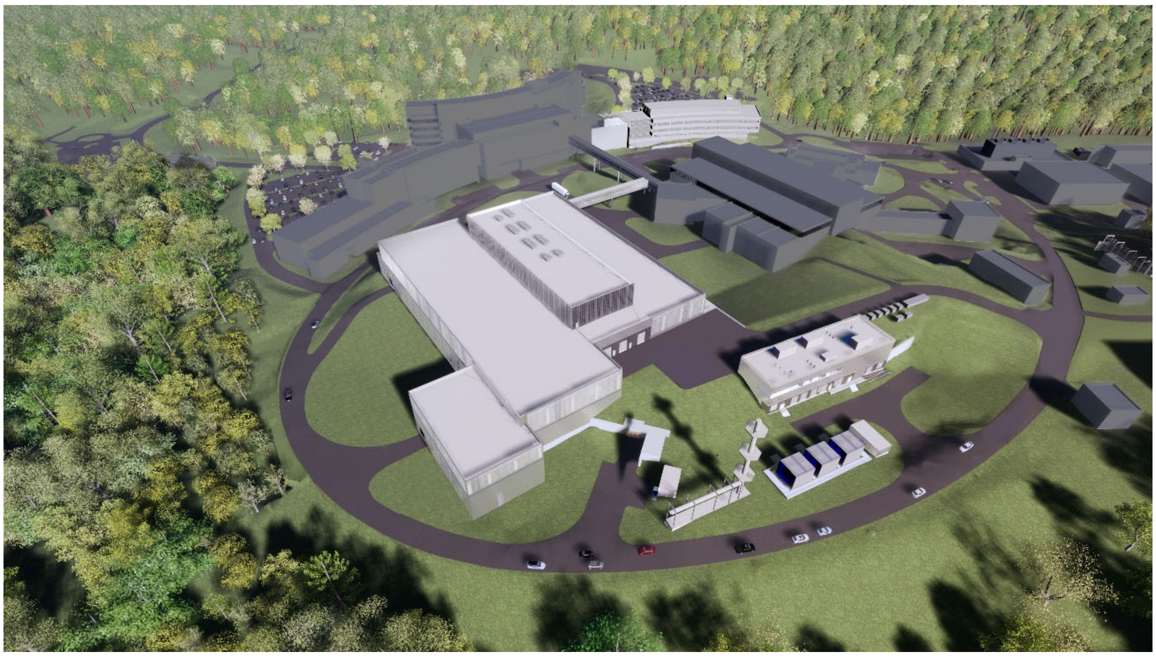
S04010000-TDO10000

SECOND TARGET STATION (STS) PROJECT

Instrument Systems Seismic Design Guidelines



Jack Thomison

August 2024

ORNL IS MANAGED BY UT-BATTELLE LLC FOR THE US DEPARTMENT OF ENERGY

S04010000-TDO10000

Second Target Station

STS TARGET SYSTEMS SEISMIC DESIGN GUIDELINES

Jack Thomison

August 2024

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US DEPARTMENT OF ENERGY
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<u>Approvals</u>

STS Instrument System Seismic Design		ISSUE DATE: July 2024
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CONTENTS

1. PURPOSE

The purpose of this document is to describe to Engineers and Analysts of the STS Instrument Systems group the expectation and methods to demonstrate compliance with the seismic design requirements of the *STS Natural Phenomena Design Hazard Basis of Design* (BoD), S01030100-ESH10001.

2. SCOPE

The scope of this document is the design and analysis of STS Instrument Systems structures, systems and components (SSC) and is not intended to apply to the SSCs of other STS L2 systems, though the analysis methods described may be appropriate.

3. ACRONYMS AND DEFINITIONS

ACI	American Concrete Institute
AISC	American Institute of Steel Construction
AE	Architect Engineer
ASD	Allowable Strength Design
ASCS	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
BoD	Basis of Design
CF	Conventional Facilities
DAC	Design Analysis Calculation
DOE	United States Department of Energy
EDRM	Enterprise Document and Record Management System
FTS	First Target Station (at SNS) (at SNS)
LRFD	Load and Resistance Factor Design
IBC	International Building Code
ORNL	Oak Ridge National Laboratory
PE	Professional Engineer
SDC	Seismic Design Criteria
SEI	Structural Engineering Institute
SNS	Spallation Neutron Source (at ORNL)
SSC	Structure, System or Component
STS	Second Target Station
USGS	United States Geological Survey

4. REFERENCES

4.1 DOCUMENTS APPLICABLE TO THE SEISMIC DESIGN OF COMPONENTS

Ref	Document Titles	Document Control System Location
1	STS-S01030000-ES0002 R02 *Second Target Station Project Preliminary Hazard Analysis Report*	https://edrm.ornl.gov/federaldox/#/irl/0902f41f804f44ce?dataSourceId=ORNL_PRD&versionLabel=CURRENT
2	S0130100-ESH10001 R0, *STS Natural Phenomena Design Hazard Basis of Design*	https://edrm.ornl.gov/federaldox/#/irl/0902f41f8063f47c?dataSourceId=ORNL_PRD&versionLabel=CURRENT
3	IBC-2018, *International Building Code 2018*	https://library.ornl.gov/az.php?t=24294
4	ASCE/SEI 7-16 *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*	https://library.ornl.gov/az.php?t=24294
5	ANSI/AISC 360-16, *Specification for Structural Steel Buildings,* July 7, 2016	https://library.ornl.gov/az.php?t=24294
6	ACI 318-14, *Building Code Requirements for Structural Concrete , September 2014*	https://library.ornl.gov/az.php?t=24294
7	DOE-STD-1020-2016 *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*	https://www.standards.doe.gov/standards-documents/1000/1020-astd-2016
8	ORNL_STS_T&I_FINAL_SD_DRAWINGS, December 20, 2023,	https://ornl.sharepoint.com/sites/sts/stsshared
9	Draft Subsurface Exploration and Geotechnical Engineering Evaluation Spallation Neutron Source Second Target Station and Site Civil Task July 19, 2023	https://ornl.sharepoint.com/sites/sts/stsshared
10	S01020000-PC0001-R21 Second Target Station (STS) Project General *Policy on Engineering Practices*	S01020000-PC0001 General Policy on Engineering Practices.url

5. REQUIREMENT ON INSTRUMENT SYSTEMS SEISMIC DESIGN

STS Instrument Systems design must follow the guidelines in Reference 2, *STS Natural Phenomena Design Hazard Basis of Design* (hereafter BoD). The BoD addresses hazards from seismic, extreme straight-line wind/tornado, precipitation/flood, lightning, and snow/ice/cold events in conjunction with requirements of the Second Target Station Project Preliminary Hazard Analysis Report (Reference 1). Many of these hazards are applied to the design of the facility within Conventional Facilities (CF) scope, but the seismic hazards are also applicable to Instrument Systems designs. Detailed requirements including exemptions are listed in section 11.1.1 of the BoD.

6. SEISMIC DESIGN AND ANALYSIS

The BoD shows that to meet the Natural Phenomena Hazard design requirements from the DOE (Reference 7), the STS must follow IBC-2018 (Reference 3) and ASCE/SEI 7-16 (Reference 4) for seismic analysis. IBC-2018 references ACI-318-14 (Reference 6) for concrete design and AISC-360-16 (Reference 5) for steel design.

Final Design of Instrument Systems SSCs should be documented with a Design Analysis Calculation (DAC) per S01020000-PC0004 as directed by Reference 10. The DAC should determine applicable design loads, select governing acceptance criteria, analyze and evaluate the design. Before it is submitted for approval all DACs and drawings that specify seismic supports, braces or anchorages must be reviewed, approved and stamped by a Professional Engineer (PE) registered in Tennessee.

Consideration of seismic forces should be determined by following ASCE/SEI 7-16 chapter 13 for static seismic loads. Those need to be combined with other loads as described below.

The Instrument Systems SSC engineer must determine the applicable codes and standards for the design of the SSC and follow their guidance to select the acceptance criteria. For instance, vacuum vessels and housings need to be designed to meet S01020000-PC0007 and possibly ASME Section VIII. Other systems will need to be designed to meet the appropriate codes and standards as determined by the SSC engineer. The qualification of the SSC itself should use the seismic loads combined with all other appropriate loads per the governing criteria.

Standard structural calculations need to be prepared to qualify attachments of Instrument Systems SSCs to the Target building concrete or steel that include seismic supports, braces or anchorages. That usually requires sizing and qualifying base plates and concrete anchors or welds. In addition, it also requires evaluating deflections that may result in adverse interactions with critical SSCs (listed in Table 1 of the BoD). Conservative design would show no interaction, but if they do interact the design must show that the critical SSC can still maintain its required integrity. These structural calculations can be part of the SSC qualification or separate ones by a structural specialist, and they may be contracted out to a qualified AE (Architect Engineer).

6.1 DETAILED DETERMINATION OF SEISMIC LOADS

Instrument System SSCs are classified as nonstructural components and seismic loads should be determined using chapter 13 of ASCE/SEI 7-16. In most cases that will mean using equations 13.3-1 through 13.3-3 to determine the horizontal static seismic forces on the SSCs, along with the concurrent vertical forces in paragraph 13.3.1.2. Below is a table (Table 1) from a spreadsheet that calculates these forces for most general Instrument System SSCs. The applicable equations from chapter 13 of ASCE/SEI 7-16 are listed below:

	EQ/para #	Equation
Basic Horizontal Seismic Force	13.3-1	$F_P = (0.4a_pS_{DS}W_p/(R_p/I_P))*(1+2z/h)$
Maximum Horizontal Seismic Force	13.3-2	$F_P = 1.6S_{DS}I_PW_p$
Minimum Horizontal Seismic Force	13.3-3	$F_P = 0.3S_{DS}I_PW_p$
Vertical Seismic Force	13.3.1.2	$E_v = +/- 0.2S_{DS}W_p$

The seismic design force should not exceed the 13.3-2 value and not be less than the 13.3-3 value.

For SSC attachments or anchorage design, these seismic loads need to be combined with the standard live and dead loads as described in paragraph 2.3.1 and 2.3.6 of ASCE/SEI 7-16 for strength design or paragraph 2.4.5 for allowable stress designs.

For determining the seismic loads:

a_p = Component amplification factor from Table 13.5-1 or 13.6-1 of ASCE/SEI 7-16.
Most Instrument System SSCs should fit one of the descriptions in Table 13.6.1 for mechanical and electrical components.
a_p shall not be less than 1, which is least conservative, and is for rigid components and rigidly attached components.
a_p =2 ½ for flexible components and flexibly attached components.

S_{DS} = Short period spectral acceleration, and S_{DS} = 0.485 (USGS, Risk Category IV & Soil Class D). (See the attached ASCE Hazard Report.) Note that there is a draft Geotech report for STS (Reference 9) that may justify a soil class C, which would give S_{DS} = 0.453. Consult with CF structural engineers for future decisions to use soil class C values. Until then it is recommended to conservatively use soil class D.

R_p = Component response modification factor from Table 13.5-1 or 13.6-1 of ASCE/SEI 7-16. (Note that smaller numbers are more conservative).

z = Height above base where attached. The seismic base of the building is level 1 at elevation 1,073'-6 ¼". For reference to the Instrument Systems coordinate system, the Proton Beam Line is at elevation 1079'-5 ⅛", or 5'-10 ⅞" above level 1 (Note this is based on preliminary data per Reference 8 and should be verified.)

h = Average roof height, top of level 3 (elev. 1,108.0'), h = 34.48' above base.) (Note higher, less conservative, elevations may be justified for h depending on the attachment. Consult with CF structural engineers or the PE who will approve the DAC.)

I_p = Component Importance factor = 1.5, which is conservative for most Instrument System SSCs. Note that a less conservative I_p = 1.0 can be justified if it does not meet any of the conditions listed in section 13.1.3 of ASCE/SEI 7-16. (i.e., they don't provide egress pathways or contain hazardous substances)

Ω_0 = Overstrength factor from Table 13.5-1 or 13.6-1 of ASCE/SEI 7-16. To be applied for anchorages to concrete or masonry per section 12.4.3. Note that seismic experience data show that the most common failure on SSCs is their anchorage.

Table 1: STS SSCs using ASCE/SEI 7-16 Chap. 13 - Seismic Requirements for Nonstructural Components (Equivalent Static Method)

(Note this assumes SSCs attached to the concrete structure and that a unimodal structural response is justified.)

	EQ/para #	Equation	
Basic Horizontal Seismic Force	13.3-1	$F_P = (0.4 a_p S_{DS} W_p / (R_p/I_P)) * (1+2z/h)$	
Maximum Horizontal Seismic Force	13.3-2	$F_P = 1.6 S_{DS} I_P W_p$	(value should not exceed this)
Minimum Horizontal Seismic Force	13.3-3	$F_P = 0.3 S_{DS} I_P W_p$	(value should at least be this)
Vertical Seismic Force	13.3.1.2	E_v = +/- $0.2 S_{DS} W_p$	

- Base or grade elevation = 1073.52' (Level 1, instrument floor level)
- W_p = Component Operating Weight
- a_p = Component amplification factor from Table 13.5-1 or 13.6-1
- S_{DS} = Short period spectral acceleration
  - S_{DS} = 0.485 from USGS, Risk Category IV & Soil Class D at SNS
- R_p = Component response modification factor from Table 13.5-1 or 13.6-1
- z = Height above base where attached
- h = Average Roof Height, top of level 3 (elev. 1,108.0', = 34.48' above base)
- I_p = Component Importance factor = 1.5, most Instrument Sys components could have 1.0 if they meet section 13.1.3 requirements.
- Ω_0 = Overstrength factor to be applied for anchorages to concrete or masonry per section 12.4.3.

Level	Elevaton	z
1	1,073.52	0
2	1,094.00	20.48
3	1,108.00	34.48
4	1,137.50	63.98
Roof	1,157.67	84.15

(Note: elevations preliminary from Building Sections AR301-D, 12/20/23)

(Note, Fp/Wp value in **bold** governs)

Structure, System or Component	F_p/W_p (Eq.13.3-1)	F_p/W_p max (Eq.13.3-2)	F_p/W_p min (Eq.13.3-3)	E_v (para.13.3.1.2)	S_{DS} (USGS)	I_p	R_p T 13.5-1 T 13.6.1	a_p T 13.5.1 T 13.6-1	z	Ω_0	
General mechanical or electrical components (other components at or below grade)	0.194	1.16	**0.22**	0.10	0.485	1.5	1.5	1.0	0.00	2.0	
General mechanical or electrical components (other components at or below Level 2)	**0.424**	1.16	0.22	0.10	0.485	1.5	1.5	1.0	20.48	2.0	
General mechanical or electrical components (other components at or below Level 3)	**0.582**	1.16	0.22	0.10	0.485	1.5	1.5	1.0	34.48	2.0	
General mechanical or electrical components (other components at or below Level 4)	**0.489**	1.16	0.22	0.10	0.485	1.5	1.5	1.0	63.98	2.0	Note: h = 84.15, top of steel. This method not recommended for the upper steel area, where a dynamic analysis per section 13.3.1.4 is more appropriate. If available, use building floor response spectra to determine F_p per Eq. 13.3-4.
B31.3 welded piping systems (SDC-1) supported at or below grade	0.061	1.16	**0.22**	0.10	0.485	1.5	12.0	2.5	0.00	2.0	
Heat exchangers, air separators, pumps, compressors, pressure vessels not on skirts and other components of high deformable materials supported at or below grade	0.109	1.09	**0.20**	0.09	0.453	1.5	2.5	1.0	0.00	2.0	
Shielding - reinforced masonry other rigid low deformable components supported at or below grade	0.109	1.09	**0.20**	0.09	0.453	1.5	2.5	1.0	0.00	1.5	

6.2 SEISMIC STRUCTURAL ATTACHMENT AND ANCHOR DESIGN

Standard structural calculations are needed to qualify attachments of the Instrument System SSCs to building concrete and/or steel unless exempt per section 13.1.4.

AISC-360-16 provides an integrated treatment of allowable strength design (ASD) and load and resistance factor design (LRFD) and should be used to qualify all steel members and fasteners of seismic attachments or anchorages.

ACI-318-14 provides minimum requirements for the materials, design, and detailing of structural concrete buildings and, where applicable, nonbuilding structures and should be used to qualify all seismic attachments or anchorages to concrete.

Most of the Instrument Systems SSCs interface with concrete design for seismic loading will involve attachments using post installed anchors and base plates. The seismic and other loadings described above need to be applied to the SSCs and the anchorage group reactions calculated. Then the base plates and anchors sized should be qualified based on the reactions. The structural design calculations for the anchorage groups can be very complex and need to evaluate all the multiple potential failure mechanisms and the anchor capacities that are beyond the scope of this guide. These structural calculations can be part of the SSC qualification or separate ones by a structural specialist, and they may be contracted out to a qualified AE.

FTS has normally specified anchor vendors like Hilti that have extensive testing and quality reports for their products that are based on both ACI and AISC requirements and consider all failure mechanisms. In addition, they publish Evaluation Reports (ERs) that have been vetted by the ICC-ES (International Code Council). A good guide for this is Hilti's Anchor Technical Guide available at their web site: https://ask.hilti.com/article/hilti-anchor-technical-guide-edition-19/adlbcm

In addition, Hilti has a software tool, PROFIS, that allows modelling, qualification, and documentation of complex base plates and anchor bolts meeting all the ACI, AISC and anchor ERs.

The deflections of the Instrument Systems SSCs need to be determined with service level loads and compared with designed gaps to other SSCs. Of course, it is best if there is no interaction, especially to the critical SSCs listed in Table 1 of the BoD. Interactions with any of the critical SSCs need to be further evaluated to show that there is no failure of the critical SSC.

6.3 GENERAL SEISMIC ATTACHMENT DESIGN CONSIDERATIONS

SSCs should be supported to assure all seismic loadings can be safely taken to the STS building structure. The anchors and attachments should be designed to handle the loads with a factor of safety (FOS) consistent with the appropriate design codes. Standard design practice is to ignore deadweight friction to resist seismic loads. Note that this is not a firm requirement but is conservative and is the easiest way to evaluate the resistance to seismic forces. However, it is acceptable to use tensioned tie rods to induce friction at the base of SSCs such as shield blocks to resist the lateral seismic loads as has been done on many FTS beamlines. Stacked shielding blocks can alternately be restrained to the blocks or slabs below with "L" shaped steel brackets or steel straps with post installed or embedded anchor bolts sized to adequately resist the seismic load and meet the code requirements.

All SSCs and stacked shield blocks should be designed to have a significant factor of safety to prevent overturning and sliding (FOS ≥ 1.5) or have anchors to resist it. Poured-in Place slabs can be anchored to the building floor with shear dowels similar to those used on the FTS as long as they can be sized for adequate shear capacity to resist the seismic loads from the mass of all the attached blocks and equipment.

6.4 FIRST TARGET STATION EXAMPLE CALCULATIONS

Listed in Table 2 are previous seismic analysis calculations from the First Target Station (FTS) that are similar to expected STS Instrument System SSCs that may be used as guides. These may be retrieved with the EDRM links shown. Note that the earlier calculations were prepared to the FTS early design basis requirements. The later ones meet more current standards.

For STS, mechanical or electrical cabinets or racks may be exempted from seismic calculations if their total weight is less than 400 lbs and center of gravity is less than four feet above the floor, as directed in section 11.1.1 of the BoD and in section 13.1.4 of ASCE 7-16 (note the building is classified as the Seismic Design Category C). Otherwise, seismic calculations similar to the last two shown in Table 2 are necessary.

Most of the FTS SSCs at or below the base level (instrument floor) were designed to equivalent static methods. Early designs were done per DOE STD 1020-1994 and UBC-1997 using the UBC static seismic equations. In the middle of detailed design, it shifted to DOE 1020-2002 and IBC 2000 where the static seismic methods were detailed in IBC 2000. However, FTS didn't adopt the new standard immediately. Shortly after FTS adopted DOE STD 1020-2002, IBC 2006 removed detailed seismic criteria and referred to ASCE 7-5 for such details. FTS designs subsequently shifted to ASCE 7-10 and currently to ASCE/SEI 7-16. As stated previously, ASCE 7-16 is now required for STS in the BoD.

Table 2 FTS Example Seismic Calculations

FTS Example Seismic Calculation	Revision	Title	Description	Date	EDRM Link
107100101-DA0002	R01	BL-11A Shielding Modification Seismic Analysis	BL-11A Stacked Shielding - ASCE 7-05 Static Equivalent PC-2 and PC-3 ZPA	Sep-2019	https://edrm.ornl.gov/federaldox/#/irl/0902f41f8009af18?dataSourceId=ORNL_PRD
SING12-50-DA0001	R01	TOPAZ, BL-12 , Stacked Shielding Seismic Restraint Analysis	BL-12 Stacked Shielding - UBC 1997 PC-2 and SSRS of ZPA PC-3 loads	Sep-2007	https://edrm.ornl.gov/federaldox/#/irl/0902f41f800b2468?dataSourceId=ORNL_PRD
SING12-50-DA0005	R02	TOPAZ, BL-12, Structural Calculations for Instrument Enclosure	BL-12 Cave - ASCE 7-05 PC-2 loads and 1.5 x peak for PC-3 with interaction evaluation in peer review	Apr-2009	https://edrm.ornl.gov/federaldox/#/irl/0902f41f800b07f1?dataSourceId=ORNL_PRD
SING209B-50-DA0001	R01	CORELLI – BL 9 -Shielding Assembly– Structural & Seismic Analysis	BL-9 Stacked Shielding - PC-2 ASCE 7-05 and PC-3 using SRSS of ZPA	Jan-2010	https://edrm.ornl.gov/federaldox/#/irl/0902f41f800bfaca?dataSourceId=ORNL_PRD
SING209B-50-DA0002	R01	CORELLI – BL 9 - Instrument Cave Seismic and Structural Calc.	BL-9 Cave - STAAD FE analysis using ASCE 7-05 Section 13 and 15 PC-2 loads with PC-3 interaction evaluation	Nov-2010	https://edrm.ornl.gov/federaldox/#/irl/0902f41f800cb03e?dataSourceId=ORNL_PRD
FUND13NAB-40-VS0001	R00	Beamline 13, Nab Experiment Work Platform	BL-13 Aluminum work platform mounted on the cave roof. ASCE 7-10 Equivalent Static - RAM Frame FE analysis by vendor	Feb-2018	https://edrm.ornl.gov/federaldox/#/irl/0902f41f800a2e47?dataSourceId=ORNL_PRD
FUND13NAB-40-DA0003	R00	NAB EXPERIMENT – UPPER MAINTENANCE CRANE ANCHORAGE	BL-13 Crane on TB 4th Floor. Seismic load per ASCE 7-10 Equivalent Static	Aug-2018	https://edrm.ornl.gov/federaldox/#/irl/0902f41f800a0c66?dataSourceId=ORNL_PRD
VENUS10-50-DA0002	R00	VENUS Project – BL 10 FE Shielding Assembly Seismic Analysis	BL-10 Front End stacked shielding - Seismic load per ASCE 7-10 Equivalent Static	May-2020	https://edrm.ornl.gov/federaldox/#/irl/0902f41f8009cf42?dataSourceId=ORNL_PRD
108030700-DAC13	R00	AR-10 Neutrino Detector Seismic Structural Calculation	Mechanical/Electrical detector anchored to wall with seismic load per ASCE 7-10.	May 2022	https://edrm.ornl.gov/federaldox/#/irl/0902f41f80385575?dataSourceId=ORNL_PRD&versionLabel=CURRENT
NOCO20000-DAC10000	R00	Seismic DAC for the Germanium Detector Array for SNS Neutrino Detection	Mechanical/Electrical detector anchored to floor and wall with seismic load per ASCE 7-16.	June 2022	https://edrm.ornl.gov/federaldox/#/irl/0902f41f8038bcaa?dataSourceId=ORNL_PRD&versionLabel=CURRENT

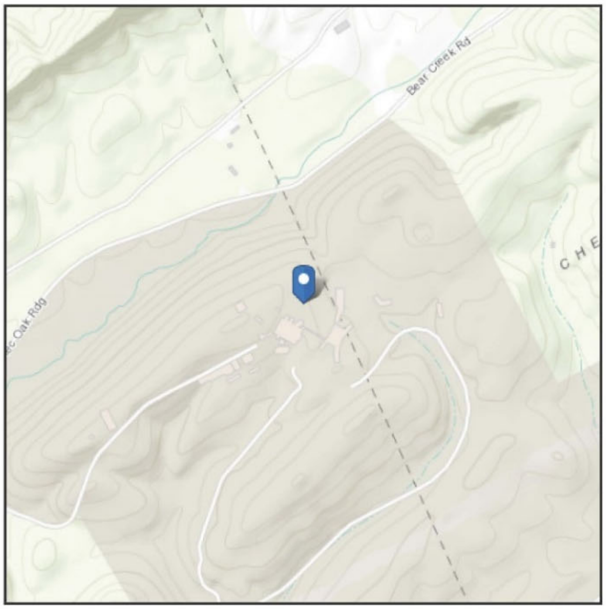
Appendix A

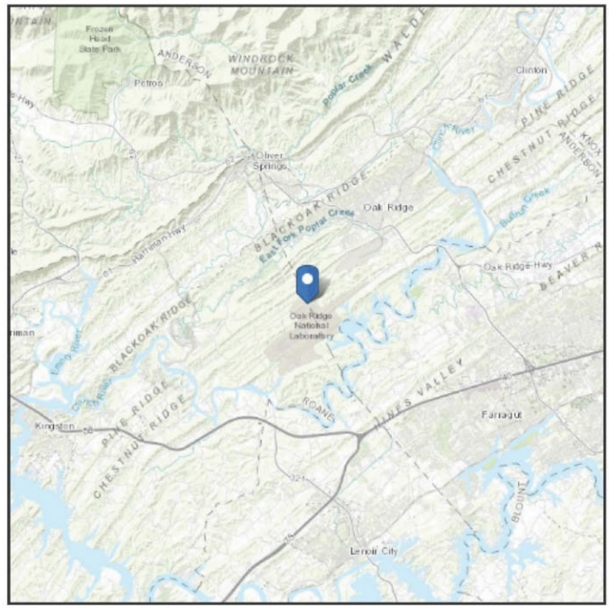
ASCE Hazards Report

Address:
No Address at This Location

Standard: ASCE/SEI 7-16
Risk Category: IV
Soil Class: D - Stiff Soil

Latitude: 35.953909
Longitude: -84.299633
Elevation: 1089.2827340007473 ft (NAVD 88)





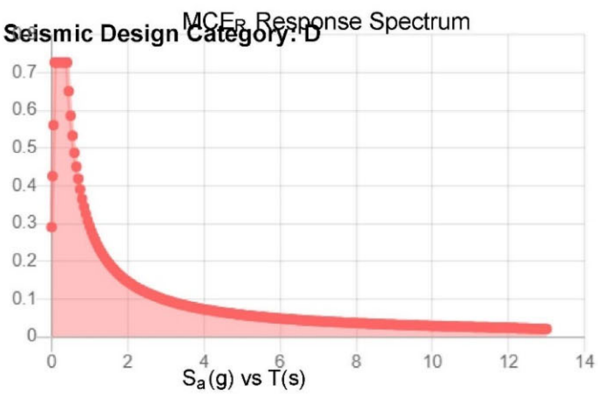
Seismic

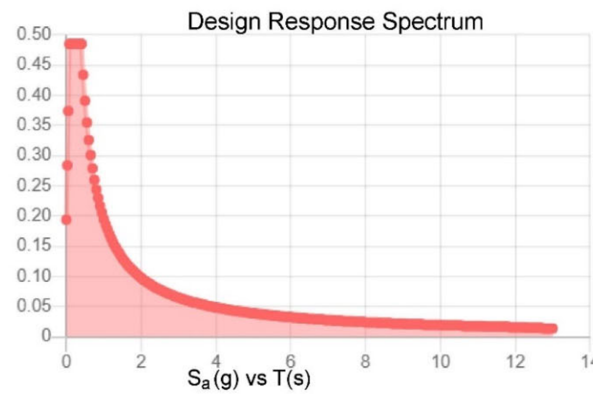
Site Soil Class: D - Stiff Soil

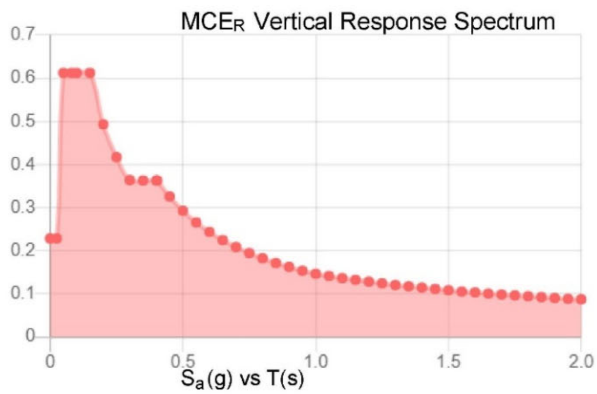
Results:

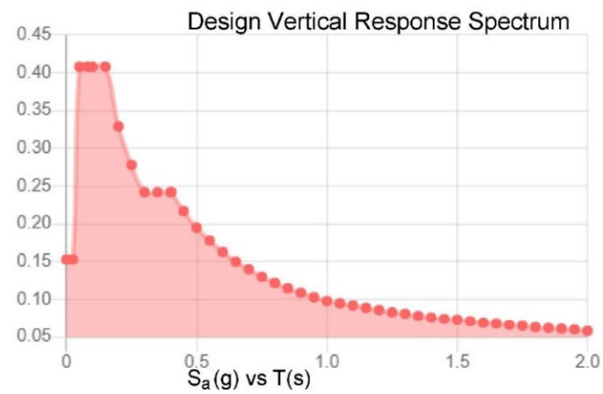
S_S :	0.528	S_{D1} :	0.195
S_1 :	0.125	T_L :	12
F_a :	1.378	PGA :	0.345
F_v :	2.351	PGA_M :	0.433
S_{MS} :	0.727	F_{PGA} :	1.255
S_{M1} :	0.293	I_e :	1.5
S_{DS} :	0.485	C_v :	1.052

Seismic Design Category: D









Data Accessed: **Mon Jan 29 2024**

Date Source:

USGS Seismic Design Maps based on ASCE/SEI 7-16 and ASCE/SEI 7-16 Table 1.5-2. Additional data for site-specific ground motion procedures in accordance with ASCE/SEI 7-16 Ch. 21 are available from USGS.

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