5.0 SEISMIC SOURCE CHARACTERIZATION

This section presents the seismic source characterization used to model ground motions at the DCPP. The logic tree for the Shoreline fault zone source is presented in Section 5.1 and is based on findings presented in Sections 3.0 and 4.0. Figure 5-1 shows a map of the Shoreline fault zone source and adjacent San Luis Bay fault sources and portions of the nearby Hosgri and Los Osos fault sources. In addition to the new Shoreline fault zone source, logic trees for the Hosgri, Los Osos, and San Luis Bay fault sources are used that are based on the current understanding of those faults and the regional tectonic setting (Section 3.0). The logic trees for these other fault sources are presented in Section 5.2. Coordinates for the ends and bends in the fault sources (e.g., the labeled dots on Figure 5-1) are presented in Table 5-1, which appears at the end of this section.

The logic trees capture the range of values that characterize each fault source. Each tree consists of various nodes that define the fault source, including rupture length, rupture width, slip sense, and slip rate. Each node consists of one or more branches with values to capture the epistemic uncertainty of that node. The weight given to each branch is based on the strength of the evidence to support the branch value. The weights are between zero and one and sum to one for each node.

5.1 Shoreline Fault Zone Source Logic Tree

The logic tree to characterize the uncertainty in source parameters for the Shoreline fault zone source (Figures 5-2 to 5-6) is based on the data collected and evaluated to date. The logic tree considers two alternative rupture scenarios for the Shoreline fault zone, one in which the fault zone ruptures as an independent source, and the other in which the Shoreline fault zone is kinematically linked to other faults in the Southwestern Boundary fault zone, and may rupture with the San Luis Bay fault. Because the results of dynamic rupture modeling show that rupture on the Hosgri fault zone is inhibited from rupturing onto the Shoreline fault zone (Appendix J), this scenario is not considered in the logic tree.

The logic tree for the Shoreline fault zone source consists of 30 nodes that define the rupture dimensions, segmentation, sense of slip, and slip rate of the seismic source (Figures 5-2 to 5-6). Nodes 1–4 define the surface trace of the Shoreline fault zone source, which is shown in map view on Figure 5-1. Nodes 5–10 define the fault source dip and width, and node 11 defines the slip sense of the fault. Node 12 defines the kinematic relationship of the Shoreline fault zone with the intersecting San Luis Bay fault zone by asking whether the two faults are "linked" (Figure 5-3). The "no" branch represents a Shoreline fault zone that is separate and distinct from the San Luis Bay fault zone, wherein the two faults move independently. The "no" branch in node 12 is followed by nodes 13 to 16 to define the rupture dimensions and fault slip rate for the Shoreline fault zone source (Figure 5-4); the independent San Luis Bay fault source is characterized in a separate logic tree (Section 5.2.3). The "yes" branch represents a structural model in which the Shoreline fault zone and East segment of the San Luis Bay fault zone are linked in the sense that they may rupture together in the same earthquake. The linked model also allows for alternative rupture scenarios in which the two faults may either partially rupture together or rupture separately. The linked Shoreline and San Luis Bay faults may partially rupture together in the same earthquake or separately. The "yes" branch in node 12 is followed by nodes 17 to 30, which define the fault geometry and dimensions of the San Luis Bay fault source, and the rupture dimensions and fault slip rate for the Shoreline and San Luis Bay fault sources (Figures 5-5 and 5-6).

The weights determined for each branch at a node are shown as a number in brackets, such as [1.0] for one branch or [0.3] and [0.7] for two branches, etc. The sum of the weights at each node is always 1.0.

Node 1

Node 1 defines the southern end of the Shoreline fault zone source (Figure 5-2). This point, labeled S1 on Figure 5-1, is located about 3.5 km south-southeast of Point San Luis and is based on the findings presented in Section 4.3. A weight of 1.0 is assigned to this location, as the approximately 0.5 km uncertainty in its exact location has negligible effect on the overall source dimensions.

Node 2

Node 2 defines the boundary between the South and Central segments of the Shoreline fault zone (Figure 5-2). This point, labeled S2 on Figure 5-1, is located about 1.2 km west of the Rattlesnake (San Luis Bay) fault intersection with the coastline (Section 4.3) near the northern termination of a distinct magnetic anomaly associated with the South segment of the fault zone (Figure 4-22). A weight of 1.0 is assigned to this location, as the <0.25 km uncertainty in its exact location has negligible effect on the overall source dimensions. The approximately 7 km distance between points S1 and S2 defines the length of the South segment of the Shoreline fault zone source.

Node 3

Node 3 defines the northern end of the Central segment of the Shoreline fault (Figure 5-2). This point, labeled S3 on Figure 5-1, is located about 0.5 km south-southwest of Lion Rock, and about 1.5 km due west of Discharge Cove. Point S3 is based on the boundary between the Northern and Central seismicity sublineaments (Section 4.2), the approximate northern end of the distinct magnetic anomaly high associated with the Central segment of the Shoreline fault zone (Figure 4-22), and the approximate geologic boundary where the N40W fault may intersect the Shoreline fault zone (Section 4.3). The location of point S3 is selected such that the shortest distance from DCPP to the Shoreline fault zone source is the same as the shortest distance from the DCPP to the Shoreline fault zone as mapped on the MBES bathymetric data (Plate 1). A weight of 1.0 is assigned to this location, as the <0.5 km uncertainty in its along-strike location has negligible effect on the overall source dimensions. The approximately 8 km distance between points S2 and S3 defines the length of the Central segment of the Shoreline fault zone source.

Node 4

Node 4 defines the northern end of the Shoreline fault zone and the length of the North segment of the Shoreline fault zone source (Figure 5-2). There are four branches to this node that reflect the epistemic uncertainty in its location (Figure 5-1). Specifically, there is uncertainty as to whether earthquakes within the Northern seismicity sublineament occur on a distinct North segment of the Shoreline fault zone or whether some or all of the seismicity in the Northern seismicity sublineament may be occurring on a steeply east-dipping Hosgri fault zone (see Section 4.2). In the former case, additional uncertainty exists regarding the location of the North segment of the Shoreline fault zone: whether the segment is spatially coincident with the Northern seismicity sublineament, either on a blind fault or along a small, en echelon fault observed in Tertiary strata, or whether the North segment is coincident with the preexisting N40W fault. As discussed below, the highest weights are assigned to the branches in which the North segment of the Shoreline fault zone source coincides entirely or in part with the Northern seismicity sublineament. In all cases, the lengths described below are surface lengths. The subsurface depth extent of the Shoreline fault zone source is limited by the Hosgri fault zone in cases where the Hosgri fault source dips to the east.

The first branch of node 4 coincides with point S6 on Figure 5-1, which represents the northern endpoint of the N40W fault. This permissible alternative assumes that seismicity at the southern end of the Northern seismicity sublineament is associated with a moderately well-defined fault in Tertiary strata (see Section 4.3). In this case, seismicity along the north part of the Northern seismicity sublineament is assumed to be related to the Hosgri fault zone. This first branch of node 4 has a weight of 0.2. The approximately 8 km distance between points S3 and S6 defines the maximum length of the North segment of the Shoreline fault zone source (Figures 5-1 and 5-2). The maximum length of the Shoreline fault zone source on this branch is 23 km (Figure 5-2, Node 4').

The second branch of node 4 coincides with point S4, which is located near the intersection of the Northern Shoreline seismicity sublineament with the Hosgri fault source. Supporting this interpretation are the best-fit trend of the Northern seismicity sublineament (see Section 4.2) and the near-surface fault within inferred Tertiary strata, tentatively imaged on the shallow seismic reflection lines, that approximately aligns with the Northern seismicity sublineament (Section 4.3). This second branch has a weight of 0.4. The length of this segment (approximately 8 km) and the total length of the Shoreline fault zone source are the same as on branch one (Figures 5-1 and 5-2).

The third branch of node 4 coincides with point S5 on Figure 5-1, which is half way between points S4 and S3. This branch considers the earthquakes north of point S5 to have occurred on faults within the steeply east-dipping Hosgri fault zone, instead of on a distinct Shoreline fault zone. The seismicity section oriented perpendicular to the Hosgri fault zone (Figure 4-8, Section 4.2) illustrates the possible association of deeper earthquakes with the Hosgri fault zone. It is reasonable to assume that most of the seismicity near the steeply east-dipping Hosgri fault zone is associated with the more active Hosgri fault zone rather than a less active secondary fault. However, this alternative is given slightly less weight [0.3] than the second branch based on the alternative that there is a fault in Tertiary bedrock, which is mapped farther to the north. The 4 km distance between points S3 and S5 defines the minimum length of the North segment of the Shoreline fault zone source (Figures 5-1 and 5-2). The total length of the Shoreline fault zone source on this branch is 19 km (Figure 5-2, Node 4').

The fourth branch of node 4 defines the northern end of the Shoreline fault zone source to be at point S3, coincident with the northern end of the Central segment of the Shoreline fault zone source. This alternative, which interprets no distinct North segment of the Shoreline fault zone, attributes all of the seismicity on the Northern seismicity sublineament to be related to a steeply east-dipping Hosgri fault zone. As described above and in Section 4.2, the seismicity seen in cross section appears to better correlate to the trend of the Northern seismicity sublineament than to the Hosgri trend. The fourth branch of node 4 has a weight of 0.1; the low weight assigned to this branch is based on consideration of both seismicity and geologic data that suggest a fault may extend further to the north. The total length of the Shoreline fault zone source on this branch is 15 km, or the combined length of the South and Central fault segments (Figure 5-2, Node 4').

Node 5

Node 5 defines the dip of the Shoreline fault zone source (Figure 5-2). This node has a single branch value of 90°, which has a weight of 1.0. This value is supported by the vertical alignment of seismicity (within the 0.5 km epicentral location uncertainty) for the entire length of the Shoreline seismicity lineament (see Section 4.2).

Node 6

Node 6 includes two branches for alternative lines of evidence used to evaluate the maximum seismogenic depth of the Shoreline fault zone source (Figure 5-3). The top of seismogenic crust is assumed to be at zero depth in all instances. Because the fault is vertical, the maximum seismogenic depth is equivalent to the maximum source rupture width. The first branch suggests that estimates of maximum seismogenic depth (i.e., seismogenic thickness) based on regional data (Section 4.2) being used to characterize other nearby faults (i.e., the Hosgri, Los Osos, and San Luis Bay seismic sources [Section 5.2]) should be used to constrain the seismogenic depth of the Shoreline fault zone source. This branch has a weight of 0.7 based on the more robust data set used to inform the values in node 7. The second branch assumes that the seismicity along the Shoreline fault zone (Section 4.2) provides a better representation of maximum depth of rupture, which may vary among the North, Central, and South segments of the Shoreline fault zone (Section 4.2). This branch, which is based on a limited seismicity data set and the assumption that the short period of time over which the seismicity lineament has manifested itself (21 years) accurately represents the full extent of the seismogenic area for all three fault segments, is thus judged less reliable and given a lower weight (0.3).

Node 7

Node 7 follows the first branch of node 6 and defines the distribution for estimated regional seismogenic thickness (Figure 5-3). As described in Section 3.2, the regional distribution of seismicity defines a preferred seismogenic thickness of the crust of about 12 km, with a range of probable values between 10 and 15 km. Branch values are assigned to this node of 10, 12, and 15 km, which are weighted 0.2, 0.6, and 0.2, respectively.

Node 8

Node 8 follows the second branch of node 6 and defines the maximum depth of the Northern Shoreline seismicity sublineament (Figure 5-3). Based on the evaluation of seismicity described in Section 4.2, the node has branch values of 12 and 15 km, which are weighted 0.8 and 0.2, respectively. The weights assigned to these two branches are consistent with the weights assigned to the regional seismogenic thickness values (i.e., the highest weight is assigned to the preferred 12 km maximum depth and a lower weight is given to the maximum hypocentral depths.

Node 9

Node 9 follows the second branch of node 6 and defines the maximum depth of the Central seismicity sublineament (Figure 5-3). Based on the evaluation of seismicity described in Section 4.2, the node has branch values of 8 and 10 km, which are weighted 0.4 and 0.6, respectively. These weights reflect a slight preference for the 10 km maximum depth because it is more consistent with the regional seismogenic thickness.

Node 10

Node 10 follows the second branch of node 6 and defines the maximum depth of the Southern seismicity sublineament (Figure 5-3). Based on the evaluation of seismicity described in Section 4.2, the node has branch values of 8 and 10 km, which are weighted equally at 0.5. The slightly shallower weighted mean depth for the Southern seismicity sublineament compared to the Central seismicity sublineament is consistent with the observation that hypocentral depths of earthquakes on the Southern seismicity sublineament are shallower than depths observed on the other two sublineaments (see Section 4.2).

Node 11

Node 11 defines the style of faulting (slip sense) of the Shoreline fault zone source (Figure 5-3). The fault dip and focal mechanisms in the current tectonic regime all suggest right-lateral strike-slip motion (Section 4.2), and this slip sense is given a weight of 1.0.

Node 12

Node 12 considers whether the Shoreline fault zone source and San Luis Bay fault source are kinematically linked or whether they are separate, independent faults (Figure 5-3). The “yes” branch represents a Shoreline fault zone and intersecting San Luis Bay fault zone to the east that are linked in the sense that the East segment of the San Luis Bay fault may rupture with the Shoreline fault (Central segment or North and Central segment) during a single earthquake. This structural model considers the Shoreline fault zone to be part of a longer system of strike-slip and oblique-slip faults within the Southwestern Boundary fault zone. The North and Central segments of the Shoreline fault, together with the intersecting San Luis Bay fault to the east, would form part of a left restraining bend in the fault system. The size of the step-over to other faults in the system such as the Oceano, Los Berros, or Wilmar Avenue faults, which is on the order of a few kilometers, suggests that ruptures on the combined Shoreline fault and San Luis Bay fault to the east would not continue onto other structures. This description of the Southwestern Boundary zone as a strike-slip fault system that accommodates regional transpression differs from the LTSP categorization of the Southwestern Boundary fault zone as a block boundary mostly accommodating reverse faulting and shortening (PG&E, 1988; Lettis et al., 1994). The “yes” (linked) branch is given a weight of 0.3, and the continuation of this branch of the logic tree is described by nodes 17–30 (Figures 5-5 and 5-6).

The “no” branch in node 12 represents a Shoreline fault zone that is separate and distinct from the San Luis Bay fault, wherein the two faults move independently and accommodate distinctly different directions of slip. This characterization is consistent with a regional kinematic model more similar to the LTSP, in which the San Luis Bay fault is part of the reverse or oblique Southwestern Boundary fault zone that forms the block boundary between the uplifted San Luis–Pismo block and the adjacent Santa Maria Valley block to the southwest (Section 3.1). The

Shoreline fault zone in this kinematic description is fundamentally separate from the Southwestern Boundary fault zone, and instead accommodates a minor amount of right-lateral strike-slip displacement within the San Luis–Pismo block. The “no” branch is given a weight of 0.7, and the continuation of this branch of the logic tree is described by nodes 13 to 16 (Figure 5-4). The higher weight for the “no” branch is based on two primary lines of reasoning: (1) the direct evidence from the San Luis Bay fault documented to date indicates reverse movement on a north-dipping fault (PG&E, 1988), whereas the “linked” model predicts a significant strike-slip component and, at least locally, a subvertical dip; and (2) several lines of evidence support the change in uplift rate documented across the San Luis Bay fault zone onshore to continue offshore to the west-northwest and across the Shoreline fault zone, rather than along it (see Sections 4.3 and 4.4; Appendix I).

Node 13

Node 13 defines the rupture mode for an independent Shoreline fault zone source (Figure 5-4). Specifically, two branches consider whether (1) the Shoreline fault zone source is segmented, with segmentation points that are strong barriers to rupture propagation, or (2) the fault source is unsegmented, with no physical barriers that are able to repeatedly arrest rupture. The branches in this node reflect the epistemic uncertainty in the rupture behavior of the Shoreline fault zone. Section 4.3 discusses the basis for the segmentation points between the South, Central, and North segments of the Shoreline fault zone (i.e., points S2 and S3 on Figure 5-1). The branch weights are 0.6 and 0.4 for the segmented and unsegmented rupture modes, respectively, reflecting the moderately strong basis for a segmented fault presented in Section 4.3.

Node 14

Node 14 defines the rupture lengths following the segmented rupture branch of node 13 (Figure 5-4). The four branches show the possible combinations of one-, two-, and three-segment ruptures involving the North (N), Central (C), and South (S) segments of the Shoreline fault zone source. The combinations [and corresponding weights] are one-segment ruptures N, C, and S [0.15]; two-segment N+C rupture and one-segment S rupture [0.6]; one-segment N rupture and two-segment C+S rupture [0.1]; and three-segment N+C+S rupture [0.15]. The distribution of weights reflects the relatively strong evidence for a segmentation point between the Central and South segments (at the intersection of the Shoreline fault zone with the Rattlesnake fault of the San Luis Bay fault zone; Section 4.3), and the relatively weak evidence for a segmentation point between the Central and North segments (Section 4.3). These rupture lengths are fixed to the defined fault source segments, implying that the segmentation points are unbreakable.

The branch values and weights of node 14 are modified for that part of the logic tree where the North segment of the Shoreline fault zone does not exist (specifically, the branch of node 4 that defines the northern end of the Shoreline fault zone source at the northern end of the Central segment; Figure 5-2). In this case, the upper two and lower two branches of node 14 combine so there are only two branches [with combined weights]: one-segment ruptures C and S [0.7] and two-segment ruptures C+S [0.3].

Node 15

Node 15 defines possible rupture lengths for the unsegmented rupture branch of node 13 (Figure 5-4). In this case, defined rupture lengths are assumed to “float” anywhere along the fault length. The distinct fault segments and segmentation points defined in Section 4.3 are thus geometric constructs, but do not affect seismogenic fault rupture. Rupture lengths considered in the unsegmented rupture model are based on an assumed rupture aspect ratio, defined as the ratio of rupture length L to rupture width W, or L:W. The three branch values [and weights] are 1:1 [0.3], 1.5:1 [0.4], and 2:1 [0.3]. Empirical data from historical continental earthquakes (e.g., Wells and Coppersmith, 1994; Leonard, 2010) provide a basis for weighing the three branch values.

Figure 5-7 is modified from Leonard (2010) and shows a log-log plot of rupture length versus width for a subset of instrumental strike-slip earthquakes (data compiled mainly from Wells and Coppersmith, 1994). The shaded gray region of the plot reflects the approximate rupture length and width of the Shoreline fault zone, and the three solid, diagonal lines provide the fits to constant aspect ratios of 1:1, 1.5:1, and 2:1. The data show considerable scatter and broadly support the three constant aspect ratios as valid rupture dimensions in the shaded region. Aspect ratios of less than 1:1 are not considered as branch values, following the widely held view that small ruptures are generally circular and larger ruptures generally are associated with larger aspect ratios and more rectangular shapes (Leonard, 2010). The preferred relationship of Leonard (2010) to fit the broader data set (shown by the thin solid and bordering dashed lines) is a power-law relationship between W and L, whereby W is proportional to $L^{2/3}$ for the range $5 \text{ km} < L < 50$ km.

For purposes of defining rupture dimensions on an unsegmented Shoreline fault zone source (which has a length not greater than 23 km), the three constant aspect ratios of 1:1, 1.5:1, and 2:1 and the rupture widths defined by nodes 5 to 10 sufficiently capture the range of probable values. Because the rupture length cannot exceed the fault source length, an important constraint on this node is that given a defined rupture width, the calculated rupture length is truncated to be no greater than the fault source length (i.e., maximum of 23 km). For example, fault length would be truncated to 23 km for rupture widths of 12 or 15 km and an aspect ratio of 2:1.

Node 16

Node 16 defines the slip rate of the Shoreline fault zone source (Figure 5-4). The uncertainty in fault slip rate and lines of reasoning supporting the range in slip rate values are presented in Section 4.4.3. Four lines of reasoning are used to provide constraints on the minimum, maximum, and preferred values for slip rate, including (1) comparison to the Hosgri-San Simeon fault zone, (2) seismicity rate, (3) observed vertical separation, and (4) observed lateral separation. These analyses provide estimates of slip rate ranging from 0.05 to 1 mm/yr, with a preferred range between 0.1 and 0.6 mm/yr. The five slip rate branches [and corresponding weights] are 1.0 [0.05]; 0.6 [0.15]; 0.3 [0.35]; 0.1 [0.35]; and 0.05 mm/yr [0.1]. Seventy percent of the weight is given to slip rates of 0.1 and 0.3 mm/yr, values most consistent with the available constraints (Section 4.4).

Node 17

Nodes 17–30 characterize the linked Shoreline and San Luis Bay seismic sources that follow the “yes” branch of the logic tree under node 12 (Figure 5-3). Node 17 defines the location and total length of the San Luis Bay fault east of its intersection with the Shoreline fault (the “East segment”; Figure 5-5). These points, labeled L2 to L6 on Figure 5-1, extend from the intersection with the Shoreline fault on the west (point L2, which is equivalent to point S2), eastward to Mallagh Landing and the probable eastern end of the San Luis Bay fault (Section 3.1). A weight of 1.0 is assigned to this location, and the points define an approximately 8 km long East segment of the San Luis Bay fault source. Intermediate points labeled L3, L4, and L5, which are considered in defining ruptures scenarios, are described in the discussion of node 25.

Node 18

Node 18 defines the average dip of the East segment of the San Luis Bay fault source in the linked model (Figure 5-5). Because the linked model includes the characterization that the Central segment of the Shoreline fault and the East segment of the San Luis Bay fault smoothly intersect and may rupture together, the dip of the East segment at the branch line must be very steeply dipping to subvertical, with the possibility of a slightly more inclined fault plane east of the fault intersection. On this basis, the 70° north dip of the San Luis Bay fault source considered in the independent San Luis Bay fault source logic tree (Section 5.2) is not considered here, as it does not allow for the required intersection geometry with the Central segment of the Shoreline fault zone source. This node has branch values [and weights] of 80° north [0.3] and 85° north [0.7]. The steeper geometry is preferred, as this dip is structurally more compatible with this rupture mode.

Node 19

Node 19 considers two alternatives for the western end of the San Luis Bay fault source in the linked model (Figure 5-5). In the linked model, the Shoreline fault zone is a barrier to rupture and a kinematic boundary such that the San Luis Bay fault east of the Shoreline fault zone (the East segment) has no physical connection with structures west of the Shoreline fault zone. The first branch describes an 8 km long West segment of the San Luis Bay fault source west of the Shoreline fault zone between points L1 and L2. This branch has a higher weight of 0.6, reflecting the preferred location of the uplift rate boundary identified from analysis of submerged marine terraces (Appendix I) that follows a strong magnetic and geologic trend (Section 4.5). The second branch to node 19 assumes that the West segment of the San Luis Bay fault does not exist under the linked model. In this case, either the Central and North segments of the Shoreline fault zone form the uplift rate boundary, or the uplift rate boundary is a poorly defined diffuse zone somewhere between the Shoreline and Hosgri fault zones that does not constitute a seismic source. This branch has a weight of 0.4.

Node 20

Node 20 defines the average dip of the West segment of the San Luis Bay fault source in the linked model following the upper branch of node 19 (Figure 5-5). Alternative branch weights are 70°, 80°, and 85° north, with a symmetric [0.3], [0.4], [0.3] weighted distribution, respectively. The dip values are determined to be at least 70° north because gentler dips would intersect the Shoreline fault zone at depths above the typical approximately 6–7 km deep nucleation depth for magnitude 5 or greater earthquakes (e.g., Sibson, 1984). The bottom and edges of the West segment source are truncated by both the east-dipping Hosgri fault source and the vertical Shoreline fault zone source where they intersect within the seismogenic crust.

Node 21

Node 21 defines the sense of slip for the West segment of the San Luis Bay fault source in the linked model following the upper branch of node 19 (Figure 5-5). Alternative branches are oblique-reverse slip with a weight of 0.35 and reverse slip with a weight of 0.65. The higher weight assigned to reverse slip, despite the overall linked and strike-slip-dominated kinematic model, is consistent with the concept that the West segment is a separate structure from the linked Shoreline-East segment of the San Luis Bay fault source and it primarily accommodates the change in uplift rate in the offshore (Appendix I).

Node 22

Node 22 defines the sense of slip for the East segment of the San Luis Bay fault in the linked model (Figure 5-5). The slip sense must accommodate both the change in uplift rate across the East segment and the strike-slip motion being transferred to it from the Shoreline fault zone. Alternative branches are strike slip, oblique-reverse slip, and reverse slip with horizontal-to-vertical ratios (h:v) of 2:1, 1:1, and 1:2, respectively. The highest weight of 0.45 is given to the oblique-reverse slip sense, followed by the reverse slip sense [0.4]. The remaining low [0.15] weight for the strike-slip branch reflects the evaluation that the East segment of the San Luis Bay fault would likely accommodate more oblique-reverse motion given its orientation relative to the strike-slip Shoreline fault zone (Figure 5-1).

Node 23

Node 23 defines the maximum depth to the bottom of rupture for the West and East segments of the San Luis Bay fault (Figure 5-5). The branch values and weights are identical to node 7 and are 10, 12, and 15 km with weights of 0.2, 0.6, and 0.2, respectively. The bottom and lateral margins of these sources are truncated by the south-dipping Los Osos fault zone, vertical Shoreline fault zone, and vertical to-east-dipping Hosgri fault zone where they intersect within the seismogenic crust (Figure 5-1).

Node 24

Node 24 defines the rupture mode for a linked Shoreline–East Segment San Luis Bay fault source (Figure 5-6). Similar to node 13 for the independent Shoreline fault zone source, two branches for node 24 consider (1) whether Shoreline–San Luis Bay fault ruptures are defined by discrete segments, with segmentation points that are strong barriers to rupture propagation, or (2) whether fault ruptures occur on an unsegmented fault source, with no physical barriers to limit rupture. Both rupture model branches consider the West segment of the San Luis Bay fault (in cases when it exists) to be a separate fault source that does not rupture with the Shoreline fault zone or the East segment of the San Luis Bay fault. The branch weights are 0.6 and 0.4 for the segmented and unsegmented rupture modes, respectively, reflecting the moderately strong basis for a segmented fault presented in Sections 4.3 and 4.5.

Node 25

Node 25 defines the rupture lengths following the segmented rupture branch of node 24 (Figure 5-6). The six branches outline possible combinations of one-, two-, and three-segment ruptures involving the North (N), Central (C), and South (S) segments of the Shoreline fault zone and the East (E) segment of the San Luis Bay fault. The combinations [and corresponding weights] are one-segment ruptures N, C, S, and E [0.15]; two-segment N+C rupture and one-segment S and E ruptures [0.1]; one-segment N and E ruptures and two-segment C+S rupture [0.05]; one-segment N and S ruptures and two-segment C+E rupture [0.3]; three-segment N+C+S rupture and one-segment E rupture [0.05]; and three-segment N+C+E rupture and one-segment S rupture [0.35]. Segmented ruptures where the S and E segments rupture together are not considered.

The distribution of weights reflects a strong preference for combined rupture of the Central segment of the Shoreline fault zone and the East segment of the San Luis Bay fault given the linked kinematic model branch of node 12. An additional source of epistemic uncertainty not defined in a separate node is whether rupture on the Central (or Central + North) segment of the Shoreline fault zone would rupture the entire 8 km long East segment of the San Luis Bay fault, or whether rupture nucleating on the Shoreline fault zone would rupture only part way into the San Luis Bay fault restraining bend (Figure 5-1). To address this, earthquakes involving the C+E or N+C+E rupture segments are considered to have an eastern rupture limit at either point L3, L5, or L6 with equal weight (see note 4 on Figure 5-6). As in node 14, the rupture lengths in node 25 are considered to be fixed to the defined fault source segments, implying that the segmentation points are unbreakable.

The branch values and weights of node 25 are modified for that part of the logic tree where the North segment of the Shoreline fault zone does not exist (specifically, the branch of node 4 that defines the northern end of the Shoreline fault zone to be at the northern end of the Central segment; Figure 5-2). In this case, the branches of node 25 combine so there are only three branches [with combined weights]: one-segment ruptures C, S, and E [0.25], and two-segment ruptures C+S, E [0.1] and C+E, S [0.65].

Node 26

Node 26 defines possible rupture lengths for the unsegmented rupture branch of node 24 (Figure 5-6). Similar to node 15, defined rupture lengths are assumed to “float” anywhere along the fault length, although node 26 has the additional restriction that the floating rupture cannot involve both the South segment of the Shoreline fault zone and the East segment of the San Luis Bay fault (Figure 5-1). The distinct fault segments and segmentation points defined in Section 4.3 are thus geometric constructs but do not affect seismogenic fault rupture. Rupture lengths considered in the unsegmented rupture model are based on an assumed rupture aspect ratio, defined as the ratio of rupture length L to rupture width W, or L:W. As in node 15, the three branch values [and weights] are 1:1 [0.3], 1.5:1 [0.4], and 2:1 [0.3]. Because the rupture length cannot exceed the fault source length, an important constraint on this node is that given a defined rupture width, the calculated rupture length is truncated to be no greater than the fault source length (i.e, maximum of 23 or 24 km), as would be the case for rupture widths of 12 or 15 km and an aspect ratio of 2:1.

Node 27

Node 27 defines the slip rate of the Central and North segments of the Shoreline fault zone source (Figure 5-6). The uncertainty in fault slip rate and lines of reasoning supporting the range in slip rate values are presented in Section 4.4.3. Because the uplift rate across the San Luis Bay fault cannot be directly tied to the Shoreline fault zone even in the linked model, the slip rate branch values and weights in the linked model are identical to those developed for the independent Shoreline fault zone source model in node 16 (Figure 5-4). The five slip rate branches [and corresponding weights] are 1.0 mm/yr [0.05], 0.6 mm/yr [0.15], 0.3 mm/yr [0.35], 0.1 mm/yr [0.35], and 0.05 mm/yr [0.1]. Because displacement on the Central and North segments is transferred to both the South segment of the Shoreline fault and the East segment of the San Luis Bay fault, the South segment of the Shoreline fault is assessed in node 29 based on a calculation described in the discussion of node 29.

Node 28

Node 28 defines the slip rate of the East segment of the San Luis Bay fault source for the linked model (Figure 5-6). The two branch values list alternative uplift rates for the San Luis Bay fault zone based on the LTSP analysis of the approximately 80,000-year-old and approximately 120,000-year-old marine terraces and longitudinal profiles of the marine terrace shoreline angles across the San Luis Bay fault (PG&E, 1990; Hanson et al., 1994). The net fault slip rates are calculated based on the fault dip (node 18) and slip sense (node 22) (Figure 5-5). The branch values for vertical uplift rate [and weights] are 0.14 mm/yr [0.8] and 0.08 mm/yr [0.2]. The greater (and more highly weighted) 0.14 mm/yr uplift rate is the difference between the uplift rate north of Olson Hill (0.2 mm/yr) and the uplift rate south of the Rattlesnake fault (0.06 mm/yr). The higher rate agrees with revised elevations and correlations of emergent marine terraces described in Appendix I, which suggest that this boundary is localized across the San Luis Bay fault zone north of Point San Luis. The lesser 0.08 mm/yr uplift rate is the difference in uplift rate across the Rattlesnake fault only. This lower-weighted value would be a valid estimate of the uplift rate for the San Luis Bay seismic source if the remaining differential uplift rate across the Olson Hill deformation zone were attributed to folding caused by another process (e.g., folding across an active axial surface tied to a deep bend in the Los Osos fault).

Node 29

Node 29 defines the slip rate of the South segment of the Shoreline fault zone source for the linked model (Figure 5-6). The alternative slip rates for this node are calculated values based on the slip rate for the Central and North segments of the Shoreline fault zone (node 27) and the slip rate for the East segment of the San Luis Bay fault zone (node 28). The South segment slip rate is calculated to be the node 27 slip rate minus the node 28 slip rate, with a minimum slip rate of 0.05 mm/yr.

Node 30

Node 30 defines the slip rate of the West segment of the San Luis Bay fault source for the linked model (Figure 5-6). The two branch values and weights are identical to those in node 28. The difference in net slip rate for the West segment source is based on the different dip and sense of slip values and weights in nodes 20 and 21 (Figure 5-5). The branch values for vertical uplift rate [and weights] are 0.14 mm/yr [0.8] and 0.08 mm/yr [0.2]. Because they are treated as separate structures, the slip rate of the West segment of the San Luis Bay fault source is independent of the slip rate of the East segment source in the linked model.

5.2 Logic Trees for Other Fault Sources

This section briefly summarizes the logic trees for other fault sources used to calculate ground motions at DCPP described in the LTSP Final Report and Addendum (PG&E, 1988, 1991a). These other fault sources are the Hosgri, Los Osos, and San Luis Bay fault zones (the last as an independent fault source compatible with the independent Shoreline fault zone source branch). The locations of these sources relative to the Shoreline fault zone source and DCPP are shown on Figures 5-1 and 5-8. Table 5-1 lists the coordinates for these fault sources. Figures 5-9 to 5-11 show the logic trees that characterize the source geometry, slip sense, and slip rate.

Modifications to the LTSP Final Report characterizations are based on current understanding of the regional seismotectonic setting (Section 3) and current assessments of specific fault source parameters. Modifications to the LTSP Final Report source characterization are being evaluated as part of the LTSP Update activities and are ongoing.

5.2.1 Hosgri Fault Zone Logic Tree

Figure 5-9 is the logic tree for the Hosgri fault zone source geometry, slip sense, and slip rate. Source parameters shown on Figure 5-9 are unchanged from the LTSP Final Report (PG&E, 1988) with the following exceptions:

Depth to Bottom of Rupture

The LTSP defined the maximum depth to the bottom of a fault rupture as 12 ± 3 km for all fault sources unless they were truncated by an intersecting fault (PG&E, 1988). A review of the regional earthquake catalog with well-located earthquakes since establishment of the PG&E–USGS network suggests a preferred value of 12 km, with alternative upper and lower values of 10 and 15 km (Section 3.2). Therefore, the branch values [and weights] for the depth to bottom of rupture for the Hosgri seismic source (node 2), as well as the Los Osos and San Luis Bay sources, are revised from the LTSP to be 10 km [0.2], 12 km [0.6], and 15 km [0.2].

Sense of Slip

The sense of slip for the Hosgri fault zone source is modeled as strike slip with a weight of 1.0 in this report (node 5). In the LTSP Final Report (PG&E, 1988), partial weight was given to oblique slip [0.3] and reverse slip [0.05] for the Hosgri fault zone. The oblique-slip and reverse-slip branches have been dropped because of information published subsequent to the LTSP that confirms strike-slip movement for the Hosgri fault zone, including geologic data (Hanson et al., 2004) and seismicity data (McLaren and Savage, 2001; Hardebeck, 2010) (Section 3).

Dip

Estimated values for the average dip of the Hosgri fault zone source (node 3) varied in the LTSP logic tree based on an assumed model for sense of slip. In the Hosgri fault source logic tree for this report, three values of dip are considered: 90°, 85° east, and 80° east. Evaluation of the Hardebeck (2010) earthquake catalog data (Section 4.2.4) plotted normal to the Hosgri fault zone (Figure 4-8) supports a vertical to steeply east-dipping zone, broadly constrained to lie within the range of these values. For this report, the branch values [and weights] are 90° [0.1], 85° east [0.4], and 80° east [0.5].

5.2.2 Los Osos Fault Logic Tree

Figure 5-10 is the logic tree for the Los Osos fault zone source geometry, slip sense, and slip rate. Source parameters shown on Figure 5-10 are unchanged from the LTSP Final Report (PG&E, 1988), with the following exceptions:

Sense of Slip

The LTSP Final Report (PG&E, 1988) heavily weighted reverse slip [0.9] over oblique slip [0.1] for the Los Osos fault zone. In this report, a higher weight is given to oblique slip [0.7] over reverse slip [0.3]. The currently preferred weighting is based on a reassessment of the regional seismotectonic setting that favors distributed dextral transpression in the south-central coastal California region (Lettis et al., 2009). In this tectonic model, strike-slip motion is transferred to the Hosgri fault zone and subparallel major strike-slip faults farther east (e.g., West Huasna and Rinconada faults) from the San Andreas fault across a broad left restraining bend or step-over (Section 3.1).

Dip

Estimated values for the average dip of the Los Osos fault zone vary between 30° and 75° southwest based on the assumed model for sense of slip in the LTSP Final Report (PG&E, 1988). The current logic tree defines the dip of the Los Osos fault zone source with branch values [and weights] of 75° [0.2], 60° [0.5] and 45° [0.3] southwest. The shallowest (30°) fault dip used in the LTSP Final Report (PG&E, 1988) is not supported by more recent studies that suggest the Los Osos fault is a more steeply dipping oblique-slip fault (Section 3.1).

Maximum Depth of Rupture

The LTSP Final Report (PG&E, 1988) considered the maximum depth of rupture for the Los Osos fault to be limited by the intersection depth of the Los Osos fault zone with the Hosgri fault zone. The intersection depth was dependent on the dip of both the Hosgri and Los Osos fault zones, and it was assumed that the Los Osos fault zone is truncated by the longer Hosgri fault zone. This geometric constraint warranted minor adjustments to the preferred values and weights for maximum depth of rupture assigned to the Hosgri fault zone. For simplicity in this report, however, the same maximum depth of faulting values and weights are adopted as were used for the Hosgri fault zone (Figure 5-9).

5.2.3 San Luis Bay Fault Logic Tree

From the onshore-offshore geologic mapping (Appendix B) and analysis of the Shoreline fault zone (Section 4), two rupture scenarios are considered for the San Luis Bay fault source. One rupture scenario treats the San Luis Bay fault zone as an independent source of earthquakes. The other rupture scenario considers the San Luis Bay fault zone to be kinematically linked to ruptures on the Shoreline fault zone, as discussed in Section 4.5. These alternatives are considered for the Shoreline fault logic tree on Figure 5-3, node 12. Figure 5-11 is the logic tree for the independent San Luis Bay fault source geometry, slip sense, and slip rate. When the Shoreline fault zone and East segment of the San Luis Bay fault zone are linked as part of a left-restraining bend in a longer system of right-lateral strike-slip and oblique-slip faults, Figure 5-11 is not needed; the appropriate characterization of the San Luis Bay fault source is provided on Figures 5-5 and 5-6. Source parameters shown on Figure 5-11 are unchanged from the LTSP Final Report (PG&E, 1988) with the following exceptions:

Total Fault Length

The San Luis Bay fault source had a maximum length of 19 km in the LTSP Final Report (PG&E, 1988). The maximum length was based on its western end terminating at the Hosgri fault source and the eastern end terminating near the Wilmar Avenue fault. This was not a preferred value in the LTSP logic tree, based on the lack of evidence supporting the westward extent at that time. In the independent San Luis Bay fault source model, the San Luis Bay fault source extends from point L1 at the Hosgri fault zone eastward to an assumed intersection with the San Miguelito fault zone near Mallagh Landing at point L6, for a total fault length of 16 km (node 1, Figure 5-11). In this scenario, the fault source crosses the Shoreline fault zone. The western part of the fault follows a distinct magnetic trend and possible south-side-down warp in the top of basement from the Shoreline fault zone to the Hosgri fault zone (Section 4.5 and Appendix B). This trend is consistent with the preferred interpretation of submerged marine terrace data, which suggests a permissible uplift rate boundary from the intersection of the Rattlesnake fault at the coast and continuing west toward the Hosgri fault zone (Sections 4.4 and 4.5 and Appendix I). The absence of a discrete lineament or mapped fault in the MBES bathymetry data suggests this structure is probably blind (Section 4.5) (Plate 1).

Maximum Depth of Rupture

Similar to the Los Osos fault zone source, the LTSP Final Report (PG&E, 1988) considered the maximum depth of rupture for the San Luis Bay fault source to be limited to the intersection depth of the San Luis Bay fault source with adjacent faults. The north-dipping San Luis Bay fault zone is considered a secondary fault to the southwest-dipping Los Osos fault zone source and the vertical to east-dipping Hosgri fault zone source, and thus is modeled as being truncated by these two fault sources. Given the distribution of dips for the Los Osos and Hosgri fault sources in the LTSP Final Report, there was a 0.4 probability that the San Luis Bay fault source was truncated at depths less than 7 km, and therefore not considered seismogenic. In this report, the steeper geometries for the Hosgri and Los Osos fault sources (Figures 5-9 and 5-10) result in greater potential depths for the San Luis Bay fault source. For simplicity, the same maximum depth of faulting values [and weights] are adopted as were used for the Hosgri and Los Osos fault sources (node 2, Figure 5-11).

Dip

The LTSP considered alternative dips for the San Luis Bay fault source of 70° north and 40° north with weights of 0.8 and 0.2, respectively (PG&E, 1988). Based on the current characterization of the San Luis Bay fault and its likely interaction with the Los Osos fault at depth beneath the Irish Hills, the slightly steeper branch values [and weights] of 50° north [0.2], 70° north [0.4], and 80° north [0.4] (node 3, Figure 5-11) are used.

Rupture Length

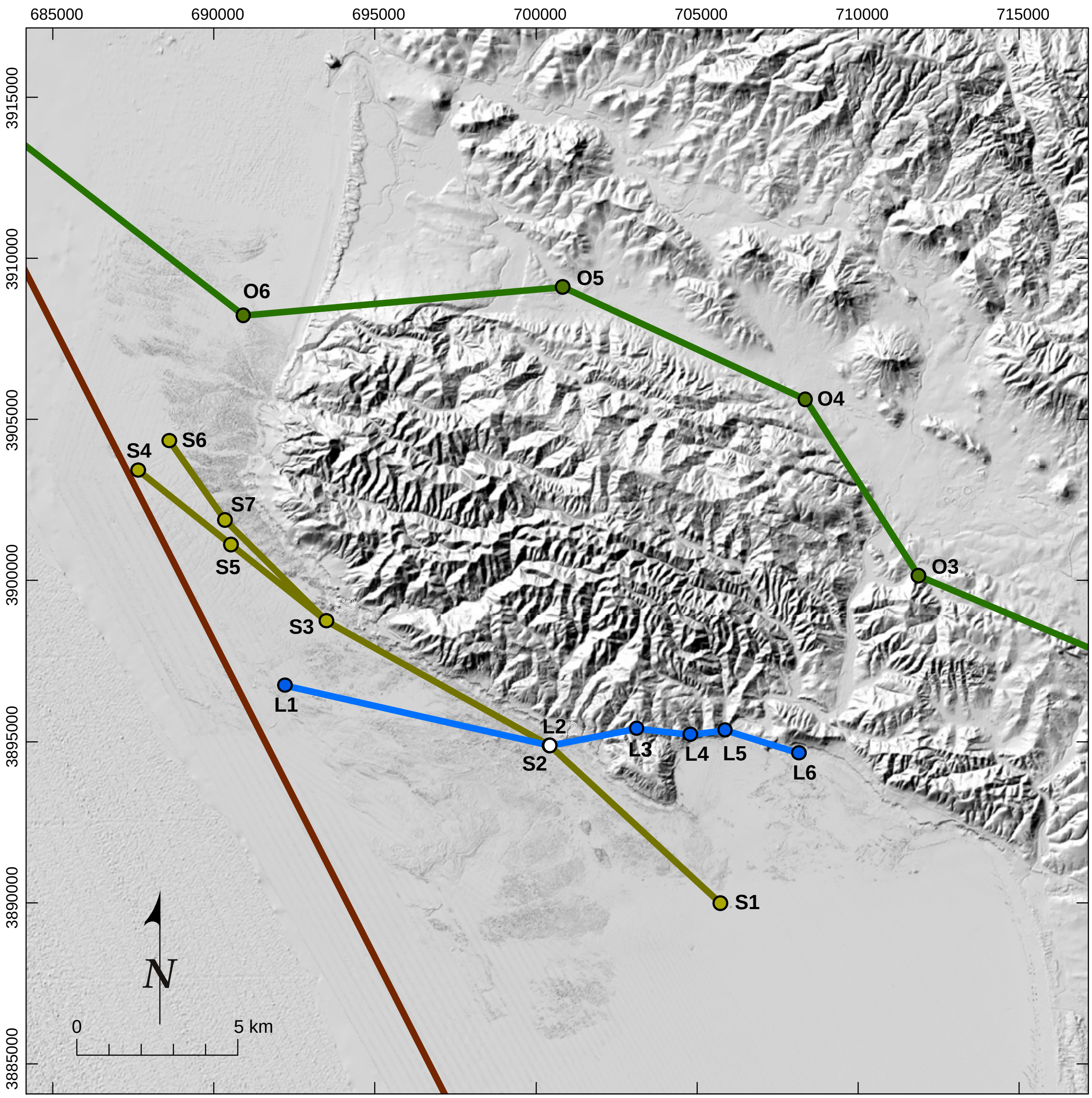
The LTSP considered alternative rupture lengths of 6, 8, and 12 km for the San Luis Bay fault source (PG&E, 1988). In this preliminary reassessment, two branch values are adopted: 8 km and 16 km for rupture length, weighted equally, consistent with rupture of separate West and East segments and rupture of the entire fault, respectively (node 4, Figure 5-11).

Sense of Slip

The LTSP Final Report (PG&E, 1988) gave a weight of 1.0 to a reverse sense of slip for the San Luis Bay fault source. In this report, equal weight is given to oblique and reverse mechanisms (node 5, Figure 5-11). The currently preferred weighting is based on a reassessment of the regional seismotectonic setting that favors distributed dextral transpression in the south-central coastal California region (Section 3).

Table 5-1. Coordinates for the Shoreline, San Luis Bay, Hosgri, and Los Osos Fault Sources

Fault Segment	Point (Long, Lat) (NAD 83)
Shoreline South	S1 (–120.742, 35.132) S2 (–120.799, 35.177)
Shoreline Central	S2 (–120.799, 35.177) S3 (–120.874, 35.213)
Shoreline North (N40W fault alternative)	S3 (–120.874, 35.213) S7 (–120.908, 35.242) S6 (–120.926, 35.264)
Shoreline North (S4 end point alternative)	S3 (–120.874, 35.213) S5 (–120.906, 35.235) S4 (–120.937, 35.256)
Shoreline North (S5 end point alternative	S3 (–120.874, 35.213) S5 (–120.906, 35.235)
Shoreline North (S3 end point alternative)	S3 (–120.874, 35.213)
San Luis Bay East	L2 (–120.799, 35.177) L3 (–120.769, 35.181) L4 (–120.751, 35.179) L5 (–120.739, 35.180) L6 (–120.714, 35.173)
San Luis Bay West	L1 (–120.889, 35.195) L2 (–120.799, 35.177)
Hosgri	H1 (–120.640, 34.670) H2 (–120.816, 35.044) H3 (–121.018, 35.386) H4 (–121.058, 35.440) H5 (–121.096, 35.496) H6 (–121.138, 35.553) H7 (–121.184, 35.618) H8 (–121.234, 35.618) H9 (–121.265, 35.694) H10 (–121.329, 35.739) H11 (–121.373, 35.772) H12 (–121.428, 35.822) H13 (–121.483, 35.865) H14 (–121.515, 35.913) H15 (–121.599, 35.977) H16 (–121.691, 36.041) H17 (–121.802, 36.122) H18 (–121.827, 36.122)
Los Osos	O1 (–120.459, 35.127) O2 (–120.523, 35.167) O3 (–120.672, 35.222) O4 (–120.709, 35.272) O5 (–120.791, 35.305) O6 (–120.900, 35.299) O7 (–120.995, 35.362)



Note: Coordinates of fault sources are in Table 5-1

Legend

Seismic Sources

S1 — S2	Shoreline
L1 — L2	San Luis Bay
O1 — O2	Los Osos
	Hosgri

Seismic source model map traces of Shoreline, San Luis Bay, and Los Osos fault sources

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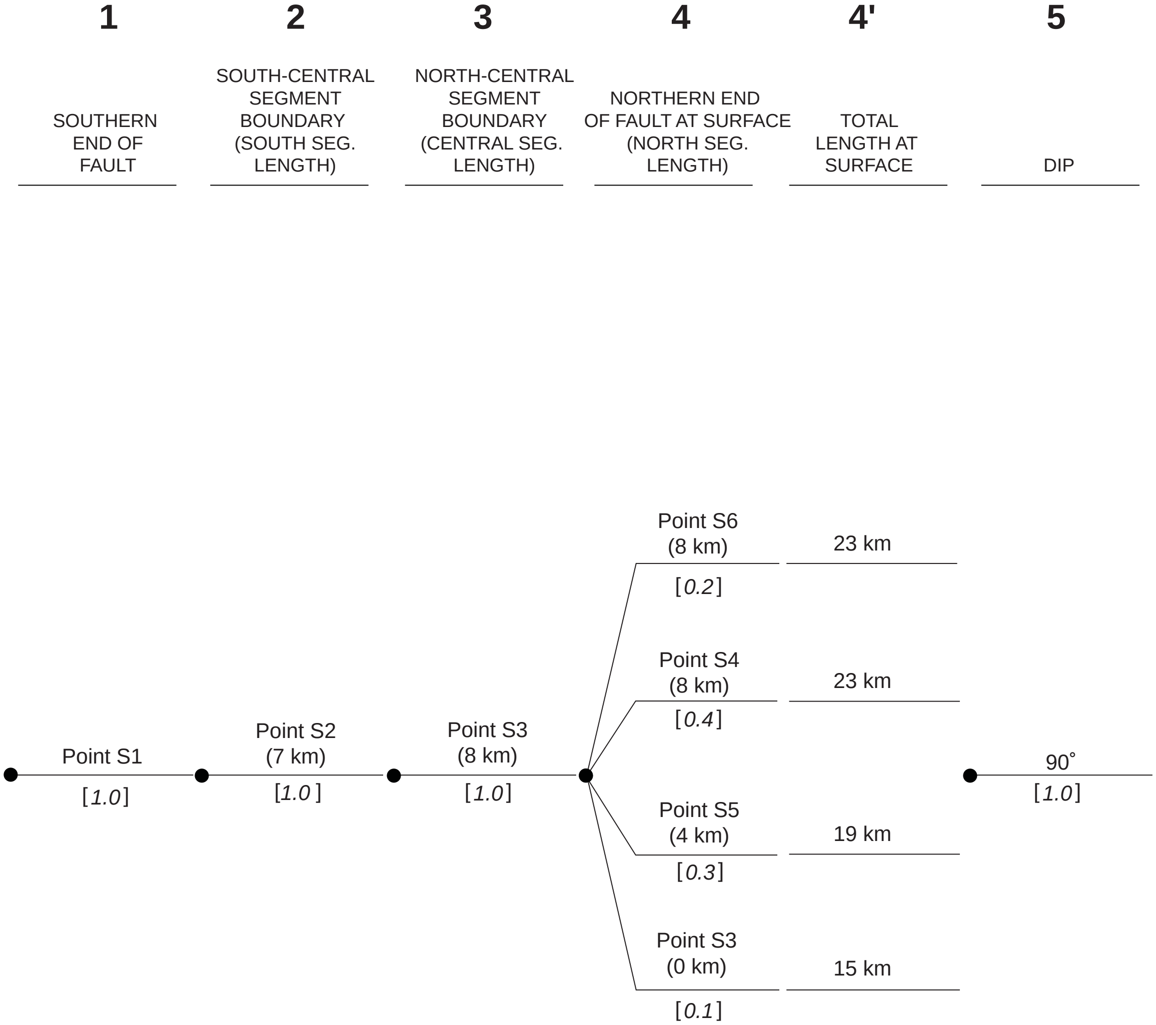
Figure **5-1**



Note: Points S1 to S6 are located on Figure 5-1.

Shoreline fault logic tree nodes 1 to 5

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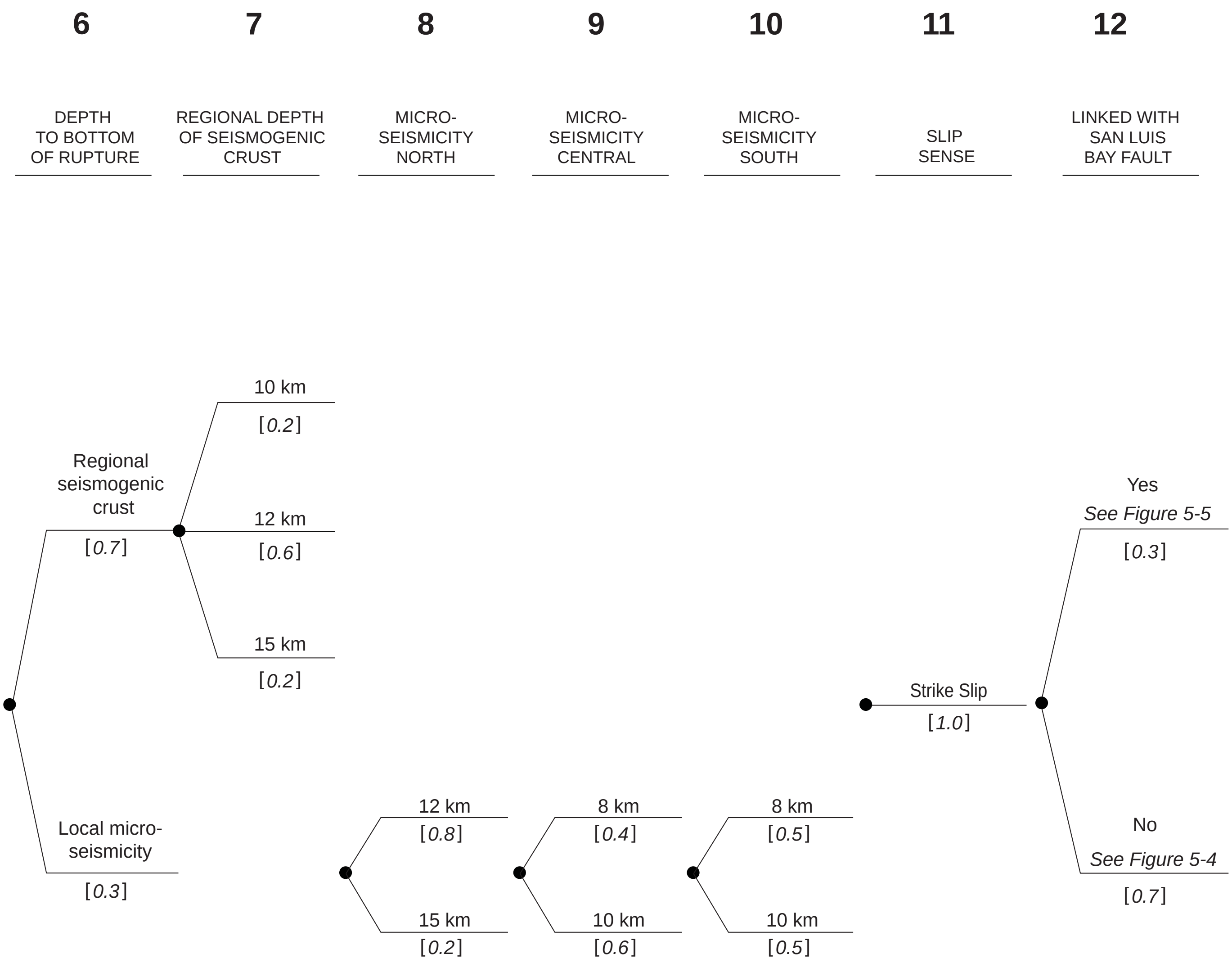
Figure **5-2**



Notes:
(1) Top of seismogenic crust is assumed to be 0 km depth.
(2) The bottom and northern edge of the Shoreline fault source is truncated by the east-dipping Hosgri fault zone source where they intersect within the seismogenic crust.

Shoreline fault logic tree nodes 6 to 12

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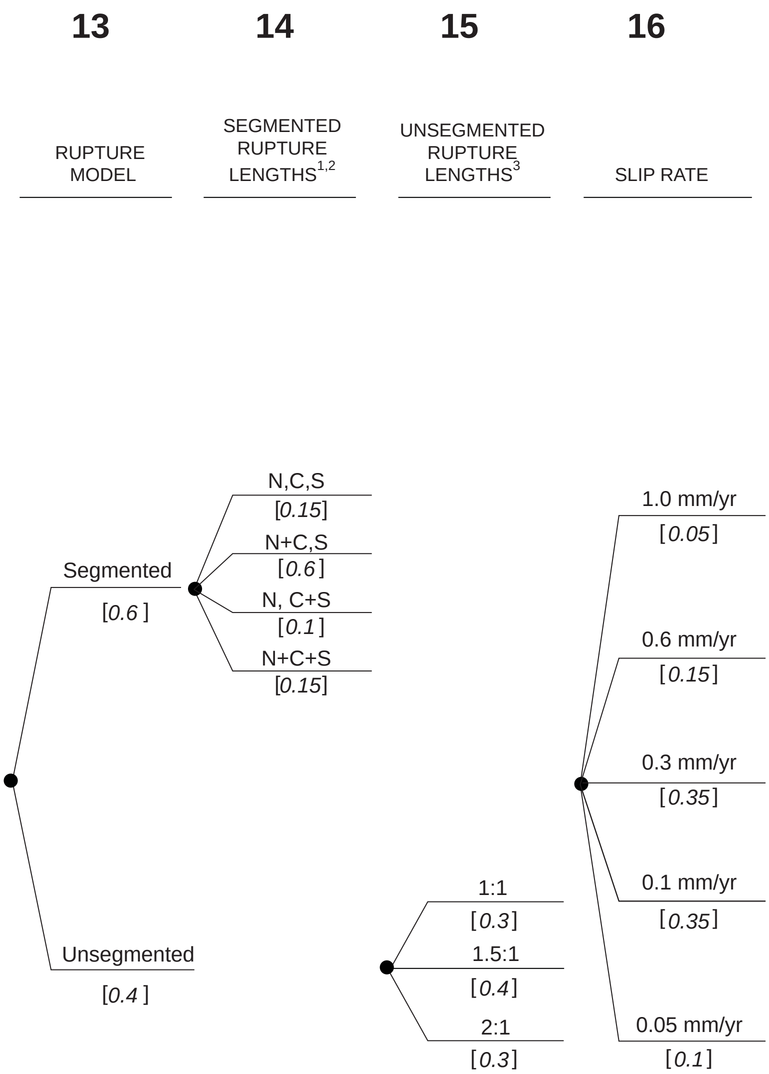

Notes:

(1) N=North Segment, C=Central Segment, S=South Segment.

(2) Under node 4 branch where northern end of fault is at Point S3, the North (N) segment does not exist, and the branches consolidate into C,S and C+S alternatives.

(3) Aspect Ratio expressed as Length:Width, with Width determined by nodes 5 to 11, and Length limited to be less than or equal to the total fault length as determined by nodes 1 to 4.

Shoreline fault logic tree not linked to San Luis Bay fault branch nodes 13 to 16

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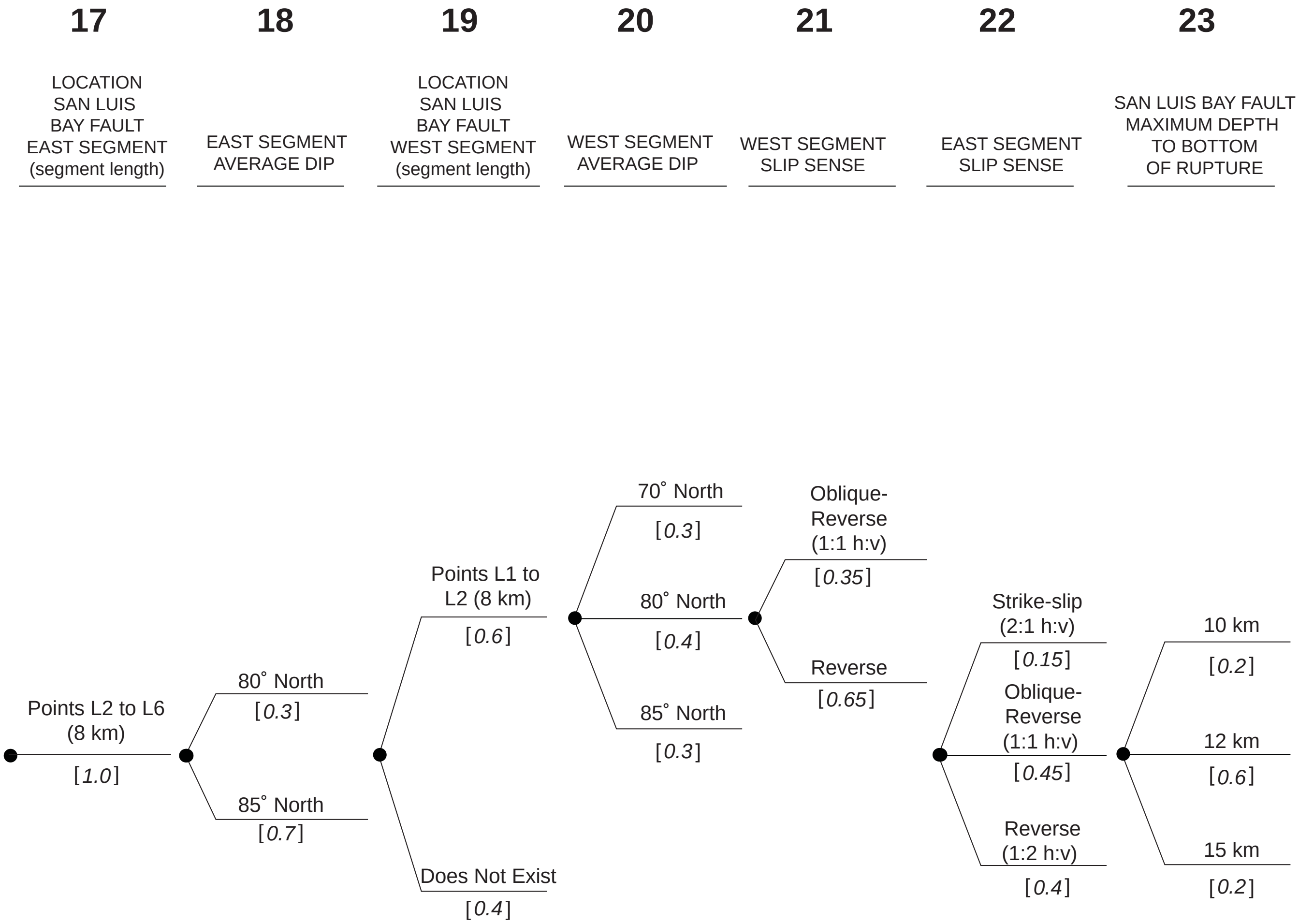
Figure **5-4**



Notes:
(1) Points L1 to L6 are located on Figure 5.1.
(2) The bottom and edges of the San Luis Bay fault West segment source are truncated by the east-dipping Hosgri fault zone source and the vertical Shoreline fault source where they intersect within the seismogenic crust.
(3) The bottom of the San Luis Bay fault East segment source is truncated by the south-dipping Los Osos fault zone source where they intersect within the seismogenic crust.

Shoreline fault logic tree linked with San Luis Bay fault branch nodes 17 to 23

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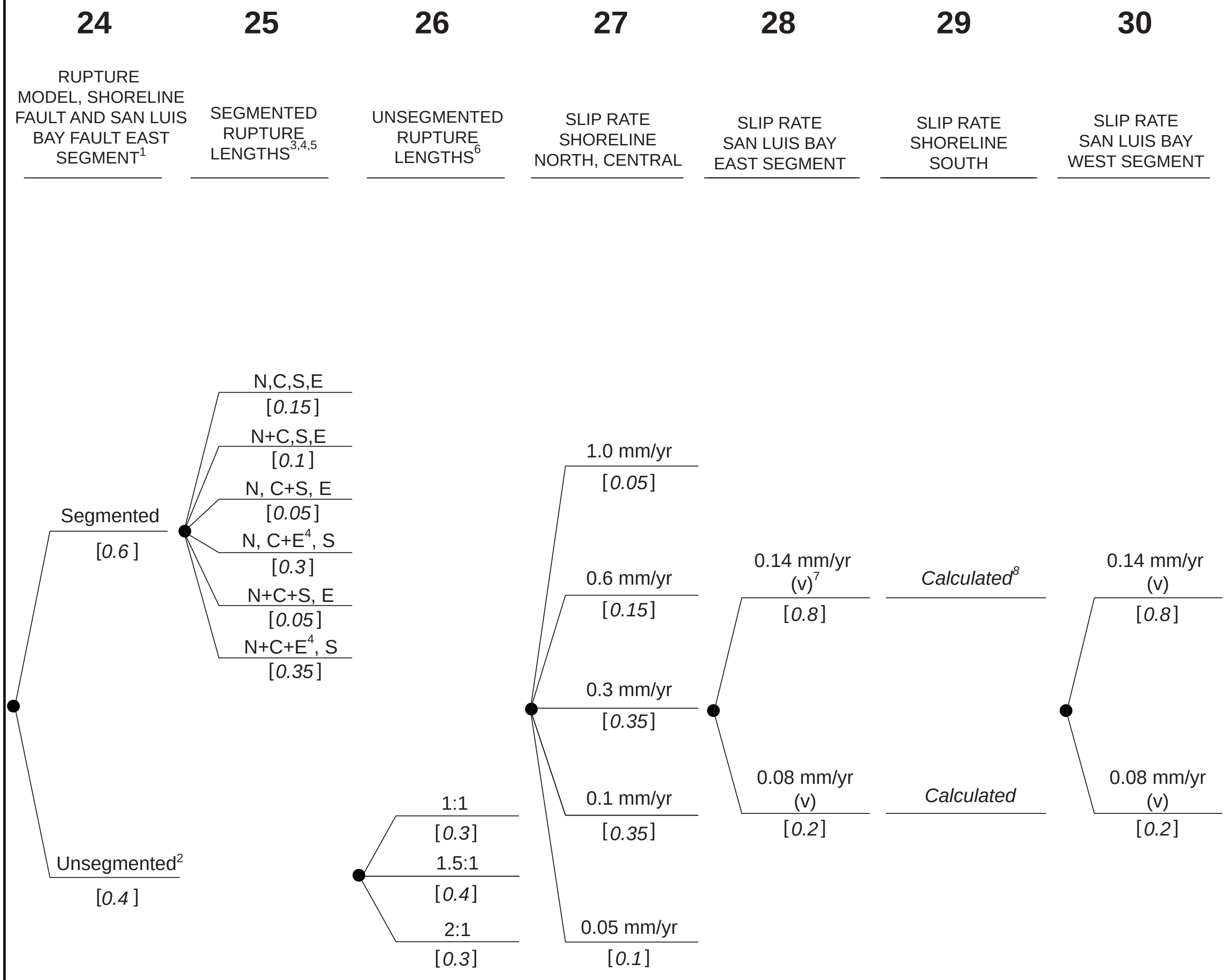
Figure **5-5**



Notes:

(1) Both rupture model branches consider San Luis Bay fault West segment a separate fault that does not rupture with Shoreline or San Luis Bay fault East segment sources.

(2) Unsegmented ruptures do not linclude simultaneous rupture of Shoreline fault South segment and San Luis Bay fault.

(3) N=Northern Segment, C=Central Segment, S=South Segment, E=East Segment (San Luis Bay fault).

(4) For segmented ruptures where Central and East segments rupture together, the east end of the rupture may occur at Point L3, L5, or L6 and each is given 1/3 weight (Figure 5-1).

(5) Under node 4 branch where northern end of fault is at Point S3, the N segment does not exist, and the branches consolidate.

(6) Aspect Ratio expressed as Length:Width, with Length limited to be less than or equal to the total fault length.

(7) (v) = vertical component of slip rate. Fault slip rate calculated based on dip and slip sense nodes.

(8) Shoreline South slip rate calculated as North+Central slip rate minus San Luis Bay East slip rate, with a minimum rate of 0.05.

Shoreline fault logic tree linked with San Luis Bay fault branch nodes 24 to 30

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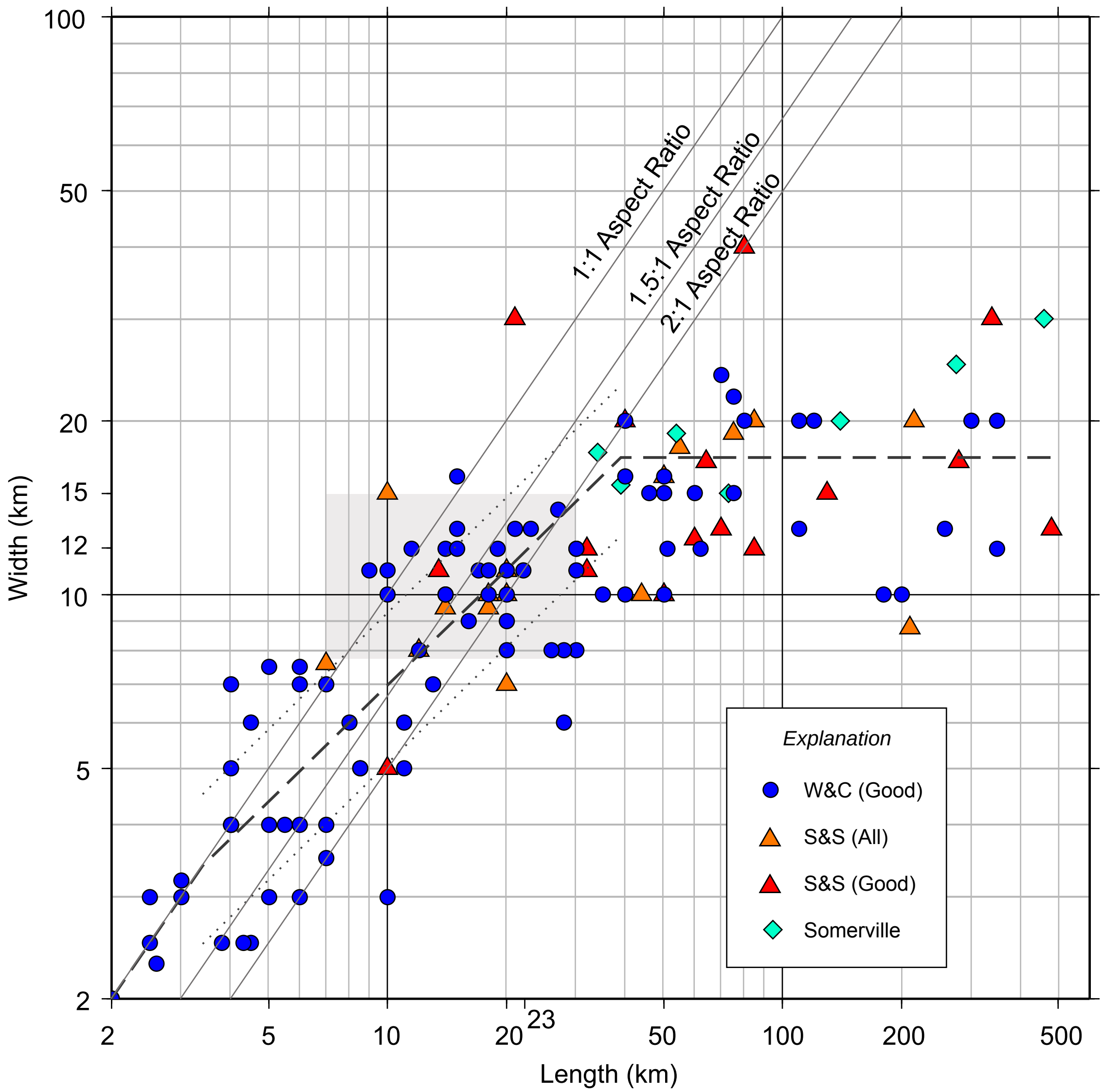

Modified from Leonard (2010), Figure 2

Notes from figure captions in Leonard (2010), Figures 1 and 2:
The length versus width data for strike-slip interplate earthquakes. As these faults become width-limited there is a narrow (5-50 km) range of the data that allows a large number of equally valid relations to fit the data. In the 50-km range a slope of 2:3 is assumed from the findings of the dip-slip data. The three gray dashed lines are from 0.5 km to 4 km with a slope of 1, from 4 km to 45 km length with a slope of 2:3, and a constant width of 17 km at lengths above 45 km. The gray dotted lines are the ±1σ uncertainties. The catalogs are W&C for Wells and Coppersmith (1994), S&S for Shaw and Scholz (2001) in Manighetti et al. (2007), and Somerville is Somerville et al. (1999).

Empirical rupture length versus width data for strike-slip earthquakes from Leonard (2010)

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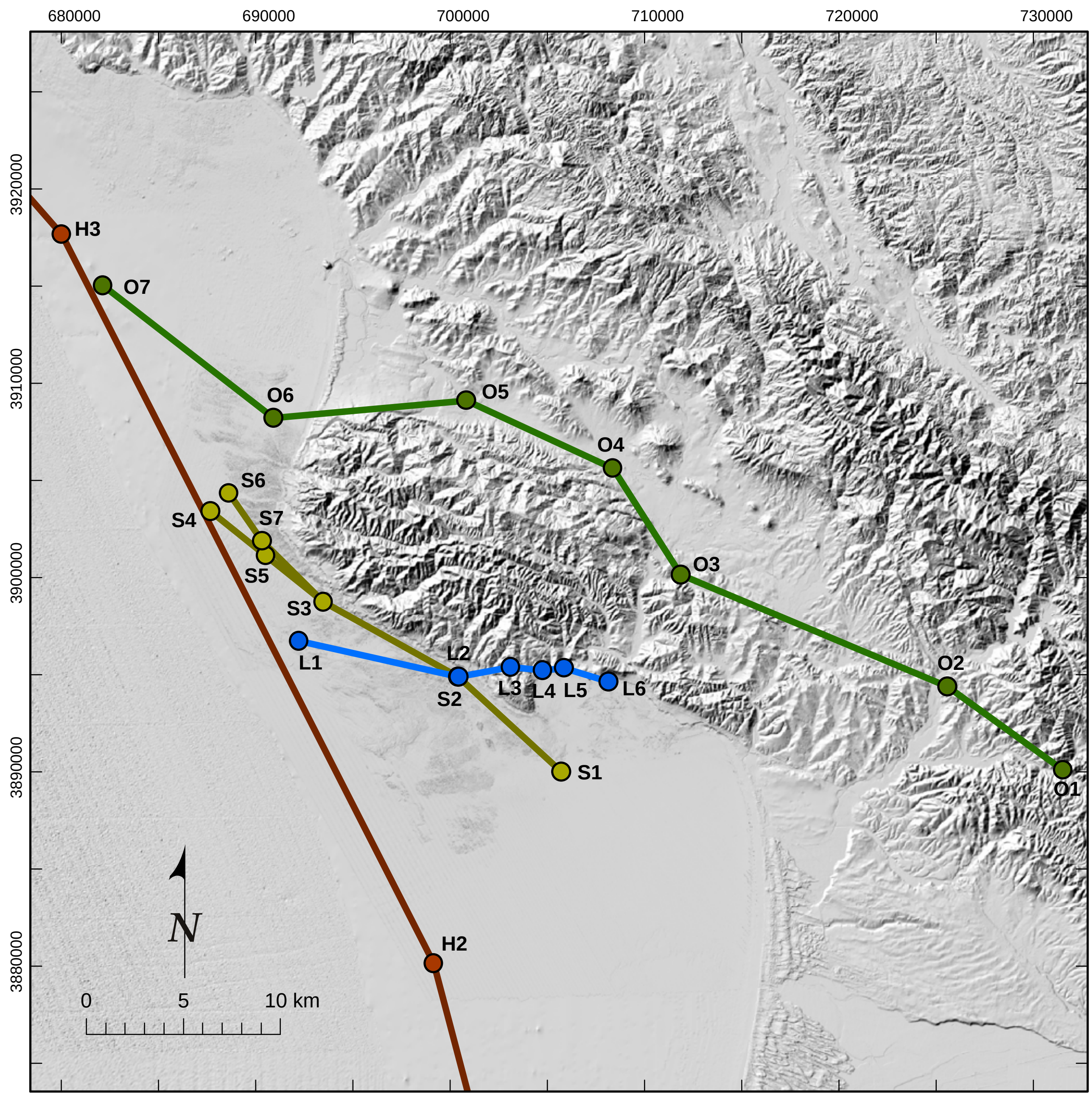
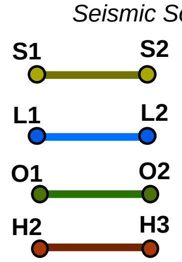
Pacific Gas and Electric Company | Figure **5-7**



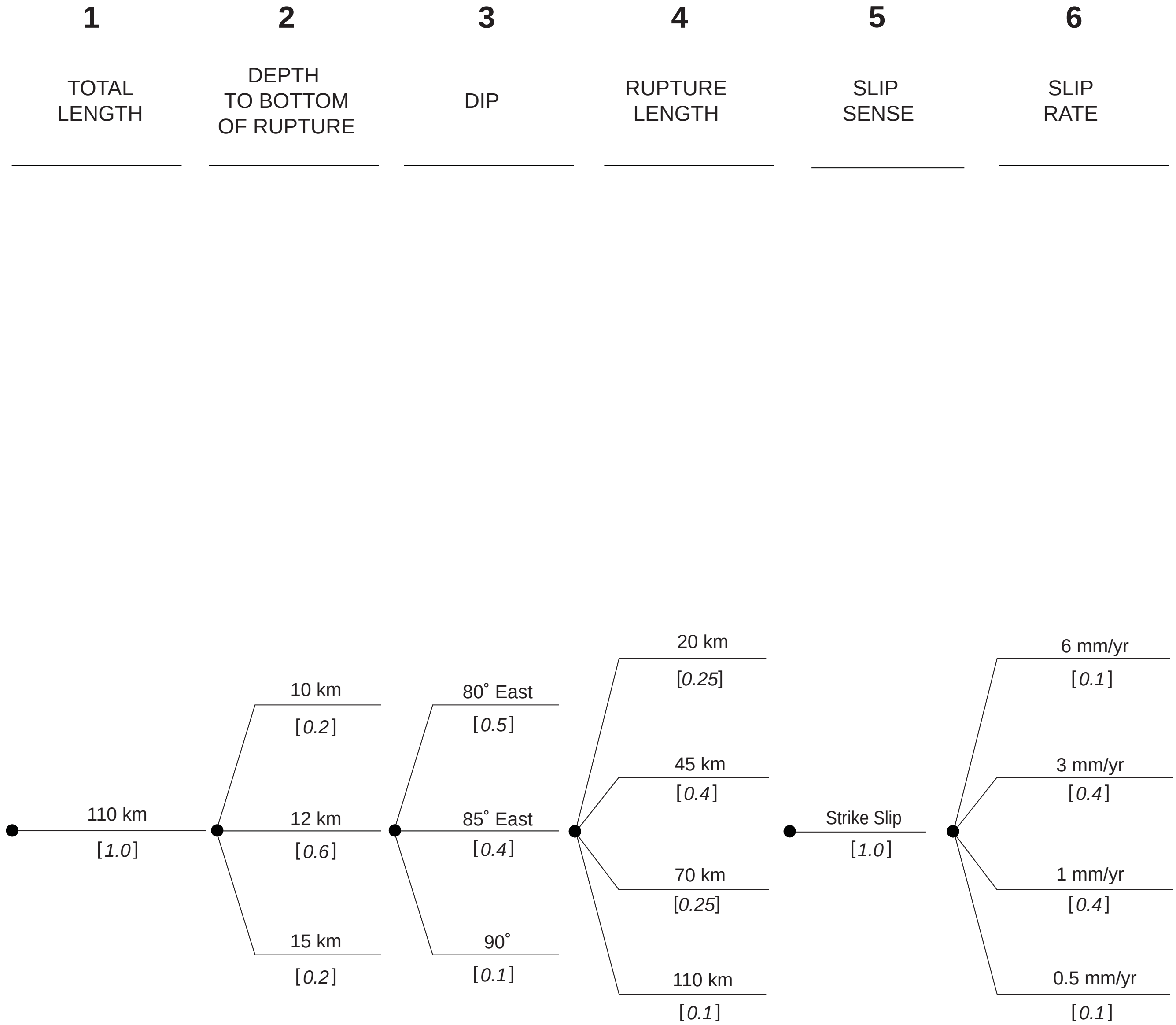
Note: Coordinates of fault sources are in Table 5-1



Seismic source model map traces of Hosgri, Los Osos, San Luis Bay, and Shoreline fault sources

SHORELINE FAULT ZONE STUDY

Pacific Gas and Electric Company | Figure **5-8**



Hosgri fault zone logic tree modified from LTSP Final Report (PG&E, 1988)

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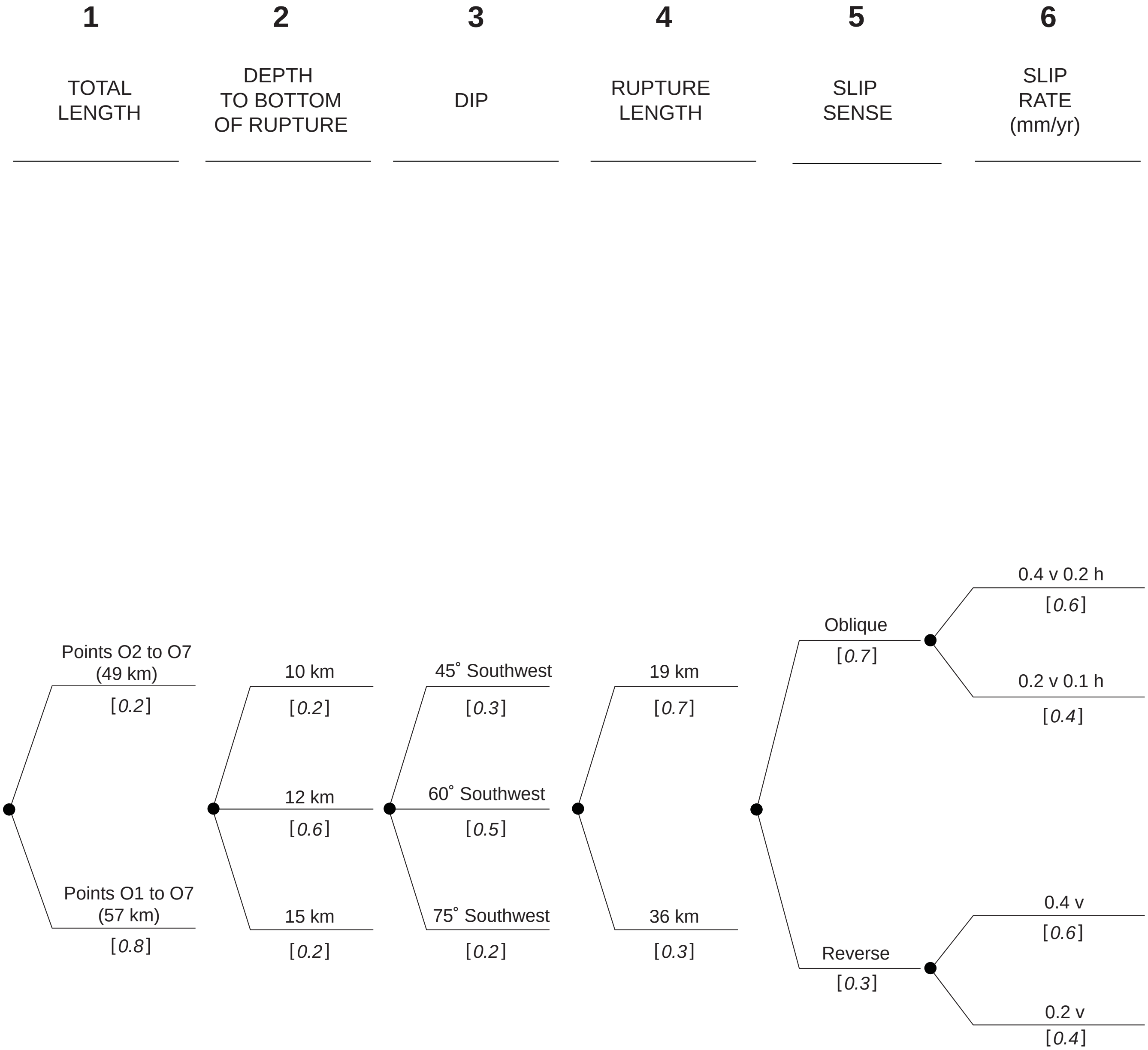
Figure 5-9

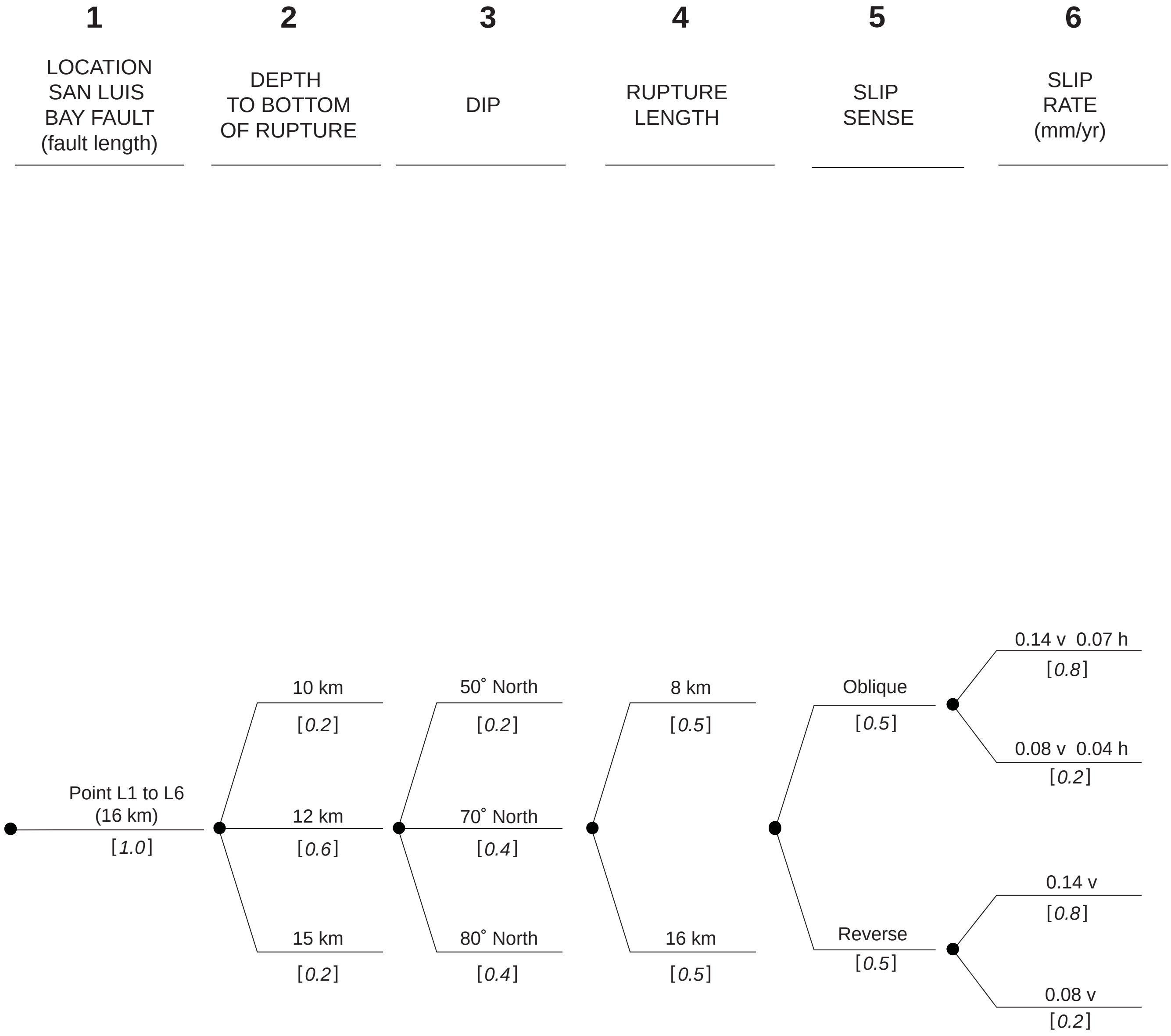


Notes:
(1) Points O1 to O7 are shown in Figure 5-8.
(2) The western margin of the Los Osos fault source is truncated by the east-dipping Hosgri fault zone source where they intersect within the seismogenic crust.
(3) h = horizontal component of slip rate
v = vertical component of slip rate

Los Osos fault zone logic tree modified from LTSP Final Report (PG&E, 1988)

SHORELINE FAULT ZONE STUDY

Pacific Gas and Electric Company | Figure **5-10**



Notes:
(1) This logic tree is valid in conjunction with the Shoreline fault logic tree branch where Shoreline and San Luis Bay faults are independent structures (node 6, Figure 5-3).
(2) Points L1 to L6 are located on Figure 5.1.
(3) The bottom and western edge of the San Luis Bay fault source is truncated by the east-dipping Hosgri fault zone source and the south-dipping Los Osos fault source where they intersect within the seismogenic crust.
(4) v = vertical component of slip; h = horizontal component of slip.

San Luis Bay fault zone logic tree modified from LTSP Final Report (PG&E, 1988)

SHORELINE FAULT ZONE STUDY

Pacific Gas and Electric Company | Figure **5-11**