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Canadian Association for Earthquake Engineering

SHORT PERIOD BASE SHEAR CALCULATION

USING THE PROPOSED PROVISIONS FOR NBCC 2015

Andy Metten, P.Eng.,Struct.Eng.
Partner, Bush, Bohlman & Partners LLP, Canada
ametten@bushbohlman.com

ABSTRACT: In preparation for the 2015 edition of the National Building Code of Canada (NBCC) the Standing Committee on Earthquake Design (SCED) undertook a major study of the seismic risk in Canada. This resulted in changes in the seismic parameters but also resulted in modifications to the philosophy of how the base shear is calculated. Modifications to how the spectrum is calculated have been proposed to prevent the base shear rising as the building softens and to prevent the limiting shear for short period buildings extending past the 0.5 second mark. The calculation of the base shear under the proposed provisions of NBCC 2015 uses period dependent foundation factors. Using a worksheet approach, this paper goes through the proposed changes and calculates the base shear for a short period brace bay building located on type D soil in Vancouver. In the example, the changes in the spectrum calculation have a greater effect on the base shear than do the changes in the location specific seismic values.

1. Introduction

During the development cycle for the 2015 edition of the National Building Code of Canada (NBCC) the Standing Committee on Earthquake Design (SCED) went through an extensive review the seismic risk for all of Canada. This resulted in changes to the seismic data for many locations with a lowering of the values for many locations in the more stable regions and an increase for some regions particularly those affected by the Westcoast subduction event. As part of the review of seismic risk, changes were made to the way that the design spectrum for the building is calculated.

This paper is a summary of the method for computing the seismic base shear using the static procedure and the proposed provisions for NBCC 2015 that have been published for public comment. At time of writing, this material has yet to be approved by the NBCC committee and at this stage is only proposed however taking the issued for public comment provisions of NBCC 2015 there are four significant changes in computation of base shear that affect the result. These are:

- Limiting the short period cut-off to periods below 0.5 seconds
- Modifying the spectrum to prevent force levels rising as the building softens.
- The changes in the seismic values throughout Canada.
- Using period dependent foundation factors.

Let us go through these on a point-by-point basis.

1.1. Limiting the short period cut-off to periods below 0.5 seconds

The proposed short period base shear calculation following the static method for computing shears is shown in figure 1. The provisions are identical to those of NBCC 2010 with the exception of sentence C which introduces a new equation for the limiting shear for short period buildings, requiring that the cap-off shear must also exceed $S(0.5)I_EW/(R_dR_o)$ this has been introduced to prevent the capping off shear from extending to periods beyond 0.5 seconds. Under NBCC 2010 buildings located on soft sites particularly in the West Coast regions of BC would have their capping off shear extending to periods of 1.0 seconds or greater, this was not the intent of the capping equation which was intended to reduce only the loads on short period buildings.

PROPOSED CHANGE

[4.1.8.11.] 4.1.8.11. Equivalent Static Force Procedure for Structures Satisfying the Conditions of Article 4.1.8.7.

[1] 2) The minimum lateral earthquake force, V, shall be calculated using the following formula:

$$V = S(T_a)M_vI_EW/(R_dR_o)$$

except

[a] a) for walls, coupled walls and wall-frame systems, V shall not be less than

$$S(4.0)M_vI_EW/(R_dR_o)$$

[b] b) for moment-resisting frames, braced frames, and other systems, V shall not be less than

$$S(2.0)M_vI_EW/(R_dR_o)$$

[c] c) for *buildings* located on a site other than Class F and having an SFRS with an R_d equal to or greater than 1.5, V need not be greater than the larger of

$$\frac{2}{3}S(0.2)I_EW/(R_dR_o) \text{ and } S(0.5)I_EW/(R_dR_o)$$

Fig. 1 – Proposed Static Procedure for NBCC 2015 base shear calculation. Taken from public comment

1.2. Governing Equations and the short period building

The main premise of the short period worksheet calculation is that for periods less than 0.5 seconds the Equations in 4.1.8.11(2c) will govern. The so called “bail-out” equation that limits the load on the structure to: $V=(2/3\ S(0.2)\ I_E)/((R_d\ R_o))\ W$ or $V=S(0.5)I_EW/(R_dR_o)$ is based on the observation that regular buildings that are well detailed and connected together do not suffer as much damage as they would be expected to when based on purely theoretical studies.

1.3. Limiting the plateau of the cut-off to less than 0.5 seconds

The cut off equation is only intended to apply to structures that have a period under 0.5 seconds and under NBCC 2010 the 2/3 cut-off would often extend to 1 second for structures on soft soils and this was not the intent of the cap. The Mexico City earthquake of 1985 showed the catastrophic damage that can occur to buildings on soft soils in the 1 second period range. For this reason the equation:

$$V=(S(0.5)\ I_E)\ /\ ((R_d\ R_o))\ W$$

is introduced in NBCC 2015 to prevent this occurring as shown in the cartoon design spectrums shown in Figure 2. The effect of this change is dependent on the location and the site class. Sites located on rock or firm ground will be unaffected while those sites located on soft soils in high seismic areas will be affected most.

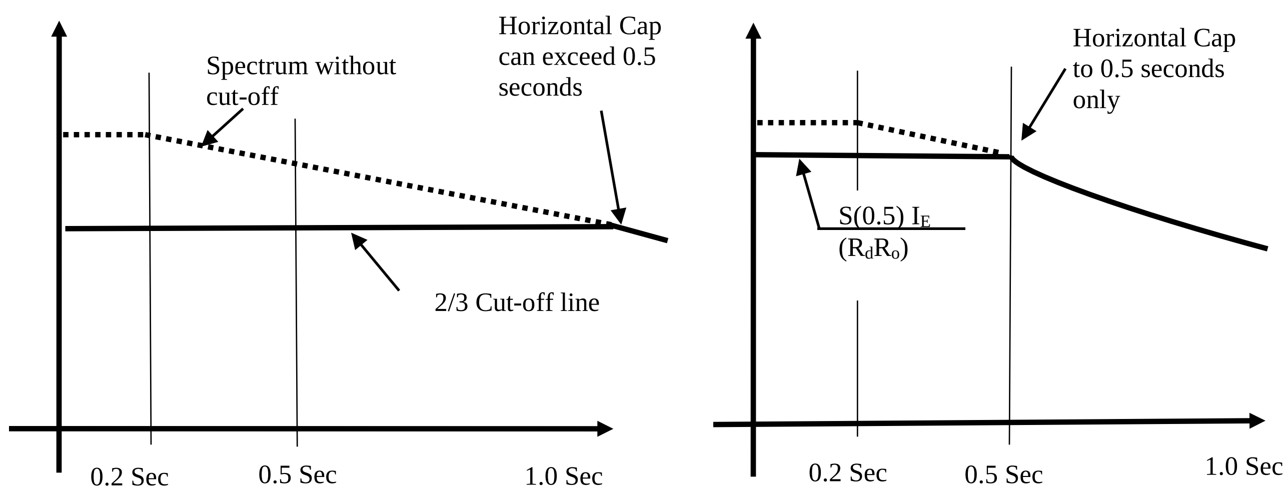


Fig. 2: Cartoon spectrums showing how the limiting value of the cut-off shear value increases under NBCC 2015 so that it does not extend beyond 0.5 seconds.

1.4. Modifying the spectrum so that the design force does not rise as the building softens

A second significant but different on the effect on the calculation of base shears for spectrum values are given below with particular interest being S(0.2) and S(0.5)

$S(T) = F(0.2)Sa(0.2)$ or $F(0.5)Sa(0.5)$ whichever is larger for $T\leq 0.2s$

$= F(0.5)S_a(0.5)$ for $T=0.5s$

$= F(1.0)S_a(1.0)$ for $T=1.0s$

$= F(2.0)S_a(2.0)$ for $T=2.0s$

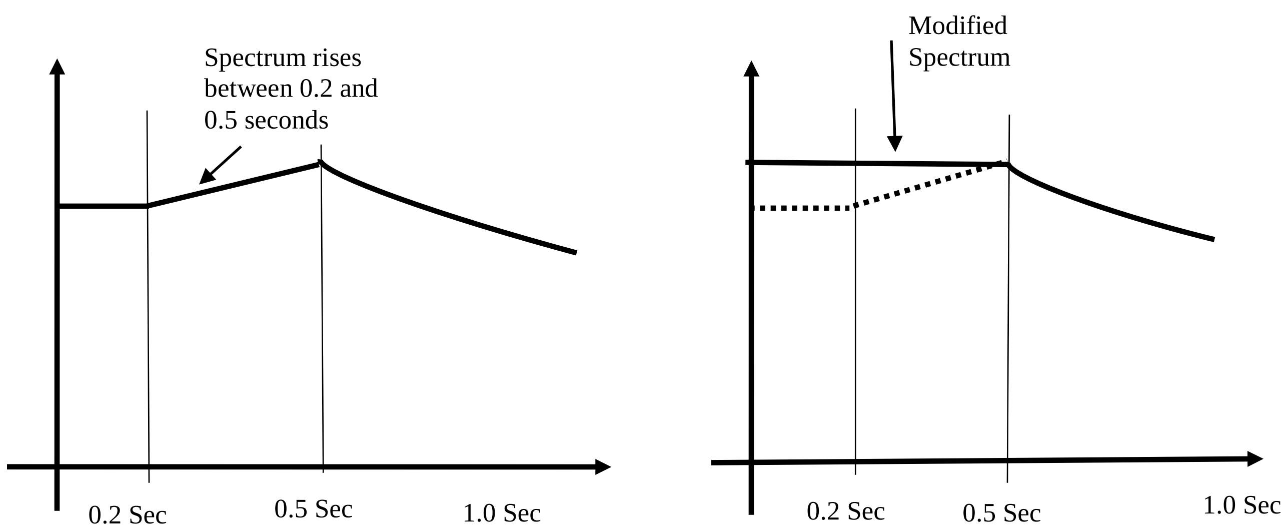
$= F(5.0)S_a(5.0)$ for $T=5.0s$

$= F(10.0)S_a(10.0)$ for $T\geq 10s$

To get S(0.2):   S(0.2) = F(0.2)Sa(0.2) or F(0.5)Sa(0.5) whichever is larger

While to get S(0.5): S(0.5)= F(0.5)Sa(0.5)

Under the NBCC 2015 proposed provisions both $S_a(0.2)$ and $S_a(0.5)$ are examined for short period buildings as the desire is not to have lower required forces for the design of stiffer buildings than for the design of more flexible buildings. If we have a building that has a fundamental period of say 0.2 seconds it will soften during a severe seismic event and the period will shift into the higher value (say 0.3 seconds) what this would mean is for a short period building the forces would increase as the event progressed. For taller buildings, their position on the spectrum results in a decrease in forces as the event progresses and the structure softens due to yielding in the plastic hinge zones. For short buildings, NBCC 2015 accounts for the softening by requiring the loads that would be appropriate for a softer structure. See Figure 3, which explains this in cartoon form.



Undesirable Spectrum. For buildings that are less than 0.5 seconds the forces go up when building softens and period increases.

Modified Spectrum. For buildings that are less than 0.5 seconds the forces used are those that correspond to those felt by the building as it softens and the period increases.

Fig. 3: Cartoon spectrums showing how the spectrum under NBCC 2015 adjusts to prevent short period buildings from undergoing increasing force as the building softens.

1.5. Updates to the seismic values throughout Canada

Under NBCC 2015 the S_a values have changed and reflect almost two decades of increased research and advances in understanding of the seismic risks. For West Coast Canada, the S_a values reflect several sources of earthquake including the major subduction event off the west coast of Vancouver Island. The proposed S_a values are given in Table 1. Instead of $S_a(4.0)$ there are values of $S_a(5.0)$ and $S_a(10.0)$ and PGV is also provided.

Proposed NBCC 2015 mean values (Site Class C)									
NBCC 2015 Localities, Class C (450 m/s) mean, 2%/50 years, peak and spectral acceleration values in g, peak velocity in m/s									
Location	**Prov.**	**Sa(0.2)**	**Sa(0.5)**	**Sa(1.0)**	**Sa(2.0)**	**Sa(5.0)**	**Sa(10.0)**	**PGA**	**PGV (m/s)**
Whitehorse	YT	0.334	0.258	0.170	0.094	0.0326	0.0124	0.154	0.184
Inuvik	NT	0.308	0.223	0.139	0.072	0.0247	0.0094	0.145	0.149
Queen Charlotte City	BC	1.622	1.373	0.842	0.452	0.1235	0.0406	0.757	0.989
Prince Rupert	BC	0.246	0.269	0.209	0.135	0.0458	0.0162	0.117	0.314
Tofino	BC	1.457	1.363	0.891	0.536	0.1699	0.0600	0.695	0.945
Campbell River	BC	0.595	0.582	0.408	0.265	0.0943	0.0336	0.283	0.487
Nanaimo	BC	1.019	0.942	0.542	0.328	0.1037	0.0367	0.446	0.684
Victoria	BC	1.304	1.160	0.676	0.399	0.1247	0.0437	0.580	0.834
Vancouver (city hall)	BC	0.848	0.751	0.425	0.257	0.0804	0.0285	0.369	0.553
Prince George	BC	0.113	0.089	0.059	0.040	0.0187	0.0059	0.049	0.079
Chilliwack	BC	0.539	0.448	0.277	0.174	0.0622	0.0214	0.242	0.347
Kamloops	BC	0.146	0.123	0.091	0.064	0.0287	0.0087	0.067	0.117
Kelowna	BC	0.143	0.122	0.091	0.063	0.0286	0.0087	0.066	0.115
Yellowknife	NT	0.052	0.032	0.017	0.007	0.0015	0.0008	0.030	0.021
Calgary	AB	0.192	0.126	0.072	0.036	0.0124	0.0048	0.098	0.075
Edmonton	AB	0.103	0.062	0.036	0.018	0.0053	0.0022	0.064	0.044
Winnipeg	MB	0.054	0.032	0.016	0.007	0.0013	0.0007	0.032	0.021
Ottawa (city hall)	ON	0.439	0.237	0.118	0.056	0.0148	0.0055	0.281	0.196
Montréal (city hall)	QC	0.595	0.311	0.148	0.068	0.0176	0.0062	0.379	0.255
La-Malbaie	QC	1.727	0.954	0.454	0.203	0.0492	0.0139	1.039	0.809
Iqaluit	NU	0.087	0.065	0.043	0.023	0.0058	0.0025	0.051	0.052
Halifax	NS	0.110	0.082	0.053	0.029	0.0076	0.0032	0.064	0.068
Charlottetown	PE	0.103	0.077	0.051	0.028	0.0074	0.0032	0.060	0.066
St. John's	NL	0.090	0.073	0.049	0.027	0.0071	0.0031	0.052	0.062

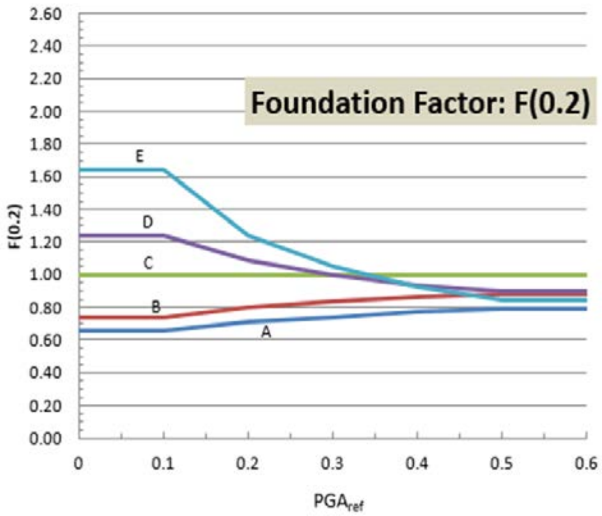
Table 1 – Proposed Seismic values for NBCC 2015

1.6. Introduction of Period Dependent Foundation Factors

Under the proposed provisions of NBCC 2015 the foundation factors are given in table form and are dependent on the period, the Site Class and a term PGA_{ref} which will be discussed in the next section of this paper. There is a different foundation factor for all of the key periods (0.2 seconds, 0.5 seconds, 1 second, 2 second, 5 seconds, and 10 seconds). These six foundation factor tables replace the two tables in NBCC 2010 that used to develop F_a and F_v.

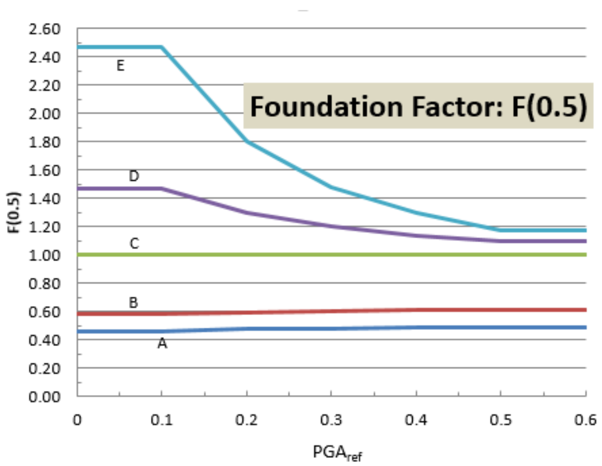
Under the proposed code change forms the values of F(0.2), F(0.5), F(1.0) and F(2.0), F(5.0) and F(10.0) are given in table form such as shown in Table 2 and Table 3.

It is however possibly better to represent these values graphically to get a much better impression of how the foundation factor changes for the various site classes and as a function of PGA_{ref}. Using a graphical approach also helps to steer the user away from using an unreasonable number of significant figures as measured values of the foundation factor are subject to considerable scatter. Shown in Table 2 are the values for F(0.2) while in Table 3 are the values for F(0.5) the graphical representation of both these foundation factors is shown to the left of the table.



Site Class	PGA_{ref} ≤0.1	PGA_{ref} =0.2	PGA_{ref} =0.3	PGA_{ref} =0.4	PGA_{ref} ≥0.5
A	0.66	0.71	0.74	0.77	0.79
B	0.74	0.80	0.84	0.86	0.88
C	1.00	1.00	1.00	1.00	1.00
D	1.24	1.09	1.00	0.94	0.90
E	1.64	1.24	1.05	0.93	0.85

Table 2 – Foundation Factor F(0.2) in table and graphical form.



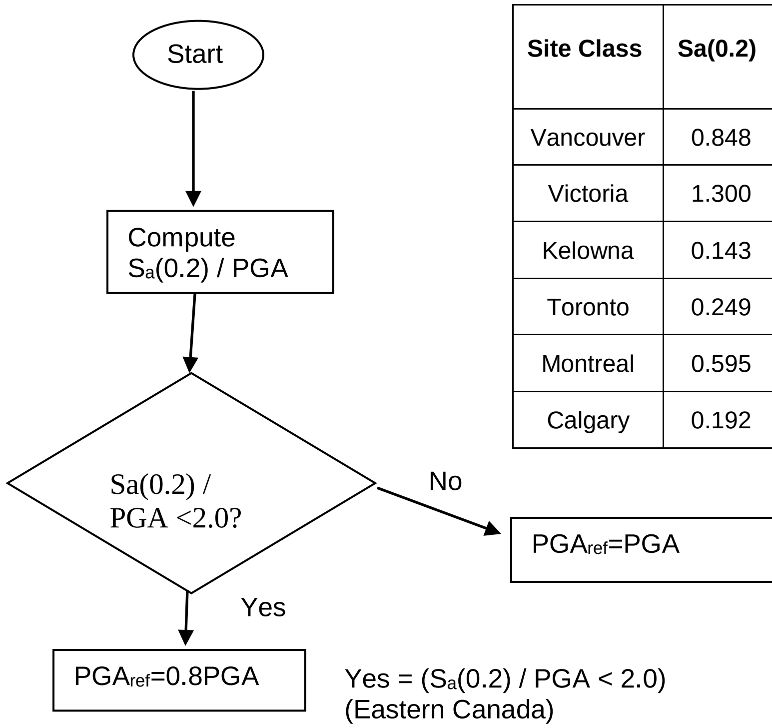
Site Class	PGA_{ref} ≤0.1	PGA_{ref} =0.2	PGA_{ref} =0.3	PGA_{ref} =0.4	PGA_{ref} ≥0.5
A	0.46	0.48	0.48	0.49	0.49
B	0.58	0.59	0.60	0.61	0.61
C	1.00	1.00	1.00	1.00	1.00
D	1.47	1.30	1.20	1.14	1.10
E	2.47	1.80	1.48	1.30	1.17

Table 3 – Foundation Factor F(0.5) in table and graphical form.

1.7. Foundation factors for Eastern and Western Canada

The determination of PGA_{ref} is dependent on the location of the site. In Western Canada PGA_{ref} is equal to PGA. However, sites in Eastern Canada where seismic events have stronger shaking over larger areas using PGA_{ref}. = 0.8*PGA. This can be shown in flowchart and table form in Figure 4.

Site Class	**Sa(0.2)**	**PGA**	**Sa(0.2)/ PGA**	**PGA_{ref}**
Vancouver	0.848	0.369	2.30	PGA_{ref} = PGA PGA_{ref} = 0.369
Victoria	1.300	0.580	2.24	PGA_{ref} = PGA PGA_{ref} = 0.580
Kelowna	0.143	0.066	2.16	PGA_{ref} = PGA PGA_{ref} = 0.066
Toronto	0.249	0.160	1.56	PGA_{ref} = 0.8PGA PGA_{ref} =0.128
Montreal	0.595	0.379	1.56	PGA_{ref} = 0.8PGA PGA_{ref} =0.303
Calgary	0.192	0.098	1.96	PGA_{ref} = 0.8PGA PGA_{ref} =0.078



No = ($S_a(0.2)$ / PGA ≥ 2.0)
(Western Canada)

Yes = ($S_a(0.2)$ / PGA < 2.0)
(Eastern Canada)

Fig. 4: Flowchart for computation of PGA_{ref}.

1.8. The last missing pieces R_d, R_o and M_v

The R_d and R_o values for the main seismic resisting systems used in structural design in seismic areas of Canada remain unchanged. The proposed provisions of NBCC 2015 show modifications and additions to the table of the R_dR_o values but these are for the most part coordination with existing and new provisions in the material Codes or development of new systems in the material standards.

While the higher mode factor (M_v factor) has changed under NBCC 2015 M_v remains 1.0 for all systems when the period is less than 1.0 seconds, therefore M_v does not affect the result for short period structures less than 1.0 seconds.

2. Using the Worksheet

2.1. Application of the new procedures

Putting all this together, and applying a single page worksheet approach shown on the following two pages the base shear for a short period building is calculated. Figure 5 is a blank version of the worksheet while Figure 6 is a worksheet completed by hand for a brace bay building in Vancouver located on site class D.

Short Period Building Base Shear NBCC 2015 Date: ____________

Title: ____________________________ Location: ______________________________

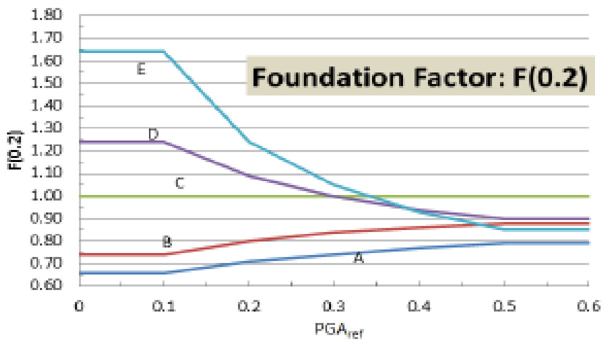
Take The Following From Appendix C: $S_a(0.2)$ =______ $S_a(0.5)$ = ______ PGA=________

Compute: S(0.2) / PGA = _____ / _____ = _____

If S(0.2)/PGA ≥ 2.0 then PGA_{ref} = PGA = ______=PGA_{ref} (Western Canada)

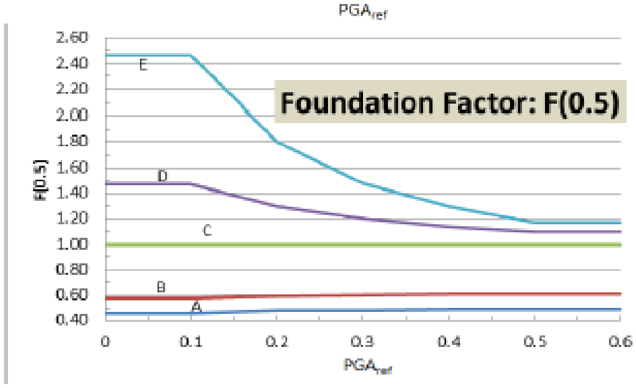
If S(0.2) / PGA < 2.0 then PGA_{ref} = 0.8*PGA =0.8* ____ =_____= PGA_{ref} (Eastern Canada incl. Calgary)

Site Class = _____A= Hard Rock B= Rock C=Very Dense Soil / Soft Rock D= Stiff Soil E=Soft Soil



F(0.2) = ____

F(0.2)*S_a(0.2) = ____ * ____=____



F(0.5) = ____

F(0.5)*S_a(0.5) = ____ * ____=____

S(0.5)=____

S(0.2) Largest of:
F(0.2)*S_a(0.2) or
F(0.5)*S_a(0.5) S(0.2)=___

Importance Factor I_E =_____ (Normal = 1.0, High=1.3 *Post Disaster* = 1.5)

System Description (Table 4.1.8.9)= ________________________ R_d= ____ R_o = _____ R_d*R_o = _______

Check R_d >=1.5 ____ (Limiting Shear Calculation does not apply if R_d<1.5)

Check Not Site Class Type F __(Limiting shear calculation only applies to site Class A,B,C,D and E)

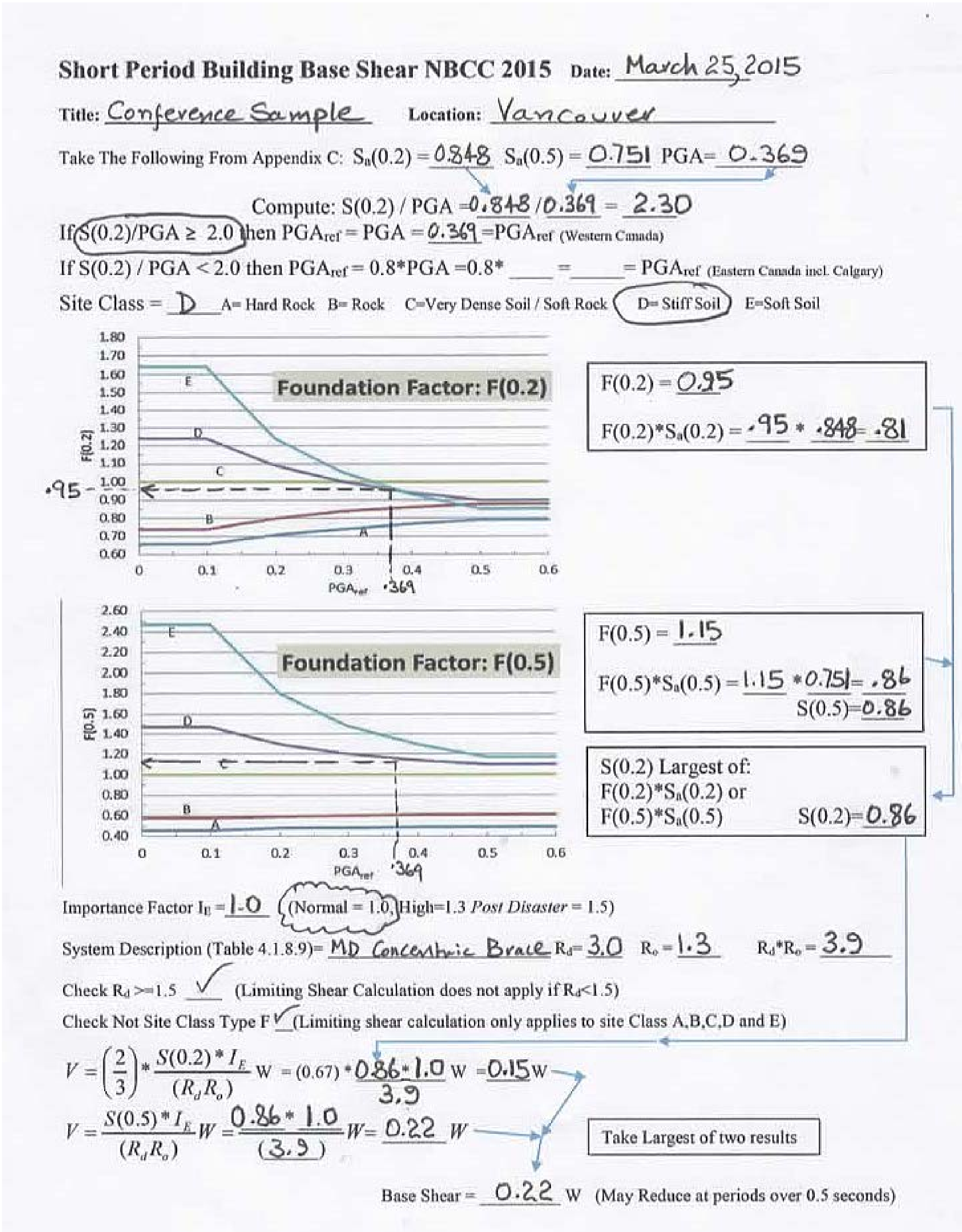
$$V = \left(\frac{2}{3}\right) * \frac{S(0.2) * I_E}{(R_d R_o)} W = (0.67) * \_\_\_\_ * \_\_\_\_ W = \_\_\_\_ W$$

$$V = \frac{S(0.5) * I_E}{(R_d R_o)} W = \frac{\_\_\_\_ * \_\_\_\_}{(\_\_\_\_)} W = \_\_\_\_ W$$

Take Largest of two results

Base Shear = ________ W (May Reduce at periods over 0.5 seconds)

Fig. 5: Blank version of worksheet for computing the base shear of a short period building.



Short Period Building Base Shear NBCC 2015 Date: March 25, 2015

Title: Conference Sample Location: Vancouver

Take The Following From Appendix C: $S_a(0.2)$ = 0.848 $S_a(0.5)$ = 0.751 PGA= 0.369

Compute: S(0.2) / PGA = 0.848 / 0.369 = 2.30

If S(0.2)/PGA ≥ 2.0 then PGA_{ref} = PGA = 0.369 = PGA_{ref} (Western Canada)

If S(0.2) / PGA < 2.0 then PGA_{ref} = 0.8*PGA = 0.8* ____ = ____ = PGA_{ref} (Eastern Canada incl. Calgary)

Site Class = D A= Hard Rock B= Rock C=Very Dense Soil / Soft Rock D= Stiff Soil E=Soft Soil

F(0.2) = 0.95

F(0.2)*S_a(0.2) = .95 * .848 = .81

F(0.5) = 1.15

F(0.5)*S_a(0.5) = 1.15 * 0.751 = .86

S(0.5)=0.86

S(0.2) Largest of:
F(0.2)*S_a(0.2) or
F(0.5)*S_a(0.5) S(0.2)=0.86

Importance Factor I_E = 1.0 (Normal = 1.0, High=1.3 *Post Disaster* = 1.5)

System Description (Table 4.1.8.9)= MD Concentric Brace R_d= 3.0 R_o = 1.3 R_d*R_o = 3.9

Check R_d >=1.5 ✓ (Limiting Shear Calculation does not apply if R_d<1.5)

Check Not Site Class Type F ✓ (Limiting shear calculation only applies to site Class A,B,C,D and E)

$$V=\left(\frac{2}{3}\right)*\frac{S(0.2)*I_E}{(R_dR_o)}W = (0.67)*\frac{0.86*1.0}{3.9}W = 0.15W$$

$$V=\frac{S(0.5)*I_E}{(R_dR_o)}W = \frac{0.86*1.0}{(3.9)}W = 0.22\ W$$

Take Largest of two results

Base Shear = 0.22 W (May Reduce at periods over 0.5 seconds)

Fig. 6: Completed version of the worksheet for a short period Moderately Ductile Brace Bay building located on Type D soil in Vancouver.

3. Conclusions

3.1. Conclusions

a) The calculation of base shears under NBCC 2015 is more complex than it was under NBCC 2010 and NBCC 2005 but the base shear for short period buildings can still be computed using a single page worksheet.

b) Changes in the proposed spectrum for NBCC 2015 result in the limiting the spectrum to the 2/3 cut-off only for buildings in the period range below 0.5 seconds.

c) For short period buildings there are now two "need not exceed" formulas in the base shear spectrum formulation, the formula that governs is dependent on the location in Canada and the site Class.

d) For Vancouver while the $S_a(0.2)$ value is less in NBCC 2015($S_a(0.2)=0.848$) than it is in NBCC 2010 ($S_a(0.2)=0.94$) the actual design base shear is higher. This is in part due to the foundation factors and in part due to the new cap equation, which limits the applicability of the 2/3 capping factor.

e) For Vancouver under NBCC 2015 site class E produces a higher base shear than does site class D. Under NBCC 2010 the highest shears in Vancouver were produced under site class D.

3.2. Acknowledgment

The author acknowledges the use of the proposed seismic provisions of NBCC 2015. At time of writing this paper, the provisions were still under review by NBCC and had not be adopted into NBCC 2015. The reader is cautioned that these provisions are not recognized as the Code in effect.

The author wishes to thank members of the Vancouver structural engineering community including John Sherstobitoff, P.Eng., Carlos Ventura P.Eng., and Ron DeVall, P.Eng. who all gently pointed out errors in my understanding of the calculation sequence during preparation of this paper for a January 2015 SEABC conference on changes in the Code. .

4. References

1) Canadian Commission on Building and Fire Codes, Nation Research Council of Canada, *National Building Code of Canada* (NBCC) 2010, Ottawa 2010

2) Canadian Commission on Building and Fire Codes, Nation Research Council of Canada, *National Building Code of Canada* (NBCC) 2015 Code Change forms issued for public comment by NBCC 2014.

3) Canadian Commission on Building and Fire Codes, Nation Research Council of Canada, *National Building Code of Canada* (NBCC) 2015 Code Change forms NBCC 2015 issued for public comment (second set of changes, September 2014)

   http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/codes_centre/2014_public_review/2014_public_review.html

4) Metten, Andy, SEABC (Structural Engineering Consultants of BC) seminar on Changes in the Codes for 2015 presented in Vancouver on January 19, 2015.