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Operating Manual for Importing Texas Bridge Data into ShakeCast

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16. Abstract Increases in the rate of seismicity in Texas and in neighboring states since 2008 motivated recent TxDOT research (0-6916), which characterized seismic hazards and bridge fragility, or likelihood of damage based on ground shaking intensity, in Texas; these factors were combined to develop a post-earthquake inspection plan. In this implementation project (5-6916-01), these research outcomes were incorporated into a conversion software—the TexasBridgeDataConverter.exe—to facilitate use of ShakeCast, the software developed by the U.S. Geological Survey (USGS) to automate the process of identifying and prioritizing post-earthquake inspection needs. The research team (1) developed a new software for updating the TxDOT bridge inventory and associated fragility functions in ShakeCast; (2) incorporated updated Vs30 maps into USGS ShakeMaps, which are used to estimate ground shaking levels in the ShakeCast software; and (3) created an operating manual and conducted a virtual workshop for TxDOT personnel on how to use ShakeCast and the researcher-developed software for inventory updating.					
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**THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH**

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Summary of Implementation Project

Overview

The purpose of this implementation project was to incorporate the research results from TxDOT project 0-6916 “Seismic Vulnerability and Post-Event Actions” into an automated tool for identifying inspection priorities quickly following an earthquake event. The tool used for this automation is the ShakeCast software developed by the U.S. Geological Survey (USGS), made available to TxDOT through its participation in the ShakeCast Transportation Pooled Fund project. The primary research outcomes from project 0-6916 that needed to be implemented in ShakeCast include updated shear wave velocity (Vs30) maps to characterize local soil conditions across the state of Texas, as well as updated fragility functions to predict the likelihood of damage to various classes of Texas bridges due to ground shaking. As part of this project, the research team (1) developed a new software for updating TxDOT bridge inventory and associated fragility functions in ShakeCast, (2) incorporated updated Vs30 maps into USGS ShakeMaps, which are used to estimate ground-shaking levels in the ShakeCast software, and (3) created an operating manual and workshop for TxDOT personnel on how to use ShakeCast and the researcher-developed software (termed *TexasBridgeDataConvertor*) for inventory updating.

Updates to ShakeMap ground shaking estimates

The ShakeCast system automatically retrieves ground shaking information from the ShakeMap system, which rapidly characterizes the extent and distribution of strong ground shaking following significant earthquakes (Lin et al., 2014). To compute ground-motion shaking intensities, the ShakeMap system requires inputs of a Vs30 map to characterize local site conditions as well as ground-motion models (GMM) to estimate ground shaking levels where observations are not available. The research team has developed an updated Vs30 map and a new GMM, termed ZR19, for Texas to improve the characterization of ground shaking by ShakeMap. The progress of implementing these two inputs into ShakeMap is reported as follows.

The updated regional Vs30 map for Texas has been published electronically (Li et al. 2020) and is now incorporated into the Global Vs30 Mosaic map available from the USGS (<https://earthquake.usgs.gov/data/vs30/>). The Vs30 map provides resolution down to one square kilometer. The updated Vs30 data from Project 0-6916 is automatically incorporated into USGS ShakeMaps, as ShakeMap calls the Global Vs30 Mosaic map for Vs30 data.

Because ShakeMap internally utilizes GMMs archived by the OpenQuake software managed by the Global Earthquake Model (<https://www.globalquakemodel.org/openquake>), the new ZR19 GMM first was implemented within OpenQuake. ZR19 has passed the computational accuracy test of OpenQuake and has been modified to comply with the standard code style that is required by OpenQuake. It is now available in OpenQuake (https://github.com/gem/oq-engine/blob/master/openquake/hazardlib/gsim/zalachoris_rathje_2019.py) and will be included in OpenQuake v 3.10 when it is released; thus, it will be available for use by others. The research

team, however, is still in communication with the USGS about how best to incorporate ZR19 into ShakeMap for earthquakes in Texas. The USGS currently utilizes the same GMMs for ShakeMap and for the National Seismic Hazard Maps (NSHM), and the NSHM use the NGA-East GMMs throughout the entire Central and Eastern United States, including Texas. Due to the broader implications of using a regional GMM (such as ZR19) within ShakeMap, which would include a change in current USGS practice, a more deliberative approach is being used to decide on an appropriate course of action. At this time, USGS ShakeMaps does not utilize the new regional ZR19 GMM.

Updates to ShakeCast bridge inventory and fragility data

This report conveys the operating manual for the TexasBridgeDataConvertor, documenting for TxDOT the procedures to extract data from the National Bridge Inventory (NBI), assign fragility functions to the bridge inventory, and upload the data into ShakeCast. This operating manual discusses how the Texas-specific fragility functions (i.e., results from project 0-6916) are assigned to Texas bridges and how fragilities were adjusted to account for skewed bridges. To facilitate this process, a software named “Texas Bridge Data Converter.exe” was generated by the research team, which is available for download (see Section 1.7 of the operating manual for the link) and is fully described in the operating manual. The operating manual also discusses the “threshold for action” that is used in ShakeCast to assign post-event inspection priorities. Moreover, the operating manual presents an example of the inspection plans provided by ShakeCast for a hypothetical earthquake with a magnitude of 6.9 in West Texas. This example demonstrates how different bridges around the earthquake epicenter are prioritized for inspection after the earthquake. This software and hypothetical ShakeCast scenario were demonstrated in a virtual workshop with TxDOT personnel on July 29, 2020, which was recorded and made available for online viewing (Khosravikia, 2020).

References for Summary

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https://utexas.zoom.us/rec/share/v_FIF4_0xEhJQ6vxqxGAWfQgN7_Ieaa8gXRLqfAEnhUmQn9HkPE0c1aBFcdbUrYd .
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1. Operating Manual for the TexasBridgeDataConverter Software: Importing Texas Bridge Data into ShakeCast

This document is an operating manual created for the Texas Department of Transportation (TxDOT), outlining the procedures to import TxDOT bridge data inventory into the ShakeCast software. This operating manual was prepared as part of a project titled “Implementation of TxDOT Seismic Vulnerability Measures and Post-Event Actions,” funded by TxDOT as implementation project 5-6916-01. Figure 1.1 depicts the import process. As the figure indicates, users first download the bridge data from the National Bridge Inventory (NBI) website in the form of a .txt file. Then, the software developed in this project—the TexasBridgeDataConverter.exe—facilitates importing that data into the ShakeCastInventory workbook. This software can also be used by other states to convert their bridge data to a file compatible with ShakeCast. Once the TexasBridgeDataConverter generates an output file, the users will import this file into the ShakeCastInventory workbook to generate the input file for ShakeCast. The following sections detail each step separately.

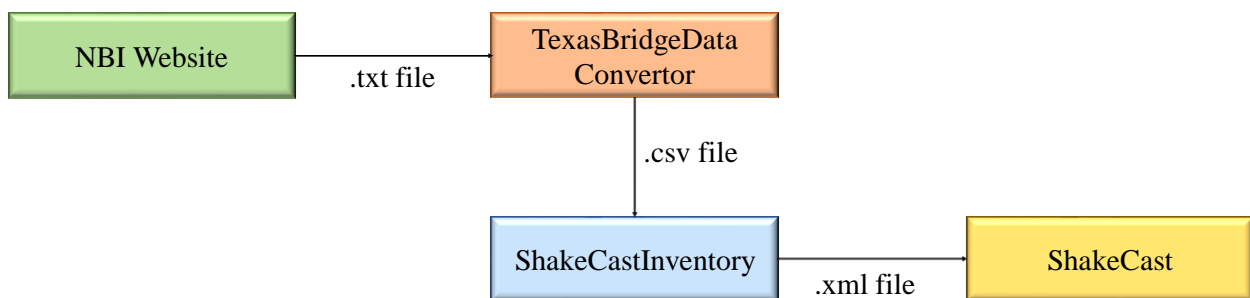


Figure 1.1 Main steps to update ShakeCast

1.1. Step 1: Download Data from National Bridge Inventory

Data for the Texas bridge infrastructure can be downloaded from the NBI website: (<https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm>). These data consist of information regarding the bridge superstructure types, geometric information, material properties, location, and so on. NBI provides users with a report (U.S. Department of Transportation, 1995) about how they can extract information of interest from data available on the NBI website.

For each state, every year, NBI provides the bridge data in two formats: “No Delimiters” and “Comma Delimited.” Both versions contain the same data but in different formats. Users should download the “Comma Delimited” version of the data. When users select the data in the NBI website, the data will be open in a browser. Users can copy and paste the data into a text file and save it into their computers. It can be saved in any directory. It is worth noting that, as mentioned on the NBI website, in the future, they will update the inventory data using both formats.

1.2. Step 2: Use “TexasBridgeDataConvertor” Software

For this implementation project, the authors developed the “TexasBridgeDataConvertor” software. The objective of this software is to extract the required data for ShakeCast from the NBI bridge inventory, including bridge ID, geometric parameters, latitude, and longitude; it also assigns fragility functions to the bridges based on their bridge characteristics. As Figure 1.1 indicated, the output will be a .csv file, which will then be imported into the “ShakeCastInventory” workbook. The following sections explain the software.

1.2.1. Importing NBI and output file paths

Figure 1.2 shows the first tab of the software, named “MainAnalysis.” Here, in the “NBI File Path” box, users will copy and paste the directory of the inventory file where they have saved the data from NBI following Step 1. Then, users can make decisions on the bridge types they want to consider in their assessment. In particular, they can determine whether they want to consider only on-system bridges (those whose maintenance is TxDOT’s responsibility), or import all Texas bridges. Furthermore, users can also identify whether or not they want to consider culverts in the assessment process. Finally, users will determine the output folder path, which is the directory in which the .csv file will be saved.

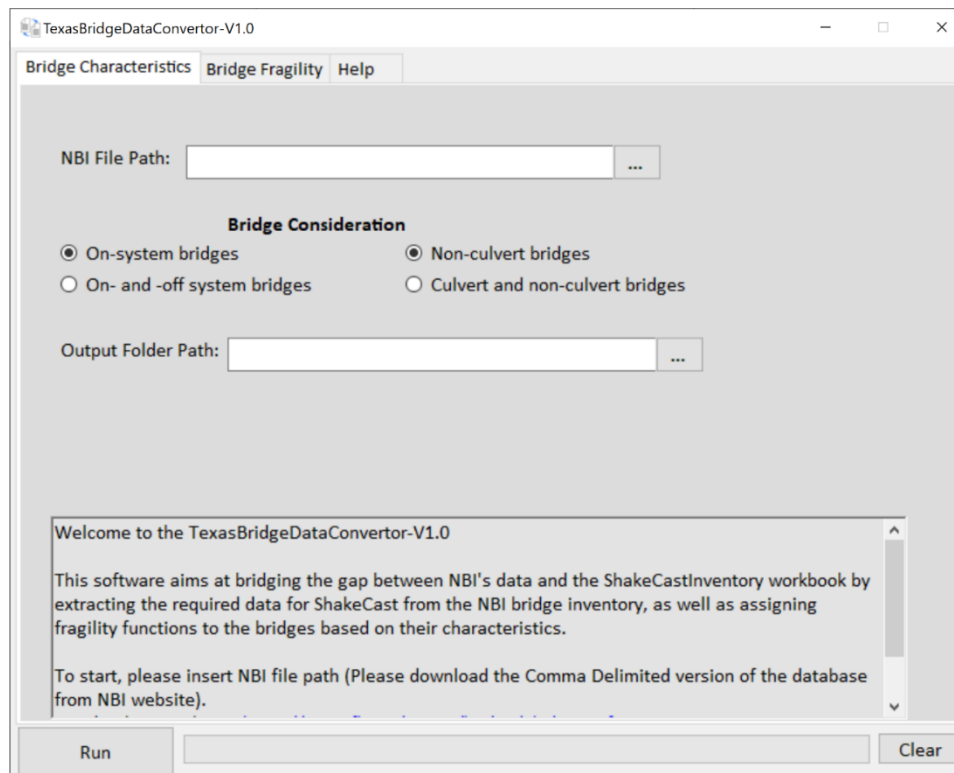


Figure 1.2 First tab of the TexasBridgeDataConvertor software

1.2.2. Assigning Fragility Functions

Fragility functions provide the probability that the structure meets or exceeds any predefined damage states, including slight, moderate, extensive, and complete, given the intensity measure (IM) of interest. Table 1.1 shows the qualitative damage state definitions, which follow the HAZUS framework with slight modifications in terminology to be more consistent with the TxDOT Bridge Inspection Manual (2018) and the TxDOT “Elements” Field Inspection and Coding Manual (2001). As a reminder, HAZUS (2003) is a software produced by the Federal Emergency Management Agency to predict potential losses from natural hazards such as earthquakes, hurricanes, floods, and more. For earthquakes, bridge fragility functions are given with respect to peak ground acceleration (PGA), and the fragility for each level of damage is assumed to follow a lognormal distribution with a median of μ and a dispersion of 0.64 (a unitless value).

Table 1.1 Qualitative damage state descriptions

Damage State	Description
Slight	Minor cracking and spalling of the abutment, appearance of minor cracking at bridge seat, minor inelastic deformation of elastomeric bearing, minor spalling and cracking of columns (damage requires no more than cosmetic repair, and no exposed reinforcing), or minor cracking of the deck (distressed area less than 2% of the deck area)
Moderate	Any column experiencing moderate cracking and spalling (column still sound structurally), moderate movement of the abutment (<2 in.), prying of masonry plate (e.g., moderate cracking or spalling of bearing area) or severally bent anchor bolts, rocker bearing instability, or moderate approach settlement.
Extensive	Any column degrading without collapse-shear failure (column structurally unsafe), significant inelastic bearing displacement, anchor bolt failure, bearing instability imminent (e.g., overturned bearing), extensive elastomeric pad damage, major approach settlement, vertical offset of the abutment
Complete	Any column collapsing, any bearing no longer supported which may lead to imminent deck collapse, tilting of substructure caused by foundation failure

Typically, it is assumed that the fragility functions follow lognormal distributions, which can be characterized by median and dispersion values. This assumed distribution is used in ShakeCast as well as in many other studies in the literature (Choi et al., 2004; Padgett, 2007), including TxDOT report 0-6916-1 that investigates the fragility of common bridge classes in Texas (Khosravikia et al., 2018).

In the second tab of the software, which is shown in Figure 1.3, users will assign the median and dispersion values of the fragility functions for different types of bridges. Here, three options are available as follows:

1. HAZUS fragility models for all bridges
2. Texas-specific fragility functions for common bridge classes and HAZUS for other bridge classes

3. Texas-specific fragility functions only for common bridge classes (ignoring other bridge classes)

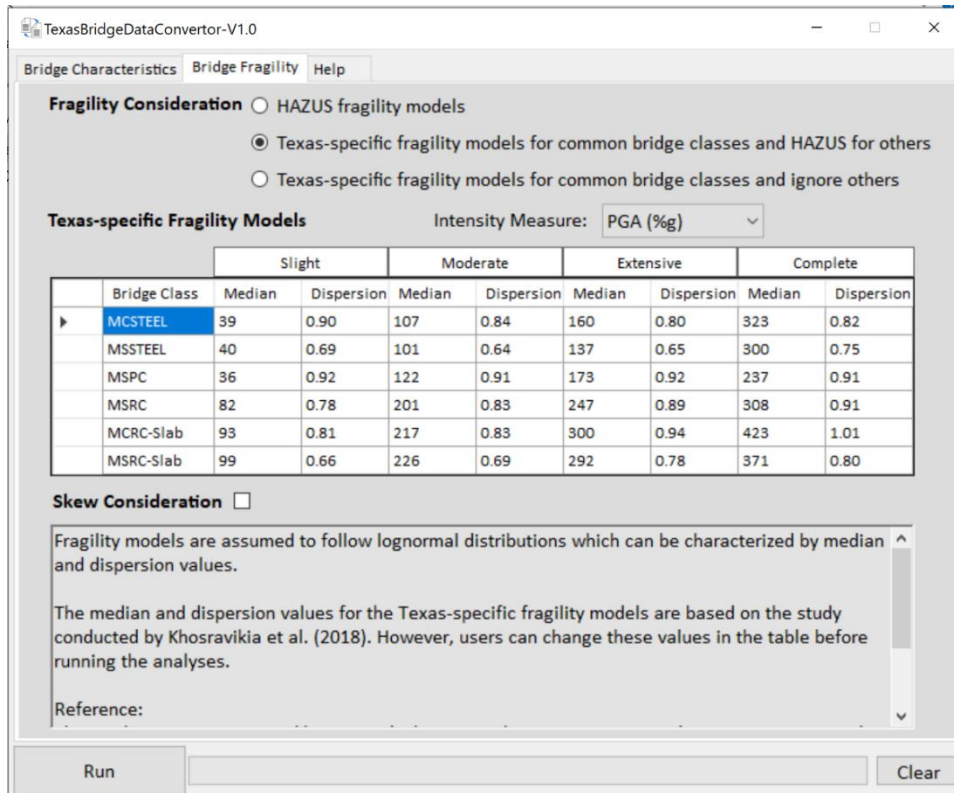


Figure 1.3 Second tab of the TexasBridgeDataConvertor software

1.2.2.1. HAZUS fragility models for all bridges

When the user selects this first option, the software will determine the HAZUS bridge classification of each individual bridge and assign the corresponding HAZUS fragility functions to them. Table 1.2 shows the HAZUS bridge classification and the median values of each level of damage. HAZUS fragility functions for different bridges classes are already embedded into the software and, therefore, cannot be changed without editing the code and compiling the software. Note that, according to HAZUS bridge classification procedures, bridges constructed prior to 1990 are considered *conventional* (non-seismic) *design*, and those constructed after 1990 are considered *seismic design* classes. This classification is currently used in the software to be consistent with HAZUS bridge classification methods, although the authors recommend classifying all bridges in Texas within conventional design classes since most bridges were built without seismic design consideration because of historically negligible seismicity in the state. This deviation from conventional HAZUS bridge classification procedures would require an update of the code used to generate the bridge inventory software.

Table 1.2 HAZUS bridge classification and corresponding median PGA values (per g) of fragility functions (dispersion = 0.64 for all fragility functions)

HAZUS Class	Description	Slight	Moderate	Extensive	Complete
HWB1	Major Bridge - Length > 150m (Conventional Design)	0.4	0.5	0.7	0.9
HWB2	Major Bridge - Length > 150m (Seismic Design)	0.6	0.9	1.1	1.7
HWB3	Single Span – (Not HWB1 or HWB2) (Conventional Design)	0.8	1	1.2	1.7
HWB4	Single Span – (Not HWB1 or HWB2) (Seismic Design)	0.8	1	1.2	1.7
HWB5	Concrete, Multi-Column Bent, Simple Support (Conventional Design), Non-California (Non-CA)	0.25	0.35	0.45	0.7
HWB7	Concrete, Multi-Column Bent, Simple Support (Seismic Design)	0.5	0.8	1.1	1.7
HWB8	Continuous Concrete, Single Column, Box Girder (Conventional Design)	0.35	0.45	0.55	0.8
HWB9	Continuous Concrete, Single Column, Box Girder (Seismic Design)	0.6	0.9	1.3	1.6
HWB10	Continuous Concrete, (Not HWB8 or HWB9) (Conventional Design)	0.6	0.9	1.1	1.5
HWB11	Continuous Concrete, (Not HWB8 or HWB9) (Seismic Design)	0.9	0.9	1.1	1.5
HWB12	Steel, Multi-Column Bent, Simple Support (Conventional Design), Non-California (Non-CA)	0.25	0.35	0.45	0.7
HWB14	Steel, Multi-Column Bent, Simple Support (Seismic Design)	0.5	0.8	1.1	1.7
HWB15	Continuous Steel (Conventional Design)	0.75	0.75	0.75	1.1
HWB16	Continuous Steel (Seismic Design)	0.9	0.9	1.1	1.5
HWB17	PS Concrete Multi-Column Bent, Simple Support - (Conventional Design), Non-California	0.25	0.35	0.45	0.7
HWB19	PS Concrete, Multi-Column Bent, Simple Support (Seismic Design)	0.5	0.8	1.1	1.7
HWB20	PS Concrete, Single Column, Box Girder (Conventional Design)	0.35	0.45	0.55	0.8
HWB21	PS Concrete, Single Column, Box Girder (Seismic Design)	0.6	0.9	1.3	1.6
HWB22	Continuous Concrete, (Not HWB20/HWB21) (Conventional Design)	0.6	0.9	1.1	1.5
HWB23	Continuous Concrete, (Not HWB20/HWB21) (Seismic Design)	0.9	0.9	1.1	1.5
HWB24	Same definition as HWB12 except that the bridge length is less than 20 meters	0.25	0.35	0.45	0.7
HWB25	Same definition as HWB13 except that the bridge length is less than 20 meters	0.3	0.5	0.6	0.9
HWB26	Same definition as HWB15 except that the bridge length is less than 20 meters and Non-CA	0.75	0.75	0.75	1.1
HWB28	All other bridges that are not classified (including wooden bridges)	0.8	1	1.2	1.7

1.2.2.2. Texas-specific fragility functions for common bridge classes and HAZUS for other bridge classes

Table 1.3 shows the common bridge classes in the state of Texas, which, according to Khosravikia et al. (2018), include over 85% of the non-culvert bridges in the state. When selecting this option, users will assign Texas-specific fragility functions for these bridge classes, while for other bridge

classes and culverts, HAZUS fragility functions will be automatically assigned since there has been no study assessing their fragility in terms of Texas earthquakes.

Table 1.3: Common Texas bridge classes

Bridge Type	Abbreviation
Multi-Span Continuous Reinforced Concrete-Slab	MCRC-Slab
Multi-Span Simply Supported Reinforced Concrete-Slab	MSRC-Slab
Multi-Span Simply Supported Reinforced Concrete-Girder	MSRC
Multi-Span Simply Supported Prestressed Concrete-Girder	MSPC
Multi-Span Continuous Steel-Girder	MCSTEEL
Multi-Span Simply Supported Steel-Girder	MSSTEEL

It is worth noting that Khosravikia et al. (2018) generated Texas-specific fragility functions for these bridges classes with respect to different IMs, including PGA and peak ground velocity (PGV); peak spectral accelerations (PSA) at 0.2s, 1.0s, and natural period of bridges—PSA(0.2s), PSA(1.0s), and PSA(T_n), respectively; and Arias Intensity (I_a). Figure 1.4 through Figure 1.9 show these fragility functions with respect to different IMs. Like HAZUS, the fragility functions are assumed to follow lognormal distributions with specific median and dispersion values. The table in the second tab of the software, which is shown in Figure 1.3, presents the median and dispersion values of the fragility functions for the IM of interest. As an option, users can change the median and dispersion values in the table for the IM of interest and then run the analyses to generate user-defined fragility curves to input into ShakeCast. The software will read the data from this table to assign the fragility curves for these six bridge classes. This option is added to the software to accommodate the possibility that future studies will propose new median and dispersion values for the fragility of these bridge classes. With this option, the updated values can be easily added to the table in the second tab of the software without necessarily requiring editing and compiling the software.

In the fragility framework, the structural response and demand are often characterized by probabilistic seismic demand models (PSDMs), which provide the relationship between the structural demand responses (e.g., component deformations, accelerations, internal forces, etc.) and the ground motion IM. PSDMs provide the conditional probability that the structural demand (D) meets or exceeds a certain value (d) given the ground motion IM ($P[D \geq d | IM]$). The reliability of the outcomes of the fragility framework depends on the level of uncertainty associated with the PSDMs, which, in turn, depends on the selection of the IM for the model. Proper selection of the IM reduces the uncertainty in the PSDMs, thereby leading to more reliable performance predictions. Khosravikia and Clayton (2020) showed that by evaluating various uncertainty measures for PSDMs based on different IMs, PGV provides the most reliable estimates for the fragility assessment of Texas bridge infrastructure; thus, the use of PGV is recommended for Texas bridges. In this case, median and dispersion values of the fragility functions with respect to PGV will be assigned for these six bridges classes, while for other bridge classes and culverts, HAZUS fragility functions, which are based on PGA, will be assigned.

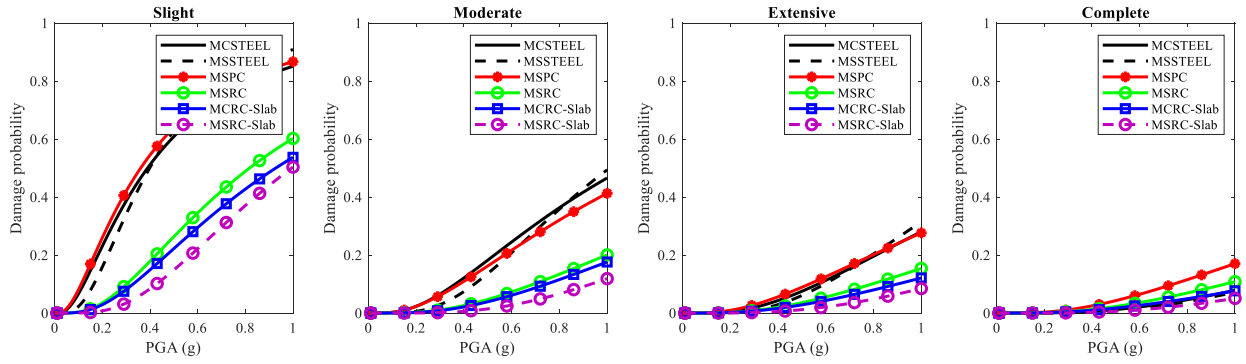


Figure 1.4 Texas-specific fragility functions with respect to PGA

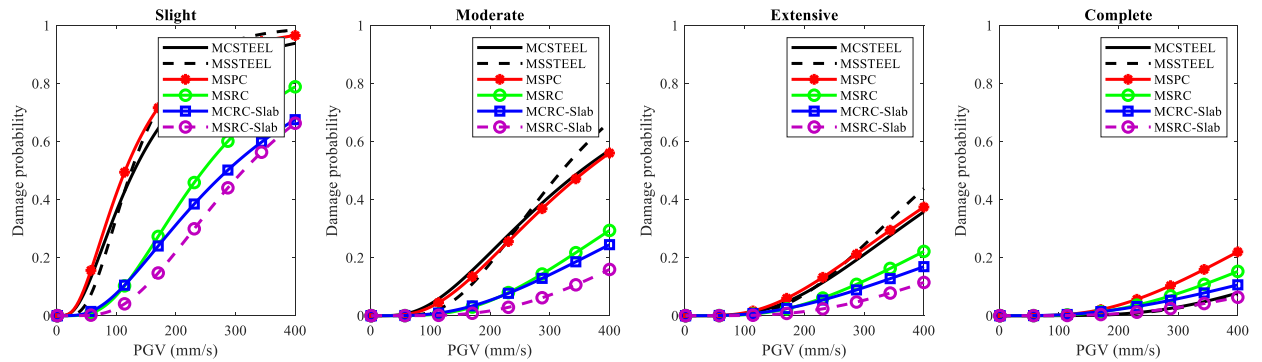


Figure 1.5 Texas-specific fragility functions with respect to PGV

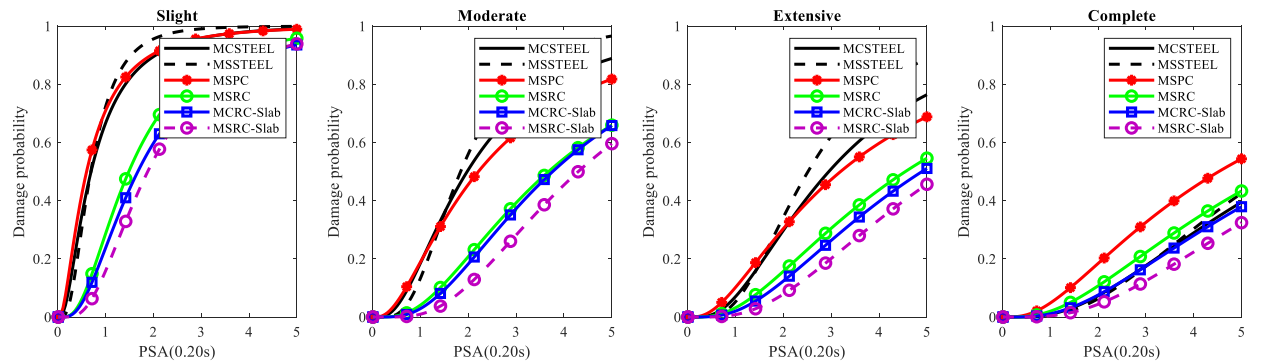


Figure 1.6 Texas-specific fragility functions with respect to peak spectral acceleration at 0.2s (PSA(0.2s))

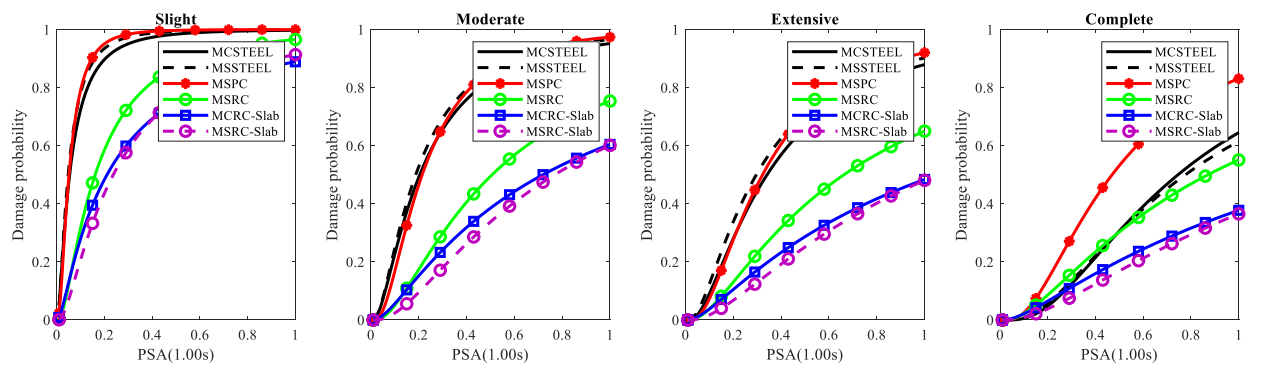


Figure 1.7 Texas-specific fragility functions with respect to peak spectral acceleration at 1.0s (PSA(1.0s))

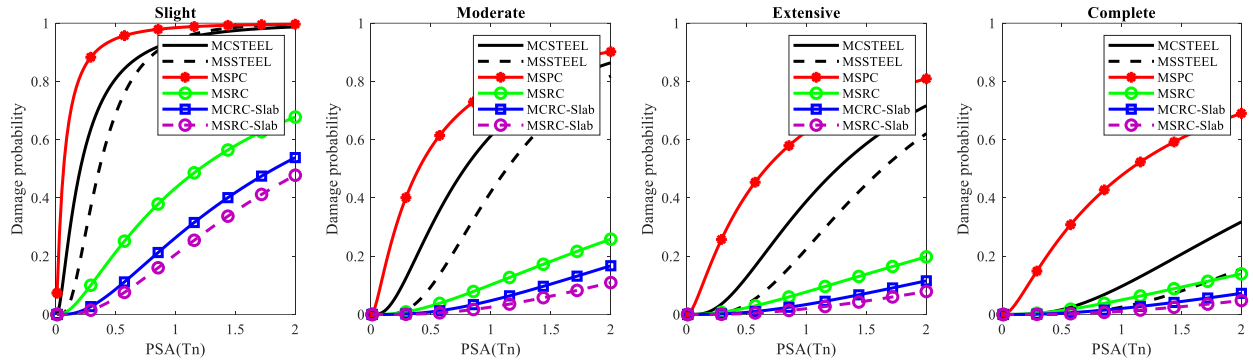


Figure 1.8 Texas-specific fragility functions with respect to peak spectral acceleration at bridge natural period ($PSA(T_n)$)

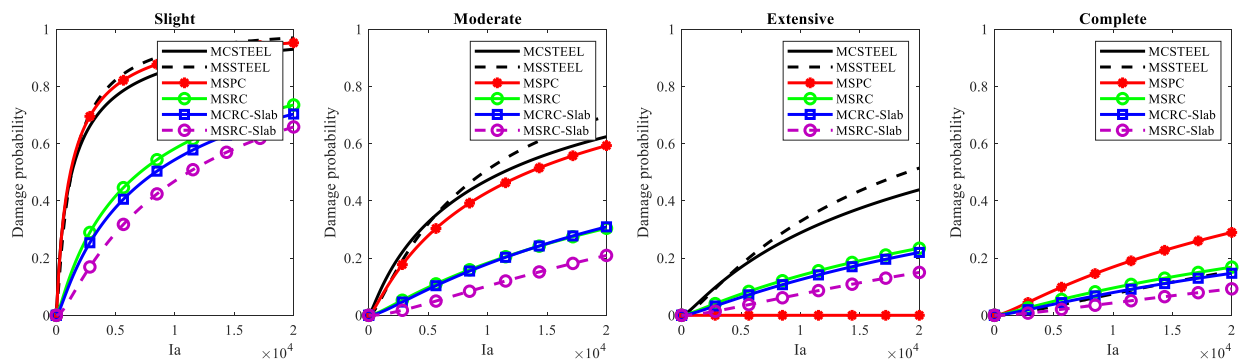


Figure 1.9 Texas-specific fragility functions with respect to Arias Intensity (I_a)

1.2.2.3. Texas-specific fragility functions only for common bridge classes

Selecting this option will assign Khosravikia et al. (2018) fragility curves to the six common bridge classes and remove all the other bridges and culverts from the dataset, instead of assigning HAZUS fragility curves for them.

1.2.3. Skew Consideration

In the second tab of the software, as shown in Figure 1.3, is an option named “Skew Consideration.” As Figure 1.10 illustrates, skew angle is measured as the angle between the centerline of supports and a line perpendicular to the centerline of the roadway. In the NBI, skew angle is recorded based on structural plan drawings or field measurements; however, for curved bridges or bridges where the skew angle varies, the average skew is recorded in NBI. In certain cases where a large variance in skew arises along the length of the bridge such that it cannot be accurately represented by an average value, a value of 99 is recorded to indicate this variation.

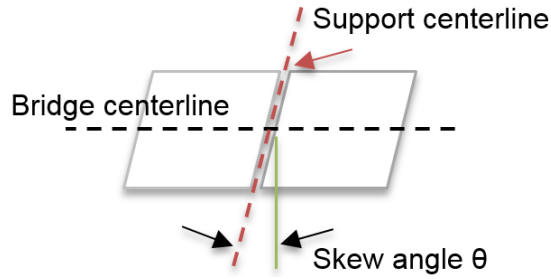


Figure 1.10 Diagram depicting skew angle

Table 1.4 shows the frequency of six common bridge classes with different skew ranges, along with some basic statistics for each bridge class. As the table indicates, on average, about 75% of bridges within these classes have less than 15° of skew. Sullivan and Nielson (2010) found that a skew angle of less than 15° has little to no effect on the seismic vulnerability of a bridge. Therefore, no skew angle was considered for the fragility assessment of bridge representatives in the study conducted by Khosravikia et al. (2018). This assumption is the same one considered by HAZUS in developing the fragility functions listed in Table 1.2.

Table 1.4: Skew angle statistics

Bridge Type	Abbreviation	Mean (deg)	Std Dev. (deg)	Median (deg)	Mode	0° (%)	1° – 15° (%)	15° – 30° (%)	> 30° (%)
Multi-Span Continuous Steel-Girder	MCSTEEL	15.0	19.1	0.0	0.0	51.0	9.1	13.9	26.1
Multi-Span Simply Supported Steel-Girder	MSSTEEL	6.6	13.7	0.0	0.0	77.5	3.5	2.8	16.2
Multi-Span Simply Supported Prestressed Concrete-Girder	MSPC	12.2	16.2	0.0	0.0	52.1	10.8	16.2	20.9
Multi-Span Simply Supported Reinforced Concrete-Girder	MSRC	5.2	12.2	0.0	0.0	81.7	4.9	7.6	5.8
Multi-Span Continuous Reinforced Concrete-Slab	MCRC-Slab	3.9	10.0	0.0	0.0	82.4	5.3	6.2	6.1
Multi-Span Simply Supported Reinforced Concrete-Slab	MSRC-Slab	9.2	17.0	0.0	0.0	72.4	0.3	3.2	24.1

Although this assumption (i.e., no skew consideration) works for most of the bridges in the state, some Texas bridges do have larger skews (i.e., $\theta > 15^\circ$). Literature showed that larger skew angles could greatly affect the seismic response of bridges and increase their vulnerability (Pottatheere & Renault, 2008; Sullivan & Nielson, 2010). Therefore, neglecting skew in the regional assessment of bridges could underestimate the impact of earthquakes. As a result, this option is added to the TexasBridgeDataConverter software to adjust the fragility of bridges according to their skew. To consider the skew parameter, this option should be selected in the software; otherwise, it is assumed that all bridges in the state have no skew.

If this option is selected, the software will adjust the median values of the fragility function based on the study done by Yang et al. (2015). They studied the impact of the skew parameter on the vulnerability of typical non-seismically detailed and seismically detailed bridges in the Central Southeastern United States. They found that as skew increases, the fragility of bridges increases, regardless of bridge class and seismic design considerations. They studied the skew angles of 0°, 15°, 30°, and 45° and presented changes in the median values of the fragility functions for the aforementioned skew angles. Figure 1.11 shows the median fragility values for bridges with different skew angles for four common non-seismically detailed bridges in that study. It is worth noting that they considered PGA as the IM of interest.

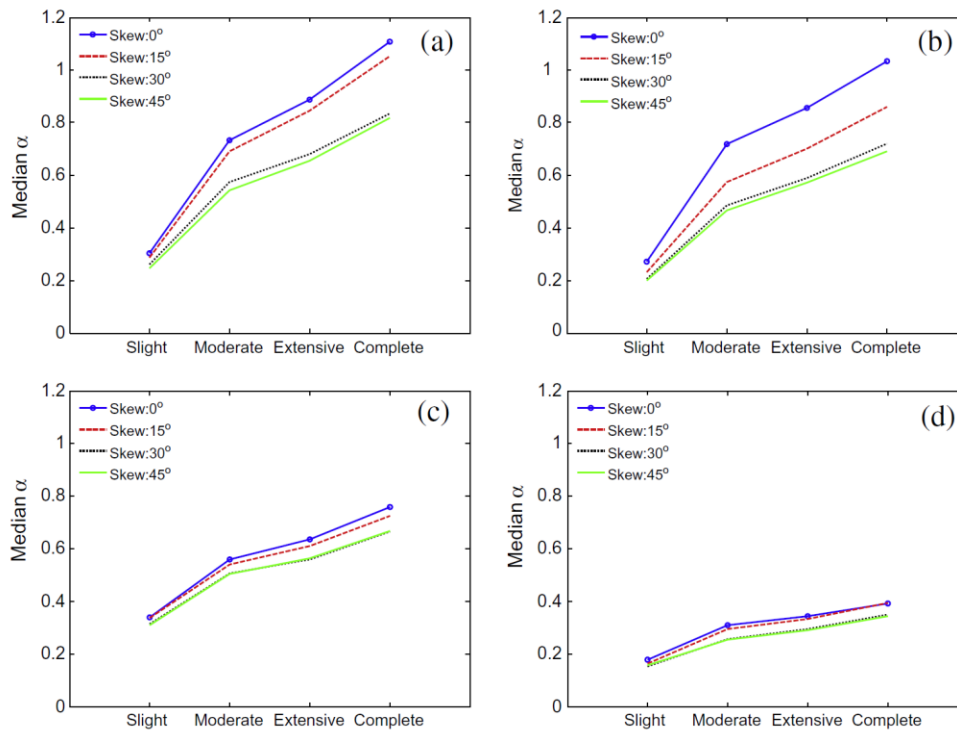


Figure 1.11 Comparison of median fragility values for bridges with different skew angles: (a) MSPC; (b) MSRC; (c) MSSTEEL; and (d) MCSTEEL (reproduced from Yang et al. (2015))

Here, this information is used to adjust the median values of the fragility functions assigned for the bridges from the previous section when no skew is considered for the bridges. Note that no adjustment is needed for dispersion values. To do so, for each bridge class and each skew angle (i.e., 0°, 15°, 30°, and 45°), the ratio between the median values of the fragility functions assigned for the skew and no-skew bridges in the Yang et al. (2015) study is considered as the adjustment factor for that skew angle. Table 1.5 shows the ratios for different bridge classes. The median values of the fragility functions will then be multiplied by the corresponding ratio to determine the adjusted median values. For bridges with skew angles between any of these two values, interpolation is conducted in the software to determine the skew adjustment ratio. Moreover, for bridges for which NBI reports 99 as a skew angle, indicating significant variation in the skew of the bridges, adjustment ratios derived for 45° are assigned. The reason is that according to Yang et al. (2015) study, as shown in Figure 1.11, skew angles greater than 30° do not have a significant

impact on the bridge fragility, and as seen in the table, the ratios will not dramatically change between 30° to 45°. Thus, when 99 is reported in NBI data, the software automatically utilizes the ratios derived for 45°. It is worth noting that the impact of the skew on the dispersion of the fragility functions is negligible; thus, no adjustment factors are considered for the dispersion values when the skew parameter is considered.

This approach is best when it is used for the fragility functions derived for PGA. However, since no information is found in the literature on the impact of skew on fragility functions with respect to other IMs, the same adjustment factors are used for other IMs. This assumption, along with the lack of research on the effects of skew on fragility with respect to IMs other than PGA, is one of the limitations of skew consideration in this project. Further studies are required to investigate the impact of the skew parameter on bridge vulnerability in Texas.

Table 1.5: Skew adjustment ratio for median values of fragility functions of different bridge classes

Bridge Class	Skew	Slight	Moderate	Extensive	Complete
MSPC	0°	1	1	1	1
	15°	0.94	0.93	0.97	0.94
	30°	0.81	0.77	0.77	0.73
	45°	0.74	0.72	0.74	0.72
MSRC	0°	1	1	1	1
	15°	0.82	0.94	0.84	0.83
	30°	0.71	0.67	0.69	0.70
	45°	0.71	0.64	0.68	0.68
MSSTEEL	0°	1	1	1	1
	15°	1.00	0.98	0.97	0.95
	30°	0.94	0.88	0.94	0.87
	45°	0.94	0.88	0.94	0.87
MCSTEEL	0°	1	1	1	1
	15°	0.94	0.97	0.97	1.00
	30°	0.89	0.81	0.86	0.90
	45°	0.89	0.81	0.86	0.90

1.2.4. Running Analyses

Once the information regarding the bridge characteristics and fragility functions are selected, users can press the “Run” button that was shown in Figure 1.2 to start the analyses. During the running process, any bridges in the inventory that do not have information regarding the latitude or longitude will be removed from the analyses, and a message will appear in the text box of the software, as shown in Figure 1.12, indicating the bridge IDs that do not have required information in the uploaded inventory file. After finishing the analyses, a .csv file will be generated by the software, which will be saved in the directory chosen by the user.

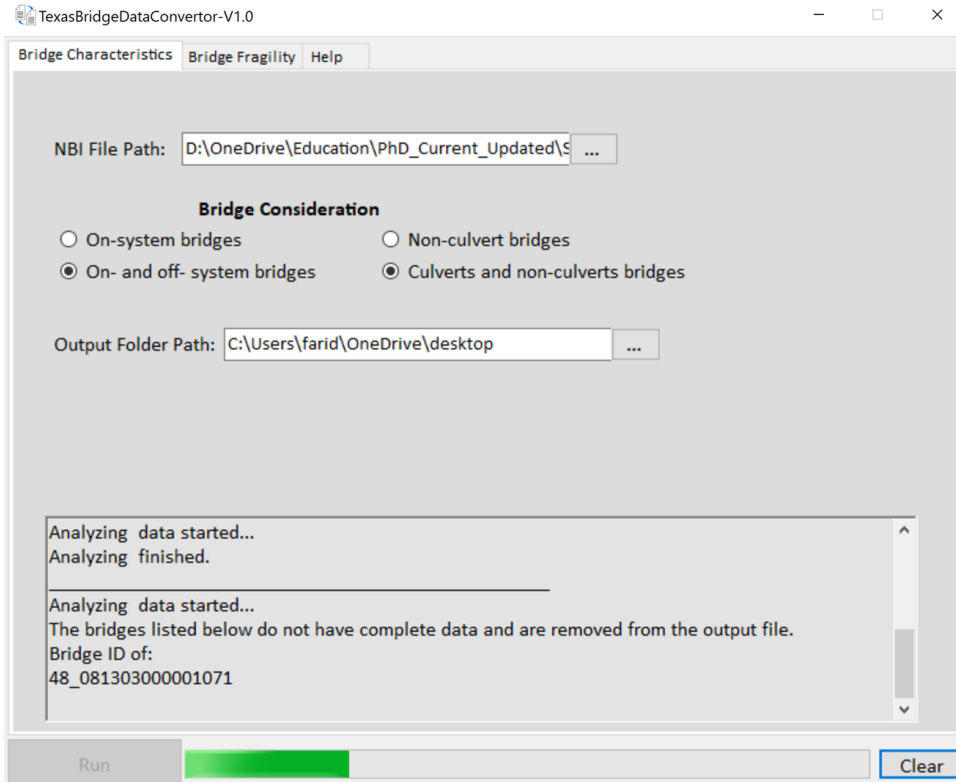


Figure 1.12 Update messages provided during the analyses

1.3. Step 3: Use “ShakeCastInventory” Workbook

The ShakeCast Inventory workbook, shown in Figure 1.13, is a collection of Excel spreadsheets used to bridge the gap between users’ data and the ShakeCast application. This workbook is produced by USGS and can be downloaded from USGS ShakeCast website: http://usgs.github.io/shakecast/inventory_workbook.html. It allows users to collect their facility, notification group, and user information in a single location. Once the data has been collected, a master XML file can be exported that contains all the required information for ShakeCast and can easily be uploaded to ShakeCast. Data is validated as it is entered into the workbook, and malformed data is not exported. This ensures that user data will fulfill the basic requirements for ShakeCast to run correctly. This workbook also serves as a stepping stone between ShakeCast versions. As noted on the USGS website, this workbook will remain compatible with future versions of ShakeCast to ensure installations of any newer versions will be hassle-free.

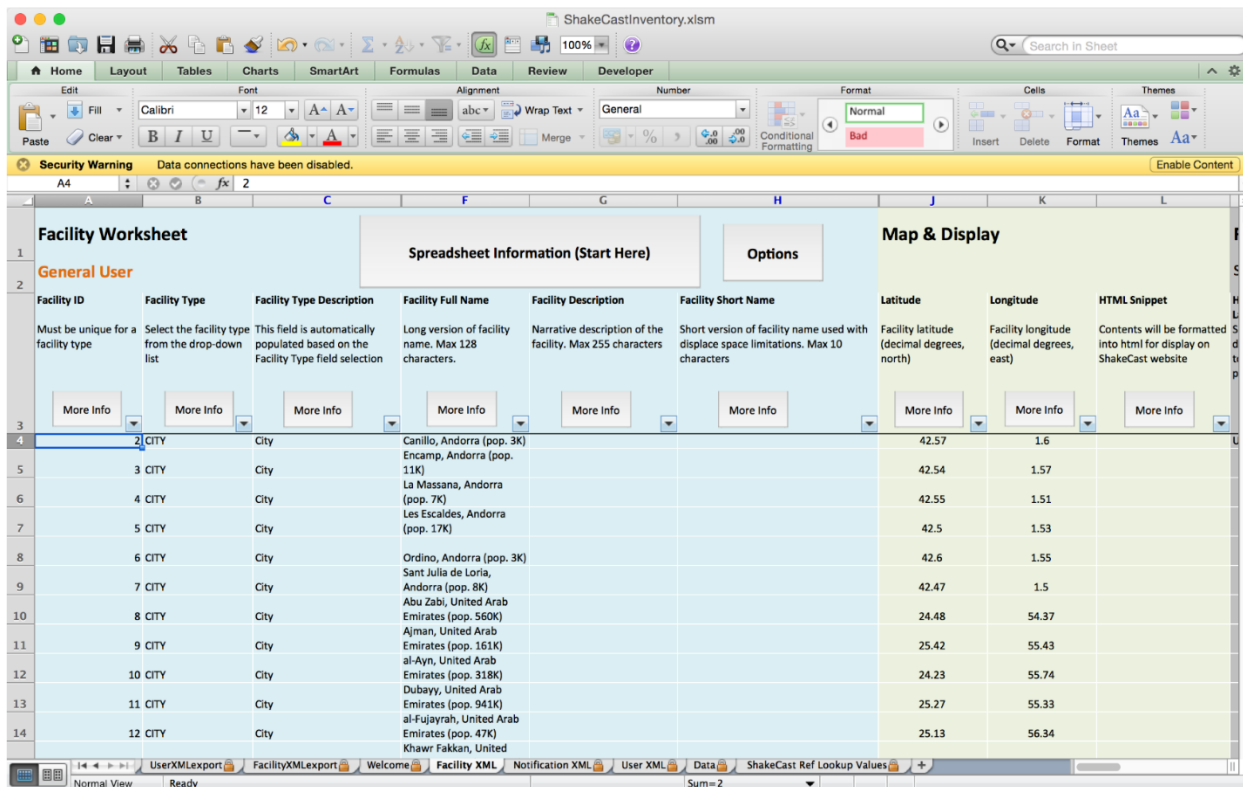


Figure 1.13 ShakeCast Inventory workbook

1.3.1. Listing Facilities

The primary function of ShakeCast is to generate a list of facilities affected by earthquakes. These facilities are technically anything that users want to monitor, such as an office building, a university campus made up of multiple buildings, a bridge, or even specific parts of a bridge—these can all be defined as facilities within ShakeCast. Here, the main objective is to import the bridge data into the workbook. To do so, the .csv file generated by the TexasBridgeDataConvertor software will be imported. To import the .csv file, users can press the “Options” button shown in Figure 1.13, select “Import CSV” option, and choose the file generated by the TexasBridgeDataConvertor software.

When selecting the “Import CSV” option, the ShakeCastInventory workbook downloaded from the USGS website can only import median values of the fragility functions assigned for bridges. In fact, it is assumed that the dispersion values will be 0.64, which is the constant dispersion value assumed by HAZUS for fragility functions. Moreover, in the importing process, only a single IM can be considered for all bridges. For example, PGA should be considered for all bridges as the IM of interest. Thus, it is not possible to assign different IMs for bridges using this version of the ShakeCastInventory workbook downloaded from the USGS website.

However, for Texas, Khosravikia et al. (2018) proposed region-specific fragility functions with different values of median and dispersion. Moreover, they generated fragility functions with respect to different IMs such as PGA, PGV, and spectral accelerations at different periods.

Recently, Khosravikia and Clayton (2020) showed that PGV provides the most reliable estimates for fragility assessment of Texas bridge infrastructure. This information motivates users to consider PGV as the IM of interest for the common bridges shown in Table 1.3; however, since no region-specific fragility functions have been developed for other bridge classes or culverts with respect to PGV, HAZUS fragility curves, which are based on PGA, could be assigned for the rest of the bridges. Therefore, the current version of the “ImportCSV” option of the workbook has limitations for using results of the Texas bridge fragility study.

To address these limitations (i.e., constant dispersion value and single IM of interest), the authors of this report edited the code written in the workbook. With this edition, the workbook can import different IMs with different dispersion values. This edited workbook (named “ShakeCastInventory-edited”) is available at the link provided in Section 1.7.

It is worth noting that the .csv file generated by the TexasBridgeDataConvertor software is compatible with both edited and general versions of the workbook. Thus, if at any time in the future users want to use an updated version of the workbook instead of the edited version, they can still import the data generated by the software. However, in this case, PGA will be considered the IM of interest and a default dispersion value of 0.64 will be considered for all bridge classes.

Moreover, the code written by Khosravikia and Clayton to edit the workbook is provided below. By adding the code to the proper Module of the workbook, users can update the ShakeCastInventory workbook in the future and change it to the edited version, too. To do so, in the downloaded workbook, users should press “alt + f11” button, which opens the Microsoft Visual Basic code of the workbook. In the “Modules” tab, they can find “AllSheets” and open it. Thereafter, in the opened document, users should search for “importCSV.” After the section titled “get info from metric columns,” they can add the code below. By saving it and closing Microsoft Visual Basic, the workbook will be changed to the edited version.

```

' get TxDOT fragility information to the metric
ElseIf InStr(CSVHead(lineCount), "GREEN:") And UBound(Split(CSVHead(lineCount), ":"))
+ 1 = 2 Then

    mySheet.Cells(rowNum, 13).value = "USER_DEFINED"
    metricHead = Split(CSVHead(lineCount), ":")
    If metricHead(1) = "METRIC" Then
        mySheet.Cells(rowNum, 15).value = arrVal
    ElseIf metricHead(1) = "ALPHA" Then
        mySheet.Cells(rowNum, 16).value = arrVal
    ElseIf metricHead(1) = "BETA" Then
        mySheet.Cells(rowNum, 17).value = arrVal
    End If

ElseIf InStr(CSVHead(lineCount), "YELLOW:") And UBound(Split(CSVHead(lineCount),
":")) + 1 = 2 Then

    mySheet.Cells(rowNum, 13).value = "USER_DEFINED"
    metricHead = Split(CSVHead(lineCount), ":")
    If metricHead(1) = "METRIC" Then
        mySheet.Cells(rowNum, 18).value = arrVal
    ElseIf metricHead(1) = "ALPHA" Then
        mySheet.Cells(rowNum, 19).value = arrVal
    ElseIf metricHead(1) = "BETA" Then
        mySheet.Cells(rowNum, 20).value = arrVal
    End If

ElseIf InStr(CSVHead(lineCount), "ORANGE:") And UBound(Split(CSVHead(lineCount),
":")) + 1 = 2 Then

    mySheet.Cells(rowNum, 13).value = "USER_DEFINED"
    metricHead = Split(CSVHead(lineCount), ":")
    If metricHead(1) = "METRIC" Then
        mySheet.Cells(rowNum, 21).value = arrVal
    ElseIf metricHead(1) = "ALPHA" Then
        mySheet.Cells(rowNum, 22).value = arrVal
    ElseIf metricHead(1) = "BETA" Then
        mySheet.Cells(rowNum, 23).value = arrVal
    End If

ElseIf InStr(CSVHead(lineCount), "RED:") And UBound(Split(CSVHead(lineCount), ":")) +
1 = 2 Then

    mySheet.Cells(rowNum, 13).value = "USER_DEFINED"
    metricHead = Split(CSVHead(lineCount), ":")
    If metricHead(1) = "METRIC" Then
        mySheet.Cells(rowNum, 24).value = arrVal

```



```

ElseIf metricHead(1) = "ALPHA" Then
    mySheet.Cells(rowNum, 25).value = arrVal
ElseIf metricHead(1) = "BETA" Then
    mySheet.Cells(rowNum, 26).value = arrVal
End If

```

```

ElseIf InStr(CSVHead(lineCount), "GREY:") And UBound(Split(CSVHead(lineCount), ":"))
+ 1 = 2 Then

```

```

    mySheet.Cells(rowNum, 13).value = "USER_DEFINED"
    metricHead = Split(CSVHead(lineCount), ":")
    If metricHead(1) = "METRIC" Then
        mySheet.Cells(rowNum, 27).value = arrVal
    ElseIf metricHead(1) = "ALPHA" Then
        mySheet.Cells(rowNum, 28).value = arrVal
    ElseIf metricHead(1) = "BETA" Then
        mySheet.Cells(rowNum, 29).value = arrVal
    End If

```

1.3.2. Defining Notification Groups

ShakeCast needs to know which people within your organization should get notifications in specific situations. For instance, first responders may need to be notified in the case of a massive earthquake, while only ShakeCast administrators are interested in receiving notifications for small quakes. Notification groups can be defined so that notifications are only generated when specific shaking or potential impact requirements are met. Users can then be linked to these notification groups in order to receive the notifications when they're generated.

In ShakeCast, notifications can be sent for new earthquakes, specified as "New Event," or when ground shaking occurs at a facility location, specified as "Damage." For "New Event," the monitoring region and minimum magnitude of interest should be specified. The monitoring region is the polygon defining the latitude and longitude boundaries of the considered region. The information must contain more than three points separated by semicolons, where the last point is the same as the first point. To set the monitoring region to Texas, the following data (listed in Table 1.6) can be copied and pasted to this cell of the notification sheet. For "Damage," there is no need to specify the monitoring region and minimum magnitude, since this type of notification will be sent any time a facility experiences ground shaking that is not necessarily associated with a specific earthquake event. For "New Event," ShakeCast automatically checks all inspection priority notifications; however, for "Damage," users should manually specify inspection priorities of interest, including "Green," "Yellow," "Orange," and "Red."

Table 1.6: Latitude and longitude boundaries of Texas

31.8659 -106.5715;31.7504 -106.5042;31.6242 -106.3092;31.4638 -106.2103;31.3912 -106.0181;31.1846 -105.7874;31.0012 -105.5663;30.8456 -105.4015;30.6462 -105.0032;30.3847 -104.8521;30.2591 -104.7437;30.0738 -104.6915;29.9169 -104.6777;29.7644 -104.5679;29.6475 -104.5280;29.5603 -104.4044;29.4719 -104.2067;29.3834 -104.1559;29.2948 -103.9774;29.2804 -103.9128;29.2481 -103.8208;29.1378 -103.5640;29.0682 -103.4692;29.0105 -103.3154;28.9601 -103.1616;29.0177 -103.0957;29.1330 -103.0298;29.2157 -102.8677;29.2565 -102.8979;29.3570 -102.8375;29.4898 -102.8004;29.6881 -102.7002;29.7691 -102.5134;29.7596 -102.3843;29.8788 -102.3047;29.7834 -102.1509;29.7572 -101.7004;29.7644 -101.4917;29.6308 -101.2939;29.5269 -101.2582;29.3642 -101.0056;29.3056 -100.9204;29.1642 -100.7707;29.0946 -100.7007;28.9012 -100.6306;28.6593 -100.4974;28.4675 -100.3601;28.2778 -100.2969;28.1882 -100.1733;28.0526 -100.0195;27.9435 -99.9344;27.7638 -99.8438;27.6641 -99.7119;27.4839 -99.4812;27.3059 -99.5375;27.1948 -99.4290;27.0175 -99.4455;26.8829 -99.3164;26.6867 -99.2065;26.4116 -99.0967;26.3574 -98.8138;26.2257 -98.6668;26.2343 -98.5474;26.1357 -98.3276;26.0457 -98.1697;26.0518 -97.9143;26.0050 -97.6643;25.8419 -97.4020;25.9074 -97.3526;25.9679 -97.0148;26.1789 -97.0697;26.8253 -97.2249;27.4230 -97.0752;28.0599 -96.6096;28.4228 -95.9285;28.7568 -95.3036;29.0742 -94.7296;29.3810 -94.3355;29.6021 -93.8205;29.8013 -93.9317;29.9157 -93.8136;30.0489 -93.7230;30.1214 -93.6996;30.2021 -93.7216;30.2792 -93.7038;30.3278 -93.7628;30.3835 -93.7587;30.4380 -93.7010;30.5079 -93.7024;30.5362 -93.7299;30.6296 -93.6694;30.7466 -93.6090;30.8114 -93.5527;30.8834 -93.5747;30.9376 -93.5307;31.0318 -93.5074;31.0812 -93.5266;31.1787 -93.5335;31.1670 -93.5980;31.3055 -93.6832;31.3830 -93.6708;31.4369 -93.6887;31.5107 -93.7202;31.5820 -93.8315;31.6440 -93.8123;31.7188 -93.8232;31.7936 -93.8342;31.8309 -93.8782;31.8869 -93.9221;31.9335 -93.9661;32.0081 -94.0430;33.4681 -94.0430;33.5414 -94.0430;33.5689 -94.1528;33.5872 -94.1968;33.5872 -94.2627;33.5689 -94.3176;33.5597 -94.3945;33.5780 -94.4275;33.6055 -94.4275;33.6421 -94.4495;33.6329 -94.4879;33.6421 -94.5236;33.6695 -94.6637;33.7061 -94.7461;33.7791 -94.8999;33.8818 -95.0757;33.9251 -95.1526;33.9604 -95.2254;33.8750 -95.2858;33.8841 -95.5399;33.8887 -95.7568;33.8408 -95.8420;33.8556 -96.0274;33.6901 -96.3528;33.8442 -96.6179;33.8898 -96.5836;33.8955 -96.6673;33.8179 -96.7538;33.8613 -96.8335;33.8613 -96.8774;33.9388 -96.9159;33.7392 -97.0917;33.7449 -97.1645;33.8978 -97.2180;33.8225 -97.3746;33.8305 -97.4611;33.8761 -97.4460;33.9798 -97.6945;33.8476 -97.8648;33.8978 -97.9651;34.0299 -98.0983;34.1141 -98.1752;34.1425 -98.3743;34.0640 -98.4773;34.1209 -98.5529;34.1232 -98.7520;34.2095 -98.9539;34.2073 -99.0637;34.2141 -99.1832;34.3593 -99.2505;34.4613 -99.3823;34.3774 -99.4318;34.4160 -99.5718;34.3706 -99.6158;34.4726 -99.8094;34.5631 -99.9934;36.4975 -100.0017;36.5008 -103.0408;32.0011 -103.0655;32.0023 -106.6168;31.8659 -106.5715;

1.3.3. Defining Users

A user is anyone within your organization who will be receiving notifications from your ShakeCast instance or accessing its web interface.

1.4. Step 4: Import Data into ShakeCast

Once the data has been collected in the ShakeCast Inventory workbook, press the “Option” button and export a master XML file that contains all the information. The XML files generated by the workbook can then be uploaded to ShakeCast. In the Amazon Web Service cloud version of ShakeCast, it is just a drag-and-drop process. USGS is currently hosting TxDOT’s instance of ShakeCast. As long as this is the case, TxDOT will need to email all inventory updates (i.e., XML files) to USGS. The current point of contact for inventory updates via USGS is Kuo-Wan Lin (klin@usgs.gov).

1.5. Step 5: Consider ShakeCast Inspection Plans

In ShakeCast, the impact of earthquakes on facilities is categorized as one of the following five levels: high, moderate-high, moderate, low, and no impact. Table 1.7 shows the descriptions of each of these levels. As the table indicates, these levels are defined based on the comparison of the shaking level at the facility location with the median values of the fragility functions of different damage states assigned for that facility in the facility XML file. The shaking level at the facility locations is quantified using the ground-motion models embedded in ShakeMaps, which are automatically imported into ShakeCast after an event, and it is based on the IM that is set by the user in the facility XML file. Recall that the IM in ShakeCast could be modified Mercalli intensity, PGA (%g), PGV (cm/s), PSA(0.3s) (%g), PSA(1.0s) (%g), or PSA(3.0s) (%g). Different IMs can be used for different levels of impact; however, the median values of the fragility functions should also be based on the IM of interest.

Given the impact of the earthquake on a facility, the inspection priority is determined for that facility. In general, ShakeCast uses five different colors to define the inspection priority: Gray, representing no need of inspection; Green, representing low priority; Yellow, representing moderate priority; Orange, representing moderate-high priority; and Red, representing high priority. This plan of inspection is determined by the likelihood of different levels of damage. The thresholds for inspection priority used in ShakeCast are based on the median values (i.e., 50% probability of damage) for different levels of damage. Figure 1.14 illustrates the inspection thresholds for facilities based on the fragility functions. Note that for bridges with the same priority level, ShakeCast also prioritizes the bridges with a higher probability of damage given the shaking level at each bridge.

If users want to change the inspection threshold in ShakeCast manually (e.g., they want to prioritize inspection for bridges with at least 10% likelihood of slight damage instead of 50%), they could change the median values input in the facility XML file. For example, they can assign the values corresponding to 10% probability of damage for each damage level instead of the median value.

In this case, the inspection criteria will be based on 10% probability of damage for each level of damage. However, such changes may cause confusion in ShakeCast because the values imported as median (i.e., “alpha”) values in the XML file are no longer representing the median values of the fragility functions; therefore, probabilistic analyses conducted within ShakeCast will no longer be correct. Other than this manual adjustment to the “median” values input into ShakeCast, there is no other feasible way to use thresholds other than the median fragility values in ShakeCast.

Table 1.7: Earthquake impact levels in ShakeCast

Impact	Description	Inspection color
High impact	$P(\text{Complete damage}) \geq 50\%$	Red
moderate-high impact	$P(\text{Extensive damage}) \geq 50\%$	Orange
Moderate impact	$P(\text{Moderate damage}) \geq 50\%$	Yellow
Low impact	$P(\text{Slight damage}) \geq 50\%$	Green
No impact	$P(\text{Complete damage}) < 50\%$	Gray

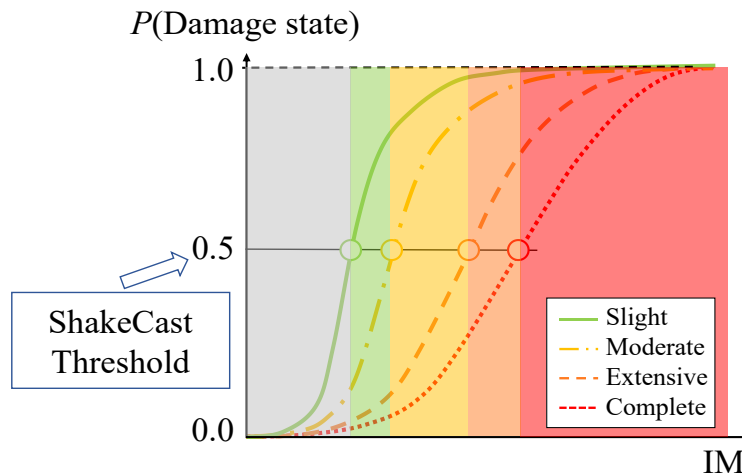


Figure 1.14 Illustration of ShakeCast thresholds for inspection plans from fragility functions

1.6. Example

This section provides an example of the XML files that can be uploaded to the ShakeCast software in order to update the bridge facility and fragility data in ShakeCast. In this example, the 2018 “Comma Delimited” version of bridge facility data is downloaded from NBI. This data, which is available at the link provided in Section 1.7, is then imported into the TexasBridgeDataConvertor software. Only on-system non-culvert bridges are considered in this example. Recall that the main objective of the software is to extract bridge facility data for ShakeCast and assign fragility functions for the bridges. In assigning fragility functions, in this example, PGA is considered the IM of interest. TxDOT fragility functions generated as part of TxDOT project 0-6916 are assumed for the six common bridge classes, while HAZUS fragility functions are used for other bridge classes. Moreover, skew is determined by adjusting the median values of the fragility functions of the skewed bridges.

The .csv file generated by the software, which is named “TX18-Comma Delimited_Converted.csv” in the supplementary documents (see Section 1.7), is then imported into the edited version of the ShakeCastInventory file. Finally, by extracting XML files from the ShakeCastInventory workbook, the XML files required for the ShakeCast software are generated. The XML files can be uploaded into ShakeCast, and by doing so, the Texas bridge data and fragility data will be updated in ShakeCast. The XML files are available in the supplementary document named “Uploaded to ShakeCast”. In the future, TxDOT can repeat this process to update the bridge facility and fragility data in the ShakeCast software.

For the purpose of demonstration, the results from ShakeCast for a hypothetical earthquake with magnitude 6.9 in West Texas with a latitude of 31.3582 and a longitude of -104.783 are shown in Figure 1.15. This figure shows the shaking levels produced by USGS ShakeMaps.

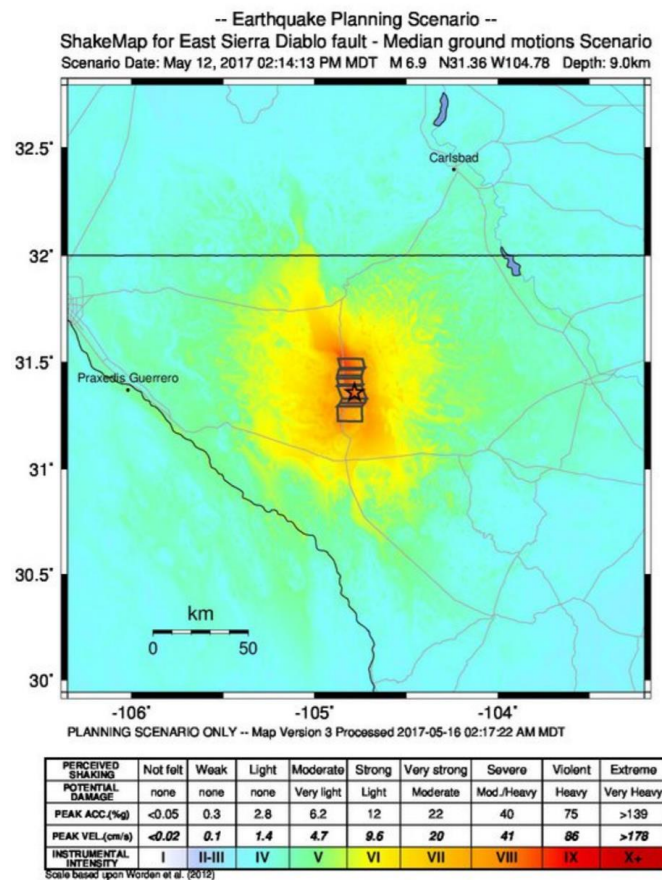


Figure 1.15 Shaking levels for a hypothetical earthquake with M6.9 in West Texas

Figure 1.16 shows the bridge conditions after this scenario as shown in ShakeCast. As the figure indicates, 295 bridges are in that area, and the earthquake is expected to have a moderate-high impact for only one bridge near the earthquake epicenter. The inspection priority for other bridges is grey, indicating no need for inspection. In fact, it is estimated that no damage will occur for those bridges because of the considered earthquake. The summary of results from ShakeCast for this earthquake is shown in Table 1.8.

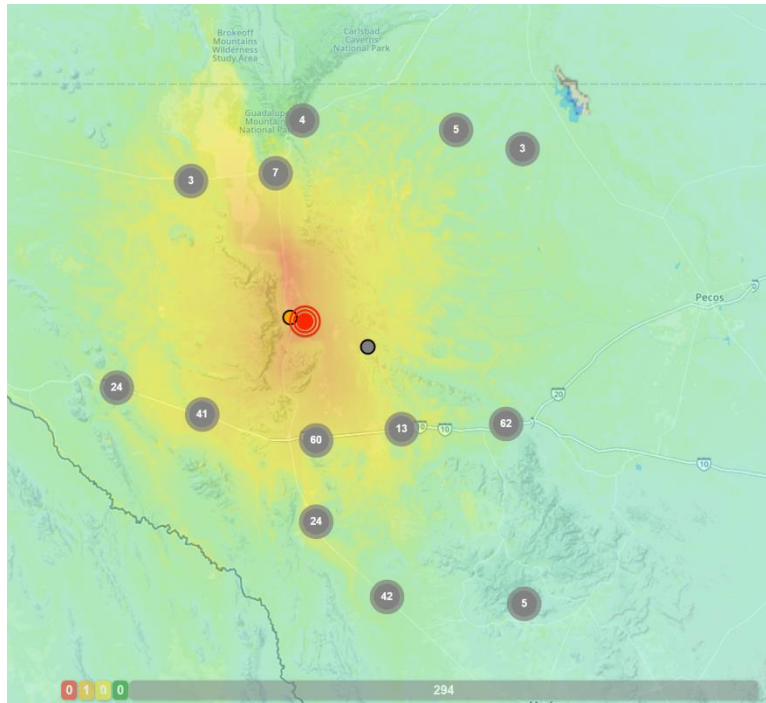


Figure 1.16 Bridge conditions for a hypothetical earthquake with M6.9 in West Texas

Table 1.8: ShakeCast report for an earthquake with M6.9 in West Texas

ShakeCast Report

Magnitude 6.86

East Sierra Diablo fault

Number of Facilities Evaluated	295
High Impact	0
Moderate-High Impact	1
Moderate Impact	0
Low Impact	0
No Impact	294

1.7. Link to the Software

The [TexasBridgeDataConvertor software is available for download from Gitlab](#). At this link is the executable file for the software, the Excel workbook template (a modified version of the workbook published by USGS), and some example input and output files that were used in the virtual training workshop provided to TxDOT staff.

Appendix A. “TexasBridgeDataConvertor” Software Source Code

The following steps guide users through the process of modifying TexasBridgeDataConvertor software source code and compiling the modified version into an executable application.

Step 1: Download and Install Microsoft Visual Studio

Microsoft Visual Studio is required for editing and compiling the software source code. Download and installation instructions are available at the link below:

<https://docs.microsoft.com/en-us/visualstudio/install/install-visual-studio?view=vs-2019>

The free version of Microsoft Visual Studio (Community) will suffice for the purpose of this guide. Make sure to check “.Net Desktop Development” at the “Choose Workloads” step of instructions.

Step 2: Open the Project in Visual Studio

After installation, open Visual Studio and select File → Open → Project/Solution (or press Ctrl + Shift + O). In the opened dialog, go to the software folder, choose “BridgeDataConvertor.sln,” and click Open.

Step 3: Apply Desired Modifications

After opening the project, the interface of the software can be modified by double-clicking on “MainForm.cs” in the “Solution Explorer” window. To modify the underlying code, right-click on “MainForm.cs” and choose “View Code”.

Step 4: Compile and Test the Modified Version

To compile and run the modified version of the software, simply select Debug → Start Without Debugging (or press Ctrl + F5). The compiled application will be opened after compilation and can be tested as needed.

Step 5: Extracting the Executable File

If everything is as expected in step 4, the compiled executable file (with “.exe” format) can be found at the software folder, in \BridgeDataConvertor\bin\Debug\ as “BridgeDataConvertor.exe”. “BridgeDataConvertor.exe” is a standalone executable, and no other file from the project is required to run it. For future uses, simply copy the executable to your desired directory and/or rename it if needed.

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