Guideline for Seismic Risk Reduction of Functional and Operational Components of Buildings

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ABSTRACT

This paper is a progress report of the Technical Committee on Seismic Risk Reduction of Functional and Operational Components of Buildings, Guideline CSA S832-2000. The Guideline is intended as a technical tool and it is expected that the document will be further developed into a CSA standard. At the time of submission of this paper, the committee had met three times and produced a fifth draft version of the document. The paper presents the salient features of the Draft 5 Guideline : scope and objectives, seismic risk reduction strategy, risk assessment, mitigation options and priorities, evaluation methods and mitigation techniques.

INTRODUCTION

Definiton of FOC

Functional and Operational Components (FOC) of buildings include all components, other than the load-bearing structural components, which are required to provide the functional and operational characteristics of a building. They include architectural components, building services (mechanical, plumbing, electrical and telecommunication equipment) and building contents specific to the use and occupancy of the building as shown in Figure 1 (CSA 1999 DRAFT 5 – Figure 1.1).

Motivation for the Guideline

Seismic risk reduction of main structural components of buildings has received a lot of attention from the research community and earthquake-resistant design and upgrading procedures are widely available. This is not the case for FOCs. However, recent moderate and strong earthquakes have demonstrated that many building structures that survived an earthquake with no significant structural damage were practically unusable due to extensive damages to FOCs. It is also widely acknowledged that many life-threatening damages caused by earthquakes involve so-called non-structural building components and contents. Failure of FOCs, especially in the egress vicinities, poses dire consequence upon both the evacuation of occupants during an earthquake and the search and rescue operations after an earthquake. Another consideration is that when post-critical facilities are considered, the building must be able to continue to operate during an earthquake or at least resume its operations as soon as possible after the strong motion. The development of a CSA Guideline that addresses all of these important issues is therefore much needed.

History of development

The Guideline has evolved from an initiative of Public Works and Government Services Canada (PWGSC 1995) to publish an internal document titled *Guideline on Seismic Evaluation and Upgrading of Non-structural Building Components.* The document acknowledged the need for a comprehensive national standard for the seismic risk reduction of non-structural building components and was restricted to normal office buildings and libraries. It was developed in conjunction with the Institute of Research in Construction of the National Research Council of Canada (IRC/NRC) and the private sector. The Technical Committee of Guideline CSA S832-2000 was formed in September 1997 and will hold its fourth meeting in February 1999. DRAFT 5 (CSA 1999) serves as the basis for this communication. The Guideline is scheduled for completion and publication in 2000.

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SCOPE AND OBJECTIVES OF GUIDELINE CSA S832-2000

The Guideline provides (a) information and methodology to identify the FOCs whose failure modes and consequences due to earthquakes may require mitigation, and (b) design approaches to achieve adequate mitigation. It covers most buildings (new or existing, including renovations) with major occupancy classifications listed in Appendix A3.1.2 of the National Building Code of Canada 1995 (NRC/IRC 1995), such as office and residential buildings, schools, hospitals and laboratories. The structural integrity of the building itself due to earthquakes is covered by Part 4 of NBCC 1995. Heritage buildings and facilities of special occupancy such as museums, art galleries, jails, penitentiaries, prisons, laboratories, power plants and facilities containing hazardous materials are beyond the scope of the Guideline, whose general principles remain nonetheless valid. As indicated in Figure 1, lifeline systems and utilities inside the building are covered, together with their interfacing details at the building junction.

The Guideline is intended for use by building owners, building inspectors, facility managers, engineers, architects, and other stakeholders. It is expected that after extensive user review and application, the Guideline will evolve into a CSA Standard.

SEISMIC RISK REDUCTION STRATEGY

The Guideline recommends a three-step strategy: 1) To determine the seismicity for the building site; 2) To assess the seismic risk of the FOCs considering the seismicity of the building site and the potential consequences of failure or damage due to earthquakes; and 3) To take mitigation actions to reduce the effects of earthquakes on the FOCs. The first step is not covered by the Guideline as it is done according to the prescriptions of NBCC 1995 Part 4 for the foundations and the structural framework of the building. Steps 2 and 3 are the essence of the Guideline.

Proposed procedure:

The proposed procedure involves the following five steps:

1) The assessment team and the owner/operator set performance objectives for the facility;
2) The assessment team obtains an inventory of the FOCs;
3) The assessment team evaluates the seismic risk of each FOC;
4) The assessment team and the owner/operator review the initial risk assessment and the performance level of each FOC in order to decide on the need for mitigation actions.
5) Mitigation actions are planned and implemented.

Performance objectives

Performance objectives of FOCs are influenced by the needs of the owner/operator, the local building regulations, and economic factors. The performance objective of the building itself is also an important consideration, especially in post-disaster facilities that must remain functional and operational during and after an earthquake.

The first and foremost level of performance objective is **life safety**. Life-threatening failures of FOCs include: moving components that can seriously injure people, blockade of exit routes, and other secondary effects such as spillage or leakage of hazardous materials, and fires or explosions. The second level of performance objective is **immediate/continued occupancy** and is usually required in post-disaster facilities. At this level, the building is safe enough for occupancy but is not necessarily fully functional or operational. The third level of performance objective demands that the facility remain **fully operational** during and after the earthquake. Property protection may also be an important economic consideration for the owner/operator and an appropriate level of performance objective must be set for those especially valuable or strategic FOCs.

RISK ASSESSMENT

The risk assessment of each FOC deemed worthy of being evaluated, based on the performance objective of the facility and of the FOC itself, entails the evaluation of the combined effects of the seismic vulnerability of the FOC and its consequences of failure under the design earthquake. In order to rationalize this crucial phase of the evaluation, the Guideline proposes the use of a parametric method which consists of determining a seismic vulnerability rating (on a scale of 1 to 10) and a consequences rating (also on a scale of 1 to 10), and the product of these two scores provides the seismic risk rating. A final rating score of 1 to 16 represents LOW seismic risk, a rating of 16 to 49 is MODERATE and a rating of 49 to 100 is HIGH. The parametric method is illustrated in Tables 1 and 2 (CSA 1999 DRAFT 5 – Figures 6.5.1 and 6.5.2). It should be noted that the relative weight factors (WF) given in the tables are not final yet as the members of the Technical Committee are still in the process of validating and calibrating the method.

Seismic vulnerability (Table 1)

The seismic vulnerability relates to the likelihood of failure of the FOC. It depends on the characteristics of the ground motion expected during the design earthquake, the dynamic characteristics of the building, the seismic response of the building framework, the potential occurrence of dynamic interactions between the FOC and its supporting structural component, and pounding effects. If the final rating score is ≥ 1 and ≤ 4 then the vulnerability is LOW, if the score is > 4 and ≤ 7 then the vulnerability is MODERATE, and if the score is > 7 and ≤ 10 the vulnerability is HIGH.

Table 1 Vulnerability Rating for FOCs – Parametric Method

Vulnerability Parameters	**Rating Scale (RS)**		**Weight Factor (WF)**	**Rating Score (RSxWF)**
	Parameter range	**RS**		
Characteristics of ground motion and soil conditions. (Product of zonal velocity ratio, v, and Foundation factor, F, as defined in NBCC)	$v \times F < 0.10$	1	**2**	
	$0.10 \leq v \times F \leq 0.20$	5		
	$v \times F > 0.20$	10		
Dynamic characteristics of building. (Period of vibration of building, T, in seconds as defined in NBCC)	$T \geq 0.50$ s	1	**1**	
	$0.50 > T > 0.25$ s	5		
	$T \leq 0.25$ s	10		
Lateral force resisting system of building structure. (Force modification factor, R, as defined in NBCC table 4.1.9.1.B)	$R > 3$	1	**2**	
	$2 \leq R \leq 3$	5		
	$R < 2$	10		
FOC location in building. (Level 0 is ground)	Level 0	1	**1.5**	
	Between levels 0 to 2	5		
	Above level 2	10		
Size and weight of FOC. (FOC weight, W_p, expressed as a percentage of weight of supporting floor, wall, ceiling, W)	$W_p \leq 5\%$ W	1	**1**	
	$5\%\ W < W_p < 10\%\ W$	5		
	$W_p \geq 10\%$ W	10		
Connection details of FOC.	Appear robust	1	**1.5**	
	Appear doubtful	5		
	Obvious weakness	10		
Pounding/Impact effects. - Internal	Gap more than adequate	1	**1**	
	Gap adequate	5		
	Gap inadequate	10		
Pounding/Impact effects. - External	Gap more than adequate	1	**1**	
	Gap adequate	5		
	Gap inadequate	10		
		Sum (WF)		▨
			Sum (RSxWF)	
			FINAL RATING SCORE = $\frac{\text{Sum(RSxWF)}}{\text{Sum (WF)}}$	

Consequences of failure (Table 2)

The consequences of failure of an FOC depend on the weight and location of the component in the building. Heavy units located on higher level floors are more likely to be subjected to important accelerations (as assessed in Table 1) and therefore more likely to be damaged if not properly restrained. Overturning of a large FOC is particularly critical in relation to size and location. The consequences of failure of the FOC are also related to the use and occupancy classification of the facility and the impact on the building functionality if the FOC were to fail. Effects on life safety have the most importance. The final rating score follows the same scale as the seismic vulnerability rating score, i.e. 1 to 4 is LOW, 4 to 7 is MODERATE and 7 to 10 is HIGH.

Table 2 Consequences Rating for FOCs – Parametric Method

Consequences Parameters	**Rating Scale (RS)**		**Weight Factor (WF)**	**Rating Score (RSxWF)**
	Parameter range	**RS**		
FOC location in building. (Level 0 is ground)	Level 0	1	1.5	
	Between levels 0 to 2	5		
	Above level 2	10		
Weight of FOC. (FOC weight, W_p, expressed as a percentage of weight of supporting floor, wall, ceiling, W)	$W_p \leq 5\%$ W	1	1	
	5% W < W_p < 10% W	5		
	$W_p \geq 10\%$ W	10		
Overturning of FOC. (Height of center of gravity of FOC above floor, CG, relative to the shortest horizontal distance, H, between supports)	CG ≤ 0.5H	1	1	
	0.5H < CG < 0.75H	5		
	CG ≥ 0.75H	10		
Building occupancy. - Impact on life safety from failure of FOC.	No or minimal injury	1	3	
	Moderate injury and hospitalization	5		
	Serious injury or death	10		
Building occupancy. - Impact on building functionality from failure of FOC.	No or minimal functional loss	1	2	
	Some or moderate functional loss	5		
	Major breakdown in function	10		
		Sum (WF)		
			Sum (RSxWF)	
			FINAL RATING SCORE = $\frac{\text{Sum(RSxWF)}}{\text{Sum (WF)}}$	

MITIGATION OPTIONS AND PRIORITIES

Mitigation options for FOCs requiring a reduction or elimination of the potential hazards from earthquakes can be classified in four categories, the " 4 R's" : Restrain, Relocate, Remove, or Replace. Top mitigation priority should be given to FOCs whose consequences of failure are a threat to life safety. However, once life safety is ensured, the owner/operator may influence the order of priority obtained with the seismic risk rating. In situation where the risk is about the same, the Guideline recommends that priority be given to FOCs with highest consequences of failure rating.

EVALUATION METHODS

In many cases, the optimum mitigation option is not obvious and it is necessary to evaluate the seismic response of the FOC in order to make a decision. For instance, if the component needs to be restrained, adequate restraining measures have to be designed and detailed. The Guideline recognizes that prescriptive methods, essentially typical details published in industry guidelines, may be sufficient for components whose behaviour is well understood. However, not many specialized industry guidelines exist for FOCs specifically located inside buildings.

Analytical methods, either simplified static methods or more refined dynamic methods, are reviewed by Villaverde (1997). Research is still needed in the field to develop methods that are rational and accurate but simple enough to be included in codes of practice. The Guideline reviews the simplified methods proposed in the NBC 1995 (NRC/IRC 1995) and discussed in Commentary J Part 4 of the NBC (NRC/IRC 1996). These methods consist of calculating an equivalent lateral inertia force, V_p, for the design of the connections of the FOC to the structural framework, or the lateral displacements of the FOC, D_p, in order to avoid potential pounding effects and deformation damages. Vertical accelerations may pose a problem for many types of FOCs and the analysis should not be restricted to horizontal effects. The Guideline gives a comprehensive list of various categories of FOCs (architectural, mechanical, electrical and communications, furnishing and building contents) with the analysis criteria that should be accounted for in their evaluation, i.e. force effects, displacement effects, or prescriptive measures. It should be noted that the Guideline cautions its users against the application of the simplified and prescriptive methods to heavy FOCs when $W_p \geq 20\%$ of the total weight of the floor where the FOC is located or $W_p \geq 10\%$ of the total weight of the structure: such components require dynamic analysis.

MITIGATION TECHNIQUES

The rest of the Guideline concentrates on the mitigation technique of restraining the FOC, since the other techniques (removal, replacement or relocation) are self-explanatory. A lot of details are given for each of the major component categories of FOCs defined in Figure 1, which pertain to the typical problems anticipated, specific restraining techniques, impacts of the mitigation measure on the response of the structure or other FOCs, examples of calculations, sketches and photographs. For example, in the building contents category, there is an entry for tall library shelving and bookcases that can slide and/or overturn during an earthquake, or books or materials can fall from shelving thus creating a hazard. The suggested mitigation technique is to anchor the shelving and the bookcase to a structural component in order to prevent sliding and overturning and to provide restraint to the books and materials to prevent them from falling. This action will have an impact on the supporting structure, which must be able to resist the inertia forces acting on the FOC and transferred through the connections.

CONCLUSION

This paper is a brief summary of the progress done to date by the Technical Committee of Guideline CSA S832-2000 on Seismic Risk Reduction of Functional and Operational Components (FOC) of Buildings. It is expected that after extensive user review and application, the Guideline will evolve into a CSA Standard. Hopefully, the Guideline will also foster some research initiatives which are essential to the solution of such an important problem.

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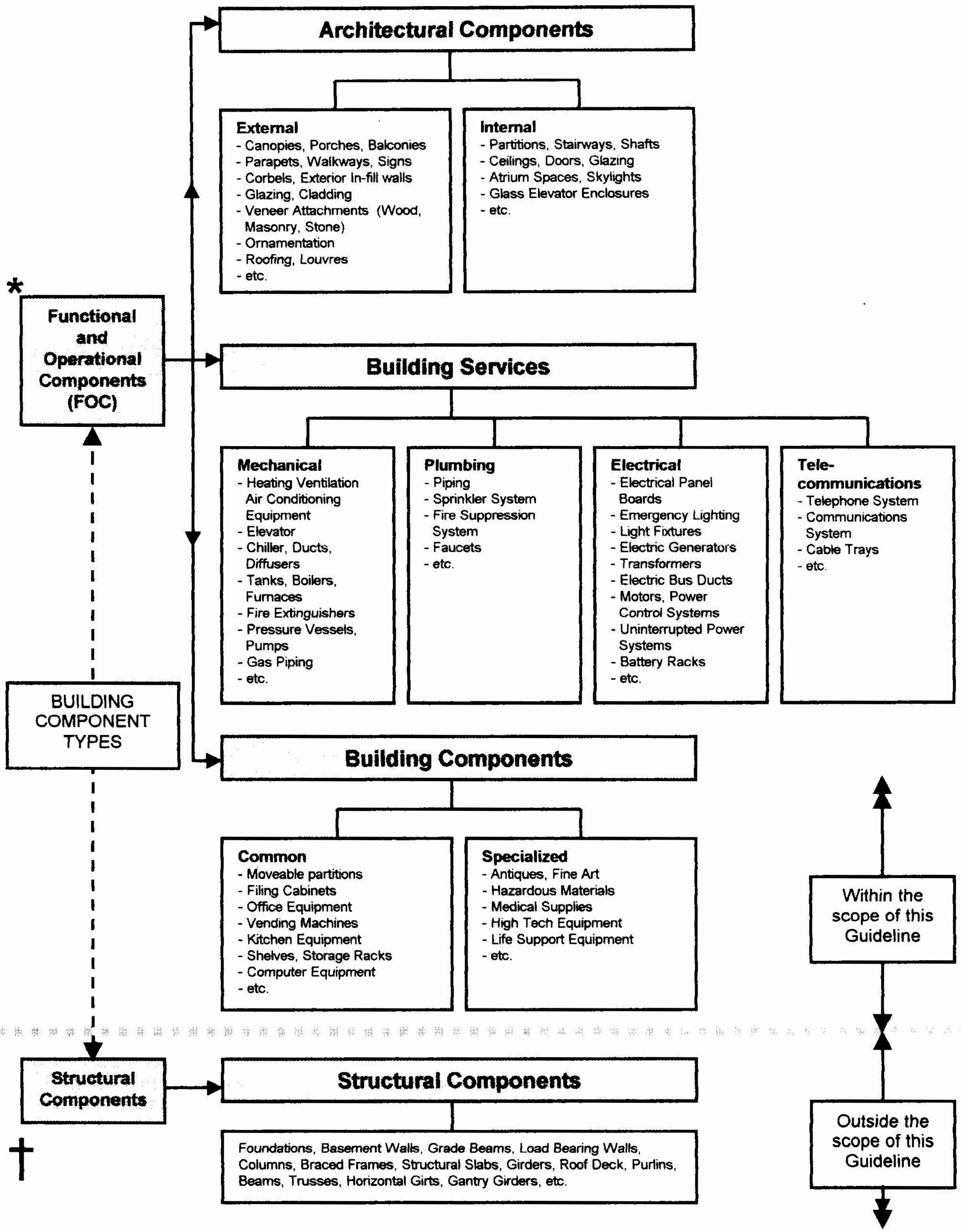

* *All components (other than structural components) that provide the functional and operational requirements in a building.*

† *Components specifically designed to carry or transfer all loads to the ground without total or partial collapse of a building.*

Figure 1 Building Component Types