The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China

Seismic Risk Assessment of Operational and Functional Components for New and Existing Buildings

MICKW WANG, P.Eng. [1]

[1] *Principal, M.WANG Engineering Ltd.,Canada*
Email:m.wang.engineering@telus.net

ABSTRACT :

CSA Standard S832-06 "Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings" represents the latest development and practice in the mitigation of seismic risk of operational and functional components (OFC) of buildings in Canada. This standard covers the seismic design provisions for OFCs in the 2005 National Building Code of Canada. Of particular interest is the seismic risk assessment procedure presented in the standard. This seismic risk assessment procedure combines requirements of the building code with a practical approach in seismic risk assessment methodology. This paper will present the CSA S832 seismic risk assessment procedures with practical applications to demonstrate the capabilities of the assessment and how it can be used in both new and existing buildings as a valuable tool in identifying and prioritizing OFCs in a seismic risk mitigation project. Assessment results are standardized and can be compared directly to results of OFCs seismic risk assessments made in different cities in other seismic regions.

KEYWORDS: S832-06, Operational and Functional Components, OFC, Seismic risk, Assessment

1. INTRODUCTION

Earthquake losses to life and properties are not restricted to building damages only. Recent studies clearly points to failure of building components and damage to building contents as the major contributing factor to the overall cost of an earthquake. CSA S832-06 was developed to address this issue.

2. WHAT ARE OPERATIONAL AND FUNCTIONAL BUILDING COMPONENTS?

Operation and functional components in a building include architectural components, building service components and building contents. Figure 1 is an illustration showing some common OFCs found in a building.

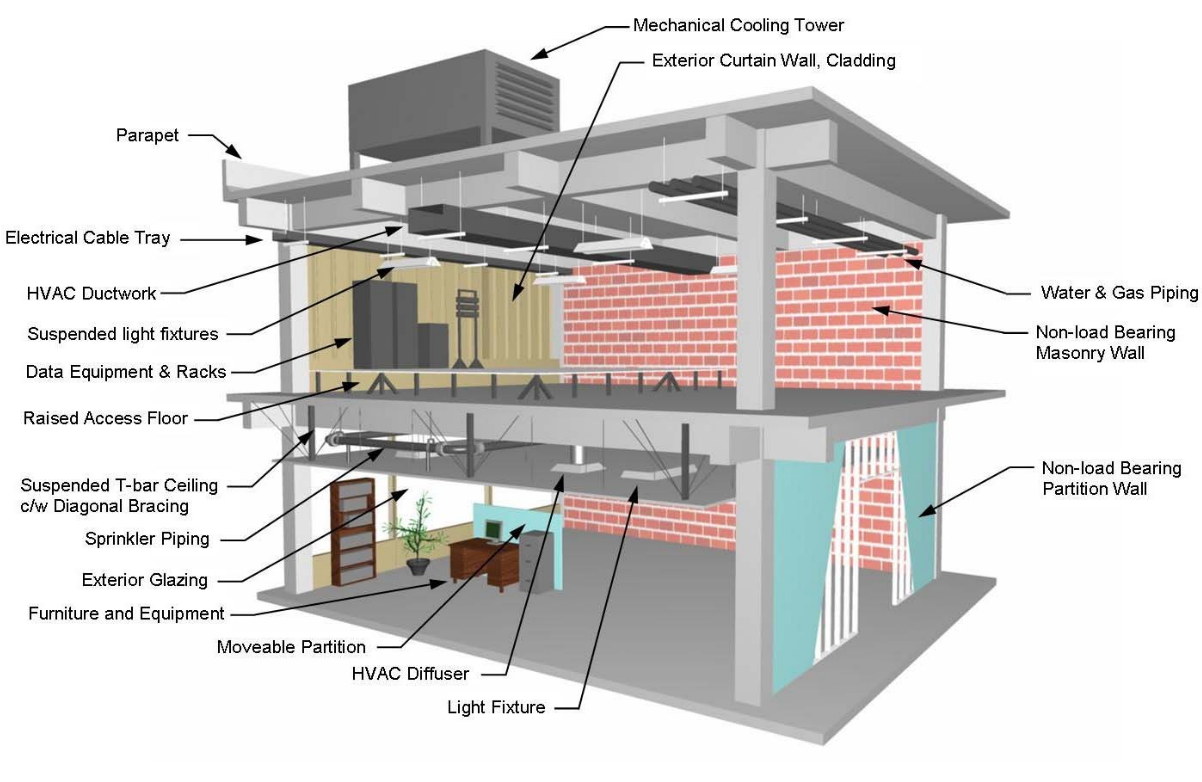

Figure 1 - Examples of Operational and Functional Components of Buildings

In a moderate size building, the number of OFCs can be in the thousands. The sheer quantity of OFCs can easily overwhelm efforts to control the level of damage in an earthquake. It is obvious that a simple and accurate method of risk assessment will be beneficial to quickly and effectively determine the type of risk involved and provide a priority list to organize the risk mitigation effort.

3. THE CSA S832-06 SEISMIC RISK ASSESSMENT PROCEDURE

A technical committee on seismic risk reduction was established in 1997 to meet the growing demand for seismic risk mitigation. During the early development phase, the committee recognized the need to redirect efforts in seismic engineering research and awareness in the area of non-structural building components. The term non-structural appeared to trivialize the importance of these building components. It was decided to adopt the term "Operational and Functional Building Components" to better represent the importance of these building elements. The standard introduced a seismic risk assessment procedure to alleviate the difficult task of dealing with numerous pieces of equipment/systems within a building and to assist the risk mitigation process by ranking OFC seismic risk using a relative scale rating system.

The assessment procedure is a useful tool for both new and existing buildings. New construction includes OFCs in new buildings, tenant improvement and owner supplied building contents. The assessment procedure provides information in structural system selection, site selection, equipment layout and arrangement, floor layout and even furniture arrangement. Seismic risk can be substantially reduced by planning ahead. In existing buildings, the assessment procedure provides a listing of OFCs and their corresponding seismic risk index. This list can form the basis of a risk mitigation program to prioritize an action plan.

3.1 Seismic Risk Index (R)

Seismic risk index is defined as the product of OFC seismic risk vulnerability index (V) and loss of function consequence index (C). The assessment procedure keeps in step with the current building code seismic requirements by including in the vulnerability index ground characteristics and building characteristics.

3.2 Vulnerability Index (V)

OFC vulnerability is defined as a function of four parameters; OFC restraint, potential impact/pounding, overturning and OFC location and construction. Table 1 shows the parameters used to determine the vulnerability index.

Determination of vulnerability index, V*, for OFCs
(See Clauses 3.1, 3.2, 10.2.5, B.1, B.4, and C.2.2 and Annex G.)

Vulnerability parameters	Parameter range	Rating scale (*RS*)	Weight factor (*WF*)
OFC restraint (*RS1*) (see Annex G for explanatory notes on restraint)	Full restraint	1	4
	Partial restraint or questionable restraint	5	4
	No restraint	10	4
Impact/pounding (*RS2*) Impact, pounding, and/or displacement-sensitive OFC (see Annex E for information on infill)	Gap adequate	1	3
	Gap questionable or gap inadequate	10	3
OFC overturning (*RS3*) h = distance from support or restraint to centre of gravity or top of the OFC d = horizontal distance between OFC supports F_a = acceleration-based site coefficient S_a = spectral response acceleration value	OFC fully restrained against overturning	0	2
	$h/d \le 1/(2F_aS_a(0.2))$	1	2
	$h/d > 1/(2F_aS_a(0.2))$	10	2
OFC flexibility and location in building (*RS4*)†	Stiff or flexible OFC on or below ground floor	1	1
	Stiff OFC above ground floor	5	1
	Flexible OFC above ground floor	10	1
Element characteristics	$RE_{i=1,4} = \Sigma(RS \times WF)$‡		
Ground characteristics *RG*§ = characteristic of ground motion and soil condition, expressed as the product of the 5% damped spectral response acceleration value for a period of 0.2 s, $S_a(0.2)$, and the acceleration-based site coefficient, F_a, as defined in the *NBCC*	$RG = F_aS_a(0.2)/1.25$		
Building characteristics *RB*** is based on the predominant type of lateral-force-resisting system of the building structure	Frame structures and all other types of structures	See Table 8	

**Vulnerability index is calculated using* V = RG × RB × RE/10
†*Stiff OFCs shall be defined as those having a fundamental period for the OFC and its connection less than or equal to* 0.06 s. *Flexible OFCs shall be defined as those having a fundamental period for the OFC and its connection greater than* 0.06 s.
‡*See Clause B.4.2 for an explanation of element characteristics,* RE.
§*See Clause B.4.3 for an explanation of ground characteristics,* RG.
***See Clause B.4.4 for an explanation of building characteristics,* RB.

Table 1

3.3 Consequence Index (C)

Consequence index is the consequence of failure of the OFC resulting in risk to life safety either directly or indirectly through loss of function. Table 2 shows the parameters used to determine the consequence index.

Determination of consequences index, C^*, for OFCs
(See Clauses 10.2.5 and A.3 to A.6.)

Consequence parameters	Parameter range	Rating scale (*RS*)
Life safety Impact on life safety from malfunction or failure of OFC during and immediately after the earthquake (e.g., items falling on or crushing people, blocking of egress, potential for fire or explosion, loss of life-support systems in hospitals, or release of toxic materials)	Threat to very few ($N \leq 1$)†	1
	Threat to few ($1 < N < 10$)†	5
	Threat to many ($N \geq 10$)†	10
Functionality OFC is required for post-disaster functions or for immediate occupancy following an earthquake	Not applicable/not important or breakdown > 1 week is tolerable	0
	Somewhat important or breakdown of 24 h to 1 week is tolerable	1
	Post-disaster facility according to the *NBCC*	5
	Fully functional immediately after earthquake	10

**Consequences index is calculated using $C = \Sigma(RS)$.*
†N = area × occupancy density × duration factor

where
N = occupancy factor as defined in Table L-5, Commentary L of User's Guide — NBCC Structural Commentaries (Part 4)
area = occupied area exposed to risk, m²
occupancy density = persons per m² *as defined in Table L-6, Commentary L of* User's Guide — NBCC Structural Commentaries (Part 4)
duration factor = average weekly hours of human occupancy/100 ≤ 1.0
Note: *The seismic risk of OFCs can be influenced by non-seismic parameters such as the special need for property protection arising from direct or indirect financial loss, heritage value of OFCs, etc., as determined by the owner/operator. Consequently, the final level of seismic risk and mitigation priority of OFCs can be affected by the owner/operator's input to the seismic risk assessment.*

Table 2

4. SAMPLE APPLICATION OF THE CSA S832-06 SEISMIC RISK ASSESSMENT PROCEDURE

The building in Figure 1 will be used as the sample building. This building is a two storey reinforced concrete moment frame building located in Victoria, British Columbia, Canada. To demonstration the ability to compare relative risk for OFCs in different seismic region, the same assessment is repeated using the same OFCs in the same building located in Montreal, Quebec, Canada. The sample seismic risk assessment includes suspended acoustical ceiling on the ground floor, fire suppression piping in the ground floor ceiling space, a roof top cooling tower and non-load bearing masonry wall on the second floor.

4.1 Background Information

The building was designed in 1978 in accordance with the 1975 NBCC. The two storey building consists of reinforced concrete moment frames in both directions. The structure is founded on site class C soil in Victoria (Sa(0.2) 5% Damped spectral response acceleration, expressed as a ratio to gravitational acceleration, for a period of 0.2 second as defined in NBCC 2005 Sentence 4.1.8.4(1) = 1.2) and site class E soil in Montreal (Sa(0.2) = 0.69).

4.2 OFC Data and Characteristics

OFC data and characteristics are obtained from building plans and walk-down survey of the building. OFC locations are illustrated in Figure 1.

4.3 Seismic Risk Assessment

4.3.1 Suspended acoustical ceiling system

The suspended acoustical ceiling system is located on the ground floor. The ceiling system was installed meeting some of the requirements of ASTM E580-78. Perimeter hangers and stabilizer struts were omitted. The two floating sides did not have the gap required.

4.3.1.1 Vulnerability index (V)

Partial restraint or questionable restraint	5
Gap questionable or gap inadequate	10
OFC fully restrained against overturning	0
Flexible OFC above ground floor	10

4.3.1.2 Consequence index (C)

Threat to few	5
Somewhat important or breakdown of 24 hours to 1 week is tolerable	1

4.3.2 Fire suppression piping

The fire suppression piping in the ground floor ceiling space is not restrained and all the hangers were installed with drop-in type concrete expansion anchors.

4.3.2.1 Vulnerability index (V)

No restraint	10
Gap questionable or gap inadequate	10
OFC fully restrained against overturning	0
Flexible OFC above ground floor	10

4.3.2.2 Consequence index (C)

Threat to many	10
Post disaster functionality	5

4.3.3 Roof top cooling tower

The roof-top cooling tower is supported on vibration isolators. The isolators are not rated for seismic forces and they are not anchored to the roof slab. There is inadequate gap provided between the cooling tower and surrounding piping. The cooling tower location is not near the edge of the roof.

4.3.3.1 Vulnerability index (V)

No restraint	10
Gap questionable or gap inadequate	10
h/d < 1/(2FaSa(0.2))	1
Flexible OFC above ground floor	10

4.3.3.2 Consequence index (C)

Threat to very few	1
Somewhat important or breakdown of 24 hours to 1 week is tolerable	1

4.3.4 Non-load bearing masonry wall

The interior non-load bearing masonry wall on the second floor is not reinforced and is constructed tight to the concrete slab above and to adjacent wall/columns. Normal office occupancy is expected on each side of the wall.

4.3.4.1 Vulnerability Index

No restraint	10
Gap questionable or gap inadequate	10
h/d > 1/(2FaSa(0.2))	10
Flexible OFC above ground floor	10

4.3.4.2 Consequence Index

Threat to few	5
Somewhat important or breakdown of 24 hours to 1 week is tolerable	1

4.4 Seismic Risk Mitigation

Seismic risk mitigation for OFCs with seismic risk index less than 16 are considered optional. The limited benefit to risk reduction makes it less urgent than those with a higher risk index. This threshold is for buildings designed to meet normal performance only. Buildings required for post disaster functionality will require additional considerations.

Effectiveness of mitigation efforts are sometimes affected by the factors not directly related to the OFCs. High risk index score as a result of ground and building characteristics can be difficult and costly to achieve. The retrofit index is an indicator of the amount of retrofit that can be done for a given OFC. This index is presented as a percentage value and is useful in assessing the cost benefit of mitigation effort for an individual OFC.

5. APPLICATION

The information collected for the seismic risk assessment is ideally suited for use in data base application. Data collected can be grouped and sorted for analysis as shown in Tables 3 and 4 below. A variety of reports can be prepared for comparison, and strategic planning. Table 5 is a page from a sample mitigation status report.

SEISMIC RISK SUMMARY TABLE

Prepared For : **Presentation**
Project : **Sample Project for Building Comparison**
Building : **Sample Building, Victoria, BC**

June, 2008
Page 1 of 1

Operational Functional Component	Risk Parameter Scores	SEISMIC RISK / RETRO-FIT	Estimated Upgrade Cost	Photograph
OFC Description: ***Fire Suppression Piping*** Flr.: Ground Floor Rm.: Ground Floor Area Tag: (none) Detail No: SR100	Restraint 10, Gap 10, Overturning 0, Location 10, Vulnerability Score 8.45 Life Safety 10, Functionality 5, Consequence Score 15.00	**Seismic Risk Score :** 126.72 **Retro-fit Index :** 78% Upgrade optional	N/A	
OFC Description: ***T-bar Ceiling*** Flr.: Ground Floor Rm.: Ground Floor Area Tag: (none) Detail No: n/a	Restraint 5, Gap 10, Overturning 0, Location 10, Vulnerability Score 6.34 Life Safety 5, Functionality 1, Consequence Score 6.00	**Seismic Risk Score :** 38.02 **Retro-fit Index :** 57% Upgrade optional	N/A	
OFC Description: ***Cooling Tower*** Flr.: Roof Rm.: Roof Tag: (none) Detail No: SR102	Restraint 10, Gap 10, Overturning 1, Location 10, Vulnerability Score 8.66 Life Safety 1, Functionality 1, Consequence Score 2.00	**Seismic Risk Score :** 17.32 **Retro-fit Index :** 80% Upgrade optional	N/A	
OFC Description: ***Non-load Bearing Masonry Wall*** Flr.: Second Floor Rm.: Second Floor Area Tag: (none) Detail No: SR101	Restraint 10, Gap 10, Overturning 10, Location 10, Vulnerability Score 10.56 Life Safety 5, Functionality 1, Consequence Score 6.00	**Seismic Risk Score :** 63.36 **Retro-fit Index :** 100% Upgrade optional	N/A	

Prepared By : M.WANG Engineering Ltd. **Building Parameters :** **Sa02:** 1.2 **Fa:** 1 **Site Class:** C **RB:** 1.1

Table 3

SEISMIC RISK SUMMARY TABLE

Prepared For : **Presentation**
Project : **Sample Project for Building Comparison**
Building : **Sample Building, Montreal, QB**

June, 2008
Page 1 of 1

Operational Functional Component	Risk Parameter Scores	SEISMIC RISK / RETRO-FIT	Estimated Upgrade Cost	Photograph
OFC Description: ***Fire Suppression Piping*** Flr.: Ground Floor Rm.: Ground Floor Area Tag: (none) Detail No: SR103	Restraint 10, Gap 10, Overturning 0, Location 10, Vulnerability Score 8.04 Life Safety 10, Functionality 5, Consequence Score 15.00	**Seismic Risk Score :** 120.56 **Retro-fit Index :** 78% Upgrade optional	N/A	
OFC Description: ***T-bar Ceiling*** Flr.: Ground Floor Rm.: Ground Floor Area Tag: (none) Detail No: n/a	Restraint 5, Gap 10, Overturning 0, Location 10, Vulnerability Score 6.03 Life Safety 5, Functionality 1, Consequence Score 6.00	**Seismic Risk Score :** 36.17 **Retro-fit Index :** 57% Upgrade optional	N/A	
OFC Description: ***Cooling Tower*** Flr.: Roof Rm.: Roof Tag: (none) Detail No: SR105	Restraint 10, Gap 10, Overturning 1, Location 10, Vulnerability Score 8.24 Life Safety 1, Functionality 1, Consequence Score 2.00	**Seismic Risk Score :** 16.48 **Retro-fit Index :** 80% Upgrade optional	N/A	
OFC Description: ***Non-load Bearing Masonry Wall*** Flr.: Second Floor Rm.: Second Floor Area Tag: (none) Detail No: SR104	Restraint 10, Gap 10, Overturning 10, Location 10, Vulnerability Score 10.05 Life Safety 5, Functionality 1, Consequence Score 6.00	**Seismic Risk Score :** 60.28 **Retro-fit Index :** 100% Upgrade optional	N/A	

Prepared By : M.WANG Engineering Ltd. **Building Parameters :** **Sa02:** 0.69 **Fa:** 1.4 **Site Class:** E **RB:** 1.3

Table 4

OFC Seismic Mitigation Status Report

Printed : June 16, 2008

Sample Building, Victoria, BC			Seismic Risk		Upgrade Status				Detail Drawing No.
Location	OFC Tag	Description	Score	Level	Immediate	Future	None	Estimated Cost	
Ground Floor Area									
	(none)	Fire Suppression Piping	127	H	☑	☐	☐		SR100
	(none)	T-bar Ceiling	38	M	☐	☐	☑		n/a
			Selected :	$0	Balance:		Total:		
Roof									
	(none)	Cooling Tower	17	M	☐	☑	☐		SR102
			Selected :	$0	Balance:		Total:		
Second Floor Area									
	(none)	Non-load Bearing Masonry Wall	63	H	☐	☑	☐		SR101
			Selected :	$0	Balance:		Total:		

Sample Building, Montreal, QB			Seismic Risk		Upgrade Status				Detail Drawing No.
Location	OFC Tag	Description	Score	Level	Immediate	Future	None	Estimated Cost	
Ground Floor Area									
	(none)	Fire Suppression Piping	121	H	☑	☐	☐		SR103
	(none)	T-bar Ceiling	36	M	☐	☐	☑		n/a
			Selected :	$0	Balance:		Total:		
Roof									
	(none)	Cooling Tower	8	L	☐	☑	☐		SR105
			Selected :	$0	Balance:		Total:		
Second Floor Area									
	(none)	Non-load Bearing Masonry Wall	60	H	☐	☑	☐		SR104
			Selected :	$0	Balance:		Total:		

No. of items: 0 Total Estimated Cost:

Prepared By : M.WANG Engineering Ltd. Page 1 of 1

Table 5

6. CONCLUSION

CSA S832-06 seismic risk assessment is a simple and easy to use tool. It is now possible to compare seismic risk levels of OFCs in a building or in different buildings or different buildings in different seismic zones. Uniform and standardized seismic risk level can be established through out an organization. The OFC seismic risk score forms the basis of prioritized mitigation programs and action plan.

REFERENCES

CSA S832-06 (2006), Seismic Risk Reduction of Operational and Functional Components (OFCs) of Buildings, Canadian Standards Association, Mississauga, Ontario, Canada

NBC (2005), National Building Code of Canada, National Research Council of Canada, Ottawa, Ontario, Canada

ASTM E580-78 (1978), Standard Practice for Application of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Requiring Seismic Restraint, American Standards Association, West Conshohocken, PA, USA