Basic Seismological Characterization for Natrona County and Surrounding Areas

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January, 1999

Background

Seismological characterizations of an area can range from an analysis of historic seismicity to a long-term probabilistic seismic hazard assessment. A complete characterization usually includes a summary of historic seismicity, an analysis of the Seismic Zone Map of the Uniform Building Code, deterministic analyses on active faults, "floating earthquake" analyses, and short- or long-term probabilistic seismic hazard analyses.

Presented below, for Natrona County and the surrounding areas, are an analysis of historic seismicity, an analysis of the Uniform Building Code, deterministic analyses of a nearby active faults, an analysis of the maximum credible "floating earthquake", and current short- and long-term probabilistic seismic hazard analyses.

Historic Seismicity

Natrona County has had a number of earthquakes recorded within the County boundaries over the last 104 years, with some causing significant damage. Residents within the county have also felt or have had property damaged by earthquakes originating outside of the County boundaries. The first reported earthquake occurred in 1894, and the last that was felt in the County occurred in 1996. Historically, the region has had a moderate level of seismicity compared to the rest of the State.

The enclosed map of "Earthquake Epicenters and Suspected Active Faults with Surficial Expression in Wyoming" (Case and others, 1997) shows the historic distribution of earthquakes in Wyoming. Significant historic earthquakes are described below, and are organized by the area in which they occurred. All earthquakes within Natrona County and many from neighboring counties are discussed.

Casper and Alcova Areas

Two of the earliest recorded earthquakes in Wyoming occurred near Casper. The first was on June 25, 1894, and it had an estimated intensity of V. In residences on Casper Mountain, dishes rattled to the floor and people were thrown from their beds. Water in the Platte River changed from fairly clear to reddish, and became thick with mud due to the river banks slumping into the river during the earthquake (Mokler, 1923).

On November 14, 1897, an even larger event was felt. An intensity VI-VII earthquake, one of the largest recorded in central and eastern Wyoming, caused considerable damage to a few buildings. As a result of the earthquake, a portion of the Grand Central Hotel was cracked from the first to the third story. Some of the ceilings in the hotel were also severely cracked. In another part of Casper, a person that was sitting in a chair was thrown to the floor (Mokler, 1923).

On October 25, 1922, an intensity IV earthquake was reported in the Casper area. The event was felt in Casper; at Salt Creek, 50 miles north of Casper; and at Bucknum, 22 miles west of Casper. Dishes were rattled and hanging pictures were tilted near Salt Creek. No significant damage was reported at Casper (Casper Daily Tribune, October 26, 1922). On August 27, 1948, another intensity IV earthquake was reported in the same area. No damage was reported (Casper Tribune-Herald, August 27, 1948).

In the 1950's, two earthquakes caused some concern among Casper residents. On January 24, 1954, an intensity IV earthquake near Alcova did not result in any reported damage. One area resident reported that he thought that an intruder in the attic of his house had fallen down (Casper Tribune-Herald, January 24, 1954). On August 19, 1959, an intensity IV earthquake was felt in Casper (Reagor, Stover, and Algermissen, 1985). The earthquake was reported to have occurred north of Casper. It is uncertain if this earthquake actually occurred in the Casper area, as it coincides with the Hebgen Lake, Montana, earthquakes that initiated on August 17, 1959. Only one earthquake was reported in the area in the 1960s. On January 8, 1968, a magnitude 3.8 earthquake occurred approximately 11 miles north of Alcova. No damage was reported.

On November 15, 1983, a magnitude 3.0, intensity III earthquake occurred approximately 15 miles northeast of Casper in western Converse County. No damage was reported. Most recently, on October 19, 1996, a magnitude 4.2 earthquake was recorded approximately 15 miles northeast of Casper in western Converse County. No damage was reported, although the event was felt by many Casper residents.

Midwest Area

One of the first earthquakes recorded near Midwest, occurred on December 11, 1942. The intensity IV event occurred approximately 15 miles south of Midwest. Although no damage was reported, the event was felt in Casper, Salt Creek, and Glenrock (Casper Tribune-Herald, December 12, 1942).

In the 1960's two earthquakes occurred near Midwest. On June 3, 1965, a magnitude 4.7 earthquake occurred in southern Johnson County, approximately 17 miles northwest of Midwest. On May 11, 1967, a magnitude 4.8 earthquake occurred in southwestern Campbell County, approximately 25 miles northeast of Midwest. No damage was associated with either event.

Most recently, on March 10, 1993, a magnitude 3.2 earthquake was recorded 17 miles west of Midwest. No damage was reported.

Gillette Area Earthquakes Felt in Natrona County

In the 1980s, the Gillette area was host to some of the largest earthquakes that have occurred in the Powder River Basin. On May 29, 1984, a magnitude 5.0, intensity V earthquake occurred approximately 24 miles west-southwest of Gillette. The earthquake was felt in Gillette, Sheridan, Buffalo, Casper, Douglas, Thermopolis, and Sundance. A rancher, living 35 miles west of Gillette, reported that he could see the ground shaking, and he heard a loud noise similar to a sonic boom. Pictures were shaken from the walls of the ranch house, but no other damage occurred at the ranch (Casper Star-Tribune, May 30, 1984). Surprisingly, all other reports only indicated that dishes rattled.

On September 7, 1984, a magnitude 5.6, intensity V earthquake occurred approximately 27 miles west of Gillette. Although the earthquake was closer to Gillette, it was felt more strongly at Buffalo, Casper, Kaycee, Linch, and Midwest. It was felt throughout northeastern Wyoming and in parts of southeastern Montana. As with the May 29, 1984 earthquake, no significant damage was reported (Laramie Daily Boomerang, September 8, 1984).

Douglas and Northern Laramie Range Area Earthquakes Felt in Natrona County

There have been a series of earthquakes recorded in the Douglas, Esterbrook, and northern Albany County areas. Although the earthquakes did not occur in Natrona County, many have been felt there. As a result, all significant earthquakes are discussed. On April 14, 1947, an intensity V event was felt near La Prele Creek southwest of Douglas. The earthquake was felt by everyone in a ranch house, and by a few outdoors. Windows were rattled, chairs were moved, and buildings shook (Murphy, 1950). Many of the earthquakes that have been felt in the area originated near Esterbrook, in the Laramie Range south of Douglas. On August 21,1952, an intensity IV earthquake was reported near Esterbrook. It was felt by several people in the area, and was reportedly felt 40 miles to the southwest of Esterbrook (Murphy and Cloud, 1954). Three additional earthquakes have occurred in the same location as the August 21, 1952 event. The first, a small magnitude event with no associated magnitude or intensity, occurred on September 2, 1952. The second, an intensity III event, occurred on January 5, 1957. The most recent, an intensity IV event, occurred on March 31, 1964. No damage was reported for any of the events. On January 15, 1978, a magnitude 3.0, intensity III earthquake occurred near Esterbrook. No damage was reported.

In the 1980's, there were a series of relatively significant earthquakes in northern Albany County that were felt over a wide area. On February 13, 1983, a magnitude 4.0, intensity IV event occurred approximately 40 miles southwest of Douglas. That non-damaging earthquake was felt in Laramie, Casper, Wheatland, and Medicine Bow (Laramie Daily Boomerang, February 15, 1983). The most significant earthquake to occur in the area, a magnitude 5.5, intensity VI event, occurred on October 18, 1984. That earthquake, with an epicenter located approximately 21 miles south of Esterbrook, was felt in Wyoming, South Dakota, Nebraska, Colorado, Utah, Montana, and Kansas. Stover (1985) reports that cracks were found in the exterior brick walls of the Douglas City Hall and a public school in Medicine Bow. Chimneys were cracked at Casper, Douglas, Guernsey, Lusk, and Rock River. A wall in a Laramie-area school was slightly cracked by the earthquake. The earthquake was one of the largest felt in eastern Wyoming. There were a number of aftershocks to the main event, with the most significant being a magnitude 4.5, intensity IV event, and a magnitude 3.8 event occurring on October 18, 1984; a magnitude 3.5 event on October 20, 1984; magnitude 3.3 events on October 19, November 6, and December 17, 1984; a magnitude 3.1 event on October 22, 1984; a magnitude 3.2 event on October 24, 1984; and a magnitude 2.9 event on December 5, 1984. On June 12, 1986, a magnitude 3.0 earthquake occurred in the same general area.

In 1993, there were a series of earthquakes recorded in the Douglas to Esterbrook areas. On June 30, 1993, a magnitude 3.0 earthquake was located approximately 15 miles north of Douglas. No damage was reported. The rest of the earthquakes in the 1990s ocurred in the general vicinity of the October 18, 1984 event, near Esterbrook. On July 23, 1993, a magnitude 3.7, intensity IV earthquake occurred 26 miles southwest of Douglas. This event was felt as far away as Laramie. On October 9, 1993, a magnitude 3.7, intensity IV earthquake occurred approximately 34 miles southwest of Douglas. The earthquake was felt in Garrett. On December 13, 1993, another earthquake occurred approximately 33 miles south of Douglas. This non-damaging event had a magnitude of 3.5.

Uniform Building Code

The Uniform Building Code (UBC) is a document prepared by the International Conference of Building Officials. Its stated intent is to "provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings and structures within this jurisdiction and certain equipment specifically regulated herein."

The UBC contains information and guidance on designing buildings and structures to withstand seismic events. With safety in mind, the UBC provides Seismic Zone Maps to help identify which design factors are critical to specific areas of the country. In addition, depending upon the type of building, there is also an "importance factor". The "importance factor" can, in effect, raise the standards that are applied to a building.

The current UBC Seismic Zone Map (1997) has five seismic zones, ranging from Zone 0 to Zone 4, as can be seen on the enclosed map. The seismic zones are in part defined by the probability of having a certain level of ground shaking (horizontal acceleration) in 50 years. The criteria used for defining boundaries on the Seismic Zone Map were established by the Seismology

Committee of the Structural Engineers Association of California (Building Standards, September-October, 1986). The criteria they developed are as follows:

Zone	Effective Peak Acceleration, % gravity (g)
4	30% and greater
3	20% to less than 30%
2	10% to less than 20%
1	5% to less than 10%
0	less than 5%

The committee assumed that there was a 90% probability that the above values would not be exceeded in 50 years, or a 100% probability that the values would be exceeded in 475 to 500 years.

Natrona County is in Seismic Zone 1 of the UBC. Since effective peak accelerations (90% chance of non-exceedance in 50 years) can range from 5%-10%g in Zone 1, it may be reasonable to assume that an average peak acceleration of 7.5%g could be applied to the design of a non-critical facility located near the center of Zone 1. Again, it must be kept in mind that the UBC is designed to provide minimum standards to protect life, health, property, and public welfare. Depending upon the type of facility, more stringent regulations and criteria may apply.

Deterministic Analysis of Regional Active Faults with a Surficial Expression

Natrona County has one suspected active fault system within the County boundary, and a known active fault system just outside of the County. The suspected system is the Cedar Ridge/Dry Fork fault system, and the known system is the South Granite Mountain fault system. The South Granite Mountain fault system trends west-northwest along the northern flanks of the Seminoe Mountains, Ferris Mountains, Green Mountain, and Crooks Mountain. The Cedar Ridge/Dry Fork fault system is located along the south flank of the Bridger and Bighorn Mountains, and extends into the northwestern part of the County.

South Granite Mountain Fault System

Geomatrix (1988b) divided the South Granite Mountain fault system into five segments. The segments, from east to west are the Seminoe Mountains segment, the Ferris Mountains segment, the Muddy Gap segment, the Green Mountain segment, and the Crooks Mountain segment. Geomatrix (1988b) investigated all segments of the South Granite Mountain fault system, and discovered evidence of late-Quaternary faulting on the Ferris Mountains and Green Mountain segment of the fault system. They concluded that the Ferris Mountains segment was capable of generating a maximum credible earthquake of magnitude 6.5 – 6.75 with a recurrence interval of 5,000 to 13,000 years. They also concluded that the Green Mountain segment was capable of generating a maximum credible earthquake of magnitude 6.75 with a recurrence interval of 2,000 to 6,000 years (1988b). Geomatrix (1988b) did not find evidence of late-Quaternary movement on the Seminoe Mountains segment, and scarps that were present were found to be fault-line scarps due to differential erosion. The Seminoe Mountains segment, however, is an extension of other segments of the South Granite Mountain fault system that have been shown to be active in the late-Quaternary. Because of this, the segment should be considered to be potentially active. Geomatrix (1988b) estimated the length of the Seminoe Mountains segment to be 22.5 miles (36 km). Such a fault length would result in a magnitude 6.85 earthquake if the entire length ruptured (Wells and Coppersmith, 1994). All other active segments of the South Granite Mountain fault system, however, have been assigned a maximum magnitude of 6.5 to 6.75. Because of this, the segment should be considered to be potentially capable of generating a magnitude 6.75 earthquake.

A magnitude 6.75 earthquake originating on Seminoe Mountains segment of the South Granite Mountain fault system, should generate a peak horizontal acceleration of 3%g in the Casper area and 6.5%g in the Alcova area (Campbell, 1987). These accelerations would be roughly equivalent to an intensity V to VI earthquake, and could cause minor damage in those areas.

Cedar Ridge/Dry Fork Fault System

Geomatrix (1988a) also conducted investigations at three sites on the Cedar Ridge/Dry Fork fault system. The westernmost Cedar Ridge fault is approximately 35 miles long, and the easternmost Dry Fork fault is approximately 15 miles long. The combined length of the entire system is approximately 50 miles. The eastern part of the fault system, which includes the entire Dry Fork fault and the eastern edge of the Cedar Ridge fault, is in northwestern Natrona County. Pleistocene-age movement was found at only one location (NE ¼ Section 10, T39N, R92W), which is in northeastern Fremont County. A short scarp, approximately 0.8 miles long, was identified at that location on the Cedar Ridge fault. Since the entire fault system is approximately 50 miles long, and only one small active segment was discovered, Geomatrix (1988a) did not estimate the magnitude of a maximum credible earthquake or a recurrence interval. In fact they stated that the "age of this scarp and the absence of evidence for late Quaternary faulting elsewhere along the Cedar Ridge/Dry Creek fault suggest that this fault is inactive." As a result of this assessment, I feel that it is not possible to conduct a reliable deterministic analysis on the fault system, however general estimates can be made.

Although there is no compelling reason to believe that the Dry Fork fault system is active, if it did activate as an isolated system, it could potentially generate a magnitude 6.5 earthquake. This is based upon a postulated fault rupture length of 15 miles (Wells and Coppersmith, 1994). A magnitude 6.5 earthquake on the fault system could generate a peak horizontal acceleration of approximately 7.8%g at Hells Half Acre and 2.5%g at Midwest (Campbell, 1987). Those accelerations would be roughly equivalent to an intensity VI earthquake at Hells Half Acre and an intensity IV earthquake at Midwest. Minor damage could occur at Hells Half Acre. Again, there is no compelling reason to believe that the Dry Fork fault system is active.

There is also no compelling reason to believe that the entire Cedar Ridge fault system is active. If the entire system did activate, however, it could potentially generate a magnitude 7.1 earthquake. This is based upon a postulated length of 35 miles (Wells and Coppersmith, 1994). Based on the fact that the easternmost edge of this fault system is just into northwestern Natrona

County, a magnitude 7.1 earthquake could generate a peak horizontal acceleration of approximately 8.5%g at Hells Half Acre and 2.7%g at Midwest (Campbell, 1987). Those accelerations would be roughly equivalent to an intensity VI to VII earthquake at Hells Half Acre and an intensity IV earthquake at Midwest. Moderate damage could occur at Hells Half Acre. Again, there is no compelling reason to believe that the entire Cedar Ridge fault system will activate and generate a magnitude 7.1 earthquake.

Maximum Tectonic Province Earthquake - "Floating Earthquake"/Seismogenic Source

Many federal regulations require an analysis of the earthquake potential in areas where active faults are not exposed, and where earthquakes are tied to buried faults with no surface expression. Regions with a uniform potential for the occurrence of such earthquakes are called tectonic provinces. Within a tectonic province, earthquakes associated with buried faults are assumed to occur randomly, and as a result can theoretically occur anywhere within that area of uniform earthquake potential. In reality, that random distribution may not be the case, as all earthquakes are associated with specific faults. If all buried faults have not been identified, however, the distribution has to be considered random. "Floating earthquakes" or seismogenic sources are earthquakes that are considered to occur randomly in a tectonic province.

It is difficult to accurately define tectonic provinces when there is a limited historic earthquake record. When there are no nearby seismic stations that can detect small-magnitude earthquakes, which occur more frequently than larger events, the problem is compounded. Under these conditions, it is common to delineate larger, rather than smaller, tectonic provinces.

The U.S. Geological Survey identified tectonic provinces in a report titled "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States" (Algermissen and others, 1982). In that report, Natrona County was roughly classified as being in the "Faulted Laramide-Age Mountain Uplift" and the "Wind River Basin" tectonic provinces. Both provinces were assigned a "floating earthquake" with a maximum magnitude of 6.1. Geomatrix (1988b) suggested using a more extensive regional tectonic province, called the "Wyoming Foreland Structural Province", which is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West longitude on the east, 40° North latitude on the south, and 45° North latitude on the north. Geomatrix (1988b) estimated that the largest "floating" earthquake in the "Wyoming Foreland Structural Province" would have a magnitude in the 6.0 – 6.5 range, with an average value of magnitude 6.25.

Federal or state regulations usually specify if a "floating earthquake", seismogenic source, or tectonic province analysis is required for a facility. Usually, those regulations also specify at what distance a floating earthquake is to be placed from a facility. For example, for uranium mill tailings sites, the Nuclear Regulatory Commission requires that a floating earthquake be placed 15 kilometers from the site. That earthquake is then used to determine what horizontal accelerations may occur at the site. A magnitude 6.25 "floating" earthquake, placed 15 kilometers from any site in Natrona County, would generate horizontal accelerations of approximately 15%g at the site. That acceleration would be adequate for designing a uranium mill tailings site, but may be too large for less critical sites, such as a landfill. If a facility is to be sited in Natrona County, regulations will have to be examined to determine at what distance a "floating" earthquake should be placed from the site.

Probabilistic Seismic Hazard Analyses

The U.S. Geological Survey (USGS) publishes probabilistic acceleration maps for 500-, 1000-, and 2,500-year time frames. The maps show what accelerations may be met or exceeded in those time frames by expressing the probability that the accelerations will be met or exceeded in a shorter time frame. For example, a 10% probability that an acceleration may be met or exceeded in 50 years is roughly equivalent to a 100% probability of exceedance in 500 years.

The USGS has recently generated new probabilistic acceleration maps for Wyoming. Copies of the 500-year (10% probability of exceedance in 50 years), 1000-year (5% probability of exceedance in 50 years), and 2,500-year (2% probability of exceedance in 50 years) maps are enclosed. The 500-year map is often used for planning purposes for average structures, because a 10% chance of meeting or exceeding the accelerations shown on the map in 50 years is considered to be acceptable for designing average structures. For more critical structures, including radioactive facilities and mill tailings containments, the 2,500-year map may be useful for design purposes. The maps reflect current perceptions on seismicity in Wyoming.

Based upon the 500-year map (10% probability of exceedance in 50 years), the estimated peak horizontal accelerations in Natrona County are near 6%g. That acceleration is comparable to an intensity V – VI earthquake, and is similar to the 7.5%g acceleration derived from the Uniform Building Code Seismic Zone Map. Based upon the 1000-year map (5% probability of exceedance in 50 years), the estimated peak accelerations in Natrona County approximately range from 10%g to 12%g. Those accelerations are comparable to an intensity VI - VII earthquake. Based upon the 2500-year map (2% probability of exceedance in 50 years), the estimated peak accelerations in Natrona County approximately range from 16%g to greater than 20%g. Those accelerations are comparable to an intensity VII earthquake.

Summary

Damaging earthquakes have occurred and will continue to occur in Natrona County. A maximum credible "random" earthquake of magnitude 6.25 is postulated for the County. In addition, known or suspected active fault systems in or near the County are capable of generating earthquakes in the magnitude 6.75 – 7.1 range.

Average facilities and homes in Natrona County should be designed to withstand an intensity VI earthquake or an earthquake that would produce a peak horizontal acceleration of 7.5%g. Critical facilities should be designed to a higher standard.

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