Disaster Resistant University

Preliminary Seismic Screening of University of Nevada, Reno Campus

August 2005

BJG | ARCHITECTURE + ENGINEERING

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Executive Summary

As a part of the University of Nevada Reno's Disaster Resistant University Project, BJG was retained to perform seismic hazard screening and preliminary evaluation of the buildings on the University of Nevada Reno's campus. This screening, using a nationally recognized scoring process from the Federal Emergency Management Agency (FEMA), produced a ranking of each building's relative propensity to suffer damage due to an earthquake. The screening was a combination of visual review, review of construction drawings and application of general engineering principles.

A number of buildings on the campus scored poorly. This is not unexpected, as the University has a large inventory of older buildings with a few over 100 years old. Seismic resistance of structures has improved steadily over the years based in many cases on observed damage to buildings in earthquakes. The FEMA standard used as the basis for the scoring suggests that any building scoring less than two be subjected to review. This additional evaluation is more in-depth than a standard screening which would only involve visual screening of the buildings. Due to this additional level of review, a more appropriate cutoff for additional review is a score of 1.0 or less. The scoring system is not an absolute determination that low-scoring buildings are "dangerous". However, these buildings have structural systems and features that have performed very poorly in past earthquakes.

There are two structural systems in use on campus that are the most likely to suffer extensive damage in a large earthquake: Un-reinforced Masonry (URM) and Ordinary Concrete Frames with URM Infill Walls. Both of these systems have URM walls that carry earthquake loads. The difference is that URM buildings' walls carry vertical loads and in the second case there are concrete columns and beams to carry vertical loads. The term "ordinary" separates these frames from "ductile" frames that are designed for earthquake loads. The problem with both of these systems is a lack of reinforcing steel in the masonry – thus any crack that develops due to shaking will continue to grow. Eventually, this leads to partial or total collapse of the wall.

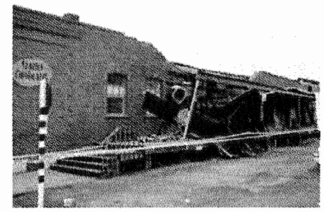
The damage that these type of buildings suffer is not only a hazard to their occupants, indeed many people have been injured or killed outside the buildings because of falling bricks from the walls. The damage is often so severe that the buildings are a total loss even if no one is injured. This level of damage presents a long term problem for the University in recovering from such an event.

The buildings that scored poorly are listed below, organized by their structural system with examples of damage to similar buildings in recent earthquakes. Only buildings that scored one or less on the FEMA scale are listed below.

Un-Reinforced Masonry (URM)
Issue: Potential partial or total collapse due to no reinforcing steel in the brick walls.

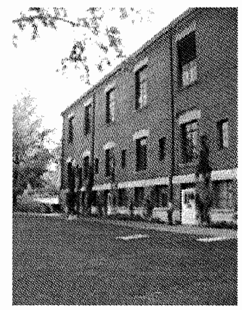
Previous Damage Example:
1933 Long Beach Earthquake

Previous Damage Example
Seattle Earthquake, 2001



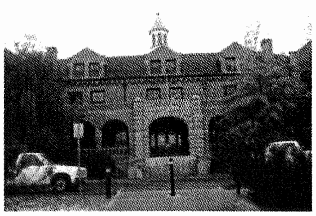
Manzanita Hall
Built 1896

Clark Administration
Built 1926



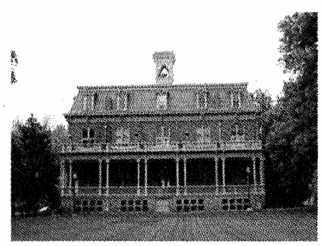
Facilities Service Building
Built 1907

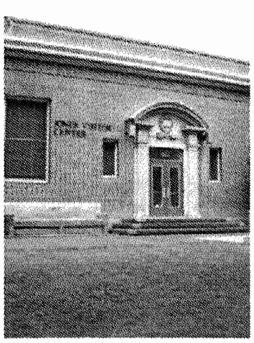
Virginia Street Gym
Built 1943



Lincoln Hall
Built 1896

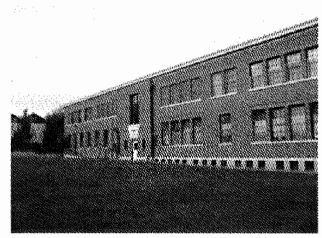
Morrill Hall Alumni Center
Built 1886, Remodeled
without significant upgrade



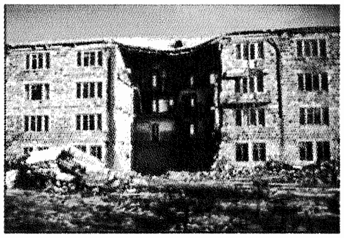


Jones Visitor Center
Built 1913

Thomson Building
Built 1920



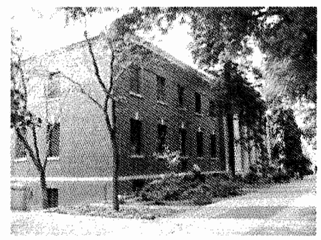
Ordinary Concrete Frame with Un-reinforced Concrete Infill Walls
Issue: Infill falls out between frame members during earthquake resulting in partial or total collapse.



Previous Damage Example:
Leninakan, Armenia,
December 1988

Palmer Engineering
Built 1941

Mackay Science
Built 1930



It is not the intent of this report to declare a crisis of dangerous buildings on the campus. Northern Nevada has had large earthquakes in the past. Large earthquakes in Northern Nevada are thought to occur on a time frame of several hundred to several thousand years. The location and dates of major earthquakes in the past are not precise so we may be "due" for another large earthquake. There *will* be another large earthquake; the timing is the only issue. The information in this report needs to be incorporated into capital projects for the next several cycles in order to mitigate the most significant hazards. This will most likely involve significant structural upgrades to the lowest-scoring buildings. It may turn out that structural modifications are so extensive and expensive that it makes better sense to replace a building rather than improve it. However, that determination can only be made after an upgrade program is defined and priced; seismic upgrades vary greatly in their complexity and costs.

The next step in this part of the Disaster Resistant University process is to create a seismic upgrade program for each building with a score of 1.0 or less or other buildings as directed by the University that may have other issues not considered within the scoring process. Each of these buildings would be analyzed in greater detail and a conceptual plan would be prepared for the upgrade of each building selected. Based on that information, a cost estimate to perform the upgrade can be prepared.

While a crisis need not be declared, complacency is also dangerous. Studies of Northern Nevada's geology and seismicity show that a large earthquake will occur eventually. The buildings that scored poorly will suffer damage – and it could be catastrophic. In beginning this process the University has the opportunity to mitigate the major safety issues before the next major earthquake.

Introduction

As a part of the University of Nevada Reno's Disaster Resistant University Project, BJG has evaluated the buildings on the University of Nevada, Reno campus for potential seismic hazard. BJG personnel reviewed all of the plans available in the university archive. Then, we visually screened buildings that did not have available plans and those that required further review. The information gathered through this two-part process was used to create a database of all the buildings. The database, located in Appendix A, outlines the basic structural characteristics of each building. We then scored each building using the structural characteristics, combined with an adjustment for the year they were built. The scoring procedure is based on the Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook (FEMA 154). The buildings were prioritized for rehabilitation using the FEMA scores and two project specific modifications. This list and the building characteristics provided in the database can be used to designate specific buildings for further evaluation. Additional investigation and detailed analysis is required before developing specific retrofitting plans and completing a cost analysis.

Northern Nevada has had large earthquakes in the past. Large earthquakes in Northern Nevada are thought to occur on a time frame of several hundred to several thousand years. As past earthquake history for location and time is not precise, we may be "due" for another large earthquake. There *will* be another large earthquake; the timing is the only issue. The Disaster Resistant University Program offers the opportunity to prepare for this eventuality and to mitigate the greatest dangers.

Data Collection

FEMA 154 is designed to allow screeners to use rapid visual screening to "identify, inventory, and rank buildings that are potentially seismically hazardous" (FEMA 154). The process of rapid visual screening involves a fifteen to thirty minute inspection of the exterior of the building and the building site. The screener gathers information on the lateral system and any building attributes that modify the lateral system. The data collection form that FEMA 154 supplies is located in Appendix C. BJG reviewed the plans for a large number of the buildings on campus, interviewed facility staff and collected data through visual screening. This enabled us to gather more information than FEMA 154 requires, resulting in a more complete screening. The review beyond the ordinary visual screening was very valuable for in many cases the lateral system for a building is difficult to determine without plans.

The main information a screener obtains using the FEMA 154 method is 1) the lateral system, 2) irregularities to the lateral system, 3) number of stories, and 4) date of construction. In addition to the information required by FEMA 154, we were also able to determine the building code date, floor system, roof system, vertical system, floor to floor height, and information about retrofits. This information was used to determine the potential seismic hazard of each building. Each structure has a building name, abbreviation, and number from the University's campus map. We used the building area to establish scale for both mass, occupancy, and potential damage. We identified the building date (the date on the construction documents), occupancy date (from University records when available) and the code date to establish potential building deficiencies. In some cases the dates were not available but could be estimated based on other information. We used the floor and roof system information to establish the building mass and the height dimensions to establish scale and evaluate seismic performance. We identified the building use to evaluate potential hazards (i.e. chemical storage) and life safety risk (occupancy issues). We combined the collected data with photographs of each building to help illustrate the irregularities and provide building identification.

Building Scoring

The basic building score "reflects the estimated likelihood that building collapse or major structural damage will occur if the building is subjected to the maximum considered earthquake ground motions for the region" (FEMA 154). For the purpose of this document, collapse and likelihood of collapse are equivalent to building structural damage of 60% or greater. The basic scores included in FEMA 154 were computed through an analysis of how buildings of different lateral systems had performed in previous earthquakes from around the world. FEMA 155, the companion report to FEMA 154, outlines the process of data collection and mathematical modeling. The basic score is the average expected performance for each building type. The basic scores vary according to the level of seismicity of the region. We have used the high seismicity values to score the buildings because Reno, Nevada is located in an area of high seismicity.

FEMA 154 Modifiers

The basic scores are modified based on building characteristics. These modifiers include: height, irregularities, pre-code, post-benchmark, and soil type. These modifications do not imply that a building is poorly designed. The irregularity modifications account for characteristics that have consistently caused poor performance in past earthquakes. The modifiers vary depending upon the lateral system. The breakdown of each modifier and its effect on the basic score of each building type is listed in a table in Appendix C. The following paragraph outlines the specific modifiers in more detail.

Building Height

The height modifiers are broken into two categories: mid-rise and high-rise. Buildings between 4-7 stories are defined as mid-rise and the score is modified accordingly. Buildings over 7 stories are defined as a high-rise have a different modifier. No modification is made to the score for buildings 4 stories or less. The modifications "improve" taller building scores because taller buildings generally have responses that are less sensitive to earthquake motions. This is not true of all conditions, but it has been observed to be the case in most earthquakes.

Irregularities

FEMA 154 divides irregularities into two categories: vertical and plan. FEMA 154 lists the following as examples of vertical irregularities: buildings with setbacks, hillside buildings, and buildings with soft stories. A building is considered to have a setback if the building is irregularly shaped in elevation or if some of the walls are not vertical. A building is classified as a hillside building if it is built on a steep hill so that over the up-slope dimension of the building the hill rises at least one story height. A building is defined as having a soft story if the stiffness of one story is dramatically less than that of most of the others. Visual examples of each of these are available in Appendix C. Buildings with any of these three vertical irregularities have the same vertical irregularity modifier. This modifier subtracts from the score because it has been observed that these features are related to observed performance problems in past earthquakes.

FEMA 154 lists the following as plan irregularities: buildings with re-entrant corners, buildings with good lateral-load resistance in one direction, but not in the other, and buildings with major stiffness eccentricities in the lateral-force-resisting system. FEMA 154 describes buildings with re-entrant corners as those with long wings that are E, L, T, U, or + shaped. Building with any of these plan irregularities have the same plan irregularity modifier.

Pre-Code Date

This modification reduces the scores of buildings designed prior to the initial adoption and enforcement of seismic codes. The default year of adoption of seismic codes is 1941 for all types of construction except tilt-up buildings (PC1), which have a default year of 1973. If any building was designed prior to 1941, its score is modified with the pre-code modifier. The default year is consistent with the code enforcement in our region. Essentially, the score improves with buildings that are more modern, a reflection of improvement in building design with building code guidance and requirements.

Post Benchmark Date

This modification increases the scores of buildings that were designed after "significantly improved seismic codes…were adopted and enforced by local jurisdiction" (FEMA 154, 41). These dates vary significantly depending on the type of construction as different types of structure design rules were changed at different times. This modifier improves the score of modern buildings assuming that they were designed in substantial compliance with the improved codes. Different types of buildings have different benchmark dates because the codes changed for these types of construction at different times.

Soil Type

The soil type modification accounts for the fact that buildings of similar design perform differently on different soils. A soil parameter of type D was used for all university buildings and the corresponding modifier is incorporated into the scores of the buildings. Measurements at the University indicate that this soil classification is accurate for most of the campus. This soil type is also the code default where soil information is incomplete. There are two classifications of soil that are associated with greater earthquake damage than soil type D.

Project Specific Modifiers

In addition to the FEMA score modifications, we have added two additional score modifications. The first is based upon ATC-21, the precursor document of FEMA 154 and 155. ATC-21 breaks vertical irregularities into two groups: soft story and vertical irregularity, and a modifier is attributed to each. This allows for a more accurate evaluation of buildings when the vertical irregularity can be classified. The data collected to determine the scores suggests that a soft story has a much greater impact on the performance of a building in an earthquake than other vertical irregularities. This is particularly important for the University as many buildings have hill-side irregularities but not soft stories. Although FEMA 154 does not include this breakdown in their scoring, we have included it in the form of our own modifier. This modifier returns a portion of the points deducted for vertical irregularity by the FEMA 154 modifier if the vertical irregularity is not a soft story. The project specific vertical irregularity modification is to reduce the FEMA modifier by ½ if a building has a hillside condition. This modifier allows us to more accurately evaluate the effect of the vertical irregularities on the overall performance of the building.

The other score modification is designed to give priority to buildings based on occupancy. FEMA 154 includes a broad occupancy classification and occupancy load estimate in the collection form, but does not use it to calculate the final score. The occupancy modification is modeled after the 2003 International Building Code's Classification of Buildings and Other Structures for Importance Factors (Appendix C). This table classifies buildings into four categories based on the nature of their occupancy and assigns "Importance Factors" (I). The intent is to provide additional safety factors to buildings based on their hazard to human life and their importance in the relief after an earthquake.

The lowest categories, I and II are typical buildings without any special use or occupancy. Category I and II buildings include almost all ordinary construction. Category III buildings include buildings where more than 300 people congregate in one area, day care facilities with and occupant load greater than 250, buildings with an occupant load greater than 500 for colleges, power-generating stations, and any other occupancy with an occupant load greater than 5000. Category III buildings are designed for 125% (I = 1.25) of the "regular" lateral force due to earthquakes. Category IV buildings are essential facilities, such as designated emergency shelters, emergency services buildings, and any other building that is necessary to be in operation after an earthquake. Category IV buildings are designed for 150% (I=1.5) of the regular lateral force due to earthquakes. In order to apply this modifier, each building's occupancy was calculated using its area and the International Building Code occupancy requirements, the same as would be performed for new construction. After placing each building into a category, the final score with all other modifiers was divided by the importance factor from the IBC. Thus a classroom building with more than 500 students would be a Category III building and its score would be divided by 1.25 to get a final score. This final score is the score that is used to rank the priority of buildings for mitigation.

A final area of score modification concerned seismic upgrades. Only two buildings on campus have had comprehensive upgrades: The Mackay Schools of Mines Building and Fransden Humanities. FEMA 154 has no guidance on how to handle these types of structures. The Mackay School of Mines was upgraded and placed on base isolators, essentially placing the building on special springs to prevent the building from experiencing earthquake accelerations. We assigned this building a lateral system score as if it was a reinforced masonry building. This improved the score as to remove the building from the need for any further review, a reasonable conclusion. Fransden Humanities was upgraded per the Uniform Code for Building Conservation, a special building code to allow the use of archaic materials and special techniques not allowed under the regular building code. While this type of upgrade is not fully new code compliant, it increases the life safety of the building sufficiently to remove it from the list of critical buildings.

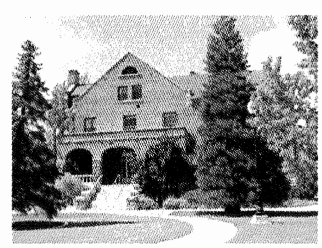
Score Interpretation

After the modifiers are applied to the basic score, the resulting final score is an indicator of the respective building's potential for seismic hazard. According to FEMA 154, final scores (raw scores) typically range from 0-7, with the higher values corresponding to better seismic performance. The scores are based on limited observed data and as a result the probability of collapse that the scores refer to is approximately 1 in 10 raised to the score power. Thus a score of 3.0 implies there is a chance of 1 in 1000 that the building will collapse if the design ground motion occurs. The final scores in this document are modified beyond the FEMA score, therefore these probabilities refer to the building's raw score before the project specific modifications.

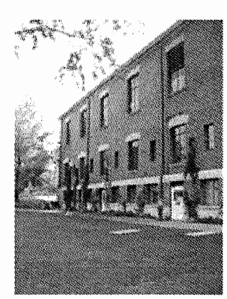
These scores "imply" probabilities – these values are quite approximate and only useful for relative performance evaluations. There is no known technique of ascertaining exactly what damage will occur to any building for any earthquake. Poorly scoring buildings have characteristics that have not performed well in historical earthquakes and are therefore suspect. The damage level in any building will be highly dependent on the actual ground motion at the site and the details of the building's design and construction.

Results

A list of all the buildings in order of their final score is available in Appendix B. The ten buildings with scores less than or equal to 1.0 (the highest potential for seismic damage and the highest life safety concern) are Manzanita Hall, Clark Administration, Virginia Street Gym, Palmer Engineering, Mackay Science, Lincoln Hall, Facility Services Building, Jones Visitor Center, Morrill Hall Alumni Center, and the Thompson Building. The majority of these buildings rely on un-reinforced masonry for lateral and in most cases vertical support. Similar types of buildings have performed poorly in previous earthquakes and as a result the basic score for this type of construction is low. The individual explanation for the scoring of each of the ten lowest scoring buildings follows:



Manzanita Hall (Final score = **0.4**): Manzanita Hall was designed before its 1896 occupancy date and prior to the 1941 adoption and enforcement of seismic codes. It has bearing/shear walls of un-reinforced masonry, which has a basic score of 1.8. Manzanita Hall has a plan irregularity due to its U-shape plan, which accounts for a modification of -0.5. In addition, it has an code occupant load of greater than 500, qualifying it for an occupancy modification. These modifications result in a final score of 0.4.

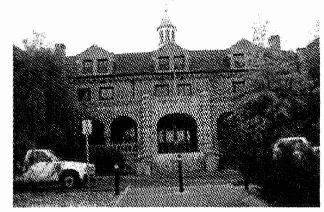


Clark Administration (Final Score = **0.5**): The Clark Administration building was designed in 1926, before the 1941 adoption and enforcement of seismic codes. It is an un-reinforced masonry building, with a basic score of 1.8. In addition, it has a vertical irregularity because it is a hillside building. These modifications result in a final score of 0.5.

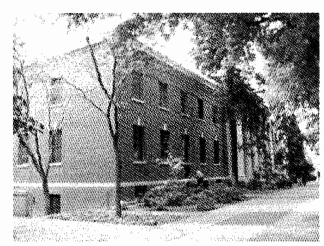
Palmer Engineering (Final Score = **0.5**): This building was designed in 1940, just prior to the adoption and enforcement of seismic codes. It has a concrete frame with an un-reinforced masonry infill lateral system, which has a basic score of 1.6. This building has a plan irregularity based on its L-shape. As a result of the basic score and modifications, Palmer Engineering has a final score of 0.5.

Virginia Street Gym (Final Score = **0.56**): The Virginia Street Gym was designed in 1941, most likely before the first code was adopted. It is an un-reinforced masonry building, with a basic score of 1.8. It has a vertical irregularity because it is a hillside building. In addition, it qualifies for the occupancy modification because more than 300 people congregate in one area. These modifications result in a final score of 0.56.

Lincoln Hall (Final Score = **0.8**): This building was occupied in 1896, prior to the 1941 adoption and enforcement of seismic codes. It was constructed with an un-reinforced masonry lateral system, which has a basic score of 1.8. Lincoln Hall has an occupancy load of greater than 500, which qualifies it for the occupancy modification. Based on these modifications, Lincoln Hall's final score is 0.8. The difference in score between Manzanita Hall and Lincoln Hall is due to the plan irregularity of Manzanita Hall.

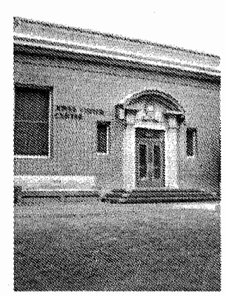


Mackay Science (Final Score = **1.0**): The Mackay Science building was designed in 1929, prior to the 1941 adoption and enforcement of seismic codes. Its lateral system is a concrete frame with un-reinforced masonry infill. This lateral system has a basic score of 1.6. Mackay Science has a final score of 1.0.

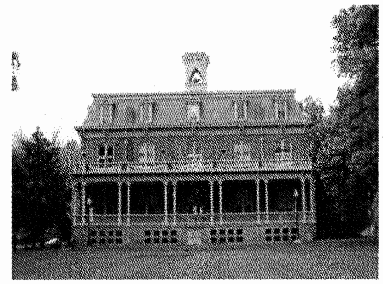


Facility Services (Final Score = **1.0**): This building was designed before its 1921 occupancy date and prior to the seismic codes, with an un-reinforced masonry lateral system. The basic score for un-reinforced masonry is 1.8, with a 0.2 deduction for pre-code. As a result of the type of construction and the modifications, the Facility Services building has a final score of 1.0.

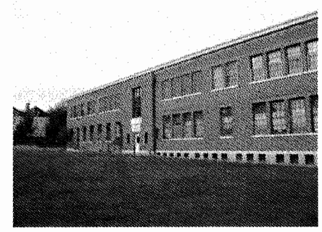
Jones Visitor Center (Final Score = **1.0**): This building was occupied in 1913, prior to the 1941 adoption and enforcement of seismic codes. It was constructed using an un-reinforced masonry lateral system, which has a basic score of 1.8. As a result of the type of construction and the modifications, the final score for the Jones Visitor Center is 1.0.



Morrill Hall Alumni Center (Final Score = **1.0**): The Morrill Hall Alumni Center was occupied in 1886, prior to the adoption and enforcement of seismic codes. Its lateral system is un-reinforced masonry, which has a basic score of 1.8. Morrill Hall has a final score of 1.0, based on the basic score and modifications. Morrill Hall had minor connection upgrades between the floor and wall installed during its remodel, but the upgrades, as shown on the drawings available, do not appear to be sufficient for adjusting its score.



Thompson Building (Final Score = **1.0**): The Thompson building was designed in 1919, prior to the adoption and enforcement of seismic codes. Its lateral system is un-reinforced masonry, which has a basic score of 1.8. The Thompson Building has a final score of 1.0, based on its basic score and modifications.



There are several buildings just above the threshold of 1.0 for further study. These buildings by and large have engineered lateral force systems that, while not current code compliant, are at less risk of major damage than the URM buildings above. Their relatively low scores are mostly due to *potential* detailing issues that have caused similar buildings to have structural problems in other earthquakes. Concrete shear wall buildings that were designed prior to 1976 have potential problems with overturning connections, trim steel and "boundary" elements with shear walls and other potential detailing issues. Not all buildings have these issues and most concrete shear wall buildings are at less risk of damage than the URM buildings. Therefore, these buildings have lower priority for mitigation than buildings with URM or concrete frames with infill URM walls.

Recommendations and Conclusions

It is not the intent of this report to declare a crisis of dangerous buildings on the campus. Northern Nevada has had large earthquakes in the past. Large earthquakes in Northern Nevada are thought to occur on a time frame of several hundred to several thousand years. As we cannot say when the last large earthquake was on the faults that are near the University, we cannot predict when the next earthquake will occur. We can only surmise that another large earthquake will occur; the timing is the only issue.

The information we have gathered provides the preliminary analysis for improving disaster resistance at the University of Nevada, Reno. The ranking of the buildings provides a starting point for the rehabilitation efforts. From here, the buildings that pose the highest potential threat in the case of an earthquake should be evaluated in greater depth. In Stanford University's Seismic Engineering Guidelines, FEMA 356 is used as a reference for the rehabilitation of older buildings on their campus. FEMA 356 focuses primarily on target building performance level in determining a rehabilitation objective. Rehabilitation can be a minimum upgrade to provide an improvement of life safety, a major upgrade to bring the building to full modern code compliant condition, or demolition and replacement. This decision tree provides a road map to mitigation method to be considered.

The next step in this part of the Disaster Resistant University process is to create a seismic upgrade program for each building with a score of 1.0 or less or other buildings as directed by the University that may have other issues not considered within the scoring process. Each of these buildings would be analyzed in greater detail and a conceptual plan would be prepared for the upgrade of each building selected. Based on that information, a cost estimate to perform the upgrade can be prepared.

While a crisis need not be declared, complacency is also dangerous. Studies of Northern Nevada's geology and seismicity show that large earthquakes have occurred and will occur again eventually. The buildings that scored poorly will suffer damage – and it could be catastrophic. In beginning this process the University has the opportunity to mitigate the major safety issues before the next major earthquake.

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