SITE C | CLEAN ENERGY PROJECT

RESPONSE TO WORKING GROUP AND PUBLIC COMMENTS ON THE SITE C CLEAN ENERGY PROJECT ENVIRONMENTAL IMPACT STATEMENT

Technical Memo

SEISMIC CONSIDERATIONS

MAY 8, 2013

Subject: Seismic Considerations

1. PURPOSE

This technical memo addresses questions raised during the comment period on the EIS about seismic considerations.

The information contained in the following sections of this technical memo is taken from EIS Sections 11.2.5, 37.1.6, 37.1.7 and 37.1.8 unless stated otherwise.

This technical memo:

- summarizes the information on the seismicity considerations contained in the EIS
- describes the regional and site-specific seismic hazard analyses
- describes how the results of the seismic hazard analysis were incorporated into the engineering design of the Project

2. REGIONAL SEISMICITY

This section of the technical memo addresses the following IRs that relate to regional seismicity:

- pub_0601-002, pub_0601-004 and pub_0601-007 from Peace River Environmental Society
- gov_0014-012 from Natural Resources Canada

EIS Section 11.2.2 provides an overview of the regional geology and regional glacial history that is pertinent to the regional seismicity and the seismic hazard analysis for the Project. This section of the EIS primarily focuses on the surface and near-surface rocks which affect the geotechnical design of the proposed Site C dam, or which influence the conditions along the proposed reservoir shoreline.

Additional details of the regional geology are included in EIS Section 11.2.5.1, which includes a description of the Peace River Arch, a regional-scale geological feature in the basement rocks that extend under Site C.

As described in the EIS, the proposed Project site is located on the western edge of the Interior Plains, which comprise up to several kilometres of sedimentary rocks that were deposited in an inland sea that existed from Jurassic[1] to Cretaceous time. These sedimentary rocks overlie the geologically-ancient and massive rocks of the North American craton. The surface bedrock in the region around the proposed Project site consists of flat to gently-dipping sedimentary rocks of Cretaceous age. These rocks are relatively undeformed by tectonic activity compared to the highly folded and faulted rocks of the Rocky Mountains to the west.

The Peace River Arch is a portion of the North American craton that was the site of recurrent uplift and deformation periodically through the late Mesozoic or early Cenozoic eras. The western portion of the initial uplift subsequently failed and became a depositional basin, referred to as the Peace River Embayment, through the early Cenozoic era. Repeated faulting of the embayment left a series of northeast and northwest-striking faults that bound grabens[2] along the former arch. None of these faults are reported to extend into the middle or upper Cenozoic deposits of the Peace River Embayment.

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[1] For geologic periods referenced herein see Table 1.

[2] A graben is a depressed block of rock bordered by parallel faults.

Table 1 – Geologic Periods Referenced in this Technical Memo

Era	Period	Start (Millions of years ago)
Cenozoic	Quaternary	2.6
	Neogene	23.0
	Paleogene	65.5
Mesozoic	Cretaceous	145.5
	Jurassic	200
	Triassic	251

One published paper (Berger et al, 2009) cited by IR PUB_0601-002 describes some interpreted relations between basement faults in the Peace River Arch and several of the petroleum fields in the overlying sedimentary rocks. The locations of basement faults and their extensions into the Cretaceous rocks have been interpreted from various well, geophysical and remote sensing data. The paper also states that “most of the deeply incised stream valleys are largely controlled by the (Fort St John) graben’s faults”, and cite the area near the confluence of the Peace and Moberly Rivers as an example. This would require that either the basement faults propagate to the surface where they were preferentially eroded by the rivers or that the faults have caused enough surface deformation/displacement that the rivers eroded along the edges of grabens or folds. Geological site investigations at the Site C damsite have not found any evidence of major faulting along the Peace River (distinct marker beds in the bedrock are visible on each side of the river indicating no offset), and the near-surface sedimentary rocks are nearly horizontal except for local shears that are interpreted to be related to valley rebound effects rather than tectonic origin. In addition, the course of the pre-last glacial Peace and Moberly Rivers is different than that of the modern rivers (see EIS Section 11.2.2.4 page 11-17, lines 37-40) as shown schematically on EIS Figure 11.2.5, and does not correspond to the faulting pattern implied by Berger et al. (2009). Thus, in the area of the proposed dam site, there is no evidence to support the geologically-young near-surface fault movements that are implied by Berger et al (2009).

IR pub_0601-007 refers to a linear feature at the ground surface in the vicinity of a landslide along the Montagnuese River near its confluence with the Peace River in Alberta. The IR subsequently refers to this linear feature as a fault and suggests a possible connection with a deep basement fault that is shown on figures in published technical papers. BC Hydro has not investigated this specific feature which is located downstream in Alberta, but notes that this interpretation is speculative and similar in nature to the cited example near the Moberly and Peace Rivers. Based on research done for the 2012 seismic hazard analysis, BC Hydro is not aware of any supporting evidence that would demonstrate that these deep bedrock faults extend to the bedrock surface and the overlying unconsolidated surficial deposits.

As noted in EIS Section 11.2.5.1 (page 11-43, lines 16-22), inland from the plate boundary region, seismic activity generally occurs at low to moderate rates across B.C. (EIS Figure 11.2.15). Although various trends and concentrations can be interpreted in the locations of recorded earthquakes, it has generally not been possible to correlate these inland earthquakes with specific fault sources. There are

only a small number of faults in southern B.C. that are considered active or potentially active; all of these faults are more than 600 km away and do not contribute to the seismic hazard at the Project.

IR gov_0014-012 requested clarification on whether it is the lack of seismicity and results from geological observations at the Project site that lead to the conclusion that the faults are inactive. As described in EIS Section 11.2.5.2.2 one of the models used in the 2012 seismic hazard assessment assumed that faults in the Peace River Arch zone were potential locations for earthquakes, even though the these faults are not known to be active.

It should be noted that the difficulty in identifying active faults applies to most of Canada, not only to the region around the proposed Project. It was not concluded that the faults are inactive. Rather, given that some earthquakes occur, there must be active faults that caused the earthquakes. However, it has not been possible to identify the specific faults that are active. Work that was done in an effort to identify active faults included review of recorded earthquake locations and depths and comparison with available geological mapping, and discussions with geological specialists familiar with the regional geology. In addition, known locations of Cretaceous faults and shears show no surface expression in LIDAR mapping done for the Project, nor are offsets visible in the overlying Quaternary deposits.

3. SITE-SPECIFIC SEISMIC HAZARD ANALYSIS

This section of the technical memo addresses questions raised during the comment period on the EIS about seismic hazard analyses for the proposed Project.

IRs received:

- pub_0601-005 from Peace River Environmental Society
- gov_0014-014 and gov_0014-015 from Natural Resources Canada

EIS Section 11.2.5.2 describes two seismic hazard analyses that were performed for the Project. The first analysis, described in EIS Section 11.2.5.2.1, was undertaken in 2009 by the Site C engineering team, with specialist input and review by a consulting seismologist with substantial experience in seismic hazard analysis (Klohn Crippen Berger and SNC Lavalin Inc. 2009). The second analysis, described in EIS Section 11.2.5.2.2, was completed in 2012 by BC Hydro. This analysis was a system-wide Level 3 probabilistic seismic hazard analysis performed in accordance with the guidance provided by the Senior Seismic Hazard Analysis Committee (SSHAC, 1997). The SSHAC guidance originated in the nuclear industry in the 1990s and is now starting to be applied on probabilistic seismic hazard analyses for other facilities such as dams.

Seismic hazard analysis is based on models that have inherent uncertainties, such as those related to whether specific geological features are seismically active or not, and if a feature is active, what are the rate of activity and the maximum magnitude that can be produced by the feature. Such uncertainties are addressed in seismic hazard analyses by incorporating alternative weighted models. Both of the seismic hazard analyses performed adopted this approach. In addition, the SSHAC process was designed with the objective of representing the centre, body and range of technically-defensible interpretations of possible models.

IR pub_0601-005 commented that the full details of the 2012 BC Hydro seismic hazard analysis were not made available for public review, and that “without the openness of peer review and public disclosure of the data and information to the private, public sector or academia the public cannot be assured that the work was completed in the public interest”.

Peer review by qualified reviewers is an inherent element of the SSHAC process. As described in EIS Section 11.2.5.2 (page 11-46), the SSHAC project participants included over 20 earth scientists, engineers, and seismologists who served as evaluators, analysts, or technical integrators. This team

was drawn from several major consulting companies, universities, individual consultants, and BC Hydro. A three-person participatory Peer Review Panel was involved throughout the SSHAC project, in particular through attendance and feedback at major SSHAC project workshops and through review of draft and final SSHAC project reports. During the SSHAC project, over 25 resource experts formally participated, and numerous other members of the scientific community were contacted to provide specific information, for example in relation to published technical papers. Resource experts were largely drawn from the Canadian and US Geological Surveys and universities, along with some independent consultants. The review by the three person panel and the involvement of the Canadian and US Geological Surveys provides confidence that the assessment was robust and completed in the public interest.

Due to the difficulty in identifying specific active faults, the seismic sources developed for the 2009 seismic hazard analysis were all defined as area sources, which is standard practice. In an area source, seismicity is modeled as being uniformly distributed across the source.

In the 2012 BC Hydro seismic hazard analysis, the seismic source model also included area source zones, including the Peace River Arch areal source zone (labelled PRA on EIS Figure 11.2.15). The Peace River Arch source zone includes the location of the 2001 MW5.4 Dawson Creek earthquake, which has not been correlated to any specific geologic feature. The Peace River Arch zone is defined by and delineated around a distinctive group of faults in the underlying craton. Although these faults are not known to be active, they are favourably oriented for reactivation relative to the present crustal stress regime. Therefore, as an alternative to the areal source zone, a source model for the Peace River Arch used in the seismic hazard analysis included this set of faults as “embedded faults” that are considered to have some potential to be the location of future earthquakes in the present tectonic environment. As such, these faults provided an alternative model for the spatial distribution of future earthquake occurrences within the Peace River Arch source zone without adding to the overall estimated rate of earthquake occurrences.

The embedded faults used in the alternative model are shown on EIS Figure 11.2.15. The fault locations and orientations are generalized from the pattern of faults mapped by O’Connell (1994) and Mei (2007), two of the references cited in IR pub_0601-007. These faults represent two near-orthogonal sets of northeast- and northwest-striking, relatively high-angle faults that are considered to be generally favourably oriented for reactivation with the present regional stress regime.

As stated in EIS Section 11.2.5.2 (page 11-47, lines 36-38), the seismic source model allows for maximum magnitudes of up to MW7.6 in the Peace River Arch, Interior Plains, and Northern Foreland Belt source zones, though at very low rates and with low weightings.

Within the seismic hazard analysis, there were numerous alternative seismic source model variations, each with their own set of alternative recurrence models and maximum magnitude alternatives. It is not possible to present the full range of maximum magnitudes and weightings in a simple manner. However, the overall low activity rates for large magnitude earthquakes are illustrated in the following table that summarizes the composite model recurrence rates for earthquakes greater than or equal to magnitudes 6 and 7 in the Peace River Arch (PRA) and Interior Plains (IP) seismic source zones which are shown on EIS Figure 11.2.15.

Seismic Source Zone	**Earthquake Recurrence (years)**					
	M≥6			**M≥7**		
	Mean	**5th**	**95th**	**Mean**	**5th**	**95th**
IP	503	2,045	162	17,746	$>10^{10}$	2,316
PRA	792	12,839	213	13,635	$>10^{10}$	3,377

As an example of how to interpret this table, the mean recurrence time for a magnitude M≥7 occurring in the PRA zone is 13,635 years. There is a 5 percent confidence that a magnitude M≥7 has a recurrence time of $>10^{10}$ years (i.e. 10 billion years), and a 95 percent confidence that a magnitude M≥7 has a recurrence time of 3,377 years.

4. CURRENT UNDERSTANDING OF HOW PETROLEUM INDUSTRY-RELATED ACTIVITIES MAY AFFECT SEISMICITY

This section of the technical memo addresses questions raised during the comment period on the EIS about current understanding of how petroleum industry-related activities may affect seismicity.

IRs received:

- gov_0010-698
- pub_0601-006 from the Peace River Environmental Society

EIS Sections 22.3.1 to 22.3.4 describe the baseline conditions for oil and gas production in the Peace River region of B.C. EIS Section 22.3.5 describes the directional drilling and high pressure fracturing technologies that are being increasingly adopted to extract natural gas from tight shale formations. This process is commonly referred to as hydraulic fracturing or “fracking”.

EIS Section 11.2.5.5 describes the current understanding of how petroleum industry-related activities may affect seismicity. It is noted that the US National Research Council (NRC) recently investigated the scale, scope, and consequences of seismicity induced during fluid injection and withdrawal activities related to geothermal energy development and oil and gas development, including shale gas recovery and carbon capture and storage (US National Research Council, 2012). It was found that only a very small fraction of injection and extraction activities at hundreds of thousands of energy development sites in the United States have induced seismicity at levels that are noticeable to the public. With respect to shale gas, it was found that:

- The process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events (only one confirmed case in the world)
- Injection for disposal of waste water derived from energy technologies into the subsurface does pose some risk for induced seismicity, although very few events have been documented over the past several decades relative to the large number of disposal wells in operation

With the expanding shale gas industry in northeastern B.C., the BC Oil & Gas Commission has also investigated the potential for induced earthquakes related to that activity (BC Oil & Gas Commission, 2012). That investigation found that more than 8,000 high-volume hydraulic fracturing completions have been performed in northeast British Columbia with no associated anomalous seismicity. However, it was found that 38 earthquakes from magnitude M_L2.2 to M_L3.8 that occurred in two areas of the Horn River Basin in 2011 were induced by movements on pre-existing faults due to fluid injection during hydraulic fracturing. Only one of these earthquakes was physically felt at surface and there were no reports of injury or property damage. Several well bores intersected faults that were mapped by 2D and 3D seismic surveys, but no earthquake events could confidently be linked to most of these faults.

The Oil & Gas Commission is now establishing procedures and requirements for monitoring and reporting of induced seismicity. Each case of induced seismicity will be evaluated on the basis of its unique site-specific characteristics, but it is proposed that hydraulic fracturing would be suspended upon detection of an earthquake of magnitude M4 or larger. It should be noted that earthquakes less than about magnitude M5 do not release enough energy to cause damage to engineered structures.

At the time of submission of the EIS there was no rationale for defining a specific distance within which to restrict hydraulic fracturing near a dam or reservoir. EIS Section 22.5, page 22-10, lines 24-30, identifies one case where fracking is already being done under a man-made reservoir.

In North Dakota, oil companies have begun tapping crude oil and gas underneath Lake Sakakawea (the state's biggest lake) using advanced horizontal drill techniques. The 180-mi.-long reservoir was created when the Garrison Dam was built on the Missouri River in the 1950s. The lake flooded more than 60,703 ha and has more than 2,736 km of shoreline. With the new technologies, wells can be situated at an environmentally safe distance from shore, drilled vertically to about 3,048 m, and then pushed an equal distance horizontally to reach the resource (MacPherson 2008).

BC Hydro has ongoing contact with the BC Oil & Gas Commission (BCOGC) with regard to fracking. The current understanding is that the BCOGC will continue to monitor fracking activity and any associated seismic activity and to restrict activities that result in unacceptable fracking-related seismic effects. BC Hydro closely monitors oil and gas activities near its facilities and would take steps if required to protect its facilities. BC Hydro also continuously reviews international standards, policies and practices with respect to hydraulic fracturing.

As described in Section 3 of this Technical Memo, the 2012 seismic hazard analysis has included the potential for large magnitude earthquakes on such faults. It should be noted that the fracking process by itself cannot generate large magnitude earthquakes, but could potentially trigger earthquakes on existing faults with stress conditions that are already close to rupturing. If such a case were to occur, the fracking would only be causing the earthquake to occur sooner than it would have occurred due to natural tectonic stress buildup.

5. SEISMIC PERFORMANCE REQUIREMENTS

This technical memo addresses questions raised during the comment period on the EIS about seismic performance requirements.

IRs received:

- gov_0014-015

EIS Sections 37.1.6 to 37.1.8 provide an overview of lessons learned from major earthquakes regarding the performance of concrete and earthfill dams. EIS Sections 37.1.8.1.1 to 37.1.8.1.5 provide a description of the seismic performance requirements for the proposed Project structures and a brief overview of the approaches to seismic design of those structures.

Seismic design of the proposed structures is based on the results of the seismic hazard analyses described in EIS Section 11.2.5.2. As noted on page 11-48, lines 1 to 10, there is a range of possible earthquake magnitudes and distances that contribute to the seismic hazard for the Project. For dynamic analysis, time histories meeting the following criteria and scaled to the response spectrum would be representative of the seismic hazard:

- Fault mechanisms: strike-slip, reverse, and reverse-oblique
- Magnitude target: M_W6.6
- Magnitude range; M_W5.5 to 7.5 excluding aftershocks
- Distance target: 50 km
- Distance range: 0 km to 200 km

These criteria do not imply that seismic design of the Project is based on earthquake scenarios matching all possible combinations of these parameters. For example, there are no existing recordings of large magnitude earthquakes at zero distance (i.e. immediately below the recording site).

EIS Table 37.3 lists 8 earthquake records that were selected for dynamic analyses of the proposed concrete structures because they were representative of the seismic for the Project. In each case, the original earthquake acceleration time history record was scaled such that its response spectrum matched the target response spectrum that was developed in the seismic hazard analyses. The scaled record was then used in numerical analyses that analysed how the structure would perform when subjected to the dynamic shaking. Multiple earthquake records were selected for the analyses in order to account for the natural variation in factors such as duration of shaking and frequency content.

6. REFERENCES

BC Hydro, 2012, Probabilistic Seismic Hazard Analysis (PSHA) Model, Engineering Report E658, 4 volumes, November.

BC Oil and Gas Commission, August 2012, Investigation of Observed Seismicity in the Horn River Basin, 29 pp.

Berger, Zeev, M. Boast, and M. Mushayandebvu, , 2009, The Contribution of Integrated HRAM Studies to Exploration and Exploitation of Unconventional Plays in North America, Part 2: Basement Structures Control on the Development of the Peace River Arch's Montney/Doig Resource Plays, Reservoir, Issue 2, pp. 40-45, February.

Klohn Crippen Berger Ltd. and SNC-Lavalin Inc., 2009, Site C Clean Energy Project, Task 2: Establish the Maximum Design Earthquake (MDE), Seismic Hazard Assessment, Report No. P05032A02-02-001 R1. April

MacPherson, J. 2008. Oil Rigs Start Drilling Beneath ND's Big Lake. News from Indian Country. Available at: http:Indiancountrynews.net. Accessed: October 2012

Mei, Shilong. 2007, Updates on Faults and Structural Framework of the Peace River Arch Region, Northwest Alberta, Obtained using a New Approach, 2007 CSPG CSEG Convention, Pp. 75-78.

O'Connell, S.C., 1994, Geological history of the Peace River Arch; in Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, Special Report 4, pp. 431–438.

Senior Seismic Hazard Analysis Committee (SSHAC), 1997, "Recommendations for probabilistic seismic hazard analysis: guidance on uncertainty and use of experts", prepared for the US Nuclear Regulatory Commission, Vol. 1, NUREG/CR-6372.

US National Research Council, 2012, Induced Seismicity Potential in Energy Technologies, The National Academies Press, Washington, D.C., Prepublication, 239 pp.

Related Comments / Information Requests:

This technical memo provides information related to the following Information Requests:

gov_0007-001	gov_0010-092	gov_0010-095	gov_0010-605	gov_0010-698
gov_0014-012	gov_0014-014	gov_0014-015	pub_0550-001	pub_0568-001
pub_0601-002	pub_0601-004	pub_0601-005	pub_0601-006	pub_0601-007
pub_0601-010	pub_0601-011	pub_0847-001	pub_0922-001	ab_0001-553

ab_0003-041				