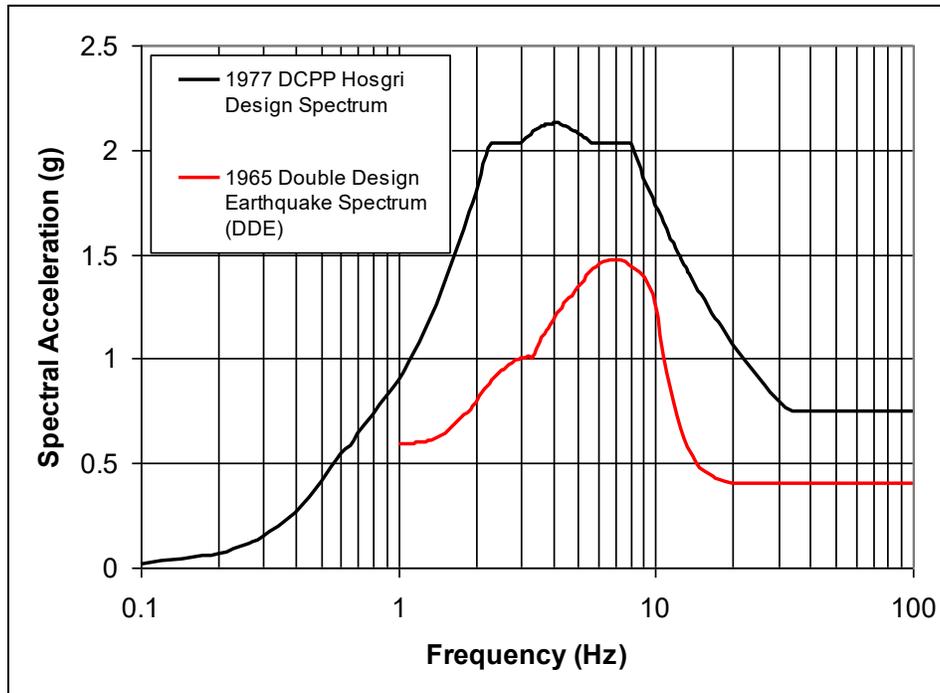


**GM1) What magnitude earthquake is DCPP designed for?**

The new design ground motions for DCPP were developed after the discovery of the Hosgri fault. In 1977, the largest magnitude of the Hosgri fault was estimated at 7.5, the peak acceleration was estimated at 0.75g, and the average spectral acceleration from 3 to 8.5 Hz (the frequency range of importance for DCPP structures) was estimated at 2.1g. The 1977 design ground motion exceeds the 1965 design ground motion (DDE). Given this larger ground motion, modifications were made to the plant so that it would withstand the increased design ground motions.



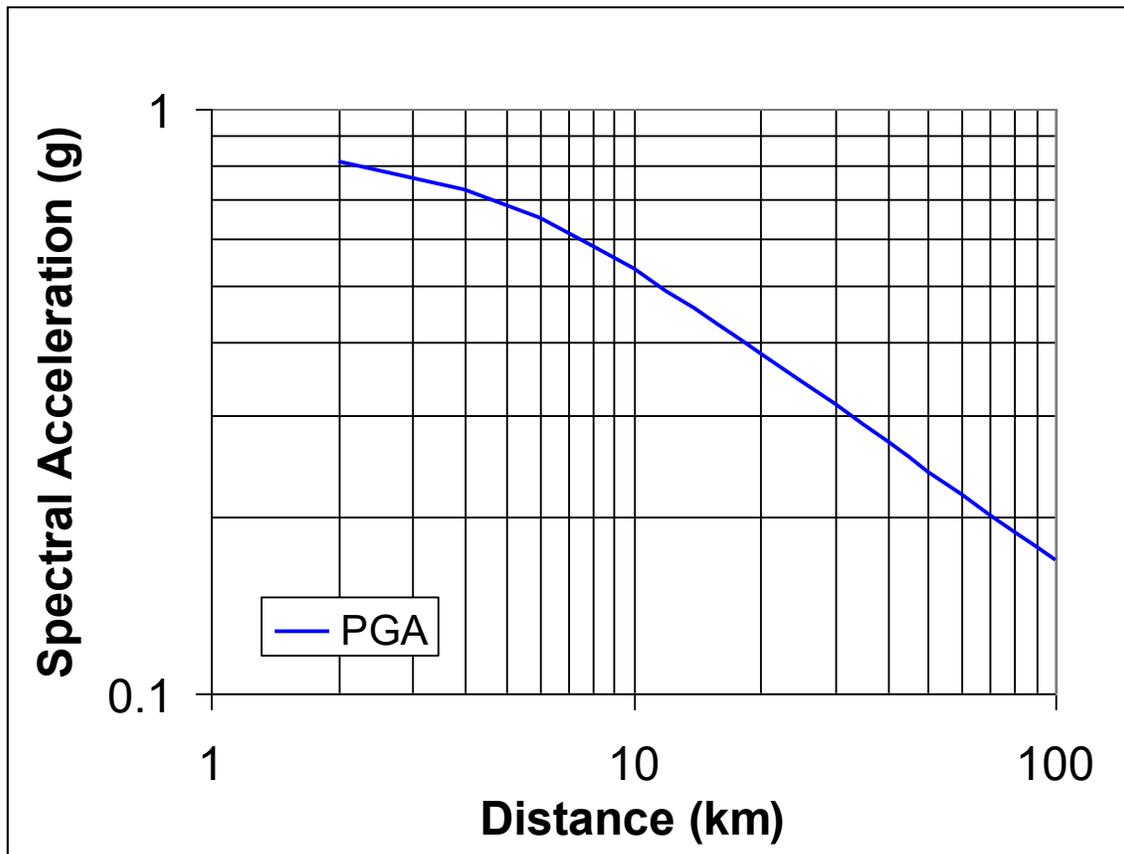
The 1977 HE Design Spectrum is an 84<sup>th</sup> percentile ground motion that was created using 1970's ground motion models. It is based on a M7.5 earthquake on the Hosgri fault at a distance of 5 kilometers.

Even though the 1977 DCPP HE Spectrum was developed based on a M7.5 earthquake on the Hosgri fault, it is important to understand that structures are designed for ground motions, not earthquake magnitudes. The development of design ground motions are based on source characterization and ground motion models using the best science available at the time. [Once the structure is built, or retrofitted, the design basis does not change with improved earthquake science. Improved earthquake science leads to changes in source characterization (earthquake magnitudes and how often they occur), and ground motion models (strength of shaking) given the magnitude and distance away. Therefore, with new earthquake science, we check what earthquakes produce ground motions that are not within the design basis and determine if the design basis is still appropriate.

A key development in the earthquake science over the last 10 years is that there has been a large increase in the recordings of ground shaking near large earthquakes. These new data have shown that the ground motion models used in the mid 1970s to develop the 1977 DCPP Hosgri and in the 1980s to develop the 1991 LTSP spectrum overestimated the strength of shaking. Using modern ground motion models that are based on the much larger data sets, the ground motion from a magnitude 7.5 earthquake on the Hosgri fault would be much smaller than the 1977 HE design spectrum shown above. Because the design basis has not been changed from the 1977 HE design spectrum, the new earthquake science data shows that DCPP can withstand the 84<sup>th</sup> percentile ground motion from earthquakes larger than magnitude 7.5 on the Hosgri fault.

**GM2) USGS says that there is a 67% chance of a magnitude 6.7 or larger earthquake over the next 30 years striking the greater Los Angeles area, why is DCPP not designed for a larger earthquake?**

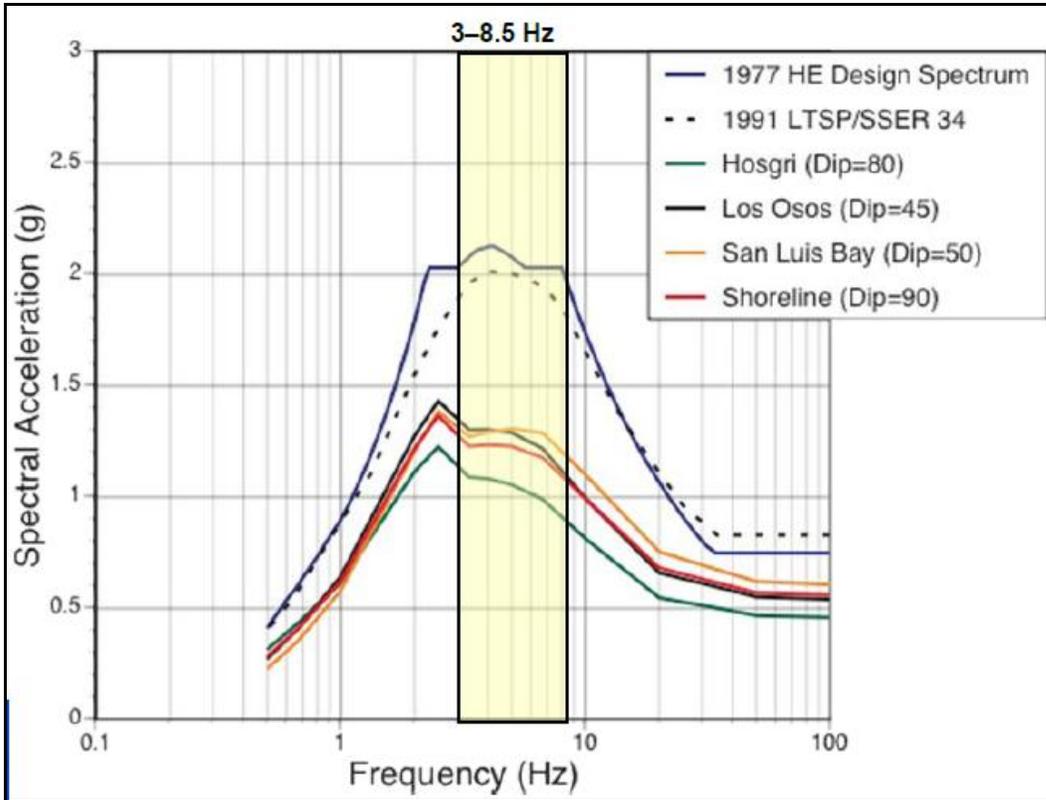
In the original design, a magnitude 8.5 earthquake on the San Andreas fault was considered. The closest distance between Diablo Canyon and the San Andreas fault is 78 km. Because of this large separation distance, the seismic waves from an earthquake on the San Andreas fault attenuate, or die out, before reaching DCPP. The result is low amplitude ground motions at the plant. This attenuation with distance is modeled with Ground Motion Prediction Equations (GMPEs). An example of the attenuation of the shaking with distance is shown below.



84<sup>th</sup> percentile spectral acceleration attenuation curves calculated using the Abrahamson & Silva (2008) NGA ground motion prediction equations for a M8.5 strike-slip earthquake ( $V_{s30}=1180\text{m/s}$ ).

The faults that can potentially cause large amounts of shaking at the plant are the faults that are located closer to Diablo Canyon. In particular, they are the faults we are currently evaluating as part of our LTSP update: the Hosgri fault, the Shoreline fault, the Los Osos fault, and the San Luis Bay fault. The plot below shows how the ground motion amplitudes for these four fault sources compare over a range of frequencies to the 1977 Hosgri earthquake design spectrum and the 1991 LTSP/SSER 34 spectrum. At all frequencies, the response spectra from the faults controlling the hazard at Diablo Canyon

are enveloped by the 1977 Hosgri earthquake design spectrum and the 1991 LTSP/SSER 34 spectrum. This is particularly important over the frequency range of 3-8.5 Hz because this is the frequency range of the important structures at Diablo Canyon. A detailed description of how these curves are developed is given in the 2011 Shoreline fault report.

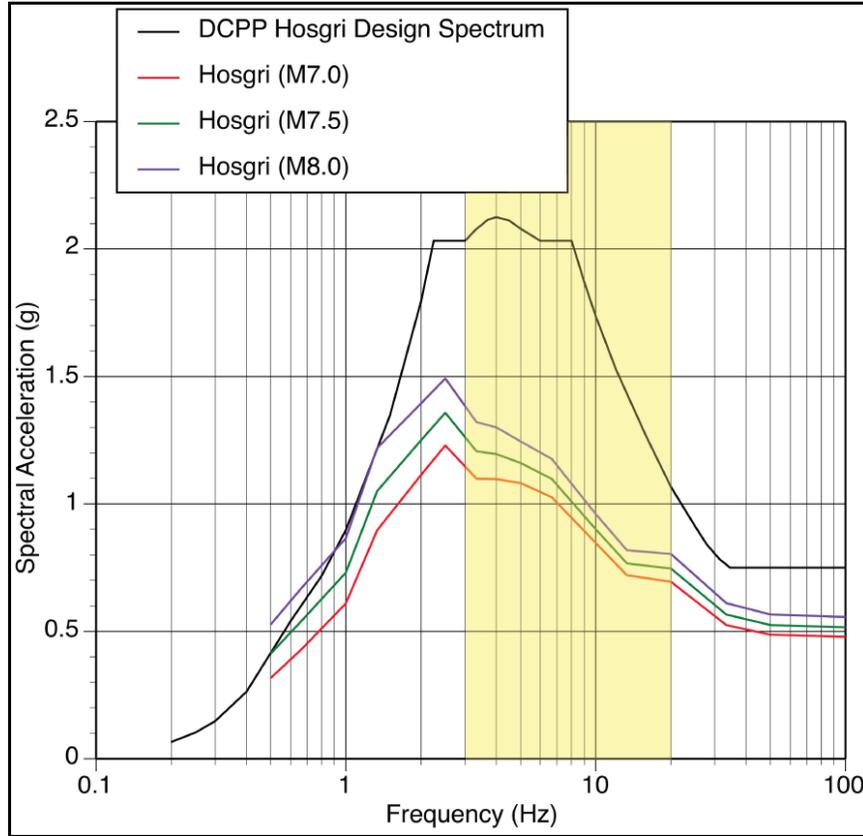


The magnitudes used to calculate the response spectra are listed in the table below. The magnitudes correspond to the 90<sup>th</sup> fractile of the mean characteristic magnitude.

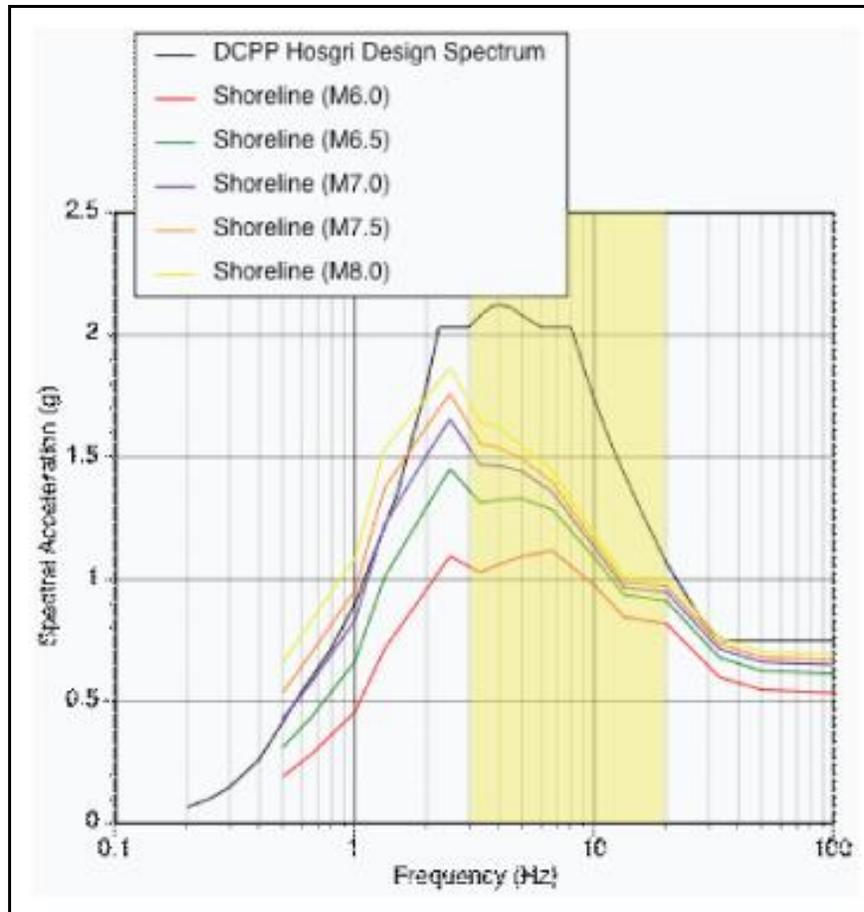
FAULT SOURCE	DETERMINISTIC MAGNITUDE
Shoreline	6.5
San Luis Bay	6.3
Hosgri	7.1
Los Osos	6.8

It is very unlikely that earthquakes with magnitudes much larger than those listed in the table above will occur near Diablo Canyon, because the brittle crust of the Earth that can rupture in an earthquake (the seismogenic crust) is thin in the vicinity of Diablo Canyon (~13 km), and the earthquake magnitudes these faults can generate is limited by the fault area (see *GM9* *How do you determine the earthquake magnitude that a particular fault can generate?*). Regardless, we have done sensitivity studies where we have evaluated the effect of larger magnitudes on our controlling fault sources.

In the following examples, we show the effect of increasing the magnitude on the Hosgri and Shoreline fault sources. As previously mentioned, the important frequency range for Diablo Canyon structures is 3-8.5 Hz, so it is important that the response spectra from the faults are enveloped by the 1977 Hosgri design spectrum in this range.



Response spectra showing sensitivity of the ground motion at DCPD to the magnitude of earthquakes on the Hosgri fault. The response spectra are based on modern ground motion models (2008 NGA models) modeling DCPD site-specific effects based on earthquake recordings at DCPD. At the high frequencies of interest at DCPD, no scenarios exceed the Hosgri design spectrum

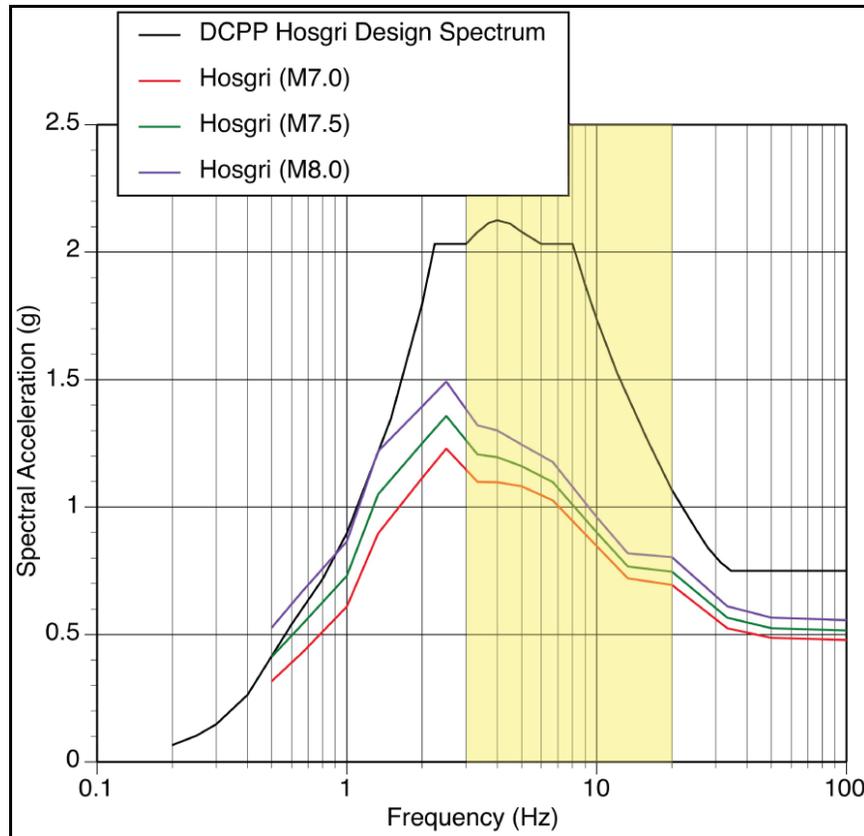


Response spectra showing sensitivity of the ground motion at DCPP to the magnitude of earthquakes on the Shoreline fault. The response spectra are based on modern ground motion models (2008 NGA models) modeling DCPP site-specific effects based on earthquake recordings at DCPP. At the high frequencies of interest at DCPP, no scenarios exceed the Hosgri design spectrum.

These examples demonstrate that the ground motion does not scale very strongly with magnitude at Diablo Canyon, and increasing the magnitude does not result in a large increase in the near-fault ground motion. Therefore, there is margin in the DCPP design

**GM3) A magnitude 8 earthquake releases 30 times more energy than a magnitude 7 earthquake, why does using a larger magnitude on the Hosgri fault not cause a large increase on the ground motions at Diablo Canyon?**

Our sensitivity studies have shown that the deterministic fault sources produce ground motions at Diablo Canyon that scale only weakly with magnitude. While the energy released in an earthquake goes up by a factor of 30 as the magnitude is increased from M7 to M8, the figure below shows that the high frequency ground motions near the fault only increase by factors of 1.2 to 1.3. The reason for this is given below.



Response spectra showing sensitivity of the ground motion at DCPP to the magnitude of earthquakes on the Hosgri fault. The response spectra are based on modern ground motion models (2008 NGA models) modeling DCPP site-specific effects based on earthquake recordings at DCPP. At the high frequencies of interest at DCPP, no scenarios exceed the Hosgri design spectrum.

The magnitude of an earthquake scales with fault area, so the larger the fault, the larger the earthquake it can produce. At Diablo Canyon the thickness of the Earth's brittle crust that can generate earthquakes, also known as the seismogenic crust, is very thin (approx. 13 km). Therefore, the only way to generate large earthquakes is to create long faults.

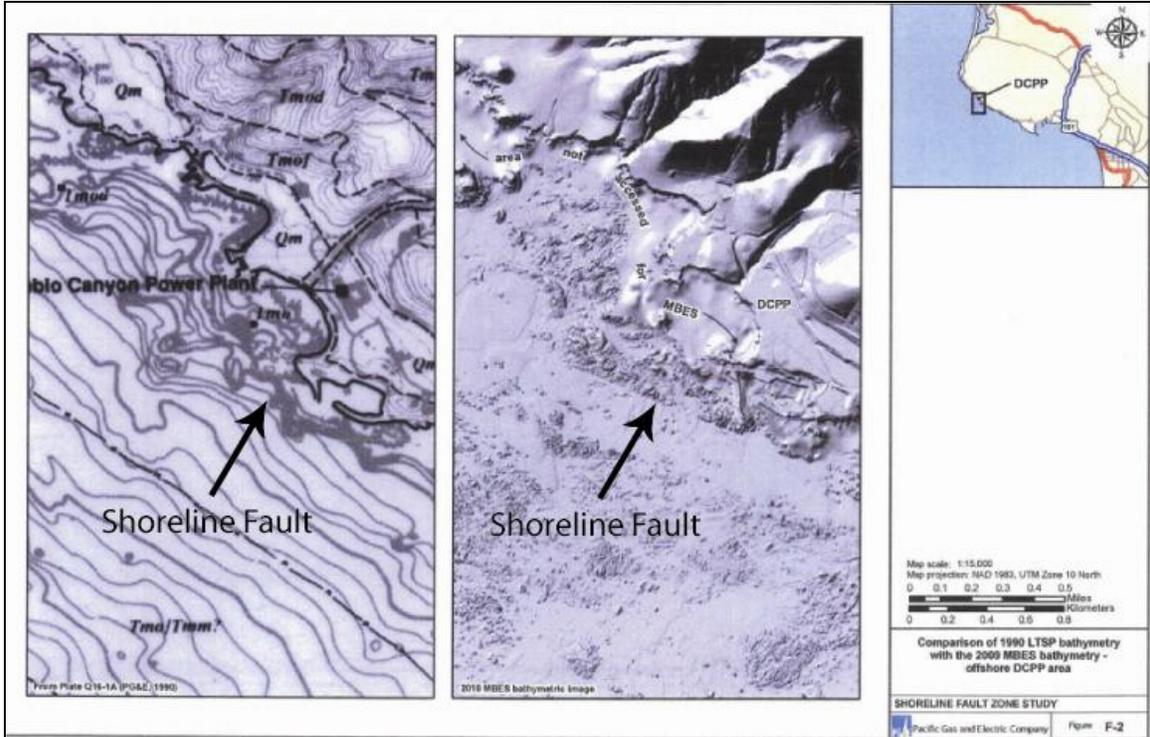
The example below demonstrates why larger faults with bigger magnitudes do not result in large increases in the ground shaking at Diablo Canyon. When seismic energy arrives

at Diablo Canyon from portions of a fault that are nearby, the shaking is strong because the radiated seismic energy does not have far to travel. However, when seismic energy arrives at the plant from portions of the fault that are far away, much of the energy has been attenuated (died out). As a result, larger faults with bigger magnitudes do not end up contributing much more high frequency ground shaking at the Diablo Canyon than a smaller earthquake located just offshore DCPD would have.



**GM4) Why was the Shoreline fault not found in previous studies?**

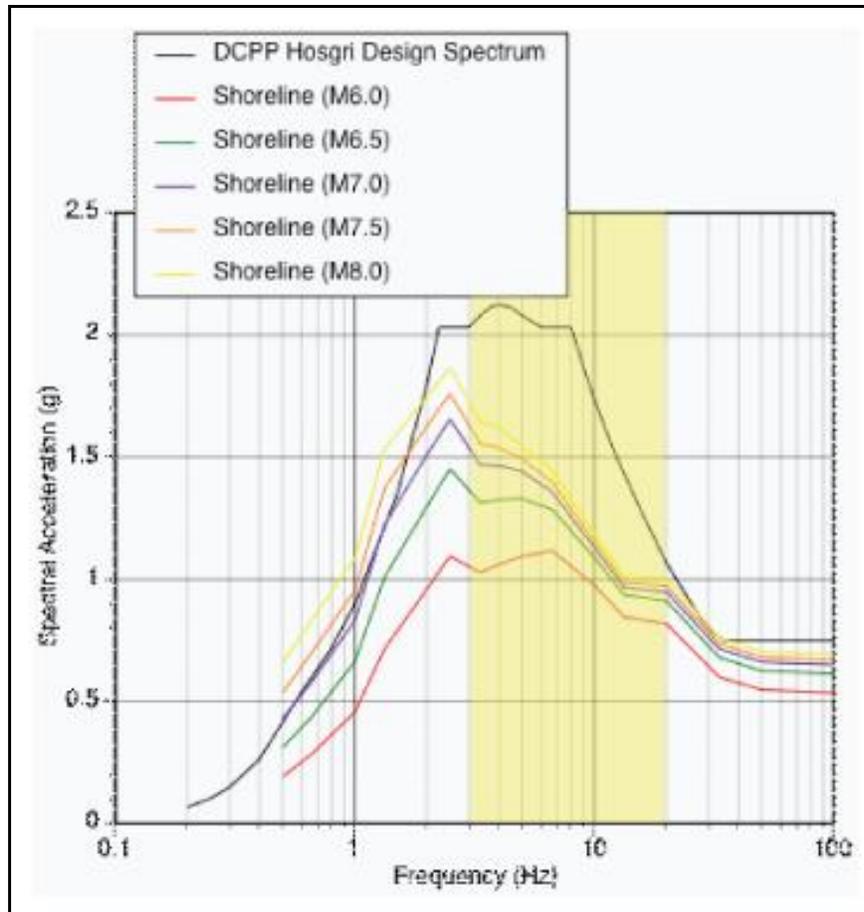
The 1988 LTSP Report and 1991 SSER 34 noted that the surf zone near the plant was not well imaged by geophysics. It was recognized at that time that a fault could be located offshore (0-2 km), but it would be less active than the Hosgri fault. Since those studies, new technology has improved how we can image the offshore data. More precise GPS boat positions have lead to improved bathymetry data, as shown below. We also have improved earthquake location methods and more earthquake microseismicity data to help locate the true fault plane.



**GM5) Has PG&E considered the possibility where the Shoreline fault is linked with the Hosgri fault?**

Currently our Probabilistic Seismic Hazard Analysis (PSHA) does not connect the Shoreline to the Hosgri fault, because we believe this is an unrealistic scenario based on two recent studies: 1) Research by Paul Sommerville (*Analysis of Inhibition of Faulting at Fault Branches by Paul Sommerville, URS, 6 April 2009 - Appendix J, Report on the Analysis of the Shoreline Fault Zone, Central Coast California, 2011*) has shown that geometry between the Shoreline and Hosgri fault zone is unfavorable for synchronous rupture; and 2) results of dynamic rupture modeling show for the geometry between the Hosgri and Shoreline fault, rupture on the Hosgri fault zone is inhibited from propagating onto the Shoreline fault zone. For these reasons, this scenario was not considered in the logic tree for our PSHA.

Even though recent studies have shown that linking the Shoreline and Hosgri fault is unlikely, a sensitivity analysis was conducted by PG&E considering up to a M8 on the Shoreline fault. Generating an earthquake of this magnitude requires linking the Shoreline to the Hosgri, the Hosgri to the San Simeon, and the San Simeon to the San Gregorio fault. Considering the 84<sup>th</sup> percentile response spectrum from a M8 on the Shoreline fault, all spectral acceleration values at DCP (using current ground motion prediction equations) are enveloped by the 1977 Hosgri spectrum for the frequency range of interest (between 3 and 20 Hz). Therefore, even though we consider this case unlikely, we have accounted for a joint rupture of the Shoreline and Hosgri faults and conclude that this scenario does not have major implications to DCP.

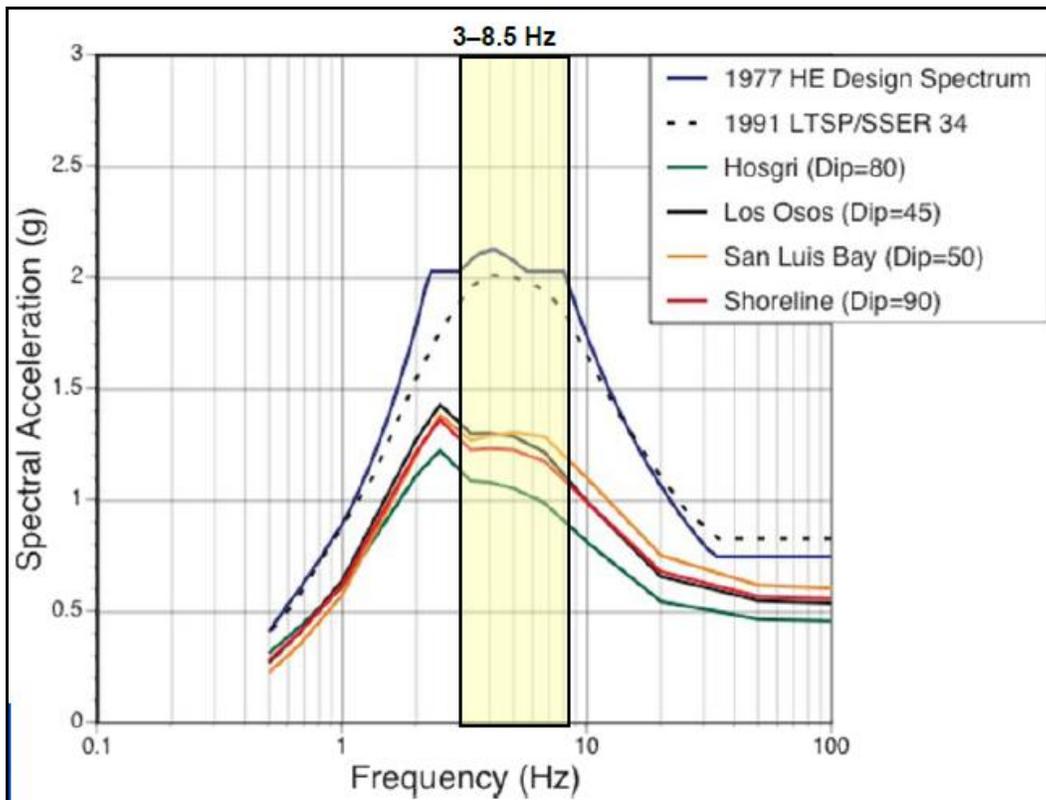


Response spectra showing sensitivity of the ground motion at DCPP to the magnitude of earthquakes on the Shoreline fault. The response spectra are based on modern ground motion models (2008 NGA models) modeling DCPP site-specific effects based on earthquake recordings at DCPP. At the high frequencies of interest at DCPP, no scenarios exceed the Hosgri design spectrum.

As part of the offshore 3D seismic surveys, PG&E will perform a check on this assumption. The intersection of the Shoreline and Hosgri fault zones will be studied to help further understand the interaction of these two fault zones at depth.

**GM6) What faults are the most important for the seismic hazard at Diablo Canyon?**

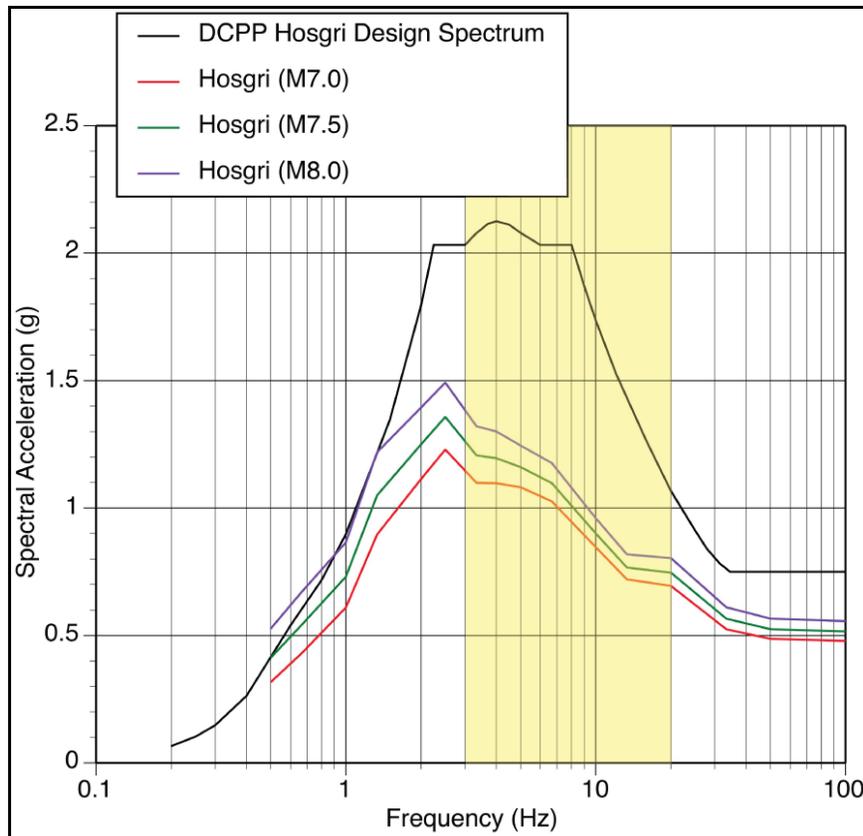
Using the state of practice in earthquake science and our current understanding of the faults in the vicinity of DCP, the faults controlling the ground motion hazard at DCP are: the Hosgri fault, the Los Osos fault, the San Luis bay fault, and the Shoreline fault. The deterministic spectra from these four fault sources are enveloped by both the 1991 LTSP spectrum and the 1977 Hosgri spectrum over the frequency range of 3 – 8.5 Hz (the frequency range of importance for DCP structures). The deterministic analysis shown below considered many different scientific models for computing the magnitude and selected the magnitude larger than 90% of the weighted models (called the uses the 90<sup>th</sup> fractile). The earthquake is assumed to occur at the closest distance from the fault to DCP, and the shallowest dip angle on the fault that is consistent with current data is used for each fault...



The table below shows the magnitudes used to compute the ground motion response spectra in the deterministic analysis. The magnitudes correspond to the value that is higher than the magnitude computed for 90% of the weighted alternative scientific models.

<b>FAULT SOURCE</b>	<b>DETERMINISTIC MAGNITUDE</b>
Shoreline	6.5
San Luis Bay	6.3
Hosgri	7.1
Los Osos	6.8

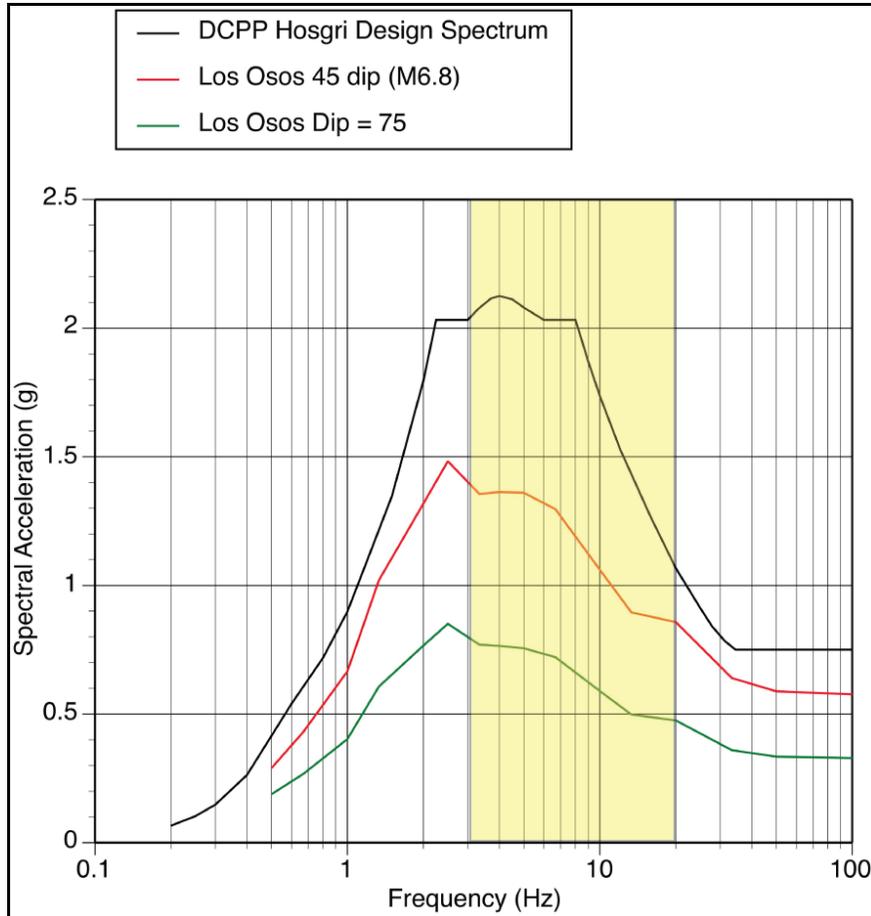
Because these faults control the ground motion hazard at Diablo Canyon, it is important that we characterize them using the best available science, focusing on the parameters that have the most impact on the ground motion calculations. For example, our sensitivity studies have shown that these sources scale only weakly with magnitude. While the energy released in an earthquake goes up by a factor of 30 as the magnitude is increased from M7 to M8, the figure below shows that the high frequency ground motions near the fault only increase by factors of 1.2 to 1.3



Response spectra showing sensitivity of the ground motion at DCPP to the magnitude of earthquakes on the Hosgri fault. The response spectra are based on modern ground motion models (2008 NGA models) modeling DCPP site-specific effects based on earthquake recordings at DCPP. At the high frequencies of interest at DCPP, no scenarios exceed the Hosgri design spectrum.

A parameter that has more effect in the ground motion calculations is the dip of the Los Osos fault. Two of the faults in our study, the San Luis Bay and Los Osos faults, are

characterized as reverse faults that dip toward DCPP. For these two faults, the dip of the fault is an important parameter for estimating the ground motion at DCPP. As the following example on the Los Osos fault shows, varying this parameter can have a large impact on the resulting ground motions.



Response spectra showing sensitivity of the ground motion at DCPP to the dip of the Los Osos fault. The response spectra are based on modern ground motion models (2008 NGA models) modeling DCPP site-specific effects based on earthquake recordings at DCPP. At the high frequencies of interest at DCPP, no scenarios exceed the Hosgri design spectrum, but the scaling is much stronger with fault dip than with earthquake magnitude.

**GM7) What is the difference between deterministic and probabilistic seismic hazard analysis?**

A deterministic seismic hazard analysis (DSHA) assumes that a large earthquake will occur on a particular fault and then uses ground motion prediction equations to compute the ground motion. For critical structures, such as nuclear power plants, the deterministic ground motion calculations are made at the 84<sup>th</sup> percentile ground motion level assuming the earthquake occurs at the closest distance to the site. The result of a deterministic analysis is a response spectrum that shows the amplitude of ground shaking over a range of frequencies at a site. The 1991 LTSP spectrum is the result of an 84<sup>th</sup> percentile deterministic analysis.

A probabilistic seismic hazard analysis (PSHA), on the other hand, can be thought of as a large set of deterministic analyses that includes all possible earthquake scenarios (magnitude, distance from the site, style of faulting, fault dip) at every possible ground motion level while tracking the rate of occurrence of each resulting earthquake scenario – ground motion pair. As a result, any scenario that may be selected in a deterministic analysis is included in the list of scenarios considered in the PSHA; the PSHA just includes more scenarios and estimates the rate of each scenario.

One key difference between the deterministic and probabilistic approaches is that the deterministic approach evaluates the ground motions at the 84<sup>th</sup> percentile statistical level for sources with single magnitude, distance from the site, style of faulting, and fault dip. In a PSHA, however, the entire ground motion distribution is sampled for every conceivable combination of magnitude, distance from the site, style of faulting, and fault dip. Another key difference between the methods is the PSHA also provides a method to formally incorporate the slip rate data on the faults to calculate activity rates and to track the rate of occurrence of each individual earthquake scenario and the chance of the ground motion given the scenario. Once rates of occurrence have been assigned to each scenario, the scenarios are then ranked in decreasing order of severity of shaking and the rates are summed to produce a hazard curve. In this way the hazard curve tells you the chance that a particular ground motion level will be exceeded from any of the earthquake scenarios.

At DCPP, the main use of probabilistic hazard curves is in seismic probabilistic risk analyses (SPRA). In SPRA, DCPP is evaluated for ground motions that are even greater than the design ground motions (See GM11)

The PSHA is an improvement over the DSHA because provides a framework for evaluating all levels of ground shaking, not the 84<sup>th</sup> percentile level that was the standard of practice in the nuclear industry up to the mid 1980s.

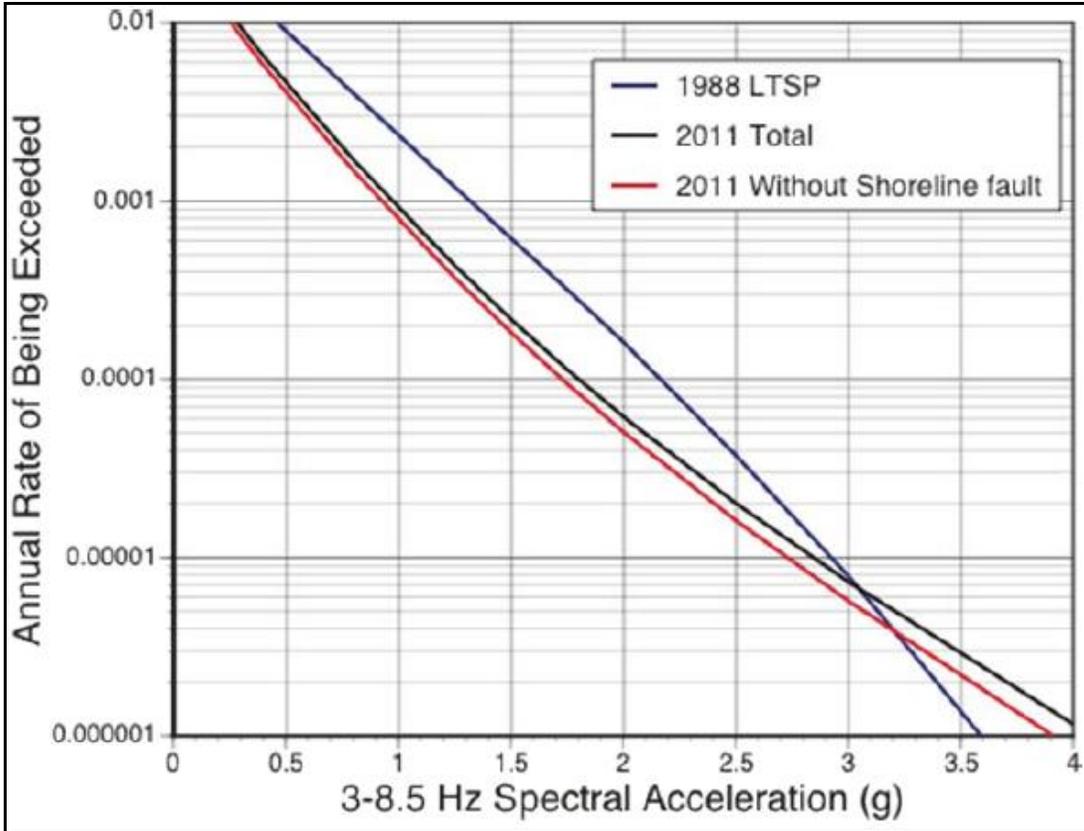
**GM8) What is the chance that a ground motion larger than the design basis will occur?**

The probabilistic hazard results (see GM10) can be used to compute the chance that there will be a ground motion that is beyond the 2.1g (3 – 8.5 Hz) 1977 HE design basis. The table below shows that the probability of exceeding the 1977 HE spectrum in the 3-8.5 Hz range is 1 in 20,000 per year.

For DCP, the structures, systems, and components that are required for safely shutting down the plant have margins to withstand ground shaking that is stronger than the design basis. This margin is measured using a term called the HCLPF (high confidence of a low probability of failure) margin. The HCLPF refers to the ground motion that has a small chance of failure (less than 5%) using conservative estimates of the capacities (5<sup>th</sup> percentile) for a particular component, system, or structure. The HCLPF margin is the ratio of the HCLPF ground motion to the design ground motion. For example, if the ground motion that led to a 5% chance of failing a component was 3g and the design basis ground motion for the component was 2g, then the HCLPF margin would be 1.5 (3g divided by 2g).

At DCP, the HCLPF margins are 1.3 or greater beyond the design basis ground motions (including nonlinear behavior). That is, even the weakest components can withstand ground motions 40% larger than the 1991 LTSP ground motions (1.9 g for 3 – 8.5), and have only a small chance of failure. The chance of a PGA more than 40% larger than the LTSP ground motion of 1.9g (3 – 8.5 Hz) occurring at the DCP site is 1 in 70,000 per year.

<b>SA 3 – 8.5 Hz</b>		<b>Annual Probability of Being Exceeded</b>
2.1g	1977 Hosgri Design	5E-05
1.9g	1991 LTSP	7E-05
2.7g	40% Beyond 1991 LTSP	1.4E-05



**GM9) How do you determine the earthquake magnitude that a particular fault can generate?**

Earthquake magnitude is dependent on the size of the fault plane that ruptures in an earthquake. There are two relationships between fault area and earthquake magnitude that are commonly used in practice: the Wells & Coppersmith (1994) Magnitude-Area scaling relation, and the Hanks & Bakun (2004) Magnitude-Area scaling relation. The forms of these relations for strike-slip faults are:

Wells & Coppersmith (1994):

$$M_w = 1.02 \log(A) + 3.98$$

Hanks & Bakun (2004):

$$M_w = \log(A) + 3.98$$

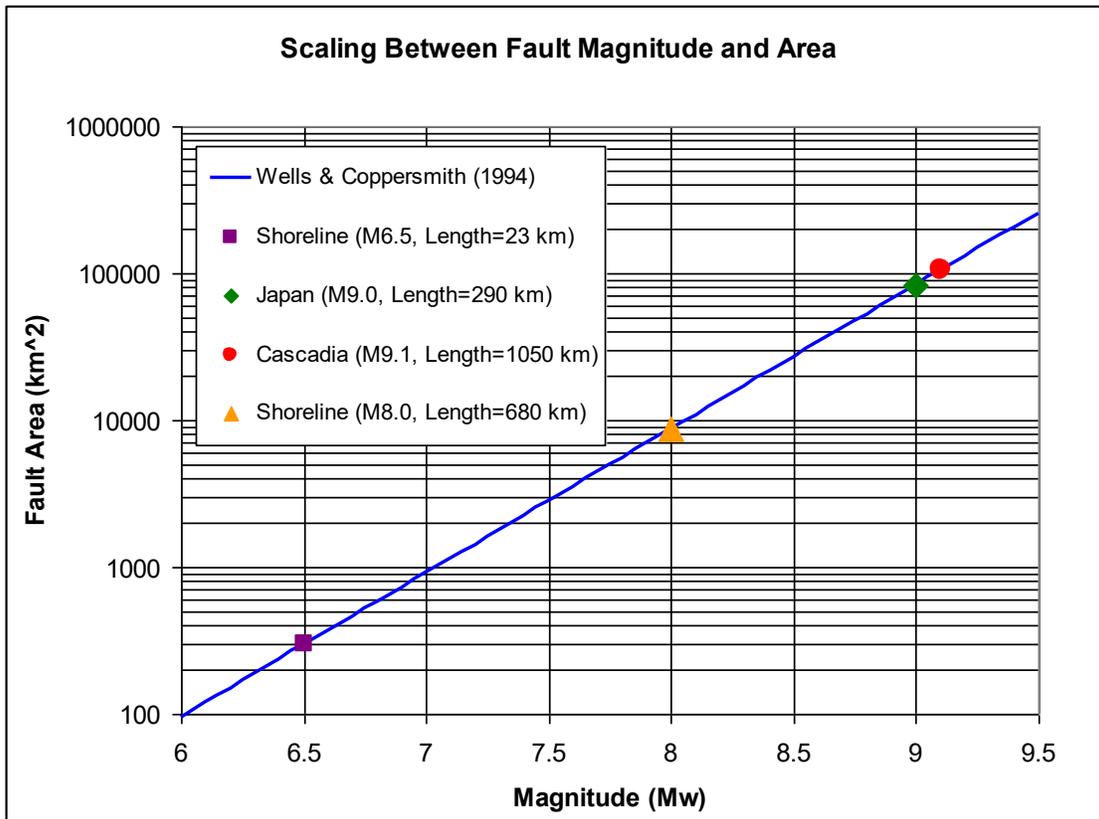
$$M_w = (4/3) \log(A) + 3.07$$

when:  $A \leq 537 \text{ km}^2$

when:  $A > 537 \text{ km}^2$

\* $M_w$  is the earthquake moment magnitude and A is the fault rupture area in square kilometers.

In the figure below, the Wells & Coppersmith (1994) magnitude-area scaling relation is used to demonstrate how earthquake magnitude scales with fault rupture area. As points of reference, four key earthquake scenarios have been included on the figure, and scenario details are provided in the table that follows.



<b>SCENARIO</b>	<b>MAG</b>	<b>DIP</b>	<b>CRUST (km)</b>	<b>AREA (km<sup>2</sup>)</b>	<b>LENGTH (km)</b>
Shoreline	6.5	90	13	296	23
Japan	9.0	10	57	83477	290
Cascadia	9.1	14	24	104620	1050
Shoreline + Hosgri + San Simeon + San Gregorio + San Andreas	8.0	90	13	8750	680

In the vicinity of the Shoreline and Hosgri faults, the depth of the seismogenic crust is approximately 13 kilometers. Because Diablo Canyon is located near a transform tectonic boundary, the faults offshore of the plant are predominantly vertical, strike-slip faults with down-dip widths equal to the depth of the seismogenic crust (~13 km). The fault lengths necessary to generate earthquakes with magnitudes ranging from 6.0 to 9.0 in the DCP region are shown in the table below.

<b>Magnitude</b>	<b>W&amp;C (94) Length (km)</b>	<b>H&amp;B (04) Length (km)</b>
6	10	10
6.1	11	11
6.2	12	13
6.3	14	16
6.4	18	20
6.5	23	25
6.6	28	32
6.7	36	40
6.8	45	48
6.9	56	57
7	70	68
7.1	88	81
7.2	110	96
7.3	138	114
7.4	173	136
7.5	217	162
7.6	272	192
7.7	341	228
7.8	428	271
7.9	536	323
8	672	383
8.1	842	456
8.2	1055	541
8.3	1322	644
8.4	1657	765
8.5	2077	909
8.6	2603	1080
8.7	3262	1284
8.8	4088	1526
8.9	5124	1814
9	6421	2156

Generating a M8.0 earthquake offshore of Diablo Canyon would require linking the Shoreline fault with the Hosgri, San Simeon, San Gregorio, and San Andreas faults, as shown in the map below. This case is very unlikely.

