Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 457

COMPARISON OF SEISMIC EVALUATION METHODS FOR NONSTRUCTURAL SYSTEMS IN CANADA AND THE USA

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ABSTRACT

Seismic evaluation of nonstructural systems in buildings is the first stage in seismic risk mitigation projects. This procedure is particularly important for existing buildings with higher performance levels, such as post disaster facilities and those, which must operate continuously during and after an earthquake.

This paper compares the seismic evaluation methods in the US and Canada by studying the ASCE/SEI 31-03 and CSA S832-06 standards and their applications. The first step in a seismic evaluation procedure is field data extraction. In this step all the nonstructural components associated with mechanical, electrical, telecommunication and other systems in the project are visually reviewed and necessary data are gathered. This information along with other site and structural specific parameters are used to produce the seismic evaluation. This report includes the seismic restraint solution and associated checklists for each nonstructural component when using ASCE 31. With CSA S832, the output is a relative seismic risk rating number. The seismic evaluation of nonstructural system follows the same conceptual purposes in both ASCE31 and CSA-S832 standards but outputs are different.

The seismic evaluation of nonstructural components for larger scale projects such as hospitals, airports and central heating and cooling plants can be a real challenge due to the massive amount of data that must be entered. The seismic risk mitigation process for these projects is broken down into separate phases to avoid confusion. The numerical results obtained in CSA S832 helps engineers, authorities, building owners to review everything in a glance and leads them through the decision making process. The output from ASCE 31 helps the users to jump one step ahead and go to next phase of mitigation process, which is the seismic restraint solution.

In order to better understand the difference between the methodologies used in each standard and compare the results more precisely, two software, one for each standard, were designed. This paper compares and contrasts inputs and outputs for ASCE 31 and the Canadian CSA S832 standards. Both these applications were recently field tested on projects at the Memphis International Airport in Memphis, Tennessee and Public Works Canada's central heating and cooling plants in Ottawa, Ontario.

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Introduction

At the start of the seismic mitigation process for nonstructural components of buildings, an inventory of the items present is necessary. In larger facilities, this can be a daunting task involving hundreds of component types and thousands of total units or restraint points. To deal with this task, Canada and the US have developed two different approaches, to get the job done. The Canadian method using CSA S832-06, uses vulnerability and consequence assessments to develop a risk rating for seismic performance during an earthquake. The American ASCE/SEI 31-03 approach generates mitigation requirements based on a checklist tied to various performance objectives. The Canadian standard is more performance oriented, while the American is more prescriptive in nature.

Each of these two approaches has their stronger and weaker points. The advantage of the Canadian standard is that it generates a risk rating number for each nonstructural building component. From a seismic mitigation project scoping and budgeting point of view, this is very helpful, particularly for building managers and owners who, generally have not had time to acquire expertise in this area. They can select work to be done based on defined engineering analysis. For multi-year programs, which most are, the highest risks can be mitigated first with the use of a logical priority system.

The American approach concentrates more on what needs to be done to achieve a desired seismic performance level. The checklist method allows for people with a wide variation in expertise to come to the same conclusion on the mitigation approach. As compared with the Canadian system where another design step is necessary, ASCE 31 presents a clear preliminary roadmap as to what to do. It does not set priority levels between the wide arrays of mitigation component options.

The following discussion takes the reader through the two basic methodologies of the Canadian and American approaches using software, which the authors developed and used in the field, most recently during projects at Public Works and Government Services Canada's central heating and cooling plants in Ottawa and at the Memphis International Airport facilities.

Seismic Risk Mitigation

Given the scale of a seismic risk mitigation program and the level of detail required, getting the sequence of elements correct is of critical importance. Our experience indicates that the following sequencing works to control costs and produce the highest seismic engineering performance:

- Facility component survey
- Seismic risk assessment (eg Canada) or Seismic evaluation (eg. USA)
- Mitigation project preliminary scoping and seismic engineering

- Costing of mitigation project and preliminary engineering
- Analysis and design of non-structural seismic restraints
- Installation and quality control.
- Progressive site inspections and quality assurance.

However the main focus of this paper is to review the elements of the second stage given in the list above. The seismic risk assessment (in Canada) and seismic evaluation (in the USA) are studied separately and the comparison and conclusion demonstrated after.

Seismic risk assessment of non-structural components in Canada

Seismic mitigation of non-structural components or OFCs (as they are called in CSA-S832) in Canada begins with seismic risk assessment. In the risk assessment stage a team of specialists (i.e. a structural engineer or a structural technologist trained by a structural engineer, an HVAC specialist, and an architect or architectural technologist) should participate. The parameters that should be considered vary, based on different building codes. For instance, in CSA S832-06 "Canadian Guideline for Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings," the parameters are divided into two main categories:

Vulnerability

The vulnerability of non-structural components can be defined as the probability of failure of the component during an earthquake. A component's vulnerability depends on the seismic forces and deformation applied to the equipment by the horizontal and vertical movement of the supporting structure or the structural elements. Table 1 provides the CSA S832-06 methodology for estimating a vulnerability rating score for non-structural components based on eight parameters. The last two columns in the table relate to the resultant risk rating for the example that follows the tables.

Consequences

The consequence of failure of any nonstructural component of a building during an earthquake is subject to the impact on life safety, building functionality and property. Table 2 provides the CSA S832 methodology for estimating the risk associated with the consequence of failure. The last two columns in the table are related to the resultant risk rating for the example that follows the tables.

Table 1. Vulnerability (CSA S832-06)

Vulnerability (V) Parameters and Rating Scores					
Parameters	Parameters Range	Rating Score (RS)	Weight Factor (WF)	Vulnerability Rating Score for the servers in Example 1 (RSXWF)	
				Server #1	Server #2
Restraint	Fully restrained	1	4		
	Partial or questionable restraint	5	4		
	No restraint	10	4	40	40
Impact/Pounding	Gap adequate	1	3		3
	Gap questionable or inadequate	10	3	30	
Overturning	Fully restrained against overturning	0	2		
	$h/d \leq 1/(2F_aS_a(0.2))$	1	2		
	$h/d > 1/(2F_aS_a(0.2))$	10	2	20	20
Flexibility and Location	Stiff or flexible OFC on or below ground floor	1	1		1
	Stiff OFC above ground floor	5	1		
	Flexible OFC above ground floor	10	1	10	
∑(RSXWF) =				100	64
Characteristics of Ground Motion	$RG=(F_aS_a(0.2))/1.25$ $S_a(0.2)$ is the 5%damped spectral response acceleration value for a period of 0.2 s, and the acceleration based site coefficient, F_a, as defined in the NBCC	$F_aS_a(0.2)$, ranges from 0.08 to 1.25.		0.71	0.71
Building Characteristics RB. $RB_{min}=1.0$ and $RB_{max}=1.5$.	This parameter is function of 2 variables. These variables are: Soil Type and Natural period of the structure. The range for RB = 1.0,1.1,1.2,1.3,1.4and1.5	For the Steel brace Frame & Site Class E		1.4	1.4
Vulnerability Rating Score, V = RG x RB x (∑(RSXWF) / 10)				9.94	6.36

Table 2. Consequences (CSA S832-06)

Consequences (C) Parameters and Rating Score				
Parameters	Parameters Range	Rating Score (RS)	Consequence Rating Score for Example 1	
			Server #1	Server #2
Life Safety	Threat to very few	1	1	1
	Threat to a few	5		
	Threat to many	10		
Functionality	Not applicable/not important or breakdown> 1week is tolerable	0		
	Somewhat important or breakdown of between 24 hours and 1 week is tolerable	1		
	Post-disaster facility according to NBC	5		
	Fully functional immediately after an earthquake	10	10	10
Consequences rating score, C=∑(RS)			11	11

Example 1:

Two IT servers (servers) are located on different levels of a four storey, steel structure in a hospital (See Figure 1 given below). The servers do not have any connection to the floor. The overturning ratio for both of the equipment are h/d=4 (h/d being height over depth ratio). Server #1 is located very close to a column on the 2nd floor, so the gap is considered questionable. Server #2 sits in the middle of the telecommunications and server room on the first floor, so the gap is considered adequate. The structure is located in Vancouver, (i.e. $S_a(0.2)=0.95$), and built on soft soils (Site class E) with a foundation factor $F_a=2.0$. The structure is designed with lateral load resistant elements such as cross bracing.

$S_a(0.2)=0.95$	5% damped spectral response acceleration (Appendix C, NBCC 2005)	(1)
Site Class=E		(2)
$F_a=0.94$	Foundation Factor (Table 4.1.8.4.A., NBCC 05)	(3)
$RG=(F_aS_a(0.2))/1.25$	(See Table 1)	(4)

RG=0.71 Characteristics of Ground Motion

Since $1/(2F_aS_a(0.2))=0.56$ and overturning ratio=4.0

$\therefore h/d > 1/(2F_aS_a(0.2))$	(See Table 1)	(5)
$T=0.025h_n$ T is Natural period of the structure and h_n= 12.4m (See Fig. 1)	(4.1.8.11. NBCC 05)	(6)
T=0.3sec		
Since the structure is steel braced frame, $0.2< T\leq 0.5$ and site class is E	(See Table 8 in CSA S832-06)	
$\therefore$ RB= 1.4 Building Characteristics	(See Table 1)	(7)
V=RG x RB x (∑(RS x WF)/10)	(See Tables 1 and 3)	(8)
C=∑(RS)	(See Tables 2 and 3)	(9)
Risk=VxC	(See Table 3)	(10)

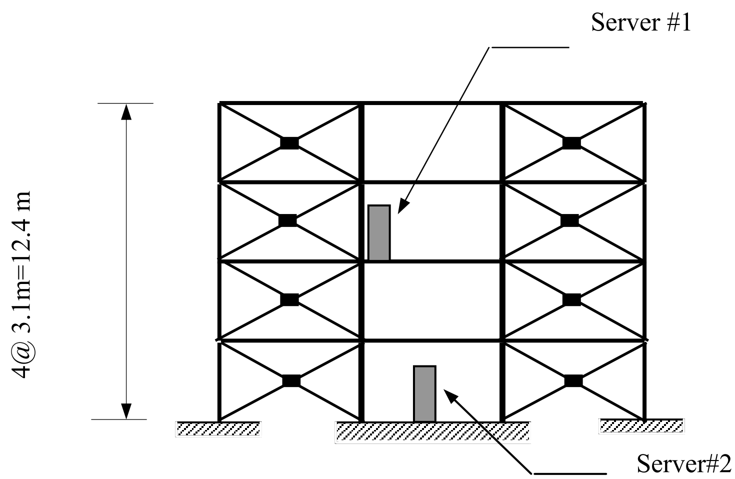

Figure 1.A four storey steel structure hospital as explained in Example 1 and Example 2

Table 3.Comparison of the Risk Assessment Results for the two Server Racks in Exampl**e 1**

Risk Assessment Calculations	Server Rack #1	Server rack #2
V = RG x RB x (∑(RSXWF) / 10)	V=9.94	V=6.63
C=∑(RS)	C=11	C=11
R=V x C	R=109	R=73

As can be seen server # 1 has a higher risk index and may be considered for restraint prior to server # 2.

Seismic evaluation of nonstructural components in United States

The main reference for seismic evaluation in United States is standard ASCE 31-03. This standard defines a unique Tier system of evaluation for both structural and non-structural components in a building. The evaluation is defined in a "checklist" format. The checklists include methods of seismic mitigation for a variety of nonstructural components. The checklists are prescriptive and can be categorized based on existing conditions, weight ranges, functionality and location of nonstructural components. The checklists are divided to 3 different types: "Basic", "Intermediate" and "Supplemental". The required checklist for nonstructural components in a specific project is a function of the "Level of Seismicity" and "Level of Performance" (See Table 4 for more detail).

Table 4.Checklist required for seismic evaluation nonstructural components (ASCE 31-03)

Level of Seismicity	Level of Performance	Required Checklists for Nonstructural Components		
		Basic	Intermediate	Supplemental
Low	Life Safety (LS)			
	Immediate Occupancy (IO)	√		
Moderate	Life Safety (LS)	√		
	Immediate Occupancy (IO)	√	√	
High	Life Safety (LS)	√	√	
	Immediate Occupancy (IO)	√	√	√

The first step in seismic evaluation based on ASEC 31-03 is to obtain these two parameters:

- Level of Seismicity
- Level of Performance

Level of Seismicity

Level of seismicity in ASCE 31-03 is based on ATC-14, FEMA 17 and MCEER documents. In summary Level of Seismicity can be defined as a function of the following variables:

- Design short-period spectral response acceleration parameter: S_{DS} (Sec.3.5.2.3.1 ASCE 31-03)
- Design spectral response acceleration parameter at a one-second period: S_{D1} (Sec.3.5.2.3.1 ASCE 31-03)

Table 5.Level of Seismicity (Design Spectral Acceleration S_{DS} and S_{D1} used in this table are based on ground acceleration)

Level of Seismicity	S_{DS}	S_{D1}
Low	<0.167g	<0.067g
Moderate	≥0.167g <0.500g	≥0.067g <0.200g
High	≥0.500g	≥0.200g

To find S_{DS} and S_{D1} the steps given below should be followed. The obtained numerical values for each parameter result from the required calculation for the Servers in the above mentioned example assuming the hospital is located in Memphis, TN (as it is explained in Example 2 given below).

S_S =1.50 The mapped spectral accelerations for short periods (ASCE 7-05). (11)

$S_1 = 0.75$	The mapped spectral accelerations for a 1-second period (ASCE 7-05).	(12)
Site Class= D	Site Class Considered as D or stiff soil (Table 20.3-1ASCE 7-05)	(13)
$F_a = 1$	Site Coefficient (Table 11.4-1 ASCE 7-05)	(14)
$F_v = 1.5$	Site Coefficient (Table 11.4-2 ASCE 7-05)	(15)
$S_{MS} = F_a S_s$ $S_{MS} = 1.5$	The maximum considered earthquake spectral response acceleration for short periods (ASCE 7-05).	(16)
$S_{M1} = F_v S_1$ $S_{M1} = 1.125$	At 1-second period, S_{M1}, adjusted for site class effects (ASCE 7-05).	(17)
$S_{DS} = 2/3\ S_{MS}$ $S_{DS} = 1.00g$	The design spectral response acceleration at short periods (ASCE 7-05).	(18)
$S_{D1} = 2/3\ S_{M1}$ $S_{D1} = 0.75g$	The design spectral response acceleration at 1 second period (ASCE 31)	(19)
$S_{DS} \geq 0.5g$ $S_{D1} \geq 0.2g$	→Seismicity=High (ASCE 31)	(20)
$T = C_t h_n^{\beta}$	Fundamental period in the direction under consideration (ASCE 31 Equation 3-8)	(21)
$C_t = 0.02$	Based on definitions in (ASCE 31 Equation 3-4 And ASCE 7-05 Equation 11.4-6).	(22)
$h_n = 40ft$	Based on definitions in (ASCE 31 page 3-14).	(23)
$\beta = 0.75$	Based on definitions in (ASCE 31 page 3-14).	(24)
$T = 0.3sec$	Natural period of structure in example 2	
$S_a = S_{D1}/T$	Spectral Acceleration (ASCE 31 Eq. 3-4 And ASCE 7-05 Eq.11.4-6).	(25)
$S_a = 1.00g$	S_a shall not exceed S_{DS}	(26)

Level of Performance

Two levels of seismic performance, Life Safety (LS) and Immediate Occupancy (IO), are defined in the ASCE 31-03 Standard. In another ASCE standard (ASCE 41-06 Seismic Rehabilitation of Existing Buildings), the levels of seismic performance are divided into 4 levels: Collapse Prevention, Life Safety and Immediate Occupancy and Operational Performance. In this paper our main purpose is to show the methodology of seismic evaluation based on the ASCE 31-03 standard. The rehabilitation of nonstructural components should be done after the seismic evaluation stage is completed. Seismic performance levels need further discussion and are beyond the scope this paper.

Example 2:

Assume the hospital in Example 1 is located in Memphis, TN. The obtained value for seismicity is high. By selecting Immediate Occupancy as the level of performance for this project, the Required Checklists for Nonstructural Components based on Table 4 given above would be: Basic, Intermediate and Supplemental. Suggested seismic mitigation solutions based on required checklist in ASCE 31 can be listed in table 6 as given below:

Table 6.Required checklist and relating seismic mitigation solutions

Checklist	Component	Seismic mitigation solutions
Basic	Mechanical and Electrical Equipment-DETERIORATION	There shall be no evidence of deterioration, damage, or corrosion in any of the anchorage or supports of mechanical or electrical equipment. (Tier 2: Sec. 4.8.12.3)
Intermediate	Mechanical and Electrical Equipment-VIBRATION ISOLATORS	Not Applicable (Equipment in the example is not on vibration isolators)
Supplemental	Mechanical and Electrical Equipment-ELECTRICAL EQUIPMENT	Electrical equipment and associated wiring shall be laterally braced to the structural system. (Tier 2: Sec. 4.8.12.7)

As can be seen from Table 6 the suggested seismic solutions based on ASCE 31 should be provided for both servers in this project, regardless of their locations in the building.

Conclusion

The intention of this paper is to demonstrate the methodologies used in the risk assessment process based on CSA S832 and seismic mitigation evaluation based on the ASCE 31 standard for nonstructural components in Canada and the USA. The two examples provided throughout this paper show the process defined in each standard. In summary the seismic risk assessment based on CSA S832 yields a numerical value, which is an indication of a risk index associated with a specific nonstructural component in a building during an earthquake. However the seismic evaluation obtained based on ASCE 31 is prescriptive and suggests seismic mitigation solutions.

Seismic mitigation is a function of site dependent variables and generalizing the solution is a challenging task that requires a unique methodology. A potential methodology can be defined based on practical knowledge in seismic restraint fabrication and installation as well as years of engineering practice (Mohseni and Ventura) and (Lewis, Mohseni and Dekoning), which is beyond the scope this paper.

There are several mitigation approaches which exist that are not part of the list included in ASCE 31. For example relocation of the nonstructural component is not an option applicable in ASCE 31, while it is a valid mitigation technique according to CSA S832. By comparing the two standards (CSA S832 versus ASCE 31) it can be seen that the risk assessment stage is eliminated in ASCE 31. For larger projects such as hospitals, airports, central heating and cooling plants with thousands of nonstructural components, where the mitigation process takes years to be completed, a priority generating system based on risk associated with each component, is very useful for budgeting and project management purposes.

The result of the seismic risk assessment based on CSA S832 yields a list of nonstructural components that can be restrained in different phases of a mitigation project. The list should be initially sorted, based on seismic risk index, but the building owner can affect the priority of the restraint installation during the decision making process. The selection of priorities for seismic restraint installation should be done under the engineer of the record's supervision for a specific project. The separation of risk assessment and seismic mitigation stages may result in a tendency for delay in the mitigation process. These issues should be further discussed in CSA S832.

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