Estimated Number and Location of Unreinforced Masonry (URM) School Buildings in the Northeast US and Potential Seismic Mitigation Opportunities

Harvard Hall Located on the Campus of Harvard University is a (URM) Building Built in 1766

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A.) <u>Background</u>

The development and implementation of effective earthquake hazard mitigation strategies and plans requires information about building vulnerability and potential losses, which are directly related to the type of building construction.

Not all buildings perform well during an earthquake. There is an abundance of consistent and conclusive evidence from past earthquakes that Unreinforced Masonry Buildings (URM's) do not perform well and result in the potential for increased loss of life, injuries and damage.

For example, the May 12, 2011 earthquakes in Lorca Spain were only of magnitude 4.4 and 5.1, yet there was incredible damage to URM buildings, significant injuries and 10 deaths. (See Figure 1)

Figure 1. Damage to Unreinforced Masonry (URM) Buildings in Spain

The probability of this magnitude earthquake (4.4 - 5.0) striking somewhere in the Northeast is approximately once every 50 years. This raises concern that older URM buildings in the Northeast, many of which are schools, could be susceptible to the same level of damage experienced in Spain.

This concern is justified due to the fact that our URM buildings were constructed as far back as the 1700's prior to modern building and seismic codes. Older sections of downtown areas in many Northeast cities, as well as across the country, contain numerous historic red brick buildings that are being used as businesses and homes. Many serve as historic landmarks. Moreover, some of these vulnerable structures are elementary and secondary schools as well as colleges and universities, which is the driving force and reason for this analysis.

In prior studies, NESEC used the building count inventories available in FEMA's Hazus Software to estimate the number and location of URM buildings in the Northeast. We did this in order to establish a baseline from which progress to mitigate these hazardous buildings could be measured.

This analysis builds upon that earlier work by using Hazus, and its new and updated Homeland Infrastructure Foundation-Level Data (HIFLD) default inventory of public schools, to more accurately estimate the number and location of URM schools. A 2500 year probabilistic earthquake ground shaking scenario was run against this inventory of schools to quantify potential post-earthquake damage and functionality, as well as and possible mitigation opportunities. Specifically, mitigation opportunities that have the potential to reduce losses and increase functionality if existing URM school buildings were upgraded to Reinforced Masonry or Steel Frame Construction.

B.) Objectives

The objectives of this analysis were as follows:

1.) Identify and analyze public schools in the NESEC States (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont) using updated Hazus HIFLD default data using a 2500-year probabilistic earthquake scenario.
2.) Using a What-If Strategy, upgrade the construction type of Unreinforced Masonry (URM) Buildings to Reinforced Masonry, rerun the Hazus analysis and compare the results.
3.) Using a What-If Strategy upgrade the construction type from Reinforced Masonry to Steel Frame, rerun the Hazus analysis again and compare the results.
4.) Develop a report that contains maps, tables and narrative text to explain the purpose, methods and results.
5.) Develop an approach, methodologies and mapping techniques easily transferrable for use in other states and communities or regions that have URM schools in their Hazus default database.
6.) Identify possible mitigation opportunities.

C.) Methods and Results

For this analysis, the count and spatial distribution or Unreinforced Masonry (URM) School Buildings was identified for the eight NESEC states utilizing Federal Emergency Management Agency (FEMA) Hazus Software. Hazus is a nationally recognized, standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. Hazus uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. FEMA developed Hazus under contract with the National Institute of Building Sciences (NIBS). The version used for this analysis was Hazus 4.2 Service Pack 3 (SP3).

This analysis was accomplished by creating a new earthquake region for each NESEC state using Hazus. (See Hazus User Manual for detailed instructions on how to create a new region). A basic Level 1 Default analysis was conducted which can be used for generalized comparisons and preliminary evaluations to assess potential mitigation opportunities. Each state was run individually due to Hazus study region size limitations that did not allow all eight NESEC states to be run as a single region.

The school layers from each individual state were mapped, saved and combined to create a multi-state database of schools. This involved creating a map for each individual state, mapping the school inventory and saving it as a file layer. Next, each state's school layer was brought into a base map that included all of the states. Each state was an individual layer on the map and by standardizing the display elements for each, the layers appear uniform.

This process results in a map of the 18,855 school buildings located in the study region (See Figure 2). We then prepared a map that illustrates the density of schools across the region (See Figure 3). See Table 1 for a breakdown of the estimated number of school buildings by state.

School Buildings in the NESEC States

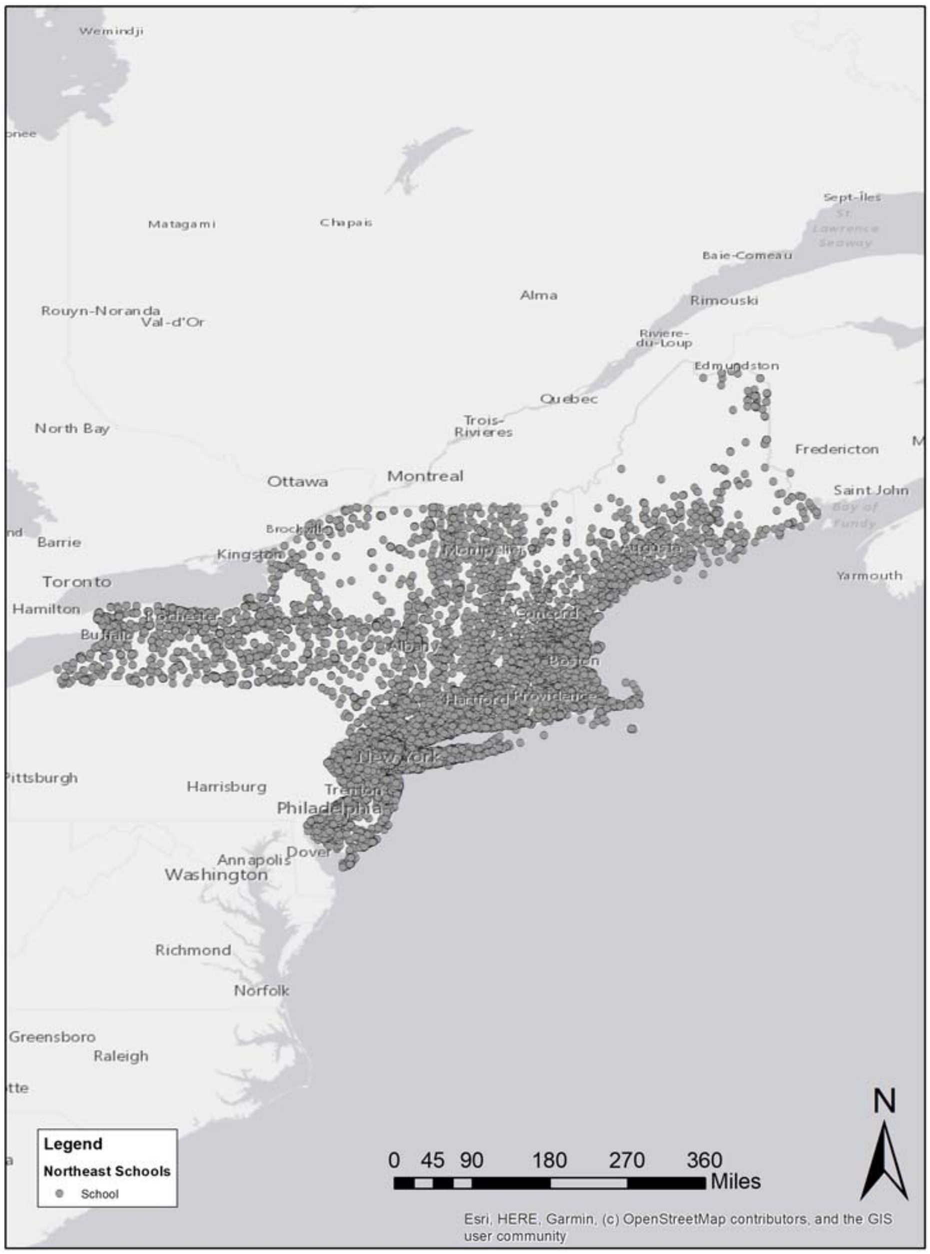

Figure 2. Hazus Map Noting the Number and Location of the 18,855 School Buildings in the NESEC States

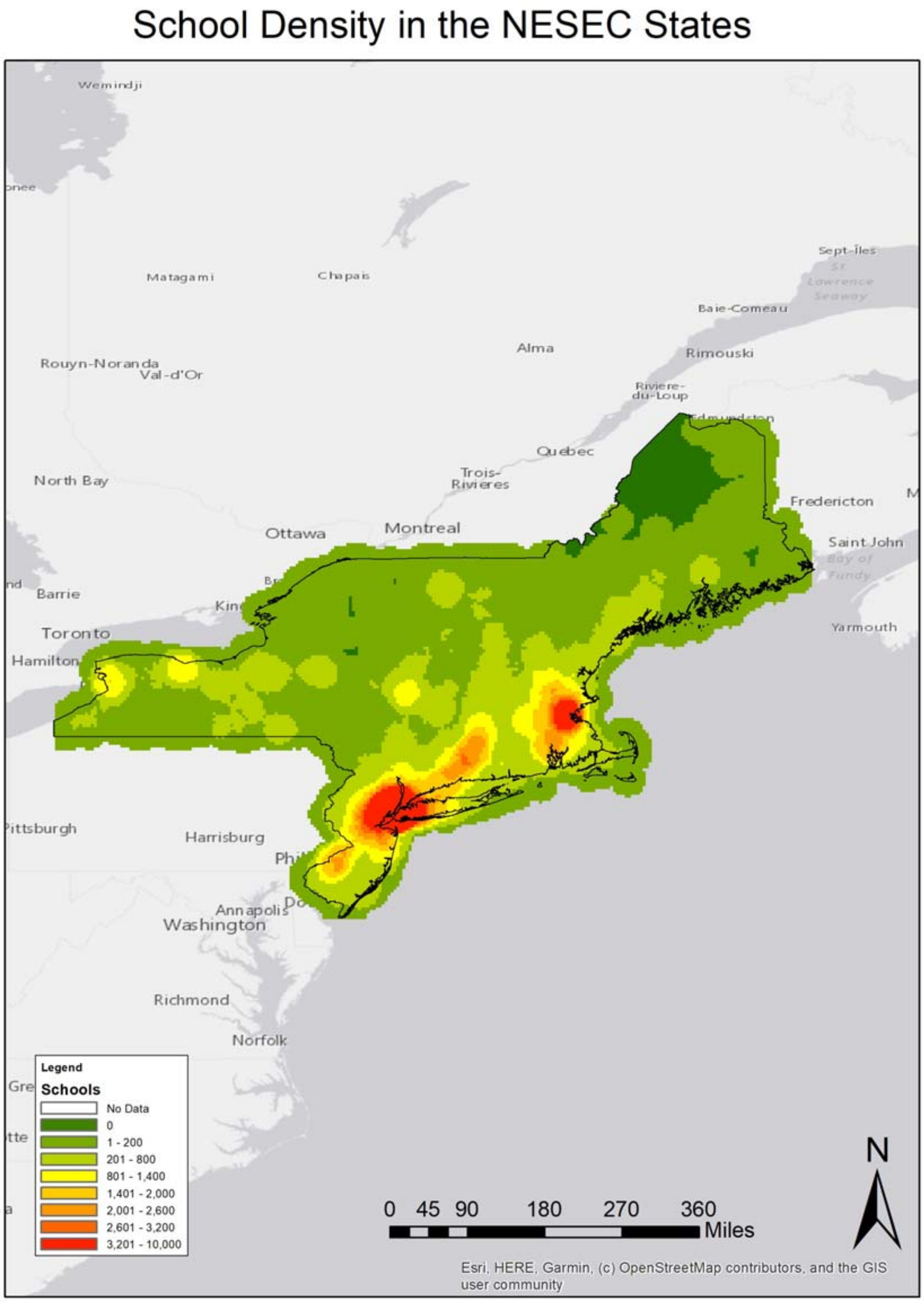

Figure 3. Hazus Map Noting the Density of the 18,855 School Buildings in the Northeast

State	Hazus Estimated Number of Schools	Hazus Estimated Number of Unreinforced Masonry (URM) Schools
Rhode Island	490	108
Vermont	477	105
New Hampshire	833	183
New Jersey	4077	897
New York	7389	1626
Massachusetts	2869	631
Maine	833	183
Connecticut	1887	415
TOTAL	**18855**	**4148**

Table 1. Estimated Number of Schools and URM Schools by State

The Hazus 4.2 Service Pack 3 release, used in this analysis, includes state database updates, defect fixes, and major functionality enhancements. The Hazus default state databases have been updated using the latest Homeland Infrastructure Foundation Level Data (HIFLD) Datasets. The Essential Facility Features updated include Care Facilities, Emergency Operations Centers, Police Stations, Fire Stations, and Schools. Hazus school data includes Primary, Secondary Schools (K-12), Community and State Colleges, State and Private Universities.

This data represents a significant improvement to the schools databases in the NESEC States. It is important to emphasize that while the basic school data has been updated, the default databases assume that all school buildings in the Northeast US are Unreinforced Masonry Buildings (URM's). The assumption is that Hazus, when run in the default mode, assigns the most predominant building type for schools, which is URM.

That assumption is acceptable for this analysis as all schools will be analyzed and compared as a group. As long as the building types are consistent for each of the analyses the results will not be adversely affected.

However, developing a more accurate assessment of the estimated number of URM school buildings is important to this analysis when evaluating the scope of any potential mitigation activities. To develop this estimate we used the pre-determined Hazus estimated distribution of floor area based on occupancy and model building types (See Table 2).

Specific Occupancy Class	Model Building Type														
	1	**2**	**3**	**6**	**9**	**10**	**13**	**16**	**19**	**22**	**25**	**26**	**29**	**31**	**34**
	W1	W2	S1L	S2L	S3	S4L	S5L	C1L	C2L	C3L	PC1	PC2L	RM1L	RM2L	URML
EFHS		24	10	7	15		8	3	2		3		4	4	20
EFHM		2	22	15			18	10	4	2	5	4	3	2	13
EFHL		2	22	15			18	10	4	2	5	4	3	2	13
EFMC		24	10	7	15		8	3	2		3		4	4	20
EFFS		8	16	11	4		13	8	3	2	4	3	4	5	19
EFPS		8	16	11	4		13	8	3	2	4	3	4	5	19
EFEO		8	16	11	4		13	8	3	2	4	3	4	5	19
EFS1		13	17	13			13	5	3			2	5	5	22
EFS2		4	18	13			14	8	3	2	4	3	5	4	22

Table 2. Distribution Percentage of Floor Area for Model Building Types within Each Building Occupancy Class, East Coast

As Table 2 indicates, occupancy class EFS1 (Elementary and Secondary Schools) and ESF2 (Colleges and Universities) have the highest percentage of URM buildings set at 22%. This differs significantly from the HAZUS assumption that all schools are presumed to be URM's. While we know that not all school buildings in the Northeast are URM's, that assumption by Hazus does not affect the analysis we conducted or the results. However, we felt it was important to develop a preliminary estimate the number of school buildings that are URM's in each of the NESEC States and across the region. We calculated those estimates using the Hazus distribution of floor area for URM school buildings for the US East Coast and the URM estimated building count for by state. Hazus assumes that 22% of all schools and colleges in the Northeast are URM's. That estimate is reasonable and the estimated count of URM school buildings by state is included in Table 3.

The 18,855 school buildings were mapped using Geographic Information Systems (GIS) technology to determine their relative earthquake hazard risk in the NESEC multi-state region. We then calculated the Hazus estimated Probability of Functionality assuming all schools were URM's. The results are contained in Table 4 and Figure 4.

State	Average Functionality (%)
Connecticut	75
Maine	65
Massachusetts	70
New Jersey	71
New York	74
Rhode Island	74
Vermont	71
New Hampshire	66

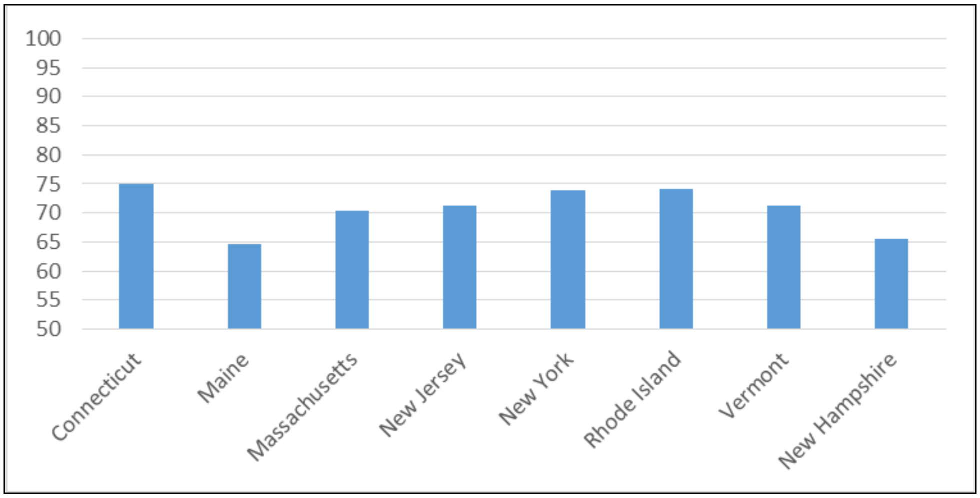

Figure 4. Estimated Probability of Functionality URM's

We then assumed, for mitigation purposes, that all schools were upgraded to the reinforced masonry category (RM1L), updated the inventory and re-ran the Hazus analysis. This provided us with comparable information on probability of functionality to help determine how mitigating these schools up one level in building type might affect their post-earthquake functionality. The results are contained in Table 5 and Figure 5.

State	Average Functionality (%)
Connecticut	87
Maine	77
Massachusetts	82
New Jersey	83
New York	85
Rhode Island	74
Vermont	84
New Hampshire	78

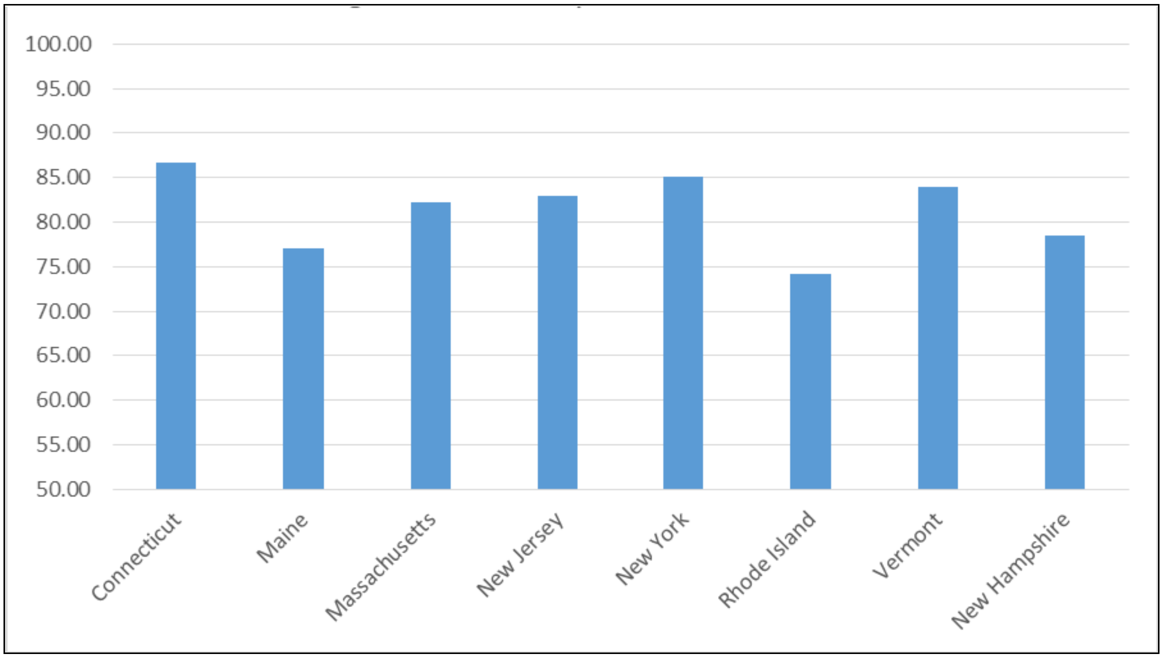

Figure 5. Estimated Probability of Functionality RM1L

Once this was complete, we similarly upgraded them two levels to steel frame buildings (S1L) to estimate the potential impact on post-earthquake functionality. The results are contained in Table 7 and Figure 6.

State	Average Functionality (%)
Connecticut	90
Maine	81
Massachusetts	84
New Jersey	86
New York	87
Rhode Island	90
Vermont	89
New Hampshire	85

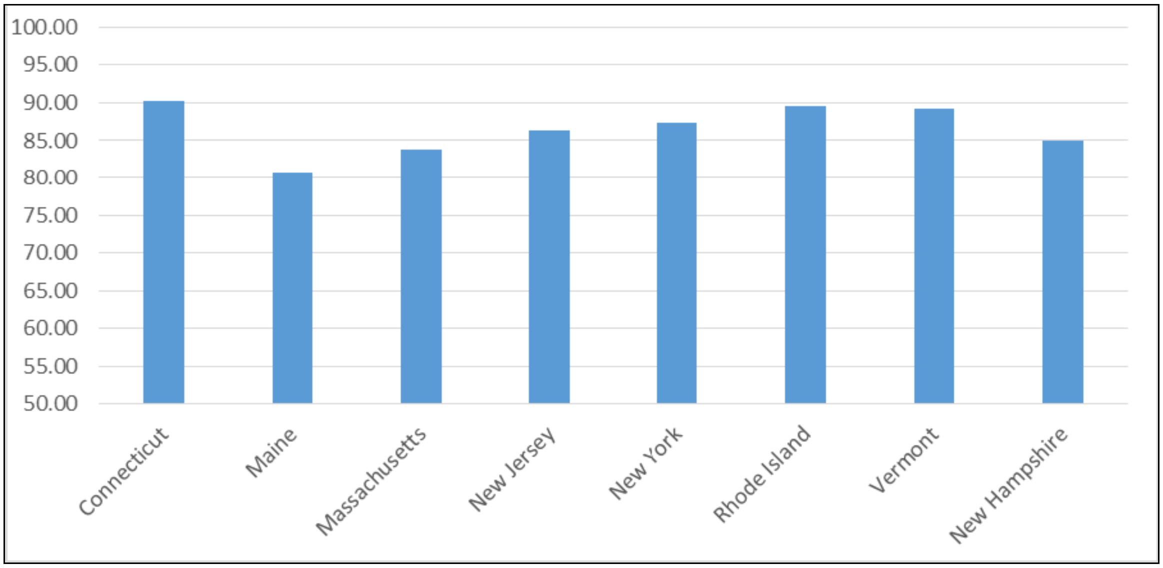

Figure 6. Estimated Probability of Functionality S1L

We then combined and analyzed the results across the eight NESEC States. As Table 6 and Figure 7 indicate, steel and reinforced masonry school buildings consistently outperform URM School buildings in terms of post-earthquake probability of functionality by as much as 19%.

	S1L	RM1L	URM
Connecticut	90	87	75
Maine	81	77	65
Massachusetts	84	82	70
New Jersey	86	83	71
New York	87	85	74
Rhode Island	90	86	74
Vermont	89	84	71
New Hampshire	85	78	66

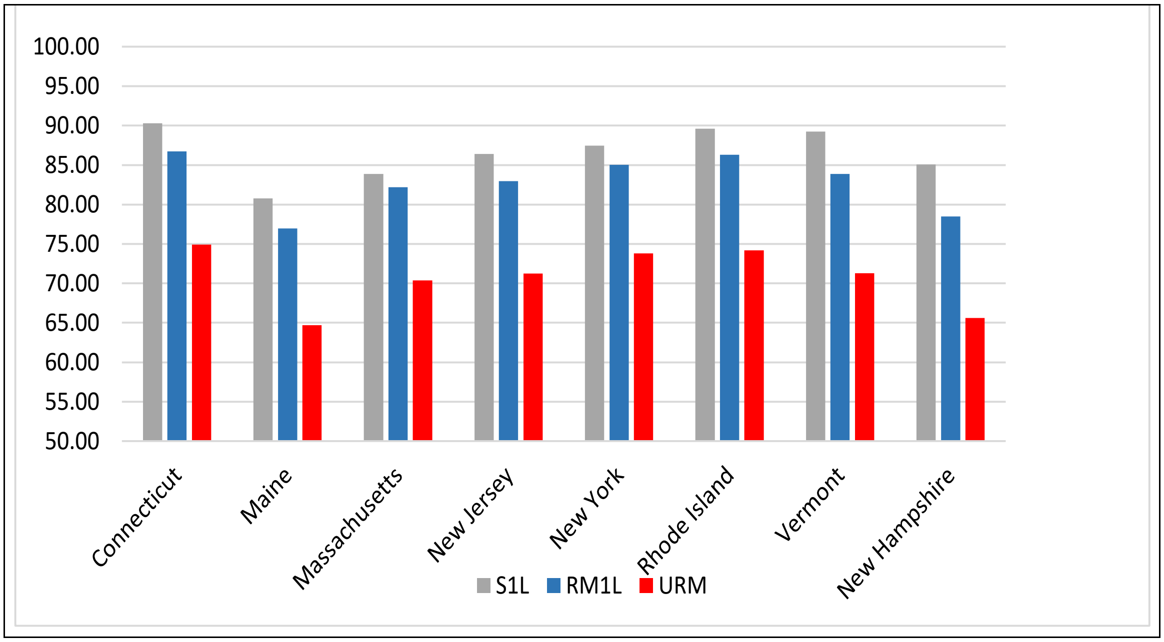

Figure 7. Estimated Probability of Functionality by Building Type

We utilized Hazus to estimate the probability of damage from none to complete for the three building construction types analyzed. These estimates are further broken down by state. The results are contained in Figures 8, 9 and 10.

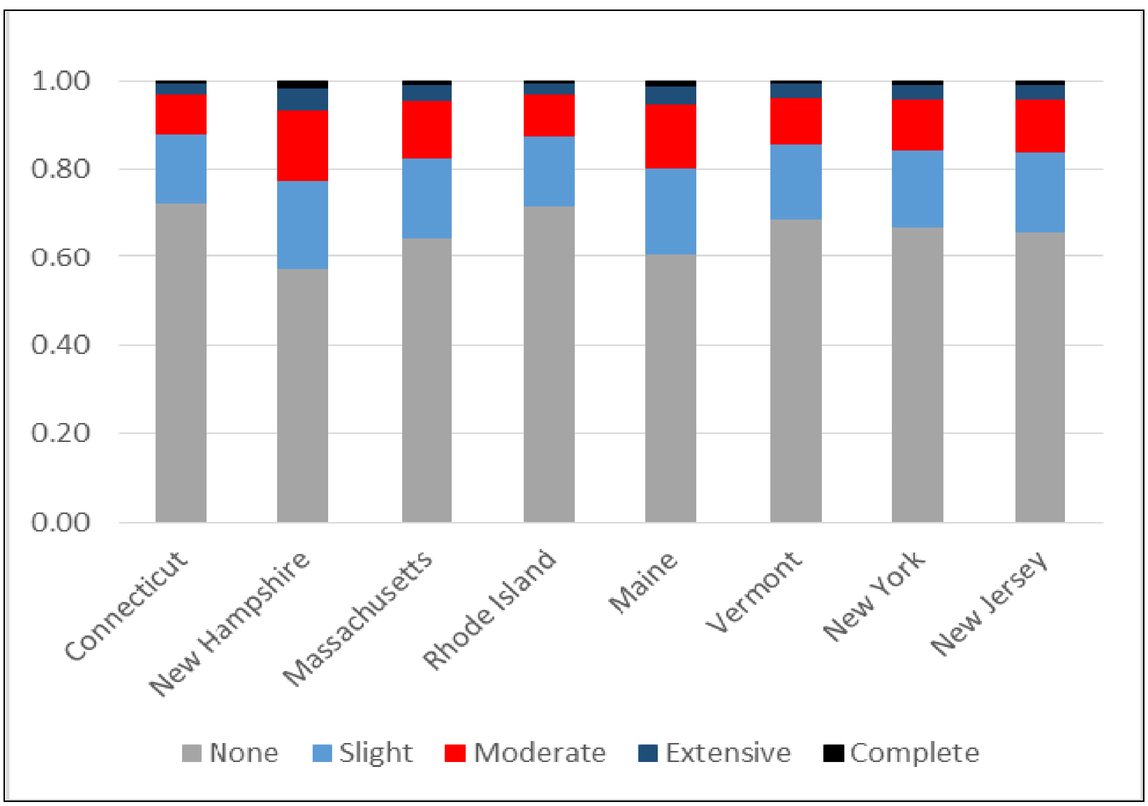

Figure 8. Estimated Probability of Damage State for URM School Buildings

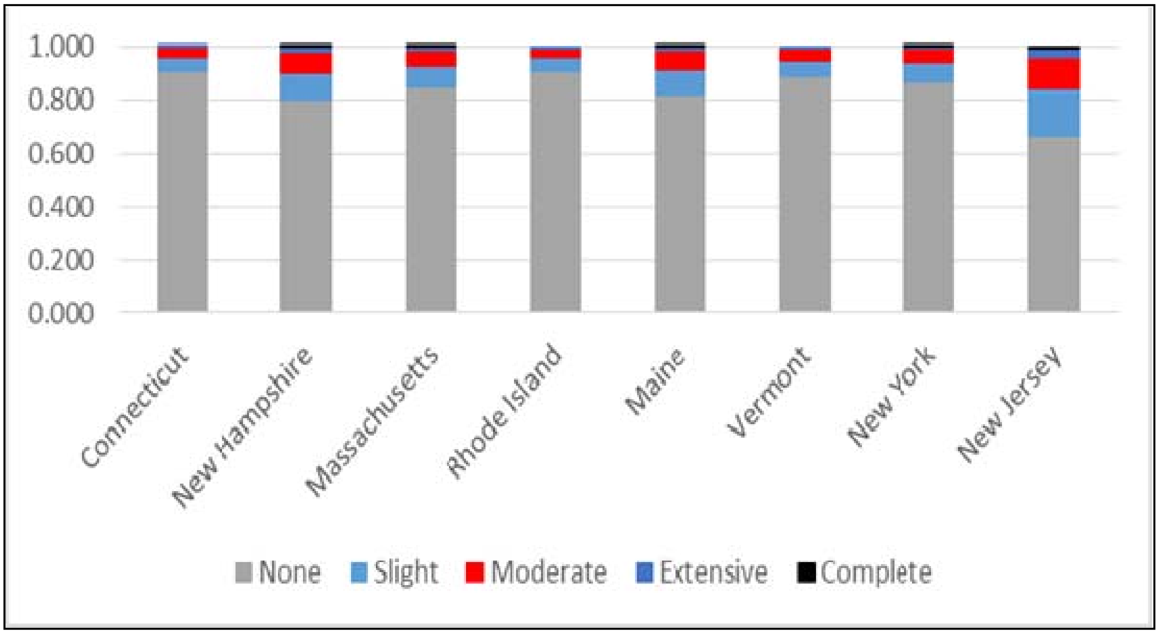

Figure 9. Estimated Probability of Damage State for RM1L School Buildings

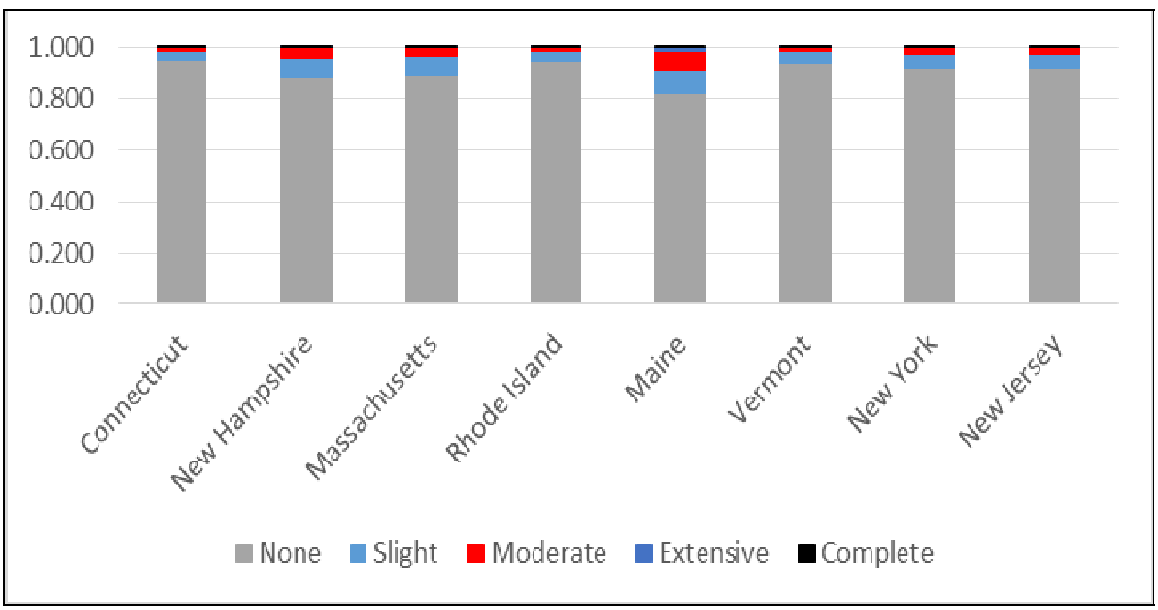

Figure 10. Estimated Probability of Damage State for S1L School Buildings

Finally, we compared the average damage state for school building by construction type for all NESEC States. The results are contained in Table 8 and Figure 11.

	None	Slight	Moderate	Extensive	Complete
URM	0.68	0.17	0.11	0.03	0.01
S1L	0.86	0.09	0.05	0.01	0.00
RM1L	0.80	0.09	0.08	0.02	0.00

Table 7: Estimated Probability of Damage by Building Type for All NESEC States

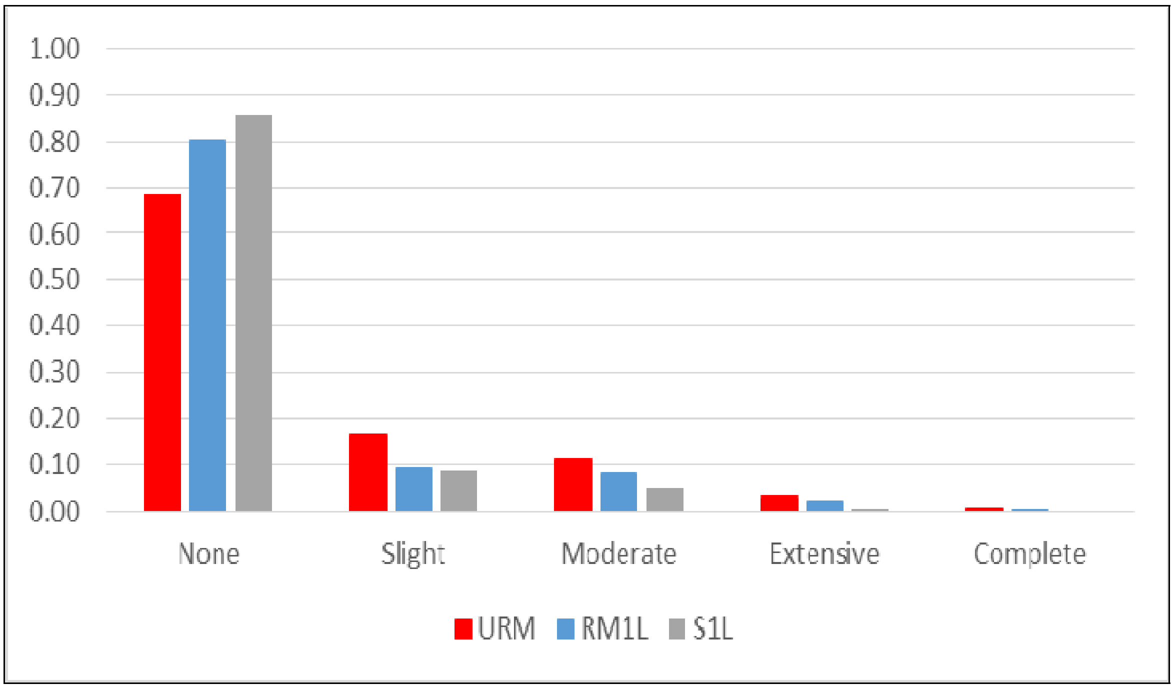

Figure 11. Estimated Probability of Damage by Building Type for All NESEC States

D.) Conclusion and Recommendations

This analysis using FEMA's Hazus Software and its new and updated Homeland Infrastructure Foundation-Level Data (HIFLD) default inventory of public schools provides a reasonable estimate of the number of schools in the NESEC eight state region and their spatial distribution and density. It also provides a preliminary estimate of the number of schools by state that are Unreinforced Masonry (URM) construction.

This analysis also provides a reasonable conclusion that URM schools in the NESEC States will not perform as well as reinforced masonry or steel frame schools in a seismic event. This could result in increased loss of life, injury and damage to school buildings.

URM school buildings present a potential danger to students, teachers, faculty, staff, visitors and other occupants in the event of an earthquake.

The decision that policy makers must consider is how to address this issue in the Northeast moderate seismic zone and other similar regions across the country.

Recommendations:

1. Local cities and towns, school districts, colleges and universities, private schools, daycare and other educational facilities should undertake an inventory of their schools to identify URM school buildings.
2. Visual screening of school buildings to identify URM structures should be undertaken using FEMA-154 Rapid Visual Screening of Buildings for Potential Seismic Hazards.
3. School emergency plans should consider whether the building is a URM and plan accordingly.
4. When deciding on priorities for school renovations or new construction, URM school building should be given the highest priority.
5. Federal and State funding for school construction should consider URM buildings the highest priority.
6. Local and State Building codes should be reviewed and evaluated related to URM school buildings.
7. Existing URM school buildings should be evaluated for structural as well as non-structural mitigation opportunities.
8. Schools should consider participation in the annual ShakeOut Earthquake Drill so that students and staff are aware of what protective actions they can take in the event of an earthquake.
9. Consideration should be given to setting a goal to eliminate or retrofit all URM schools by a specific date similar to the Schools shall be URM Free by 2033 initiate established by the Earthquake Engineering Research Institute.

Link to additional FEMA Information:

Federal Emergency Management Agency (FEMA) Multi-hazard Emergency Planning for Schools Toolkit

E.) Disclaimer

The regional inventory of URM School buildings in this report was developed using FEMA's Hazus Loss Estimation Methodology Software that is based on current scientific and engineering knowledge. URM inventories contained in Hazus were estimated in the Hazus software using criteria and professional engineering judgment specific to each state. Nevertheless, there are uncertainties inherent in any loss estimation models and software Therefore, there may be significant differences between the regional estimates contained in this report and the actual number of URM School buildings. The only way to obtain an accurate number of URM School Buildings is to undertake an inventory.