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Seismic Testing of a Static Power Static Transfer Switch

James Wilcoski

November 2021



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Seismic Testing of a Static Power Static Transfer Switch

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Abstract

This test report documents seismic qualification testing of a Static Power Static Transfer Switch (STS). The STS is a mission-critical unit that will be installed at Eareckson Air Station (EAS), on the island of Shemya, Alaska. Two units were built, one of which was tested on the ERDC-CERL shake table on 10 November 2020, and the other delivered to EAS for installation. This report presents details on the STS configuration, seismic tests conducted, and the performance of the unit. The unit passed the final seismic test and can now confidently be installed at the EAS.

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Contents

Abstract.....	ii
Figures and Tables.....	v
Preface.....	vii
1 Introduction.....	1
1.1 Background.....	1
1.2 Objectives.....	1
1.3 Approach	1
1.4 Scope.....	2
1.5 Mode of technology transfer	2
2 Static Transfer Switch Configuration Details.....	3
2.1 Test laboratory contacts:	3
2.2 Unit manufacturer.....	3
2.3 OSHPD certification California licensed structural engineer.....	4
2.4 Details for the STS	4
2.4.1 STS drawings and other details.....	7
3 Seismic Hazard and Test Motions	16
4 Seismic Evaluation of Bolts Anchoring the STS	21
5 Instrumentation, Functional Requirements, Seismic Test Steps, Test Equipment Specifications and Calibrations.....	26
5.1 Instrumentation	26
5.2 Functional requirements	27
5.3 Component product line extrapolation and interpolation.....	28
5.4 Installation instructions.....	28
5.5 Seismic test steps.....	29
5.6 Test equipment specifications and calibrations	30
6 STS Seismic Test Results	31
6.1 System identification tests.....	31
6.2 Seismic test response motions and test response spectra	32
6.3 Functional test results and visual observations after seismic tests.....	43
7 Summary	50
References.....	51
Acronyms and Abbreviations	52
Unit Conversion Factors.....	54
Appendix A: Scale and Accelerometer Calibration Certificates	55

Appendix B: Photographs of Accelerometers used to Document Seismic Tests	81
Appendix C: Functional Tests Conducted Prior to Seismic Testing	85
Appendix D: Functional Tests Conducted After Seismic Testing	86
Appendix E: Static Power STS Transfer Function Plots	87
Appendix F: STS Testing Coherence Function Plots.....	89
Report Documentation Page.....	91

Figures and Tables

Figures

1	Electrical specifications overleaf for the STS. (Image reproduced from Static Power with permission.)	6
2	Nameplate to be installed on the STS. (Image reproduced from Static Power with permission.)	7
3	Perspective view of Static Power Static Transfer Switch (STS) showing standard base mounting without steel channels. (Image reproduced from Static Power with permission.)	8
5	Front external and left-hand side internal elevation views of the STS (dimensions in mm). (Image reproduced from Static Power with permission.)	9
6	Front internal, right-hand side internal elevation and bottom external views of the STS (dimensions in mm). (Image reproduced from Static Power with permission.)	10
7	Construction layout and details for the Static Power STS. (Image reproduced from Static Power with permission.)	11
8	Locations and orientation channels at base of Static Power STS—note the bolt anchoring the channels to the 2 in. (51 mm) plate at the <i>front-right corner</i>	12
9	Right side of the STS interior showing anchor bolts and A3 accelerometers	13
10	Drawing of raised access floor framing at the EAS MET site	14
11	Photograph of the raised access floor framing	15
12	Required response spectra for Shemya, Alaska (5% of critical damping)	19
13	Generated longitudinal test motions for $S_{DS} = 1.5$ g and $z/h = 1.0$	19
14	Generated lateral test motions for $S_{DS} = 1.5$ g and $z/h = 1.0$	19
15	Generated vertical test motions for $S_{DS} = 1.5$ g	20
16	TRS plotted relative to the RRS, and RRS upper and lower bounds for the 40% seismic test	34
17	Recorded motions in the x-axis in the 100% seismic test	34
18	100% seismic motions in x-axis, 16 to 17 seconds	35
19	100% seismic motions in x-axis, 16.6 to 16.8 seconds	35
20	Recorded motions in the y-axis in the 100% seismic test	37
21	100% Seismic motions in y-axis, 16 to 17 seconds	37
22	100% Seismic motions in y-axis, 16.5 to 16.8 seconds	38
23	Recorded motions in the z-axis in the 100% seismic test	40
24	100% Seismic motions in z-axis, 16 to 17 seconds	40
25	100% Seismic motions in z-axis, 16.5 to 16.6 seconds	41
26	TRS plotted relative to the RRS, and RRS upper and lower bounds for the 100% seismic test	42
27	Front view of the STS with the front panel closed and electrical power and load bank connected	44

28	Front view of the STS with the front door opened	44
29	Front view of the STS with the front door opened and front plate removed	45
30	Bottom interior of the STS.....	46
31	Right side of the STS prior to seismic tests.....	47
32	Back right corner of the STS after seismic tests	47
33	Front left corner of the STS after seismic tests	48
34	Close-up view of front left corner of the STS after seismic tests	48
35	Bottom of vertical cold-formed steel door latching bar.....	49
36	Top of vertical door latching bar.....	49
B-1	Overall front view of Static Transfer Switch with the door and cover plate opened showing sensor locations	81
B-2	Bottom left (south) side of the STS showing the A1x, A1y, and A1z accelerometers installed at the bottom left corner.....	82
B-3	Bottom-right corner of the STS showing the A2x, A2y, and A2z accelerometers.....	82
B-4	Interior view of the bottom right side of the STS, showing the A3x, A3y, and A3z accelerometers.....	83
B-5	Interior view of the STS near the center of gravity showing the A4x, A4y, and A4z accelerometers.....	83
B-6	Top exterior view of the STS showing the A5x, A5y, and A5z accelerometers at the top-right rear corner	84
E-1	Transfer function plots for the x-axis sine-sweep test	87
E-2	Transfer function plots for the y-axis sine-sweep test	88
E-3	Transfer function plots for the z-axis sine-sweep test	88
F-1	Coherence plots for 1.0 Hz frequency increment	89
F-2	Coherence plots for 2.0 Hz frequency increment	90

Tables

1	Required response spectra for Shemya, Alaska (5% of critical damping)	18
2	Static Power STS accelerometer locations, purpose, measurement range, and resolution.....	27
3	Static Power STS transfer functions and modes	31
4	Maximum and minimum acceleration measured at the base of the channels.....	43

Preface

This study was conducted for the U.S. Army Corps of Engineers, New England District under MIPR number W13G8602258329; EARDB0562-Eareckson D-B Seismic RC5 [450048]—Project No.: 450048; and Work Item Code, WIC FLoDKJ. The technical monitor was Stephen W. Dunbar.

The work was performed by the Materials and Structures Branch of the Facilities Division, U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Vicki VanBlaricum was Chief, Giselle Rodriguez was Acting Chief, and Kurt Kinnevan was the Technical Director for Installations. The Deputy Director of ERDC-CERL was Ms. Michelle Hanson, and the Director was Dr. Andy Nelson.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

1.1 Background

Eareckson Air Station (EAS) at Shemya, Alaska is being upgraded with a new Modernized Enterprise Terminal (MET). Several equipment components at this site are critical to the operation of the MET and must remain operational following a possible large earthquake. The Static Transfer Switch (STS) is considered a Mission-Critical Level 1 (MC-1) component by Unified Facilities Criteria (UFC) 3-310-04, *Seismic Design for Buildings*, Section 4-13.2.1.2 (DoD 2013). This section of the UFC states that “MC-1 components shall be certified as operable immediately following the Risk-targeted maximum considered earthquake (MCE_R) ground shaking in accordance with the provisions of American Society of Civil Engineers (ASCE) 7-10, Section 13.2.2, as modified by Chapter 2 of this UFC” (DoD 2013, Section 4-13.2.1.2).

This testing was considered a site-specific qualification test, where the unit was qualified for the seismic hazard for that site. The unit will be installed in a single-story building and will be anchored to a raised floor. A second identical unit may be tested in the future to obtain California Office of Statewide Health and Planning and Development (OSHPD) approval.

1.2 Objectives

The objective of this testing was to certify the STS in accordance with the requirements of the International Code Council Evaluation Service (ICC-ES) *Acceptance Criteria for Seismic Qualification by Shake-Table Testing of Nonstructural Components*, AC156 (2010). This certification was required to install the STS at EAS.

1.3 Approach

This report documents these tests by defining the following details:

1. STS configuration and anchorage details
2. Definition of the seismic hazard and test motions
3. Seismic evaluation of bolts anchoring the STS
4. Instrumentation
5. Functional test requirements

6. Seismic test steps
7. Test equipment specifications
8. Sensor and scale calibrations
9. Seismic test results

1.4 Scope

This report provides the STS configuration details, seismic hazard definition for the location at which this unit will be installed, seismic test plans, and test results. This report documentation provides sufficient basis for installing this STS at the EAS site. This seismic testing of a single unit does not provide a basis for installing the unit at other sites that require OSHPD approval, because OSHPD requires testing at least two units.

1.5 Mode of technology transfer

This report is the sole documentation of the seismic qualification tests. In the future, another STS may be tested, and if so, another report will be generated to gain OSHPD approval of the STS for use at other sites.

2 Static Transfer Switch Configuration Details

This chapter presents details on the test laboratory and configuration of the STS.

2.1 Test laboratory contacts:

Written by James Wilcoski, ERDC-CERL,
Structural Engineer and shake table testing manager
Email: James.Wilcoski@usace.army.mil
Phone: 217-373-6763
Cell: 217-898-6413

Test Laboratory Address:
ERDC-CERL
Attn: James Wilcoski
2902 Newmark Dr.
Champaign, IL 61822

Shake Table Operator:
Thomas Carlson
Materials Engineer
Email: Thomas.A.Carlson@usace.army.mil
Phone: 217-373-3343
Cell: 217-979-3394

2.2 Unit manufacturer

Static Power Pty Ltd.
5, Candlebark Court
Research, 3095 Victoria
Australia
Static Power primary contact:
James Tong / Robert Heezeman
+61425368352/ +31414323890
Office Phone: +61-3-9437-0494
Email: jamest@staticpower.com.au
Email: roberth@staticpower.com.au
www.staticpower.com.au

2.3 OSHPD certification California licensed structural engineer

Derek Manwill
Manwill Engineering
P.O Box 1194
Bend, OR 97709
Email: derek@manwillse.com
Cell: 541-241-2102

2.4 Details for the STS

Static Power, the manufacturer of the STS, provided the following detailed specifications for their unit: model number i-STS H 3P4 0160 (Type: i-STS160Hs3P4-120/208-S).

A Static Transfer Switch (STS) provides seamless switching between two power sources to provide interrupted power to a critical load(s). Figure 1 is an electrical specification overleaf for this STS.

The STS continuously monitors the supply sources for failure or degeneration and switches automatically to the alternate source if the connected source was to fail or degrade before the critical load would be affected.

The transition from connected to alternate sources is break-before-make; the break in the supply transition is so short that it is not seen by the critical load. Break-before-make transfers prevent overlapping, which can cause large and unpredictable currents that would otherwise occur while the supplies are connected. In this transfer, the active conductor and the neutral are switched through the use of thyristors. In the case of the neutral, it is overlapping until all the active conductors have been switched.

In the case of downstream load fault conditions, the fault current drawn from the supply may degrade or damage the supply sources; consequently, should a fault current exist in the load, the STS will inhibit a transfer to the alternate source even if this causes source supply degradation or loss. This is to ensure that the fault will not be transferred to the alternate supply with the possibility of degrading both sources.

The STS model used in the testing was a 3-Phase/4 wire, 160 ampere, 120/208 volts, and 50/60 Hz model.

The enclosure consisted of a single door of sheet steel with a mounting plate and open base plates for cable entry and cooling air. The enclosure sheet steel was 1.5 mm (0.06 in.) thick; the door sheet steel was 2 mm (0.08 in.) thick and foamed all around with a polyurethane (PU) seal. The door was hinged with a three-point lock system with a double-bit insert. The mounting plate sheet steel was 3 mm (0.12 in.) thick.

The physical dimensions were 1320 mm high × 600 mm wide × 300 mm deep (52.0 in. high × 23.6 in. wide × 11.8 in. deep); and the weight of the STS without the supporting channels was 117 kg (259 lb), and 123 kg (271 lb) with them. * The STS was weighed using a scale at the ERDC-CERL warehouse, and the scale calibration certificate is provided in Appendix A.

The elevation of the center of mass is 567 mm (22.3 in.) above the channels used to anchor the STS to its supporting structure.

The seismic importance factor I_p equaled 1.5

The seismic version of the STS includes the following improvements over the standard version:

1. Additional mechanical support for holding the door closed during seismic activity was added, consisting of domed nuts to through bolt holding the door against the cubicle.
2. Knurled lock screws were added to the circuit breaker mechanical interlock.
3. Loctite, locknuts, or Nylocks, were applied to all nuts.

* Static Power submitted specification with metric units, but the U.S. participants use U.S. standard units.

Figure 1. Electrical specifications overleaf for the STS. (Image reproduced from Static Power with permission.)

iSTS Model H	
STATIC POWER SMART SOLID SAFE	
Type: i-STS160Hs3P4-120/208-S	
Current rating	3Ph: 160A max
Voltage rating	208/120 V $\pm 10\%$
Type	3-Phase/4-Pole (4-wire + Earth)
Frequency	50Hz and 60Hz, $\pm 10\%$ - Auto detection
Transfer type	Break-Before-Make zero current transfer by Thyristors / SCR
Synchronous break time	<1ms - asynchronous break time up to 1/2 cycle
MTBF	>800,000 hours
Maintenance bypass	5 Mechanically interlocked circuit breakers
Isolation	Incoming sources and output isolator switch (Total 5)
Display	Bi-colour LED mimic decal with graphic backlit LCD display and information interface
Interface	Preferred supply selection, Source transfer selection and Alarm cancel button
Contact	2 Self wetting transfer control inputs 5 Voltage free change-over status indicators, Form C
Ethernet	HTTP, SNMP, MODBUS TCP, Email & NTP
Input options	Terminals M10 - viagland plate
Output options	Terminals M10 - viagland plate
Dimensions H x W x D	1320 x 600 x 300mm
Weight	145kg
Temperature	0 – 45°C
IP rating	IP21
Detection	Digital: <1ms
Asynchronous break time	0ms, 10ms, 50ms or Vt proportional, 0° to 180°
Loading	0 - 100% @45°C ambient
Device ratings	1250A _{ave} , 1800V, 20kA 1 cycle
Overload @40°C ambient	125% for 10min 150% for 30s 1kA for 1s 20kA for 1 cycle
Fault current setting	350% peak with load fault transfer inhibit
Safe install environment	20kA for 1 cycle - Fuseless design
Protection	Circuit breakers
Power factor	No practical limit
Max THDV	10% - Max allowable source voltage distortion
Crest factor	3.5 : 1
dV/dt max	800V/µs
Cooling	Redundant fans
Humidity @40°C ambient	5 – 95% non-condensing
Standard warranty	24 months on-site repair or part replacement

Specifications are subject to change without notice

Figure 2 shows the details of a nameplate that is mechanically fastened to the STS. The test date and report number were added to this plate.

Figure 2. Nameplate to be installed on the STS. (Image reproduced from Static Power with permission.)

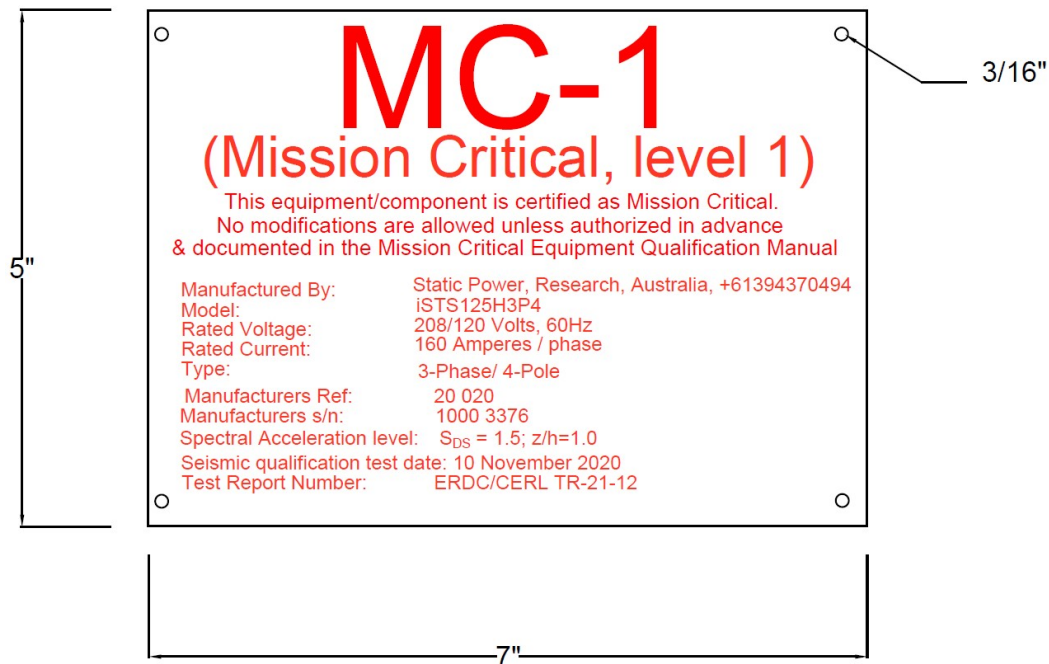


Plate size is 7 inch wide x 5 inch high

"MC1" is 1 Inch lettering

"(Mission Critical, Level 1)" 3/8 inch high Equipment Criticality Note is 5/32

inch high Rating Details is 1/8 inch high

Additional Notes are 1/8 inch high

Engraved Trafalite or equivalent White with Red lettering engraved

Figure 3 is a perspective view of the STS, and Figure 4 is a single line electrical schematic diagram of the unit. Figure 5 and Figure 6 are elevation and bottom views of this unit. Figure 7 provides further details on the construction and layout.

All power components are solidly bolted to the aluminum heat sink and back panel mounting plate of the enclosure. Circuit breakers are bolted onto a rigid, 1.2 mm (0.047 in.) galvanized iron channel, which is bolted to the mounting plate. All ancillary items and terminals are bolted directly to the back panel mounting plate.

Figure 3. Perspective view of Static Power Static Transfer Switch (STS) showing standard base mounting without steel channels. (Image reproduced from Static Power with permission.)

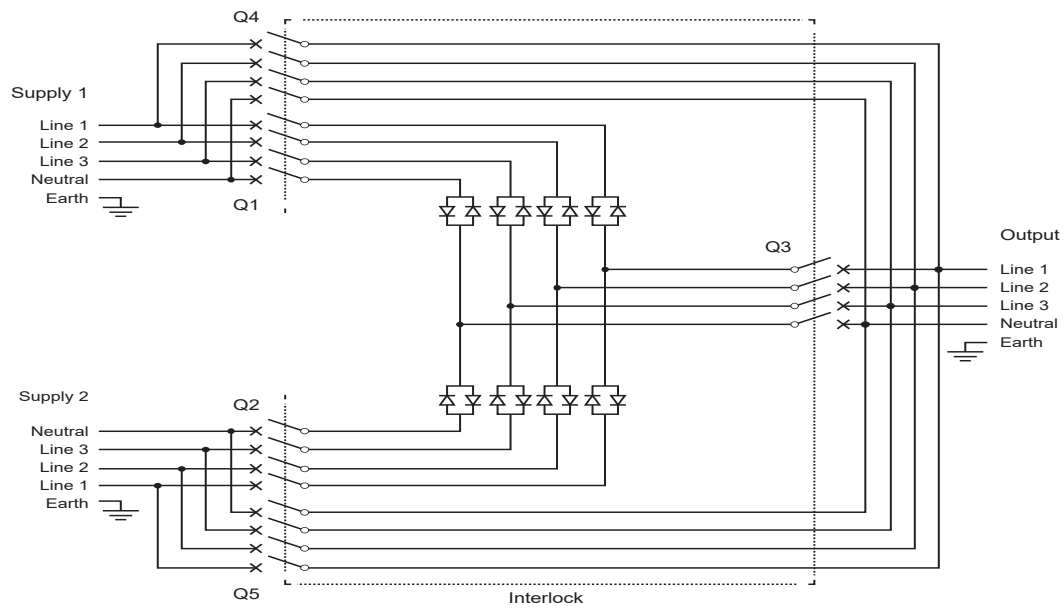
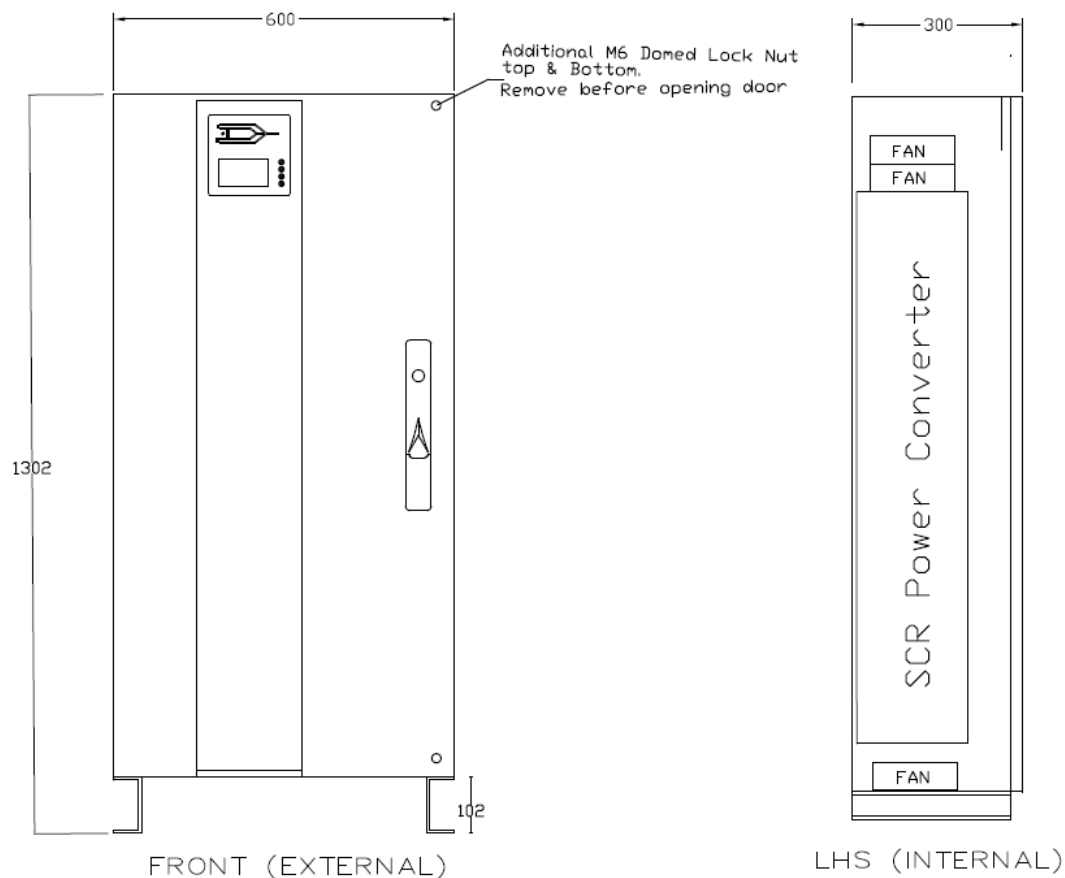


Figure 5. Front external and left-hand side internal elevation views of the STS (dimensions in mm). (Image reproduced from Static Power with permission.)



For seismic applications, the STS incorporated the following features:

- Heavy-duty doors, 2 mm (0.079 in.) thick, were used, with high-quality hinges and at least three latch points.
- The STS gravity and lateral load-resisting elements consist of welded and folded cold-formed steel sheets with 1.5 mm (0.059 in.) thickness.
- Locking nuts and washers were used to strengthen the rack-mounted components.
- Subcomponents were installed on a rear mounting plate, while additional subcomponents were fastened to a secondary mounting plate to the enclosure.
- All components of the STS had four points of bolted screws, with no free-flowing items.

- The two C4×6.5 steel channels were anchored to the base of the STS using one American Society of Testing and Materials (ASTM) Grade A307, 3/8 in.-16 bolt at each of the four corners, where the bolts were located 1½ in. (38 mm) from the ends of the channels. The same size and grade of bolts were used to anchor the channels to the supporting raised floor. Figure 8 provides a plan and elevation view of the base of the STS, showing the details of the supporting channels. The distance between bolts is 8 in. (203 mm) in the depth direction and 20⅞ in. (530 mm) in the width direction.
- The bolts fasten to the raised floor framing at EAS and to the heavy steel plates that are anchored to the shake table. The adequacy of these bolts is evaluated later in this report by calculating the applied loads and comparing with the allowable. A torque specification is used to ensure the bolts do not vibrate loose during an actual earthquake or shake table qualification testing. The same details used in shake table testing must be used at the EAS installation.

Figure 6. Front internal, right-hand side internal elevation and bottom external views of the STS (dimensions in mm). (Image reproduced from Static Power with permission.)

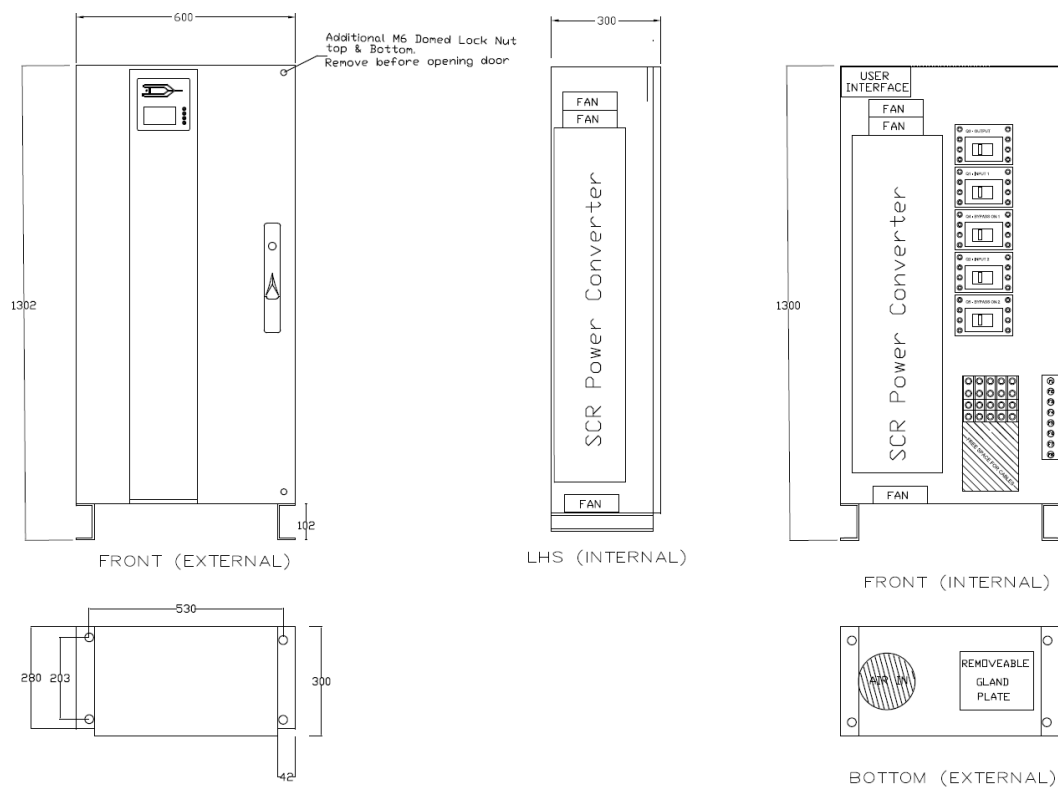


Figure 7. Construction layout and details for the Static Power STS. (Image reproduced from Static Power with permission.)

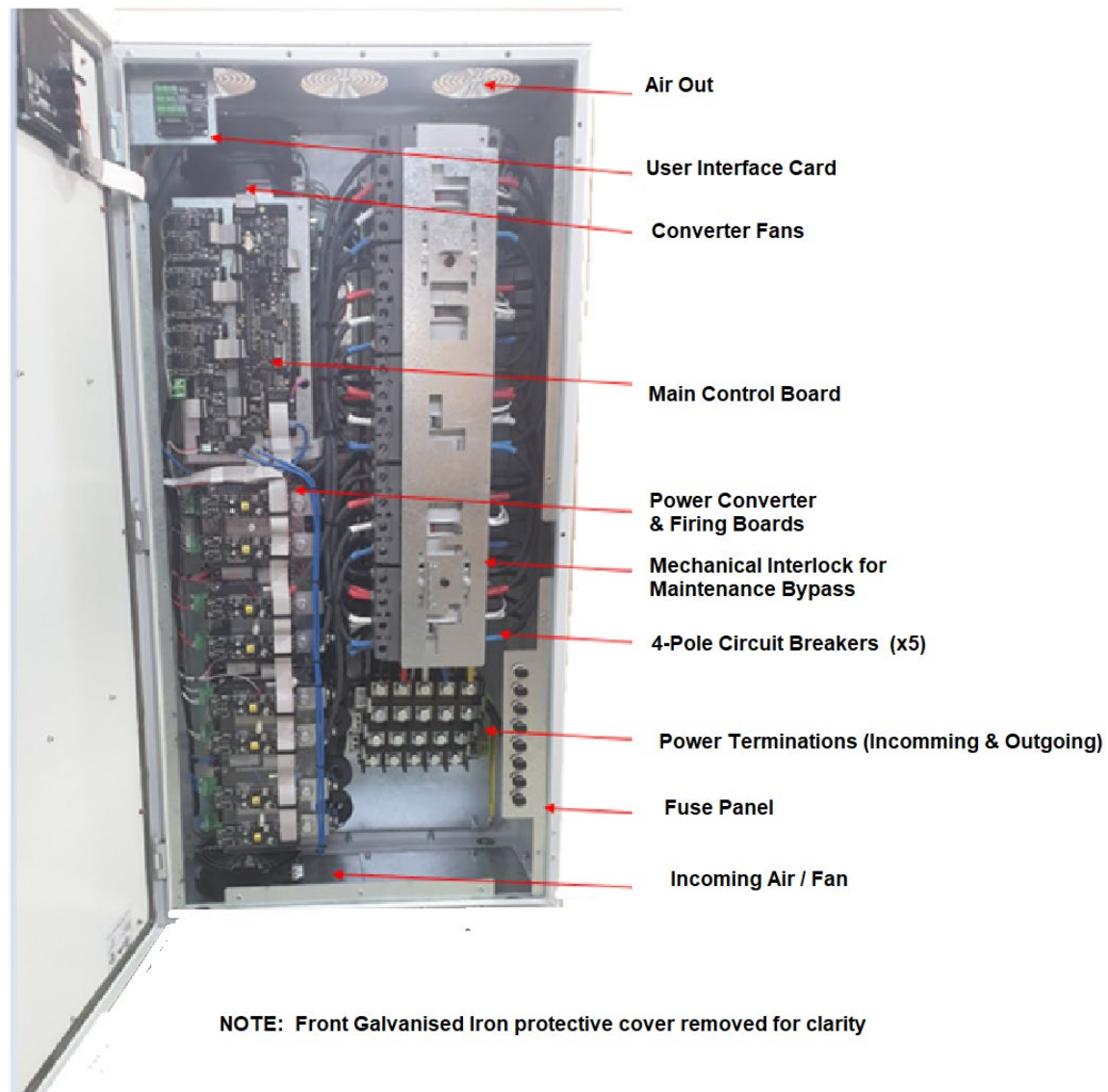


Figure 8. Locations and orientation channels at base of Static Power STS—note the bolt anchoring the channels to the 2 in. (51 mm) plate at the *front-right corner*.



The enclosure thickness is 1.6mm (0.063 in.), and it has a 1.2mm (0.047 in.) thick galvanized (GAL) iron sheet metal plate below. The channels are fastened to the STS with an ASTM Grade A307, 3/8 in.-16 bolt at each corner, as shown in Figure 9. The same grade and size of bolts were used to fasten the channels to a heavy steel plate for the unit tested, as seen in Figure 8. This size and grade of bolts should be used at EAS to anchor the channels to the raised floor. ERDC-CERL shipped the same channels and bolts shown in Figure 9 to EAS for installation there. Figure 8 shows the flanges of these channels facing the exterior of the STS for ease of installation. Figure 9 shows the right-side, bottom interior of the STS. This picture shows the bolts anchoring the unit to the channels, plus the A3 accelerometers that measured the acceleration at the base of the STS.

Figure 9. Right side of the STS interior showing anchor bolts and A3 accelerometers.

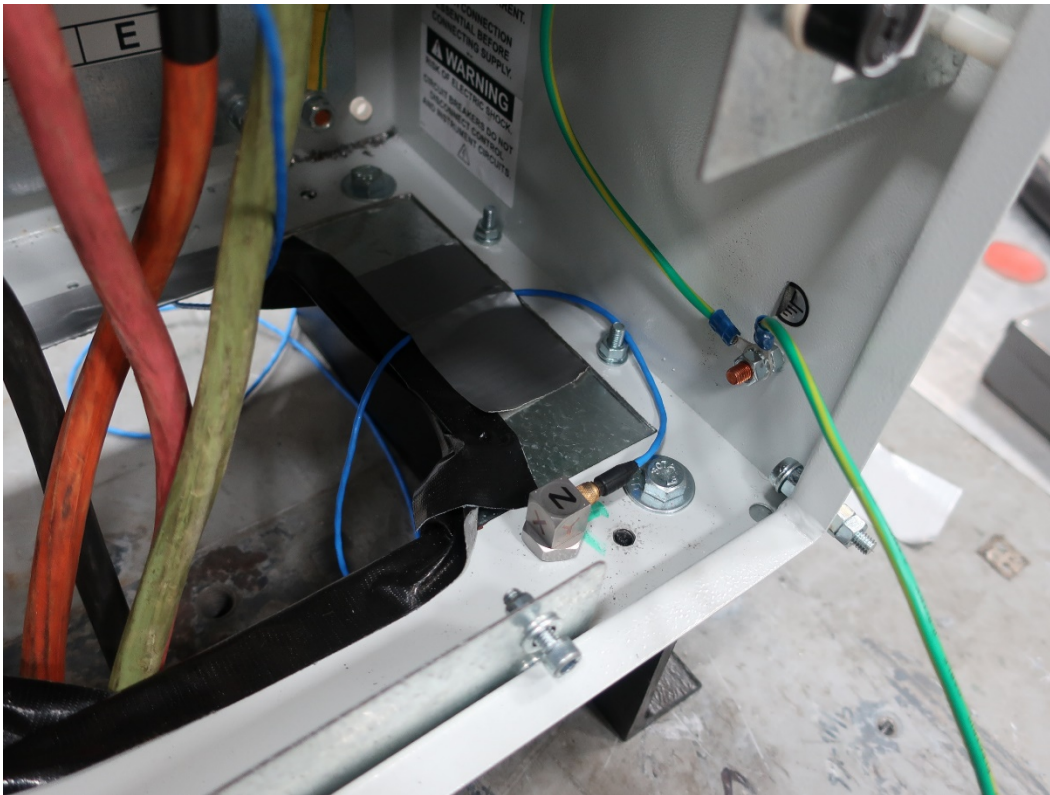


Figure 10 is a drawing of the raised access floor at the EAS MET site, showing all the vertical (called “post” in drawing) and horizontal framing members were hollow structural sections (HSS). Typical floor mounting details shown in Drawing S-503* indicate that most of the vertical and horizontal framing members were HSS 4 in. × 4 in. × 1/4 in. Figure 10 shows that some of these members were smaller; the smallest were HSS 3 in. × 1 in. × 3/16 in. The C4×6.5 channels at the base of the STS will be bolted to the horizontal HSS members at EAS. Figure 11 is a photograph of this raised floor framing.

Figure 9 shows the top of the 41 in. × 29 in. × 2 in. (1041 mm × 737 mm × 51 mm) ASTM A36 steel plate, which was drilled and tapped with the bolt-hole pattern shown in Figure 8. These 3/8 in.-16 bolt holes were spaced 8 in. (203 mm) apart in the depth direction and 20 7/8 in. (530 mm) apart in the width direction to match the bolt-hole pattern at the base of the

*EAR042 MET Site Preparation Eareckson Air Station, Structural Detail Drawing, S-503, Coffman Engineers, File 161528_S-503, 07 July 2020.,

channels. This plate was previously drilled with holes needed to anchor to the ERDC-CERL shake table.

Figure 10. Drawing of raised access floor framing at the EAS MET site.

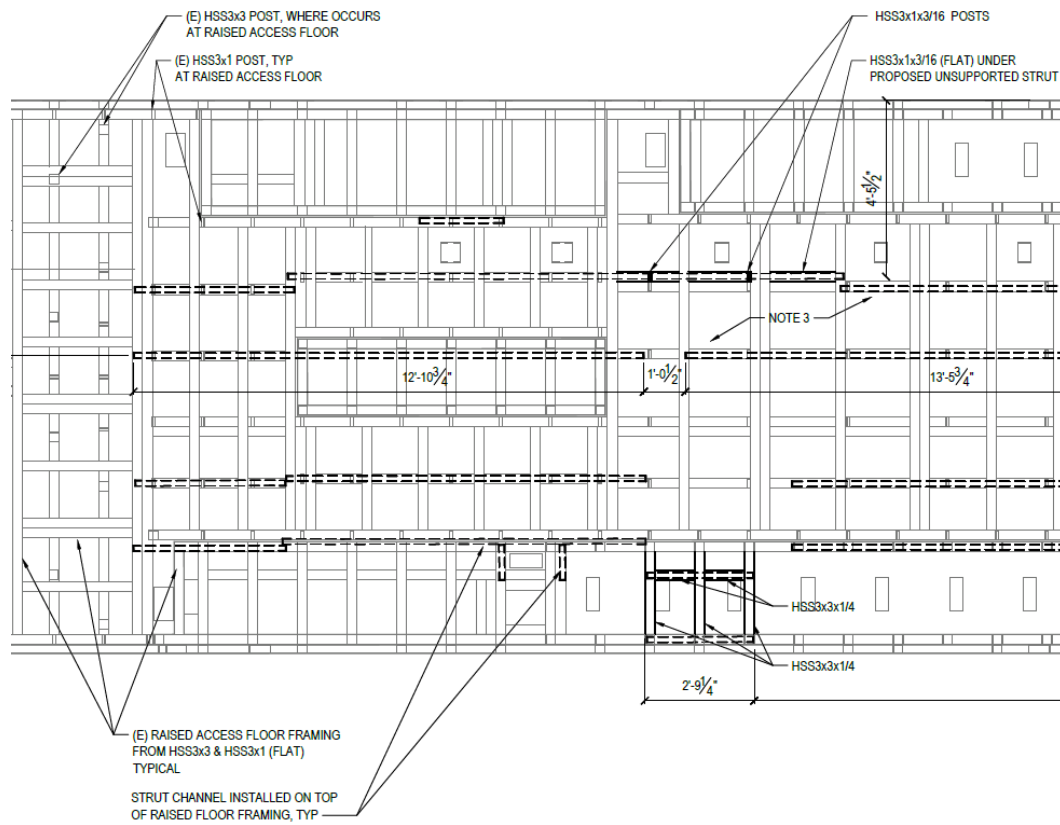


Figure 11. Photograph of the raised access floor framing.



3 Seismic Hazard and Test Motions

The STS will be installed in MET shelters inside Building 585 at EAS. The MET shelters are steel enclosures supported by tie-down anchors that are bolted to the building's concrete floor. The enclosure floors consist of a steel plate with W6×9 beams (6 in. deep beams weighing 9 lb/ft) spanning, in the short direction between channels, along the east and west edges of the enclosure base (Coffman Engineers 2020). The bottom horizontal raised-floor framing members (typically HSS 4 in. × 4 in. × 1/4 in.) are welded to the W6×9 beams, vertical HSS posts are welded to the bottom members, and top HSS members are welded to the tops of the posts. The equipment inside these enclosures is then bolted to the raised floor horizontal HSS members.

Mechanical, electrical, and miscellaneous equipment must withstand seismic motions in accordance with UFC 3-301-01 and UFC 3-310-04. Chapter 4 of UFC 3-310-04 has unique requirements for seismic design for the enhanced performance objectives for Risk Category V buildings, Seismic Use Group IV (DoD 2013). Several critical components inside the MET shelters, including the STS, are mission-essential assets, and the MET shelters and Building 585 is a strategic military asset and Risk Category V building. The "MET Site Preparation, Eareckson Air Station, Shemya, Alaska," Section 3.2.5 Seismic Protection of Equipment, shows the short period spectral acceleration S_s should be 1.5, and S_{MS} should be 1.5 g (Coffman Engineers 2020). Section 4-11.4.1 of UFC 3-310-04 states that S_{DS} shall be replaced with S_{MS} for Risk Category V buildings (DoD 2013).

This value of S_{DS} is used to define equivalent required response spectra (RRS) in accordance with AC156. For S_{DS} equal to 1.5 g and assumed z/h value 1.0, the AC156 RRS is defined by the coordinates in Table 1 and plotted in Figure 12. The MET building is single story, where the STS is installed on the ground floor. Generally, when equipment is installed on the ground floor a z/h value of 0 should be used. However, the STS will be installed on a raised floor inside a MET enclosure that is anchored to the building with tie-down anchors, all of which would amplify ground motions at the natural frequency of these components. The effect of amplified motions can be accounted for by assuming $z/h = 1.0$, as when the equipment is installed on the roof of a multi-story building. This increases the horizontal motions while the vertical motions remain the same. ERDC-CERL recommended the STS be tested with the raised floor using motions

generated when $z/h = 0$, or alternatively, without the raised floor but with $z/h = 1.0$. Drawing S-503, "Typical Floor Mounting Detail," shows the shelter resting directly on the concrete and, presumably, well anchored to the floor (Coffman Engineers 2020). The shelter and shelter tie-down anchors should be quite stiff, but some amplification of motions by these components is expected. A decision was made by the U.S. Army Corps of Engineers (USACE), New England District and ERDC-CERL to test without a raised floor and a z/h value of 1.0, and this approach also accounted for any minor amplification of the enclosure and its tie-down anchors. Table 1 and Figure 12 define the RRS in accordance with AC156, Section 6.5 (ICC-ES 2010). Figure 13 through Figure 15 plot synthetic earthquake test motions generated in accordance with AC156 with $S_{DS} = 1.5$ and $z/h = 1.0$.

AC156, Section 6.5.3.2.3, requires that the peak acceleration at the base of the unit equal or exceed 90% of A_{Rig} , which for the S_{DS} value of 1.5 g and $z/h = 1.0$ gives required peak acceleration values of 1.62 g in the longitudinal (x-axis) and lateral (y-axis) and 0.365 g in the vertical (z-axis) (ICC-ES 2010). These large acceleration values are achieved at ERDC-CERL by superimposing two 40 Hz sinusoidal pulses in each direction. Earlier versions of this test plan (through 18 March 2020) did not include the sine pulses because the technical community who drafted an ASCE standard to replace AC156 agreed this requirement should be removed. These sine pulses could erroneously cause failure of the STS if this unit happens to have natural frequencies near 40 Hz. Normally, equipment tested at ERDC-CERL is large enough that the first modes of vibration in each direction are far below 40 Hz so that the unit itself isolates out the 40 Hz motion. The STS may have modes of vibration near 40 Hz, especially since the unit is hard mounted with steel channels.

USACE New England District determined they may seek OSHPD approval of this STS by eventually testing a second unit and submitting a report to OSHPD for approval. This approval, based on the current version of AC156, requires seismic motions where the peak accelerations exceed 90% of A_{Rig} . Therefore, these seismic tests included the 40 Hz sine pulses. The sine pulse amplitude for the x- and y-axes were 1.8 g and 2.1 g, respectively, well above the 1.62 g minimal required amplitude. These conservatively high values were used because the shake table attenuates higher-frequency motions. These values are normally used for more massive specimens where the attenuation is greater, but they are also used here. In the vertical direction (z-axis), the sine pulse amplitude was 0.5 g, well above

the 0.365 g required, as shown in Figure 15. The actual natural frequencies in each direction were measured on the day of testing so that if a natural frequency were seen near 40 Hz, the sine pulse amplitude in that direction could be reduced. The full sine pulse amplitudes were used for the 40% seismic tests, and ERDC-CERL was prepared to reduce their amplitude if the attenuation was less than expected and natural frequencies do occur near 40 Hz. On the day of testing, the sine pulse amplitudes were higher than needed because they attenuated very little. However, the natural frequencies were less than 40 Hz, and these pulse motions were judged not be a threat to the STS; therefore, the pulse amplitudes were not reduced for the 100% test.

AC156 requires that the test motions be phase incoherent in all three axes, meaning the records are all unique (ICC-ES 2010). Appendix IEEE 344 defines coherence and states that plots must demonstrate that the maximum coherence between any two records of the same test must be less than 0.5 g/g (IEEE 2005). See Appendix F of this report for the coherence plots.

Table 1. Required response spectra for Shemya, Alaska (5% of critical damping).

			S_{DS} (g) =	1.50
			A_{FLX-H} (g) =	2.40
			A_{RIG-H} (g) =	1.80
			A_{FLX-V} (g) =	1.005
			A_{RIG-V} (g) =	0.405
Target & Lateral Actual (Hz)	Long Actual Freq (Hz)	Horiz (g)	Actual Freq (Hz)	Vert (g)
1	1.7	1.42	2.0	0.595
1.3	1.8	2.40	2.1	1.005
3.5	3.5	2.40	3.5	1.005
8.3	8.3	2.40	8.3	1.005
33.3	33.3	1.80	33.3	0.405

Figure 12. Required response spectra for Shemya, Alaska (5% of critical damping).

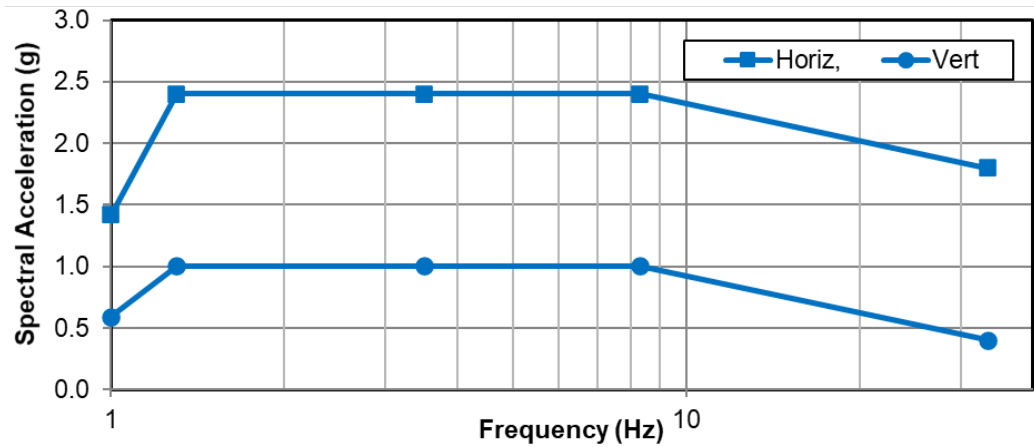


Figure 13. Generated longitudinal test motions for $S_{DS} = 1.5$ g and $z/h = 1.0$.

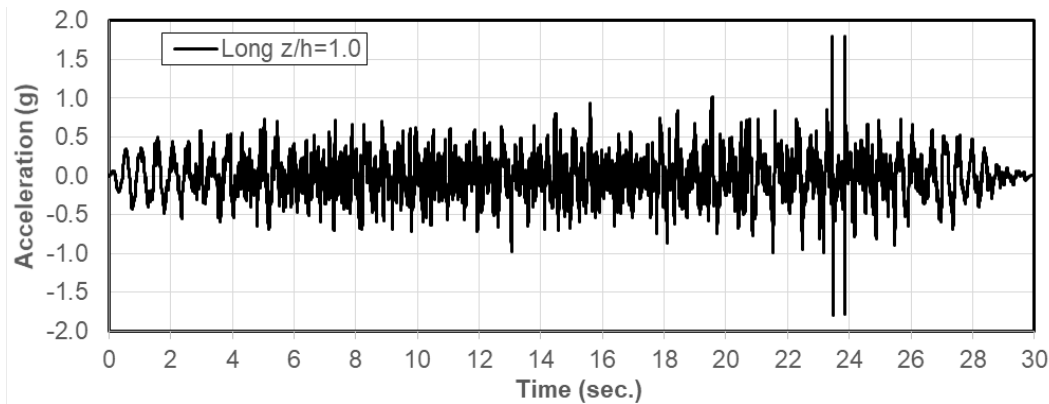


Figure 14. Generated lateral test motions for $S_{DS} = 1.5$ g and $z/h = 1.0$.

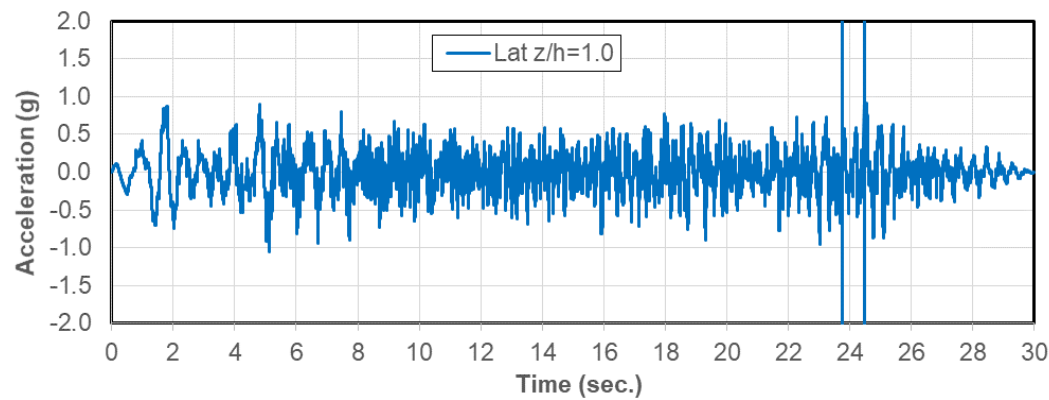
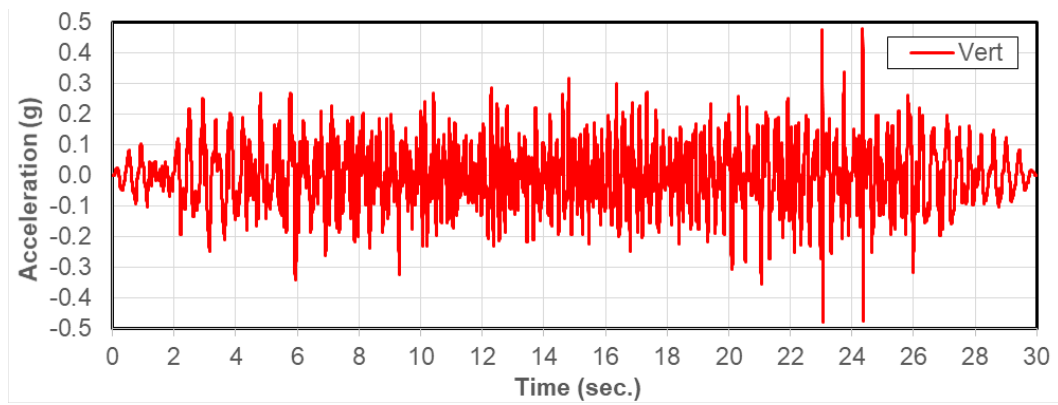


Figure 15. Generated vertical test motions for $S_{DS} = 1.5$ g.



4 Seismic Evaluation of Bolts Anchoring the STS

The seismic capacity of the bolts used to anchor the base of the STS to the top of the channels and to anchor the channels to the raised floor framing are evaluated here. The bolts above and below the channels are the same size, even while the forces below the channels will be greater. The vertical uplift or tensile forces in the bolts will be greater at the bolts below because of the greater overturning moment. The horizontal forces at the bottom of the channels will be greater than at the top because of the added weight of the channels. The maximum horizontal forces applied to these bolts are calculated by conservatively assuming the natural frequencies in all three directions are below 8.3 Hz. The STS is then assumed to vibrate as a single degree of freedom oscillator, where all the mass of the unit participates in the first mode of vibration in each direction. This is a conservative assumption, because the first modes of vibration of this rigidly anchored unit are expected to be above 8.3 Hz, and all the mass will not participate in these modes. The RRS assumes damping of 5% of critical.

The value of A_{FLX-H} , shown in Table 1 and plotted in Figure 12, is defined in AC156, Section 6.5.1 (ICC-ES 2010). The controlling maximum is $1.6 \times S_{DS}$, or 2.4 g, and this limit is based on ASCE 7-16, equation 13.3-2, expressed in AC156, Section 6.5.1 as “the importance factor, I_p , does not increase the seismic test input motion but does affect the requirement for the unit under test (UUT) to demonstrate a level of functionality following seismic simulation testing, and is used in this criteria to determine post-test UUT functionality compliance in accordance with section 6.7 [of AC156]” (ASCE 2017). Therefore, the horizontal seismic design force, F_p , limit defined in ASCE 7-16, equation (13.3-2) has been modified by dropping the I_p term as shown in equation (1) below. This value of A_{FLX-H} is the estimated response of a single degree of freedom oscillator and estimated response of the STS at its center of gravity. The peak horizontal force (F_p) that must be resisted by all four bolts below the channels is defined by equation 1:

$$F_p = A_{FLX-H}W = (2.4 g)(271 lb) = 650 lb (2.89 kN) \quad (1)$$

where

A_{FLX-H} = the RRS horizontal spectral acceleration between 1.3 and 8.3 Hz from Table 1, and

W = the weight of the STS, 259 lb (117.5 kg), plus 12 lb (5.4 kg) for the two 11 in. (279 mm) long C4×6.5 channels.

This horizontal force is assumed to be shared equally by the four bolts. The peak acceleration in the x-direction is conservatively assumed to occur at the same instant in time as the peak acceleration in the y-direction. The peak horizontal force or shear force applied to a single bolt can then be assumed equal to the square root of the sum of the squares (SRSS) of the force in each horizontal direction. These applied forces are calculated for each of the four 3/8 in. diameter bolts below the channels (F_{pH}) according to equation (2):

$$F_{pH} = \sqrt{\left(F_p/4\right)^2 + \left(F_p/4\right)^2} = 230 \text{ lb } (1.02 \text{ kN}) \quad (2)$$

The peak vertical tensile forces applied to the bolts below the channels are estimated by calculating an overturning moment (horizontal force times the height above the bolts to the center of gravity) divided by the distance between the mounts in the direction resisting overturning moment. To these vertical forces, the peak vertical acceleration, A_{FLX-V} times the weight (W) of the STS is added minus the gravity weight of the STS. The bolts for the channels on one side of the STS will resist the overturning force, while the vertical seismic force and gravity are shared equally by the bolts below the channels. This overturning moment at the bottom of the channel (M_B) can be estimated by equation (3):

$$M_B = F_p h_B = (650 \text{ lb})(26.3 \text{ in.}) = 17,095 \text{ in.} \cdot \text{lb}, (1.931 \text{ N} \cdot \text{m}) \quad (3)$$

where

h_B = the height to the center of gravity of the STS above the bottom of the channels = 22.3 in. + 4 in. = 26.3 in. (566 mm + 102 mm = 668 mm).

The peak vertical force per bolt at the bottom of the channels, F_{BV} , can be estimated by equation (4):

$$F_{BV} = (A_{FLX-V} - 1.0 \text{ g})(W/4) + \sqrt{\left(\frac{M_B}{2W_m}\right)^2 + \left(\frac{M_B}{2D_m}\right)^2} \quad (4)$$

$$F_{BV} = (1.005 g - 1.0 g) \left(271 \text{ lb} / 4 \right) + \sqrt{\left(\frac{17,095 \text{ in.} \cdot \text{lb}}{(2)(20.875 \text{ in.})} \right)^2 + \left(\frac{17,095 \text{ in.} \cdot \text{lb}}{(2)(8.0 \text{ in.})} \right)^2}$$

$$= 1145 \text{ lb (5.09 kN)}$$

where

A_{FLX-V} = the vertical spectral acceleration, from Table 1, between 1.3 and 8.3 Hz = 1.005 g;

W_M = the width distance between the bolts, shown in Figure 8, = 20.875 in. (530 mm); and

D_M = the depth distance between the bolts, shown in Figure 8, = 8.0 in. (203 mm).

The applied bolt forces defined above are less than the allowable forces on these fasteners. The bolt capacity will be defined based on the AISC Steel Manual for combined tension and shear loading. The calculations below show the estimates of tensile and shear capacities for these bolts. The bolt shear strength when the bolt threads are in the shear plane, P_v , can be determined in accordance with equation (5). The STS was conservatively tested using the weakest standard bolt, ASTM A307. This equation shows the capacities for the ASTM A307, 3/8 in. diameter bolts:

$$P_v = (0.6)(F_y)(A_R), \quad (5)$$

where

F_y = the bolt yield strength. The yield strength for A307 bolts is 36,000 psi (248 MPa); and

A_R = the bolt thread root area or minor-diameter area for when the threads are within the shear plane = 0.067 in.² (43 mm²) for 3/8 in. diameter bolts.*

For 3/8 in. diameter A307 bolts, the shear capacity, calculated below, is 1,447 lb (6.44 kN), which far exceeds the applied shear of 230 lb (1.02 kN):

$$P_v = (0.6)(36,000 \text{ psi})(0.067 \text{ in.}^2) = 1,447 \text{ lb} \geq 230 \text{ lb}$$

* See https://www.engineersedge.com/fastener_thread_stress_area.htm

The bolt allowable tensile strengths, P_t , where net tensile area of the bolts is taken as equal to the minor diameter area, A_R , is calculated according to equation (6):

$$P_t = (0.9)F_y A_R. \quad (6)$$

For the 3/8 in. diameter Grade 5 bolts, equation 6 gives a tensile strength of 2,171 lb (9.66 kN), which far exceeds the applied tension at the top of the mounts, P_t , of 1,145 lb (5.09 kN):

$$P_t = (0.9)(36,000 \text{ psi})(0.067 \text{ in.}^2) = 2,171 \text{ lb} \geq 1,145 \text{ lb}.$$

The shear and tensile capacities of the 3/8 in. bolts at the bottom of the channels far exceed the applied loads. These weak bolts were used in the shake table tests. The same grade of bolts could be used at EAS, or stronger ones could be substituted if they are more readily available.

These bolts should be tightened following a torque specification, such as the one recommended by Fastenal,^{*} which describes a method for estimating an applied torque needed to meet the recommended clamping load at each bolt (Fastenal 2009, 9–12). This expression for applied torque, T , is defined in equation (7) below:

$$T = KdF = (0.2)(d)(0.75)(F_p)(A_T), \quad (7)$$

where

- K = the torque variable or nut factor, where for non-lubricated torque a value of 0.20 is recommended;
- d = the diameter of the bolt to be torqued in inches;
- F = the recommended clamping load, which is 75% of the proof load, F_p , which for A307 bolts is 33,000 psi (228 MPa) $\times$ the tensile stress area of the bolt, A_T [†]; and
- A_T = 0.077 in.² (50 mm²) for 3/8 in. diameter bolts.[‡]

For the 1/2 in. diameter bolts at the top and bottom of the channels this applied torque, T , becomes

^{*} See <https://www.fastenal.com/content/feds/pdf/Article%20-%20Bolted%20Joint%20Design.pdf>

[†] See <https://www.fmwfasteners.com/blogs/faq/astm-and-sae-specifications>.

[‡] See https://www.engineersedge.com/fastener_thread_stress_area.htm.

$$T = KdF = (0.2)(0.375 \text{ in.})(0.75)(33,000 \text{ psi})(0.077 \text{ in.}^2) = 143 \text{ in.} \cdot \text{lb} = 12 \text{ ft} \cdot \text{lb} \text{ (16 Nm)}.$$

The bolts at the top and bottom of the channels should be tightened in accordance with this value. The achieved torque at these bolts will be measured with a torque wrench and documented in this report. The value of 12 ft·lb (16 N·m) is conservative because the bolts should only be loaded to 53% of their allowable capacity. The measured torque for the shake table STS will become the torque specification that needs to be used at EAS.

5 Instrumentation, Functional Requirements, Seismic Test Steps, Test Equipment Specifications and Calibrations

This chapter documents other test details, including instrumentation, functional test requirements, component product line extrapolation, detailed test steps, test equipment specifications and calibrations.

5.1 Instrumentation

Five triaxial accelerometers were installed at the locations shown in Table 2 (see ICC-ES 2010, AC156, Sections 6.4.4 and 6.4.5). These sensors were calibrated, with calibration certificates that are traceable back to the National Institute of Standard and Technology (NIST) standard (ICC-ES 2010, AC156, Section 6.4.4). Calibration certificates are provided in Appendix A of this report. The A1x, A1y, and A1z sensor designations indicates a triaxial accelerometer at the 1 location that measured acceleration in the longitudinal (x), lateral (y), and vertical (z) directions. The STS was oriented on the shake table so that the long width direction shown in Figure 8 was in the x axis of the shake table. The door of the STS faced to the east where the ERDC-CERL power panel was located. Both the A1 and A2 accelerometers were installed on the 2.0 in. (51 mm) thick steel plate to which the channels were fastened. This plate was bolted directly to the shake table. The A1 and A2 accelerometers recorded test motions were reported in the test report, and test response spectra (TRS) were generated from one of the recorded motions. Two reference accelerometers were used to provide redundancy. Appendix B provides photographs showing the overall STS and zoomed-in views of all the accelerometers.

Table 2 shows that a triaxial accelerometer (A3) was installed (see center of Figure 9) inside the STS enclosure above the front right bolt anchoring the STS to the channel. Another triaxial accelerometer (A4) was installed at approximately the center of gravity of the STS near the center of the mounting plate, 762 mm (31.0 in.) above the bottom of the channels (see Figure 7). The final triaxial accelerometers (A5) were installed on the exterior near the right rear corner of the STS enclosure. The A4 accelerometers measured the modes of vibration and response motions of the overall STS near where many of the electronic subcomponents were installed. The A5

accelerometers measured the overall modes of vibration and response of the enclosure.

Table 2. Static Power STS accelerometer locations, purpose, measurement range, and resolution.

Sensor	Channel	X* (in.)	Y* (in.)	Z* (in.)	Location	Purpose	Full Range (g)	Resolution (g)
ATLG	0	Triaxial Earthquake and Shock Simulator (TESS) platform average acceleration and pitch rotational acceleration			Inside the TESS	Used to control the TESS	15	0.0005
ATLT	1						15	0.0005
ATV	2						15	0.0005
ATROLL	3						6883	0.2100
ATPITCH	4						6290	0.1919
ATYAW	5						6290	0.1919
A1x					Left of the rear corner of left side supporting channel	Reference accelerometer near the base of the rear end of left supporting channel	10	0.0003
A1y		23.5	2.0	0.0			10	0.0003
A1z							10	0.0003
A2x					Right of the front corner of the right-side supporting channel	Reference accelerometer near the base of the front end of the right supporting channel	10	0.0003
A2y		-0.5	12.0	0.0			10	0.0003
A2z							10	0.0003
A3x					Inside enclosure, above front end of right supporting channel	Response or deformation of the supporting channels and base of the enclosure	30	0.0009
A3y		3.5	9.5	4.0			30	0.0009
A3z							30	0.0009
A4x					Near center of gravity on mounting plate	Overall STS response at internal mounting plate	30	0.0009
A4y		10.5	5.0	31.0			30	0.0009
A4z							30	0.0009
A5x					Top of enclosure at the right rear corner	Overall response of STS enclosure	30	0.0009
A5y		2.0	1.5	51.2			30	0.0009
A5z							30	0.0009
*Origin is the bottom NW corner of the STS enclosure at the bottom of the supporting channels								

5.2 Functional requirements

The functionality requirements were initially defined in a test script from Static Power, dated 21 March 2017. These requirements were converted to the format shown in Appendix B and Appendix C by ERDC-CERL. Prior to testing, these documents were reviewed by Static Power on 13 March 2020 (per ICC-ES 2010, AC156, Sections 4.4 and 6.3). Appendix B defines the

functional tests conducted prior to seismic testing, and Appendix C after the seismic tests. These were checked off, signed, scanned, and incorporated in the test report as these appendices. These are check-list type descriptions of all functional tests conducted before and after seismic testing to demonstrate operation of the STS.

ERDC-CERL provided electrical service at 100 amperes, 208 volts and 60 Hz, by two off three-phase 4-wire + earth supplies. These were from the same source as only a maximum of 160 amperes was drawn from either supply at any one time. Two sets of cables were provided so that the power could be quickly switched between sources. The cable link lengths were between 12 in. (305 mm) and 15 in. (381 mm), (four wire), flexible (fine stranded), 35 mm² (2 American Wire Gauge [AWG]) for each current carrying conductor and ground. Each conductor had a compression type single barrel lug, with a 3/8 in. (9.5 mm) hole to make bolted connections to the STS terminals.

A U.S. Army Corp of Engineers New England District contractor provided a fan cooled resistive load bank with switchable load (in approximately 10kW steps) and cabling with a three-phase (4-wire with ground) capacity of at least 160 amperes per phase at 120/208 volts, 60Hz. This load bank was located to the south of the Triaxial Earthquake and Shock Simulator (TESS) platform, in an area capable of dissipating more than 60,000 Watts of hot air outside an open overhead door.

5.3 Component product line extrapolation and interpolation

Product line extrapolation or interpolation is not needed because this test is site specific, qualifying only the specific STS tested (see ICC-ES 2010 AC156, Section 4.5). No discussion on product line subassembly options, mass distribution, or component variations is needed because this test is site specific, where the unit tested is identical to the units to be installed at the EAS site (per ICC-ES 2010, AC156, Sections 4.5.3-5).

5.4 Installation instructions

The electrical connections are made to terminals (cassette type) for lugged connections through a 10 mm² (3/8 in.) bolt and should be tightened to 10 N·m (89 in.-lb).

5.5 Seismic test steps

The seismic qualification tests were completed by conducting the following shake table tests at ERDC-CERL:

1. **Model Measurement Tests** were conducted using a frequency range of 0 to 128 Hz and 3-sigma amplitude values of 0.3 g for translations and 120 degrees/s² for rotational degrees of freedom. These tests were used to create a compensation model to better control the shake table. The random motion test results were used to create inverse transfer functions between the desired and achieved motions that were then multiplied by the subsequent drive signals, in the frequency domain, to produce the compensated drive signals.
2. **System Identification Tests** were conducted to measure the natural frequencies of the STS using uniaxial sine-sweep tests. They used an amplitude of 0.1 g, a sweep rate of 2 octaves per minute, and swept through a frequency range of 1.3 to 33.3 Hz. The tests were repeated in all three translational directions, and natural frequencies defined based on transfer functions (as required by ICC-ES 2010, AC156, Section 6.4.5).
3. **Triaxial Seismic Simulation Tests (40% and 100%)** Motions were generated that fit the RRS shown in Figure 12 and had 5 seconds ramp-up, 20 seconds full amplitude, and 5 seconds of ramp down (per ICC-ES 2010, AC156, Section 6.5.2). The motions in each direction were phase incoherent. The motions were compensated to account for the effects of the dynamic response of the shake table and STS. Seismic tests were conducted at 40% of these motions, and TRS were generated from the achieved motions at the base to determine if they met the requirements of AC156, Section 6.5.3 (ICC-ES 2010). The TRS along with the RRS and the 90% and 130% reference lines were plotted to confirm the TRS met RRS. Seismic tests were next conducted at 100% of these motions, and TRS again generated, demonstrating the achieved motions met the requirements. ERDC-CERL and the California-licensed structural engineer inspected the STS, and ERDC-CERL documented that no significant damage was seen (per ICC-ES 2010, AC156, Section 6.6) (see Section 6 of this report for documentation). University of Illinois Urbana-Champaign electricians conducted the functional tests in accordance with the guidance from Static Power both before and after the seismic tests. Appendix C documents the checklist results of the functional tests conducted before the seismic tests, and Appendix D provides the checklist for the result after the seismic tests. The next chapter of this report documents the functional tests, demonstrating that the operability requirements defined by AC156, Sections 4.4

and 6.3 were met (ICC-ES 2010). ERDC-CERL also video recorded the front left corner of the STS for the 40% and 100% tests. The video was recorded in frame mode so that still views could be obtained from any portion of the video record in 1/30th second increments. They provided edited video files of the 100% seismic test to the project sponsor.

5.6 Test equipment specifications and calibrations

The TESS surface dimensions, motion limits, and accelerometer and scale calibration certificates are defined as follows:

1. The ERDC-CERL TESS is a triaxial shake table with a table surface that is 12 ft × 12 ft. (3.66 m × 3.66 m) The force limits are 450,000 lb (2,000 kN) longitudinally, 150,000 lb (667 kN) laterally, and 810,000 lb (3,600 kN) vertically. The stroke limits are ± 2.75 in. longitudinally, 6.0 in. laterally, and 1.375 in. vertically. The velocity limits are 50 in./s longitudinally and laterally and 30 in./s vertically (these shake table specifications are required by ICC-ES 2010, AC156, Section 5.2.2.5).
2. Appendix A provides the calibration certificates for accelerometers that were installed on the steel plates (per ICC-ES 2010, AC156, Sections 5.2.2.5 and 6.4.4).
3. The ERDC-CERL warehouse scale weighed the STS, and Appendix A shows the calibration certificate for this scale.

6 STS Seismic Test Results

This chapter documents the test results for the system identification (SI), seismic and functional tests.

6.1 System identification tests

The SI tests were conducted using sine-sweep motions to measure the natural frequencies of the STS. They used an amplitude of 0.1 g, a sweep rate of 2 octaves per minute, and swept through a frequency range of 1.3 through 33.3 Hz. Appendix E provides plots of all the transfer functions used to define the natural frequencies of the STS. Table 3 shows the modes of vibration.

Table 3. Static Power STS transfer functions and modes.

#	Transfer Function	Measured Frequencies (Hz)		Mode of Vibration
		1st Mode	2nd Mode	
1	A3x/A1x	97	-	Channel response
2	A3y/A1y	-	-	
3	A3z/A1z	272	-	
4	A4x/A1x	10.4	209	Overall STS response at mounting plate
5	A4y/A1y	6.4	-	
6	A4z/A1z	32, 40	180, 300	
7	A5x/A1x	10.4	23	Overall STS response at top of enclosure
8	A5y/A1y	6.4, 21.5	50, 60	
9	A5z/A1z	32, 40	236, 265	

The transfer functions in Appendix E and modes of vibration in Table 3 show the lowest natural frequency in the y-axis is 6.4 Hz. This mode consisted of overall flexural deformation of the STS enclosure in the narrow direction. Similarly, a flexural mode in the x-axis or wide direction of the STS was seen at 10.4 Hz. The dynamic response of the STS to seismic motions is expected to be dominated by an amplified response at these two modes. AC156 also requires that the TRS envelopes the RRS down to the lesser of 75% of the lowest modes or 3.5 Hz (ICC-ES 2010). Since the lowest mode is above 5.0 Hz, the 3.5 Hz requirement controls. The transfer functions and modes in Table 3 also show that higher modes (23, 21.5, 32, and 39.5 Hz) were recorded at the top of the enclosure in the x-, y- and z-axes at both the internal mounting plate (A4z) and top of the enclosure

(A5z). The small amplitudes of the transfer functions at these high-frequency modes indicate that the response at these modes should be minimal.

Table 3 shows additional modes at even higher frequencies, with the channel response in the x-axis measured at A3x at 97 Hz, the overall STS response measured at a mounting plate in the x-axis at A4x at 209 Hz, the top of the enclosure response in the y-axis measured at A5y at 50 and 60 Hz, and the enclosure response in the z-axis measured at A5z at 180 and 300 Hz. These modes are seen in Figure E-1 through Figure E-3. These very high-frequency modes were not intentionally excited by the sine-sweep motion tests, and they are relatively unimportant to the response to seismic motions. However, they do explain the high-frequency spikes superimposed on the accelerations recorded at the sensors named above. This high-frequency content could have been filtered out, using a low-pass filter, but it was not, and therefore some discussion is warranted. Vibrations at these frequencies are often the dominant motions recorded at the sensors, and for this reason, they are presented in the next section of this report.

6.2 Seismic test response motions and test response spectra

Seismic tests were conducted at 40 and 100% of the motions defined in Table 1 and Figure 12 through Figure 15. The 40% tests were conducted prior to the 100% tests to determine if any adjustments were needed in the motions to ensure the full 100% levels would be reached. The 40% level was low enough to ensure there should be no damage to the STS. The TRS were plotted relative to the RRS for the 40%, as shown in Figure 16. This plot also shows the 90% and 130% plots of the 40% RRS, defined as Horiz 36%, 52%, Vert 36%, and Vert 52% in the plots. This shows that the achieved TRS fell within these upper and lower bounds. The peak accelerations levels at the base of the STS (A1 and A2 sensors) were checked to ensure they exceeded 40% of the 90% of A_{RIG} , as required by AC156, Section 6.5.3.2.3 (ICC-ES 2010).

AC156, Section 6.5.2, indicates that the seismic motions should be independent from one another and stipulates that the motions in each axis should be phase incoherent in the principal horizontal and vertical axes of the shake table (ICC-ES 2010). The shake table testing community uses the IEEE 344 definition for phase incoherent motions (IEEE 2005). Appendix E, "Statistically Independent Motions," of IEEE 344 indicates that

either coherence or correlation coefficient functions can be used to verify statistical independence of test records (IEEE 2005). The coherence plots should have maximum values less than 0.5 for sufficient statistical independence. Appendix F provides plots for the 100% seismic tests, showing that this test was statistically independent.

The 100% seismic test was next conducted using the motions defined in Table 1 and Figure 12 through Figure 15 without adjustments. Figure 17 plots the motion recorded in the x-axis for the entire 30 second duration of the 100% seismic test. Figure 18 and Figure 19 zoom in on the 16 to 17 second and 16.6 to 16.8 second portions of the x-axis motions to highlight observations. Figure 17 shows that the response motions recorded near the center of gravity of the STS (A4x) and top of the enclosure (A5x) were almost always greater than the motions at the base of the channels (A1x and A2x) or top of the channel inside the bottom of the STS (A3x). The motion recorded near the base of the channels at A1x and A2x agreed very well with, but were slightly greater than, the desired motions for the x-axis plotted in Figure 13. This slight increase is because the control of the TESS is based on an average of several accelerometers mounted inside the shake table, while A1x and A2x were individual accelerometers. The average used for the shake table control results in slightly reducing the amplitude because the peak recorded motions can occur at slightly offset times. The average peaks are subsequently slightly less than the peaks of individual accelerometers inside the table and, similarly, less than the peaks recorded at A1x and A2x.

Figure 16. TRS plotted relative to the RRS, and RRS upper and lower bounds for the 40% seismic test.

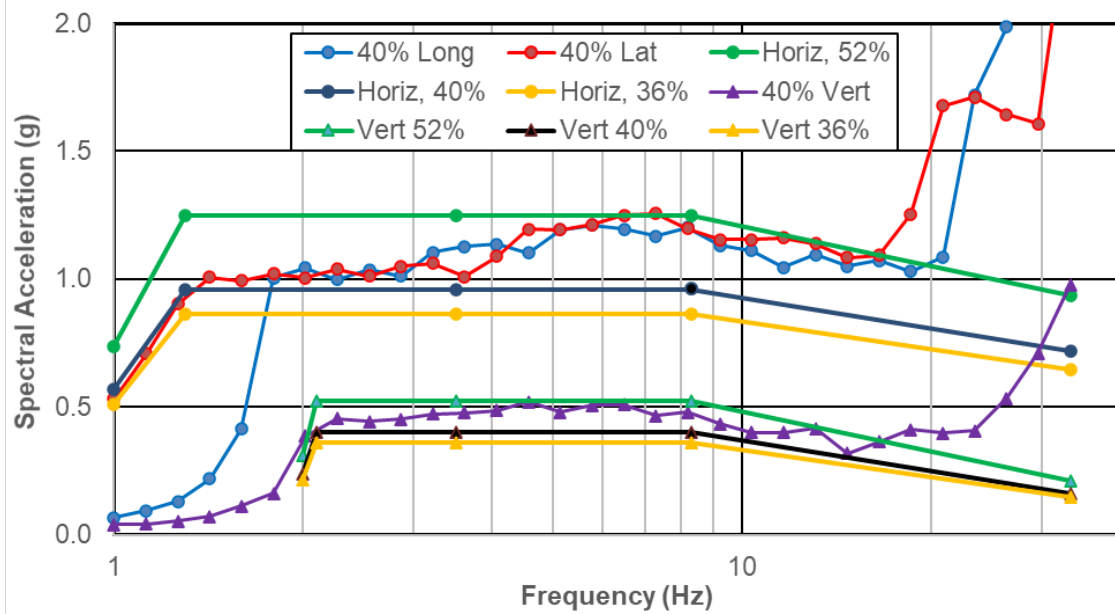


Figure 17. Recorded motions in the x-axis in the 100% seismic test.

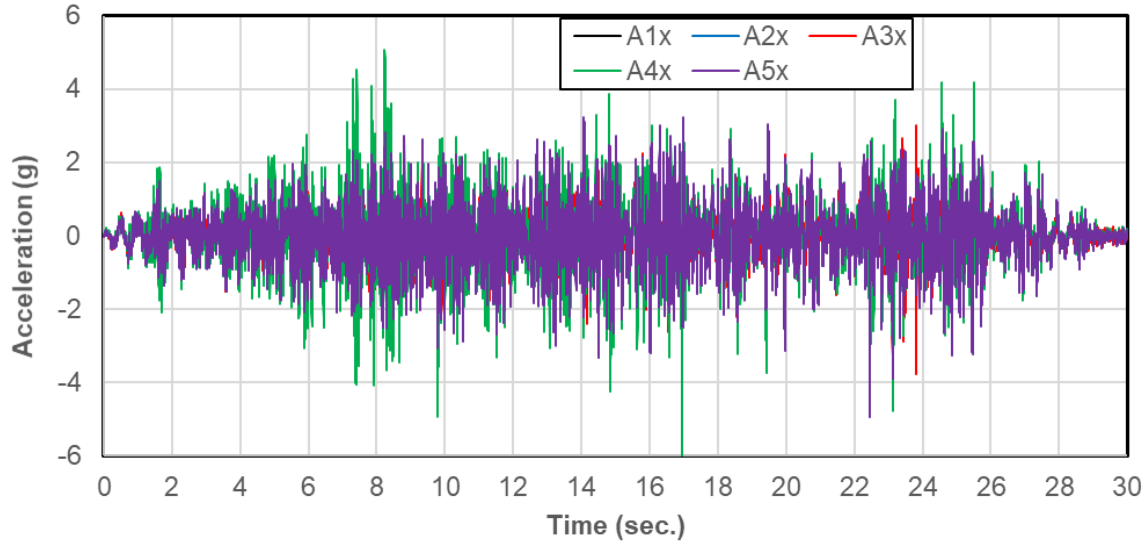


Figure 18. 100% seismic motions in x-axis, 16 to 17 seconds.

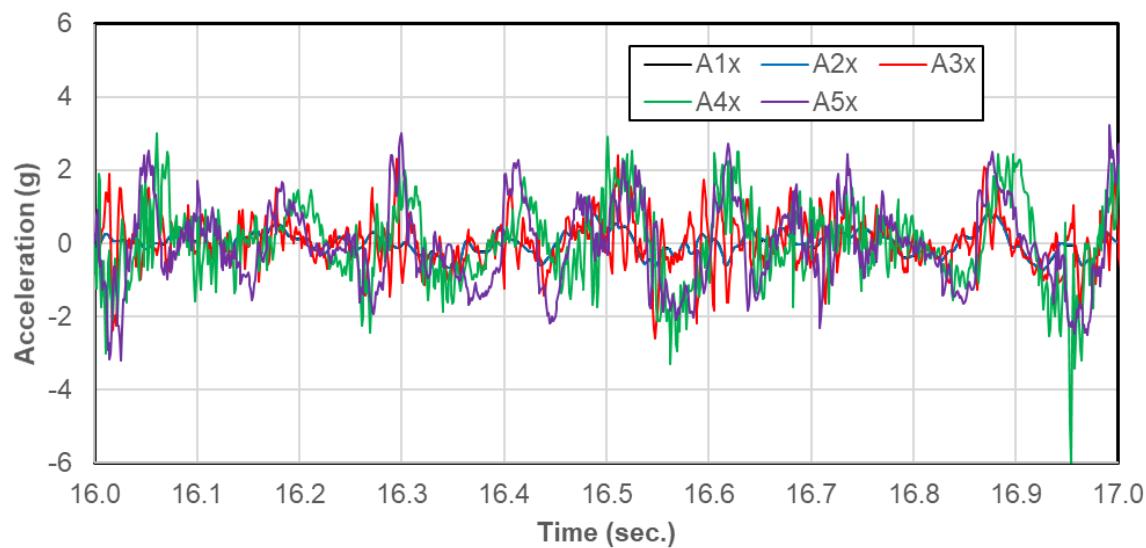
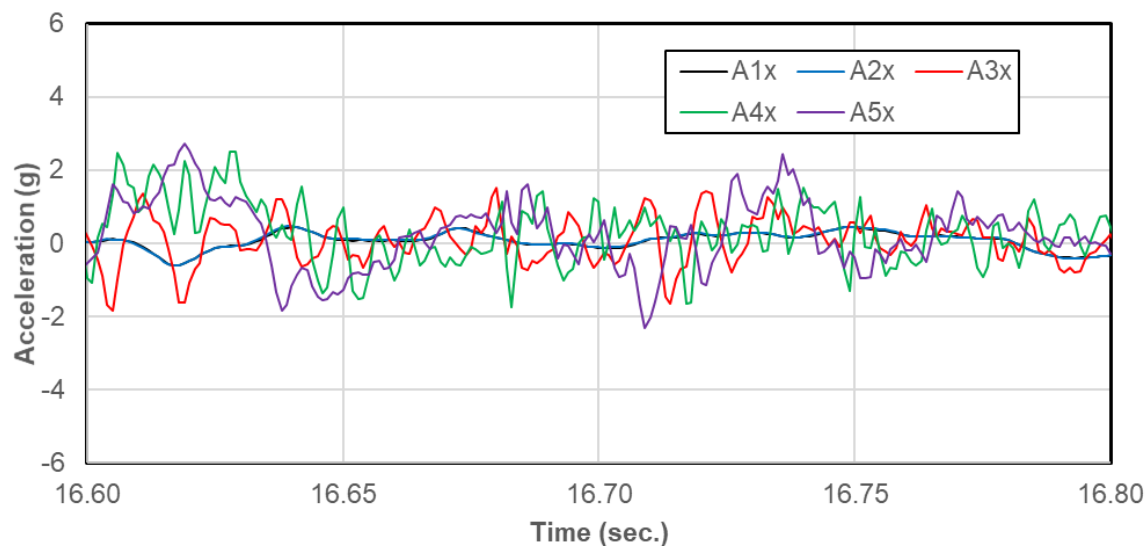


Figure 19. 100% seismic motions in x-axis, 16.6 to 16.8 seconds.



The relatively high-amplitude spikes recorded at A3x at about 23.6 seconds corresponds well to the time of the 40 Hz sine pulse super-imposed on the desired motions plotted in Figure 13.

The zoomed-in view of this data shown in Figure 19 show how much greater the motions at the top of the channels inside the STS (A3x), center of the STS (A4x), and top of the enclosure (A5x) are relative to on the plate near the bottoms of the channels (A1x and A2x). The A1x and A2x sensors were both attached to the 2-inch-thick steel plate at the bottom of the channel, so that the motions recorded in the x-axis at these locations are almost identical and plot exactly on top one another in Figure 19. The

slight offset can be seen when zooming into the data much more in amplitude and time than shown in Figure 19.

Figure 18 plots 1 second worth of x-axis motion data, and this shows that approximately 10 cycles of acceleration oscillations occur at A4x and A5x during this 1 second segment of the test. This demonstrates a clear response of the overall STS in the x-axis during the seismic test, and this amplified response was expected based on the 10.4 Hz mode measured during the SI test, as shown in Table 3. This response near 10 Hz is the only significant response to seismic motions in the x-axis.

Figure 17 through Figure 19 also show a higher-frequency response motion, seen as high-frequency spikes in this data. These high-frequency motions cause very little deformation, do not significantly load the STS, and are only discussed below to explain the high-frequency spikes. The supporting channels did deform slightly in their weak axis, which is the x-axis, and this deformation causes the 97 Hz mode shown for A3x/A1x in Table 3. The 97 Hz response is well above frequency content of the seismic tests, yet there was some high-frequency noise in this test, which did cause the oscillations at A3x shown in Figure 19. Approximately 17 cycles are seen at A3x over the plotted duration of 0.2 seconds, and this equates to 17 cycles divided by 0.2 seconds, which equals 85 Hz, which is close to the 97 Hz mode.

Figure 19 also shows that 21 cycles can be counted at A4x between 16.65 and 16.75 seconds, and this equates to 210 Hz motion (21 cycles/0.10 s). These high-frequency motions agree well with the 209 Hz mode shown in Table 3. This mode must be a localized high-frequency response of a component to which the A4x accelerometer was mounted. If these measured accelerations were double integrated to estimate the displacements at this location, the deformations would be shown to be very small and would not significantly load the STS. Small participating mass would be involved with such localized response. Similar, but lower frequency oscillations are seen at the top of the enclosure as measured at A5x, and these oscillations are similarly not of concern.

Figure 20 plots the motion recorded in the y-axis for the entire 30 second test duration. Figure 21 and Figure 22 zoom in on the 16 to 17 second and 16.5 to 16.8 second portions of the y-axis motions to highlight some observations. Figure 20 and, more clearly, Figure 22 show the response motions

recorded near the center of gravity of the STS (A4y) and top of the enclosure (A5y) are again always greater than at the base of the channels (A1y and A2y) or top of the channel inside the bottom of the STS (A3y). The motion near the base of the channels, recorded at A1y and A2y, agree very well with the desired motions plotted for the y-axis in Figure 14.

Figure 20. Recorded motions in the y-axis in the 100% seismic test.

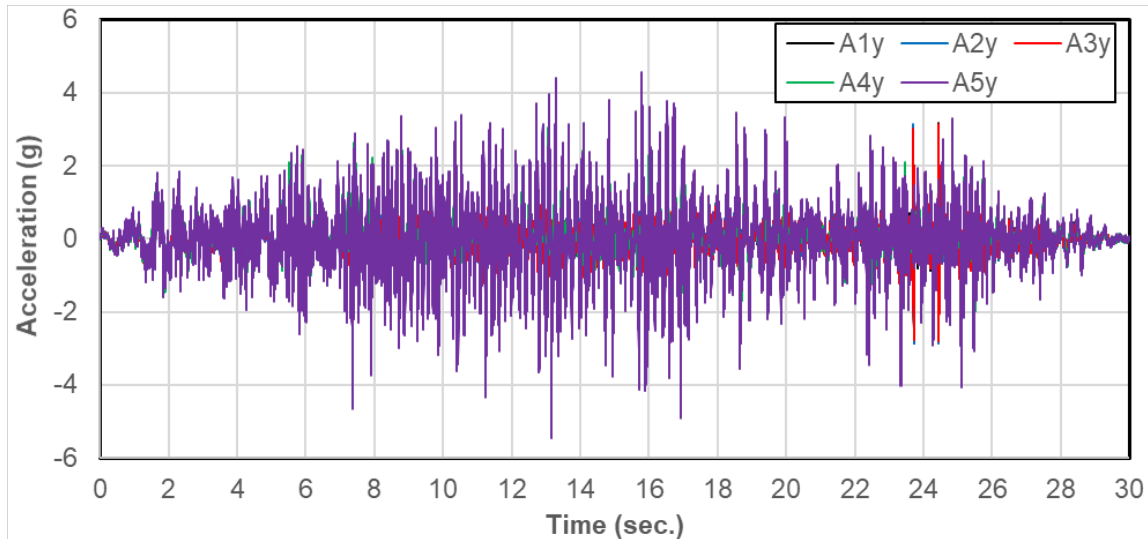


Figure 21. 100% Seismic motions in y-axis, 16 to 17 seconds.

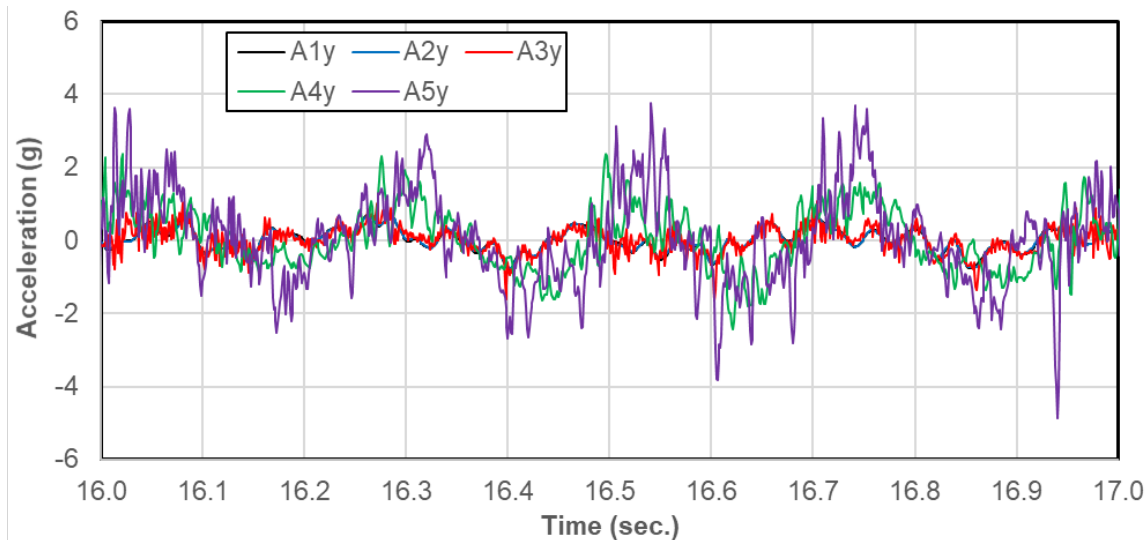
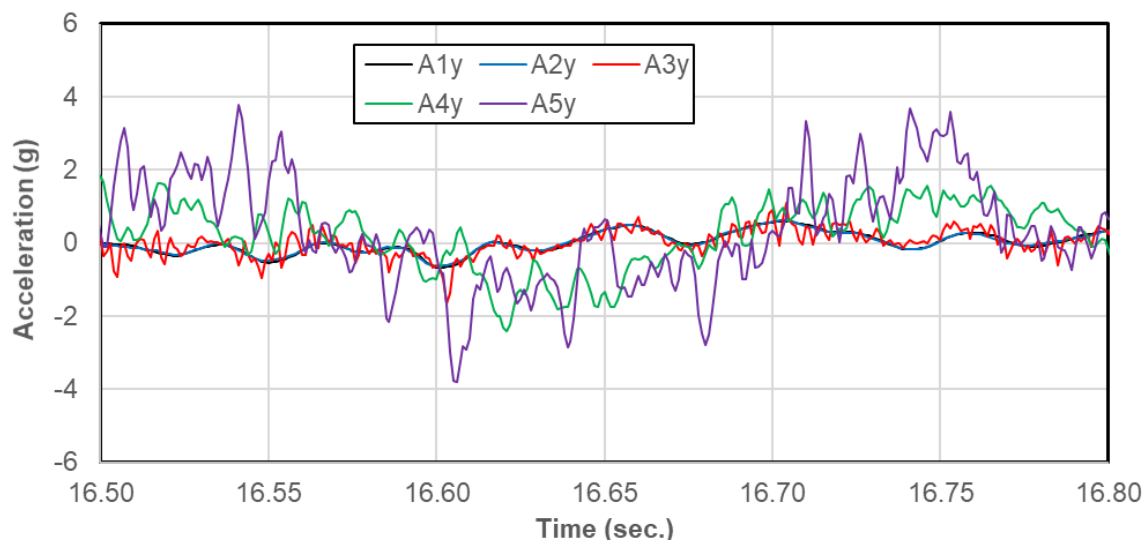


Figure 22. 100% Seismic motions in y-axis, 16.5 to 16.8 seconds.



The relatively high-amplitude spikes recorded at A3y just before and after 24 seconds correspond well to the time of the 40 Hz sine pulses superimposed on the desired motions plotted in Figure 14.

The zoomed-in view of this data shown in Figure 22 shows the motions recorded at the top of the channels inside the STS (A3y) are almost identical to the motions on the plate at the base of the channels (A1y and A2y). Counting the small-amplitude, high-frequency cycles in Figure 22 shows that the top of the channel or base of the STS where the A3y sensor is mounted oscillates at 230 Hz. The motions recorded on the heavy steel plate at the base of the channels at A1y and A2y are almost identical to one another.

Figure 21 plots 1 second of y-axis motion data, and this shows about 4.5 cycles of oscillations at the center of the STS (A4y) and top of the enclosure (A5y). This demonstrates a resonant response that agrees well with the 6.4 Hz mode defined by the SI tests, as shown in Table 3 (A4y/A1y and A5y/A1y). The lower-frequency response seen in the seismic test at 4.5 Hz may have been caused by minor softening of the STS. This response near 5 Hz is the only significant response to seismic motions in the y-axis.

Figure 20 through Figure 22 also show higher-frequency response motion, seen as high-frequency spikes in this data. Like the x-axis, these high-frequency motions cause very little deformation, do not significantly load the STS, and are only discussed below to explain the high-frequency spikes. The supporting channels were much stiffer in their strong y-axis, where

the motions recorded at A3y agreed very well with A1y and A2y. The only difference between the top and bottom of channels were the low-amplitude, high-frequency cycles near 230 Hz, as presented above.

Table 3 and Figure E-2 show higher-frequency modes in the y-axis at 21.5, 50, and 60 Hz. Figure 22 shows amplified response motions at these frequencies at the top of the enclosure (A5y). This figure shows that there is more amplification at the 50 and 60 Hz modes, than at 21.5 Hz, consistent with the more dominant peaks at the higher frequencies in the transfer functions plotted in Figure E-2. This higher-frequency response caused smaller deformations than the low-frequency response near 6 Hz. The high-frequency motions should not be a threat to the STS unless they cause large amplitude impact, and the data here do not show evidence of impacts. These higher-frequency motions could be caused by minor impacts, but they did not cause damage, as will be later presented.

Figure 23 plots the motion recorded in the z-axis for the entire 30-second test duration. Figure 24 and Figure 25 zoom in on the 16 to 17 second and 16.5 to 16.6 second portions of the z-axis motions to highlight some observations. Figure 24 and Figure 25 show the response motions recorded near the center of gravity of the STS (A4z) and top of the enclosure (A5z) are again always greater than at the base of the channels (A1z and A2z) or top of the channel inside the bottom of the STS (A3z). The motions near the base of the channels, recorded at A1z and A2z, agree well with, but are approximately 20% greater than, the desired motions plotted for the z-axis in Figure 15.

The high-amplitude spikes recorded at A3y at 23 and just after 24 seconds can barely be seen in Figure 23 because the desired spike amplitude in Figure 15 are marginally greater than the rest of the records. These spikes are less in amplitude than the response motions at A4z and A5z in Figure 23.

The zoomed-in view of this data shown in Figure 25 show the motions recorded at the top of the channels inside the STS (A3z) are much greater than those on the plate at the base of the channels (A1z and A2z). Twenty-four high-frequency cycles can be counted between 16.5 and 16.6 seconds, equating to 240 Hz, which appears to correspond to a softened, more flexible version of the 272 Hz mode defined in Table 3.

Figure 23. Recorded motions in the z-axis in the 100% seismic test.

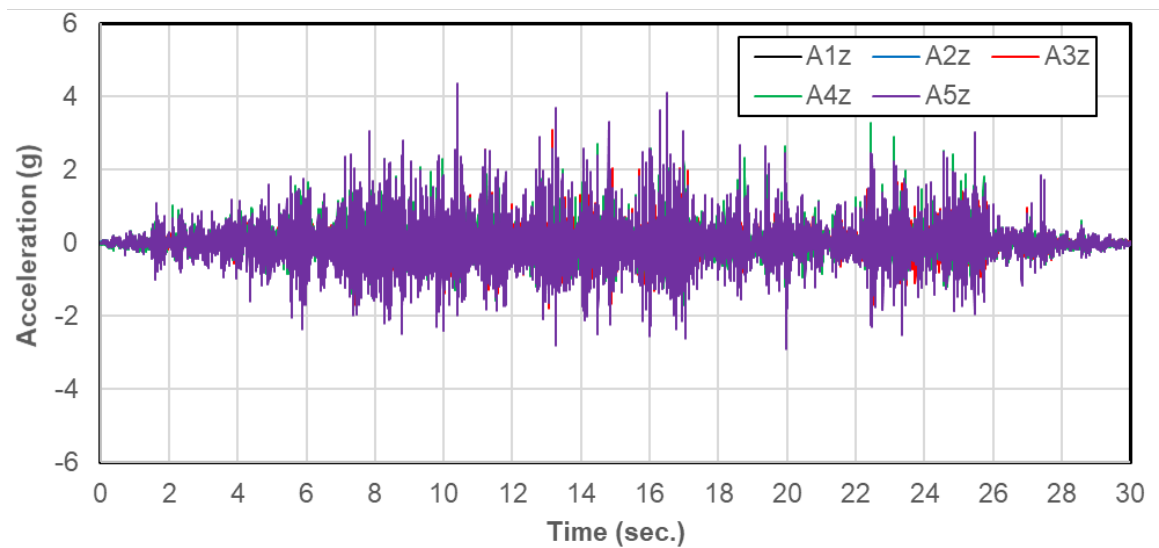


Figure 24. 100% Seismic motions in z-axis, 16 to 17 seconds.

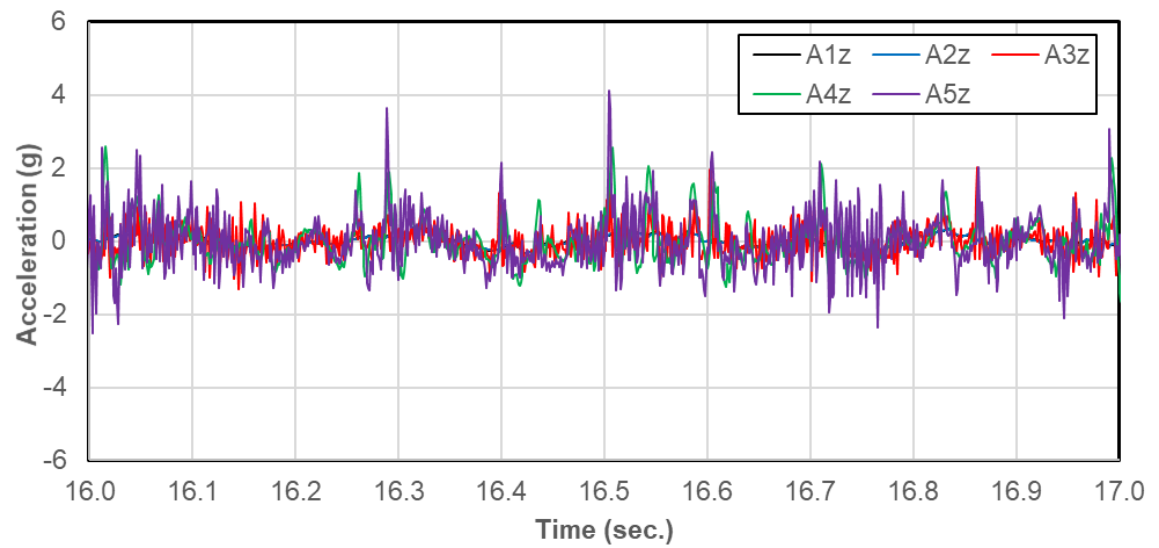


Figure 25. 100% Seismic motions in z-axis, 16.5 to 16.6 seconds.

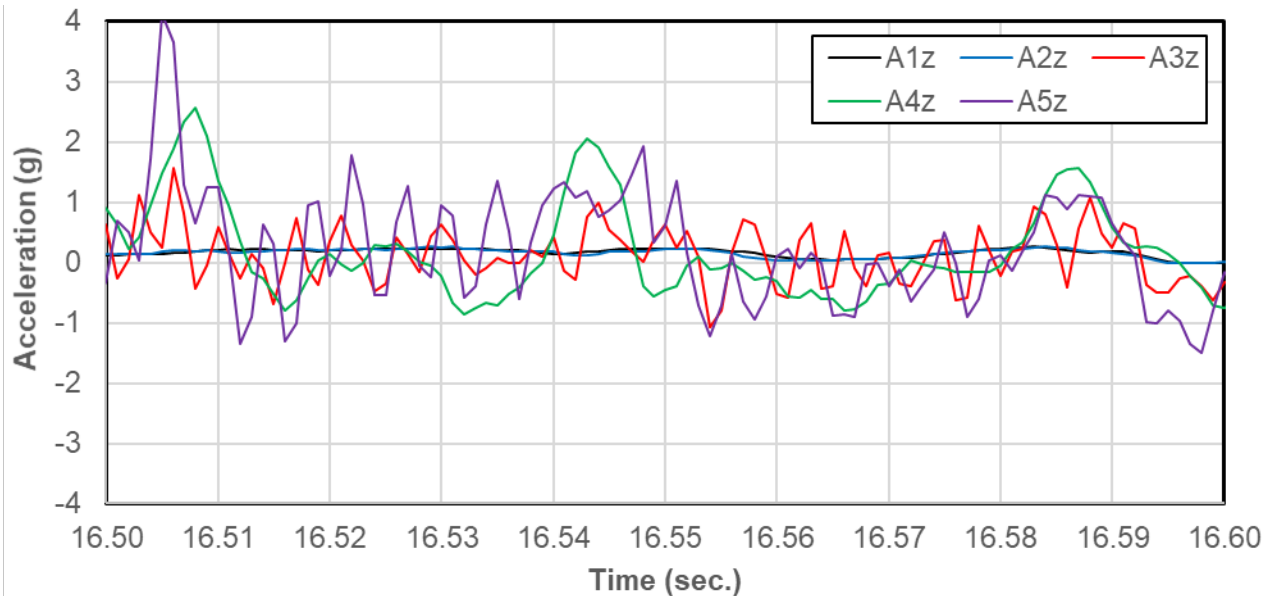
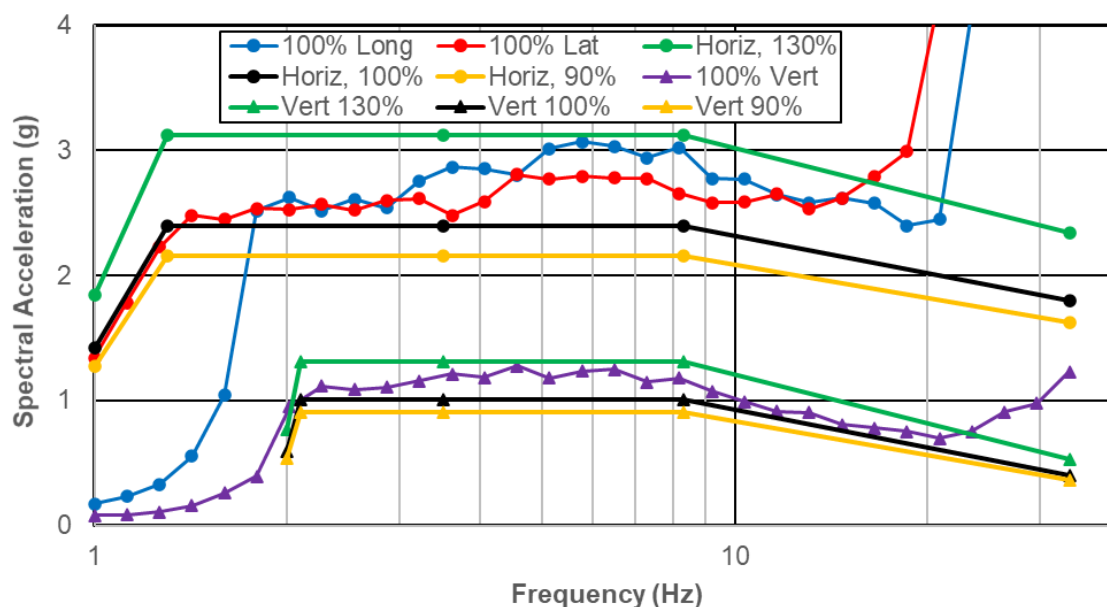


Figure 25 shows slight oscillations of the motions recorded at A4z, at the center of gravity of the STS, where approximately 5 cycles are seen between 16.5 and 16.6 seconds, equating to a 50 Hz response, which is close to the weak 40 Hz mode shown in Table 3. This is the only relatively low-frequency response of the STS seen in the vertical (Z) axis. An even weaker response is seen at the top of the enclosure measured at A5z, where 4 cycles, or a 40 Hz response, can be seen between 16.5 and 16.6 seconds.

Figure 25 shows stronger high-frequency motions, measured at the center of gravity of the STS (A4z), where 6 cycles can be counted between 16.55 and 16.57 seconds, equating to 300 Hz cycles. This agrees with the 300 Hz mode identified in Table 3 for A4z/A1z. At the top of the enclosure (A5z), 18 cycles can be counted between 16.5 and 16.58 seconds, equating to 225 Hz. This is similar to the 236 Hz mode identified in Table 3 by A5z/A1z. These higher modes would not be excited by seismic motions. If the high-frequency acceleration oscillations were double integrated, they would result in very small displacements, demonstrating that they cause very small deformations. This high-frequency response motion in the vertical direction is more dominant than in both horizontal directions, but it also results in very small deformations that would not be a threat to the STS. This discussion explains the high-frequency content that dominates the measured acceleration data.

The TRS are plotted relative to the RRS for the 100% seismic test, as shown in Figure 26. This plot also shows the 90 and 130% plots of the 100% RRS, defined as Horiz 90%; Horiz 130%; Vert 90%; and Vert 130% in the plots. This shows that the achieved TRS fell within the upper and lower bounds. Figure 16, for the 40% test, and Figure 26, for the 100% tests, show that the TRS drifts above the 130% upper bound between 16 and 26 Hz. This indicates a degree of over-testing at relatively high frequencies. However, these frequencies are well above the most critical low-frequency response measured at 5 Hz in the front-to-back direction (y-axis) and 10 Hz in the side-to-side direction (x-axis). There was no important vertical (z-axis) response of concern. This “drifting” of the motions above 16 Hz appears to be due to the 40 Hz sine-pulse motions that were superimposed on the test motions.

Figure 26. TRS plotted relative to the RRS, and RRS upper and lower bounds for the 100% seismic test.



The peak acceleration levels at the base of the STS (A1 and A2 sensors), measured in the 100% seismic test are summarized in Table 4. In the two horizontal axes, 90% of A_{RIG} equals 1.62 g, while 90% of A_{RIG} in the vertical axis is 0.365 g. The maximum positive and negative values measured at all six accelerometers at the bottom of the channels were all well above the 1.62 and 0.365 g required values, showing that the requirements of AC156, Section 6.5.3.2.3 were fulfilled in this test (ICC-ES 2010).

Table 4. Maximum and minimum acceleration measured at the base of the channels.

		A1x	A2x	A1y	A2y	A1z	A2z
		(g)	(g)	(g)	(g)	(g)	(g)
Positive Maximum		2.24	2.29	3.16	3.12	0.64	0.62
Negative Maximum		-2.25	-2.31	-2.87	-2.86	-0.51	-0.55

6.3 Functional test results and visual observations after seismic tests

Functional tests of the STS were conducted prior to and after the seismic tests on the same day. Appendix C and Appendix D provide checklists that document the function of the STS before and after seismic testing. Appendix D shows the STS continued to function as required after seismic testing.

Photographs were taken of the STS prior to and after seismic testing. Electrical power was provided to the STS on two circuits (Supply 1 and Supply 2), and a load bank was connected to the unit to provide a means to fully load the STS. Figure 27 shows a front view of the STS with the front panel closed and the electrical power and load bank connected prior to seismic testing. Figure 28 shows the STS with the front door opened, so that the power could be manually switched from one circuit to another. Figure 29 shows the STS with the front plate removed so that the internal components could be seen and inspected.

Figure 27. Front view of the STS with the front panel closed and electrical power and load bank connected.



Figure 28. Front view of the STS with the front door opened.

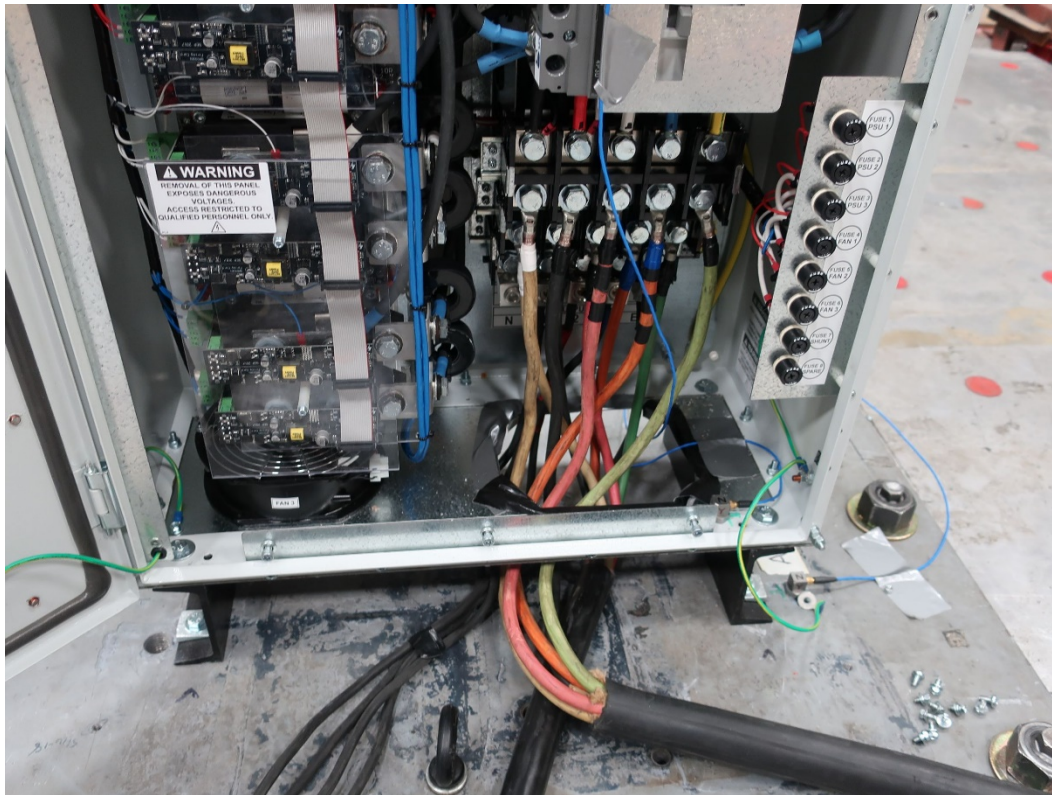


Figure 29. Front view of the STS with the front door opened and front plate removed.



The bottom of the STS was bolted to channels, which were bolted to a heavy steel plate, which was bolted to the shake table. Identical channels will be installed with the same mounting details below the STS when the STS is installed at EAS. These channels provide the needed space below the STS for cooling the unit and for electrical connection. Figure 30 shows a cooling fan at the left side, inside the bottom of the STS. One 3/8 in. (9.5 mm) diameter bolt at each of the four corners of the STS anchors the unit to the channels. Figure 30 shows the bottom of the STS when it was opened for visual inspection after the seismic tests.

Figure 30. Bottom interior of the STS.



The center front (east face) of the bottom of the STS seen in Figure 30 shows metal shavings. These were left over from when holes were drilled in the base of the STS, through which it was bolted to the channels. The shavings were not seen prior to seismic testing because they were hidden below other components. When shaken, the shavings moved to the locations shown here. Figure 31 shows the right side (north face) at the bottom of the STS prior to testing, and Figure 32 shows the right back corner after seismic testing. Figure 32 also shows shavings that had shaken loose and moved during the seismic tests. Figure 33 appears to show metal shavings near the anchor bolt at the front left (southeast) corner, and Figure 34 even more shavings at the back left (southwest) corner of the base of the STS.

Figure 31. Right side of the STS prior to seismic tests.

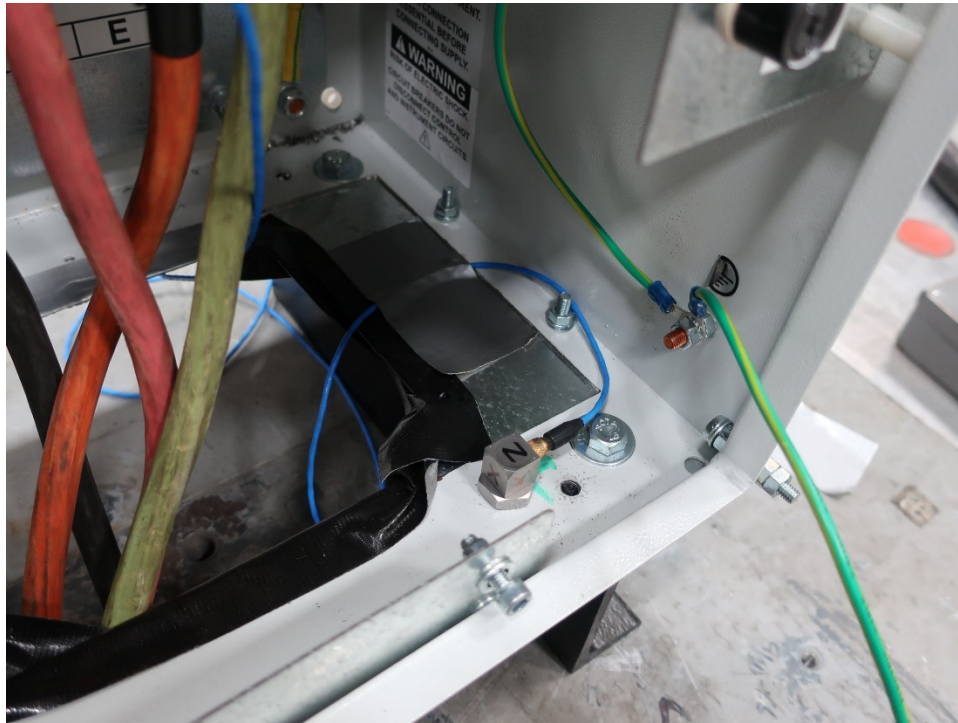


Figure 32. Back right corner of the STS after seismic tests.



Figure 33. Front left corner of the STS after seismic tests.

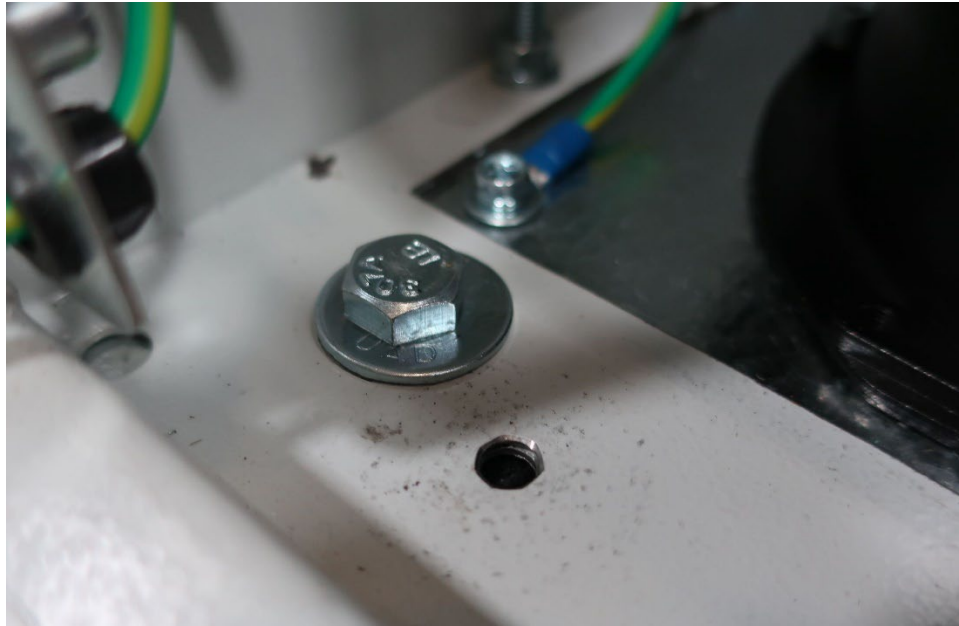


Figure 34. Close-up view of front left corner of the STS after seismic tests.

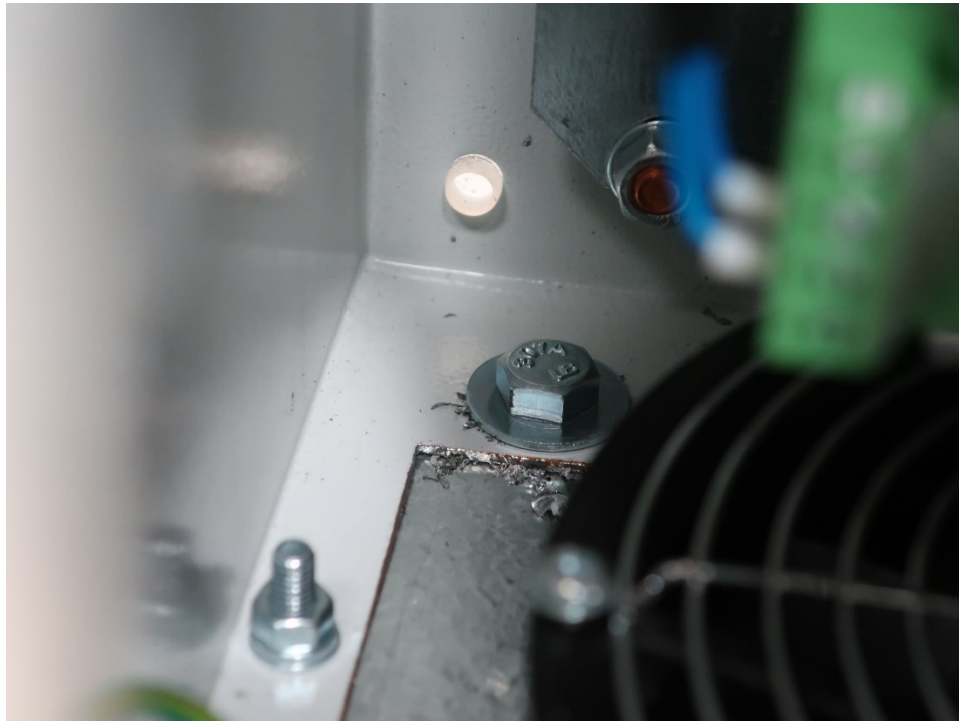


Figure 35 shows a vertical cold-formed steel latching bar for the door. Figure 36 shows the same bar approximately 5 in. (127 mm) below the top of the door. The door remained closed during the seismic test.

Figure 35. Bottom of vertical cold-formed steel door latching bar.



Figure 36. Top of vertical door latching bar.



7 Summary

This report documents the STS configuration, defines the seismic hazard and test motions, calculates the loading and capacity of the hardware used to anchor the STS, and defines test details and seismic test results.

The functional testing conducted after the seismic testing demonstrated no loss of function of this unit, and visual observations indicated that there was no physical damage to the STS. This testing demonstrated that the STS met the seismic testing requirements and can be installed at EAS.

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Acronyms and Abbreviations

Acronym	Term
AC	Acceptance Criteria
ASCE	American Society of Civil Engineers
ASTM	American Society of Testing and Materials
AWG	American Wire Gauge
CERL	Construction Engineering Research Laboratory
EAS	Eareckson Air Station
ERDC	Engineer Research and Development Center
GAL	Galvanized
HSS	Hollow Structural Sections
ICC-ES	International Code Council Evaluation Service
IEEE	Institute of Electrical and Electronics Engineers
MC-1	Mission-Critical Level 1
MCE _R	Risk-Targeted Maximum Considered Earthquake (see ASCE 7-16, Chapter 11.2 Definitions)
MET	Modernized Enterprise Terminal
OSHPD	Office of Statewide Health and Planning and Development
PU	Polyurethane
RRS	Required Response Spectra
SI	System Identification
SRSS	Square Root of the Sum of the Squares

STS	Static Transfer Switch
TRS	Test Response Spectra
UFC	Unified Facilities Criteria
UUT	Unit Under Test

Unit Conversion Factors

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
pounds (force)	4.448222	newtons
pounds (force) per inch	175.1268	newtons per meter
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
square inches	6.4516 E-04	square meters

Appendix A: Scale and Accelerometer Calibration Certificates

Below is the calibration certificate for the scale at the ERDC-CERL warehouse used to weigh the STS.

[illegible]

TMDE CALIBRATION AND REPAIR DATA				1. JOB ORDER NUMBER		2. PRIORITY		3. IDENTIFICATION CODE	
For use of this form see 750-25; the proponent agency is USAMC									
4. TECHNICAL BULLETIN				5. TECHNICAL MANUAL				6. SCHEDULE UIC	
8. SERIAL NUMBER				9. MODEL NUMBER				7. OWNER UIC	
11. NATIONAL STOCK NUMBER				12. DUE DATE		13. INT		14. SYSTEM CODE	
16. WORK CENTER TEAM				17. LEVEL		18. ACTION DATE		19. PERFORMING UIC	
21. EQUIP READINESS CODE				22. UPDATE ☐ ADD ☐ CHANGE ☐ DELETE		23. REPORT CODE		20. TYPE STANDARD ☐ PHYS ☐ IR ☐ MW ☐ ELEC	
25. DEFICIENCIES/SYMPTOMS				24. CHANGE DATA					
26. STATUS				27. CALIBRATION CONDITION		28. REPAIR/ADJUSTMENT		29. REPAIR	
a. PUIC b. CODE c. DATE d. INIT				a. WITHIN TOLERANCE		a. BY TEAM/LAB		TECH CODE HOURS	
				b. OUT OF TOLERANCE		b. DEFERRED MAINT		TECH CODE HOURS	
				31. PARTS ADJUSTED		c. NRTS/CODE OUT			
				32. PARTS REPLACED					
				33. REMARKS					
34. PARTS REQUISITIONED				e. QTY		f. UNIT		g. UNIT	
a. REF DESIG b. NOMENCLATURE c. MFG CODE d. NATIONAL STOCK NO./ PART NO.				ISSUE		COST		h. DOCUMENT NUMBER	
								i. RECEIVED	
35a. SUBMITTED BY								35b. DATE	
36a. RECEIVED UNDER LIMITED TECHNICAL INSPECTION BY								36b. DATE	
37a. ACCEPTED								37b. DATE	

DA FORM 7372, DEC 96

AMXTM 34A, 1 Dec 87, and AMSMI 34A, 1 Apr 96, are obsolete.

USAPPC V1.00

WHEN COMPLETING THIS FORM, SEE TB 750-25.																																																																																																											
BLOCK 8 - SERIAL NUMBER. Must have entry. Do not precede with zeros. If longer than ten digits, delete from left side. Must use joint electronics type designator system (JETDS) serial number. Manufacturer's serial number will be used for non-JETDS items. Do not include special characters, e.g., "f", "-", or "@", etc.																																																																																																											
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BLOCK 10 - MFG CODE. Must have entry. See TB 43-180 or SB 708-43 and SB 708-48. Entry will be five zeros if JETDS item, or where no MFG CODE is known.																																																																																																											
BLOCK 13 - INTERVAL CODES. Reference TB 43-180 <table border="1"> <thead> <tr> <th>CODE</th> <th>INTERVAL/DAYS</th> <th>CODE</th> <th>INTERVAL/DAYS</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>30</td> <td>2</td> <td>720</td> </tr> <tr> <td>B</td> <td>60</td> <td>3</td> <td>1080</td> </tr> <tr> <td>C</td> <td>90</td> <td>5</td> <td>USAPSL Special Only</td> </tr> <tr> <td>D</td> <td>120</td> <td>6</td> <td>960</td> </tr> <tr> <td>E</td> <td>150</td> <td>7</td> <td>Training</td> </tr> <tr> <td>F</td> <td>180</td> <td>8</td> <td>CNR</td> </tr> <tr> <td>G</td> <td>210</td> <td>9</td> <td>CBU (Admin storage)</td> </tr> <tr> <td>H</td> <td>240</td> <td></td> <td></td> </tr> <tr> <td>J</td> <td>270</td> <td></td> <td></td> </tr> <tr> <td>K</td> <td>300</td> <td></td> <td></td> </tr> <tr> <td>L</td> <td>330</td> <td></td> <td></td> </tr> <tr> <td>M</td> <td>360</td> <td></td> <td></td> </tr> <tr> <td>N</td> <td>450</td> <td></td> <td></td> </tr> <tr> <td>O</td> <td>One time only</td> <td></td> <td></td> </tr> <tr> <td>P</td> <td>540</td> <td></td> <td></td> </tr> <tr> <td>Q</td> <td>630</td> <td></td> <td></td> </tr> <tr> <td>R</td> <td>480</td> <td></td> <td></td> </tr> <tr> <td>S</td> <td>600</td> <td></td> <td></td> </tr> <tr> <td>T</td> <td>390</td> <td></td> <td></td> </tr> <tr> <td>U</td> <td>420</td> <td></td> <td></td> </tr> <tr> <td>V</td> <td>510</td> <td></td> <td></td> </tr> <tr> <td>W</td> <td>570</td> <td></td> <td></td> </tr> <tr> <td>X</td> <td>660</td> <td></td> <td></td> </tr> <tr> <td>Y</td> <td>690</td> <td></td> <td></td> </tr> <tr> <td>Z</td> <td>840</td> <td></td> <td></td> </tr> </tbody> </table>				CODE	INTERVAL/DAYS	CODE	INTERVAL/DAYS	A	30	2	720	B	60	3	1080	C	90	5	USAPSL Special Only	D	120	6	960	E	150	7	Training	F	180	8	CNR	G	210	9	CBU (Admin storage)	H	240			J	270			K	300			L	330			M	360			N	450			O	One time only			P	540			Q	630			R	480			S	600			T	390			U	420			V	510			W	570			X	660			Y	690			Z	840		
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DA FORM 7372, DEC 96

AMXTM 34A, 1 Dec 87, and AMSMI 34A, 1 Apr 96, are obsolete.

USAPPC V1.00

Calibration certificates for the accelerometers shown in Table 2 are shown on the pages that follow.

~ Calibration Certificate ~
Per ISO 16063-21

Model Number: TLD356A14

Serial Number: 279677 (x axis)

Description: ICP® Triaxial Accelerometer

Manufacturer: PCB Method: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 97.8 mV/g
(9.97 mV/m/s²)

Output Bias 11.2 VDC

Discharge Time Constant 1.2 seconds

Transverse Sensitivity 2.4 %

Sensitivity Plot

Temperature: 73 °F (23 °C) Relative Humidity: 34 %

Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.4	300	-0.7
15	1.2	500	-1.0
30	0.7	1000	-1.2
50	0.4	3000	-0.5
REF. FREQ.	0.0	5000	2.3

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted Vertical
Acceleration Level (g): 10.0 g (98.1 m/s²)
*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)². **The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Michael Ferrio MAF Date: 9/21/2020

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PAGE 1 of 1
ICS-17
CAL-1-3683547401.969+0

~ Calibration Certificate ~

Per ISO 16063-21

Model Number: TL356A14

Serial Number: 279677 (y axis)

Description: ICP® Triaxial Accelerometer

Manufacturer: PCB

Method: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 100.6 mV/g

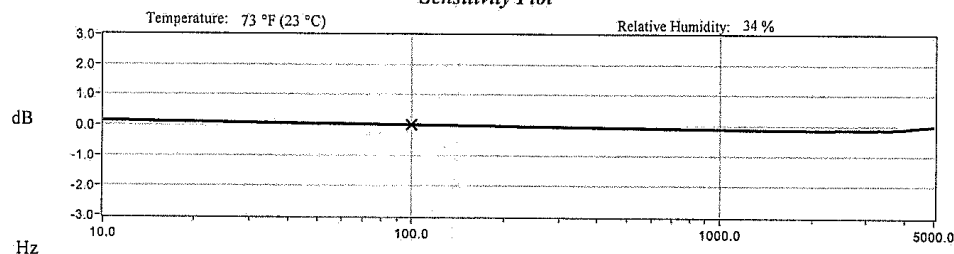
(10.26 mV/m/s²)

Output Bias 11.2 VDC

Transverse Sensitivity 1.0 %

Discharge Time Constant 2.6 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.4	300	-0.7
15	1.2	500	-1.0
30	0.7	1000	-1.4
50	0.4	3000	-1.7
REF. FREQ.	0.0	5000	-0.3

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Vertical

Acceleration Level (pk): 30.0 g (98.1 m/s²)

¹The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)². ²The gravitational constant used for calculations by the calibration system is: $1\text{ g} = 9.80665\text{ m/s}^2$

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance.

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz +/- 2.5%, 10-15 kHz +/- 5%.

Technician:

Michael Ferrio HAF

Date:

9/21/2020



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CAL1-3683547667.170+0

~ Calibration Certificate ~

Per ISO 16063-21

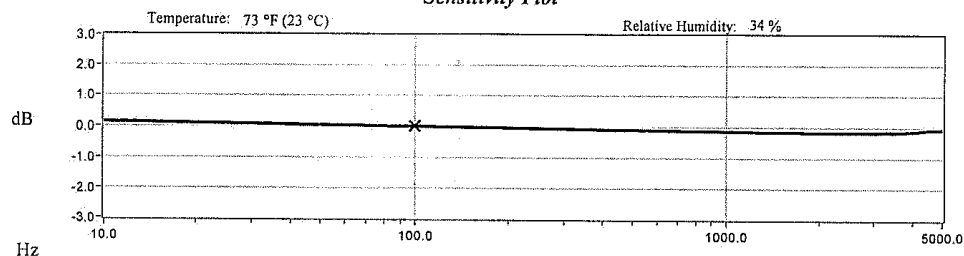
Model Number: TLD356A14Serial Number: 279677 (z axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 99.4 mV/g Output Bias 11.2 VDC
 (10.14 mV/m/s²) Transverse Sensitivity 0.9 %
 Discharge Time Constant 2.4 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.5	300	-0.9
15	1.2	500	-1.3
30	0.7	1000	-1.7
50	0.3	3000	-2.1
REF. FREQ.	0.0	5000	-1.0

Mounting Surface: Beryllium w/Silicone Grease Fastener: 10-32 Female Fixture Orientation: Vertical
 Acceleration Level (pk): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the issued level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)². *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Michael FerrioHAFDate: 9/21/2020

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ACS-17

CAL1-3683548090.704+0

~ Calibration Certificate ~

Per ISO 16063-21

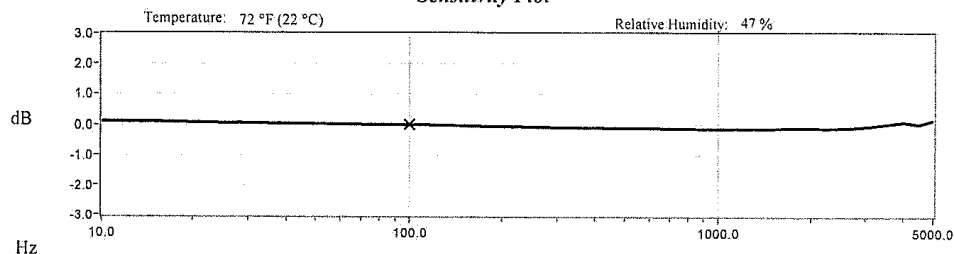
Model Number: TLD356A14Serial Number: 296842 (x axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 96.3 mV/g
 (9.82 mV/m/s²) Output Bias 11.3 VDC
 Discharge Time Constant 2.2 seconds Transverse Sensitivity 1.2 %

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.1	300	-1.1
15	1.0	500	-1.3
30	0.5	1000	-1.7
50	0.2	3000	-0.9
REF. FREQ.	0.0	5000	1.6

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted Vertical
 Acceleration Level (g): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s²

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: HUP

Holli L. Parks

Date: 9/23/2020

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CAL2-3683714191.71x10

~ Calibration Certificate ~

Per ISO 16063-21

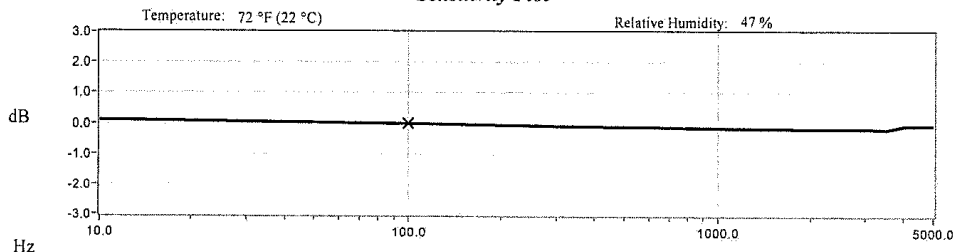
Model Number: TLD356A14Serial Number: 296842 (y axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz **98.1 mV/g** Output Bias 11.5 VDC
 (10.00 mV/m/s²) Transverse Sensitivity 0.3 %
 Discharge Time Constant 2.3 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.1	300	-1.0
15	1.0	500	-1.2
30	0.5	1000	-1.7
50	0.2	3000	-2.0
REF. FREQ.	0.0	5000	-0.6

Mounting Surface: Benlium Fastener: Adhesive Fixture Orientation: Vertical
 Acceleration Level (g): 10.0 g (98.1 m/s²)

The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

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HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
 TEL: 888-684-0013 - FAX: 716-685-3886 - www.pcb.com

CAL2-3683714464-123-0

~ Calibration Certificate ~

Per ISO 16063-21

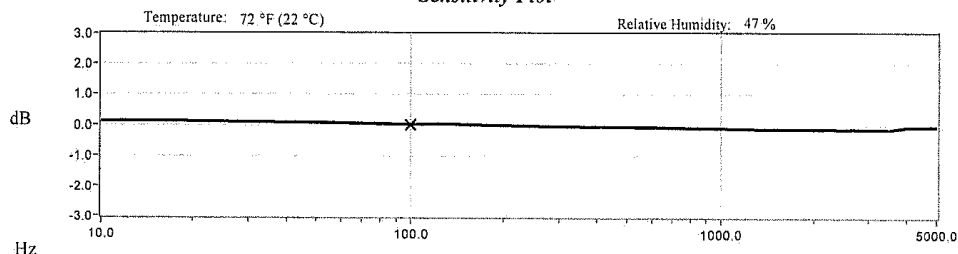
Model Number: TLD356A14Serial Number: 296842 (z axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 102.3 mV/g
 (10.44 mV/m/s²) Output Bias 11.3 VDC
 Discharge Time Constant 1.7 seconds Transverse Sensitivity 3.4 %

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.3	300	-0.5
15	1.4	500	-0.7
30	1.0	1000	-1.2
50	0.7	3000	-1.6
REF. FREQ.	0.0	5000	-0.6

Mounting Surface: Beryllium w/Silicone Grease Fastener: 10-32 Female Fixture Orientation: Vertical
 Acceleration Level (pk): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. Parks *HLP*Date: 9/23/2020

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HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
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CAL2-368371/MS6-211-00



~ Calibration Certificate ~

Per ISO 16063-21

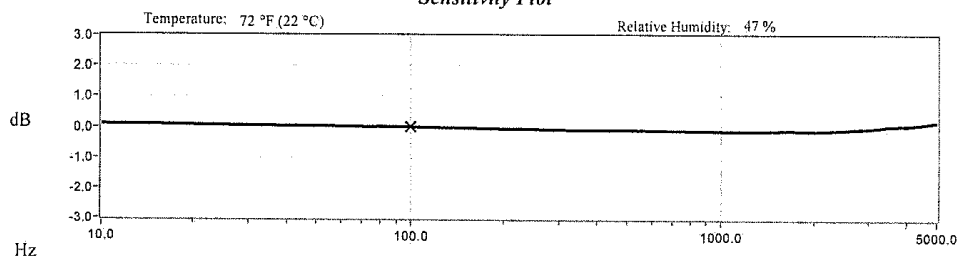
Model Number: TLD356A14Serial Number: 296843 (x axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 104.7 mV/g
 (10.68 mV/m/s²) Output Bias 11.3 VDC
 Discharge Time Constant 1.6 seconds Transverse Sensitivity 3.2 %

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.0	300	-1.1
15	0.9	500	-1.2
30	0.4	1000	-1.6
50	0.2	3000	-0.6
REF. FREQ.	0.0	5000	1.8

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted Vertical

Acceleration Level (pk): 10.0 g (98.1 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)¹. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. Parks *HLP*Date: 9/23/2020

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
 TEL: 888-684-0013 - FAX: 716-685-3886 - www.pcb.com

CAL2-3683713920-247-0



~ Calibration Certificate ~

Per ISO 16063-21

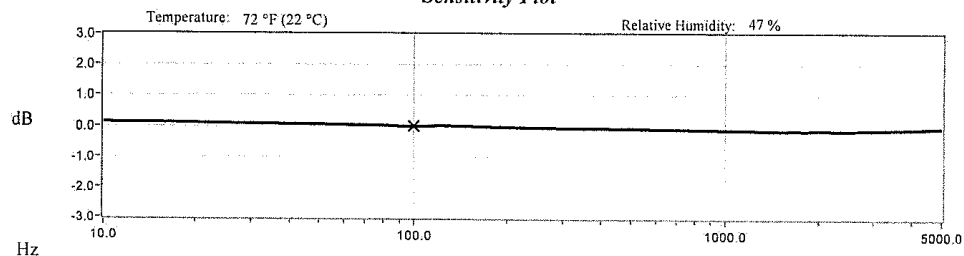
Model Number: TLD356A14Serial Number: 296843 (y axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 94.5 mV/g Output Bias 11.3 VDC
 (9.63 mV/m/s²) Transverse Sensitivity 3.7 %
 Discharge Time Constant 2.1 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.3	300	-0.7
15	1.2	500	-0.9
30	0.8	1000	-1.4
50	0.5	3000	-1.5
REF. FREQ.	0.0	5000	-0.5

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Vertical

Acceleration Level (pk): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: HUP

Holli L. Parks

Date: 9/23/2020

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
 TEL: 888-684-0013 - FAX: 716-685-3886 - www.pcb.com

CAL2-1681713652 145+0

~ Calibration Certificate ~

Per ISO 16083-21

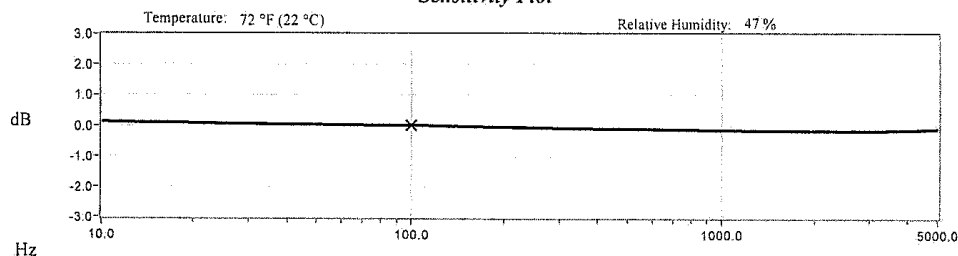
Model Number: TLD356A14Serial Number: 296843 (z axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 96.1 mV/g
 (9.80 mV/m/s²) Output Bias 11.3 VDC
 Discharge Time Constant 2.3 seconds Transverse Sensitivity 0.7 %

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.3	300	-1.1
15	1.1	500	-1.3
30	0.5	1000	-1.7
50	0.3	3000	-2.0
REF. FREQ.	0.0	5000	-1.3

Mounting Surface: Beryllium w/Silicone Grease Fastener: 10-32 Female Fixture Orientation: Vertical

Acceleration Level (g): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude, Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
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3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
 TEL: 888-684-0013 - FAX: 716-685-3886 - www.pcb.com

CAL2-3683712128 894-0

~ Calibration Certificate ~

Per ISO 18063-21

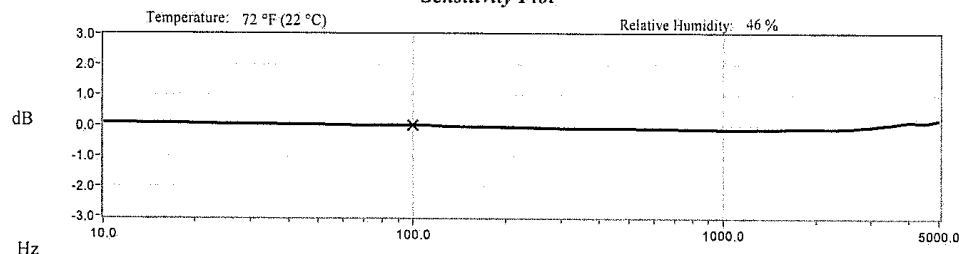
Model Number: TLD356A14Serial Number: 296844 (x axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 102.2 mV/g Output Bias 11.3 VDC
 (10.42 mV/m/s²) Transverse Sensitivity 2.5 %
 Discharge Time Constant 1.8 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	0.9	300	-1.1
15	0.8	500	-1.3
30	0.4	1000	-1.6
50	0.1	3000	-0.5
REF. FREQ.	0.0	5000	2.0

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted Vertical
 Acceleration Level (pk): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 * (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: HUP

Holli L. Parks

Date: 9/23/2020

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
 TEL: 888-684-0013 - FAX: 716-685-3886 - www.pcb.com

CAL2-3683712844 203+0

~ Calibration Certificate ~

Per ISO 16063-21

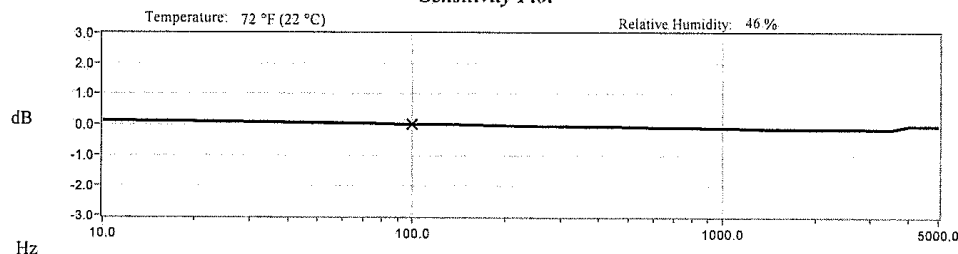
Model Number: TLD356A14Serial Number: 296844 (y axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 99.0 mV/g Output Bias 11.3 VDC
 (10.09 mV/m/s²) Transverse Sensitivity 1.9 %
 Discharge Time Constant 2.0 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.3	300	-0.7
15	1.2	500	-1.0
30	0.7	1000	-1.4
50	0.5	3000	-1.8
REF. FREQ.	0.0	5000	-0.6

Mounting Surface: Berghill Fastener: Adhesive Fixture Orientation: Vertical
 Acceleration Level (pk): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 s (freq). *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s²

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
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3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. Parks HLPDate: 9/23/2020

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CAL2-3683713329-513-0



~ Calibration Certificate ~

Per ISO 16063-21

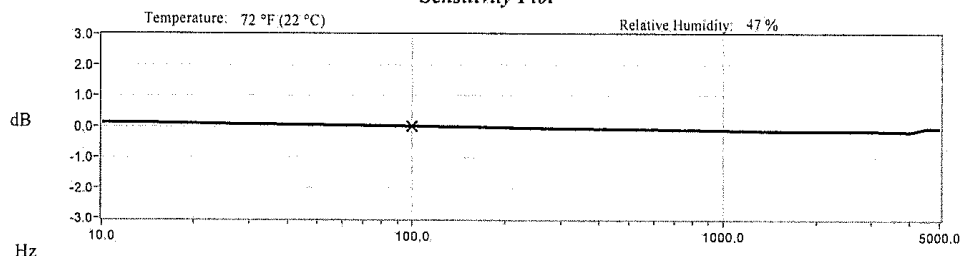
Model Number: TLD356A14Serial Number: 296844 (z axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz **99.9 mV/g** Output Bias 11.3 VDC
 (10.19 mV/m/s²) Transverse Sensitivity 0.9 %
 Discharge Time Constant 2.0 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.4	300	-0.9
15	1.2	500	-1.1
30	0.7	1000	-1.5
50	0.4	3000	-1.9
REF. FREQ.	0.0	5000	-0.9

Mounting Surface: Beryllium w/Silicone Grease Fastener: 10-32 Female Fixture Orientation: Vertical

Acceleration Level (g): 10.0 g (98.1 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.009 x (freq)^{1.5} *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s²

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

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3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksHLPDate: 9/23/2020

PCB PIEZOTRONICS INC.

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
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CAL2-3683712338-765+0

ACS-17

~ Calibration Certificate ~

Per ISO 18063-21

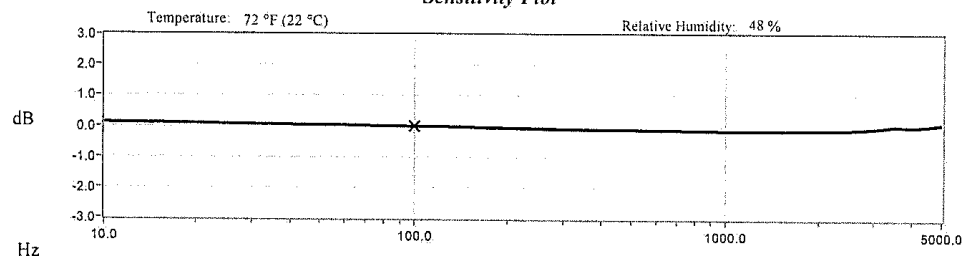
Model Number: TLD356A14Serial Number: 297385 (x axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 99.5 mV/g Output Bias 11.1 VDC
 (10.15 mV/m/s²) Transverse Sensitivity 0.7 %
 Discharge Time Constant 1.8 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.2	300	-1.1
15	1.1	500	-1.3
30	0.6	1000	-1.6
50	0.3	3000	-0.8
REF. FREQ.	0.0	5000	0.9

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted Vertical

Acceleration Level (pk): 10.0 g (98.1 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
 TEL: 888-684-0013 - FAX: 716-685-3886 - www.pcb.com

CAL2-3683705018.974+0

~ Calibration Certificate ~

Per ISO 16063-21

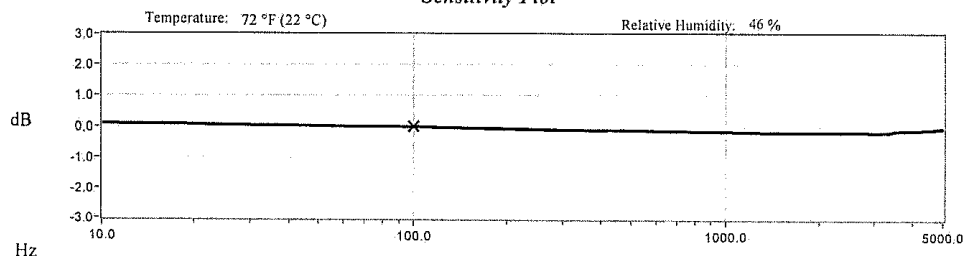
Model Number: TLD356A14Serial Number: 297385 (y axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 98.3 mV/g Output Bias 11.2 VDC
 (10.03 mV/m/s²) Transverse Sensitivity 0.4 %
 Discharge Time Constant 2.2 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.0	300	-1.2
15	0.9	500	-1.4
30	0.4	1000	-1.9
50	0.1	3000	-2.2
REF. FREQ.	0.0	5000	-0.7

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Vertical

Acceleration Level (g): 10.0 g (98.1 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
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3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. Parks *HLP*Date: 9/23/2020

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
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 TEL: 888-684-0013 - FAX: 716-685-3886 - www.pcb.com

CAL2-3683705383 177-0

~ Calibration Certificate ~

Per ISO 16063-21

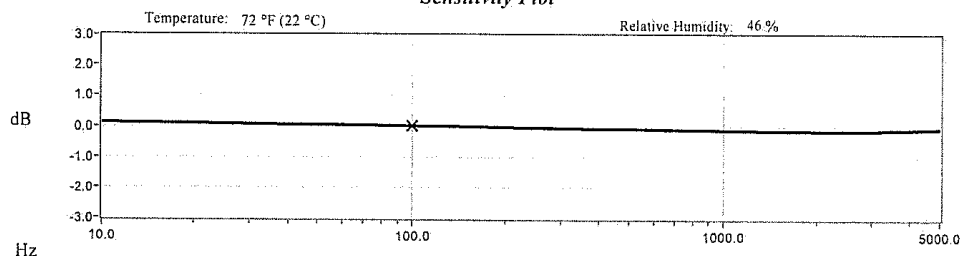
Model Number: TLD356A14Serial Number: 297385 (z axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz **98.3 mV/g** Output Bias 11.3 VDC
 (10.02 mV/m/s²) Transverse Sensitivity 2.0 %
 Discharge Time Constant 2.5 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.3	300	-0.9
15	1.1	500	-1.1
30	0.7	1000	-1.6
50	0.4	3000	-1.9
REF. FREQ.	0.0	5000	-1.0

Mounting Surface: Beryllium w/Silicone Grease Fastener: 10-32 Female Fixture Orientation: Vertical

Acceleration Level (g): 10.0 g (98.1 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude. Acceleration Level (g) = 0.008 * (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit. In Tolerance

Notes

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3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: HLP

Holli L. Parks

Date: 9/23/2020

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CAL2-3683710220-139-00

~ Calibration Certificate ~

Per ISO 16063-21

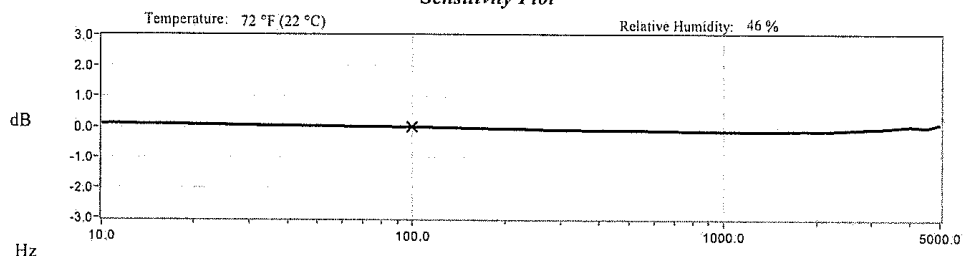
Model Number: TLD356A14Serial Number: 297387 (x axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 94.1 mV/g Output Bias 11.4 VDC
 (9.60 mV/m/s²) Transverse Sensitivity 1.1 %
 Discharge Time Constant 1.5 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.2	300	-1.1
15	1.0	500	-1.3
30	0.5	1000	-1.7
50	0.2	3000	-0.8
REF. FREQ.	0.0	5000	1.2

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted Vertical
 Acceleration Level (pk): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit. In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
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CAL2-3683706467 448*0

ACS-17



~ Calibration Certificate ~

Per ISO 16063-21

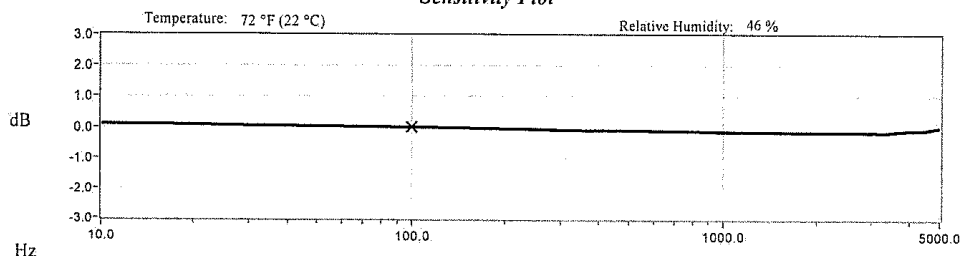
Model Number: TLD356A14Serial Number: 297387 (y axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 102.6 mV/g Output Bias 11.3 VDC
 (10.46 mV/m/s²) Transverse Sensitivity 1.6 %
 Discharge Time Constant 2.0 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.0	300	-1.0
15	0.9	500	-1.2
30	0.5	1000	-1.7
50	0.3	3000	-2.0
REF. FREQ.	0.0	5000	-0.1

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Vertical

Acceleration Level (g): 100 g (981 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

HEADQUARTERS: 3425 WALDEN AVENUE - DEPEW, NY 14043
 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
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CAL2-3683706174 386+0

ACS-1T



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Per ISO 16063-21

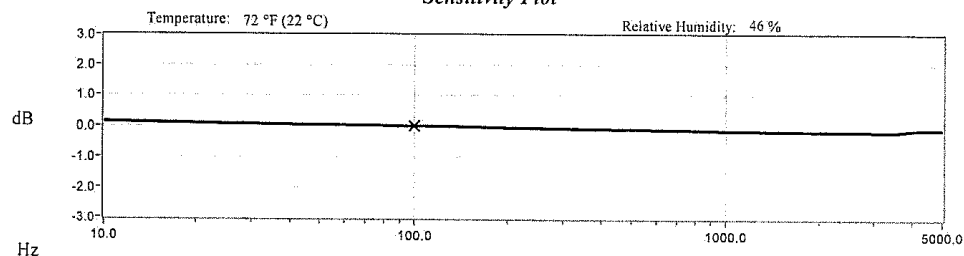
Model Number: TLD356A14Serial Number: 297387 (z axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 99.6 mV/g Output Bias 11.3 VDC
 (10.16 mV/m/s²) Transverse Sensitivity 1.2 %
 Discharge Time Constant 2.1 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.5	300	-0.9
15	1.2	500	-1.2
30	0.6	1000	-1.6
50	0.4	3000	-2.1
REF. FREQ.	0.0	5000	-1.2

Mounting Surface: Benlium w/Silicone Grease Fastener: 10-32 Female Fixture Orientation: Vertical
 Acceleration Level (pk): 0.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: HUP

Holli L. Parks

Date: 9/23/2020

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CAL2-3683716038.864+0



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Per ISO 16063-21

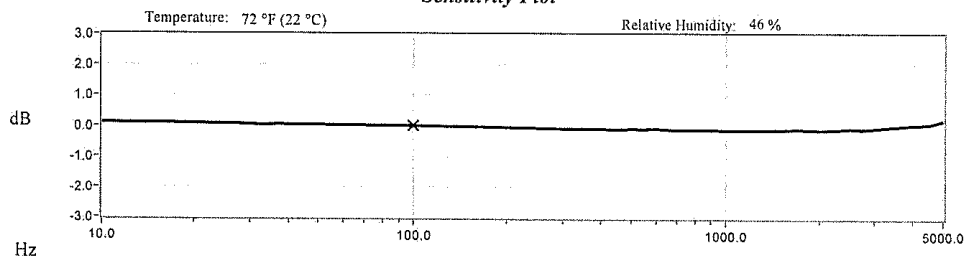
Model Number: TLD356A14Serial Number: 297388 (x axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 101.4 mV/g Output Bias 11.3 VDC
 (10.34 mV/m/s²) Transverse Sensitivity 0.9 %
 Discharge Time Constant 2.2 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.2	300	-1.1
15	1.0	500	-1.2
30	0.5	1000	-1.7
50	0.3	3000	-1.0
REF. FREQ.	0.0	5000	2.0

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted VerticalAcceleration Level (g): 10.0 g (98.1 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.006 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s²

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

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CAL2-3683707478.136+0

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Per ISO 18063-21

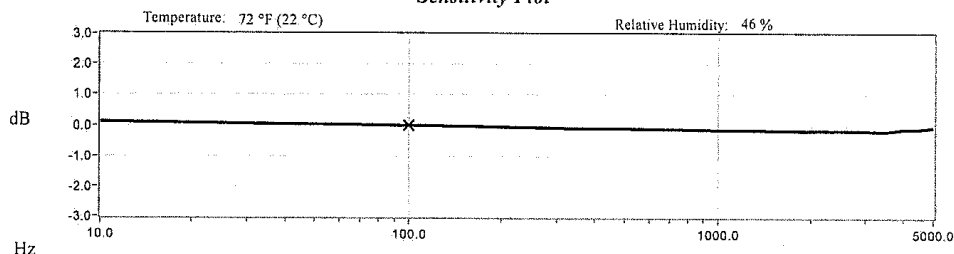
Model Number: TLD356A14Serial Number: 297388 (y axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 96.8 mV/g
 (9.88 mV/m/s²) Output Bias 11.3 VDC
 Transverse Sensitivity 2.2 %
 Discharge Time Constant 2.5 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.2	300	-1.0
15	1.0	500	-1.2
30	0.5	1000	-1.6
50	0.3	3000	-2.1
REF. FREQ.	0.0	5000	-0.7

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Vertical
 Acceleration Level (pk): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.006 s (freq)². *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s²

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. Parks *HLP*Date: 9/23/2020

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CAL2-3683707109 4014-E

~ Calibration Certificate ~

Per ISO 16063-21

Model Number: TLD356A14Serial Number: 297388 (z axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

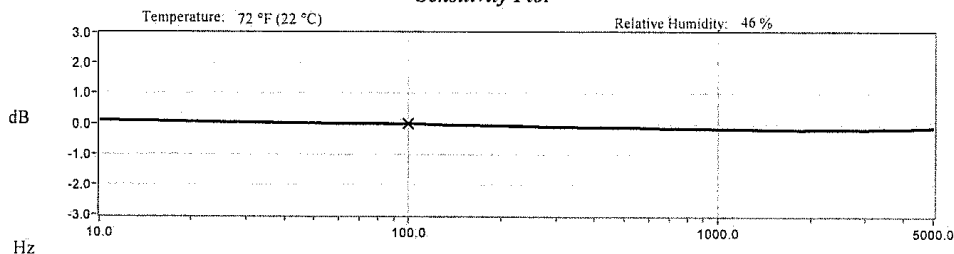
Sensitivity @ 100 Hz 101.4 mV/g
 (10.34 mV/m/s²)

Output Bias 11.4 VDC

Transverse Sensitivity 2.2 %

Discharge Time Constant 2.2 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.1	300	-1.2
15	0.9	500	-1.4
30	0.4	1000	-1.9
50	0.1	3000	-2.1
REF. FREQ.	0.0	5000	-1.4

Mounting Surface: Beryllium w/ Silicone Grease Fastener: 10-32 Female Fixture Orientation: Vertical

Acceleration Level (pk): 10.0 g (98.1 m/s²)

*The acceleration level may be limited by shaker displacement at low frequencies. If the tested level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude. Acceleration Level: (g) = 0.006 x (freq)². *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

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CAT2-3683709845-9/16/10

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Per ISO 16063-21

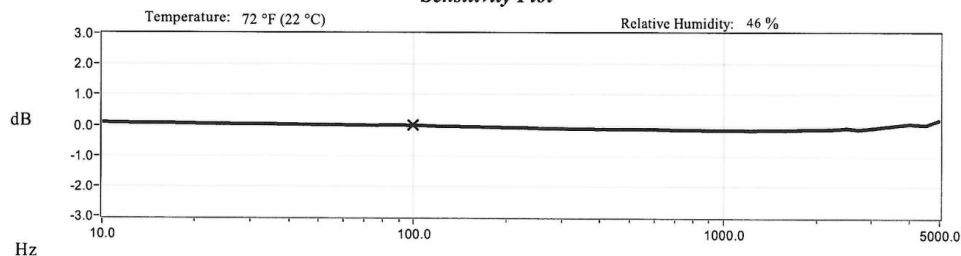
Model Number: TLD356A14Serial Number: 297389 (x axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 99.4 mV/g Output Bias 11.2 VDC
 (10.13 mV/m/s²) Transverse Sensitivity 1.8 %
 Discharge Time Constant 1.8 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.0	300	-1.2
15	0.8	500	-1.4
30	0.3	1000	-1.8
50	0.1	3000	-1.0
REF. FREQ.	0.0	5000	2.1

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Inverted Vertical

Acceleration Level (g_k): 10.0 g (98.1 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

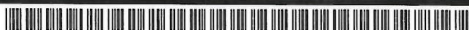
1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

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CAL2-368370779.480+0

ACS-17



~ Calibration Certificate ~

Per ISO 16063-21

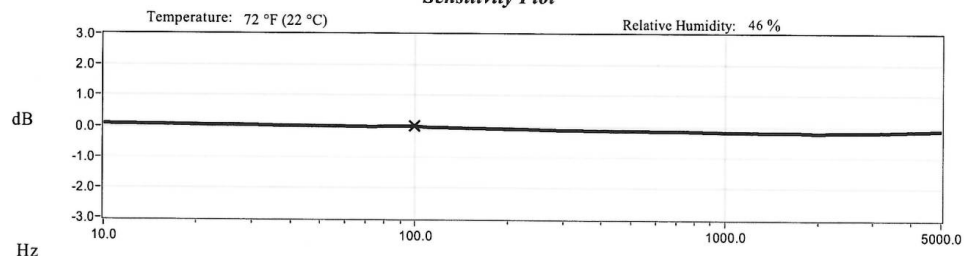
Model Number: TLD356A14Serial Number: 297389 (y axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 97.4 mV/g Output Bias 11.8 VDC
 (9.94 mV/m/s²) Transverse Sensitivity 1.6 %
 Discharge Time Constant 2.1 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	0.8	300	-1.5
15	0.7	500	-1.7
30	0.2	1000	-2.1
50	-0.1	3000	-2.3
REF. FREQ.	0.0	5000	-1.4

Mounting Surface: Beryllium Fastener: Adhesive Fixture Orientation: Vertical

Acceleration Level (g): 10.0 g (98.1 m/s²)*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

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 CALIBRATION PERFORMED AT: 10869 HIGHWAY 903, HALIFAX, NC 27839
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CAL2-3683708150.807+0



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Per ISO 16063-21

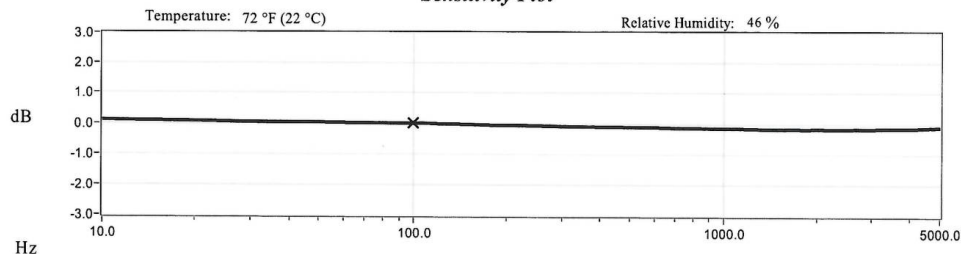
Model Number: TLD356A14Serial Number: 297389 (z axis)Description: ICP® Triaxial AccelerometerManufacturer: PCBMethod: Back-to-Back Comparison AT401-3

TEDS: This Sensor has been programmed with IEEE 1451.4 Template 25

Calibration Data

Sensitivity @ 100 Hz 97.0 mV/g Output Bias 11.4 VDC
 (9.89 mV/m/s²) Transverse Sensitivity 2.5 %
 Discharge Time Constant 2.7 seconds

Sensitivity Plot



Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10	1.1	300	-1.1
15	0.9	500	-1.3
30	0.4	1000	-1.8
50	0.2	3000	-2.1
REF. FREQ.	0.0	5000	-1.4

Mounting Surface: Beryllium w/Silicone Grease Fastener: 10-32 Female Fixture Orientation: Vertical

Acceleration Level (pk): 10.0 g (98.1 m/s²)

¹The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude: Acceleration Level (g) = 0.008 x (freq)^{1.5}. ²The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/aAs Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 684/O-0000000851 and PTB Traceable thru Project 17016.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 10012-1, ANSI Z540.3 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%, 10-15 kHz; +/- 5%.

Technician: Holli L. ParksDate: 9/23/2020

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CAL2-3683709651.805+0

ACS-17



Appendix B: Photographs of Accelerometers used to Document Seismic Tests

Five triaxial accelerometers were used to document the motions recorded during the system identification and seismic tests. Figure B-1 shows an overall view, and Figure B-2 through Figure B-6 show each triaxial accelerometer.

Figure B-1. Overall front view of Static Transfer Switch with the door and cover plate opened showing sensor locations.

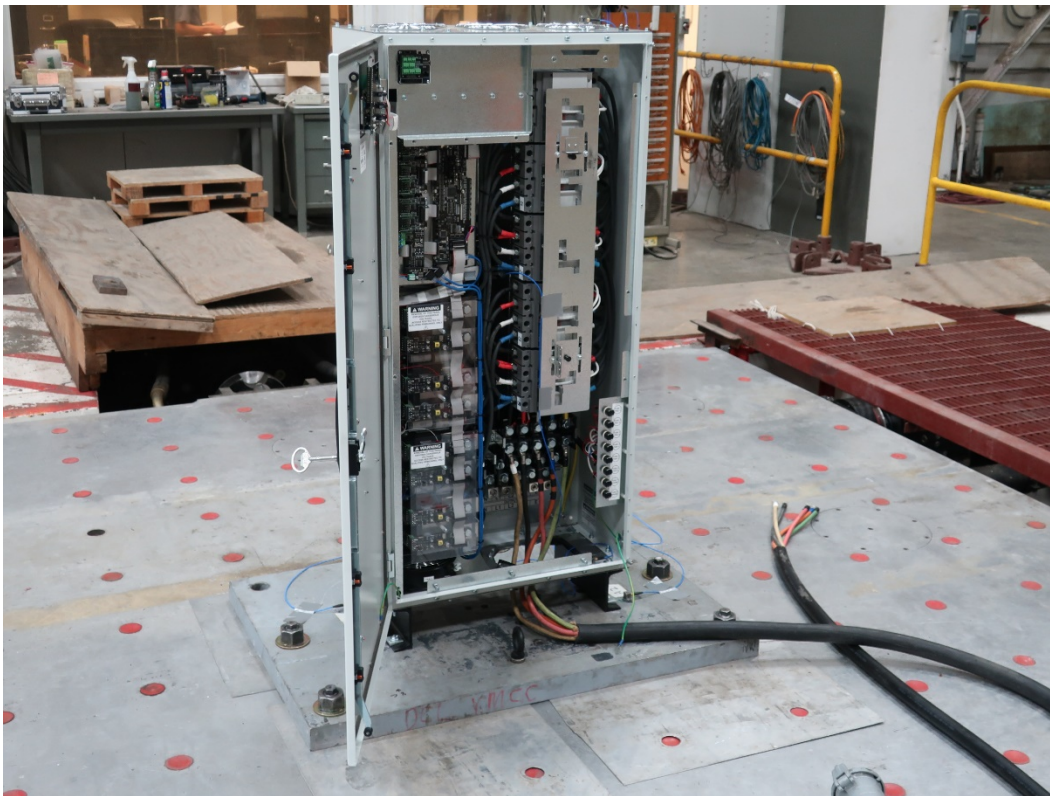


Figure B-2. Bottom left (south) side of the STS showing the A1x, A1y, and A1z accelerometers installed at the bottom left corner.

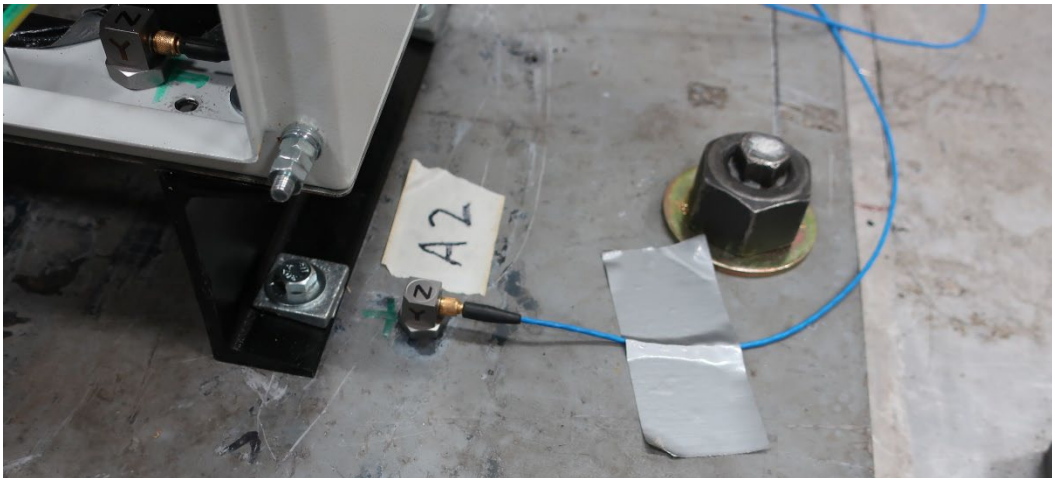


Figure B-4. Interior view of the bottom right side of the STS, showing the A3x, A3y, and A3z accelerometers.

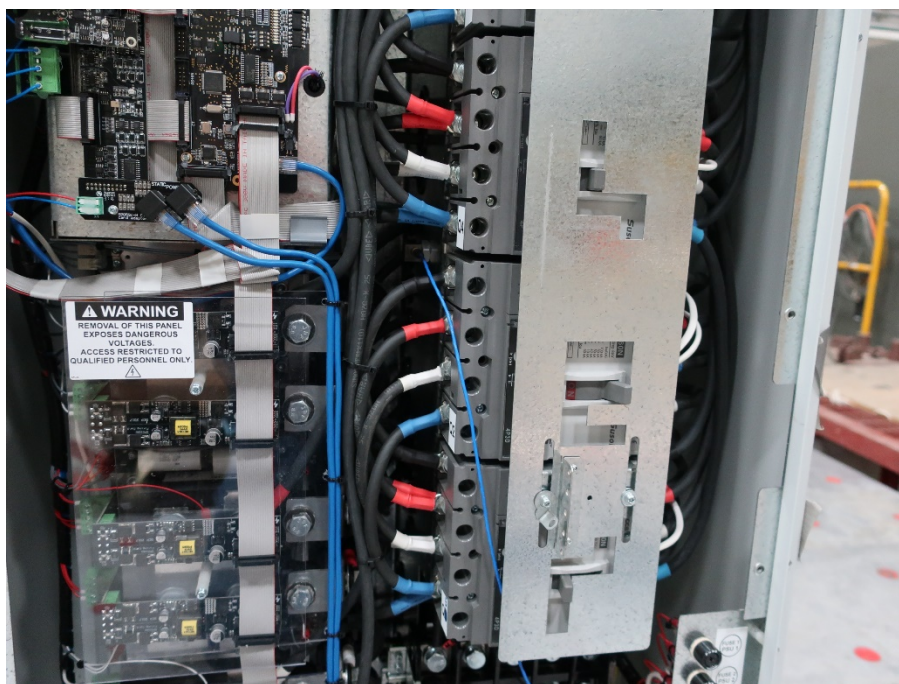
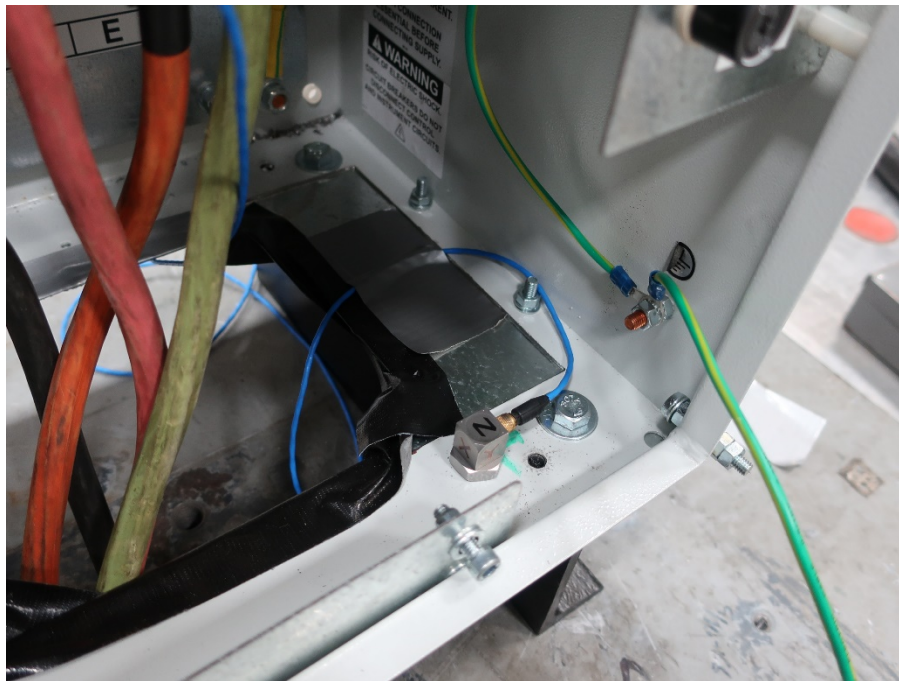
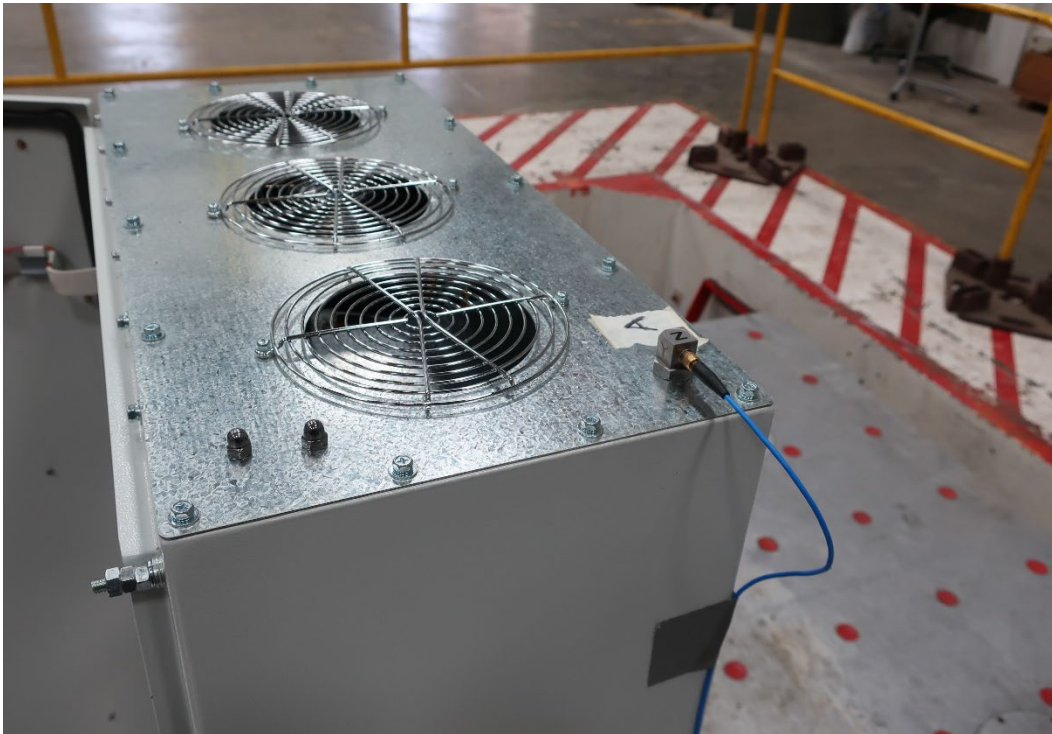


Figure B-6. Top exterior view of the STS showing the A5x, A5y, and A5z accelerometers at the top-right rear corner.



Appendix C: Functional Tests Conducted Prior to Seismic Testing

The sheet below summarizes the steps taken for the functional testing prior to seismic testing, verifying that the STS was fully operational prior to seismic tests.

Static Power Static Transfer Switch		AUT Name: I-ST5160Hs3P4		Version: 2.3.15																					
Power-up with no-load to verify basic operability - requires two switchable 3-phase sources (e-phase, 4 wire + ground). - two source may have the same phase, voltage and frequency, but separately switchable. - sources should have greater than 160 amperes capacity for 120 and 208 volts. - Electricians operating the STS will confirm measurement accuracy using a multimeter and current clamp they supply																									
Test Steps: 1) Remove panels and inspect - Ensure power is off and unplugged from the source - Remove panels and inspect, checking for loose panels - internal panels will be removed to provide access. - Inspect STS to ensure ribbon connectors are seated properly and pluggable connectors are fully inserted. - With the User H Manual identify all components. - Check unit for signs of damage, if seen do not proceed. - Connect disconnected power cables. - Reinstall removed panels prior to power-up. - Connect fully flexible cables using ring lugs to terminals (tighten terminals to maximum of 88.5 in.lb (10 N-m), do not over tighten). Do not use gland plate or gland for this process. - Remove cables from the STS for seismic testing.																									
Initial boxes below once function is verified Nate Adamson, Derek Marwill, UIUC Electrician Marwill Engineering <table border="1"> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> </table>						NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM
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2) LCD - close Q1, Q2 and Q3 (Q4 and Q5 open), apply power STS (observe MIMIC), then navigate through LCD menus. - Check that fans to confirm they are operating. - MIMIC bars are initially red. - Alarm state is on. - After STS is online, all MIMIC bars are green except for either On S1 or On S2 - Alarm state is off. - Navigation buttons respond to a push (short beep and screen changes). - Buzzer (beep) - LCD screen OK																									
<table border="1"> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> </table>						NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM
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3) Calibration Check - Power up STS, apply 10 to 50 amp load, measure incoming and outgoing voltage with multimeter, and confirm they are similar to those shown on the variables/data display of the STS (line to neutral voltages displayed and measured). - measure outgoing current with current clamp & perform simulated overcurrent test - Measured Supply 1 voltage is within 2% of reported Supply 1 voltage. - Measured Supply 2 voltage is within 2% of reported Supply 2 voltage. - Measured Output voltage is within 2% of the reported Output voltage. - Measured Output current within 2% reported Output current.																									
<table border="1"> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> </table>						NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM
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4) Functional Test - Remove all power from the STS and with Q1, Q2 and Q3 only closed, apply only supply 1 and confirm start-up and incoming source to the output. - Remove all power from the STS, then apply only Supply 2, and repeat the above. - Apply both Supplies (1 and 2), Activate a transfer using the transfer pushbutton and confirm that the STS transfers between source 1 and source 2 (and source 2 to source 1). - Bypass Test (optional): Force STS to Supply 1, force STS to Supply 2 - Bypass the STS with Supply 1, by closing Q4 and opening Q3 (in accordance with procedure manual) - Return STS from Bypass to Normal Mode - Bypass the STS with Supply 2, but closing Q5 and open Q3 (in accordance with procedure manual) - STS starts up and supplies power on Supply 1 without issue - STS starts up and supplies power on Supply 2 without issue - STS transfers power without issue - STS transfers power off Supply 1, then back on after auto re-transfer - STS transfers power off Supply 2, then back on after auto re-transfer - Force STS to Supply 1, simulating a bad supply without issue. - Force STS to Supply 2, simulating a bad supply without issue. - Bypass the STS with Supply 1 (MB to 1) without issue. - Bypass the STS with Supply 2 (MB to 2) without issue.																									
<table border="1"> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> <tr><td>NA</td><td>DM</td></tr> </table>						NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM	NA	DM
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Approval Signatures and Date: Nate Adamson, Derek Marwill UIUC Electrician Marwill Engineering																									

Appendix D: Functional Tests Conducted After Seismic Testing

The sheet below summarizes the steps taken for the functional testing after seismic testing, verifying that the STS was fully operational after seismic tests.

Static Power Static Transfer Switch		AUT Name: i-STS160Hs3P4 Version: 2.3.15																									
Power-up with no-load to verify basic operability - requires two switchable 3-phase sources (e-phase, 4 wire + ground). - two source may have the same phase, voltage and frequency, but separately switchable. - sources should have greater than 160 amperes capacity for 120 and 208 volts. - Electricians operating the STS will confirm measurement accuracy using a multimeter and current clamp they supply																											
Initial boxes below once function is verified Nate Adamson, Derek Manwill, Thomas Carlson, UIUC Electrician Manwill Engineering ERDC-CERL																											
Test Steps:																											
1) Remove panels and inspect - Ensure power is off and unplugged from the source - Remove panels and inspect, checking for loose panels - internal panels will be removed to provide access. - Inspect STS to ensure ribbon connectors are seated properly and pluggable connectors are fully inserted. - With the User H Manual identify all components. - Check unit for signs of damage, if seen do not proceed. - Connect disconnected power cables. - Reinstall removed panels prior to power-up. - Connect fully flexible cables using ring lugs to terminals (tighten terminals to maximum of 88.5 in.lb (10 N-m), do not over tighten). Do not use gland plate or gland for this process. - Remove cables from the STS for seismic testing.																											
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2) LCD - close Q1, Q2 and Q3 (Q4 and Q5 open), apply power STS (observe MIMIC), then navigate through LCD menus. - Check that fans to confirm they are operating. - MIMIC bars are initially red. - Alarm state is on. - After STS is online, all MIMIC bars are green except for either On S1 or On S2 - Alarm state is off. - Navigation buttons respond to a push (short beep and screen changes). - Buzzer (beep) - LCD screen OK																											
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3) Calibration Check - Power up STS, apply 10 to 50 amp load, measure incoming and outgoing voltage with multimeter, and confirm they are similar to those shown on the variables/data display of the STS (line to neutral voltages displayed and measured). - measure outgoing current with current clamp & perform simulated overcurrent test - Measured Supply 1 voltage is within 2% of reported Supply 1 voltage. - Measured Supply 2 voltage is within 2% of reported Supply 2 voltage. - Measured Output voltage is within 2% of the reported Output voltage. - Measured Output current within 2% reported Output current.																											
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4) Functional Test - Remove all power from the STS and with Q1, Q2 and Q3 only closed, apply only supply 1 and confirm start-up and incoming source to the output. - Remove all power from the STS, then apply only Supply 2, and repeat the above. - Apply both Supplies (1 and 2). Activate a transfer using the transfer pushbutton and confirm that the STS transfers between source 1 and source 2 (and source 2 to source 1). - Bypass Test (optional): Force STS to Supply 1, force STS to Supply 2 - Bypass the STS with Supply 1, by closing Q4 and opening Q3 (in accordance with procedure manual) - Return STS from Bypass to Normal Mode - Bypass the STS with Supply 2, but closing Q5 and open Q3 (in accordance with procedure manual) - STS starts up and supplies power on Supply 1 without issue - STS starts up and supplies power on Supply 2 without issue - STS transfers power without issue - STS transfers power off Supply 1, then back on after auto re-transfer - STS transfers power off Supply 2, then back on after auto re-transfer - Force STS to Supply 1, simulating a bad supply without issue. - Force STS to Supply 2, simulating a bad supply without issue. - Bypass the STS with Supply 1 (MB to 1) without issue. - Bypass the STS with Supply 2 (MB to 2) without issue.																											
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Approval Signatures and Date: Nate Adamson, Derek Manwill Thomas Carlson, UIUC Electrician Manwill Engineering ERDC-CERL																											

Appendix E: Static Power STS Transfer Function Plots

The system identification tests were conducted using uniaxial sine-sweep motions in the x-, y- and z-axes. Figure E-1 shows a plot of the transfer functions for the response motions in the x-axis for the sine-sweep test in the same axis. Figure E-2 and Figure E-3 provide similar plots for the y- and z-axes.

Figure E-1. Transfer function plots for the x-axis sine-sweep test.

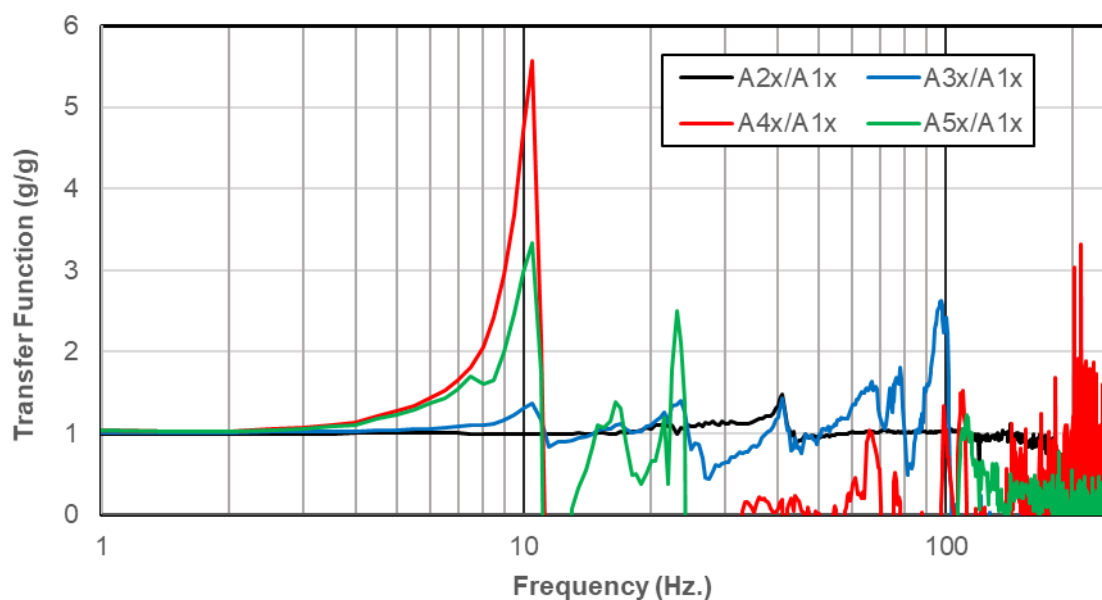
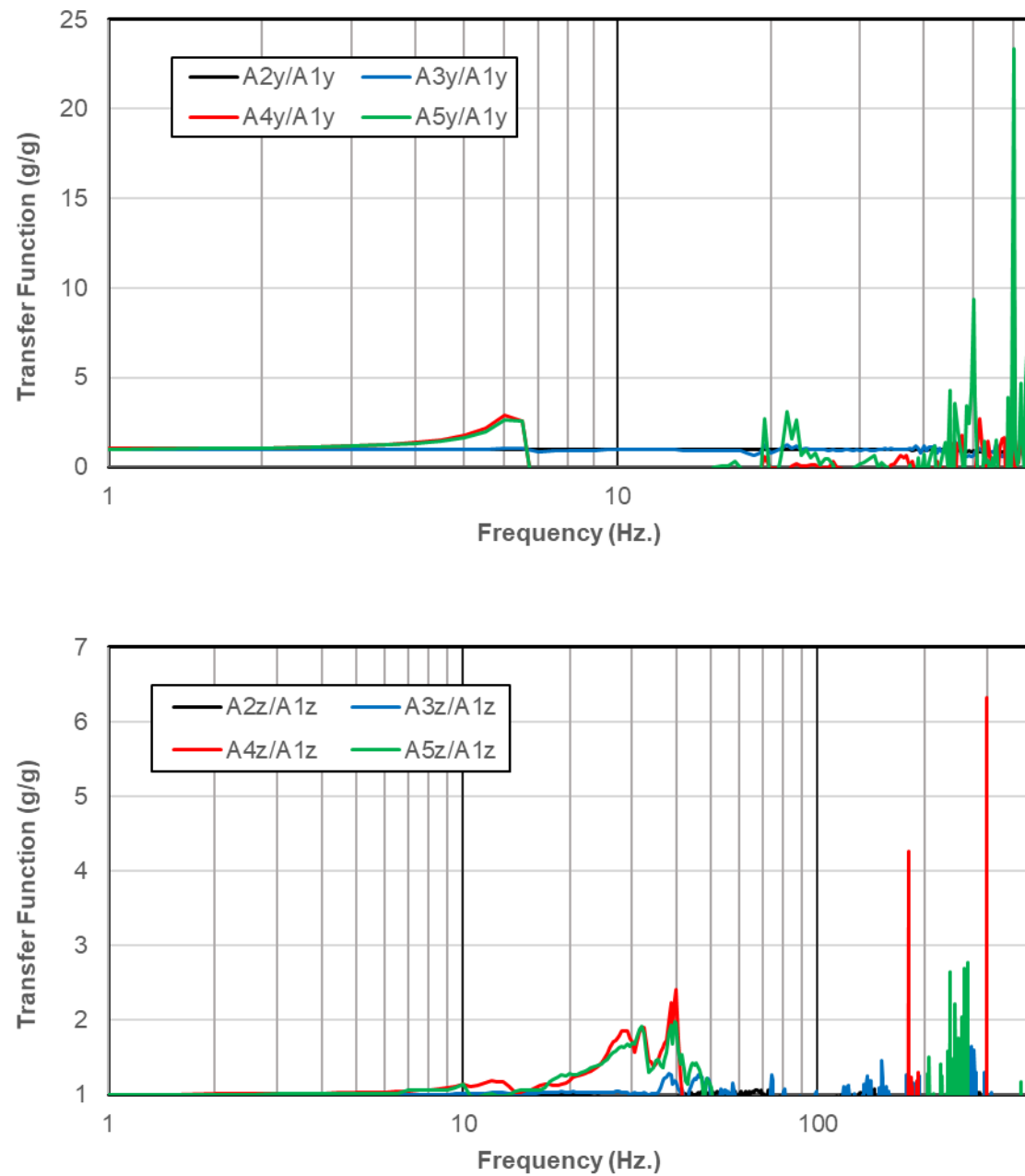


Figure E-2. Transfer function plots for the y-axis sine-sweep test.



Appendix F: STS Testing Coherence Function Plots

Figures Figure F-1 and Figure F-2 are coherence plots for the accelerations recorded on the base plate at accelerometers A1x, A1y, and A1z. The plots in Figure F-1 were generated using a frequency increment of 1.0 Hz, while those in Figure F-2 used a frequency increment of 2.0 Hz. The coherence should be below 0.5 g/g between 1.3 and 33.3 Hz for the test motions to be considered statically independent in the three test axes. The values shown in Figure F-2 are much smaller for the larger frequency increment. The 2.0 Hz frequency increment is more typical of values used for AC156 seismic qualification testing.

Figure F-1. Coherence plots for 1.0 Hz frequency increment.

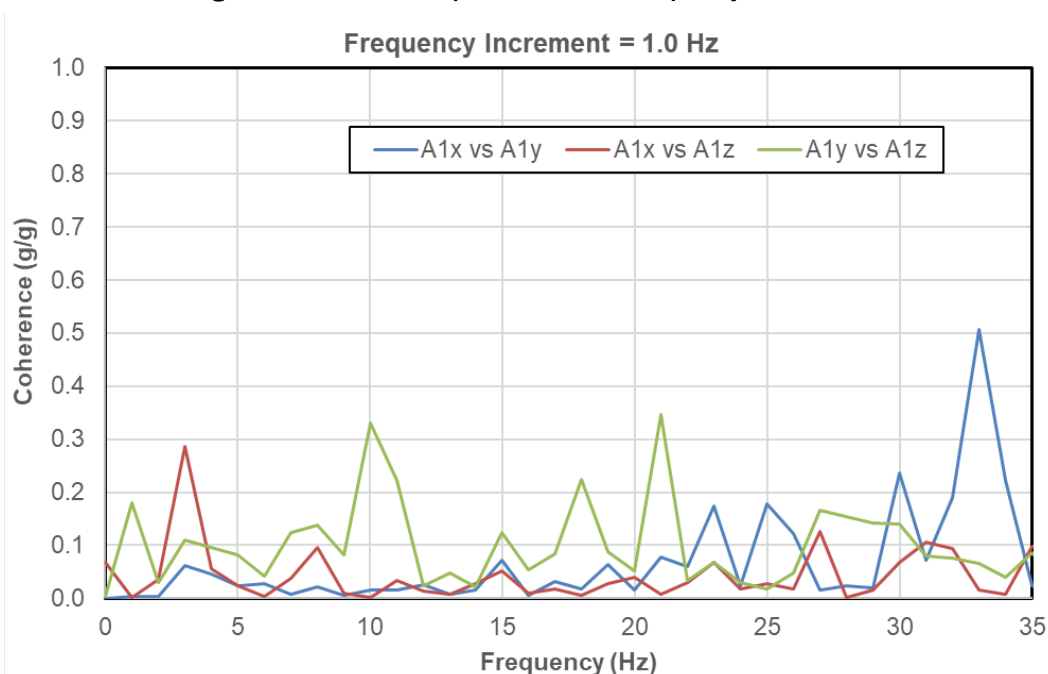
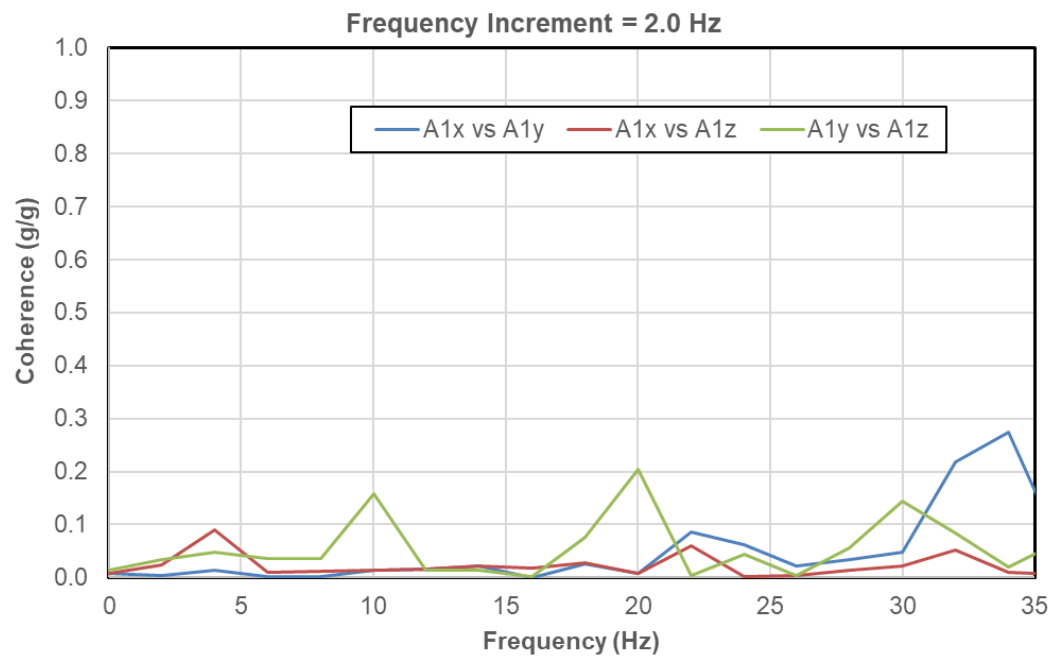


Figure F-2. Coherence plots for 2.0 Hz frequency increment.



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14. ABSTRACT This test report documents seismic qualification testing of a Static Power Static Transfer Switch (STS). The STS is a mission critical unit that will be installed at Eareckson Air Station (EAS), on the island of Shemya, Alaska. Two units were built, one of which was tested on the ERDC-CERL shake table on 10 November 2020, and the other delivered to EAS for installation at this site. This report presents details on the STS configuration, seismic tests conducted and the performance of the unit. The unit passed this seismic test and can now confidently be installed at the EAS.					
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