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Leading Community Risk Reduction

Assessing Local Seismic Risk Factors for Better Community Preparedness

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Abstract

The problem was that the Vancouver Fire Department had little understanding of pre-existing conditions that could determine the extent of damage from an earthquake. The project investigated the seismic threats and recommended guidelines for enhancing preparation, planning and response efforts. Using descriptive methodology, the research identified likely earthquake scenarios, local infrastructure and facilities vulnerabilities, and measures to prepare the city and citizens for an earthquake. The procedures included a review of scientific and emergency management literature, analysis of response areas using geologic maps, informal interviews with building and planning officials, and systematic evaluation of critical structures. The results included focused hazard assessments and emergency facility vulnerability analyses. Recommendations included pre-earthquake structural upgrades, planning and education measures.

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Introduction

Recent research has shown that the Pacific Northwest is at much greater seismic risk than had been previously assumed. Vancouver, the oldest and largest city in southwest Washington State, was built without regard for earthquake risk in general, and may be woefully unprepared for the very large earthquakes now regarded as inevitable in the region. (S. Thirunagari, personal communication, June 5, 2006) Area citizens and emergency responders tend to minimize the regional seismic risks based on the paucity of recent large earthquakes, and they pay virtually no attention to local geologic factors that may either attenuate or worsen the risk of damage and injury from these events.

The problem is that the Vancouver Fire Department and the citizens it serves in southern Clark County have little understanding of the pre-existing conditions that may determine the severity of damage and injury from an earthquake. Damage to specific buildings and neighborhoods can vary based on factors including building construction, slope, and soil types, yet current local emergency planning and public education efforts are only just beginning to address this variability. As a consequence, citizens and the emergency service infrastructure may be exposed to unnecessary risk.

The purpose of this research is to identify the factors affecting seismic risk in southern Clark County, and to recommend specific guidelines for future public education, emergency planning, and critical infrastructure upgrade efforts within the Vancouver Fire Department service area. Using the descriptive research method, the following questions will be answered:

1. What types of seismic events are likely to occur in the region, and what local conditions exist in southern Clark County that may worsen effects of those events?
2. What are the specific seismic risk factors within each of Vancouver's 10 fire response areas based on local geology and typical building construction types?
3. What guidelines should the Vancouver Fire Department adopt to minimize risk through better public education, and better internal planning, before the next earthquake?

Background and Significance

The community now known as Vancouver, Washington began as a Hudson's Bay Company fort and trading post on the Columbia River, not long after Lewis and Clark passed through with the Corps of Discovery. It is thought to be the second oldest continuously occupied European settlement west of the Mississippi. (City of Vancouver, n.d.)

The Vancouver Fire Department (VFD), organized in 1867, now protects more than 239,000 people in an area of 92 mi² (148 km²), which includes both the City of Vancouver and Clark County Fire District 5. The VFD is the largest fire and emergency medical service (EMS) agency in the four-county Southwest Region. (J. Mackey, personal communication, May 5, 2006) In addition to the provision of all-risk emergency response services within Vancouver and Fire District 5, the VFD is also responsible for Technical Rescue and Hazardous Materials services, as well as related planning and response duties, within the Southwest Region, an area of 3700 mi^2 (5953 km^2) and 500,000 people.

Clark County lies at the north end of the Willamette trough, a very large structural depression aligned with, and related to, the Puget trough to the north. Together, these troughs contain the broad Willamette Valley and Puget Sound lowlands that separate the coast ranges of Oregon and Washington from the Cascade Mountains to the east. (King, 1959/1977) These lowlands are heavily populated, with an almost contiguous string of major urban areas extending from Vancouver, British Columbia, south to Eugene, Oregon. Because of their position on the “ocean side” of the Cascade Range, these lowlands are often referred to as a part of the *maritime* Pacific Northwest. The *inland* Pacific Northwest stretches from the Cascade Range eastward to the westernmost ranges of the Rocky Mountains.

Since European settlement of the area began, a number of sizeable earthquakes have been recorded within these lowlands. Damage has occasionally been severe, but has usually been localized. Compared to southern California’s frequent earthquakes, this region’s sporadic seismic activity seemed insignificant, so building standards for structures of all types did not take seismic activity into account until quite recently. (S. Thirunagari, personal communication, June 5, 2006)

In fact, because of the volcanic history of the area, much more public attention was paid to the potential for volcanic eruptions, especially after Mt. St. Helens’ current eruptive cycle began in 1980. However, recent work by geologists along the coasts of both states has clearly established a history of very large earthquakes, each of which affected the entire region. Because the last one occurred in 1700, before written records were kept in the area, the likelihood of occurrence of these catastrophic earthquakes was simply not known prior to this investigative work.

Even if the potential for very large earthquakes is ignored, the Vancouver area's older buildings and bridges appear to be at risk of serious damage in the next modest local quake. Their design and construction simply did not take earthquake risk into account. Vancouver's oldest operating fire station was opened in the 1930's, and its tallest building, a 16-story residential hi-rise, was built in the 1960's. Two of its three major bridges across the Columbia River, components of a nationally-significant rail and highway transportation corridor, were built in the very early 1900's.

Further complicating the picture is the fact that the damage any earthquake produces can vary greatly over short distances. The underlying geology of a neighborhood may have a profound effect on the ability of structures to withstand an earthquake. Depending on its characteristics, the local geology may attenuate or worsen ground motion. Because of the size and nature of the area that VFD protects, it is known in general terms that there are local features of the underlying geology that may produce this ground motion (and consequent damage) variability.

This research project intends to explore the possible variability in some detail across the VFD's response area, and apply it to what is known about the area's overall earthquake potential. In addition, typical building construction, as well as critical infrastructure, within each of the VFD's 10 response areas, will be considered in an effort to further delineate local factors that affect the VFD's overall exposure to seismic risk. The VFD is responsible for City-wide emergency planning, and participates in the Southwest Region's Type III All-Risk Incident Management Team. New insights into the local and regional seismic threats will be put to good use throughout the VFD service area, and across the region.

Overall, this project is intended to broaden the seismic hazard knowledge of all emergency service providers, through an exploration of the science of both general earthquake behavior, as well as the potential localized variability described above. There are a number of other cities across North America that share Vancouver's gaps in preparedness, often for the same reasons; an inadequate understanding of the local-scale seismic threats facing them, and a consequent lack of locally-based assessment and planning.

The information produced should directly relate the project to the U.S. Fire Administration's fourth operational objective, which is to "promote within the community a comprehensive, multi-hazard risk reduction plan led by the fire service organization." (Federal Emergency Management Agency [FEMA], 2004) Additionally, this aligns the project with one of the Leading Community Risk Reduction course goals, which strives for the same objective. Finally, the project will employ the descriptive research method throughout.

Literature Review

Earthquake Fundamentals

Earthquake energy is transmitted through the earth as a series of waves that produce motion. (FEMA, 1994) Earthquake waves affect the earth and the structures upon it through three characteristics of ground motion. These characteristics are mathematically and physically related to each other. The first is *duration*, or the length of time, measured in seconds, that the strong ground motion lasts. Longer duration contributes to the weakening of structures, and, consequently, to greater building damage. *Velocity*, the second characteristic, is a measure of the rate of motion at any given point in time. It is measured in inches or centimeters per second. The third characteristic is *displacement.* Displacement is a measure of the distance that a point on the earth's surface is moved from its initial location by the ground motion, and it is expressed in inches or centimeters. (FEMA, 1994)

To determine the degree to which a structure may be damaged by ground motion, the physical properties of the structure must also be evaluated against the *acceleration* of the waves causing the shaking. (FEMA, 1995) Acceleration is the rate of change of the velocity of the waves, and is measured by a comparison to the rate of acceleration of gravity or "g", which is 32 ft/second^2 (9.8 m/sec^2). An object or person in free-fall experiences one "g."

A structure subjected to earthquake waves experiences "g" forces in rapidly alternating directions. This motion is often in both the horizontal and vertical planes. Buildings that are poorly constructed may begin to sustain damage at 0.1g, and moderate earthquakes often produce several seconds of 0.2g. Very large earthquakes can produce sustained accelerations as high as 0.7g. (FEMA 1994)

Magnitude and *intensity* are terms often used in association with earthquakes. (FEMA, 1995) The Richter magnitude scale is the most commonly used measure, and it expresses amplitude, as well as the total energy released by an earthquake, in numerical terms. Earthquakes of Richter magnitude 9.0 (M9) are rare, and only a few larger than M9.1 have ever been recorded. Earthquakes less than M3 are generally imperceptible to humans. Richter magnitude is calculated through the interpretation of the amplitude and arrival time of several types of earthquake waves at seismometers around the world. The scale is logarithmic; each whole-number increase represents a 10-fold increase in amplitude, and a 30-fold (or greater) increase in total energy released. An earthquake's place of origin can be calculated by the use of the arrival time data, source direction, and triangulation between multiple seismometer stations. (FEMA, 1995)

Intensity is a location-specific characteristic not measured directly by instruments. The Modified Mercalli Intensity scale ranks earthquakes from I-XII based on local effects observed during and after an event. (FEMA, 1995) Reports of these effects are collected in the field after an earthquake. The effects include human experience (including what people felt), damage to structures, and ground displacement. Using this scale, an event of intensity I is one not felt by humans. An intensity XII event would be one that produced nearly total destruction.

Typically, each earthquake is assigned one magnitude based on direct measurements, but one earthquake can have several intensities, each based on the observed extent of local damage and disruption. (FEMA, 1995)

Finally, the *period* of earthquake waves is of considerable importance when assessing a structure's ability to withstand ground motion. (FEMA, 1994) The period of seismic waves may vary based on the size and source of the earthquake. Additionally, all objects, including buildings and the ground, have a natural period, which is the rate at which they will oscillate when pushed horizontally by some force. The period of the ground in a given area depends on the local geology, and the period of a building is determined by its design and construction materials. Inflexible materials (like hard rock and concrete buildings) have a short natural period, while softer materials (like soft sediment and wood structural members) have a long natural period. (FEMA, 1994)

When an earthquake's waves cause the ground period and the period of a building resting upon that ground to coincide, resonance may occur. Resonance can greatly amplify acceleration within a building, in some cases up to 1g. Avoiding the possibility of resonance is a major focus of seismic engineering; on hard (short period) ground, flexible (long period) buildings would be least likely to encounter resonance in an earthquake. Conversely, soft ground requires short period (relatively inflexible) structures to avoid resonance. (FEMA, 1994)

Clark County's Likely Seismic Events

The Pacific Northwest (PNW) region occupies the western margin of the North American tectonic plate, a large, mobile segment of the earth's crust. The boundary between this continental plate and the small Juan de Fuca oceanic plate to the west is a dynamic fault feature known as the *Cascadia Subduction Zone* (CSZ). The denser oceanic plate is being bent downwards and driven beneath the more buoyant continental plate, in a process known as subduction. (The Cascadia Region Earthquake Workgroup [CREW], 2005) As the oceanic plate descends into the earth's mantle, it is subjected to increasing temperature and pressure, finally reaching the conditions at which its constituent rocks begin to melt.

Some of these molten materials eventually reach the surface again to create and sustain the Cascade Range volcanoes (Mt. St. Helens, Mt. Rainier and may others). While these large volcanoes are difficult to ignore, they are relatively insignificant secondary features of subduction, which directly shapes the continent, and produces stresses and energy transfers on an almost incomprehensibly large scale. (Alt & Hyndman, 1984)

With the Juan de Fuca plate continually “in collision” with the North American plate, tremendous forces are at work. The mountains along the Oregon and Washington coasts are largely a result of “crumpling” and folding of the continental plate edge. (CREW, 2005) Compressional stress results in faulting and fracturing many miles inland, and is thought to be related to the fault-blocking (dropping of large sections of crust, bounded by faults) that appears to have played a major part in the building of the lowlands that contain most of the region’s population.

Movement of the oceanic plate into the subduction zone is sporadic. Some sections of the oceanic plate move continuously, usually at about the same rate as that of human fingernail growth. Conversely, other sections are locked together, and strain across a large segment of the zone may be built up for very long periods, then released catastrophically. This relatively shallow (0-20 mi/32km below the surface) rupture of the plate boundary, producing what is known as a subduction zone earthquake, is the most powerful of the three possible sources for PNW earthquakes. (Pacific Northwest Seismic Network [PNSN], 2004)

The most recent CSZ earthquake occurred on January 26, 1700. This date is based on tsunami records in Japanese monastery journals, as well as physical evidence from the Oregon and Washington coasts. (CREW, 2005) Based on the physical evidence, the calculated energy needed for tsunamis to cross the Pacific basic, and on modern analogs at other subduction zones (including the source of the 2004 Indian Ocean tsunami), the 1700 CSZ earthquake is thought to have been at least an M9 event. This size estimate ranks it among the most powerful earthquakes ever recorded. Based on evidence of earlier events found underneath the 1700 deposits at the coast, it is estimated that the CSZ produces one of these huge earthquakes every 400-600 years. (CREW, 2005)

The next CSZ earthquake is likely to result in very strong shaking across the entire region. Huge tsunamis are possible along the entire Pacific Northwest coast, as well as throughout the North Pacific basin. The VFD service area, well inland from the sea, should not experience any direct effects of a tsunami, but the potential for very violent ground motion (0.3g locally, and 0.5g or higher near the coast), coupled with long duration (1-3 minutes or more) in the area is sobering. Numerous aftershocks can be expected, including some as large as M7.5. The exact location and length of the rupture would determine which inland areas were hardest-hit, but the results would be regional in scope and disastrous in scale, according to every model put forward to date. (CREW, 2005)

Interestingly, the next CSZ earthquake may be preceded by some general warning signs that indicate a massive rupture is imminent. The scientific community now recognizes some telltale precursor events, related to strain and uplift, that may be evident in the weeks or months preceding a rupture. (PNSN, 2004) This may allow some level of warning message to be released to the public. A successful pre-quake alert would be an unprecedented development, but it is important to note that precursor event detection is not available for the other sources of PNW earthquakes, and that the monitoring and interpretation of these phenomena at subduction zones is a technology in its infancy.

The second source for PNW earthquakes is the deep crustal zone (30-40 miles or 48-64 km below the surface) where melting begins as the oceanic plate descends. (PNSN,

2004) This is referred to by some sources as the *Benioff Zone*. Gravitational pull and phase changes (melting effects) within the descending plate can cause rupture here, producing earthquakes. (Friedman & Sanders, 1978) Since 1900, the PNW region has experienced six large earthquakes of this type; five M6, as well as one M7. The upper size limit for these events is considered to be M7.5. The typical duration of these events is 15-30 seconds of strong ground motion. Fortunately, damaging aftershocks from these events are unlikely.

The *focus* (actual location of the rupture at depth) for the next one of these events is likely to be directly beneath the Willamette Valley or Puget Sound lowlands. Obviously, the closer the *epicenter* (point on the earth's surface directly above the focus) is to the VFD service area (VFDSA), the more likely it is that Vancouver will sustain major damage. The Nisqually earthquake, a deep crustal event in February 2001, was felt strongly throughout Clark County, although its epicenter was near Olympia, in the Puget Sound lowlands, 100 miles (161 km) north of Vancouver. Serious damage was limited to the Puget Sound area. (PNSN, 2004)

The third source for PNW earthquakes is the network of shallow faults that underlie the entire region. (PNSN, 2004) These faults are incompletely understood and mapped, and it is quite likely that many remain to be discovered. There is growing consensus, however, that the regional tectonic stresses described above are a major reason these smaller faults exist.

These faults are usually less that 15 miles (24 km) deep, and may, in some cases, be visible at the surface. Such faults have been shown to directly underlie Seattle, Portland, and many other communities in the region. The largest possible event expected from this category of faults is less than M8. Four such events of M7 or greater are known to have occurred in the last 1100 years. The duration of ground motion is likely to be 20-60 seconds, and many aftershocks can be expected, including same as large as 6.5. Accelerations greater than 0.5g are possible. (PNSN, 2004) Many PNW residents have experienced small earthquakes that originated locally on faults of this type. A number of these small events have shaken VFD facilities in the past 20 years, without causing serious damage. (J. Mackey, personal communication, May 5, 2006)

Surface Effects

When an earthquake shakes an area of the earth's crust, geologic conditions at shallow depths determine how that shaking is propagated to a person or structure on the surface. If the local underlying geology is solid rock, the ground has a relatively short natural period, and ground motion is attenuated. (FEMA, 1994) A relatively sound and flexible structure built on this footing is likely to survive. If the underlying geology is soft sediment, the natural period is long, and ground motion may be significantly amplified. In fact, the acceleration figures given for the scenarios above are calculated for solid rock; each earthquake type will produce much higher accelerations in areas underlain by soft sediment. (FEMA, 1994)

Shear, or the tendency for the sediment particle bonds to fail with horizontal ground motion, becomes more probable with softer sediment. Shear can lead to displacement, and consequent great damage, at the surface. In addition, soft sediment will likely undergo settling as it is shaken. The settling may be more pronounced if the sediment is composed of *unconsolidated* (mixed size) particles, such as those deposited by floods, glaciers, or humans (as fill material). (FEMA, 1994)

Worse yet, if these sediments are already saturated by groundwater, the shaking motion can force the water molecules out of the spaces between particles, causing the simultaneous settling of the particles and the expulsion of the water. The once solid material now behaves like a liquid. This process, known as *liquefaction* or dynamic settling, can dramatically amplify ground motion while causing severe displacement at the surface. Structures built atop this material are likely to sink into the sediment as it subsides, while at the same time receiving severe damage from shaking. (Freeze & Cherry, 1979)

The surface of an area that has undergone liquefaction will be severely disturbed. What once was flat ground often becomes an unrecognizable jumble of hummocks, depressions and displaced man-made infrastructure. The traditional Hollywood movie earthquake effects, especially those depicting buildings and people being "swallowed by the earth," were no doubt influenced by past descriptions of the effects of liquefaction. (FEMA, 1994)

The effects of ground motion on sediments are often exacerbated by slope. (FEMA, 1994) As an example, consider two adjacent, well-built neighborhoods, both underlain by unconsolidated flood deposits. One neighborhood is virtually flat, while the other spans a steep hillside. A strong earthquake might leave the newer buildings in the flat area with only minor damage, including some disruption of infrastructure.

Conversely, the adjacent hillside neighborhood could experience slope failures (landslides) in addition to direct damage from shaking. All buildings within the slope failure areas would essentially be destroyed as they were carried downhill. Utilities and other infrastructure would be damaged beyond repair. If the sediments in the area were saturated because of recent heavy rain, liquefaction would likely increase damage in both neighborhoods, but the hillside could experience catastrophic widespread slope failure. Liquefaction-induced sliding and subsidence could devastate the entire hillside neighborhood, as occurred in Anchorage, Alaska during the 1964 M9.2 earthquake. (CREW, 2005)

The interaction of structures and ground in motion during an earthquake is the subject of much scientific study worldwide. In the United States, geologists, seismologists and the engineering community have come together with emergency planners to take on the arduous task of updating building codes and standards, as well as educating the public about the real risks inherent in earthquakes.

One of the primary avenues for the development and dissemination of this work is the National Earthquake Hazards Reduction Program (NEHRP). (FEMA, 1995) Provisions set forth by the NEHRP have begun to form the basis for major changes in seismic standards nationwide. While California has been dealing with the question of seismic standards since the San Francisco and Long Beach earthquakes in the early 1900’s, the NEHRP has helped to begin conversations and action in many other regions with a less publicized level of seismic risk.

One of the most important products produced as a result of the NEHRP standards are Site Class maps. These maps identify zones of sub-surface geology (rock or soil type), based on a nationally standardized rating system, that will have a direct bearing on amplification and shear effects of earthquake ground motion. (FEMA, 1995)

Structural Risk Factors

Construction methods, materials and design all affect a structure's ability to survive an earthquake. The scope of this project does not allow an in-depth exploration of structural seismic resistance. Readers are strongly encouraged to review FEMA Publications 154 and 83 for more information on this subject. (FEMA, 2002)

There are, however, some basic tenets of building construction that affect earthquake resistance. The following examples illustrate common seismic considerations.

Wood frame, single family dwellings often withstand ground motion well. (FEMA, 1994) Their flexibility and shape is often helpful in avoiding resonance. If, however, the foundation is not tied to the bottom plate (sill plate) of the exterior stud walls, this inherent resistance is useless. The lack of robust connections between house and foundation can result in an ultimate horizontal displacement from which the house cannot return. In other words, the house, otherwise sound, may come to rest several inches offset from, but still atop, the foundation. All utilities are sheared off in the process, and the structure is usually declared a total loss. Many older homes were lost in this manner in the 1971 Sylmar earthquake in southern California. (FEMA, 2002)

The most problematic construction type, common in older cities, is the unreinforced masonry (URM) building. (FEMA, 2002) Bearing walls of these building are little more than stacks of bricks, designed to resist the vertical force of gravity, but not the horizontal forces of an earthquake. In a strong earthquake, every URM building that has not undergone seismic upgrade work can be expected to collapse. There are many other construction types, such as concrete tilt-up, that may have serious inherent problems if left unmodified. (FEMA, 2002)

Much of the western U.S., including Clark County, has adopted the Uniform Building Code (UBC). (S. Thirunagari, personal communication, June 5, 2006) The UBC incorporates seismic standards into its regulations, based on local and regional predicted risk. For a given locale, there is a UBC seismic zone rating that governs the degree to which buildings must be built to withstand earthquakes, based on that locale's relative earthquake potential. Areas of high earthquake risk are given a zone rating of 4. Many areas of the Pacific Northwest had been rated 2a (low risk) for decades. Re-evaluation of the threats posed by the CSZ and other sources began to change those ratings in the early 1990's. The UBC codes applied to zone 4 require far higher seismic resistance design and construction than those for zones 2a, 2b or 3. In particular, emergency service facilities must meet the highest possible standards. (FEMA, 2002)

It appears that the best method for simple field evaluation of structures for potential seismic hazards is the Rapid Visual Screening (RVS) method outlined in FEMA Publication 154. (2002) The RVS method is designed for use by emergency responders, building officials and others, including those with no technical training. Its design was closely coordinated with other NEHRP efforts.

The method evaluates structural features, and takes NEHRP Site Class into account. It considers the maximum considered earthquake (MCE) potential for the area. The method ultimately produces a numerical score for each building evaluated. Each reduction of 1 whole number indicates an exponentially greater probability that the building will collapse in an MCE event. For example, a building score of 3 implies a collapse probability of 1-in-1000, a score of 2 implies a 1-in-100 probability, and a score of 1 implies a 1-in-10 probability. A score of 2 is the usual “cut- off” score; buildings with a score of 2 or less are normally flagged for further assessment by a professional engineer. (FEMA, 2002)

Risk Factors within the VFD Response Area

Southern Clark County receives over 40 inches (102 cm) of rain per year, keeping the ground constantly saturated in the fall and winter. The Vancouver area is underlain almost entirely by soft sediment, much of it unconsolidated flood deposits. (Palmer, 2004b) Some of the topography, especially along the Columbia River, results in those deposits being exposed in steep hillsides or low-angle cliff faces. In short, there are a number of areas where liquefaction, slope failure, or combinations of both are serious problems. Since no real bedrock exists near the surface in the Vancouver area, the evaluation of natural period of the ground and its relationship to structures is skewed towards the long period, soft sediment side of the scale across most of the VFD service area. (Palmer, 2004b)

Following the Nisqually earthquake, a grant program combined Washington State and federal funds to promote statewide earthquake hazard survey and mapping work. There are two main products from this work; liquefaction susceptibility maps and NEHRP Site Class maps. The maps are intended to be used for hazard mitigation, emergency planning and response, planning of local zoning ordinances, and building code enforcement. (Palmer, 2004a, 2004b) Both types of maps have been produced for Clark County, and zoning has begun to reflect this new information for “new construction” purposes. (M. Lahav, personal communication, May 16, 2006) Through this mapping, local emergency planners are now aware of the obvious hazard zones, but have not spent significant time examining the operational impacts these areas may represent.

The liquefaction susceptibility mapping is based on groundwater modeling, combined with local geology. In essence, areas underlain by certain soft sediments are evaluated for the degree to which they are saturated with groundwater, or influenced by slope. These areas are then ranked according to their susceptibility to liquefaction, and marked by colored zonation on the map. (Palmer, 2004a)

The site class mapping was done through an examination of surface and near-surface geology. Rock and soil types are labeled by colored zonation according to their tendency to amplify or attenuate ground motion in an earthquake. The site classes used are the NEHRP national models, with amplification tendencies increasing from “A” to “F” classes. “A” class sites are solid rock. “F” class sites are those where very poor, unusual soil conditions require more technical, site-specific investigation. (Palmer, 2004b)

In addition to the two maps discussed above, there are a few locally-produced geologic products that describe some specific hazards in finer detail, but they are limited as to the areas they cover, and the degree to which they incorporate the most recent scientific data. Long range planning staff members in Vancouver and Clark County have taken seismic hazards into account in recent years, as code requirements and mapping technology have improved. (S. Thirunagari, personal communication, June 5, 2006)

Some site-related geologic hazard avoidance planning was done locally as far back as 1975, based on work done by a state geologist. For decades, however, the UBC rated Vancouver and Clark County as 2a, which is considered low seismic risk. (FEMA,

2002) In essence, this meant that virtually no special seismic resistance features were required by code, even for emergency facilities. In 1992, the local potential for large earthquakes began to be recognized in the building codes, when the area was moved to a UBC 3, or moderate, rating. Clark County was finally recognized by the UBC as having a high seismic risk when the rating moved to 4 in 2002. (M. Lahav, personal communication, May 16, 2006) The 2002 upgrade is considered the local benchmark year for RVS rating purposes, as it marks full seismic code adoption and enforcement. (S. Thirunagari, personal communication, June 5, 2006)

With regard to planning for seismic risks, much of the new effort in both the city and county concentrates on identification of hazardous areas, and restriction of development within those areas.

As for its own buildings, the City of Vancouver has produced a very basic facilities inventory document that assesses building construction type and age, and identifies seismic code compliance where applicable. (T. Haldeman, personal communication, May 9, 2006)

Guidelines for the VFD

There is very little published information dealing specifically with the effects of local seismic hazards on emergency service operations and facilities. Several Applied Research Projects published through the National Fire Academy's Executive Fire Officer Program address the problem tangentially, and there are a few fire and police agencies in the western U.S. that have undertaken seismic upgrades of facilities based on regional risks. (J. Wray, personal communication, April 7, 2005)

With regard to facilities, FEMA's "Rapid Visual Screening" workbook, (FEMA, 2002) covers all building types comprehensively, and should suffice for any emergency service organization's initial survey of their seismic vulnerabilities. (S. Thirunagari, personal communication, June 5, 2006)

Procedures

This project began with an extensive review of both scientific and emergency planning literature. As with many projects using the Descriptive Research methodology for technical subject matter, considerable effort was devoted to "setting the stage" for the scientific concepts presented. Review of the literature began at The National Fire Academy's LRC in November 2005. Early in the project, it was clear that most of the information available on the subject would be found outside of the Fire Service. FEMA publications were an indispensable resource at all stages of the research.

There is no shortage of scientific information available on earthquakes at the macro scale, but some effort was required to bring the focus down to the small-area hazards at the center of this project. Several Pacific Northwest-oriented projects, especially those produced by the Cascadia Region Earthquake Workgroup (CREW, 2005) served to connect the broad scientific concepts to the specific risks faced in the cities of the region.

The geologic and engineering-oriented map products that have been produced for the region and Clark County formed the basis of the small-area hazards research in this project. Specific facility locations could be found on these maps, allowing the identification and quantification of the applicable small-area hazards for the facility. In addition, informal interviews with a VFD Deputy Chief (in charge of VFD operations), a Vancouver building code specialist, the City's Risk Manager, as well as a City Long Range Planning staff member were conducted to further clarify the local problem. A retired Fire Captain from Glendale, CA was interviewed for his perspectives on pre-planning, as well as post- earthquake operations. During his career, he experienced several major earthquakes and their aftermaths.

The Rapid Visual Screening method (FEMA, 2002) was used to evaluate each emergency service facility examined. Its techniques were also used for a general evaluation of predominant construction types in each response area. Site visits, in conjunction with the City of Vancouver's most recent facilities inventory documents, were used as the basis for assigning age, construction type, relative condition, and seismic code compliance status to each facility mentioned.

The site visits also included estimation of each building's size and shape, as well as a physical inspection to determine the accuracy of the facilities inventory document for building construction type. Several errors were found in the city's records, and this had an effect on the risk rating for several facilities, using the Rapid Visual Screening method.

The chief limitations faced in this project involved gaps in available information. Nationally, very little published material deals with the effects of earthquakes on emergency service facilities and operations. Further, because Clark County has only recently been assigned a high seismic risk rating, little attention has been paid to the issue locally. It proved difficult to relate general earthquake hazard mitigation information to the local problem without appearing to have taken an unnecessarily alarmist approach.

As a consequence of the dearth of information found regarding emergency service earthquake operations, the project was subtly re-focused with regard to research question 3, which seeks to identify guidelines for minimizing risk through public education and internal planning. The facilities and response area assessments developed for Appendices A and B would provide the data necessary to focus internal planning on the predicted degree of survival of emergency service facilities and other infrastructure.

In turn, public education efforts would be tailored to address the largest gaps in survival probability identified therein. For example, an area in which no police or fire facilities are likely to survive may need very focused public education emphasizing self-reliance.

The available mapping is generally scaled for the entire county. Some professional extrapolation of that work was done previously for the City of Vancouver to allow finer-detail examination of some urban areas. This is reflected in some of the small scale mapping mentioned in the literature review. However, some interpretation and field investigation by the author was necessary for use of the larger-scale map information across the remainder of the VFDSA. This involved additional site visits and cross-referencing of sources, and was aided by the author's previous training in geology.

Results

The first research question sought to identify the types of seismic events that may affect the VFDSA. It is apparent that the area is susceptible to large earthquakes from three sources. These include the Cascadia Subduction Zone, deep crustal sources, and shallow crustal sources. The worst-case scenarios include any CSZ event, or a large event from either a shallow or deep source that has an epicenter near Vancouver. In any of these scenarios, strong accelerations could cause catastrophic damage, and local conditions could cause liquefaction and slope failure, potentially in multiple large areas. Because groundwater plays such a large role in sediment stability, any of the scenarios would be worse during a period of heavy precipitation, where soils remain saturated for long periods.

The second research question involved the systematic review of each VFD response area for specific seismic hazards. It also led to a vulnerability analysis of selected fire and police stations, as well as other critical facilities, in these response areas. The detailed response area hazard assessments can be found in Appendix A.

Overall, the response area assessments identified some real trouble spots. In particular, slopes along the Columbia River and in other areas have all the ingredients to create serious problems during an earthquake. Slope failures may destroy some property directly, by carrying structures away, and shearing utilities and roads. They may also damage property indirectly, by depositing material below these slopes, in areas that may have otherwise escaped serious damage.

In the Station 81 response area, many square miles of poor, saturated soils elevate the amplification potential. In addition, in much of this area, the liquefaction susceptibilities are elevated. The potential is that widespread damage and disruption will occur here, in an area that contains the VFD headquarters, major transportation corridors, and major concentrations of retail businesses.

The west side of Vancouver, specifically the Station 82, 84, and 86 areas, has a number of serious hazard combinations. Geology, building construction trends, transportation corridor concentrations, and population densities make the potential for problems here stand out. Unfortunately, the police and fire facilities located here appear to be the worst in Vancouver, from an earthquake resistance perspective.

The detailed vulnerability analysis results for each emergency facility can be found in Appendix B. According to Sreekanth Thirunagari, a City of Vancouver building code specialist, the seeming disregard for seismic considerations in local buildings is a direct result of the UBC seismic risk zonation. In an informal telephone interview conducted on June 5, 2006, he indicated that, until the greater risks began to be reflected locally in the UBC, even fire and police stations were not required to meet any special standards with regard to seismic resistance. Since that process of code improvement did not begin here until 1992, much of the local emergency infrastructure was simply built without regard to earthquakes.

For this project, the Rapid Visual Screening method was used to gauge the probable level of resistance of each building to a Maximum Considered Earthquake event. The following emergency facilities received an RVS score of 2 or less; Fire Stations 81, 82, 83, 85, 86, as well as Police Headquarters and Central Precinct. A score of 2 or less implies that immediate engineering evaluation is needed to address structural deficiencies. The remaining facilities were scored as follows: Fire Station 84, 2.4; Fire Station 87, 5.4; Fire Station 88, 3.4; Fire Station 89, 3.8; Police East Precinct, 5.2; Clark Regional Emergency Services Agency (911 and EOC), 2.6.

Evidently, several of the Fire Stations that scored poorly in the RVS evaluation had already been identified by the city as problematic, without taking seismic resistance into consideration. Essentially, extensive remodels have been ruled out at Fire Stations 82, 84 and 86 because these facilities are too outdated to salvage. This information, coupled with the seismic risk ratings, make it clear that wholesale replacement is the only option for these buildings.

The VFD headquarters, Station 81, deserves special consideration. With its marginal RVS score of 2, as well as its general lack of suitability for extended operations, the facility's planned roles (as emergency operations center and VFD base-of-operations) in an earthquake event need to be reexamined. Other VFD facilities, particularly Fire Station 82 (which scored 1.4), have such serious problems that their suitability for continued operation is in doubt.

For the remaining facilities, even those where the RVS rating is relatively good, much could be done to bolster sustainability. That is, food, water and shelter issues for both the VFD members and the neighborhood need close examination. The need for education of VFD members comes into focus again here; a stark picture of the probable post-earthquake conditions must be painted for all, so that members may begin the psychological, as well as physical, preparation necessary for these eventualities.

The third research question sought to identify guidelines that the VFD should adopt to better prepare itself and the citizens it protects. The aforementioned lack of published information on earthquake effects to emergency service facilities and operations subtly changed the focus of the research for this question. Specific risks that each facility and its neighborhoods may face, and the consequent post-event functionality (or lack of same) of emergency services, utilities and transportation corridors, became the major determinant of educational and planning efforts.

In other words, given the lack of available pre-quake planning information for emergency providers, the focus for question three became more strictly reactive than initially expected. Clearly, better public education is necessary, and it must emphasize self-sufficiency for at least 48 hours. The educational efforts must, however include fire and police personnel, as well as the rest of city government.

Throughout the VFDSA, a lack of seismic awareness, coupled with decades of rapid growth, has resulted in prolific development without regard to seismic hazards. The very strong emphasis currently put on this issue by city and county planners will help to insure that no new problems are created, but the number of existing problems makes it clear that seismic upgrades to all existing buildings is impractical. In the short term, it appears that emergency agencies should concentrate on public education, with an eye towards citizen preparedness and self-sufficiency.

Discussion

It is evident that the depth of risk that the community faces has not been well understood by citizens, responders, or local government. Local planning and building codes have only recently begun to reflect the regional earthquake risk. (S. Thirunagari, personal communication, June 5, 2006) Local emergency service organizations have not incorporated the known regional and local risks into facility or operational planning. (J. Mackey, personal communication, May 5, 2006) Emergency service agency internal planning needs to be accelerated and emphasized, as the threat to the community from an

MCE event is enormous, especially given the special hazards some neighborhoods and their emergency facilities face.

All scientific sources now agree that the Pacific Northwest is very vulnerable to major earthquakes. As the Cascadia Regional Earthquake Workgroup (2005) emphasizes, an earthquake of truly huge proportions is likely in the region. Two other possible earthquake scenarios could be almost as devastating locally. (PNSN, 2004) With all of these scenarios in mind, the Rapid Visual Screening method (FEMA, 2002) has provided site-specific information that presents real cause for alarm with regard to many emergency service facilities in the VFDSA.

VFD public risk-reduction education already emphasizes that citizens must be self-sufficient for some time after a disaster strikes. It is generally assumed that emergency services will be overwhelmed with calls for service for several days, in a typical disaster scenario. (J. Mackey, personal communication, May 5, 2006) The MCE event scenario is far larger than the typical disaster envisioned in the region. (CREW, 2005)

Any new Vancouver-focused public education efforts should clearly illustrate the degree to which local emergency services might be severely crippled by an earthquake. This may have the added effect of precipitating discussions within the community about levels of acceptable risk. (M. Lahav, personal communication, May 16, 2006)

Finally, the degree to which Vancouver Police and Fire forces are susceptible to total incapacitation by an MCE event is evidently much higher than previously thought. (J. Mackey, personal communication, May 5, 2006) Appendix B illustrates the vulnerability of emergency service facilities across the VFDSA. (FEMA, 2002) It seems clear that the public cannot rely on any level of fire and police protection after an earthquake if critical facilities, as well as the people and apparatus they house, are at risk of major damage. Moreover, the argument (well proven elsewhere) that fire stations can become local dispensers of basic municipal services after an earthquake is moot if the buildings no longer function. (J. Wray, personal communication, May 6, 2005)

If these agencies are to remain viable parts of the community during earthquake response and recovery, the City and community must come together to fund needed improvements before disaster strikes. Standard of Cover planning efforts currently underway within the VFD address the immediate shortage of people and companies in day-to-day operations. It is unclear, however, whether funding sources will be found to cover these basic shortages. (J. Mackey, personal communication, May 5, 2006)

Further, when likely disaster scenarios are taken into account, the most ambitious current planning efforts fall short. An executive summary of this project will be added to the Standard of Cover document, but facility upgrades or replacements are not a part of any current VFD planning, and it is clear that VFD facilities are a major weak link in the community's disaster preparedness. (Tim Haldeman, personal communication, May 9, 2006)

The VFD's current post-disaster operational plans include earthquake-specific components borrowed from California agencies with long experience in these matters. (J. Mackey, personal communication, May 5, 2006) It appears that adoption of these components some years ago was prescient, considering that the vulnerability of Vancouver to major earthquakes was even less well understood then. (J. Wray, personal communication, May 6, 2005) The evidence suggests that these components, which include fire station damage assessment, windshield surveys, and disaster operations guidelines, should be strengthened and emphasized internally.

Plans must take into account the current vulnerabilities of some emergency facilities, in an effort to keep members safe, and apparatus operational. With the vulnerabilities outlined in Appendix B in mind, this may result in some difficult choices. These choices may include closure of some facilities now, to avoid likely injury or death during a future earthquake.

The VFD's position as the largest fire agency in the region should lead to dissemination of its (internal and external) planning and education efforts. There are many agencies (and populations) in the region with similar vulnerabilities. (J. Mackey, personal communication, May 5, 2006)

Recommendations

In response to the results of this research, the author recommends that the Vancouver Fire Department take the followings steps:

- Begin immediate inclusion of the earthquake risk in current planning efforts, and immediate inclusion of City staff and City Council in discussion of the current risks to the city and its facilities.
- Begin a systematic technical evaluation of all VFD facilities immediately. Sub-standard facilities should be marked for upgrade or replacement, and facilities found to be dangerous should be closed.

- Begin accelerated education efforts within the VFD regarding seismic hazards and risk, building upon the existing disaster plan. Modify disaster-aftermath operational plans where necessary.
- Begin accelerated public education initiatives within the community, outlining in greater detail the possible results of a large earthquake on Vancouver's critical infrastructure, businesses, and private homes. Additional emphasis should be placed on neighborhoods with locally heightened risks.
- Continue to support and expand the Citizen's Emergency Response Team (CERT) training efforts within Clark County, with an emphasis on the probability of a major earthquake as the greatest local threat

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Appendix A

Response Area Hazard Assessments

The following response areas are listed in ascending order, using the regional numbering system currently in use. The Station 810 response area boundaries are those in use in May 2006, and do not reflect possible redistricting planned for that part of the VFDSA.

Fire Station 81 Response Area

This area of 9.4 mi^2 (15 km^2) and 15,000 population, has little topographic relief (mostly flat, or gently sloping hills), and is entirely underlain by soft, unconsolidated sediments. Several broad flood-drainage channels (ice-age flood remnants) produce multiple wetlands, or contiguous near-wetland conditions. Some development has occurred within these often-saturated areas.

There are several concentrations of dense retail and office development, as well as two major transportation corridors, State Route (SR) 500, and Interstate (I) 205. Overpass bridges built along SR500 here are all very recent, and conform to applicable seismic standards. Overpass bridges built along I-205 here date from the 1980’s, and conform to less-stringent standards.

Nearly all soils in the Station 81 area are rated as NEHRP site class D. This puts structures here at moderate risk (or higher) for ground motion amplification due to the underlying geology. There are large areas of low-to-moderate liquefaction susceptibility. These areas generally follow the old drainage channels (and related nearby areas) mentioned above, but they are broad and not always obvious based on topography. There are few areas of potential slope failure, and those are very small and isolated, except along the I-205 right-of-way where road cuts have left potentially over-steepened sediments exposed.

Building construction in this area is predominately wood-frame single-family residences and apartments. The vast majority of development has occurred since 1970. The office complexes, shopping malls, and other retail structures are all generally modern; the oldest usually date from the late 1970's or early 1980's. Most of the multi-story offices are much more recent, and are likely to have been built under at least basic seismic standards.

Fire Station 82 Response Area

This area, of 13.4 mi² (22 km²) and 15,000 population, includes Vancouver's historic downtown, as well as its traditional industrial core. The area's original European settlement site (Fort Vancouver National Historic Monument), its oldest buildings, largest industries, and most of its hi-rise buildings are located here. Most of the area is gently sloping river bank, river terrace or floodplain. Soft, unconsolidated river deposits (gravel and sand) and flood deposits underlay all of this area. Terrace margins facing the river form steep slopes in several neighborhoods, with structures built above, below, and sometimes on, these slopes. There are several large areas subject to high landslide risk.

Most of the populous parts of the area are NEHRP site class C or D. Large areas of NEHRP site class E exist in the heavily industrialized Columbia Industrial Park and the Port of Vancouver, as well as the natural areas between Vancouver Lake and the Columbia River downstream of the Port. These natural areas skew the population density, as virtually no one lives in the western half of this response area. Most of the heavily populated portions of the Station 82 area are rated very low or low for their liquefaction susceptibility.

However, an area of high liquefaction susceptibility has been identified along the Columbia River through downtown. It is generally limited to the first few blocks upslope from the river, but it includes the following: the footings for the Interstate Bridge (I-5); the area around (and downstream of) the city docks, (currently slated for residential and retail development); the entire port; the BNSF rail yard complex; the BNSF Columbia River Bridge; and the Fruit Valley neighborhood. The margin of this high susceptibility area, as mapped, is less than one block west and south of Fire Station 82.

The Interstate Bridge was constructed in 2 phases, the second phase being completed before 1930. The BNSF Railway Bridge downstream was constructed in 1908. Significantly, the next highway bridge downstream of the Interstate Bridge is at Astoria, OR, 90 miles (145 km) to the west. There are no other railway bridges across the Columbia between the ocean and Wishram, WA, 80 miles (129 km) upstream from Vancouver.

Overall, this area's seismic risks are the highest in the VFDSA. The population density, older construction, geology, and special hazard occupancies make the area stand out. Included in the special hazard occupancies are several hi-rise residential buildings, including the 16-story Smith Tower, built in the mid-1960's. This facility, owned by the Vancouver Housing Authority, houses senior citizens with varying levels of mobility. It's calculated RVS score may be as low as 1.2 because of a soft-first story design and other construction considerations.

Bulk fuel and chemical facilities, fuel pipelines and terminals, as well as major grain terminal complexes in the port are examples of some of the other large special hazards in this area.

Fire Station 83 Response Area

This area, 6.5 mi² (10.5 km²) in size, has a population of 34,000 people. Topographically, it is characterized by a huge gravel bar (several hundred feet high) that forms a ridge paralleling the Columbia River. The top of the ridge has been intensely developed, so that it now forms one of the densest retail areas in the region. I-205 and SR14 intersect here, and the area includes the second highway bridge across the Columbia. The Glen Jackson Bridge, on I-205, is part of the heavily used east-side bypass around the downtown areas of Portland and Vancouver. The next highway bridge crossing the Columbia upstream of I-205 is at Cascade Locks, OR, roughly 30 miles (48 km) upriver.

The entire area is rated very low for liquefaction susceptibility. Most of the area is rated NEHRP site class C. A narrow band of NEHRP class “B to C” is found along the Columbia River, extending north to SR14. This band contains significant slopes and narrow terraces above the river. Many of the sloped areas are considered to have a high landslide potential, and evidence of past slides abounds in the area. These areas vary from light to moderate population density, but contain some of the most expensive private homes in the region. The BNSF Railway’s mainline to Spokane parallels the river here, as it does through the Station 89, 84 and 82 areas. It is at risk of being blocked by landslides at a number of locations because of its location between the slope and the river.

There is another linear section of landslide-prone terrain, prominent here, that actually extends from the Station 89 area west almost to I-5. Roughly following NE 18th Street, this north-facing slope is highly developed in some places, and open land in others. The slope is the northern edge of the flood-deposit gravel bar mentioned earlier. The geology of the entire area is soft sediment, consisting of river or glacial flood-deposited sand, gravel, and larger “erratic” boulders.

Overall, this response area contains modern buildings. Most development has occurred since 1980. There are three predominant building types in the area: light wood frame single family residences; light wood frame apartments; and light wood frame commercial buildings.

Fire Station 84 Response Area

This area comprises 6.3 mi² (10.1 km²) of hilly terrain, and has a population of 26,000 people. It occupies the western end of the gravel bar ridge described above. There are parallel bands of NEHRP site class D along the Columbia, C across the ridge, and B out to the northern fringes of the area. Those areas nearest the river have steep slopes, and a consequently high landslide potential. A large area, predominately south of SR14, is in the moderate to high liquefaction susceptibility range.

All of this response area is densely populated. It contains thousands of single family homes, most built between 1940 and 1970. The area also contains Southwest Washington Medical Center, the largest such facility in SW Washington. This facility is a composite of many buildings, and a new hi-rise section is currently under construction. RVS analysis is impractical at present, but the site is rated NEHRP class C, with very low liquefaction susceptibility.

Fire Station 85 Response Area

The Fire Station 85 area is 7.6 mi^2 (12 km^2) in size, and has a population of 34,000. The southern boundary of this area is on the north slope of the large gravel bar ridge mentioned above. The balance of the Station 85 area is essentially flat, and includes sections of the large flood-drainage channels that continue through the Station 81 area. Burnt Bridge Creek flows year-around through one of these shallow channels. The geology of the area is uniformly soft sediment, mostly glacial flood gravels.

Liquefaction susceptibility is rated as very low throughout this area, including the Station 85 site. NEHRP site class C predominates, with small areas of “B to C” and F along Burnt Bridge Creek, east of the station. The F areas are wetlands, and have largely been spared from development. There are some areas of landslide hazard along the north sloping hillsides mentioned above, and some of these intersect with the I-205 right-of-way.

This response area is predominantly residential, with a mix of single-family homes and apartment complexes. Most structures here are modern, with the majority having been built since 1970. However, in the center of the area, just a few blocks north of Station 85, is one of the largest industrial facilities in the county. This is a silicon wafer production facility, with very large bulk storage of hydrogen and oxygen gases, as well as smaller working quantities of a number of hazardous materials. There are homes, apartments, and elementary school, and other business adjacent to the facility on all sides. The facility was built in several phases starting in the mid-1980s, and it is assumed that all applicable seismic standards were applied in the most recent additions.

I-205 and SR500 meet at a large interchange within the Station 85 area. The traffic flow through this interchange is one of the densest in the region. Near the interchange is the Washington State Department of Transportation regional headquarters. This facility includes the regional State Patrol offices, and other critical operations. Its role as an emergency facility and coordination center is currently evolving, and insufficient information was available to further evaluate its changing roles for this project.

Fire Station 86 Response Area

This area is the smallest in the VFDSA, at 5 mi² (8 km²). The area's population is 26,000 people. The topography is hilly, with steep slopes along the western margins where the hilly terrain meets the Columbia River and Vancouver Lake lowlands. These steep slopes afford spectacular views, so there area number of neighborhoods built on or adjacent to the slopes. I-5 bisects the area north-to-south, and intersects here with SR500. As with the Station 82 area, a number of overpass and underpass structures provide east-west passage through the I-5 corridor. These structures are of critical importance in an earthquake, as their failure would severely limit mobility within the city, as well as block travel on I-5. The I-5 corridor has undergone continual upgrades, so most of these structures are fairly modern, and are assumed to be fairly resistant to earthquake damage. There is no exposed bedrock here, as the entire area is underlain by glacial flood or river-derived gravels, sand and other debris.

Most of the area is NEHRP site class C, with small areas of "C to D" and D. There are, however, several areas with locally elevated risks of amplification (and consequently higher implied site class ratings) along SR500 east of the I-5 interchange, including northern parts of the Rosemere neighborhood, and in the northern Lincoln neighborhood. These ratings were determined by finer-scale work conducted for the City of Vancouver since 1994. Liquefaction susceptibility is rated very low to low across the area.

Fire Station 87 Response Area

The Station 87 area is 10.2 mi^2 (16.4 km^2) in size and contains 15,000 people. Other than a few shallow glacial flood channels, the area contains no significant hills or valleys. Glacial flood deposits, mostly unconsolidated sand and gravel, underlie the entire area. Liquefaction susceptibility is considered very low, except in the bottoms of the channels mentioned, where wet conditions give a low to moderate rating. NEHRP site class ratings grade from D in the south to C in the north. A few areas of F rated soils exists in the lowest parts of the drainages, including Salmon Creek on the northern boundary.

The area contains no major industries, and much of it is still characterized as rural, with low population densities and much open agricultural land. I-205 passes through the area in a deep road cut. Localized landslide risks are no doubt present along this corridor, but the detailed city landslide hazard work did not cover this unincorporated area.

Fire Station 88 Response Area

This area, 11 mi^2 (18 km^2) in size, has a population of 33,000 people. It is topographically flat, with Burnt Bridge Creek and another small drainage providing the only variation. The area is underlain by glacial flood deposits, all of which can be classified as soft sediment. Soils here are either NEHRP site class C or “B to C,” with a small region of F occurring along the Burnt Bridge Creek bottomland. As is the case elsewhere in the VFDSA, this bottomland is generally left as open space here. Liquefaction susceptibility is rated very low across this area, except for some small regions of moderate rating in the aforementioned bottomlands.

The character of this response area is changing rapidly. Once almost exclusively rural, it saw rapid residential development starting in the 1980's. Today, high density retail development is claiming most of the remaining available land, and infill with high density subdivisions and apartments accompanies this development.

Fire Station 89 Response Area

The Station 89 area is the fastest-growing region of Clark County. The response area is 14.7 m² (24 km²) in size, and its current population is 42,000. The large gravel bar ridge (described above) begins in this area, at the point at which it connects to Prune Hill, a small extinct volcano. The southern third of this response area slopes from the ridge down to the Columbia River, where a number of steeply sloping neighborhoods and road cuts constitute a significant landslide risk. Some NEHRP site class B and "B to C" zones exist on the southern and eastern fringes of this area, but the bulk of the area is rated class C. Liquefaction susceptibility is considered very low throughout the area.

The geology and topography are a bit more varied here than in most other parts of the VFDSA. The Prune Hill volcanic complex provides some bedrock in the southeast corner of the area, and the ridge that dominates response areas further west is broader here. Wide areas of bottomland along Lacamas Creek, in the northeast corner of the area, have been left as open space because of their value for wildlife habitat, and unsuitability for development.

One of the biggest concerns within this response area is the proliferation of facilities designed to house large numbers of elderly residents. Many of these combine "assisted living" with nursing home services, and house hundred of occupants in multi-story lightweight buildings. Most of these facilities are less than 10 years old, and it is assumed that some seismic standards have been applied to their construction, but they remain a large life-hazard concern in an MCE event, and additional, even larger facilities are being planned at present.

Fire Station 810 Response Area

This is the least-populated and most rural part of the VFDSA. It contains only 2,000 people at present, in an area of 8 mi^2 (13 km^2). The area is a mix of older farms and newer, high-end homes. There are no large industries or commercial developments here, nor are there major transportation corridors. The geology includes the same glacial flood gravels discussed above, as well as volcanic rock on and around Green Mountain, another small volcanic complex. In addition, the east end of this response area slopes up onto the foothills of the Cascade Range. This affords additional soil stability, as bedrock underlies the foothill areas, and the slopes are gentle.

The Lacamas Creek bottomlands here are rated low to moderate for liquefaction susceptibility, while the remainder of the area is rated very low. The bedrock areas have no susceptibility. NEHRP site class ratings are A for the bedrock, and either B or "B to C" for the remainder of the area.

Appendix B

Emergency Facilities Vulnerability Analyses

Facilities are listed according to their location within the VFD response areas discussed in Appendix A. Some police and fire facilities were not included in this evaluation work because they are not essential to emergency operations. At present, all facilities except Fire Station 810 and the Fire Cache are staffed 24 hours per day.

FEMA Publication 154 (Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook) was used in these analyses. The “High Seismicity” data collection form was used for each building rated; 1992 is the “year of initial seismic code adoption and enforcement,” and 2002 is the “benchmark year for code improvement.” These years were established by upgrades to local UBC seismic zonation, from 2a through 3, and finally to 4.

Fire Station 81 Area Facilities

Fire Station 81, the VFD headquarters complex, was completed and opened in 1981. The main building is a 2-story structure, of wood frame construction with brick veneer (W2). The building sits atop a concrete slab. As it was built before seismic code adoption, there are no indications that any seismic standards were considered in its design or construction, and it has never been modified. It is situated in a slight depression, formerly a seasonal wetland (and part of one of the ice-age flood drainage complexes mentioned above). The site is rated NEHRP class D (moderate to high amplification), and is in the moderate liquefaction susceptibility range. Groundwater is at the surface year-around in a small remnant wetland at the eastern edge of this complex.

The station, training tower and maintenance shop were built on fill material. The station building has experienced minor cracking of structural components. This damage has been attributed to settling or subsidence, but no recent seismic or engineering study has been done. The training tower is currently exhibiting significant structural cracking, the cause of which is under investigation. The emergency generator for the complex is modern, but undersized. It powers the main building, but only part of the maintenance facility.

The score calculated for this facility using RVS is 2. The inference for this facility is that it is likely to sustain major damage, and possible collapse, in an MCE event. The score also infers that further evaluation by a professional engineer is warranted. Clearly, loss of the functions this facility provides, including: VFD headquarters; Area Command Center facility; regional apparatus maintenance facility, and others, could be catastrophic to emergency operations during a major earthquake.

Fire Station 82 Area Facilities

Fire Station 82 is a 2-story concrete tilt-up building with basement (PC1), built in 1968, before seismic code adoption. The building has never been modified with regard to seismic safety. The emergency generator is quite modern, and powers the entire facility. The site is rated as NEHRP class C, and in the low liquefaction susceptibility category. The building's calculated RVS score is 1.4. The inference is that the building is likely to suffer major damage, and possible collapse, in an MCE event. Additionally, the low score infers that professional engineering evaluation is required.

The Clark Regional Emergency Services Agency (CRESA) headquarters facility is located 2 blocks north of Fire Station 82. CRESA provides regional emergency management and planning from this facility. The facility is also the regional 911 (public safety answering point) dispatch center for every police, fire, and EMS agency in Clark County, as well as parts of Cowlitz and Skamania Counties. The regional Emergency Operations Center is located here as well.

The site is NEHRP class C. The building is a modern, single story steel frame building (S2) with partial basement, built in 1995. It was built as an emergency service (critical infrastructure) facility, and apparently conformed to the higher standards required for same locally under the 1992 UBC. It has a good emergency power system, with significant fuel storage capacity. The building's calculated RVS score is 2.6. The inference is that this is a modestly sound facility, which may survive an MCE event without major damage. However, considering this facility's multiple critical roles, its location, construction, and overall seismic vulnerability should be professionally reviewed.

The Vancouver Police Department's Administrative Headquarters facility is located east of I-5, in the Historic Reserve area. It is equipped with an emergency generator system and other operational upgrades. The location's NEHRP class is C. The facility is a 1.5 story masonry building (RM1) constructed in 1978, before seismic code adoption. There are no records of any seismic modifications at this site. Its calculated RVS score is 1.4. The inference is that this facility could sustain significant damage or collapse in an MCE event. The low score infers that professional engineering evaluation is required.

Fire Station 83 Area Facilities

Fire Station 83 was built in 1972. It was built before seismic code adoption, and it has never been seismically updated. The facility's emergency generator system was recently upgraded to better power all operations. The site has an NEHRP class C rating, and very low liquefaction susceptibility. The building is of reinforced masonry construction (RM1) atop a concrete slab, and it's calculated RVS score is 1.4. The inference is that this building could sustain major damage in an MCE event, with collapse a real possibility. Evaluation by engineering professionals is warranted by the low score.

The Vancouver Police Department's new East Precinct station is currently under construction approximately 1 mile east of Station 83. The site is rated NEHRP class C, with very low liquefaction susceptibility. The building is a multi-use facility, with a bit more than half of its area to be used by police initially. It has a large emergency generator system, and the facility may ultimately provide some alternate EOC functions during major events. The building is a single story reinforced masonry structure (RM1) with a calculated RVS score of 5.2. The inference is that this building should withstand an MCE event well.

Fire Station 84 Area Facilities

Fire Station 84 is an unusual, flat-roofed, single story, wood frame structure (W2). It was built as a fire station in 1957, and has been remodeled several times. No seismic upgrades have been done. The station is situated on NEHRP class C soils, in an area of very low liquefaction susceptibility. The building's calculated RVS score is 2.4. This rating infers that the building might withstand an MCE event, because of its simple wood construction. It could not be determined, however, whether the foundation and the frame’s bottom plate are tied together.

The emergency generator system here is inadequate, as it is undersized and outdated. Complicating this site is the adjacent municipal water facility, which includes a covered surface reservoir and a massive steel pressure-reservoir tower. The tower’s height may be greater than its horizontal distance from the station. If this structure were to fail, and fall towards the fire station, the tower or its contents could potentially obliterate the station. RVS analysis is not intended for structures of this sort, and the relative seismic resistance of this structure was not determined.

The Vancouver Police Department’s Central Precinct is located in this area, several blocks north of Station 84. The site is rated NEHRP class C, with very low liquefaction susceptibility. The single-story building, constructed in 1978, is masonry (RM1), and underwent a remodel in 1998. There are no records of seismic code conformance for the original construction or the remodel. The calculated RVS score is 1.4. The inference is that an MCE event could severely damage or collapse this building. Professional engineering evaluation is warranted.

Fire Station 85 Area Facilities

Fire Station 85 was a single story wood frame residence (W1) built in 1979. It was converted to a Fire Station in 1987. The conversion included the addition of a 2-bay apparatus room, also of wood frame construction (all now W2). The addition’s shape gives the building “plan irregularity,” lowering its overall score. Both the original construction and the conversion occurred prior to seismic code adoption. The NEHRP class is C for the station and neighborhood. It is assumed that the foundation and frame components are tied together, but this could not be confirmed. The calculated RVS score for Station 85 is 1.9. The inference is that the building may suffer significant damage during an MCE event. Professional engineering evaluation is warranted.

Fire Station 86 Area Facilities

Fire Station 86 is the oldest fire facility in Vancouver. It was a private residence that was converted into a fire station in 1934. The actual age of the original structure is not known, but it may have been several decades old (or more) when it was converted. It has a very modern emergency generator system that can easily power the entire facility.

It is a single-story structure with a partial basement. The living quarters (the original house) are of wood frame construction (W1) with heavy masonry veneer. The foundation-to frame interface is not visible, so it could not be determined if the frame is tied to the foundation. The current 2-bay apparatus room, constructed of masonry, (URM), was likely built in the 1940s, and the two sections were joined together by unknown means. This appears to complicate the RVS evaluation, and implies an increased susceptibility to serious damage when the attached URM component is taken into account, because of the attached construction type and “vertical irregularity.”

The facility has an NERHP site class rating of C, and very low liquefaction susceptibility. The calculated RVS score is 3.9 for the living quarters, and 1.4 for the apparatus room. The inference is that the living quarters structure, more robust on its own, could be damaged or destroyed by the collapse of the apparatus room structure, so the overall facility could be considered to have a score of 1.4. Further engineering evaluation of this combination of structures is indicated by the low apparatus room rating.

Fire Station 87 Area Facilities

Fire Station 87 is the VFD's newest building. It was opened in 2006, and conforms to all current seismic codes for an essential facility. It has a large emergency generator, and was placed on the least-saturated soils found on a large parcel of land.

Station 87 is a single story wood frame structure (W2) on a concrete slab. The building has a calculated RVS score of 5.4. This infers that it is an extremely robust structure, unlikely to sustain serious damage in an MCE event, despite the NEHRP class D rating for the site overall.

The VFD Fire Cache is a small complex of buildings a few blocks south of Station 87. One of the buildings is used as the department's supply warehouse for operational equipment, including tools, hose, foam, and much more. This building is a small, single story masonry structure (RM1) constructed in 1968. On NEHRP class D soils, its calculated RVS score is 1.2. The inference is that this building is likely to sustain major damage or collapse in an MCE event, and it should be professionally evaluated.

Fire Station 88 Area Facilities

Fire Station 88 is a single story wood frame (W2) structure constructed in 1995. The building is clad with an external brick veneer, and was built on a concrete slab. Records of seismic code compliance are unavailable, but it appears that it was built according to the 1992 upgraded code. There have been no structural upgrades since 1995. The site is rated as NEHRP class C and is thought to have very low liquefaction susceptibility. The calculated RVS score for the facility is 3.4. The inference is that this building should withstand an MCE event without major damage.

This facility has been equipped to act as a back-up dispatch center for CRESA (911) in the event that the main CRESA building is rendered inoperable or inaccessible. It has a very capable emergency generator system, but few other enhancements to support this operation.

Fire Station 89 Area Facilities

Fire Station 89 was built in 1992. It is a single story wood frame structure (W2) with concrete slab footings. The site is rated NEHRP class C, with very low liquefaction susceptibility. There are no written records of conformance to seismic standards for this building's construction, but it appears that it may have been built according to the 1992 upgraded code. The calculated RVS score for this building is 3.8. This infers that the building may withstand an MCE event without major damage. The emergency generator here is modern and adequate, and a recent (2006) interior remodel, while not addressing seismic resistance, has made the living quarters suitable for a larger number of people than called for in the original design.

The Vancouver Police Department's current East Precinct, in a business park adjacent to Station 89, was not rated for this project. It occupies rented commercial space, and the precinct will relocate to the new facility in Station 83's response area in mid-2006.

Fire Station 810 Area Facilities

Fire Station 810 is an inactive volunteer station. A small masonry (RM1) structure built in 1968, it was deemed substandard for occupation several years ago. This evaluation was based on the building's location, size, water supply, and physical condition. Because of this situation, an RVS rating is not warranted. There are several possible sites under consideration for a new station 810. Both of the most likely sites are rated NEHRP class C or better, with very low liquefaction susceptibility.