British Columbia Smart Infrastructure Monitoring System

Overview

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Abbreviations

BC: British Columbia

BCSIMS: British Columbia Smart Infrastructure Monitoring System

EEW: Earthquake Early Warning

MoTI: BC Ministry of Transportation and Infrastructure

NRCan: Natural Resources Canada

PGA: Peak ground acceleration

SGMN: Strong Ground Motion Network

SSHM: Seismic Structural Health Monitoring

USGS: United States Geological Survey

1. Introduction to BCSIMS

MoTI is responsible for over 400 km of Provincial Disaster Response Routes and maintains over 2500 bridges and other infrastructure located in the highest seismic zones of BC. The loss of any portion of these routes or infrastructure after a major earthquake could significantly impact emergency response efforts, affect public well-being, and hinder the economic recovery of the region. For these reasons, MoTI has placed a great emphasis on seismic safety including stringent design requirements for new infrastructure, a comprehensive retrofit program for existing and deficient structures, and development of detailed disaster response plans. As an enhancement to each of these areas, MoTI has maintained BCSIMS, a Province-wide seismic monitoring network since 2009.

BCSIMS is comprised of two major subnetworks: the Strong Ground Motion Network (SGMN) and the Seismic Structural Health Monitoring (SSHM) network. Both connect to the BCSIMS Data Centre, which hosts several virtual servers that collect, store, and analyse the data generated by these networks. The data is available to users through automated reports and a publicly accessible website **bcsims.ca**.

The purpose of the SGMN is to report on seismic activities in and around BC. This is done using a network of earthquake sensors installed on the ground that measure the local shaking levels in near-real time. In the event of a strong earthquake, data from the sensors is collected and analyzed to automatically create shake-maps and earthquake reports which are emailed to users and accessible through the website. These maps and reports can be used by Emergency Responders, different levels of Government, Industry, and the Public to enhance their awareness and better prioritise decision making and deployment of resources in the event of an earthquake.

In the SSHM network, various types of sensors are installed on selected MoTI infrastructure (e.g., bridges on lifeline routes) to monitor their response to loads such as traffic, wind, and earthquakes in near-real time. The measured sensor data is stored and analysed at the BCSIMS Data Centre to provide reports that can be used by MoTI personnel (e.g., Engineers and Bridge Inspectors) for planning, training and post-earthquake response. The data from the SSHM network is also used in Academia for research to increase knowledge of this infrastructure, which contributes to enhanced safety and more cost-effective long-term maintenance.

This document provides a description of the organization and interconnectivity of the main components of BCSIMS (Section 2), an overview of the SGMN (Section 3), the SSHM network (Section 4) and the Data Centre (Section 5). It also includes a brief history of the major milestones of earthquake monitoring in BC and BCSIMS (Section 6).

2. Organization of BCSIMS

BCSIMS is organized into three main components:

1. Strong Ground Motion Network – SGMN,
2. Seismic Structural Health Monitoring Network - SSHM, and
3. BCSIMS Data Centre

The interconnectivity of these components is shown in Figure 2.1. The SGMN is comprised of a series of individual earthquake sensors (three sensors are shown as an example; however, BCSIMS can support any number). Each earthquake sensor connects to a Relay server at the Data Centre over the Internet. The SGMN data is analyzed on the Applications server and analysis results stored in the SQL Database server.

The SSHM Network is comprised of monitoring systems installed on selected MoTI infrastructure (three systems are shown as an example; however, BCSIMS can support any number). Each system has a series of sensors that connect to an on-site Data Recorder which in turn sends sensor data to the SSHM Collector Server. The collected sensor data is analyzed on the SSHM Data Analysis server, and the analysis results are stored in the SQL database.

Raw sensor data and earthquake reports are accessible through a public website (bcsims.ca) which is hosted on the web server.

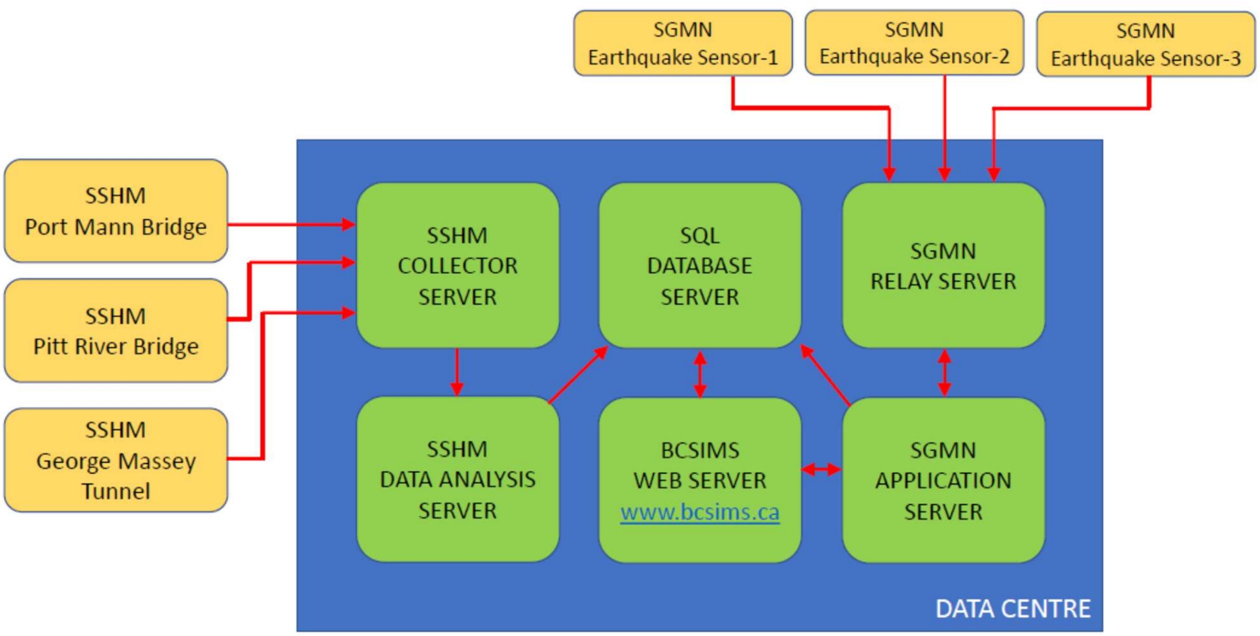

Figure 2.1: Organization of BCSIMS

3. Strong Ground Motion Network

During a strong earthquake, the level of ground shaking across a region can vary substantially even at close distances. This is true for both the actual shaking and the human perception of the shaking. The sensors in the SGMN are used to limit any misperception of the severity of the earthquake, by reporting the on-the-ground shaking level at as many locations as possible, across the entire affected region. This substantially enhances the ability for emergency responders and the MoTI earthquake response teams to prioritize and enable efficient deployment of available resources.

The SGMN consists of over 120 earthquake sensors installed across the Province that continuously monitor seismic activities. Once triggered by an earthquake, these sensors automatically connect to multiple servers at the Data Centre to report the level of ground shaking at their installed locations. A shake-map and an earthquake report will be automatically generated and can be used by MoTI Earthquake Response Teams and other Emergency Responders to prioritize and enable efficient deployment of available resources.

3.1. BCSIMS connection to USGS network

The USGS operates a Weak Ground Motion Network with a dense global distribution of earthquake sensors. Selected Canadian locations are included using data from NRCan earthquake sensors. Once triggered by an earthquake, the USGS network will immediately collect seismic data from all sensors in the affected region and report the date and time, magnitude, and epicenter. This earthquake meta-data is then made available to registered users. BCSIMS maintains a continuous online link to the USGS data center to obtain recent earthquake activities in Canada as well as in the US states of Washington, Oregon, and Alaska.

BCSIMS in turn features an automated service that sends out earthquake notifications by e-mail to registered users. Notifications contain the meta-data of the earthquake as well as any earthquake report that was generated. The registration for the earthquake notification service is open to public users from the BCSIMS website (bcsims.ca).

The automatic earthquake notifications include the following meta-data:

1) Earthquake magnitude,
2) Epicentral location,
3) Hypocentral depth,
4) Date and time of the earthquake,
5) Region and closest cities to epicenter, and
6) Earthquake report if created.

3.2. Earthquake Sensors in the SGMN

The SGMN is currently managed by MoTI and consists of more than 120 earthquake sensors installed in urban areas across the province. Locations include various public schools, government offices, fire halls, BC ambulance stations, private residences, and businesses. A complete list of earthquake sensor locations is given in the Appendix of BCSIMS Document 2.3. Examples of typical BCSIMS earthquake sensors are shown in Figure 3.1.

Earthquake sensors are typically installed in an 'Urban' configuration (with the sensor mounted on a building foundation) and oriented to True North. They continuously measure the ground vibration in three perpendicular directions: East-West, North-South, and Up-Down. Each earthquake sensor features capabilities for measurement (accelerometer), seismic data analysis (Linux board), seismic data storage (non-volatile memory), and communications (ethernet) to remote data centers.

Figure 3.1 Typical BCSIMS Earthquake Sensors on foundation.

In addition to 'Urban' installations, sensors are installed in 'Free Field' and 'Down Hole' configurations. A free field sensor is installed on its own foundation away from any nearby structure. These are common throughout BCSIMS close to bridge monitoring systems. A downhole sensor is installed at depth, to either be closer to bedrock, measure a specific soil layer and/or get away from surface noise. Downhole sensors are often setup as 'Downhole Arrays' with a group of sensors (and possibly sensor types) installed at the same location with varying depths. Table 3.1 summarizes the sensors in the BC SGMN.

Table 3.1: Number of Sensors in the BC SGMN

Sensor Type	**Number of Locations**
Urban Earthquake Sensor	88
Free Field Earthquake Sensor	20
Downhole Earthquake Sensor	5
Downhole Array	7

3.3. Shake-maps and earthquake reports

Earthquake sensors in the SGMN are designed to trigger during a strong earthquake and will send information about the level of ground shaking to the BCSIMS Data Centre over the internet. This information is used to automatically generate a shake-map and an earthquake report (in 15 minutes on average) if the following conditions are met:

1) Epicenter of the earthquake is less than 250 km from the nearest earthquake sensor,
2) Magnitude of the earthquake is larger than 3.5, and
3) At least 2 earthquake sensors are triggered by this earthquake.

A shake-map is a color-coded heat-map that shows the estimated distribution of the strong ground motion parameters (e.g., PGA or earthquake intensity) over an earthquake affected region. Hot colours (e.g., red) indicate high-levels of ground shaking whereas cool colours (e.g., grey) indicate low-levels of ground shaking. Other meta-data can be superimposed onto the shake-map interactively on the BCSIMS website including geographical boundaries, roads, schools, and MoTI infrastructure (e.g., bridges, tunnels, culverts, marine structures). This provides an at-a-glance picture of the risk to MoTI infrastructure in the immediate aftermath of an earthquake. An example of a shake-map as generated by BCSIMS is shown in Figure 3.2 (shown with bridge layer on).

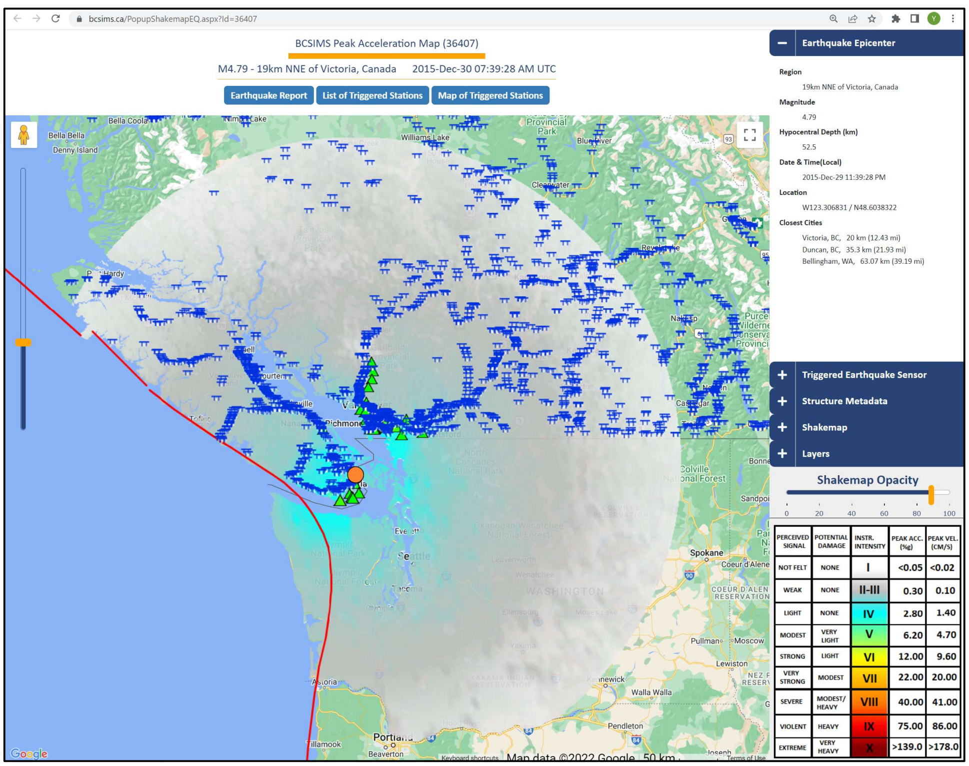

Figure 3.2: Shake-map with MoTI Bridge layer; generated by BCSIMS for an earthquake in December 2015

Whenever a shake-map is created, an earthquake report is automatically generated. This report is publicly available via the BCSIMS website and includes the following:

- Snapshot of the shake-map,
- The meta-data of the earthquake (e.g., location, magnitude, depth, etc.),
- The population count of MoTI infrastructure (e.g., bridges, tunnels) around the epicenter,
- List of all MoTI Infrastructure and other specific structures (e.g., schools) with estimated level of earthquake shaking, and
- List of the earthquake sensors that are triggered by that earthquake and their peak responses.

A sample report is available on the BCSIMS website.

4. Seismic Structural Health Monitoring Network

A *Structural Health Monitoring* system uses various sensors to measure the response of a structure (e.g., bridge or tunnel) subjected to different types of loading such as wind, traffic, and earthquakes. The sensor data is analyzed to provide information on the condition, or 'health' of the monitored infrastructure.

Seismic Structural Health Monitoring focuses on earthquake response, with sensors intended to measure the shaking level of components such as bridge decks, towers, and abutments. The response of a structure to earthquakes is often amplified by the structure itself; therefore, the level of shaking on the structure is higher than on the ground. The amount of shaking depends on the structure type (e.g., arch bridge, suspension bridge, tunnel), its size, its construction material (e.g., steel, concrete), its age, its design requirements, and how it moves (e.g., expansion joints, bearings) among other factors.

A typical SSHM system in BCSIMS includes various sensors (e.g., acceleration sensors, wind sensors, displacement transducers, etc.) connected to on-site data recorders. The data recorders continuously store and send data from each sensor over the Internet to the SSHM Collector Server at the Data Centre. Data is stored in a ring buffer (of at least six months) and then automatically analyzed by the SSHM Data Analysis Server in near real-time. The data analysis includes the following:

a. Statistical parameters for each sensor,
b. Drift analysis,
c. Modal identification (e.g., modal frequency, damping ratio, and mode shapes), and
d. Damage detection

The analysis results are permanently stored in the SQL database and are compared with historical results to determine possible damage on the structure. A one-page Structural Event Report is created if any of the following conditions are met:

a) A shake-map and an earthquake report are created by the SGMN
b) Data analysis detects damage on the structure

Two of the main benefits of SSHM for MoTI infrastructure include:

1. Assisting in decision-making for post-earthquake inspection prioritization. There will be many slight-to-moderately damaged bridges after an earthquake and the ability to quickly determine their safety will allow inspectors to focus on higher priority structures.
2. Assisting in the ongoing maintenance decisions by providing data on day-to-day performance of the infrastructure.

Currently the BCSIMS SSHM network includes 14 MoTI bridges and 1 tunnel, with more being added in the future. A list of all MoTI monitored infrastructure is given in Table 4.1.

Table 4.1 MoTI Infrastructure with SSHM

No	Structure name	Location	Total length	Year Instrumented
1	George Massey Tunnel	HW99 Richmond to Surrey	660 m	1996
2	Queensborough Bridge	HW91A New Westminster to Surrey	914 m	1996
3	French Creek	HW19 Between Qualicum Beach and Parksville	200 m	1997
4	William R. Bennett Bridge	HW97 West Kelowna to Kelowna	1077 m	2008
5	Pitt River Bridge	HW7 Coquitlam/Port Moody	380 m	2009
6	Ironworkers Memorial Second Narrows Crossing	HW1 North Vancouver to Vancouver	1290 m	2011
7	Port Mann Bridge	HW1 Coquitlam to Surrey	850 m	2013
8	176th Underpass	HW15 over HW1 Surrey	75 m	2013
9	Gaglardi Way Underpass	Gaglardi over HW1 Burnaby	65 m	2013
10	Kensington Avenue Underpass	Kensington over HW1 Burnaby	75 m	2013
11	Fraser Heights - Wetlands	HW17 (SFPR) north of Golden Ears Connector Surrey	476 m	2013
12	Portage Creek Bridge	McKenzie Ave (1A) over Interurban Rd Victoria	129 m	2001/2014
13	BNSF Sunbury Bridge	SFPR (HW17) North of HW91A Connector	68 m	2014
14	BNSF Viaduct East Mill Access	SFPR (HW17) West of Alex Fraser Bridge	195 m	2014
15	Hwy-17 Deltaport Bridge	HW17 over Deltaport Way Delta	133 m	2014
16	Lions Gate Bridge (Future)	HW99 North Vancouver to Vancouver		2022
17	Pattullo Bridge (Future)	King George Boulevard between Surrey and New Westminster		2024

5. Data Centre

BCSIMS runs several software applications hosted on virtual servers at the Provincial Data Centre in Kamloops, BC. These severs are maintained by the MoTI Information Management Branch. Each server has a different function as described in Table 5.1. The second Provincial Data Center in Calgary, AB hosts backup servers to ensure the continuous operation of the BCSIMS in the event of a large disruptive earthquake in BC.

The software applications that run at the Data Centre include:

- Operation of the Relay server to collect data from the SGMN,
- Collection of sensor data from each of the SSHM systems,
- Maintaining a database for the SGMN and SSHM systems,
- Creating Shake-Maps from the SGMN data,
- Generating and emailing automated earthquake reports (using the SGMN data),
- Creating simulated Shake-Maps and reports (for education, training, and system tests),
- Processing of data from the SHM systems,
- Generating and sending SHM reports, and
- Hosting a website that is used to access the shake-maps, earthquake reports, SGMN and SHM data.

Table 4.1: BCSIMS Servers

Name	**Function**
SGMN Relay Server	Connects to remote earthquake sensors in the SGMN: • Listens for earthquake event messages when sensors trigger • Retrieves earthquake data as needed • Allows for remote sensor configuration
SGMN Application server	Runs multiple software applications to analyse seismic data from the SGMN: • Create shake-maps and earthquake report • Logs earthquake activities in the SQL Database Server • Creates simulated earthquakes for testing of the system
SHM Collector Server	Collects and temporarily stores data sent by each data recorder in the SSHM network
SHM Processing Server	Analyzes the data from each SSHM system and sends the results to SQL Database Server
Web Server	Hosts public BCSIMS website (www.bcsims.ca)
Cloud Storage	Data Archiving