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# Relative Earthquake Hazard Map

## OF THE PORTLAND, OREGON 7 1/2 - MINUTE QUADRANGLE

Prepared by the Oregon Department of Geology
and Mineral Industries and Metro

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## I. INTRODUCTION

During the late 1980s the scientific understanding of earthquake hazards in the Portland metropolitan area advanced significantly. It is now widely accepted that damaging earthquakes much larger than any in the historical record are possible. To minimize economic losses and casualties in these future events, a wide variety of mitigation measures may be necessary. These measures should be based on the best possible assessment of the likely extent and distribution of earthquake damage.

It is difficult to predict the amount of damage any individual structure would sustain in an earthquake. The amount of damage will depend on the size, type and location of the earthquake, the response of the soil and geologic materials at the site, and the characteristics of the structure. The scientific understanding of earthquake sources that might affect the Portland area is currently too limited to allow an accurate assessment of the likely size and location of future earthquakes. It is possible, however, to measure and predict the behavior of the geologic and soil columns at a site. A free standing map (available at the Oregon Department of Geology and Mineral Industries and Metro) and this report depict the relative degree of earthquake hazards for areas within the United States Geological Survey (USGS) Portland, Oregon, 1:24,000 Quadrangle for any given earthquake. This map does not depict the absolute degree of earthquake hazard at any site, which means that in any given earthquake it is possible that damage in even the highest relative hazard category will be light. This map also contains no information about how frequently earthquake damage of any level is likely to occur.

This assessment of relative hazard is based on detailed mapping of the area's geology and specialized geophysical/geotechnical measurements, which are combined with state-of-the-practice geotechnical analysis and Geographic Information System (GIS) methodology and tools. The result is a map that categorizes the map area into one of four relative hazard categories. The categories are ranked from greatest hazard (category A) to least hazard (category D).

The map has been developed as data layers in a GIS and can be easily combined with earthquake source information from selected hypothetical events to produce earthquake scenarios. The map also can be combined with future maps of earthquake probability to provide an assessment of the absolute level of hazard and an estimate of how often that level will occur.

This map is the result of a pilot project funded by USGS Award No. 14-08-0001-G2132. The methodology is being applied to the remainder of the Portland metropolitan area as quickly as resources permit.

## II. EARTHQUAKE HAZARD

The understanding of earthquake hazards within the Portland area has been undergoing rapid change in the last five years. Recently published geologic and seismologic studies have detailed the potential for earthquakes from three different sources. In Portland, the most common are ***crustal earthquakes***, which occur at depths of 6-10 miles below the surface. The few moderate earthquakes that have originated in Portland in its brief recorded history have been this type.

***Intraplate*** or ***Benioff earthquakes*** are the type that severely rocked the Puget Sound region in 1949 and again in 1965. Those who lived in Portland in 1949 may recall that the Portland area suffered some damaging and frightening effects of that earthquake. Intraplate earthquakes occur within the remains of the ocean floor, which has been shoved (subducted) beneath North America. It is now believed that this type of earthquake could occur closer to Portland, perhaps 25-35 miles directly beneath the city.

***Great subduction earthquakes*** occur around the world in subduction zones, where continent-sized pieces of the earth's crust are shoved deep into the body of the earth. These earthquakes consistently are among the most powerful recorded, often having magnitudes of 8 to 9 on the moment magnitude scale. The Cascadia Subduction Zone, which has long been recognized off the coast of Oregon and Washington, has had no great subduction earthquakes during our short 200-year historical record. However, in the past five years, a variety of studies have found widespread evidence that these great events have occurred repeatedly in the past, most recently about 300 years ago in the latter part of the 17th century. The best evidence available suggests that these great earthquakes have occurred, on average, every 350 to 700 years, and there is reason to believe that they will continue to occur in the future.

Portland is threatened by all three types of earthquakes. But there is currently significant uncertainty about exactly where, how often and how big future earthquakes will be. This uncertainty makes it difficult to rely on a traditional probability-based (probabilistic) approach to hazard mapping, which would provide information about absolute levels of ground shaking to be expected and how often such levels might be reached. When reliable probabilistic ground motion maps become available, they can be integrated with the relative hazard mapping presented here.

## III. EARTHQUAKE EFFECTS

That damaging earthquakes will be a part of the Portland area's future is certain. The exact details of those future earthquakes are still vague, and we will not be able to predict exactly when, where and how big the next one, or ones, will be. It is possible, however, to evaluate the influence of site geology on potential earthquake damage. This can be done while the exact sources of the earthquake shaking still are being evaluated.

The most severe damage done by an earthquake is commonly concentrated in limited areas. The damage in these areas is generally caused by one or more of the following phenomena:

- Amplification of ground shaking by a "soft" soil column.
- Liquefaction of water-saturated sand, creating areas of "quicksand."
- Landslides triggered by the shaking of the earthquake.

These effects can be evaluated before the earthquake if good data are available on the thickness and nature of the geologic materials and soils at the site. The exact nature and magnitude of these effects are useful to technical professionals such as geologists and engineers, and separate maps of these details have been prepared by the Oregon Department of Geology and Mineral Industries for the Portland Quadrangle. For others, what is more significant is that the modifications imposed by any of these effects increases the damage caused by an earthquake and localizes the most severe damage.

The Relative Hazard Map of the Portland Quadrangle is a composite hazard map depicting the relative hazard at any site, due to the combination of all three effects. It delineates areas that likely will experience the greatest effects from any earthquake. Those effects could range from people waking from their sleep to buildings collapsing or gas lines rupturing. These simple composite hazard maps can be used by planners, lenders, insurers and emergency responders for first-order hazard mitigation and response planning. It is very important to note that the relative hazard map predicts the <u>tendency</u> of a site to have greater or lesser damage than other sites in the area. These zones, however, should not be used as the sole basis for any type of restrictive or exclusionary policy.

## IV. <u>HAZARD MAP METHODOLOGY</u>

### Geologic Model

The geology of the Portland Quadrangle is relatively simple, with two distinct geologic domains. One domain consists of the Portland Hills, which rise to elevations more than 1,000 feet in the southwest corner of the Portland Quadrangle. The second domain consists of the relatively flat Portland Basin, which extends to the north and east of the Portland Hills. In both domains, the local bedrock or geologic basement consists of relatively hard, dense basalt flows of the Columbia River Basalt Group. In the Portland Basin domain, this rock unit is underneath several layers of younger, softer sedimentary rock composed of sand, silt, clay and gravel. The Sandy River Mudstone lies directly above the basalt and is composed of soft siltstone, sandstone and claystone up to several hundred meters thick. Troutdale Formation gravel covers the Sandy River mudstone and is composed of pebble and cobble gravel, and conglomerate up to 330 feet thick. The Troutdale Formation is covered with sand, silt and gravel deposited by catastrophic floods at the end of the last ice age. The flood sediments are divided into a lower gravel layer, and an upper sand and silt layer. The flood sediments are covered by alluvial sand, silt and clay along and adjacent to the channels of the Willamette and Columbia Rivers.

In the Portland Hills domain, most of the geology is simple. The basalt bedrock is covered by wind-blown silt (called loess) up to 30 meters thick. In the southwest corner of the map, near Sylvan, there are deposits of siltstone and young Boring lava between the bedrock basalt and the wind-blown silt.

Thousands of bore holes drilled for water wells and foundation investigations, etc. were used to determine the thickness of each of the six geologic units over the entire map, and these data were entered into a GIS database. Where there were not enough boreholes, seismology was used to find the thicknesses. This information defines the soil and rock beneath any location on the map so that their effect on earthquake damage can be assessed.

To assess the effects of the local geologic materials, more than just their thickness is needed. Many of the required measurements are acquired in the normal course of a foundation investigation such as the Standard Penetration Test (SPT). Thus, the needed information is available from many of the same sources as the thickness information.

In addition to the data acquired from existing borehole records, the assessment technique requires measurements of the speed with which the soils transmit vibrations. These measurements, called shear-wave velocities, were made at more than two dozen carefully selected sites. About half were on the map and half were at other locations in the Portland area.

All this information combines to give a detailed computer map of what lies beneath the surface throughout the map area. With this information the response to earthquake shaking at a specific location can be assessed.

## V. HAZARD ANALYSIS

An earthquake causes damage through ground shaking, liquefaction, landslides, fault rupture, and tsunamis and seiches. The severity of any one of these effects, or hazards, is influenced by a number of factors. Many of these factors can be assessed in relative terms without knowing the exact details of the earthquake itself.

The Relative Earthquake Hazard Map integrates three separate earthquake hazard components. They are: A) ground shaking amplification, B) liquefaction, and C) earthquake-induced landsliding. Each of these phenomena is a distinct and separate hazard, and in concert can increase the severity total hazard at a given locality. The distinction between each component is important to technical specialists, but the distinctions are not useful to a non-technical audience. It, therefore, makes sense to generate a map of each of the individual hazard components that will be available to those able to use them and to then combine the individual maps into a simple, unified hazard map that generalizes the issues in a way useful to non-specialists.

## A. Ground Shaking Amplification

Bedrock ground shaking caused by an earthquake can be modified by the soils and soft sedimentary rocks near the surface. This modification can increase the strength of shaking (or alternatively decrease it) or change the frequency of the shaking. For example, the shaking could be changed from a rapid vibration (like a jet flying low overhead) to a long rolling motion (like being on a boat in a storm). The nature of these modifications is determined by the thickness of the geologic materials and their physical properties such as shear-wave velocity. With these parameters, sophisticated computer programs can estimate the effects of the local geology on ground shaking. In this way, areas where the ground shaking will <u>tend</u> to be strongest have been identified.

Mapping of the amplification resulting from near-surface geology has been done previously in other areas such as the San Francisco Bay area and Mexico City. Damage to the Nimitz Freeway during the 1989 Loma Prieta or "World Series," Earthquake was localized by near-surface amplification. Fortunately, the areas of the Portland Quadrangle that are affected by large amplifications are small. The magnitude of the most severe amplifications in the Portland Quadrangle does not appear to be as great as has been found in other parts of the world. Unfortunately, one of the areas with the greatest amplification includes portions of downtown Portland.

## B. Liquefaction Analysis

Liquefaction is a phenomenon in which shaking, or otherwise disturbing, a soil causes it to rapidly change its material properties so that what was solid begins to behave like a liquid. Soils that have this problem tend to be fairly young loose granular soils (as opposed to clay) that are saturated with water. Unsaturated soils will not liquefy, but they may settle. If liquefaction is induced by the earthquake shaking, several things can happen. The liquefied layer of soil and everything lying on top of it can either move downhill or oscillate back and forth with displacements that are large enough to rupture pipelines, move bridge abutments, and pull buildings apart. Light objects such as underground storage tanks can float up toward the surface, and heavy objects such as buildings sink. These displacements can range from inches to feet. Obviously, if the soil at a site liquefies, the damage caused by the earthquake is significantly increased over what the shaking would have done alone. Soils that are subject to liquefaction can be identified, as can their thickness and their influence on the severity of the effects.

Maps of liquefaction hazard similar to what has been done for this map have been done in many areas including Seattle, Washington and Salt Lake City, Utah, where they have been incorporated into emergency response planning and development planning.

### C. Landslide Analysis

Landslides are a problem familiar to Oregonians. The shaking resulting from an earthquake tends to cause existing landslides to move as well as generating forces that create new landslides. Because of this, known landslide masses have been identified as areas with a potential for severe damage during an earthquake. In addition, the steepness of a slope and soil thickness are indicators of the stability of a slope. These two factors have been used to estimate the hazard of landslides in those parts of the hills that have no existing landslides. Using the slope and soil thickness information, a factor of safety against sliding was computed for the West Hills portion of the map. The hazard was rated based on these results.

This type of landslide mapping was pioneered in the San Francisco Bay area and has been applied in many areas of the world where landslides are prevalent.

### D. Other Hazards

Other hazards have not been factored into the relative hazard map. Certainly bodies of water (e.g., the Willamette River) are subject to waves being generated by the ground motion accompanying an earthquake. Such waves are known as seiches. The effects of a seiche will be limited to the immediate vicinity of the water body, but the size of the waves can be damaging and deadly. The effects of any tsunami generated in the Pacific Ocean by an earthquake are likely to be small along the rivers in the Portland area. Although many faults have been identified and mapped in the Portland area the hazard that specific faults represent is still unknown. The "activity" of these faults will be defined by studies in coming years. It should be noted that the magnitude 6 to 6.5 range is the threshold at which fault rupture generally begins to be apparent. Because 6 to 6.5 is the likely maximum magnitude for any crustal earthquakes in the area, fault rupture is likely to be absent altogether or will be of very limited extent. Therefore, the number of structures affected and the severity of the effects also will be limited.

## VI. RELATIVE EARTHQUAKE HAZARD MAP

The relative earthquake hazard map was created to show which areas will have the greatest tendency to experience damage due to any one of, or a combination of, these hazards. Hazard maps were generated for each of the individual hazards on which areas of the map were categorized as zones 0, 1, 2, or 3 with 3 being the greatest hazard. For every point on the map, the zone rating for each individual hazard (amplification, liquefaction and landslide) was squared and the resulting numbers were added together. Then the square root of this sum was taken and rounded to the nearest whole number. A result of 4 is assigned to category A, a result of 3 is assigned to category B, a result of 2 is assigned to category C and a result of 1 is assigned to category D.

> Example: Suppose that the block on which your house sits had a ground shaking amplification rating of 2, a liquefaction rating of 2, and a landslide rating of 0. We would take the ground shaking amplification rating of 2 and square it to get 4. We would do the same with the liquefaction rating and also get 4. Squaring the landslide rating of zero gives zero. So we add 4 + 4 + 0 to get a sum of 8. The square root of 8 is 2.8284, which rounds to 3 or a rating of B for this hypothetical block. Since B is the next to the highest rating, this block is thus of greater concern, from an earthquake hazards standpoint, than would be a block a few miles away that has a rating of D.

It should be pointed out that with this system a numeric result of 0 or 5 is theoretically possible, but in practice neither is likely to be seen. If such a rating were to result, it would have been assigned to the D or A group, respectively.

The result of this system is that areas with a high hazard from a single local effect to be assigned the rating of B (next to highest overall hazard rating) as well as areas with a combination of lesser single ratings. The rating of A represents a combination of high ratings. The rating of B should not be understated since it can result from a single hazard being very severe. This approach to arriving at a single relative hazard map is novel, but has the benefit of quickly delineating areas of greater earthquake hazard without requiring a detailed understanding of the individual hazards or how they are measured.

## VII. <u>USE OF RELATIVE EARTHQUAKE HAZARD MAP</u>

The Relative Earthquake Hazard Map delineates the areas where earthquakes present the greatest hazard on average. This information can be used to develop a variety of hazard mitigation policies. It also can be used inappropriately without careful consideration and a thorough understanding of the map and its basis. One of the key uses for this map is to develop emergency response plans. The areas indicated as having higher hazard will be the areas where the greatest and most abundant damage will tend to occur. Efforts and funds for both urban renewal and strengthening or replacing older and weaker buildings can be focused on the areas where the effects of earthquakes will be the greatest. The location of future urban expansion or intensified development certainly should consider earthquake hazards.

Requirements placed on development could be based on the hazard zone in which the development is located. For example, the type of site specific earthquake hazard investigation that is required could be based on the hazard zone. Since the Relative Earthquake Hazard Map is part of the Metro's Regional Land Information System (an ArcInfo based GIS), it can easily be combined with any of the other land use or hazard information in that system.

Equally important is to recognize the limitations of the Relative Earthquake Hazard Map. It in no way includes information with regard to the probability of damage occurring. Rather, it shows that when the map area is shaken by an earthquake, the damage is more likely to occur or be more severe in the higher hazard area. The exact probability of such shaking occurring is yet to be determined.

Neither should the higher hazard areas be viewed as unsafe. Except for landslides, the earthquake effects that are factored into the Relative Earthquake Hazard Map are not life threatening in and of themselves. What is life threatening is the way that structures such as buildings and bridges respond to these effects. Locations are not necessarily unsafe, or even less safe, but structures there may be.

The map depicts trends and tendencies. In all cases the actual threat at a given location can be assessed only by some degree of site specific assessment. This is similar to being able to say demographically that a zip code zone contains an economic middle class, but within that zone there easily could be individuals or neighborhoods significantly richer or poorer

In summary, just as some parts of the state are snowier than others, thus influencing the type of planning and development that occurs, some parts of the Portland area are more prone to earthquake effects than others. This fact should be taken into account in planning, development and decision making.

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