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SEISMIC SCREENING OF BUILDINGS IN CANADA

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ABSTRACT

The National Research Council of Canada developed a Canadian seismic screening manual in 1993 for rapid seismic screening of buildings. The manual is based on the computation of seismic priority index, which reflects parameters that affect building performance during earthquakes. These parameters are calibrated relative to the seismic requirements of the 1990 National Building Code of Canada (NBC-1990), which is based on the Canadian seismic hazard information incorporated into the 1985 edition of NBC (1985). Since then, the Geological Survey Canada (GSC) reassessed the Canadian seismicity. The new seismic hazard information was incorporated into the 2005 edition of NBC (2005). The new hazard levels are different not only in content but also in the manner they were implemented into the building code. Accordingly, seismic hazard is introduced through Uniform Hazard Spectra (UHS) specified for different municipalities in Canada. This necessitated the revision of coefficients in the Seismic Screening Manual. Because the seismicity is specified using location-specific UHS, rather than seismic zones of earlier codes, it has become necessary to develop computer software (SCREEN) to identify seismic priority index for each city for which the UHS is defined. The paper presents the revised screening manual while demonstrating the use of the associated computer software with an example.

Introduction

The "*Manual for Screening of Buildings for Seismic Investigation*" was developed by the National Research Council of Canada in 1993 for rapid seismic screening of buildings in Canada (NRC 1993). The manual, referred to as the "*Screening Manual*" in this paper, is intended to identify buildings that require further investigation to assess their seismic vulnerabilities and

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potentials for seismic retrofit needs. Hence, the manual is intended for initial screening of a multi-phase assessment process. Buildings that are found to require further investigation need to be analyzed by means of more refined techniques before they can be identified as seismically vulnerable.

The methodology followed in the Screening Manual was developed by modifying the ATC-21 document, entitled "*Rapid Visual Screening for Buildings for Potential Seismic Hazards: A Handbook,*" developed by the U.S. Federal Emergency Management Agency for use in the U.S. (ATC 1988). The ATC-21 document was revised and updated since then (ATC 2002). It was also adapted to the Canadian seismicity and building practices on the basis of the 1990 edition of the National Building Code of Canada (NBC-1990). It was further modified to include the inspection of buildings not only from outside (walk down survey) but also from inside, as well as the inspection of building drawings. The scoring system was revised to include non-structural vulnerabilities in addition to those associated with structural elements and systems. In addition, a new process was introduced for establishing building importance on the basis of use and occupancy.

The method used in the Screening Manual is based on the computation of seismic priority index as the product of factors that affect building performance during earthquakes. These factors are related to the seismic requirements of the 1990 National Building Code of Canada (NBC-1990), which reflect the Canadian seismicity incorporated into the 1985 edition of the National Building Code. Since then, the Canadian seismic hazard has been revised by the Geological Survey Canada based on the most recent knowledge on Canadian seismicity. This new information has been incorporated into the 2005 edition of the National Building Code (NBC-2005), and is different not only in substance but also in the manner it was implemented. Accordingly, the new Canadian seismicity is based on 2% probability of exceedance in 50 years, and is reflected through Uniform Hazard Spectra (UHS) specified for different municipalities in Canada. This necessitated the revision of coefficients in the Seismic Screening manual to incorporate the new Canadian seismicity with revised soil classifications. Because the seismicity is specified using location-specific UHS, rather than the seismic zones used in earlier codes, it has become necessary to develop computer software (SCREEN) to identify the coefficients for seismic priority index for each city in the country. The software facilitates easy processing of coefficients that make up the seismic priority index. This paper describes the procedure followed in incorporating the new seismic hazard into the existing Seismic Screening Manual while also demonstrating the use of the computer software developed.

Incorporation of NBC-2005 Seismicity into the NRC Seismic Screening Manual

Design Force Levels Prescribed in NBC

The seismic design forces defined in the NBC-1990 are based on the computation of equivalent static base shear force, V and the distribution of the base shear along the height of the building. Accordingly, the maximum lateral seismic base shear force, V, is;

$$V = \frac{V_e}{R} U \qquad (1)$$

U is the calibration factor representing the level of protection based on experience and is equal to 0.6. R is the force modification factor that reflects the inelastic energy dissipation capacity of structure, commonly known as the "ductility based force modification factor." V_e is the elastic base shear design force level computed on the basis of the seismicity of region as modified for local soil conditions, the dynamic characteristics of structure, the importance of building and structural mass.

$$V_e = v\,S\,I\,F\,W \tag{2}$$

v is the zonal velocity ratio specified in the climatic data for each seismic region provided in the code reflecting the intensity of design earthquake when multiplied by the seismic response factor S. The seismic response factor S provides design response spectrum for a unit value of v. F is the foundation factor reflecting possible soil amplification relative to the reference soil condition which is taken as *rock or dense and/or stiff soil*, as defined in the code. W is weight associated with tributary mass for inertia forces, taken as the dead load plus 25% of snow load, plus 60% of storage load (if present) and the full content of any tank.

The seismic design force requirements in the NBC-2005 are primarily based on dynamic analysis of buildings using the Uniform Hazard Spectra (UHS) or ground motions compatible with UHS, except for regular buildings with certain height restrictions in which case the equivalent static force approach is permitted. The dynamic analysis procedure has been identified as the preferred approach because of recent advances in structural modelling, analysis software development and increased confidence in using these analyses techniques in addressing irregularities in buildings and higher mode effects that may be significant in tall buildings. However, while the dynamic analysis procedures is advocated in the NBC-2005, including the increased confidence placed on period calculations through analytical techniques, the use of equivalent static base shear force levels, permitted for regular buildings, may be used in establishing the correlation with NBC-1990 design force levels. This is deemed sufficiently accurate for the purpose of rapid seismic screening intended as an initial step towards assessing seismic vulnerabilities. Therefore, the equivalencies of relevant coefficients of seismic priority indices between the NBC-1990 and NBC-2005 are based on the comparison of equivalent static force requirements.

The equivalent static base shear force V in the NBC-2005 is calculated as shown below:

$$V = \frac{S(T_a)M_v I_E W}{R_d R_o} \tag{3}$$

except that V shall not be less than: $\dfrac{S(2.0)M_v I_E W}{R_d R_o}$

and for $R_d \geq 1.5$, V need not exceed: $\dfrac{2}{3}\dfrac{S(0.2)I_E W}{R_d R_o}$

where $S(T_a)$ is the design spectral value for fundamental period T_a as modified for site soil conditions. M_v is a factor that accounts for higher mode effects, I_E is the importance factor and W is the weight associated with seismic inertia forces. R_d is the ductility-related force modification factor reflecting the seismic energy dissipation capacity of structure through inelastic behaviour. R_o is the over-strength related force modification factor accounting for the dependable portion of reserve strength. $S(T_a)$ is computed by multiplying spectral acceleration obtained from the climatic data, $S_a(T_a)$, by either the acceleration-based site coefficient F_a or the velocity-based site coefficient F_v, based on the fundamental period T_a, as indicated below:

$S(T_a)$	$= F_aS_a(0.2)$	for; $T_a \leq 0.2$ s
	$= F_vS_a(0.5)$ of $F_aS_a(0.2)$, whichever is smaller	for; $T_a = 0.5$ s
	$= F_vS_a(1.0)$	for; $T_a = 1.0$ s
	$= F_vS_a(2.0)$	for; $T_a = 2.0$ s
	$= F_vS_a(2.0)/2$	for; $T_a \geq 4.0$ s

Linear interpolation can be made for the intermediate values of T_a.

Seismicity Factor (A)

The effect of seismicity on the NBC-1990 base shear expression given in Eq. 2 is reflected through the product *vS*, where *v* represents the zonal velocity ratio for a given location and *S* represents the design response spectrum for $v = 1.0$ for a given seismic zone. The effect of seismicity on the NBC-2005 base shear expression given in Eq. 3 is reflected through $S(T_a)$, which provides site specific design spectral values after modifications for different site soil conditions. For the reference soil condition (Site Class C), the acceleration and velocity based site coefficients both become 1.0 and the effect of soil condition can be decoupled from seismicity. For the reference soil/foundation condition (i.e., when F = 1.0) in the NBC-1990 and $F_a = F_v = 1.0$ in the NBC-2005, the relationship between the seismicities in these two codes can be establish by comparing *vS* and $S(T_a)$. Both of these quantities vary with structural period and building location. However, the seismic response factor *S* is defined for three different ranges of period; i) $T \leq 0.25$ *sec*, ii) 0.25 *sec* $< T < 0.5$ *sec*, and iii) $T \geq 0.5$ *sec*, whereas the spectral values $S(T_a)$ are specified at periods of *0.2, 0.5, 1.0* and *2.0 sec* with $S(T_a)= S(0.2)$ for $T_a \leq 0.2$ and $S(T_a)= S(2.0)/2$ for $T_a \geq 4.0$. This difference in period ranges for which seismicity is specified, creates a large number of cases for establishing the *Seismicity Factor A* in the Screening Manual. Therefore, the sensitivity of the ratio [$vS / S(T_a)$] to structural period, T_a was investigated in an effort to reduce the number of period ranges for which seismic risk index may be determined. The results indicate that the variation of $vS / S(T_a)$ with period T_a within the short and long period ranges, i.e., for $T_a < 0.5$ *sec* and $T_a \geq 2.0$ *sec.* remain relatively constant within each range. Therefore, it is deemed possible to specify a constant average *Seismicity Factor A* within each of these two period ranges. This implies that the factor *A* is computed for; i) $T_a < 0.5$ *sec,* ii) 0.5 *sec* $< T_a < 2.0$ *sec* and iii) $T_a \geq 2.0$ *sec*.

Higher mode effects in the NBC-1990 were incorporated by increasing the design response spectra in the high period range. This was done explicitly in NBC-2005 through the introduction of M_v factor. The M_v factor is based on the type of lateral force resisting system, as *Moment Resisting Frames or Coupled Walls (MRF), Braced Frames (BRF) and Walls, Wall-*

frame Systems and Other Systems (SWF). The effects of higher modes are introduced within the high period range when $T_a \geq 2.0$ *sec*. Sample values of seismicity factors for Vancouver and Montreal are presented in Table 1.

Table 1. Sample seismicity factor (A) for Vancouver and Montreal

Location	Period, sec		Design NBC			
			Pre-65	65-84	85-05	Post-05
Vancouver (Zone-4)	$T_a \leq 0.5$		1.4	0.9	0.7	1.0
	$0.5 < T_a < 2.0$		1.8	1.2	0.9	1.0
	$2.0 \leq T_a$	MRF	3.0	2.0	1.5	1.0
		BRF	3.0	2.0	1.5	1.0
		SWF	2.6	1.7	1.3	1.0

Location	Period, sec		Design NBC			
			Pre-65	65-84	85-05	Post-05
Montreal (Zone-3)	$T_a \leq 0.5$		0.9	0.6	0.6	1.0
	$0.5 < T_a < 2.0$		1.7	1.1	1.1	1.0
	$2.0 \leq T_a$	MRF	3.3	2.2	2.2	1.0
		BRF	2.7	1.8	1.8	1.0
		SWF	1.7	1.1	1.1	1.0

Soil Condition Factor (B)

The Soil Condition Factor specified in the Seismic Screening Manual is based on soil classifications of older codes. The soil site classification was revised in the NBC-2005. The reference soil condition has also been changed from "*Rock, dense and very dense coarse-grained soils, very stiff and hard fine-grained soils; compact coarse-grained soils and firm and stiff fine-grained soils from 0 to 15 m deep*" to "*Very dense soil and soft rock*." Hence, the reduced seismic vulnerability associated with hard rock and rock site conditions are now recognized in the NBC-2005 relative to the reference site condition. Furthermore, the interdependency of site classifications and spectral accelerations in the short and long period ranges has been incorporated as acceleration and velocity dependent soil factors, respectively. These refinements in the NBC-2205 are now reflected in the Soil Condition Factor (B). Accordingly, the factors have been revised and re-classified based on the site classes given in the NBC-2005. The specifics of site classification are reproduced in Table 2 from the NBC-2005.

Other Factors in NRC Seismic Screening Manual

Factor for Type of Structure (C)

The factor for type of structure (C) reflects the toughness of the structure. A low value of *C* indicates that the structure has sufficient strength and deformability to absorb seismic induced energy. A high C value indicates relatively brittle behaviour or limited deformability. Toughness is provided by implementing the seismic design requirements of relevant CSA (Canadian

Standards Association) Standards, or may be partially present simply because of the inherent characteristics of the material used. The ability to deform in the inelastic range of deformations was reflected in earlier editions of the NBC through coefficient *K* and then by coefficient *R*. The 2005 edition of NBC uses R_dR_o product to reduce elastic force levels in exchange of improved seismic design and detailing of individual elements for improved toughness. Although the NBC-2005 provides a more refined approach for categorizing different building types based on their toughness, the product of R_dR_o can be perceived to be approximately equal to the *R/U* ratio used in the NBC-1990 for the purpose of initial seismic screening of buildings. Therefore, no revision is deemed necessary in the Table that describes "*Type of Structure*" in the Screening Manual. This implies that a structure with C = 1.0 is expected to perform similar to a building that conforms to the seismic requirements of the NBC-2005 when all other parameters are identical.

Table 2. Site classification for seismic site response (NBC 2005)

Site Class	Soil Profile Name	Average Properties in Top 30 m		
		Soil Shear Wave Average Velocity, V_s (m/s)	Standard Penetration Resistance, N_{60}	Soil Undrained Shear Strength, s_u
A	Hard Rock	$V_s > 1500$	Not applicable	Not applicable
B	Rock	$760 < V_s < 1500$	Not applicable	Not applicable
C	Very Dense Soil and Soft Rock	$360 < V_s < 760$	$N_{60} > 50$	$s_u > 100$ kPa
D	Stiff Soil	$180 < V_s < 360$	$15 < N_{60} < 50$	$50 < s_u < 100$ kPa
E	Soft Soil	$V_s < 180$	$N_{60} < 15$	$s_u < 50$ kPa
E		Any profile with more than 3 m of soil with the following characteristic: • Plastic index PI > 20 • Moisture content w ≥ 40% and • Undrained shear strength $s_u < 25$ kPa		
F	Others*	Site Specific Evaluation Required		

* Other soils include:

a. Liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils and other soils susceptible to failure or collapse under seismic loading.
b. Peat and/or highly organic clays greater than 3 m in thickness.
c. Highly plastic clays (PI > 75) with thickness greater than 8 m.
d. Soft to medium stiff clays with thickness greater than 30 m.

Building Irregularity Factor (D)

Irregularities in buildings may pose significant deficiencies in seismic performance. Most structural failures during previous earthquakes were attributed to structural irregularities. Soft storeys, short (or captive) columns, vertical discontinuities or significant changes in the strength and stiffness of structural elements (vertical irregularities) play very significant roles on increasing seismic demands. Similarly, plan irregularities (horizontal irregularities) that result from irregular shapes of buildings and/or significant eccentricities between the centre of mass and the centre of rigidity (walls or elevator cores concentrated on one side of the building) may result in excessive torsional stresses increasing seismic deformation demands. The Seismic Screening Manual provides a comprehensive coverage of the majority of irregularities known to produce seismic deficiencies, as well as other factors such as pounding, major structural modifications and visible deteriorations. These factors were adopted in establishing the *Building Irregularity Factor (D)*. Although improved treatment of structural irregularities were provided in the 2005 edition of the National Building Code of Canada, no revision is deemed necessary for preliminary screening of buildings.

Building Importance (E)

Building importance is covered in the Seismic Screening Manual through Factor E. Higher score is assigned to post disaster buildings, high-occupancy buildings and critical infrastructure that may be identified by the owner or authority controlling the operation of the facility. No further refinement is felt necessary based on the NBC-2005.

Non-Structural Hazards Factor (F)

Non-structural hazards include those that are associated with falling objects and damage to vital operations of strategic facilities. These factors, as covered in the 1993 edition of the Seismic Screening Manual are deemed appropriate based on the NBC-2005.

Ranking of Screening Indices

Initial screening of buildings is intended to be the first step towards a more detailed assessment of seismic vulnerabilities and risks in buildings in a given inventory. Once the "Structural Index (SI)," "Non-Structural Index (NSI)," and the combination of the two, "Seismic Priority Index (SPI)" are computed, they should be ranked individually based on each index. This may be necessary because non-structural hazards can be more serious than structural hazards in regions of low seismicity. In such regions, the building may remain intact from structural perspective but may experience partial or total failure of non-structural elements, posing a serious life safety hazard. Furthermore, the seismic retrofit of non-structural components may be relatively easy to implement.

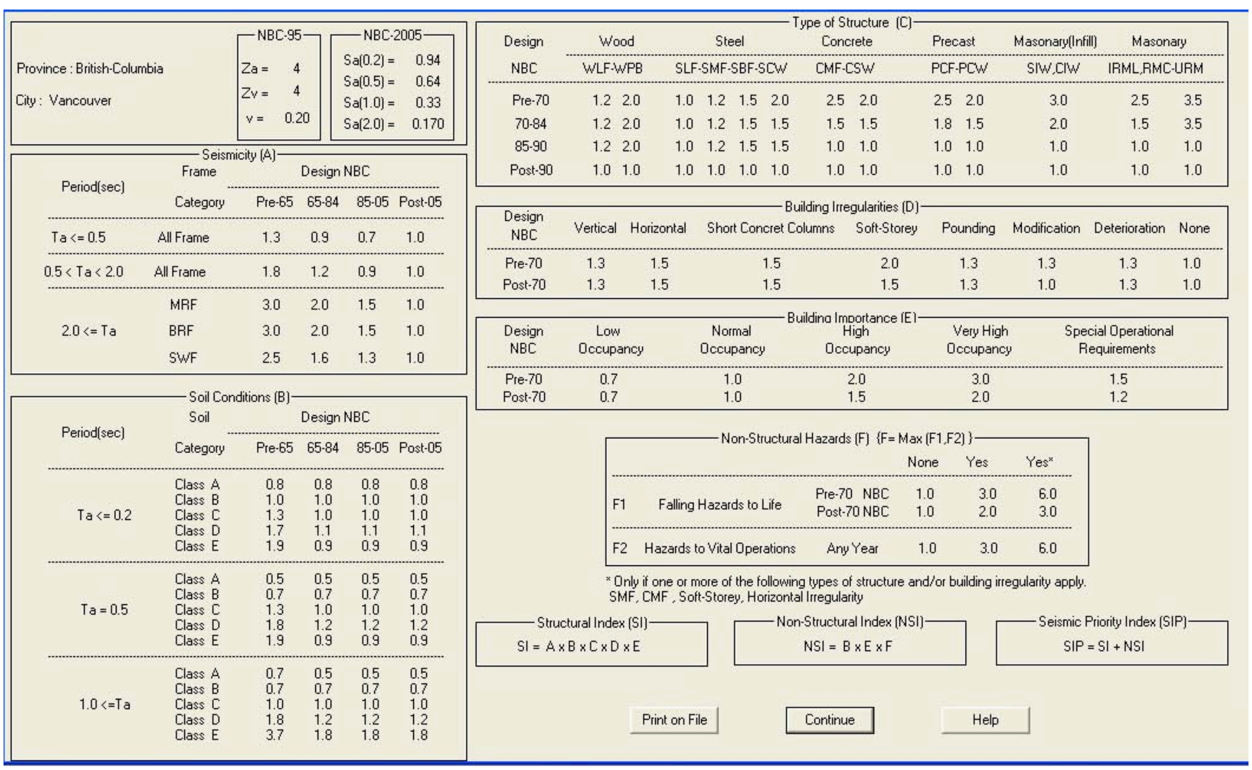
The ranking approach outlined in the original Seismic Screening Manual is summarized in this section. Higher scores in screening indices indicate higher priority for further evaluation. It is difficult to define the level of "acceptable score." This depends on the delicate balance between the costs of safety (in terms of detailed evaluation and seismic retrofit) versus benefits. It is the responsibility of the owner or the authority that has jurisdiction over the building to weigh costs against benefits. An SI or NSI score of 1.0 to 2.0 indicate compliance with the NBC-2005. Buildings with such low scores may be viewed as meeting the requirements of the current seismic provisions of the NBC-2005. The 1993 NRC Seismic Screening Manual suggests that SPI scores of less than 10 indicate low priority, score between 10 and 20 indicate medium priority and those having higher than 20 indicate higher priority. Buildings with SPI scores over 30 can be considered potentially hazardous.

Example of Seismic Screening

An example is provided in this section for seismic screening of a reinforced concrete building in Canada using the newly developed “SCREEN” software. The software provides either the appropriate “Seismic Screening Form” for manual computation of “Structural Index (SI),” “Non-structural Index (NSI)” and “Seismic Priority Index (SPI),” or computed values of these indices on the basis of specific set of input data.

Consider a 5-storey reinforced concrete office building in Vancouver, B.C., Canada with a 2,500 m^2 of floor area, built in 1972 using the 1970 edition of the NBC. The lateral load resisting system consists of symmetrically placed regular frames without any apparent irregularity. The building has exterior block masonry infill walls with a possibility of out-of-plane failure and associated falling debris hazard. Some of the masonry walls create short columns due to the window openings. The building is away from any nearby building without any pounding possibility. It is located on Class D “Stiff Soil.” The building has occupancy density of 0.1 persons/m^2 and 50 hours of average weekly use.

Fig. 1 illustrates the output of computer software SCREEN for Vancouver, BC for manual computation of Structural Index (SI), Non-structural Index (NSI) and Seismic Priority Index. Fig. 2 illustrates another output of SCREEN for computed values of these indices, as well as each contributing factor. The SPI score of 6.62 (less than 10) indicates low priority for further assessment and seismic retrofitting.



Province : British-Columbia
City : Vancouver

NBC-95: Za = 4, Zv = 4, v = 0.20

NBC-2005: Sa(0.2) = 0.94, Sa(0.5) = 0.64, Sa(1.0) = 0.33, Sa(2.0) = 0.170

Seismicity (A)

Period(sec)	Frame Category	Pre-65	65-84	85-05	Post-05
Ta <= 0.5	All Frame	1.3	0.9	0.7	1.0
0.5 < Ta < 2.0	All Frame	1.8	1.2	0.9	1.0
2.0 <= Ta	MRF	3.0	2.0	1.5	1.0
	BRF	3.0	2.0	1.5	1.0
	SWF	2.5	1.6	1.3	1.0

Soil Conditions (B)

Period(sec)	Soil Category	Pre-65	65-84	85-05	Post-05
Ta <= 0.2	Class A	0.8	0.8	0.8	0.8
	Class B	1.0	1.0	1.0	1.0
	Class C	1.3	1.0	1.0	1.0
	Class D	1.7	1.1	1.1	1.1
	Class E	1.9	0.9	0.9	0.9
Ta = 0.5	Class A	0.5	0.5	0.5	0.5
	Class B	0.7	0.7	0.7	0.7
	Class C	1.3	1.0	1.0	1.0
	Class D	1.8	1.2	1.2	1.2
	Class E	1.9	0.9	0.9	0.9
1.0 <=Ta	Class A	0.7	0.5	0.5	0.5
	Class B	0.7	0.7	0.7	0.7
	Class C	1.0	1.0	1.0	1.0
	Class D	1.8	1.2	1.2	1.2
	Class E	3.7	1.8	1.8	1.8

Type of Structure (C)

Design NBC	Wood WLF-WPB		Steel SLF-SMF-SBF-SCW				Concrete CMF-CSW		Precast PCF-PCW		Masonary(Infill) SIW,CIW	Masonary IRML,RMC-URM	
Pre-70	1.2	2.0	1.0	1.2	1.5	2.0	2.5	2.0	2.5	2.0	3.0	2.5	3.5
70-84	1.2	2.0	1.0	1.2	1.5	1.5	1.5	1.5	1.8	1.5	2.0	1.5	3.5
85-90	1.2	2.0	1.0	1.2	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Post-90	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Building Irregularities (D)

Design NBC	Vertical	Horizontal	Short Concret Columns	Soft-Storey	Pounding	Modification	Deterioration	None
Pre-70	1.3	1.5	1.5	2.0	1.3	1.3	1.3	1.0
Post-70	1.3	1.5	1.5	1.5	1.3	1.0	1.3	1.0

Building Importance (E)

Design NBC	Low Occupancy	Normal Occupancy	High Occupancy	Very High Occupancy	Special Operational Requirements
Pre-70	0.7	1.0	2.0	3.0	1.5
Post-70	0.7	1.0	1.5	2.0	1.2

Non-Structural Hazards (F) {F= Max (F1,F2) }

			None	Yes	Yes*
F1	Falling Hazards to Life	Pre-70 NBC	1.0	3.0	6.0
		Post-70 NBC	1.0	2.0	3.0
F2	Hazards to Vital Operations	Any Year	1.0	3.0	6.0

* Only if one or more of the following types of structure and/or building irregularity apply.
SMF, CMF , Soft-Storey, Horizontal Irregularity

Structural Index (SI): SI = A x B x C x D x E

Non-Structural Index (NSI): NSI = B x E x F

Seismic Priority Index (SIP): SIP = SI + NSI

Print on File | Continue | Help

Fig. 1 Seismic Screening Form, printed from computer software SCREEN

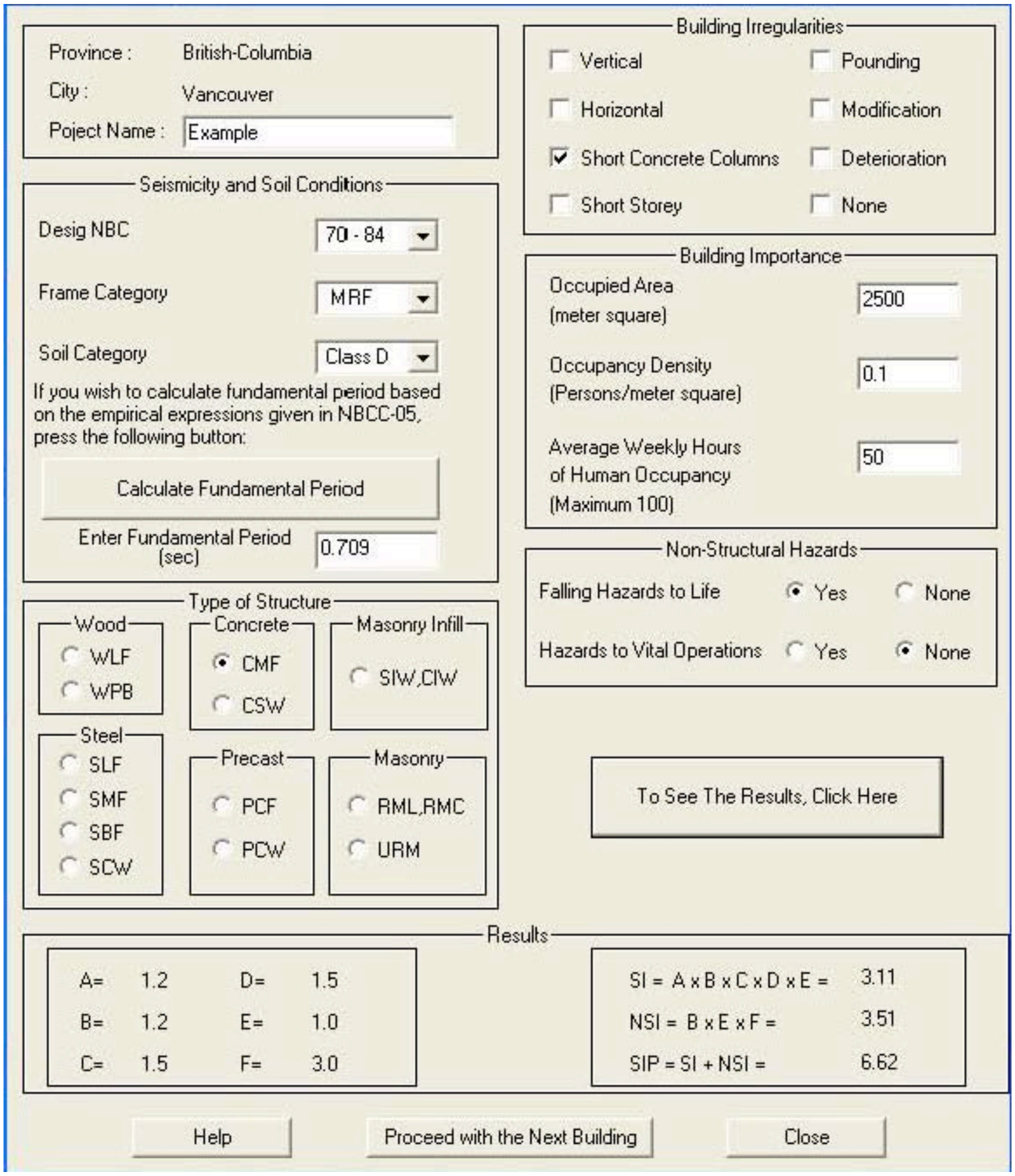


Fig. 2 Output of software SCREEN for computed values of structural, non-structural and seismic priority indices

Summary and Conclusions

Seismic assessment of buildings is a multi-facetted process. Seismic screening often forms the first step towards identifying potential seismic vulnerabilities in buildings. This triggers further investigation of buildings and their seismic retrofit needs, often through more vigorous analyses.

The National Research Council of Canada developed a seismic screening manual, entitled: "*Manual for Screening of Buildings for Seismic Investigation*" (NRC 1993). The manual used the Canadian Seismic Hazard Maps developed for the 1985 edition of the NBC (1985), which was also used by the 1990 and 1995 editions of the code. The seismic hazard information has since been updated and incorporated into the NBC (2005) in the form of site-specific Uniform Hazard Spectra with revised soil classifications. This necessitated the revision of the manual. A computer program was developed to incorporate the new Canadian seismic hazard information into the Seismic Screening Manual. The program either regenerates the required Seismic Screening Form or computes seismic priority index for a specific building under investigation. The application of the revised manual is demonstrated in this paper, with the background information provided for the introduction of the new seismic hazard data into the manual. With the help of computer software, the manual can be used to as a seismic screening tool.

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