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Seismic Code Provisions for Post-Disaster Buildings per National Building Code of Canada and ASCE 7-22 A Comparison

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ABSTRACT

The 2020 National Building Code of Canada (NBCC) has recently introduced new provisions and performance requirements for post-disaster and High Importance Category buildings (provision 4.1.8.23.). This new provision aims to improve the serviceability of such buildings when subjected to lower intensity ground motions that occur more frequently than the design ground motions in moderate to high seismic regions. The post-disaster buildings must now be designed elastically with RdRo = 1.3 and must meet reduced drift limits of 0.5% when subjected to a seismic hazard corresponding to 5% probability of exceedance in 50 years. This new NBCC provision has a significant impact on the design of the lateral system for post-disaster buildings in high seismic regions in Canada.

This paper presents a comparative study between the seismic design of a post-disaster building located in Greater Victoria using 2020 NBCC and the seismic design of a post-disaster building located in Seattle using the newly updated ASCE/SEI 7-22 Minimum Design Loads and Associated Criteria for Buildings and Other Structures. First, a brief description of the evolution and backgrounds of each regulation is given. A discussion of the two design procedures is then presented, both based on a prescriptive approach. Finally, the seismic design of a sample twelve – story building located in Greater Victoria and Seattle is compared. Greater Victoria and Seattle were chosen as the seismic demand between the two regions is very similar. The results of the design comparison present a significant difference between the two design practices.

Keywords: Code comparative study, National Building Code of Canada, ASCE/SEI 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures, seismic design methods, post-disaster buildings.

INTRODUCTION

ASCE 7 (American Society of Civil Engineers 7) [1] and NBCC (National Building Code of Canada) [2] are two codes that provide guidelines for seismic design requirements for buildings. Both codes aim to provide guidelines to ensure the safety of structures in the event of earthquakes. While there are similarities between the two codes, there are also some differences. One of the main key differences between the seismic design requirements in ASCE 7 and NBCC is that ASCE 7 uses the DBE (Design Basis Earthquake) as the seismic hazard level for the design of structures, while NBCC uses MCE (Maximum Considered Earthquake). The MCE level is generally higher than the DBE level.

Additionally, the 2020 National Building Code of Canada (NBCC) has recently introduced new provisions and performance requirements for post-disaster and High Importance Category buildings (provision 4.1.8.23.) [2]. This new provision aims to improve the serviceability of such buildings when subjected to lower intensity ground motions that occur more frequently than the design ground motions in moderate to high seismic regions. Specifically, this new provision requires the following for post-disaster buildings:

- Buildings designed using seismic isolators or supplemented energy dissipators do not need to comply with these new provisions.
- The design of post-disaster buildings in Seismic Category SC2, SC3 or SC4 shall be verified using 5%-damped spectral acceleration values based on a 5% probability of exceedance in 50 years and shall satisfy the following requirements:
    - a) the building shall be shown to behave elastically for a specified lateral earthquake force, V, determined in accordance with Sentence 4.1.8.11.(2) [2] using I_E =1.0 and R_dR_o =1.3,

b) the largest interstorey deflection at any level of the building, as determined in accordance with Sentence 4.1.8.13.(2) using I_E =1.0 and R_dR_o =1.0, shall not exceed 0.005hs.

This paper presents a comparative study between the seismic design of a post-disaster building located in Greater Victoria using 2020 NBCC and the seismic design of a post-disaster building located in Seattle using the newly updated ASCE/SEI 7-22 Minimum Design Loads and Associated Criteria for Buildings and Other Structures. First, a brief description of the evolution and backgrounds of each regulation is given. A discussion of the two design procedures is then presented, both based on a prescriptive approach. Finally, the seismic design of a sample twelve – story building located in Greater Victoria and Seattle is compared. Greater Victoria and Seattle were chosen as the seismic demand between the two regions is very similar. The results of the design comparison present a significant difference between the two design practices.

CONCRETE POST-DISASTER BUILDING

A sample twelve-story building is used for this study. The footprint of the building is 100 ft x 100 ft providing 10,000 sq.ft. of floor. The typical plan is shown in Figure 1. The typical floor-to-floor height is 15 feet with an overall building height of 180 feet above grade. Special reinforced concrete shear walls, designed according to ASCE 7-22 and NBCC2020, provide the lateral system in both directions. Conventional concrete flat plate slabs with a thickness of 350 mm provide the gravity support at each floor, including the roof. General dead loads for each floor were used to estimate the seismic weight of the building. The loads used are as follows:

- Superimposed Dead Load (SDL) for Typ. Floor: 1.5 kPa.
- Roof SDL: 2.5 kPa.

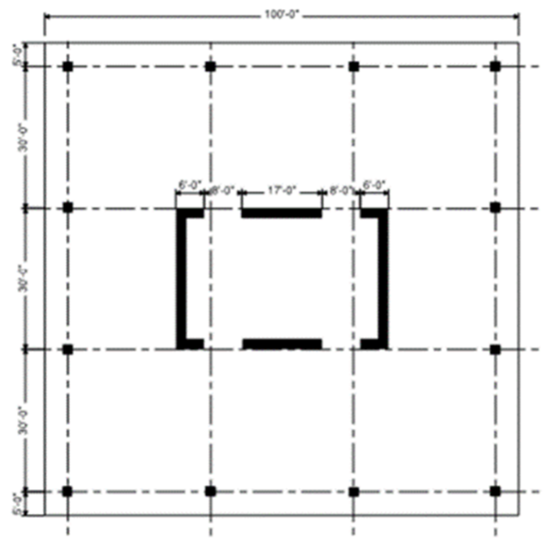


Figure 1. Typical plan for the sample 12-story post-disaster building

SEISMIC HAZARD

The sample buildings in Victoria and Seattle are assumed to be located on a soil site B. Figure 2 shows the Uniform Hazard Spectrum (UHS) with 2% in 50% probability of exceedance in 50 years for both Victoria and Seattle with the average ground motions chosen for the nonlinear time history analysis.

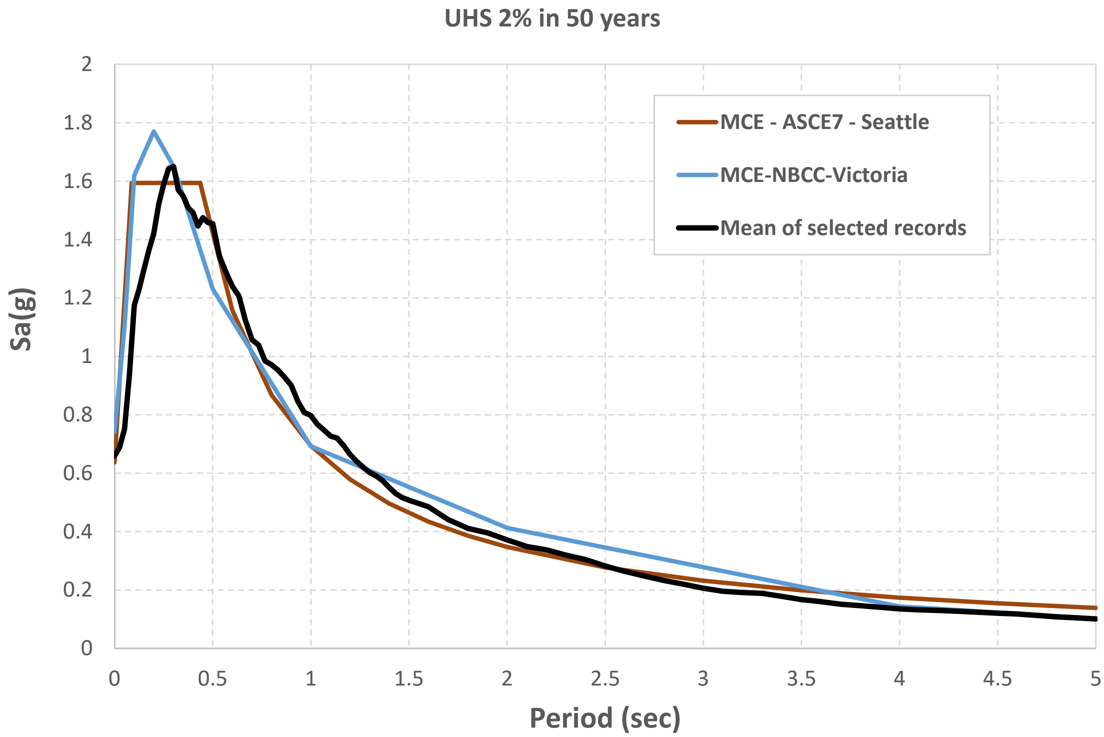


Figure 2. UHS of 2% in 50 years for both Seattle and Victoria

LATERAL DESIGN METHODOLOGY AND RESULTS

The design of the concrete shear walls complies with the ASCE 7-22 and NBCC2020 seismic design provisions. The seismic design of the shear walls involves the following steps:

1. Determine the seismic hazard (Figure 2).
2. Select the design earthquake (DBE for ASCE 7 and MCE for NBCC).
3. Determine the seismic forces. The seismic loads were calculated using the Response Spectrum Procedure.
4. Determine the required wall thicknesses and reinforcement.
5. Evaluate the design using 11 ground motions that matched the UHS for the Seattle region (Figure 2).

Though full detailing is beyond the necessary scope of the study, the shear walls meet all seismic strength and drift criteria. The sample 12-story building was designed for the three different cases below:

- Using ASCE 7 – located in Seattle.
- Using NBCC 2020 (w/o requirements for provision 4.1.8.23.) – located in Victoria.
- Using NBCC 2020 (including requirements for provision 4.1.8.23.) – located in Victoria.

Table 1 shows the seismic parameters used in the design of the building for the three cases above. Shear wall thicknesses of the building for the three cases is governed by strength demands (shear demand). The design responses, shear wall thicknesses and reinforcement are summarized in Table 2.

Table 1. Summary of Design Seismic Parameters (SW: Shear Wall; CW: Coupled Wall)

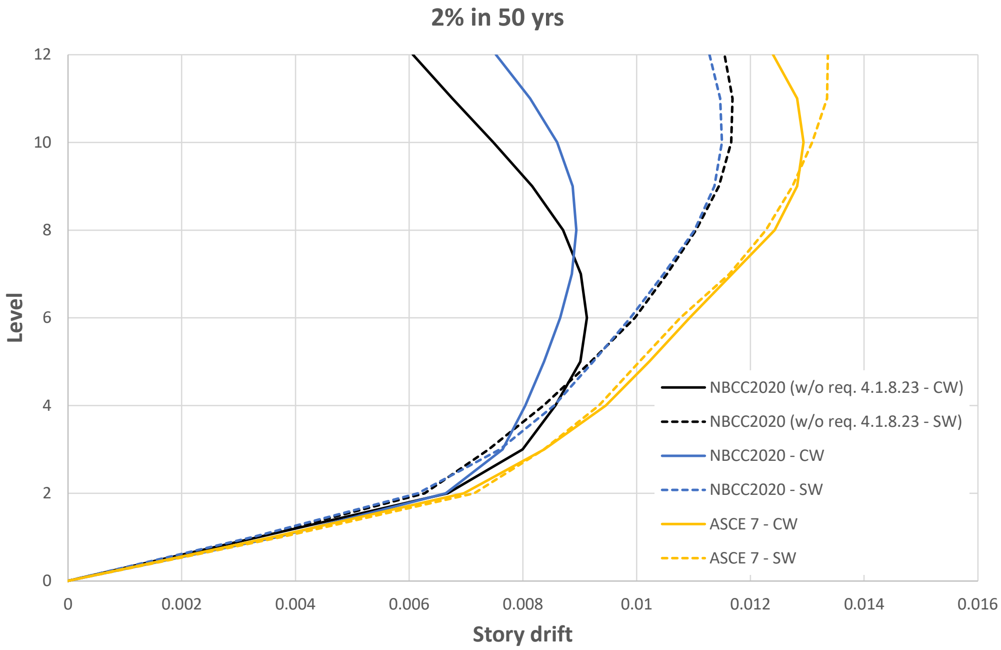
Seismic Parameters	**ASCE 7 – located in Seattle**	**NBCC 2020 (w/o requirements for provision 4.1.8.23.) – located in Victoria**	**NBCC 2020 (including requirements for provision 4.1.8.23.) – located in Victoria**
S_S or S(0.2)	1.328	1.77	1.239
S_1 or S(1.0)	0.463	0.693	0.485
Site Class	C	C	C
R or R_dR_o	8	3.5x1.6 (SW direction) 4.0x1.7 (CW direction)	1.3 (for 5% probability of exceedance in 50 years)
I	1.5	1.5	1.0
Allowable Story Drift	0.01hs	0.01hs	0.005hs (for 5% probability of exceedance in 50 years)

Table 2. Summary of Design Seismic Parameters (SW: Shear Wall; CW: Coupled Wall)

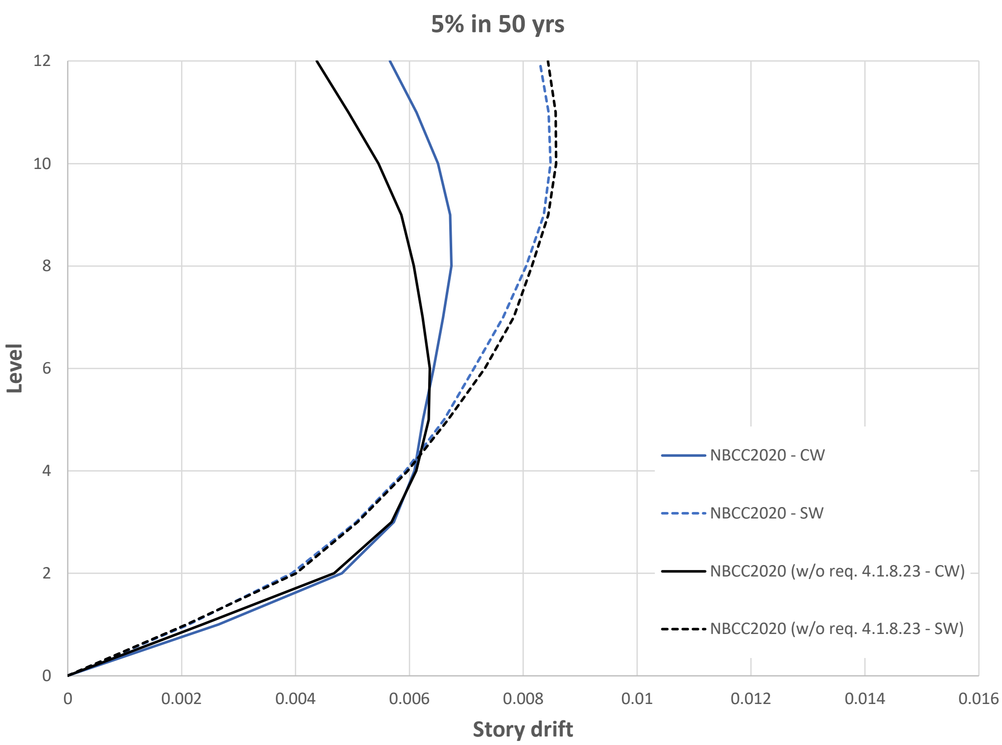
Design Responses	**ASCE 7 – located in Seattle**	**NBCC 2020 (w/o requirements for provision 4.1.8.23.) – located in Victoria**	**NBCC 2020 (including requirements for provision 4.1.8.23.) – located in Victoria**
T_a (sec)	1.20	1.40	1.00
Base Shear (kN)	8930 (SW direction) 9995 (CW direction)	24000 (SW direction) 20900 (CW direction)	59300 (SW direction) 70300 (CW direction)
Maximum Story Drift	0.008hs	0.01hs	0.0048hs
Shear Wall Thickness **@ Base (mm)**	813 (SW direction) 1067 (CW direction)	914 (SW direction) 914 (CW direction)	1219 (SW direction) 1219 (CW direction)
Wall Zone Reinforcement **@ Base** **@ each corner**	34 – 35M	56 – 35M	272 – 35M
Coupling Beam Size **@ Base (W x D - mm x mm)**	813 x 914	914 x 1219	1219 x 1219
Coupling Beam Reinforcement **@ Base**	10 – 35M	15 – 35M	50 – 35M
Foundation Demand (kN.m)	730,820 (SW direction) 842,403 (CW direction)	1,200,407 (SW direction) 1,241,251 (CW direction)	2,709568 (SW direction) 1,922,346 (CW direction)

SEISMIC RESPONSES

Nonlinear model for the three cases is carried out using a set of 11 ground motions (Figure 2). The average responses for the three cases are plotted in Figures 3 – 7 for story drift responses (Figure 3), coupling beam rotation (Figure 4), wall shear response (Figure 5), tensile stain in the wall zone (Figure 6) and floor accelerations at center of mass (Figure 7). The corresponding limit is also shown in Figure 5.

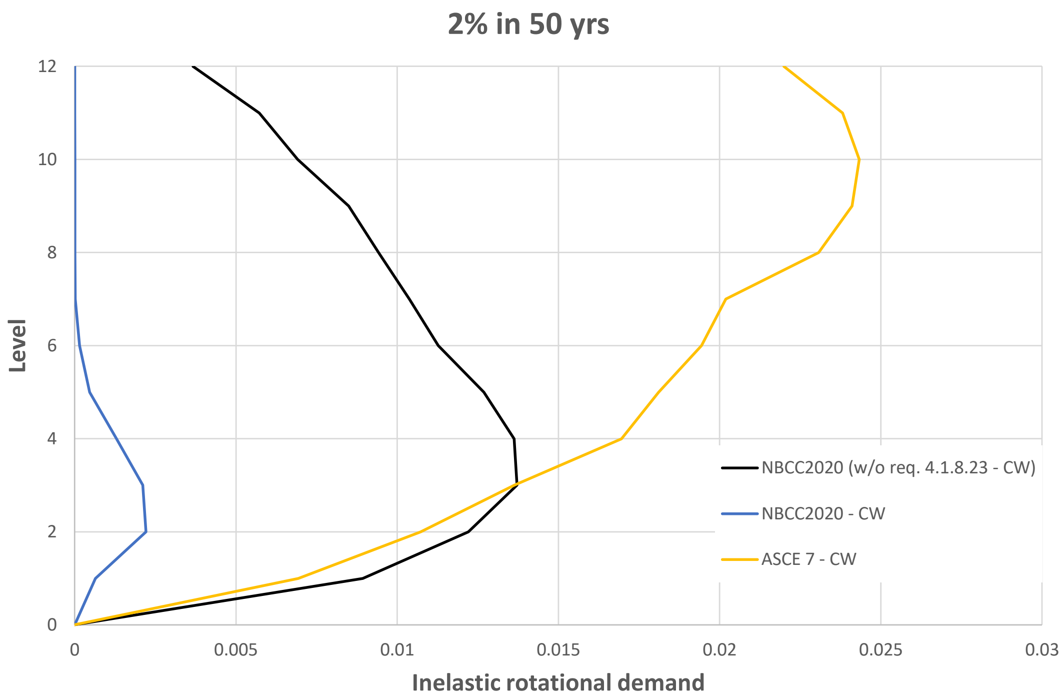


(a) Results for 2% in 50 yrs

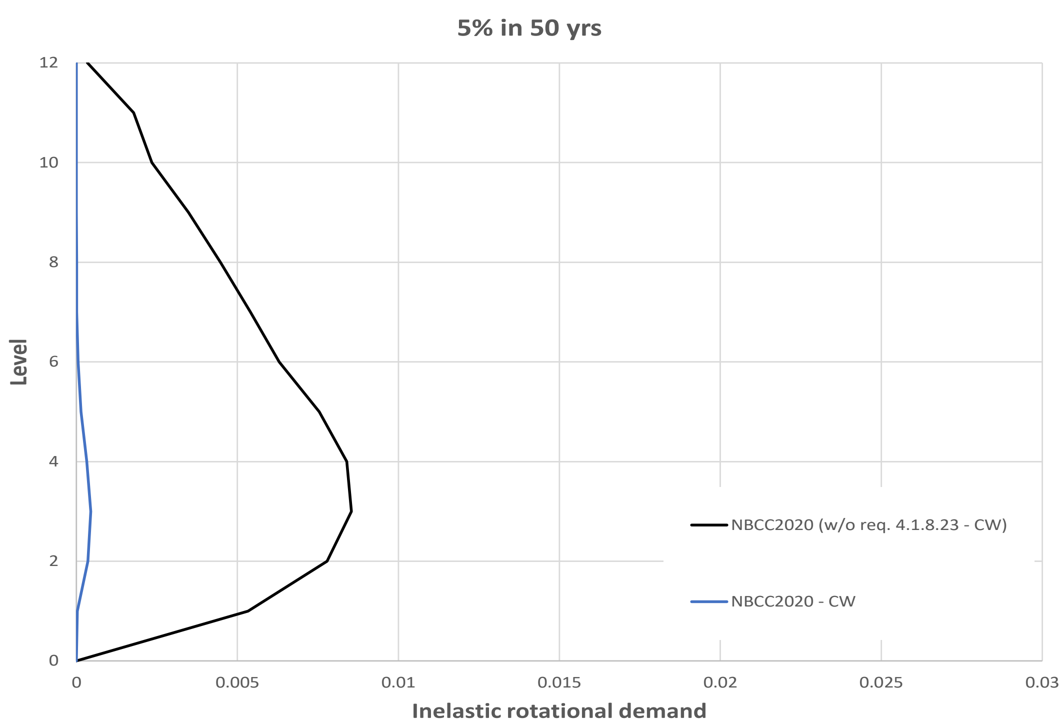


(b) Results for 5% in 50 yrs

Figure 3. Story drift responses for the three cases in both directions SW (Shear Wall direction) and CW (Coupled Wall direction) and for both 2% and 5% in 50 yrs hazard levels

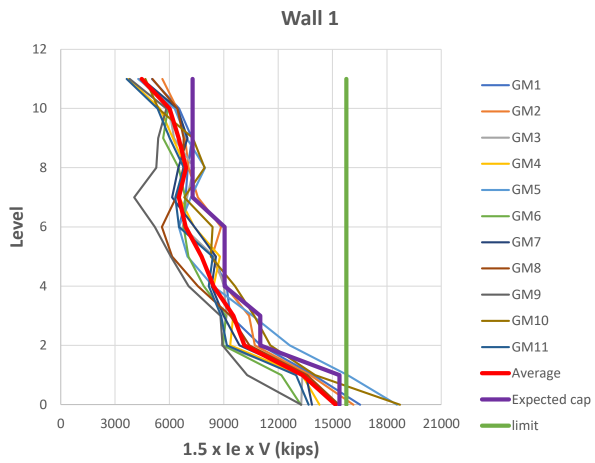


(a) Results for 2% in 50 yrs

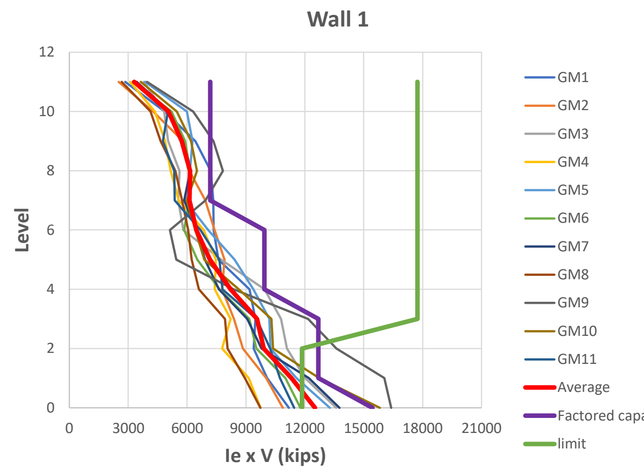


(b) Results for 5% in 50 yrs

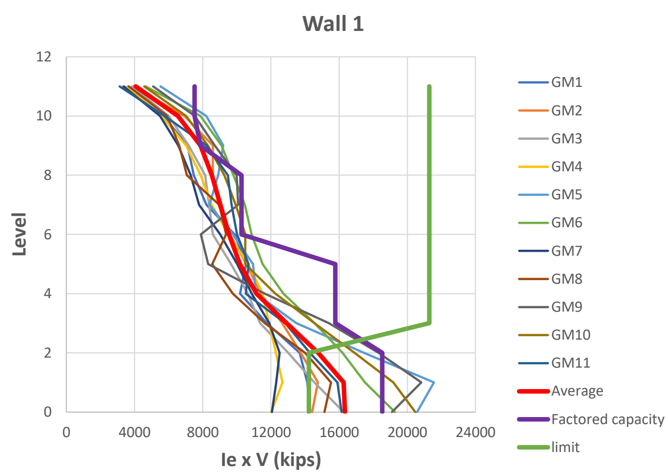
Figure 4. Coupling beam inelastic rotation responses for the three cases for both 2% and 5% in 50 yrs hazard levels



(a) ASCE 7 – located in Seattle

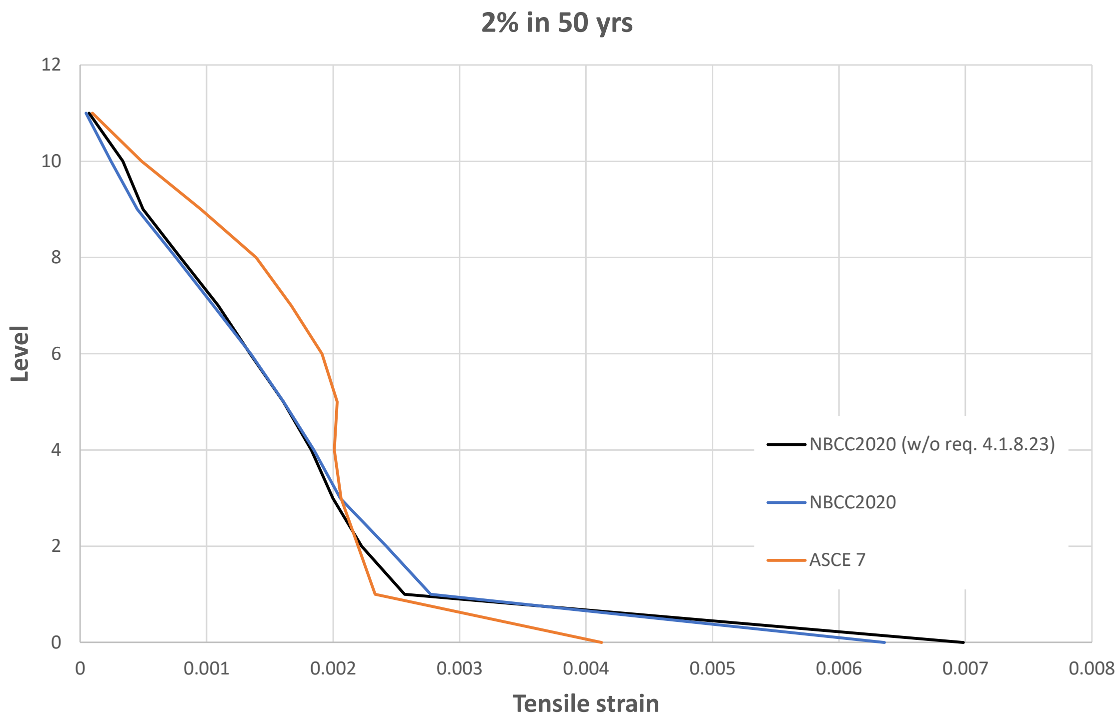


(b) NBCC 2020 (w/o requirements for provision 4.1.8.23.) – located in Victoria

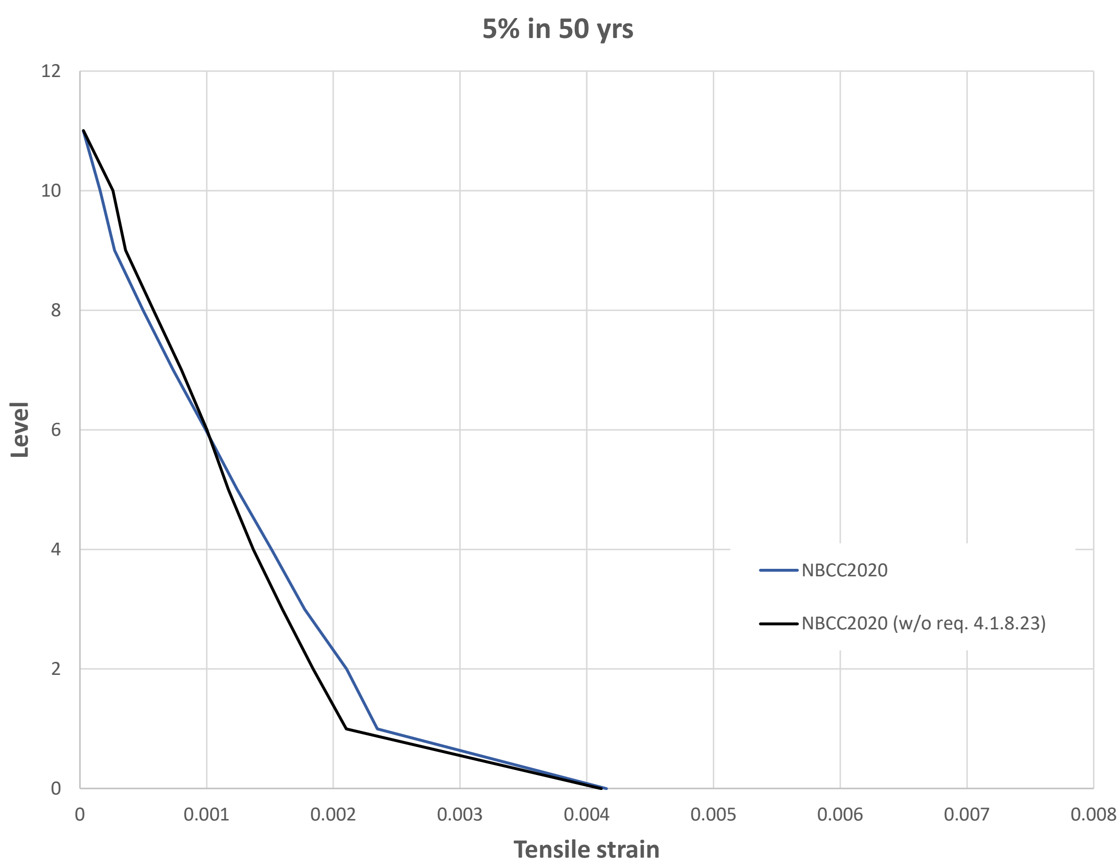


(c) NBCC 2020 (including requirements for provision 4.1.8.23.) – located in Victoria

Figure 5. Wall shear responses for the three cases for 2% in 50yrs hazard level

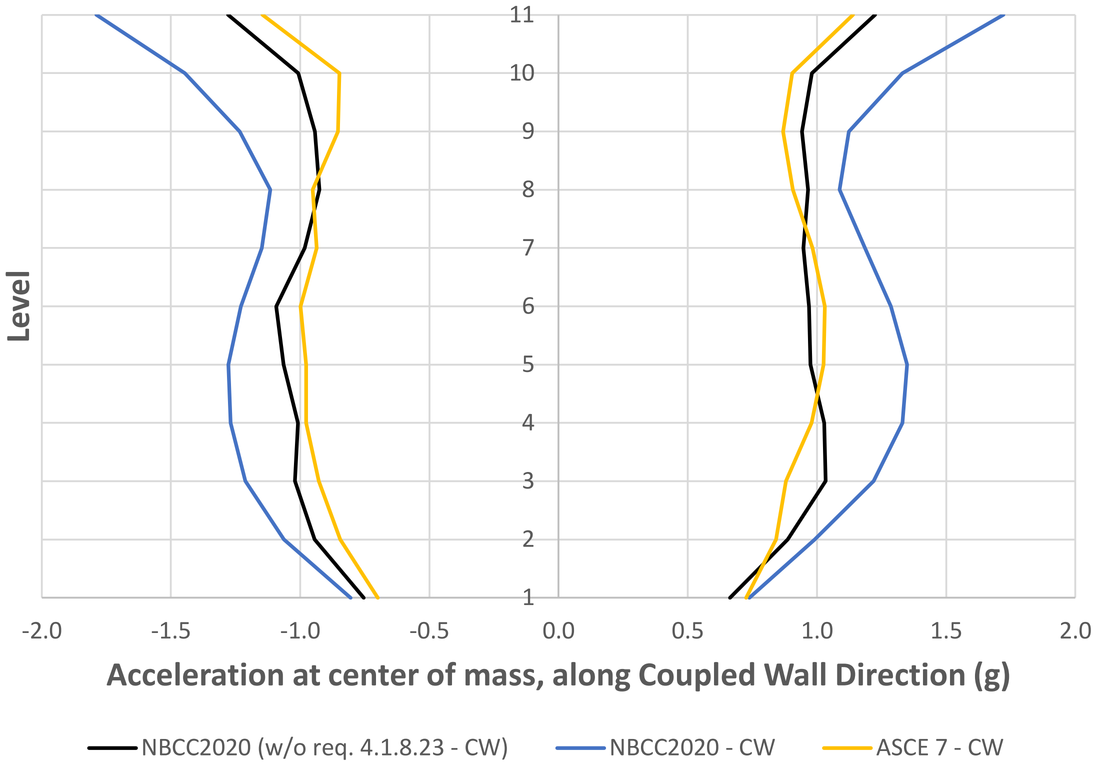


(a) Results for 2% in 50 yrs

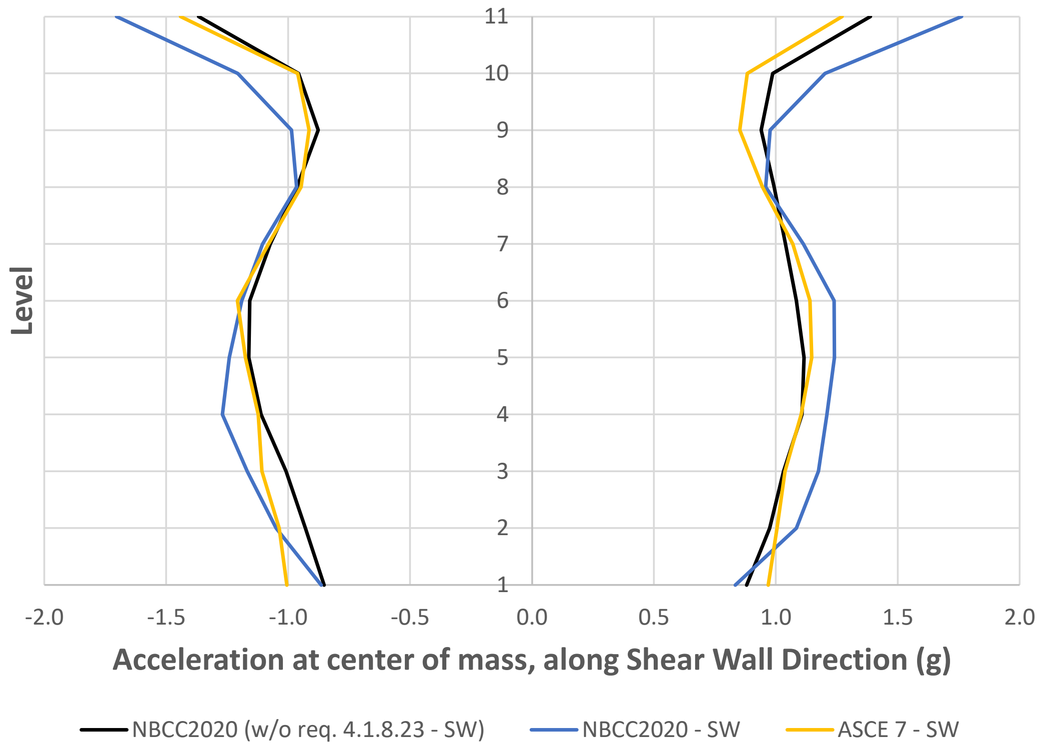


(b) Results for 5% in 50 yrs

Figure 6. Tensile strain in wall zone responses for the three cases for both 2% and 5% in 50 yrs hazard levels



(a) Results along the Coupled Wall (CW) direction



(b) Results along the Shear Wall (SW) direction

Figure 7. Floor accelerations at center of mass for the three cases for 2% in 50 yrs hazard level and along the coupled and shear wall directions

SUMMARY OF RESULTS

In review of Tables 2 and 3 and Figures 3 to 7 the following can be concluded:

- Due to the thicker walls and extra reinforcement, the NBCC 2020 case ends up with the highest foundation demands and will result in thicker and bigger shear wall rafts.
- Comparing the story drifts, it seems the story drifts are similar for the NBCC 2020 with and without the 4.1.8.23 clause designs which are both slightly less than the ASCE 7 design.
- Comparing the inelastic rotational demands for the coupling beams, it is clear that the coupling beams show minor inelastic demands for the building designed based on the NBCC 2020 with the 4.1.8.23 clause compared to the other design cases.
- Comparing the wall shear demands, it seems both design cases designed based on NBCC 2020 with and without the 4.1.8.23 clause go slightly beyond the limit in the plastic hinge region. This is mainly due to the thicker walls and heavier reinforcement which ends up with higher flexural demands.
- Comparing the tensile strains in the wall zone reinforcements, it seems there is still some minor yielding even in the building designed based on the NBCC 2020 with the 4.1.8.23 clause (2 x ε_y). The strains are very similar for both cases designed based on NBCC 2020 with and without the 4.1.8.23 clause.
- Comparing the accelerations at the center of mass along both the coupled and shear wall directions, it seems the acceleration is higher for the building designed based on the NBCC 2020 with the 4.1.8.23 clause compared to the other two buildings. This is mainly due to the NBCC 2020 building having a lower period. This higher acceleration could have an impact on the nonstructural acceleration sensitive components in post-disaster buildings.

CONCLUSIONS

This paper presents a comparative study between the seismic design of a post-disaster building located in Greater Victoria using 2020 NBCC and the seismic design of a post-disaster building located in Seattle using the newly updated ASCE/SEI 7-22. The sample building is designed for three different cases, a) ASCE 7 – located in Seattle, b) NBCC 2020 (w/o requirements for provision 4.1.8.23.) – located in Victoria, and c) NBCC 2020 (including requirements for provision 4.1.8.23.) – located in Victoria. The design and the corresponding responses for eleven ground motions are compared in this paper. As seen in the results, case 3 "NBCC 2020 (including requirements for provision 4.1.8.23.) – located in Victoria" design results in walls ~33% thicker with ~500% more zone rebars. The requirement under provision 4.1.8.23 to keep the lateral system elastic under the 5% probability of exceedance in 50 years seismic hazard level is the main reason for having such thicker walls. Comparing the results for different responses clearly indicates that the building designed based on NBCC 2020 with the 4.1.8.23 clause does not necessarily perform better than the case designed without the 4.1.8.23 clause. The 4.1.8.23(1) clause could benefit by incorporating the following suggestion:

> **4.1.8.23. Additional Performance Requirements for Post-Disaster Buildings, High Importance Category Buildings, and a Subset of Normal Importance Category Buildings**
>
> 1) *Buildings* designed in accordance with Articles 4.1.8.19. to 4.1.8.22. ***in addition to buildings that their performance is reviewed and verified based on a three-dimensional Non-linear Dynamic Analysis (in accordance to Article 4.1.8.12.)*** to need not comply with this Article.

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