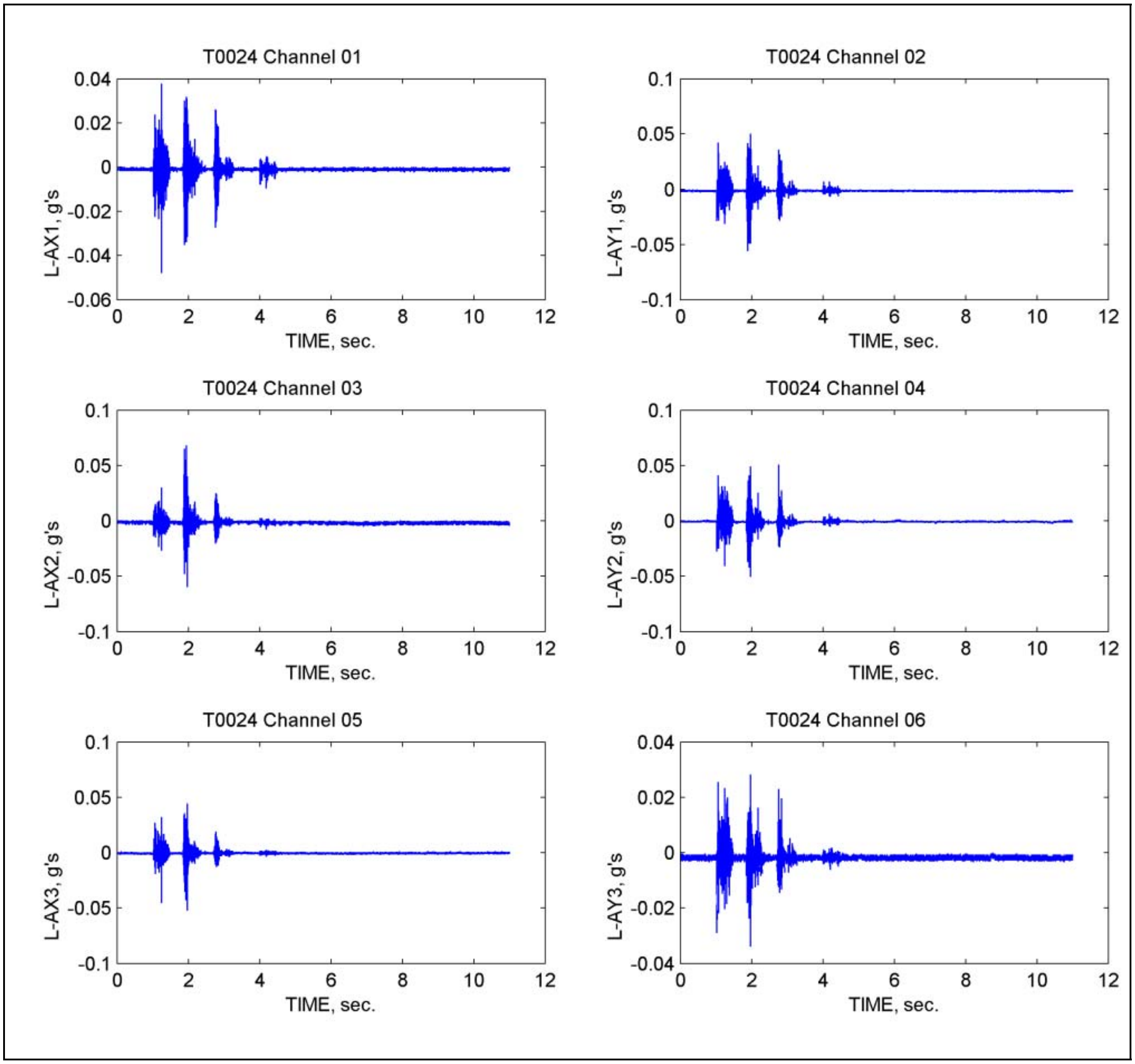
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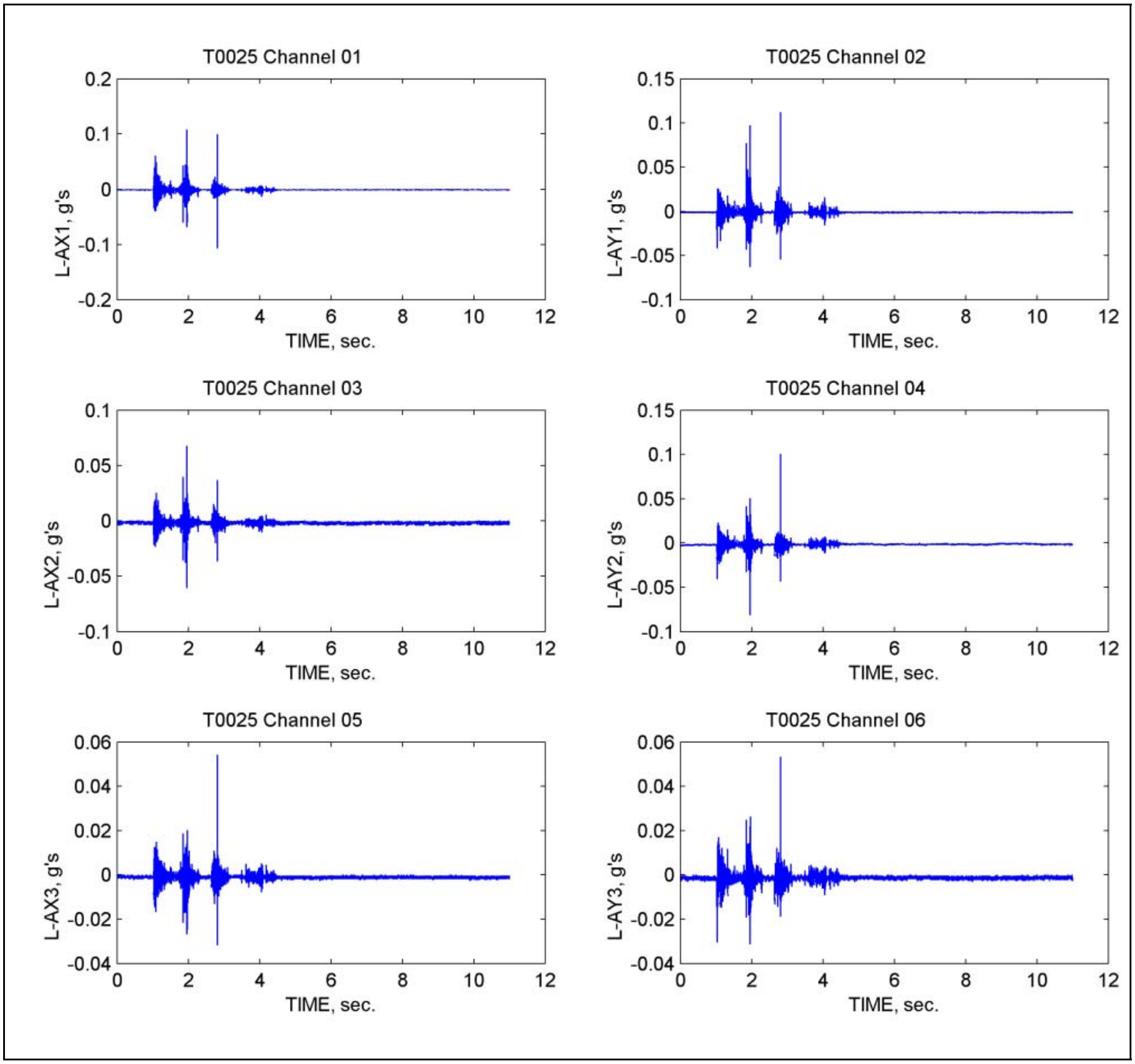
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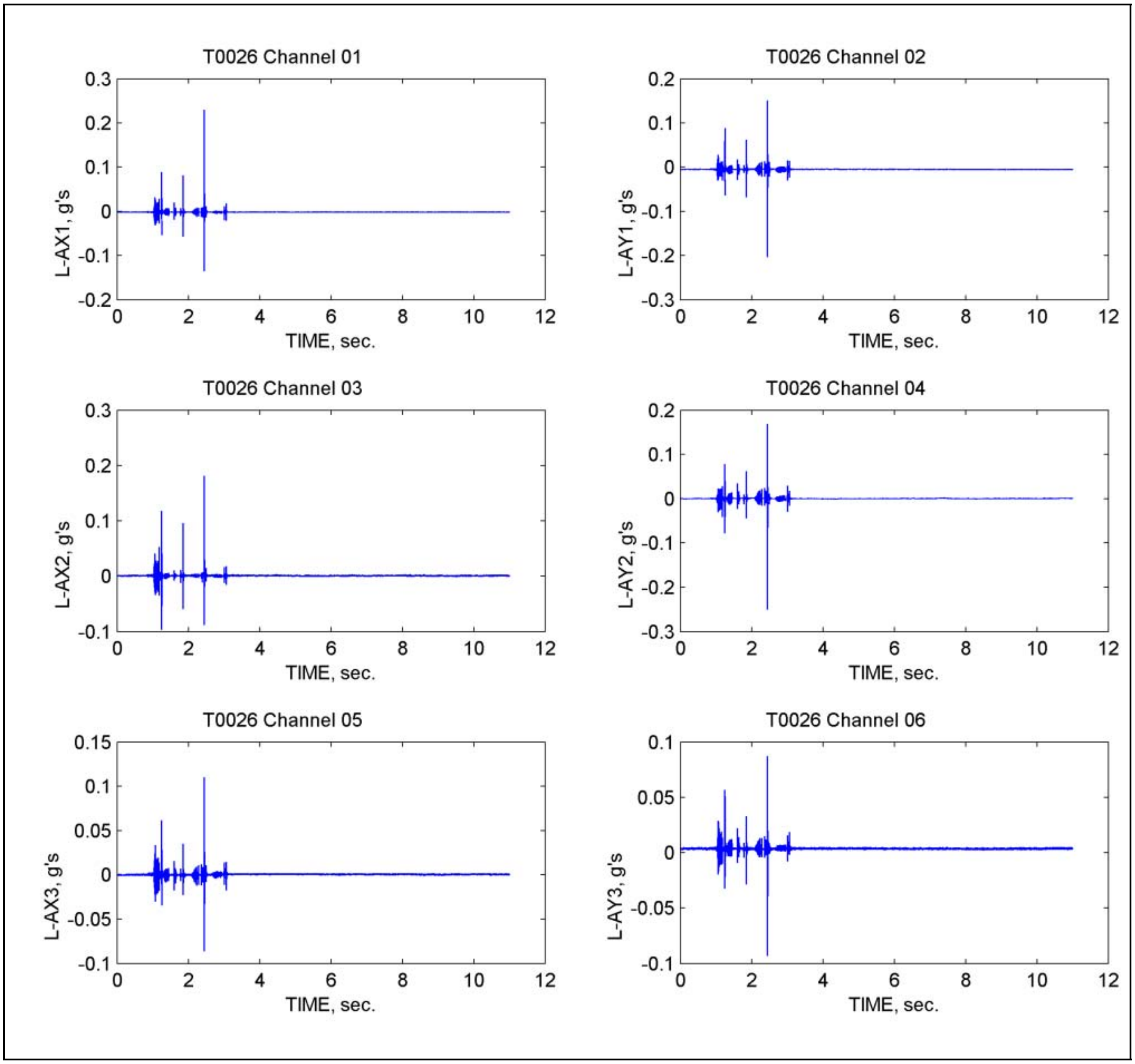
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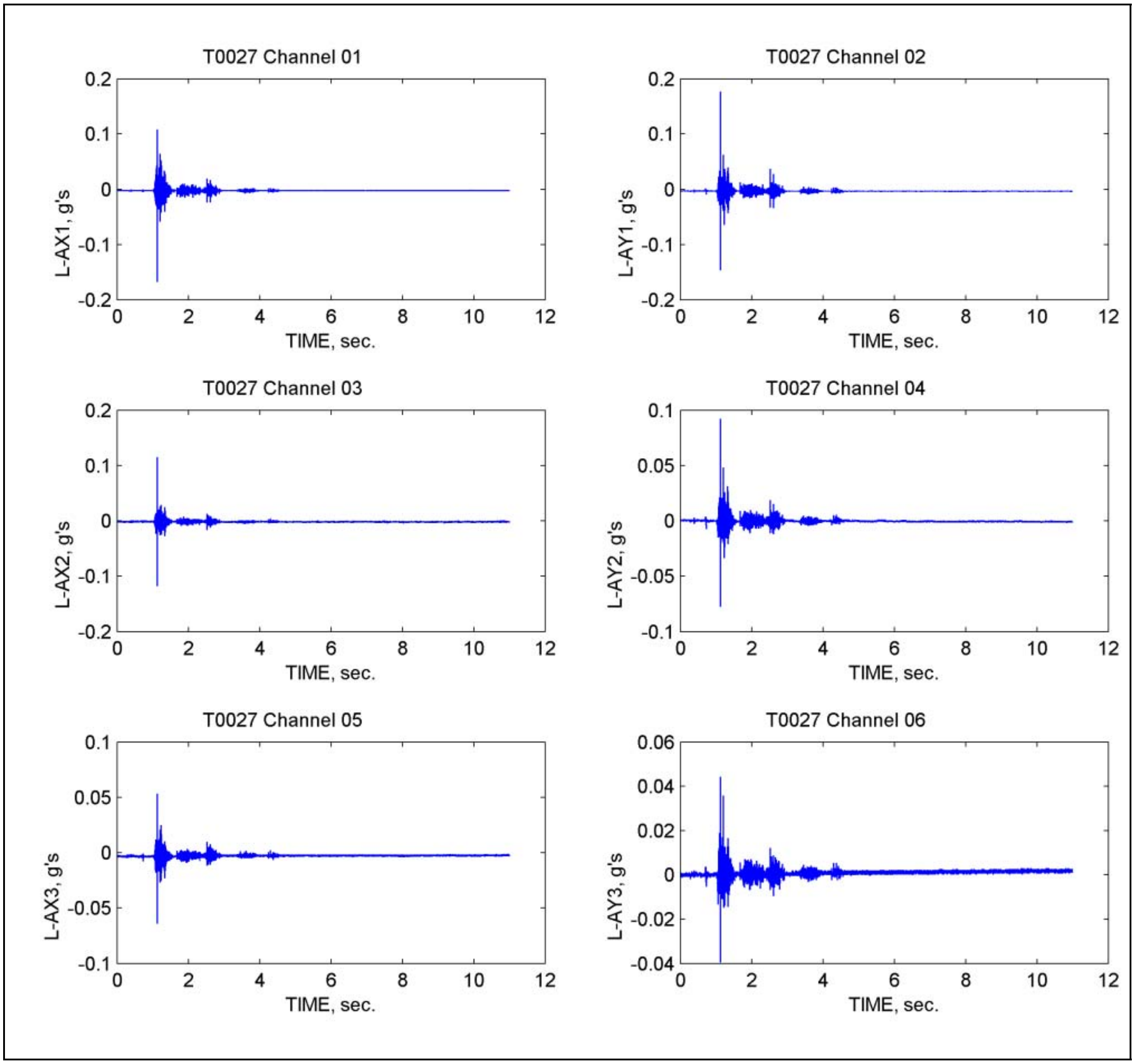
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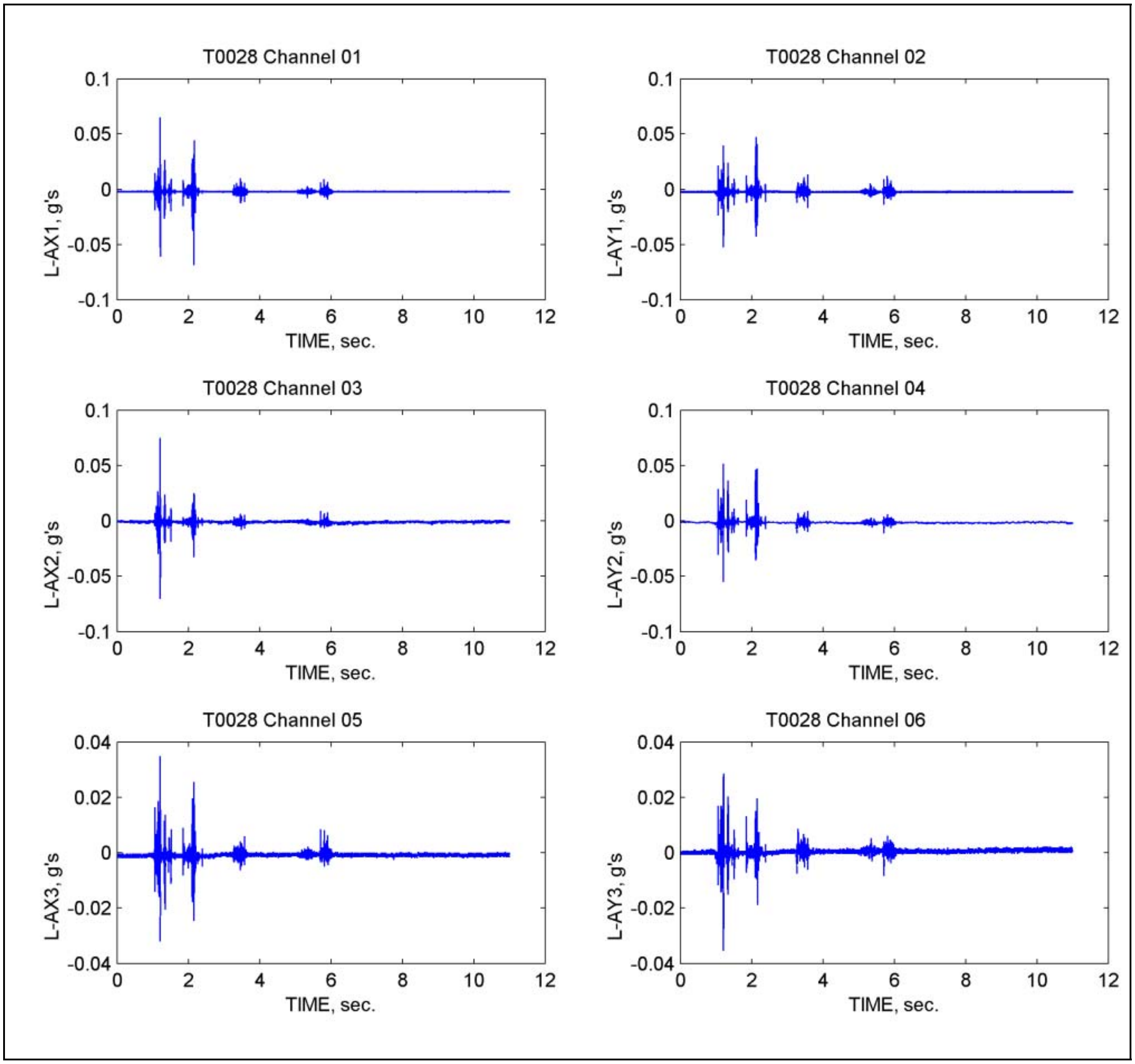
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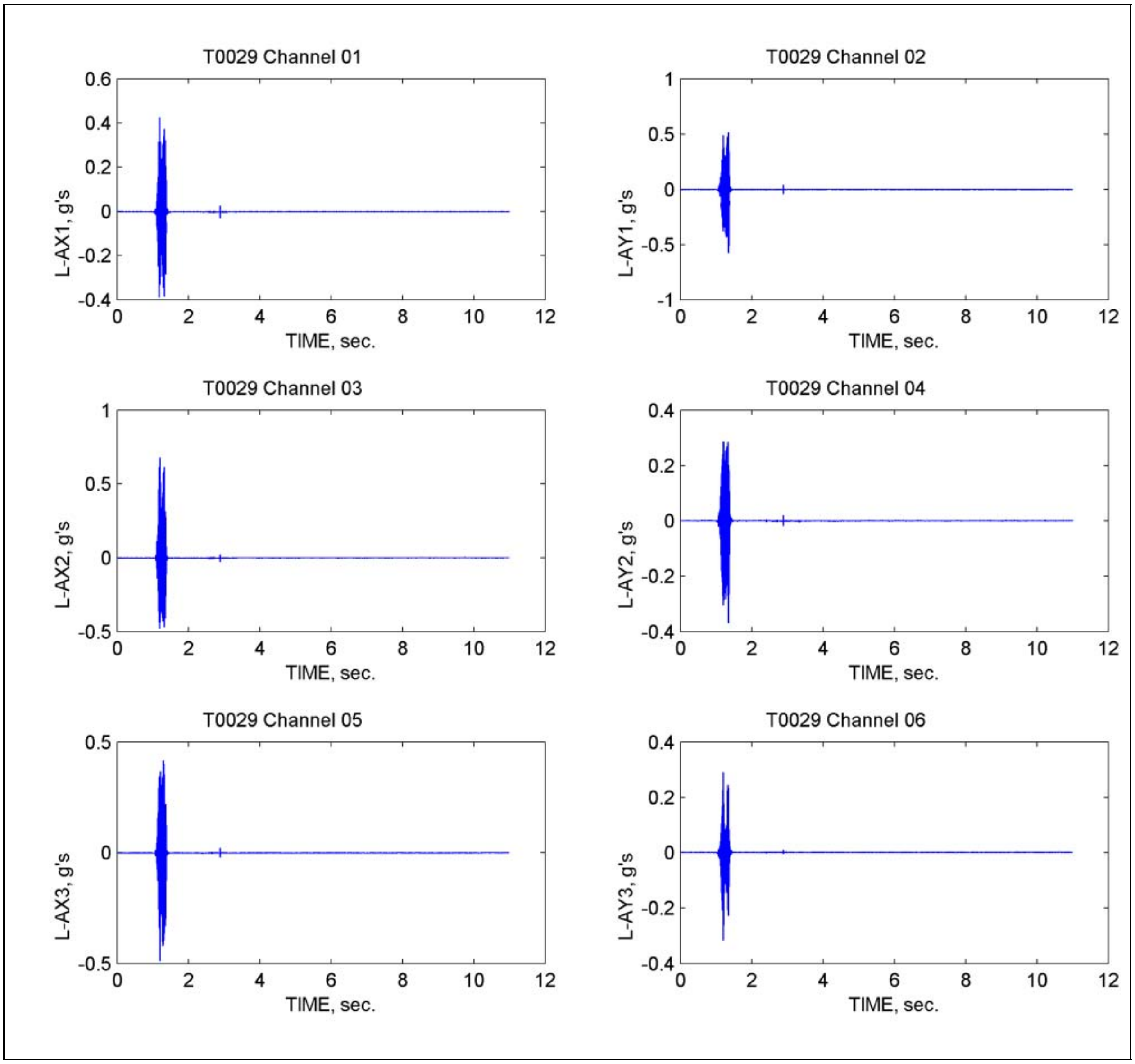
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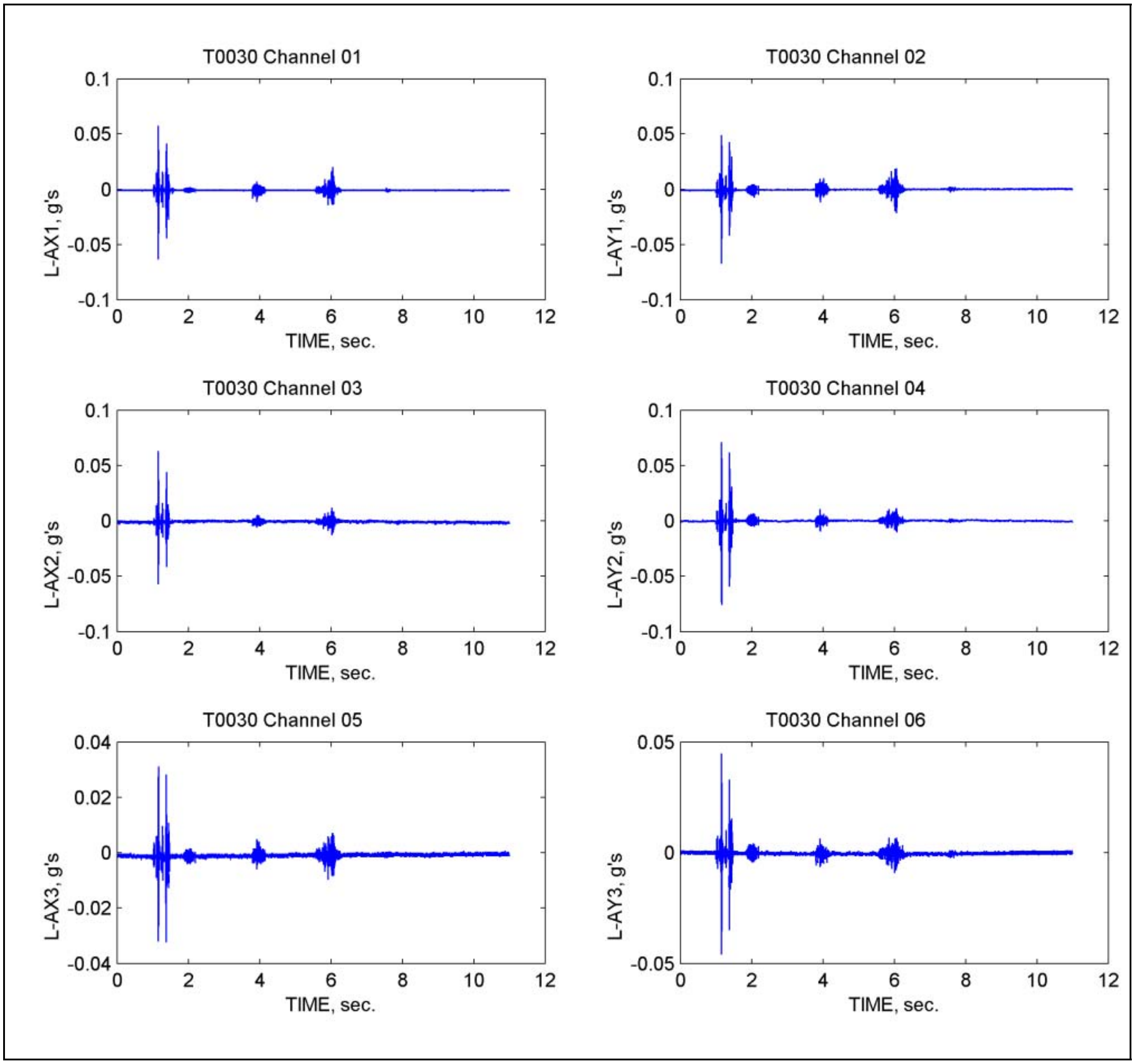
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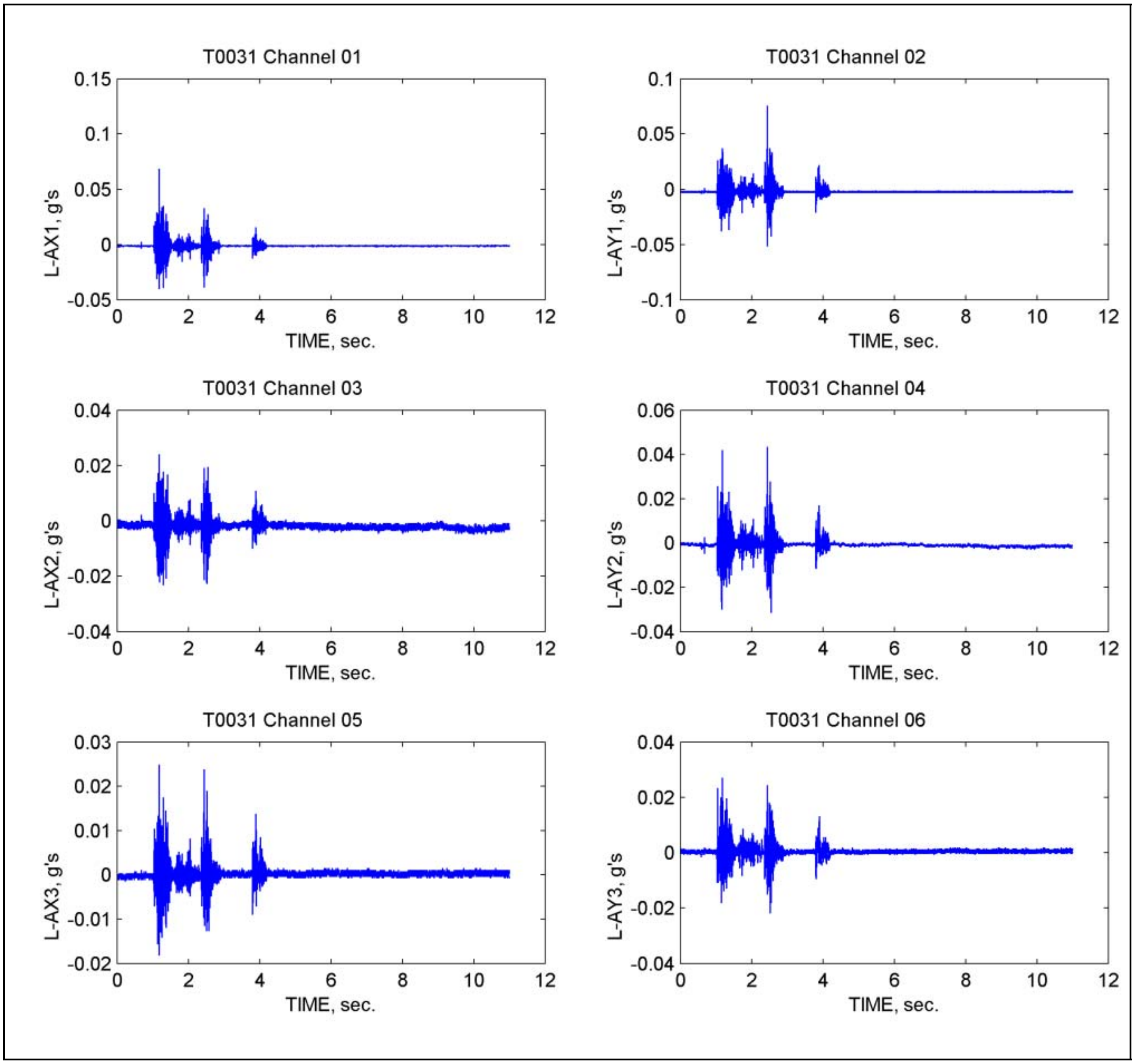
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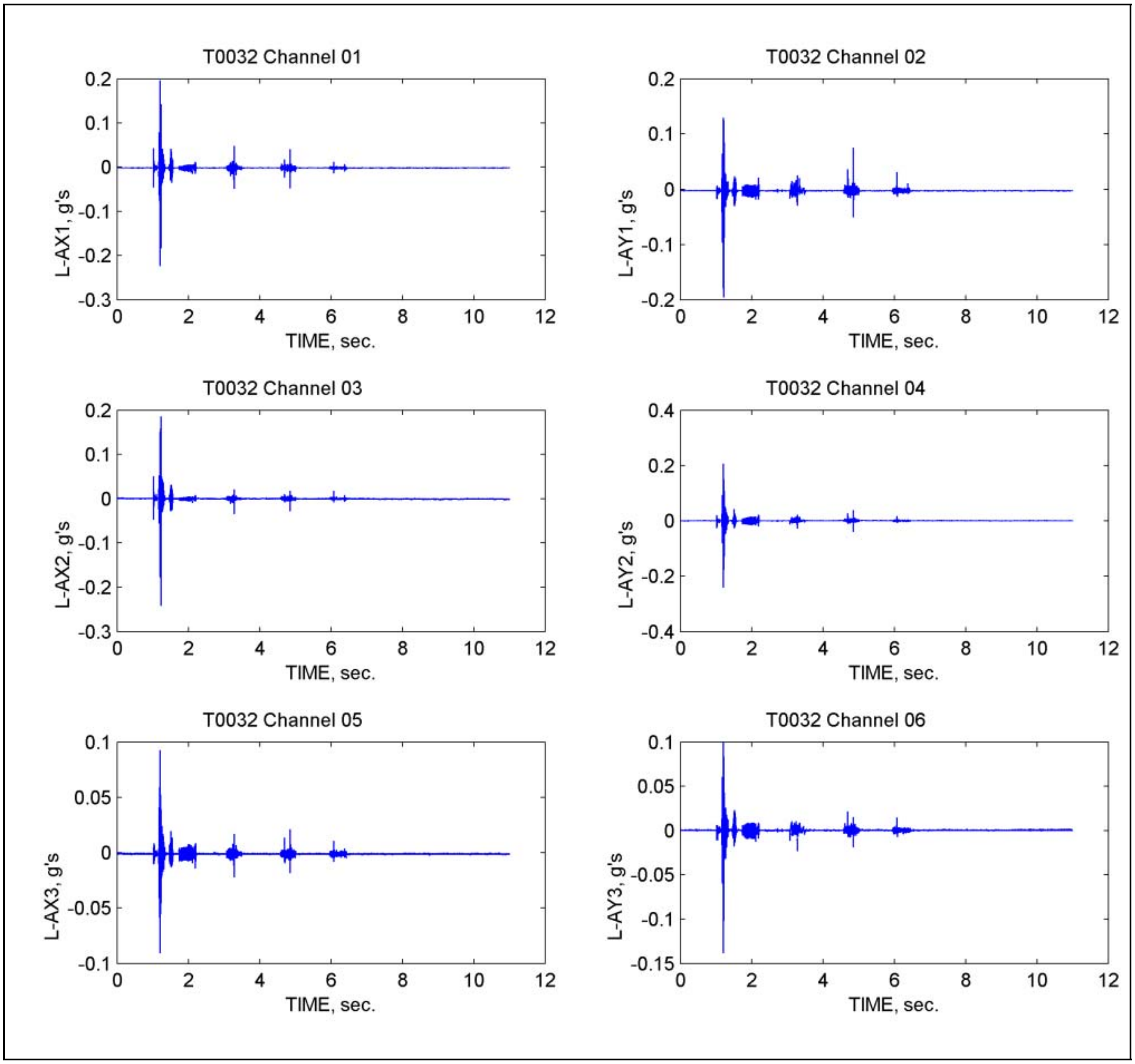
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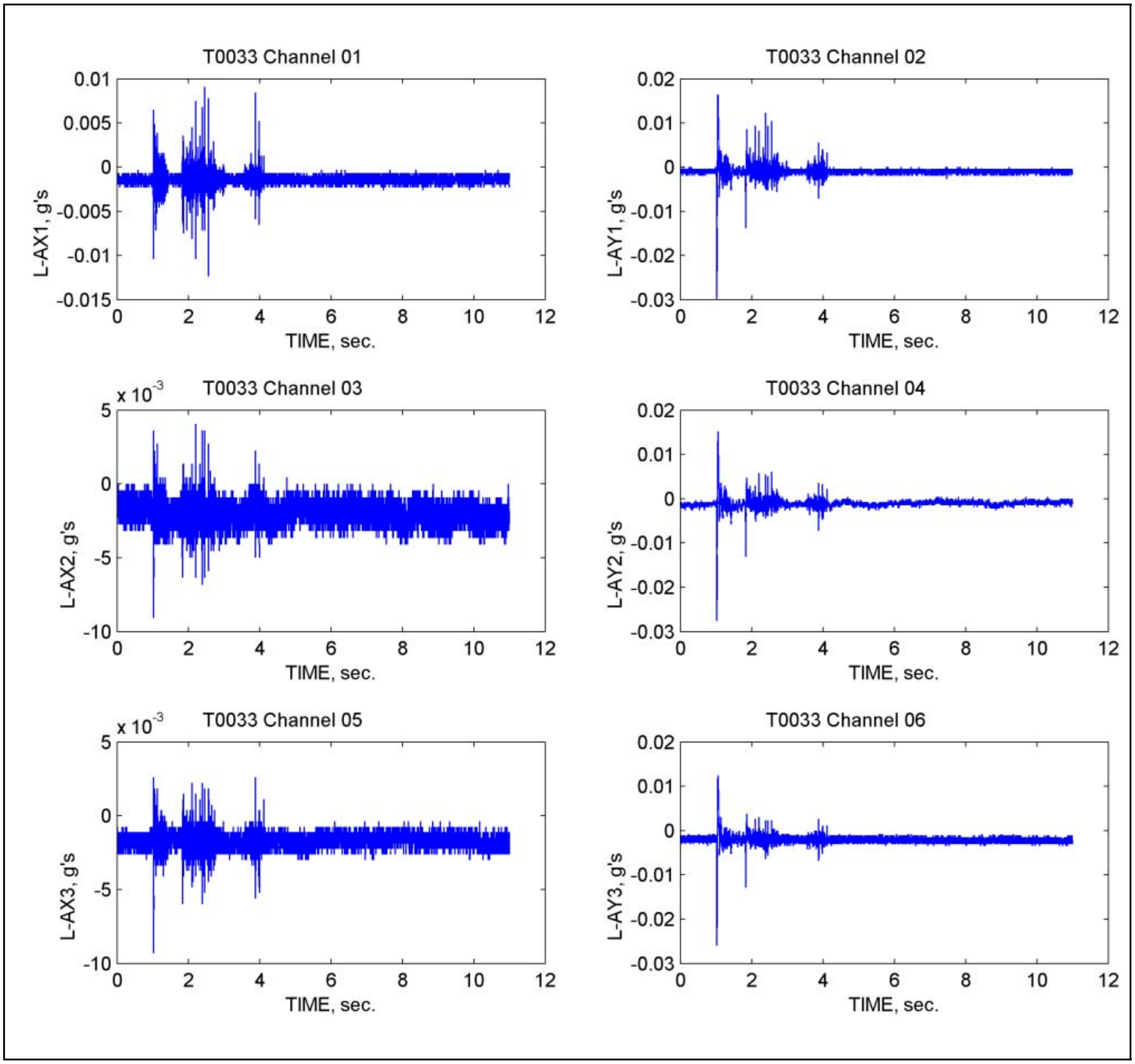
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TIME, sec.
T0033 Channel 03
x 10^-3
L-AX2, g's
TIME, sec.
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TIME, sec.
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x 10^-3
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TIME, sec.
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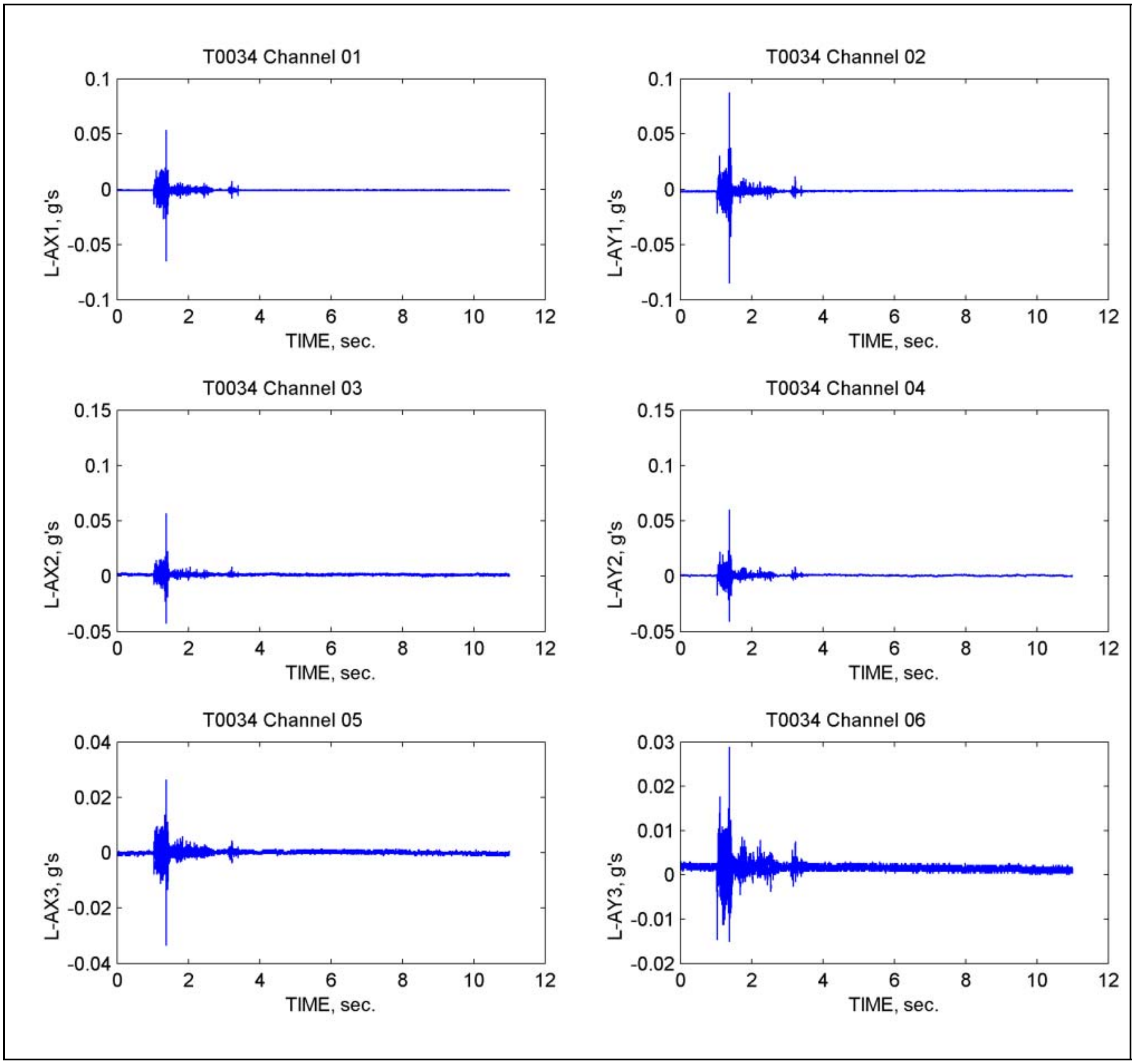
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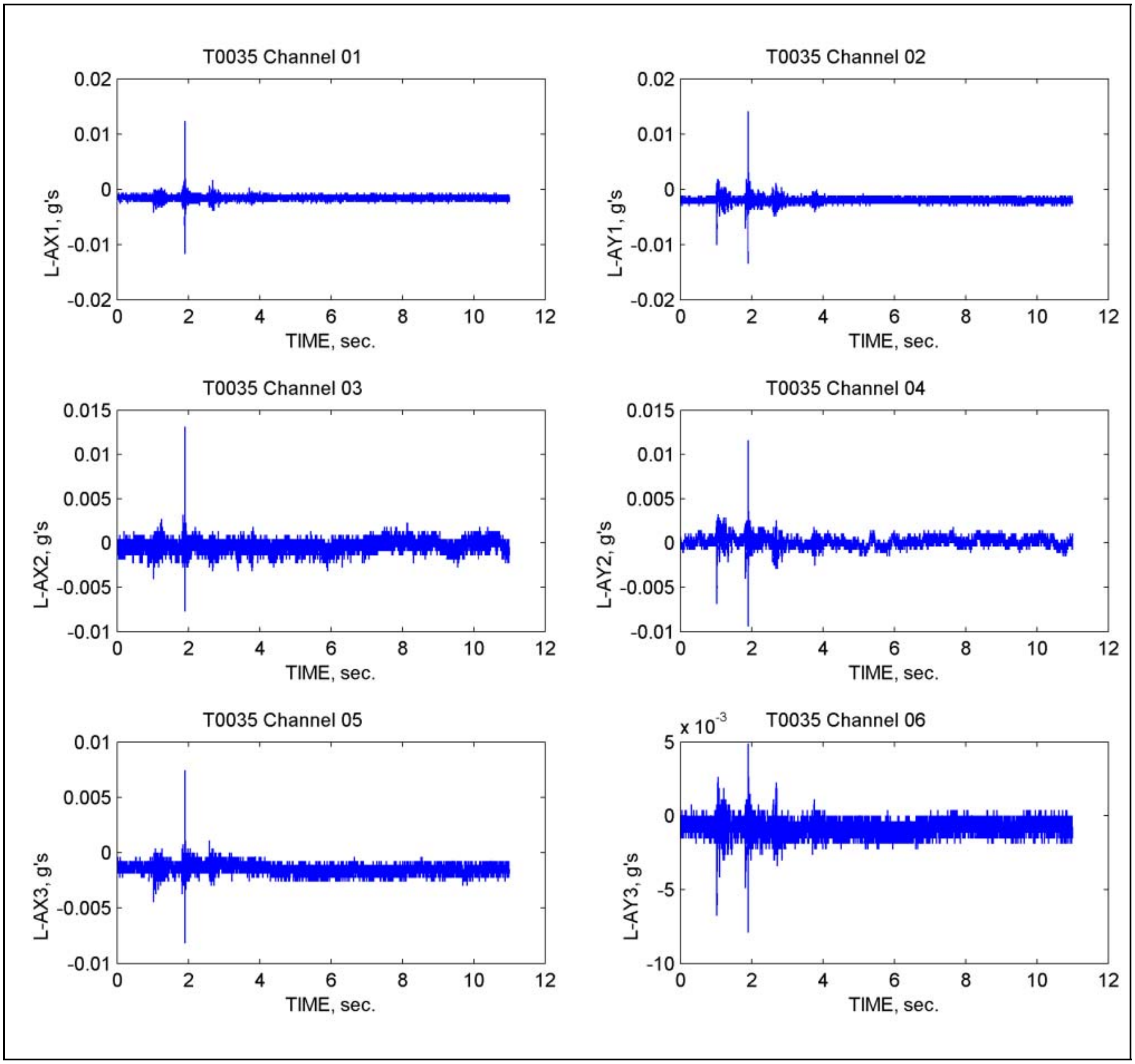
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x 10^-3
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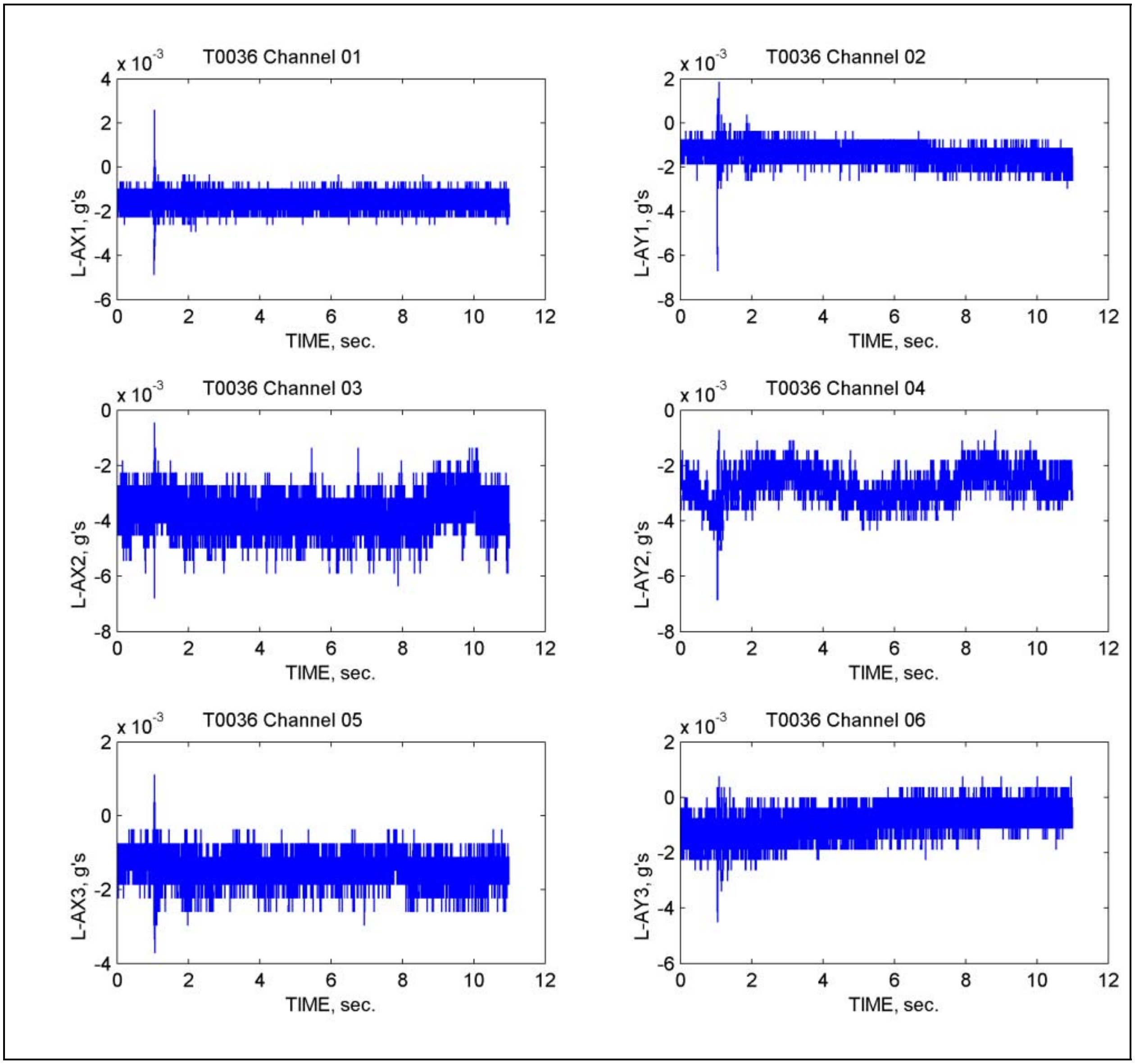
TIME, sec.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x 10^-3
L-AY2, g's
TIME, sec.
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x 10^-3
L-AX3, g's
TIME, sec.
T0036 Channel 06
x 10^-3
L-AY3, g's
TIME, sec.

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14. ABSTRACT

"Prototype" full-scale barge impact experiments were conducted in late August 1997 at Old Lock and Dam 2 on the Allegheny River, just north of Pittsburgh, PA. The purpose of these experiments was to assist researchers in examining and quantifying the behavior of a barge system during impacts to a rigid lock wall.

These types of full-scale impact experiments—using a working towboat and inland waterway barges—have never been attempted before. Therefore, detailed research and development of instrumentation and data collection equipment was required to properly capture the behavior of an inland waterway tow during an impact into a rigid lock wall. The state-of-the-art instrumentation program used for these experiments was also developed with the idea that a similar instrumentation program (at yet a larger scale) could be applied to a true full-scale impact experiment using a fully ballasted 15-barge flotilla.

The experiments were conducted using a four-barge tow system that was composed of standard open-hopper rake barges. The tow was ballasted to 8.5 ft (2.4 m) of draft with an approximate mass of 4,000 short tons (3.6 million kg). A total of 36 prototype experiments were successfully conducted during the 3 days of testing. Twenty-five of these experiments were on a rigid concrete lock wall, and nine experiments were on ultra-high molecular weight (UHMW) plastic bumpers. These UHMW plastic bumpers were used to examine the energy transfer effects of barge systems impacting on a near-"frictionless" surface. The experiments yielded velocities ranging from 0.5 to 3.2 fps (0.1 to 0.9 m/sec) with angles of impact that ranged from 5 to 27 deg.

(Continued)

15. SUBJECT TERMS

Barge impact	Impact angles	Instrumentation	Tow
Flotilla	Impact velocities	Lock walls	Ultra high molecular weight (UHMW) bumpers
Full-scale experiments	Inland waterway	Prototype experiments	

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14. (Concluded)

The report includes descriptions of the experiment site, test schedule, and the towboat and barges used for the experiments. Detailed explanations are given of the instrumentation used, including data acquisition systems, barge and lock wall instrumentation, differential global positioning system (DGPS), and high-speed camera and videotape equipment. Concepts and installation of the UHMW bumpers are also discussed. Conclusions and recommendations are presented, in support of the layout and instrumentation required for the future full-scale experiments using a 15-barge flotilla. Appendixes to the report present the DGPS survey plots and a full collection of raw data plots from all 36 experiments.