Seismic Safety of Schools

Washington Schools

Earthquake Performance Assessment Tool (EPAT)

USER GUIDE

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Preface

This User Guide provides detailed documentation of the data inputs for the Earthquake Performance Assessment Tool (EPAT) and explains how these data are used to calculate the results.

See also the **Quick Start Checklist** which provides step by step guidance for data entries.

Printing copies of these two documents is recommended for easy reference as users enter data into EPAT and interpret the results.

1.0 Background

The Earthquake Engineering Research Institute (EERI) is an international nonprofit technical society of engineers, geoscientists, architects, planners, public officials, and social scientists. The objective of EERI is to reduce earthquake risk by 1) advancing the science and practice of earthquake engineering, 2) improving understanding of the impacts of earthquakes on the physical, social, economic, and cultural environment and 3) advocating comprehensive and realistic measures for reducing the harmful effects of earthquakes.

The focus of the EERI School Earthquake Safety Initiative (SESI) is to promote safe buildings for school children. The fundamental principle of SESI is that:

Schoolchildren have a right to learn in buildings that are safe from earthquakes.

At present, the state of seismic safety of schools is definitely mixed:

- Schools designed and built to current or recent building codes generally provide an excellent level of earthquake safety, while

- Schools designed and built to older building codes typically provide a lower level of earthquake safety, with a commensurate increase in the level of life safety risk in future earthquakes, and
- Some schools have major seismic deficiencies and may pose a high level of life safety risk in future earthquakes.

Development of the Washington Schools EPAT was supported by EERI with funding from the Federal Emergency Management Agency (FEMA). The tool drew heavily on a benefit-cost analysis tool developed for the Office of Superintendent of Public Schools (OSPI) with funding from a separate FEMA grant.

The Washington Schools EPAT is designed to help school districts better understand the seismic vulnerability of their school buildings. The goal is to help districts prioritize the limited resources available for seismic evaluations and retrofits on the buildings most likely to pose the highest risks for life safety, severe damage and extended downtimes for repairs in future earthquakes.

2.0 Overview of the EPAT

The assessment tool is designed to provide a preliminary, but quantitative, determination of the level of seismic risk for school buildings. The tool aims to:

- Require a limited number of data inputs for each building, supplemented with other data already built into the Campus Data worksheet of the tool,
- Be understandable to district staff, and
- Provide technical data about the seismic vulnerability of a district's buildings so that the district can systematically prioritize retrofit or replacement of buildings with the highest level of seismic risk.

The assessment tool is complementary to existing methods, including FEMA's Rapid Visual Screening (RVS) 3rd Edition methodology, FEMA's HAZUS Loss Estimation methodology, and the American Society of Civil Engineers Standard for Seismic Evaluation and Retrofit of Existing Buildings (ASCE 41-13). The assessment tool is not intended to replace any of these well-established methodologies.

School districts can use this tool in two different ways:

1. Districts that have not completed seismic evaluations of buildings using any of the three existing methodologies listed above can use the tool to make preliminary, but quantitative, seismic risk assessments of buildings in their inventory. In this case, users must enter only a few key data necessary for the evaluation. These data entries are identified and explained in Section 4.0 of this report.
    - Ideally, the key data should be entered by an engineer experienced with seismic evaluations, to ensure that the data entries correctly reflect the buildings being evaluated.

- However, the key data can also be entered by district staff or other professionals with a working knowledge of the District's buildings and an understanding of the seismic data terms discussed in Section 3.0, including the definitions of the Building Types (HAZUS) and of the vertical and plan irregularities.
- Accurate data entry into the tool is essential for accurate results.

2. Districts that have completed seismic evaluations of buildings using FEMA's Rapid Visual Screening (RVS) methodology, ASCE 41-13 or similar evaluations can enter the necessary data into the tool from these existing evaluation reports.

The EPAT includes a campus database that automatically provides all of the seismic hazard data that are necessary for the risk calculations for each school location and automatically completes all of the calculations for a given building, once users enter data for the building. The EPAT includes:

1. Automated incorporation of GIS-based information including the latitude and longitude of each K-12 campus in Washington and the corresponding seismic hazard information.
   a. USGS National Seismic Hazard data,
   b. Washington Department of Natural Resources estimates of Site Class (soil/rock type) and Liquefaction Potential,
   c. The expected probability and intensity of future earthquake ground motions at each campus location, including adjustments for Site Class.
2. Automated incorporation of a detailed time history of seismic provisions in building codes, including Seismic Zone changes and the corresponding increased seismic design forces for various regions in Washington. These data support estimates of the seismic vulnerability of schools built at different times.

The technical details of the seismic vulnerability calculations for each building, which are intended primarily for engineers, include:

1. Automated assignment of seismic fragility curve parameters commensurate with the stepwise increases in seismic design forces in various regions of Washington, including interpolations between the four HAZUS-defined code levels of Pre-, Low-, Moderate- and High-Code.
2. Automated adjustments in the fragility curve parameters to reflect building irregularities: Severe Vertical, Moderate Vertical and Plan (horizontal) including combinations of the vertical and plan irregularities.
3. Automated generation of report tables including the estimated probability of each of the four HAZUS-defined building damages states and the loss ratios (damage as a percentage of a building's replacement value) for earthquake ground motions with 20%, 10%, 2/3rds of 2% and 2% chances of being exceeded in 50 years. These results are presented for three states of each

building: existing building, life safety retrofit, and replacement with a current code building.

3.0 Pre-Screening: Prioritizing Buildings for Seismic Assessments

It is typically not necessary for school districts to undertake seismic performance assessments for all their buildings. Buildings designed and built to recent codes generally have significantly better seismic performance than buildings designed and built to older versions of the building codes. The level of seismic risk, especially life safety risk, also varies markedly with building type.

The suggested priorities presented in this section are based heavily on the time-history of seismic provisions contained in building codes typically used in Washington State. Code adoption varies markedly with location and the expected seismic performance of buildings also varies according to code used for design. A summary of the building code history with corresponding estimates of seismic fragilities are shown in Table 1. The locations in Table 1 are shown on a Washington State map in Figure 1. In Table 1, UBC stands for Uniform Building Code.

Table 1: Washington State Building Code History[1]

Existing Buildings HAZUS Fragility Assignments

UBC Version	Range Year Built	Coastal	Puget Sound	Extended Puget Sound	Eastern
2003 IBC	2005-present	High	High	High	Low-Moderate
1997 UBC	1999-2004	High	High	High	Moderate
1994 UBC	1996-1998	Moderate-High	Moderate-High	Moderate-High	Low-Moderate
1988 - 1991 UBC	1990-1995	Low-Moderate	Moderate-High	Moderate-High	Low-Moderate
1976 - 1985 UBC	1978-1989	Low	Moderate	Low	Low
1973 UBC	1976-1977	Pre-Low [a]	Low-Moderate	Pre-Low	Pre-Low [a]
1900	<= 1975	Pre- [a]	Pre- [a]	Pre- [a]	Pre- [a]

[a]W1 buildings in the Pre-Code time period are classified as Low-Code, per HAZUS.

[1]Washington State Building Code History (2017)

Fragility assignments with split names, such as Moderate-High, are interpreted as being halfway between the two HAZUS code levels.

The Geographic Regions for UBC Seismic Zones - Coastal, Puget Sound, Extended Puget Sound and Eastern Washington - are shown in Figure 1 on the following page (and is also provided in the "Building Data" worksheet of the tool).

Washington typically adopted building codes mid-year (most often July 1st) of the year following code editions. The tool assumes that buildings built one year after the code adoption year were designed to a given code. The one-year lag accounts for the lag in buildings permitted under the preceding code but completed later.

Example: the 1976 UBC was adopted in mid-1977. Buildings built in 1976 or 1977 are assumed to be designed to the 1973 UBC. Buildings built in 1978 or later are assumed to be designed to the 1976 UBC, until the time period for the 1979 UBC.

The tool allows users to enter the specific code to which a building was designed, if this information is available. If not, the above assumptions are applied.

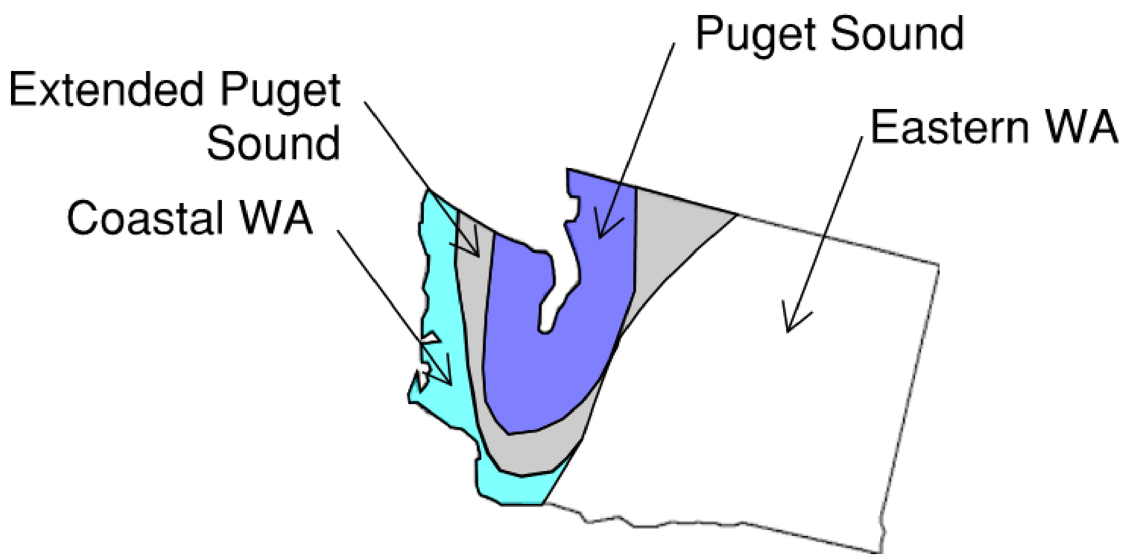

Figure 1: Geographic Regions for UBC Seismic Zones

Seismic evaluations may not be necessary for buildings built in 1999 or later, that are designed and built to the 1997 UBC, or any editions of the IBC. Buildings in this time period almost generally have seismic performance comparable to new, current-code buildings.

Priorities for seismic assessments – from highest to lowest – are generally in the following order, excluding buildings that are in the time periods referenced above:

1. Buildings built in 1975 or earlier.
2. Buildings designed and built to the 1991 UBC or earlier (Year Built = 1995 or earlier) in the Coastal Region.
3. Buildings designed and built to the 1973 though 1985 UBC (Year Built = 1989 or earlier.
4. Buildings designed and built to the 1988 to 1994 UBC (Year Built = 1990 to 1998) in the Puget Sound and Extended Puget Sound Region.

For each of the time periods shown above, the priority for seismic assessment is highest for non-ductile building types, in the following approximate priorities – from highest to lowest priorities:

1. Unreinforced masonry buildings,

2. Reinforced masonry buildings,
3. Concrete buildings, especially pre-cast or tilt-up concrete buildings, and
4. Steel building types, especially if designed before the 1994 UBC.

However, wood frame buildings with tall walls and large spans such as gymnasiums, auditoriums, cafeterias, and multipurpose rooms are likely to have more severe seismic vulnerabilities than other wood frame buildings. Thus, such wood frame buildings have a higher priority for seismic assessments than other wood frame buildings.

A district may select the buildings for which the evaluations using this tool will be completed using the priorities outlined in this section of the User Guide.

However, a district may also use its own criteria, including historical significance, importance to the community, schools designated as emergency shelters, or any other district-specific criteria.

4.0 Data Entry: Step-By-Step Instructions

The Read-Me Page of the EPAT has a condensed summary of the data entries necessary to complete the seismic assessment of a building using the EPAT.

Data entries are made on two pages in the EPAT: the Main Page and the Building Data Page. The data entry cells are color coded, with explanations on the Main Page and the Building Data Page. Data in white (unshaded) data cells are automatically populated with data from the Campus Database Page.

4.1 EPAT Main Page

An example EPAT Main Page for a hypothetical district is shown below:

Washington Schools Earthquake Performance Assessment Tool (EPAT)
MAIN PAGE

Full District Name	ABC School District 123		
Point of Contact	John Q. Admin		
Telephone	(999) 123-4567		
E-Mail	JQA@galaxy.net		
File Name	ABC-Elementary-Gymasium.xlsm	**File Date:**	7/4/2017

District	ABC Example
Facility Name	ABC Elementary
Building Part Name	Gymnasium

Earthquake Ground Motion (% g)		**Earthquake Hazards**	
20% in 50 year PGA	23.5%	**Site Class**	D
10% in 50 year PGA	30.9%	**Ground Shaking Hazard**	High
2% in 50 year PGA	49.4%	**Liquefaction Potential**	Low
Percentile S_s *Among all WA Campuses*	46%	**Combined Earthquake Hazard Level**	High

Total Building Part Area (Square Feet)	**Building Evaluated By**	**Input Data by Person(s)**
15,155	Abigal Smith, Smith Engineering	John Jones, ABC School District

The Earthquake Ground Motion and Earthquake Hazard Hazards data shown above are primarily for use and interpretation by engineers.

Figure 2: Example EPAT Main Page

Step-By-Step instructions for the data entries on the EPAT Main Page are provided in this section and in the Quick Start Checklist.

Main Page: Pale Green Highlighted Cells

These data cells are for information and reference:

1. Enter the District's Full Name.

2. Enter the name for the point of contact person.

3. Enter the Telephone number for the point of contact person.

4. Enter the e-mail for the point of contact person.

5. Enter the name(s) and affiliation(s) of the person(s) who evaluated this building. Examples: John Smith, ABC School District or Suzanne Jones, XYZ Engineers.

6. Enter the name(s) and affiliation(s) of the person(s) who entered the data into EPAT.

Main Page: Bright Green Highlighted Cells

The following data entries are <u>mandatory and must be done using the dropdown menus in each cell:</u>

7. Select the District Name and Facility Name (School Name) from the dropdown menus.

   Drop down menus are selected by clicking on the cell and then clicking on the down arrow box at the right of an Excel cell.

   These selections automatically load data from the Campus Database page of EPAT. This is why the District Name and Facility Name <u>must</u> be entered using the dropdown menus, to ensure that the names match exactly with those in the Campus Database.

Main Page: Orange Highlighted Cells

The following data entries are <u>mandatory:</u>

8. Enter the File Name for this Excel file. Each EPAT analysis for a different building or building part **<u>must</u>** be saved as a separate Excel file. File names should be descriptive to clearly identify the building or building part that is analyzed in each Excel file.

9. Enter the Date for the current analysis.

10. Enter the Building Part Name - a descriptive name to clearly identify which building or building part is being evaluated. The school "building" may be the

entire school if it was built at the same time with the same building type (such as Wood Frame). If so, enter “Whole School.”

However, if a given “building” has more than one part with different structural systems and/or different year built, then each structurally different building part must be evaluated separately.

For example, an elementary school may have a classroom wing and a gymnasium built at different times with different building types. In this case, the classroom wing and the gymnasium may have different levels of seismic vulnerability and the two building parts must be evaluated separately.

In cases where it is unclear whether or not different parts of a building have different structural systems, it may be necessary to review the as-built drawings for the building or to consult with a structural engineer.

11. Enter the building area (total square feet of for the building). For example, if a school building has two stories, each with 10,000 square feet, the building area is 20,000 square feet.

4.2 EPAT Building Data Page

An example EPAT Building Data Page is shown below.

Washington Schools Earthquake Performance Assessment Tool (EPAT)
BUILDING DATA PAGE

Facility Name	ABC Elementary
Building Name	Gymnasium
Building Use	Sports practices and games

Data Entry Item	User Entered Values	Default Values	Used for BCA
Seismic Data			
Decimal Latitude	48.49937	48.5	48.49937
Decimal Longitude	-123.81234	-123.8	-123.81234
Site Class (Soil/Rock Type)		D	D
Liquefaction Potential		Low	Low
Geographic Region for Seismic Zones		Coastal	Coastal
Building Structural Data			
HAZUS Building Type***	W2	Wood, Commercial & Industrial (>5,000 SF)	W2
Number of Stories (Excluding Basement)***	1		1
Year Built***	1980		1980
Code for Building Design (if known)	UBC	**Use the Drop-Down menus to Select Data Entries for the Bright Green Shaded data cells.**	UBC
Design Code Year (if known)	Unknown		Unknown
Severe Vertical Irregularity***	Yes		Yes
Moderate Vertical Irregularity***	No		No
Plan (Horizontal) Irregularity***	Yes		Yes

***** Mandatory data entries**

Figure 3: Example EPAT Building Data Page

Step-By-Step instructions for the data entries on the EPAT Building Data Page are given in this section and in the Quick Start Guide.

Building Data Page: (Light Green Highlighted Cells)

1. Building Use. Optional: enter the use of the building, if desired.

Building Data Page: (Violet Shaded Cells)

2. The latitude and longitude for each campus in the Campus Database are automatically entered into the Default column. If the default values are incorrect, users can enter the correct values from Google Earth or other sources. If the Default Values have less than 5 decimals, it is recommended to replace these with user-values with at 5 decimals.

Building Data Page: (Bright Green Highlighted Cells)

The following data entries are optional – necessary only if the district wishes to revise the default values auto-loaded from the Campus Database.

The entries must be done using the dropdown menus in each cell:

3. Site Class (soil/rock type). Enter user data here to override the default values, 0if the District has site-specific information from a geotechnical evaluation of the soil/rock at this building location.

4. Liquefaction Potential. Enter user data here to override the default values, if the District has site-specific information from a geotechnical evaluation of the liquefaction potential at this building location.

5. Geographic Region for Seismic Zones. The four areas – Coastal, Puget Sound, Extended Puget Sound and Eastern – reflect areas of Washington with different time histories of Seismic Zones under the Uniform Building Code (UBC). See Figure 1 - the map on Page 5.

   For locations very near the UBC Zone boundaries, the most accurate way to determine the Geographic Region is to determine the specific UBC code that a given building was designed from. This can be determined from the design drawings or other design documents prepared by the engineers that designed the building.

The following entry is mandatory and must be done using the dropdown menu in the HAZUS Building Type cell.

6. Select the HAZUS Building Type from the dropdown menu. See the HAZUS abbreviations and the full Building Type names on the right side of this page in the EPAT. Detailed definitions are given in Appendix 1.

Building Data Page: (Orange Highlighted Cells)

These entries are mandatory:

7. Enter the Number of Stories (Excluding Basement) for this building.

8. Enter the Year Built for this building. Year built is used to infer the building code for seismic design to which the building was built. If the specific building code to which the building was built is known, it can be entered later.

Building Data Page: (Bright Green Highlighted Cells)

These entries are optional, but users are encouraged to enter these data when available. These entries must be made using the dropdown menus.

9. Code for Building Design: UBC or IBC. UBC is the Uniform Building Code that was used in Washington until adoption of the IBC in 2005. IBC is the International Building Code, which replaced the UBC.
10. Design Code Year: the edition (year) of the building code used for the seismic design of the building. UBC code years are very three years; for example, 1973, 1976, 1979…up to the last UBC code in 1997. IBC code years are every three years starting with 2000, 2003, 2006…up to the latest code.

    The specific building code (UBC or IBC) and the code year can usually be determined from the building's structural drawings for construction and/or from other design/construction documents.

    For UBC code years 1976 to 1985, the seismic design forces changed very little. The EPAT lumps these code years together as 1976-1985. For buildings designed to these UBC codes, select the 1976-1985 option on the dropdown menu.

The following data entries are mandatory and must be done using the dropdown menus in each cell:

11. Select Severe Vertical Irregularity – Yes/No – from the dropdown menu.

12. Select Moderate Vertical Irregularity – Yes/No – from the dropdown menu.

13. Select Plan (Horizontal) Irregularity – Yes/No – from the dropdown menu.

    Vertical and Plan Irregularities are defined as in FEMA's Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, Third Edition. FEMA P-154. Further guidance about vertical and plan irregularities is provided in the following section.

    The Severe and Moderate Vertical Irregularity designations are either/or – if one is designated as Yes the other must be No. If User's enter Yes for both, the EPAT assumes that the Severe Vertical Irregularity governs. If the irregularity is unknown, the user should choose No as a default.

5.0 Data Definitions and Guidance

Ideally, the key technical data inputs – Geographic Region, HAZUS building type, Year Built (or the Design Code and Code Year) and the designation of severe vertical irregularity, moderate vertical irregularity and plan irregularity – should be determined by an engineer experienced in seismic evaluation of buildings.

However, these data can also be entered by a district employee or other person with a solid knowledge of buildings and of the earthquake engineering terms including HAZUS/ASCE 41-13 building types and the definitions of the vertical and plan irregularities.

The following text defines key technical terms used in the EPAT and provides further guidance to users.

Site Class

Correct identification of the Site Class at a given building location is important for the accuracy of the results. Site Class affects the amplification of earthquake ground motions and thus directly affects the damage estimates. Whenever a site-specific determination of Site Class is available, it should be entered.

Geographic Regions for UBC Seismic Zones

In most cases, the Geographic Regions are auto-loaded from the latitude and longitude of each building. For locations very near the UBC Zone boundaries, the most accurate way to determine the Geographic Region is to determine the specific UBC code two which a given building was designed. This can usually be determined from the design drawings or other design documents prepared by the engineers that designed the building.

- The Puget Sound Region is defined as the area designated as Seismic Zone 3 in the 1970 and later editions of the UBC.
- The Extended Puget Sound Region is defined by the area that went from Seismic Zone 2 to Seismic Zone 3 in the 1988 UBC.
- The Coastal Region is defined by the area that went from Seismic Zone 2B to Seismic Zone 3 in the 1994 UBC.
- The Eastern Washington Region is the area eastward of the regions defined above, with stepwise changes commensurate with the regions above.

HAZUS Building Type

Correct identification of the HAZUS Building Type is <u>essential</u> for obtaining meaningful results from the tool. The HAZUS Building Type definitions are included in Appendix 1 of this document. The building types are based the structural systems that are designed to resist lateral (horizontal) forces from earthquakes.

In determining Building Types, it is essential to distinguish between nonstructural building components and the structural building components that resist seismic forces on the building. For example:

- A building with a brick exterior may be an unreinforced masonry building, but it may also be a reinforced masonry building, a wood frame building, or a building of almost any structural system with a brick veneer.
- A building with wood interior partition walls may be a wood frame building, but it may also have almost any other structural system.

In cases where the HAZUS building type is unclear, it may be necessary to review the as-built drawings for the building or to consult with a structural engineer.

Year Built or Design Code Year

The building code for the seismic design of a building is defined by either:

- The Year Built (completion date of the building) with an allowance for the time lag between Building Code edition date and when the Code as used, or
- By entering the Building Code Year on the Building Page of the Tool. Whenever possible, entering the Building Code Year based on review of construction drawings or documents is strongly encouraged. Review of the construction drawings or documents is best done by an engineer.

Vertical and Plan Irregularities

Buildings with significant vertical or plan (horizontal) irregularities generally have higher levels of damage in earthquakes than otherwise similar buildings without such irregularities. Correct designation of these irregularities per FEMA's Rapid Visual Screening (3rd Edition or the ASCE 41-13 Seismic Evaluation and Retrofit of Existing Buildings definitions is important for accurate results.

Determination of whether a building has Severe or Moderate Vertical Irregularities and/or Plan (Horizontal) irregularities is best done by an engineer or a person thoroughly familiar with the ASCE or FEMA definitions of irregularities. However, this determination can also be made by a non-engineer who is familiar with these definitions of building irregularities.

Vertical Irregularities include:

- Stories setback from or overhanging other stories,
- Stories with different heights,
- Stories with larger window openings than other stories,
- Stories with large garage openings, and
- Buildings on sloping sites.

See Figure 4.

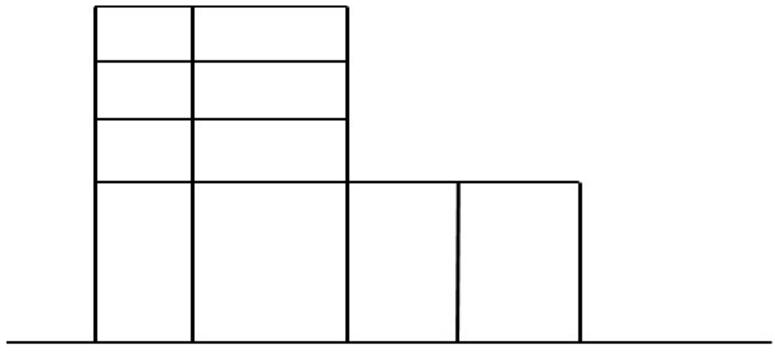

Figure 4: Vertical Irregularity (building elevation view shown)

Horizontal Irregularities include buildings that are not square or rectangular in plan view or buildings that contain large openings in the center of the building. Figures 5 and 6 show these irregularities and include:

- Buildings with wings such as T-shapes or L-shapes,
- Buildings with re-entrant corners, and
- Buildings with large diaphragm openings, such as an open area in the center of a building.

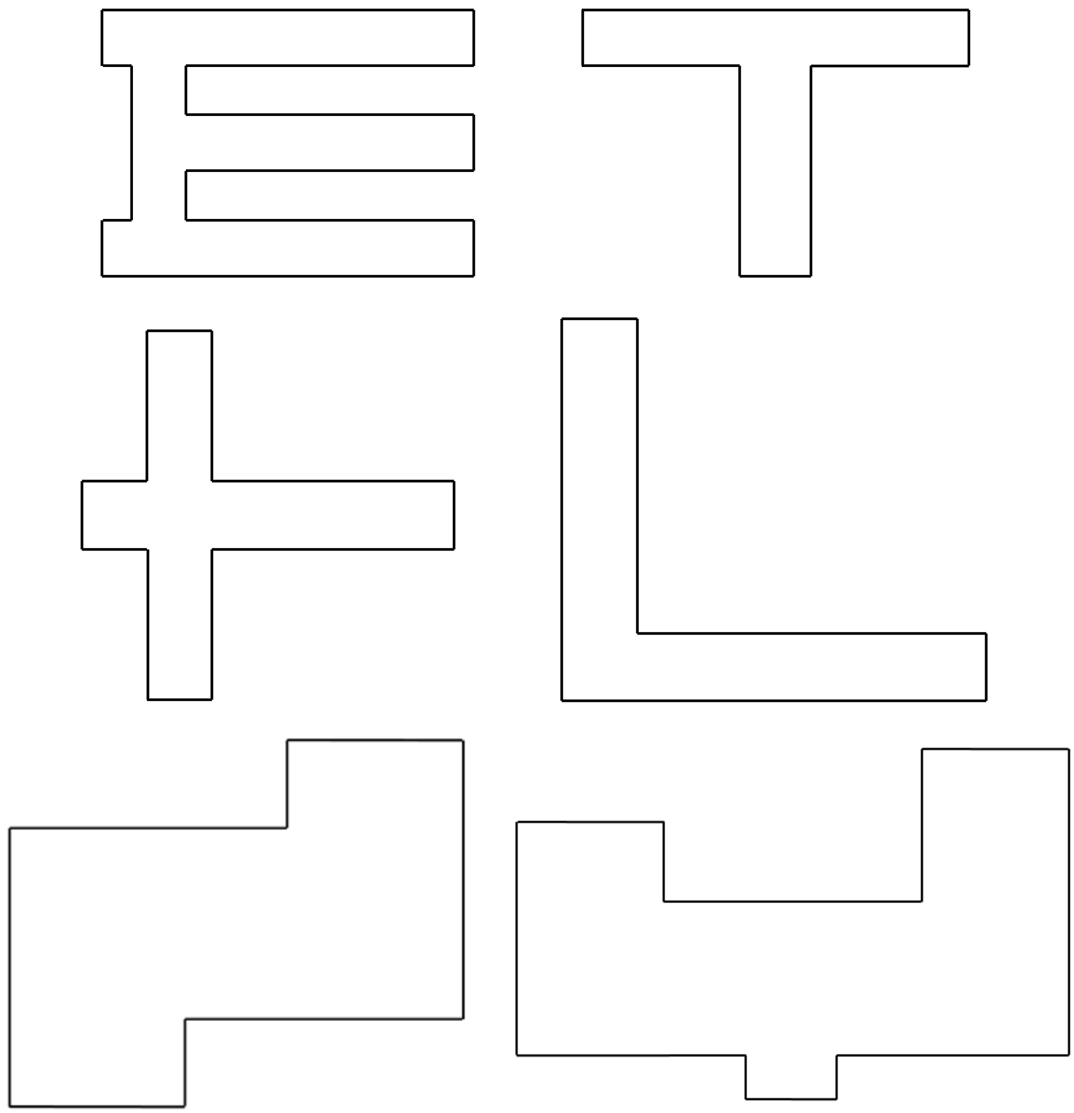

Figure 5: Plan (Horizontal) irregularities showing re-entrant corners

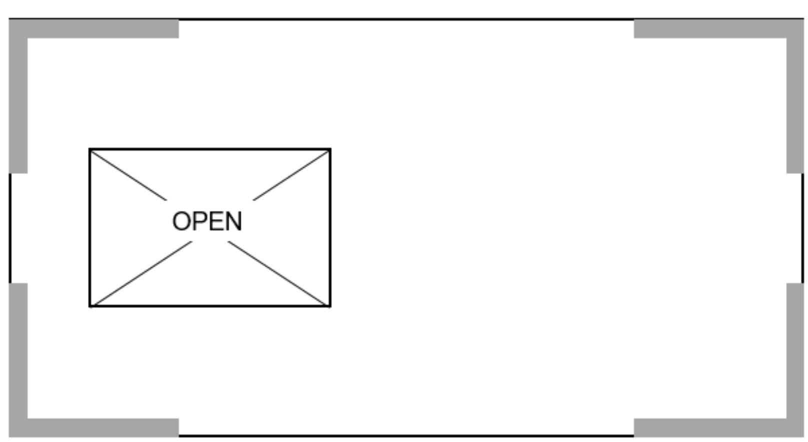

Figure 6: Plan (Horizontal) Large Opening in Diaphragm

6.0 EPAT Results

The results of an EPAT analysis of a school building are presented in two tables:

- A **Results Summary Table** to help users understand and interpret the results from EPAT and to support decision making regarding which buildings on a given campus or in a district overall likely pose the greatest risks in future earthquakes. This report is meant to communicate the results to non-technical individuals.
- A **Technical Results Table** with more detailed, quantitative results that is intended primarily for earthquake engineers.

The Results Summary Table for a hypothetical building for the ABC School District are shown in Figures 7 and 8. These results are shown and discussed to help users understand and interpret the results from the EPAT.

6.1 Results Summary Table: For School Districts and Engineers

The Results Summary Table contains two types of information:

- Documentation of the data inputs that identify the building evaluated and the key data inputs that govern the risk assessment results, and
- Quantitative and qualitative results that document the level of risk and help Districts identify which buildings pose the greatest seismic risk.

The white cells in the Results Summary Table contain documentation which building is evaluated and the input data for this building, including:

- Identification of the District, School, and Building,
- Building data that determine the level of risk, and
- Earthquake hazard data that govern the probability and severity of ground shaking in future earthquakes.

The yellow cells in the Results Summary Table contain the risk assessments results, including:

- A qualitative ranking of the level of life safety risk and the priority for retrofit or replacement for the existing building from low to very high.
- Results for three conditions – existing building, after retrofit building, and a new, current-code building – for a design-level earthquake (the level of earthquake ground motion that current-code buildings are designed for):
    - Building damages as a percentage of building replacement value,
    - Probability that the building would be demolished,
    - Level of life safety risk, and
    - Expected post-earthquake tagging level (green, yellow, red).

1. School and building name information
2. Summary of data input from "Building Data" worksheet
3. Summary of seismic data (hazard) and soil type
4. Summary of projected building damage in a design-level earthquake (what engineers would design a new building for)
5. Summary of who entered the data to the tool, where the data came from, and any user overrides implemented.
6. Risk level of school building (low, moderate, high, very high)
7. Life safety risk levels and expected post-earthquake building tagging

Washington Schools Earthquake Performance Assessment Tool (EPAT) RESULTS SUMMARY				
District Name	ABC Example		Existing Building Life Safety Risk & Priority for Retrofit or Replacement	
School Name	ABC Elementary			
Building Name	Gymasium		Very High	
Building Data				
HAZUS Building Type	URM	Unreinforced Masonry Bearing Walls		
Year Built	1950	These parameters determine the capacity of the existing building to withstand earthquake forces.		
Building Design Code	<1973 UBC			
Existing Building Code Level	Pre			
Geographic Area	Coastal			
Severe Vertical Irregularity	No	Buildings with irregularities have greater earthquake damage than otherwise similar buildings that are regular.		
Moderate Vertical Irregularity	No			
Plan Irregularity	No			
Seismic Data				
Earthquake Ground Shaking Hazard Level		Very High	Frequency and severity of earthquakes at this site	
Percentile S_s Among WA K-12 Campuses		94%	Earthquake ground shaking hazard is higher than 94% of WA campuses.	
Site Class (Soil or Rock Type)		E	Soft Clay Soil	
Liquefaction Potential		Low	Liquefaction increases the risk of major damage to a building	
Combined Earthquake Hazard Level		Very High	Earthquake ground shaking and liquefaction potential	
Severe Earthquake Event (Design Basis Earthquake Ground Motion)[1]				
Building State	Building Damage Estimate[2]	Probability Building is not Repairable[3]	Life Safety[4] Risk Level	Expected Post-Earthquake Tagging[5]
Existing Building	84%	83%	Very High	Red
Life Safety Retrofit Building	25%	17%	Low	Green/Yellow
Current Code Building	21%	12%	Very Low	Green/Yellow
1. 2/3rds of the 2% in 50 year ground motion		4. Based on probability of Complete Damage State.		
2. Percentage of building replacement value.		5. Most likely post-earthquake damage state per ATC-20.		
3. Probability building is in the Extensive or Complete damage states. For existing buildings, the probability that the building is not economically repairable may be higher: some buildings in the Moderate Damage state are also likely to be demolished.				
Source for the Data Entered into the Tool				
Building Evaluated By:	Abigal Washington, XYZ Engineering			
Person(s) Who Entered Data in EPAT:	Arthur Jefferson, ABC School District			
User Overrides of Default Parameters:	Existing Building Fragility Data, Site Class			

Figure 7: Example EPAT Results Summary Annotated

Figure 6 shows an example of the “Summary Report Table. This summary table contains seven sections:

1. District name, campus name and building name. If the entire school was built at one time, with each part being the same building type, the building name should be identified as “whole school.” If different parts of the school were built at different times and/or with different building types, the building part being evaluated needs to be specified. For example: 1938 original school, 1972 addition, gymnasium, etc.

2. Building data. This is a summary of the building data inputs entered on the “Building Data” page of EPAT.

3. Seismic data. This section contains a summary of the seismic data:

- The seismic hazard level at the building is rated from low to very high
- The earthquake ground shaking hazard level at the building relative to the seismic hazard level at all K-12 schools in Washington State is expressed as a percentile. For example, the 46% percentile means that the seismic ground shaking level is higher than that at 46% of the campuses. The ground shaking percentile is based on the short-period spectral acceleration (S_s) which is the type of ground motion used by engineers to design buildings.
- Site Class is the soil/rock type at the building location. Softer soils typically amplify earthquake ground motions. Thus, a building on a soft soil site is likely to have more damage than an identical building on a stiff (firm) soil site.
- Liquefaction means the soil loses bearing strength during earthquake ground shaking, with settlement or lateral spreading and increased damages.
- The combined earthquake hazard level combines ground shaking and liquefaction potential hazard on a qualitative scale of low to very high.

4. Severe earthquake event. This section summarizes the estimated building damage and post-earthquake operability after a design-level earthquake. The design-level earthquake is an earthquake that structural engineers would use to design a new building at this site. In technical terms, this is the level of earthquake ground motion that is 2/3rds of the ground motion with a 2% chance of being exceeded in a 50-year time period. For example, if the earthquake ground motion with a 2% chance of being exceeded in 50 years is 0.66 g (the acceleration of gravity), then 2/3rds of this is 0.44 g. A new building would be designed to the seismic forces corresponding to 0.44 g earthquake ground shaking, with the assumption that the margin of safety built into seismic design codes would prevent collapse up to at least 0.66 g.

- Three building states are considered: the existing building, after a life-safety retrofit, and a new current seismic code building.
- For each building state, the building damage is expressed as a percentage of building replacement value. If a building has a replacement value of $5 million and the damage percentage is 10% the repair costs are estimated to be $500,000.

- For each building state, the probability that the building is not repairable after a design-level earthquake is estimated. The EPAT defines this probability as the sum of the probabilities that the building is in the extensive or complete damage state.

5. Source for the data entered into the EPAT. This section documents the person(s) and their affiliation(s) who evaluated the building to determine the building data inputs and the person(s) and their affiliation(s) that entered data into the EPAT.

6. Life Safety Risk and Priority for Further Evaluation, Retrofit or Replacement. These results are for the existing building and classify the level of life safety and priority for further evaluation, retrofit or replacement on a qualitative scale ranging from low to very high. Simply put, the buildings with the highest risk ratings high or very high) are likely to be the buildings in a district with the highest risk. For example, if a district completes the EPAT for ten buildings and three buildings have ratings of high or very high and the others have lower ratings, then these three buildings are identified as the highest priorities for further evaluations, retrofits, or replacement.

7. Life Safety Risk Level and Post-Earthquake Tagging Level. Life Safety Risk level and the Expected Post-Earthquake Tagging level are shown for all three building states: the existing building, after a life-safety retrofit and a new current code building to replace the existing building

- The EPAT defines the Life Safety Risk Level quantitatively as the probability that the building is in the complete damage state because the likelihood of major injuries or deaths is substantially lower in the lower damage states (extensive, moderate or slight).
- The expected Post-Earthquake Tagging level is shown for all three categories of buildings. Post-earthquake tagging is a standard way of inspecting buildings with visible damage after an earthquake to determine whether a building is safe to enter. The standard method is as defined by the ATC-20-1 Field Manual: Post Earthquake Safety Evaluation of Building (Applied Technology Council, 2005). There are three levels of tagging – placards that are posted on a building after inspection:
    - Green Tag – building is safe to occupy,
    - Yellow Tag – building is safe enough for very brief visits to remove critical documents or equipment, but not to occupy without further evaluation and/or temporary repairs, and
    - Red Tag – building is unsafe to enter even briefly.

  After an earthquake:

    - Green Tag buildings are very likely repairable at relatively low cost,
    - Yellow Tag buildings are likely repairable, although some may be demolished, especially those that have high repair costs, are functionally obsolete, in poor condition, have poor energy efficiency,

have widespread asbestos or are in districts with declining enrollments.

- o Red Tag buildings will necessarily be demolished.

6.2 Technical Results Table (Intended Primarily for Engineers)

The Technical Results Table shown in Figure 8 documents the data and estimates used to quantify the expected building damage levels for four specified levels of earthquake ground shaking for three states of each building: 1) the existing building, 2) the building after a life safety retrofit, and 3) a new current seismic code building.

6.2.1 Seismic Fragility Data Inputs

The Seismic Fragility Data for existing buildings are derived from the HAZUS PGA-based seismic fragility estimates for pre-code, low-code, moderate-code and high-code buildings. However, the EPAT seismic fragility data are adjusted to reflect the specific time-history of seismic design forces in various regions of Washington State, including interpolations between the raw HAZUS data and adjustments to reflect Severe Vertical Irregularities, Moderate Vertical Irregularities and Plan irregularities. Each HAZUS building type has different sets of fragility curves.

The fragility parameters define lognormal probability distributions that a building is in each of the four HAZUS damage states (slight, moderate, extensive and complete). The values for each damage state are the median PGAs for each damage state. For example, the 0.11 (PGA) value for the Existing Building slight damage state means there is a 50% chance that the building will be in the “slight” damage state or higher at this level of earthquake ground shaking. The “beta” value is a lognormal dispersion parameter analogous to the standard deviation in a normal distribution.

For buildings where the auto-generated fragility data are not appropriate for a given building, users may enter building-specific fragility data in the User-Entered column. This may be necessary when a building has unusual or mixed structural systems and/or when a building has undergone a previous partial seismic retrofit. In such cases, the auto-generated fragility parameters would not accurately reflect the seismic vulnerability of the building.

Washington Schools Earthquake Performance Assessment Tool (EPAT)
TECHNICAL DATA FOR ENGINEERS

Facility Name	ABC Elementary
Building Name	Gymnasium
Building Use	Sports practices and games

Data Entry Item	User Entered Values	Default Values	Used for Calculations
Seismic Fragility Data			
Existing Building			
Slight Damage State		0.20	0.20
Moderate Damage State		0.42	0.42
Extensive Damage State		0.86	0.86
Complete Damage State		1.56	1.56
Beta		0.66	0.66
Life Safety Retrofit Building			
Slight Damage State		0.23	0.23
Moderate Damage State		0.50	0.50
Extensive Damage State		1.04	1.04
Complete Damage State		1.87	1.87
Beta		0.62	0.62
Damage State Percentages			
Slight Damage State		5%	5%
Moderate Damage State		20%	20%
Extensive Damage State		90%	90%
Complete Damage State		100%	100%

Damage State Probabilities and Loss Ratios			
20% in 50 Year Ground Motion			
Building Damage State	Existing Building	Life Safety Retrofit	Current Code
Slight	42.48%	39.96%	36.68%
Moderate	17.10%	10.57%	7.38%
Extensive	2.38%	0.86%	0.43%
Complete	0.23%	0.05%	0.02%
Loss Ratio	**7.91%**	**4.93%**	**3.71%**
10% in 50 Year Ground Motion			
Building Damage State	Existing Building	Life Safety Retrofit	Current Code
Slight	42.97%	46.32%	46.57%
Moderate	28.53%	21.54%	17.10%
Extensive	6.38%	3.02%	1.78%
Complete	0.94%	0.26%	0.11%
Loss Ratio	**14.53%**	**9.60%**	**7.46%**
2/3rds of 2% in 50 Year Ground Motion			
Building Damage State	Existing Building	Life Safety Retrofit	Current Code
Slight	39.94%	45.62%	47.73%
Moderate	33.88%	27.94%	23.49%
Extensive	9.53%	5.10%	3.24%
Complete	1.74%	0.55%	0.26%
Loss Ratio	**19.10%**	**13.02%**	**10.25%**
2% in 50 Year Ground Motion			
Building Damage State	Existing Building	Life Safety Retrofit	Current Code
Slight	26.22%	33.78%	38.52%
Moderate	41.38%	41.50%	39.71%
Extensive	20.77%	14.65%	11.10%
Complete	6.74%	2.96%	1.68%
Loss Ratio	**35.02%**	**26.14%**	**21.54%**

Figure 8 Example EPAT Technical Data for Engineers

6.2.2 Building Damage Estimates for Various Levels of Earthquake Ground Shaking

The damage estimates shown in Figure 8 are necessarily probabilistic because it is not possible to predict the exact extent of building damage to a given building for any specific earthquake.

Building damage estimates shown in the EPAT do not include contents. The extent of contents damage depend on the level of building damage, the types of contents, and the extent to which contents are braced or restrained to minimize damage in earthquake.

The Damage State Probabilities and Loss Ratios section of the Technical Data for Engineers Page includes the probabilities of the building being in each of the four HAZUS damage states and the loss ratio for:

- Three states of the building (existing building, building after life safety retrofit, and a new current code building),
- Four levels of earthquake ground shaking.

The four HAZUS damage states (slight, moderate, extensive, and complete) are as defined by HAZUS for each building type. The HAZUS building types and the definitions of the four damage states for each of the building types are given in the two appendices to this User Guide:

- Appendix 1: HAZUS Building Types, and
- Appendix 2: HAZUS Building Damage States.

The Loss Ratio is the expected building damage (structural and nonstructural) estimate expressed as a percentage of the replacement value of a building. The replacement value of a building is the cost to build a new, current-code building of the same size, functionality and level of amenity as the existing building. For example, if the replacement value of a building is $10,000,000 and the estimated loss ratio for a given level of earthquake ground shaking is 30%, the estimated repair cost after this earthquake is $3,000,000.

Building damages in earthquakes are frequently expressed as a loss ratio because the higher the loss ratio, the more likely it is that a building will be demolished after the earthquake, rather than being repaired. The loss ratios are shown with two decimal places for the sole purposed of avoiding “zero” values, which might be misinterpreted as the building being “earthquake proof” which is never true.

The Loss Ratios for all states of a building increase with the severity of the earthquake, with the lowest loss ratios for the earthquake ground motion with a 20% chance of being exceeded in a 50 year time period and the highest loss ratio for the earthquake ground motion with a 2% chance of being exceeded in a 50 year time period.

The loss ratios shown in Figure 8 depend on the fragility parameters which determine the probabilities of being in each of the four damage states and on the damage levels as a percentage of the replacement value of the building estimated for each of the damage states. The damage state percentages assume that nearly all buildings in the extensive damage state will be demolished rather than repaired, and that a small percentage of the buildings in the moderate damage state will also be demolished. To the extent that these estimate underestimate the percentages of buildings that will be demolished, the actual loss ratios may be somewhat higher than estimated.

For every earthquake, the expected damage level is highest for the existing building and lowest for a new, current code building. The expected damage levels for the life safety retrofit are between those for the existing building and the new, current code building, but much closer to those for the new, current code building.

A seismic retrofit to the Immediate Occupancy performance objective would be even closer to the new, current code building. A new, current code building designed to the Immediate Occupancy performance objective would have even lower damages in each earthquake.

To help non-technical readers understand the probabilistic earthquake ground motions used in Figure 8, these earthquake ground motions are described in more qualitative terms.

The columns under the Damage State Probabilities and Loss Ratios headers show the expected damage levels for four levels of ground shaking:

- 20% chance of occurring in 50 years – a moderately large earthquake
- 10% chance of occurring in 50 years – a large earthquake. This level of ground motion was used the seismic design under the Uniform Building Code.
- 2/3rds of the ground shaking with a 2% chance of occurring in 50 years. This level is used for the seismic design under the International Building Code. This level of ground shaking is generally similar to the 10% in 50 year ground motion used under the Uniform Building Code. However, in some in some locations in Washington there are significant differences between the UBC and IBC earthquake ground motions for seismic design.
- 2% chance of occurring in 50 years. This level of ground motion may be interpreted as approximately the “worst case” scenario – the most damaging earthquake. On the Washington Coast this would represent a M9 earthquake on the Cascadia Subduction Zone, while in the Seattle area this would represent a M7 earthquake on the Seattle Fault. In eastern WA this would represent a relatively large magnitude earthquake near a given school.

Buildings that are in the “slight” or “moderate” damage state are likely to receive a “Green Tag” or a “Yellow Tag” after the specified earthquake event occurs. Most buildings in these damage states, but not all, are likely to be repaired after an earthquake. Some buildings in the “moderate” damage state may be demolished.

Buildings in the “extensive” damage state are expected to have a “Red Tag” after the specified earthquake event occurs. Buildings in the “extensive” damage state may be repairable from an engineering perspective, but are almost certain to not be repairable from a pragmatic economic perspective. The repairs costs will be a high fraction of the cost of replacement with a new, current-code building, especially if a building contains asbestos. The cost of repair plus seismic retrofit may be comparable to or exceed the cost of replacement with a new current-code building. Furthermore, older buildings also have other issues, including deferred maintenance, poor energy efficiency, obsolete functionality vis-à-vis modern school design and other shortcomings.

Buildings that are in the “complete” damage state will receive a “Red Tag” after the specified earthquake event occurs. Buildings in this damage date will necessarily be demolished, rather than repaired.

7.0 Interpreting Results

The results for each building and the relative results between buildings provide important information to school districts:

1. Buildings with the highest Loss Ratios have the greatest seismic vulnerability. This means that they are expected to have the highest damage levels and the highest life safety risk in future earthquakes, as well as the longest downtime for post-earthquake repairs and the highest likelihood that the buildings are not repairable.
2. Buildings with the highest probabilities of the "complete" damage state are estimated to have highest life safety risk. The level of life safety risk is predominantly determined by the likelihood that a given building is in the complete damage state, because the majority of deaths and injuries in future earthquakes will likely occur in buildings in the complete damage state as this damage level means that the building is on the brink of collapse or may be partially or fully collapsed.
3. For a given level of earthquake ground shaking, the probabilities of the slight, moderate, extensive and complete damage stage are generally correlated with the expected post-earthquake "tagging" per ATC-20 Building Safety Evaluation Forms and Placards, which is the widely used method for evaluating the safety of earthquake damaged buildings. From these correlations, those buildings with the highest probabilities of the "complete" and "extensive" damage states are buildings that have the highest probability of being red-tagged after an earthquake. This means the building will be closed until repairs and re-inspection can occur.
    a. Slight: Green Tag, building safe to occupy,
    b. Moderate: Yellow Tag, building probably safe to occupy after evaluation,
    c. Extensive: Red Tag: building may or may not be safe to occupy after evaluation,
    d. Complete: Red Tag, building unsafe to occupy, even temporarily and will be demolished.
4. Buildings with the highest expected Loss Ratios <u>may</u> be the highest priorities for seismic retrofit, but there are important caveats as noted below.

Buildings with high expected loss ratios will likely have high retrofit costs, in many cases a substantial fraction of or more than the cost of replacing the buildings with new, current code buildings. In this case, replacement with a new current code building may be the preferred alternative, especially for buildings that are:

- Located on sites with moderate or high liquefaction potential which is likely to increase damage levels of damage,

- Functionally obsolete and/or in poor condition with significant non-seismic deficiencies and/or are likely to be closed in a relatively few years, or
- Unreinforced masonry or other non-ductile building types as listed previously.

8.0 Next Steps

The Washington School EPAT can be used to evaluate the seismic vulnerability of buildings selected by a district. The results from the tool provide data to support decision-making regarding which buildings are the highest priorities for retrofit or replacement.

For example, if a district screens eight or ten buildings, one or two or three buildings may stand out as the clear priorities for retrofits or replacement. Decisions about which buildings are the "finalists" for retrofit are best made with inputs from a structural engineer experienced with seismic evaluations and retrofits.

For the highest priority buildings for retrofits, the next steps are:

1. Complete ASCE 41-13 Tier 1 evaluations, if not already completed, to identify the specific structural and nonstructural building components that require retrofitting. These checklists will quantifiably tell a district whether a building meets the Life Safety performance objective.
2. Develop retrofit concepts and preliminary cost estimates.
3. Make a decision about which building is the highest priority
4. Make a decision whether seismic retrofit or replacement with a new current-code building is the best choice for the district.
5. Complete the seismic retrofit or replacement for the highest priority building, as funding becomes available from district resources or grants.
6. Continue this process over time and retrofit or replace additional buildings, as funding becomes available.

As a district is evaluating existing buildings for retrofit or replacement or considering building new schools, a district is encouraged to evaluate the possibility of designing retrofits or new buildings to a higher earthquake performance objective than the code-minimum life-safety performance objective.

Buildings being retrofitted to and new buildings designed to the immediate occupancy performance objective will perform better in future earthquakes than buildings retrofitted to the minimum life-safety standard. Better performance means less damage, shorter repair times, and lower life safety risks. In many cases, the incremental cost will be low to retrofit an existing building or design a new building to the immediate occupancy performance objective.