The Development and Implementation of a Rapid Visual Screening Method for Non-structural Damage Due to Seismic Forces

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INTRODUCTION

Non-structural building components are the systems and components of a building that are not directly used within the primary structural building system. Non-structural components include non-bearing walls, pipes, ducts, lighting, parapets, doors, windows, shelving, etc. The reality is that a relatively small percentage of a building's cost goes into structural systems. The structural cost of a typical office building is only 18% of the total cost with non-structural components being 62% and the content of the building being 20% (Whittaker 2003). Seismic damage to a building's non-structural elements can not only be costly but can also be a life safety issue to the building's occupants when a non-structural element fails to remain in place and can be a life safety issue to a community if the failure of a non-structural element causes a toxic element to be released from a building.

The issue of non-structural damage due to seismic events first became apparent after the Great Alaskan earthquake of 1964 and was reemphasized by the San Fernando earthquake of 1971 and the 1972 earthquake in Managua, Nicaragua (Mertz 1976). In these earthquakes, structural components suffered relatively little damage while the non-structural damage was extensive. The building codes were revised after these earthquakes to require non-structural elements to be tied back to the structure in such a way to reduce the potential of harming people during an earthquake (ICBO 1973). These building codes have been updated many times in the last 35 years to reduce these chances further and to address such issues as hazardous materials.

The problem that had not been address is a method to identify buildings that may be potentially dangerous from a non-structural aspect of seismic design from a large pool of buildings within a city or a part of a city such as a university campus. This method needs to be relatively quick and needs to be done by people with a relatively small amount of training. This paper will describe the research carried out at a university to develop and test such a system. The non-structural rapid visual screening method was used evaluate the building stock owned by the university in order to prioritize building remodeling expenditures with regards to seismic on campus.

BACKGROUND FOR RAPID VISUAL SCREENING FOR SEISMIC EVALUATION OF BUILDINGS

The rapid visual screening (RVS) method for quick evaluation of buildings based upon their structural systems was developed by the Applied Technology Council (ATC) in conjunction with the Federal Emergency Management Agency (FEMA) in 1987-88 (FEMA 1988). The method developed was intended to "provide a tool to evaluate the danger of building collapse due to earthquakes, … a method whereby buildings can be rapidly identified via a 'sidewalk survey' as seismically acceptable or potentially seismically hazardous" (FEMA 1988, pg. 1). The tool (Figure 1) developed allows a minimally trained surveyor to examine a building without ever entering the building and to evaluate it based upon its age, structural system type and ir-

ATC-21/ (NEHRP Map Areas 5,6,7 High)

Rapid Visual Screening of Seismically Hazardous Buildings

Scale:

Address ______________________
______________________ Zip ________
Other Identifiers ______________________
No. Stories ________ Year Built ________
Inspector ________ Date ________
Total Floor Area (sq. ft) ______________________
Building Name ______________________
Use ______________________

(Peel-off label)

INSTANT PHOTO

OCCUPANCY

	No. Persons
Residential	0–10
Commercial	11–100
Office	100+
Industrial	
Pub. Assem.	
School	
Govt. Bldg.	
Emer. Serv.	
Historic Bldg.	

Non Structural Falling Hazard

DATA CONFIDENCE

* = Estimated, Subjective, or Unreliable Data

DNK = Do Not Know

STRUCTURAL SCORES AND MODIFIERS

BUILDING TYPE	W	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	C1 (MRF)	C2 (SW)	C3/S5 (URM INF)	PC1 (TU)	PC2	RM	URM
Basic Score	**4.5**	**4.5**	**3.0**	**5.5**	**3.5**	**2.0**	**3.0**	**1.5**	**2.0**	**1.5**	**3.0**	**1.0**
High Rise	N/A	-2.0	-1.0	N/A	-1.0	-1.0	-1.0	-0.5	N/A	-0.5	-1.0	-0.5
Poor Condition	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Vert. Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-1.0	-0.5	-0.5	-1.0	-1.0	-0.5	-0.5
Soft Story	-1.0	-2.5	-2.0	-1.0	-2.0	-2.0	-2.0	-1.0	-1.0	-2.0	-2.0	-1.0
Torsion	-1.0	-2.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-1.0	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-1.0	-1.0	-1.0	-1.0
Pounding	N/A	-0.5	-0.5	N/A	-0.5	-0.5	N/A	N/A	N/A	-0.5	N/A	N/A
Large Heavy Cladding	N/A	-2.0	N/A	N/A	N/A	-1.0	N/A	N/A	N/A	-1.0	N/A	N/A
Short Columns	N/A	N/A	N/A	N/A	N/A	-1.0	-1.0	-1.0	N/A	-1.0	N/A	N/A
Post Benchmark Year	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	+2.0	N/A	+2.0	+2.0	+2.0	N/A
SL2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
SL3	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
SL3 & 8 to 20 stories	N/A	-0.8	-0.8	N/A	-0.8	-0.8	-0.8	-0.8	N/A	-0.8	-0.8	-0.8
FINAL SCORE												

COMMENTS

Detailed Evaluation Required?

YES NO

Figure 4-1a Data collection form

Figure 1 – Rapid Visual Screening Evaluation (FEMA 1988, pg. 54)

regularities, soil type and condition. The surveyor also can note the occupancy type and load and whether non-structural falling hazards exist but these items are not part of evaluating the building based upon its potential to collapse.

The RVS method was designed to be carried out by a surveyor who has had some training at identifying various aspects of a building from the street without going into it. These aspects include the building's age, structural type, condition, plan and vertical irregularities, occupancy, size, and soil type. The accuracy of the survey can be increased by determining many of these items in advance using tools such as Sanborn Maps, geological maps, and building permit documents. When a surveyor is finished with the RVS method the building is assigned a score. Depending on the depth of the survey being conducted and the amount of information collected before the street survey begins, this process can take between ten and thirty minutes per building.

The purpose of the survey is to determine the likelihood of a building to collapse during an earthquake. The building's final score is that indicator. The larger the number of the final score, the less likely that the building will collapse while the smaller the number the more likely it will happen. The scale of the survey is approximately a 16-point scale with the high score being a 10.5 in regions with low seismic activity and the high score being a 7.5 in regions with high seismic activity. No single number is given to determine when a building has crossed over from being a building within the normal range and when it is a building with a score low enough to be of concern. This is usually determined for each study using statistical methods of analysis.

The RVS method has been used many times since its development and has become the standard for determining the seismic readiness of buildings of interest. It has proven useful when looking at large numbers of buildings such as a city or university. It has been modified by FEMA and ATC over the years as needed and has been modified by groups of researchers to meet their particular needs. Portland Oregon was the first city in the country to survey its entire building stock for seismic readiness and the State of Oregon has just competed surveying every educational and emergency facility in state (Lewis 2007). It has become an invaluable tool but one limited by its original objective which was to determine the likelihood of a building to collapse during a seismic event.

DEVELOPMENT OF A RAPID VISUAL SCREENING METHOD FOR NON-STRUCTURAL SYSTEMS

The rapid visual screening method for non-structural systems (RVS-NS) is not to be a replacement to the earlier RVS method but to be a compliment to it. Much of the data necessary to complete the RVS-NS is already collected during the process of completed the RVS study but is not used to evaluate the building since this information would not aid in process to determine if the building is likely to collapse. The goal of the RVS-NS study is to evaluate a building for potential failure of the non-structural systems, which could be a risk to life safety, property, and building function.

Life safety is obviously the most important of the risks due to non-structural failure and the RVS-NS (Figure 2) considers this by establishing the base score for the building on its occupancy. The more people inside a building during an earthquake, the more likely someone will be injured during the event. The base scores range from 10 points for fewer than 10 occupants in the building to 6 points for more than 10,000 people.

Once the building's base score is established, then points are deducted as determined by the surveyor based upon what is observed. Life safety is the first area which points can be deducted. First is to determine if the building is occupied more than 18 hours a day. If it is, then it is more likely that if an earthquake happens, the building will be occupied. Next, the occupants themselves need to be examined to see if they can egress from the building on their own or if they would need help. Examples of occupancies that would need help would include daycare centers, retirement homes, and hospitals. The presence of hazardous or toxic material within a building could pose threat to life safety and the surveyor needs to determine the extent of that threat. Finally, the existence of falling hazards needs to be assessed. This is accomplished by determining if they are present in the form of content such as shelving and whether the building predates building codes that required the bracing of non-structural elements such as ducts and lights. In the area of author's study, the code in effect at the time of most of the buildings being

Photograph

Building Name ____________________
Building Number ____________________
Total Floor Area ____________________
Year Built ____________________

Non-Structural Score __________ pts.
Life Safety Percentage _____ %
Property Percentage _____ %
Function Percentage _____ %

Occupancy Types and Loads

Type	Occupancy Load	Gross Floor Area (sq. ft.)	Number of Occupants
Agricultural	1 per 300 sq. ft.		
Assembly			
Fixed Seating	1 per seat		
Non Fixed			
- Chairs only	1 per 7 sq. ft.		
- Standing	1 per 5 sq. ft.		
- Chairs & Tables	1 per 15 sq. ft.		
Bowling	5 per lane		
Business Areas	1 per 100 sq. ft.		
Dormitories	1 per 50 sq. ft.		
Educational			
Classrooms	1 per 30 sq. ft.		
Shops & Vocational Rooms.	1 per 50 sq. ft.		
Exercise	1 per 50 sq. ft.		
Fabrication and Manufacturing	1 per 200 sq. ft.		
Industrial	1 per 100 sq. ft.		
Institutional			
Inpatient Treatment	1 per 240 sq. ft.		
Outpatient	1 per 100 sq. ft.		
Sleeping	1 per 120 sq. ft.		
Kitchens - commercial	1 per 200 sq. ft.		
Laboratory	1 per ??? sq. ft.		
Library			
Reading Rooms	1 per 50 sq. ft.		
Stacks	1 per 100 sq. ft.		
Lockers	1 per 50 sq. ft.		
Mercantile			
Basement and First Floor	1 per 30 sq. ft.		
Other Floors	1 per 60 sq. ft.		
Storage, stock, shipping	1 per 300 sq. ft.		
Parking Garages	1 per 200 sq. ft.		
Residential	1 per 200 sq. ft.		
Skating Rinks & Swimming Pools			
Rink or pool	1 per 50 sq. ft.		
Decks	1 per 15 sq. ft.		
Stages and Platforms	1 per 15 sq. ft.		
Accessory Storage & Mechanical	1 per 300 sq. ft.		
Warehouse	1 per 500 sq. ft.		
Remaining Area	1 per 100 sq. ft.		
Totals			

Non-Structural Scores

Category	Description	Points
Base Score based upon Occupancy	0 to 10 people = +10 pts. 11 to 100 people = + 9 pts. 101 to 1000 people = + 8 pts. 1001 to 10,000 people = + 7 pts. Greater than 10,001 people = + 6 pts.	
Life Safety		
Occupancy	Hours of Occupancy Greater than 18 hrs.per day = - 0.25 Inability of occupants to egress on their own = - 0.25	
Hazardous Materials	Hazard to people in building = - 0.5 Hazard to Campus = - 0.75 Hazard to Greater Population = - 1.0	
Falling Hazards	Shelving and content = -0.25 pts Pre 1973 construction = - 0.25 pts	
Property		
Content	Large Monetary Value = -0.5 pts. Very Important Content = -0.5	
Non-Structural Damage	Ductile Structure = -0.5 pts. Pre-1973 Construction = -0.5 pts.	
Function		
Importance	Important to Neighborhood = - 0.5 pts. Important to City = - 1.0 pts.	
Ability to operate without connection to outside community	Can partially function = - 0.5 Can not function = -1.0 pts.	
Total		

Notes

Figure 2 – Rapid Visual Survey for Non-Structural Elements

build was the Uniform Building Code, which first required bracing in 1973 (ICBO 1973). The potential deduction for "Life Safety" is 2 points from the base score.

The "Loss of Property" is the next area evaluated by the RVS-NS. This is accomplished by examining the content to determine if it is valuable and then examining the building to see if the content is in danger due to non-structural failure. The buildings content is determined to be valuable if it is either monetarily valuable or if non-monetarily valuable. An example of a non-monetarily valuable object would be an object that has historic significance such as journal of a western pioneer during the mid-1800's. Its historic value may be large while its monetary value may be only a couple hundred dollars. The evaluation of the building is whether it has a ductile structure since moving more during an earthquake and whether it predates the bracing requirements of the relevant building code. The potential deduction for "Loss of Property" is 2 points.

The final area of evaluation is for "Loss of Function." It is given that the function of every building is important to the occupants of that building. The survey is interested in whether the function of the building is important to more than the occupants of the building. A house is clearly important to the family that lives inside it but probably is not as important to those down the block. A firehouse is important to not only the persons working in the building but also the city or region for which serve. The more important the function of the building is, the more points deducted by the survey. Finally, the surveyor needs to determine if the function of the building can happen even if the building is cut off from community services such as water, sewer, electricity, phone, etc. An emergency phone center could not function without phone service but probably could function, at least for a time, without sewer and water. A house without any of these services can at least partially function after an earthquake as long as the building is not in danger of collapse. The less a building can function after the event, the more points are deducted. The potential deduction for "Loss of Function" is also 2 points.

The final evaluation of the building determined in a final "Non-Structural Score" and three percentages, which aid in determining whether a building is problematic due to life safety, loss of property, or loss of function. The "Non-Structural Score" is determined by subtracting any deductions from the base score. Like the RVS score, the RVS-NS score is interpreted as the smaller the number, the greater the propensity of failure in the building. The percentages given for each of the three non-structural problems based upon the number of points deducted in an area divided by the possible number of points in the area. These score can help differentiate between two buildings with similar score. Figure 3 demonstrates the usefulness of this process. The evaluation on the left is an educational / laboratory building while the one on the right is a large library. They were both built in the same year and both were given a Non-Structural Score of 5.0. Without the additional information given by the percentages, the two building would be considered similar. With the percentages, one can quickly determine that the primary problem with the laboratory building is life safety while with the library it is loss of function. This additional information could be very useful to someone who is trying to make a decision on which building should be remodeled first.

INITIAL TESTING OF RAPID VISUAL SCREENING NON-STRUCTURAL METHOD

The initial testing of the RVS-NS method was on a large western university campus. The location was chosen since it is the authors' university and all of the data was readily available but also because it had previously had a RVS study performed by an outside engineering consulting firm in 1989, which was also available to the authors.

All buildings owned or operated by the university where part of the original scope of the study but in the end 126 building comprised the survey. The occupancy groups included industrial, classroom, laboratory, medical, office and sports facilities. The floor areas of the buildings ranged from 80 square feet to 600,000 square feet with a median size of 41,500 square feet. The number of occupants ranged from 0 to 45,000 people. The earliest building was built in 1900 and the latest was in 2006 with half of the buildings being built before 1967.

The data for the survey was mainly collected from various offices on campus by research assistants. This data included floor areas, occupancy loads, occupancy types, existence of hazardous materials and the determination on how hazard-

Building Name	Fletcher Building
Building Number	83
Total Floor Area	76153
Year Built	1965
Non-Structural Score	5.00
Life Safety Percentage	75.0%
Property Percentage	25%
Function Percentage	50%

Non-Structural Scores

Category	Description	Points
Base Score based upon Occupancy	0 to 10 people = +10 pts. 11 to 100 people = +9 pts 101 to 1000 people = +8 pts. 1001 to 10,000 people = +7 pts Greater than 10,001 people = + 6pts.	5
		5
Life Safety		
Occupancy	Hours of Occupancy Greater than 15 hrs. per day = -0.25	-0.25
	Inability of occupants to egress on their own = -0.25	0
Hazardous Materials	Hazard to people in building = -0.5 Hazard to Campus -0.75 Hazard to Greater Population = -1.0	0 -0.75 0
Falling Hazards	Shelving and content = -0.25 pts.	-0.25
	Pre-1974 Construction = -0.25	-0.25
Property		
Content	Large Monetary Value = -.05	0.
	Very Important Content -= -0.5	0
Non-Structural Damage	Ductile Structure = -0.5 pts.	0
	Pre-1974 Construction = -0.5	-0.5
Function		
Importance	Important to Campus = -0.5 Important to Region -1.0	-0.5 0
Ability to operate without connection to outside community	Can partially function = -0.5 Can not function = -1.0	0. 0 -0.5
Totals		5.00

Notes

Building Name	Library
Building Number	86
Total Floor Area	508094
Year Built	1965
Non-Structural Score	5.00
Life Safety Percentage	25.0%
Property Percentage	50%
Function Percentage	75%

Non-Structural Scores

Category	Description	Points
Base Score based upon Occupancy	0 to 10 people = +10 pts. 11 to 100 people = +9 pts. 101 to 1000 people = +8 pts. 1001 to 10,000 people = +7 pts. Greater than 10,001 people = + 6pts.	5
		5
Life Safety		
Occupancy	Hours of Occupancy Greater than 15 hrs. per day = -0.25	0
	Inability of occupants to egress on their own = -0.25	0
Hazardous Materials	Hazard to people in building = -0.5 Hazard to Campus -0.75 Hazard to Greater Population = -1.0	0 0 0
Falling Hazards	Shelving and content = -0.25 pts.	-0.25
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Property		
Content	Large Monetary Value = -.05	-0.5
	Very Important Content -= -0.5	0
Non-Structural Damage	Ductile Structure = -0.5 pts	0
	Pre-1974 Construction = -0.5	-0.5
Function		
Importance	Important to Campus = -0.5 Important to Region -1.0	0 -1
Ability to operate without connection to outside community	Can partially function = -0.5 Can not function = -1.0	0 0. -0.5
Totals		5.00

Notes

Figure 3 – RVS-NS Evaluation of Two Buildings with the Same Non-Structural Score

ous it was, the year of construction, the value of content, they type of structural system, and the building's importance to the campus, the city and the state. This data was collected from Summer 2006 to Summer 2007 and the evaluation of that data was completed in August 2007.

The Non-Structural Scores where the primary evaluation tool used on the 126 buildings. The median score was 6.25 points with the high score being a 9.25 points and the low score being a 3.0 points. Using statistical methods to analyze this data, the buildings were categorized into three areas: Buildings of Considerable Concern, Buildings within a Normal Range of Concern, and Buildings of Little Concern. The number of buildings in each of these categories was 15, 88, and 23 respectively.

The 15 Buildings of Considerable Concern belong to five occupational types: Sports, Theater, Classroom, Educational / Laboratory, Administrative, and Retail. The sport facilities accounted for a third of these buildings. These buildings tend to be high occupancy, expensive buildings that are important to the university in terms of revenue and important to the city and region as large emergency evacuation centers. In all cases, it was the Function Percentage that controlled these buildings. Four educational / laboratory facilities were of considerable concern with life safety being the determining factor for all them. Each of these building contains hazardous material that varied in there degree of hazard. The classroom building and one of the retail buildings were loss of property concerns and the last two buildings were loss of function issues.

In comparing this study to the earlier RVS study of 1989, one building was on both lists for buildings of concern. This building was the university bookstore, which was built, in 1960 of mainly unreinforced masonry. It was a concern to the engineers because of its structural system and it was a concern to the architects because of the potential loss of function to the university. Many of the other buildings of concern to the architects where built in the post-war era and were built with steel moment frames. These buildings did not concern the engineers since they were of little danger of collapse. They were of issue from a non-structural standpoint since they are very ductile and many of them predate the 1973 Uniform Building Code changes having to do with the bracing of non-structural elements. The buildings of concern to the engineers but not to the architects tended to also be post-war buildings but those make of concrete or steel with masonry infill. These were of less concern from a non-structural basis since these building contained fewer people, less expensive equipment, and/or few hazardous materials.

Combining the RVS and the RVS-NS studies for the university, there are 22 buildings of concern. It was the recommendation of the study team that the university should examine these buildings more closely to determine which are truly of concern.

CONCLUSIONS

The Rapid Visual Screening for Non-Structural Elements seems to be potentially as powerful as a tool as the Rapid Visual Screen for Structural Elements has been for the last 20 years. The initial study indicates that even though the RVS-NS uses much of the same data as the RVS method, the analytic techniques provide additional information beyond the scope of the RVS method and therefore provide a broader picture of the true dangers due to an earthquake. The RVS-NS needs to be run on other building samples and by other researchers to test its potential. The entire subject of non-structural evaluation techniques also needs to be discussed. Copies of the RVS-NS evaluation form can be downloaded at www.arch.utah.edu/tripeny/earthquake/RVS_NS.pdf .

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