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Reference Rock Site Condition for Central and Eastern North America

NGA East Geotechnical Working Group

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Outline

- Reference rock site condition
 - Definition
 - Importance for seismic hazard
- Existing recommendation
- Reference velocity
 - Defining reference velocity
 - Evaluation of collected data
 - Recommendation
- Reference local attenuation
 - Published models
 - Recommendation
- Conclusions

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Reference Rock Site Condition

- Defined by:
 - Shear-wave velocity (V_s)
 - Compression-wave velocity (V_p)
 - Local attenuation ($\kappa_{0,ref}$)
 - Unit weight
- Appropriate for the Central and Eastern North America (stable continental)

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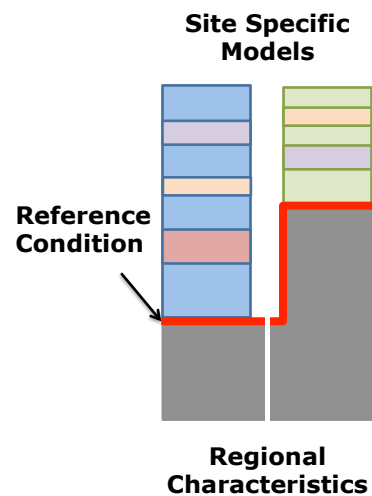
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Importance of Reference Condition

- Present in all velocity profiles in the region
- Interface between regional and site-specific models
- The reference condition for amplification models



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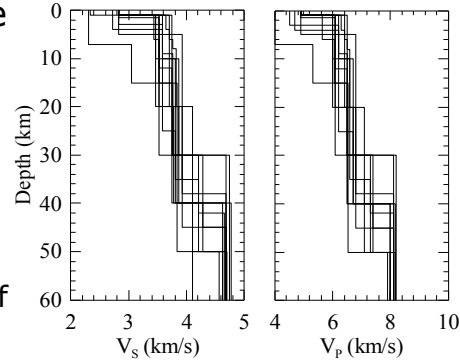
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Existing $V_{s,ref}$ Recommendation

- EPRI (1993) study is the basis of current values
 - $V_{s,ref}$ of 2.83 km/sec (9,200 ft/sec)
 - Based on 16 crustal structure regions
 - V_s values computed from V_p inversions and an assumed Poisson's ratio of 0.25
- Published GMPEs use 2.00 to 2.88 km/sec
 - Based on simulations
 - $V_{s,ref}$ values based on top of assumed crustal profile



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Existing $\kappa_{0,ref}$ Recommendation

- EPRI (1993) reported a median $\kappa_{0,ref}$ of 0.006 sec and initially proposed a σ_{ln} of 0.40.
- EPRI (1993) and Toro *et al.* (1997) used equally weighted values 0.0003, 0.006, and 0.012 sec

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Collection of Velocity Data

- V_s and V_p measurements that penetrate hard-rock were collected
 - Journal publications and technical reports
 - Nuclear power plant applications
- Located 283 profiles in study region
 - 68 $V_{s,ref}$ values at 27 different locations
 - 60 $V_{p,ref}$ values at 22 different locations

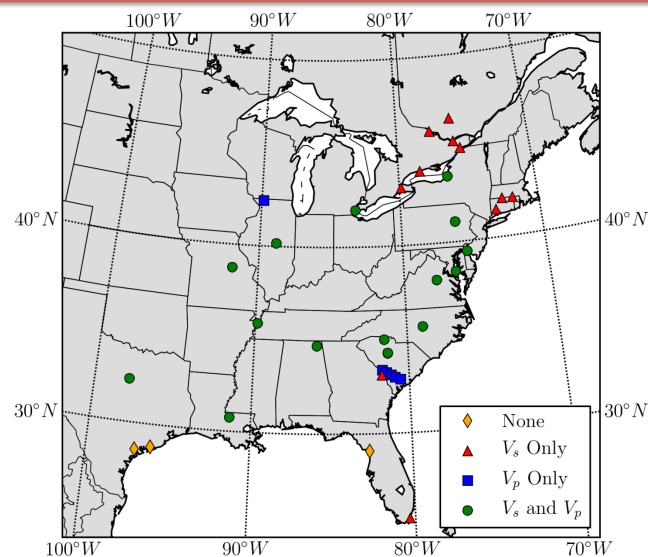
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Locations of Collected Data



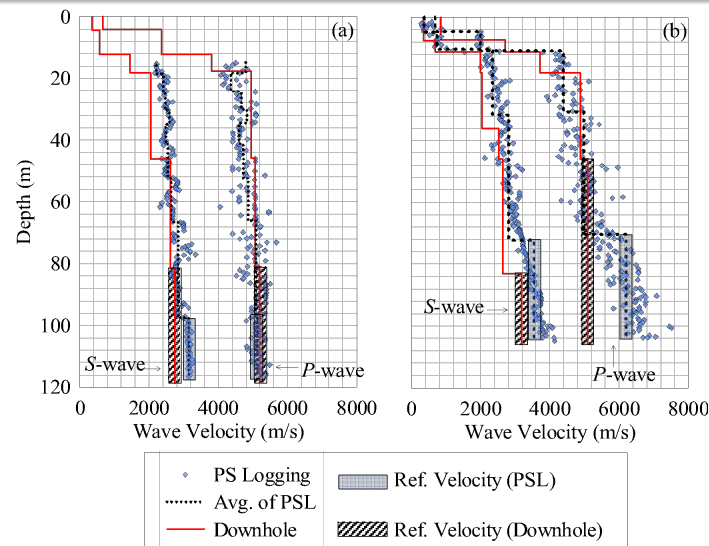
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Example Velocity Profile



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Definition of Reference Velocity

- Based on characteristics of collected velocity profiles
- Typical profiles transition from soil to weathered rock to intact rock
- Established a criteria based on:
 1. Velocity
 2. Measurement penetration
 3. Velocity gradient
 4. Geologic age

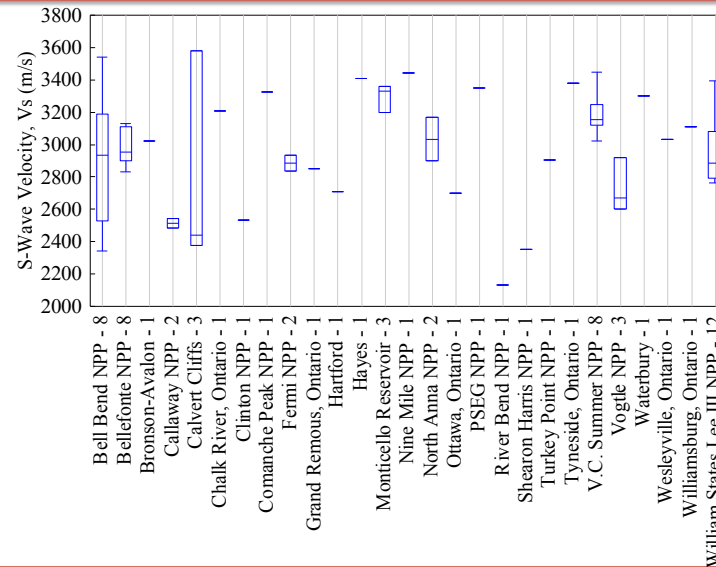
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Reference V_s Measurements



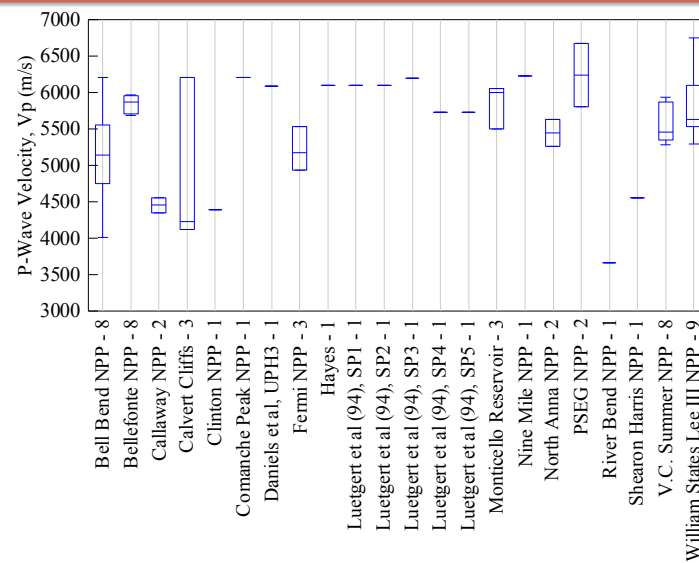
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Reference V_p Measurements



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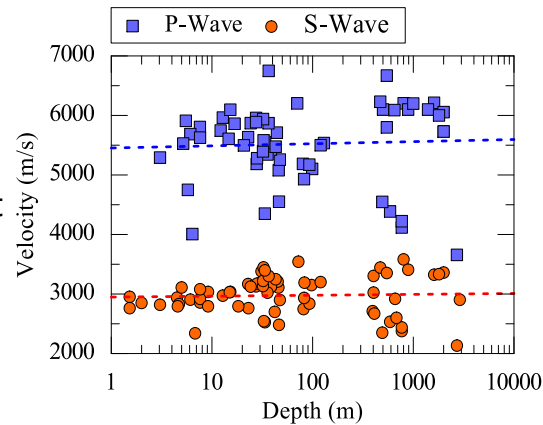
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Trend with Depth

- Compared selected reference velocities with depth
- Potential to select higher velocities at greater depth (bias)
- Part of the QA process
- No trend observed



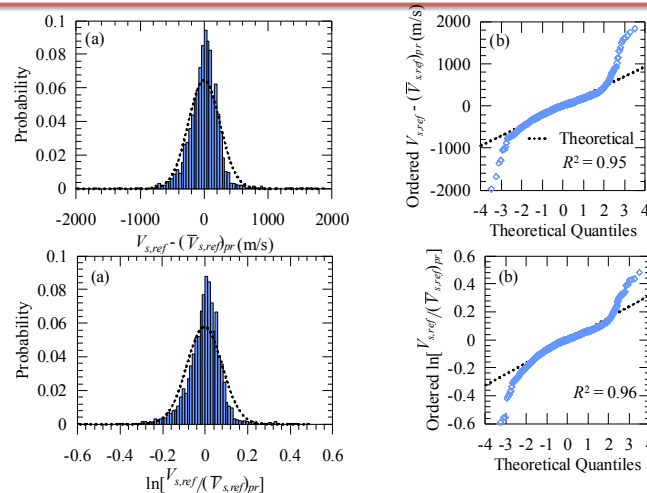
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Within-Profile $V_{s,ref}$ Distribution



Comparing assumed normal and log-normal distributions indicated that velocities tended to be normally distributed

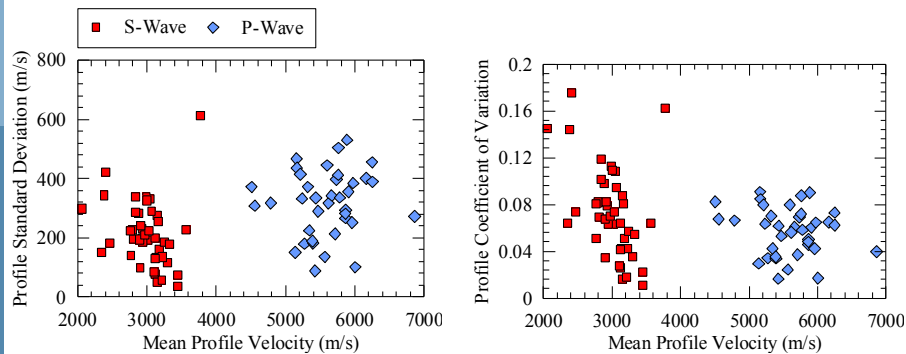
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Characterizing the Uncertainty



The observed trend in the standard deviation with mean profile velocity is removed by characterizing the uncertainty using the coefficient of variation (standard deviation / mean)

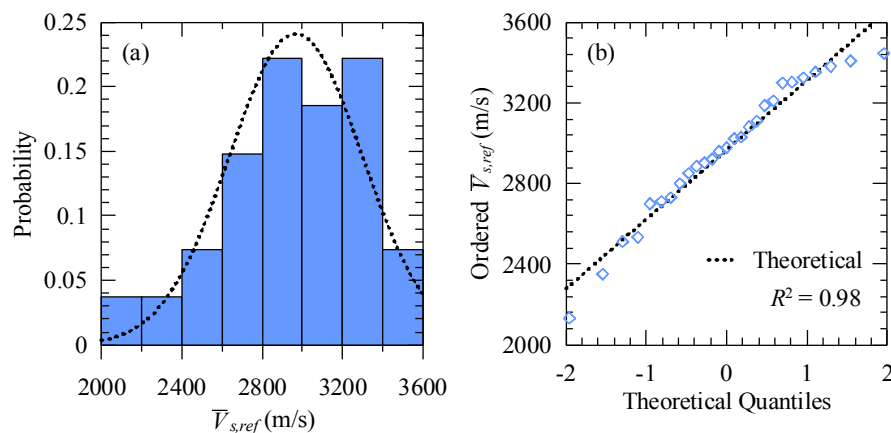
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Within-Region $V_{s,ref}$ Distribution



Distribution of mean values from each location indicate a slightly skewed distribution that can be approximated by a normal distribution.

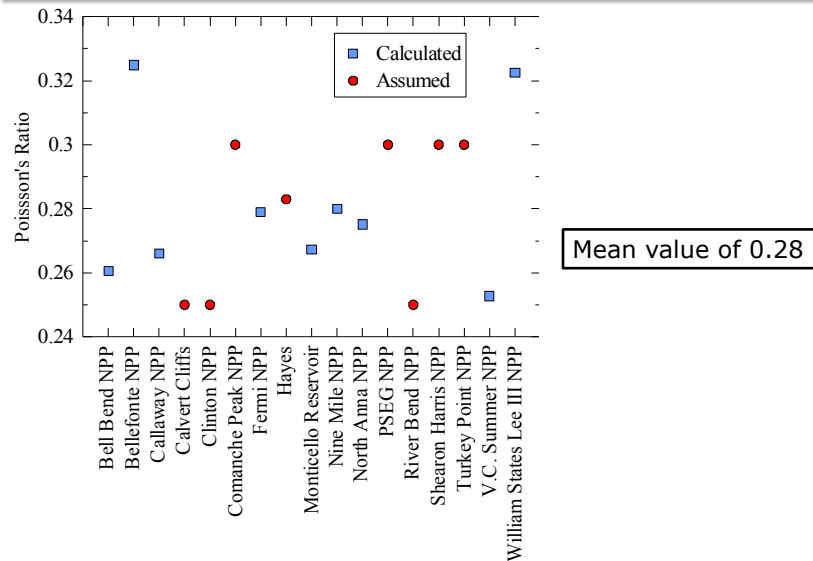
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Poisson's Ratio



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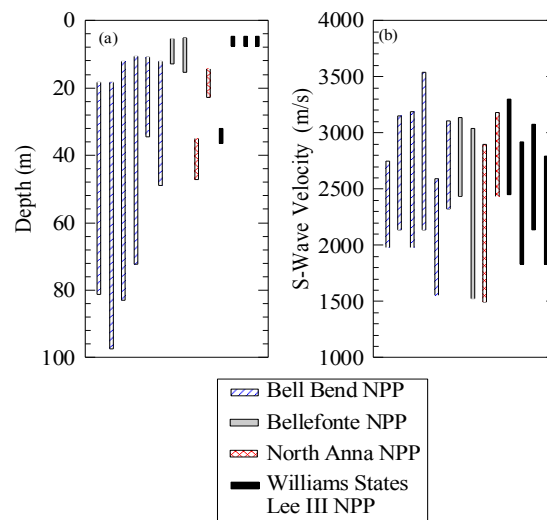
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Weathered Zone

- Collected information on the weathered rock
- Clearly observed at four locations
- Identified:
 - Thickness
 - Velocity range



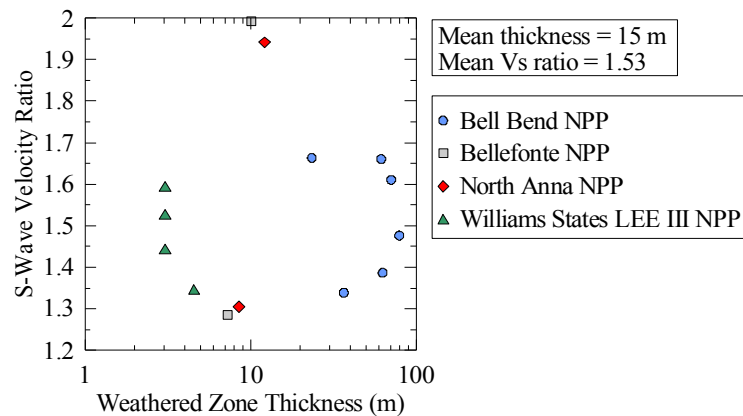
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Weathered Zone Properties



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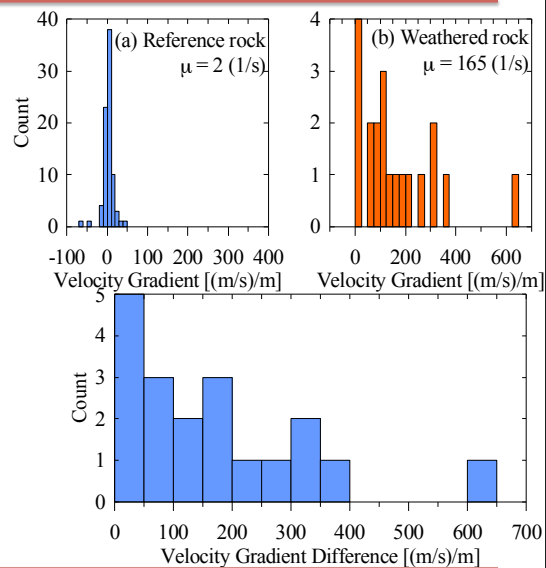
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Velocity Gradient

- Defined by increase in velocity with depth
- Mean gradient:
 - Reference rock 2 per sec
 - Weathered rock 165 per sec



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Range of $V_{s,ref}$

- Collected data indicate $V_{s,ref}$ varies between locations
- Two potential methods define the range:
 - Statistics:
 - 95% confidence interval: 2.12 to 3.78 km/sec
 - Influence of $V_{s,ref}$ range on the ground motion?
 - Amplification
 - Specify range using 5% difference in amplification
 - Amplification estimated by $\sqrt{V_{\downarrow 1} / V_{\downarrow 2}}$
 - 2.7 to 3.3 km/sec

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Recommended Reference Velocity

	Best Estimate	Range
$V_{s,ref}$	3.0 km/sec	2.7 - 3.3 km/sec
$V_{p,ref}$	5.5 km/sec	5.0 - 6.1 km/sec

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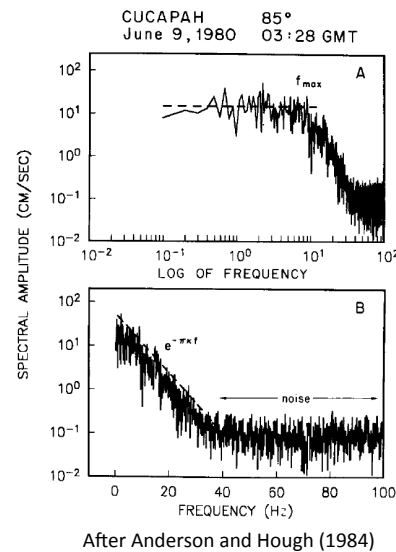
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Reference Local Attenuation ($K_{0,ref}$)

- Local attenuation parameter $K_{0,ref}$ characterizes high-frequency attenuation
- Defined from high-frequency characteristics of recorded ground motions
- Interpreted as damping due to near-site effects (additional to Q)



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Sources Considered

- Existing studies used:

Anderson (91)	Edwards (12)
Atkinson (84)	Hough et al. (88)
Atkinson (96)	Silva and Darragh (95)
Atkinson and Boore (06)	Silva et al. (88)
Campbell (09)	Silva et al. (99)
Chandler et al. (06)	Toro and McGuire (87)
Chapman et al. (03)	Van Houtte et al. (11)

- Use recorded CENA ground motions

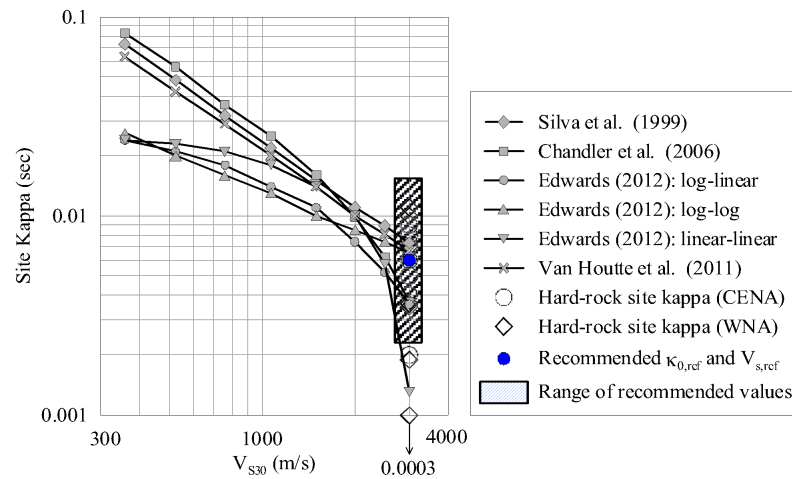
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Local Attenuation Models



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Recommended local attenuation

Distribution Parameter	Value
Type of Distribution	Lognormal
Median, $\kappa_{0,ref}$ (sec)	0.006
Aleatory Standard Deviation, $\phi_{\ln \kappa_{0,ref}}$ (sec)	0.43
Epistemic Standard Deviation, $\epsilon_{\ln \kappa_{0,ref}}$ (sec)	
Excluding source, path, and site uncertainty	0.12
Including source, path, and site uncertainty	0.20
Total Standard Deviation, $\sigma_{\ln \kappa_{0,ref}} = \sqrt{\phi_{\ln \kappa_{0,ref}}^2 + \epsilon_{\ln \kappa_{0,ref}}^2}$	
Excluding source, path, and site uncertainty	0.45
Including source, path, and site uncertainty	0.47
Coefficient of Variation ($COV = \sqrt{\exp(\sigma^2) - 1}$)	
Aleatory variability	0.45
Epistemic uncertainty	
Excluding source, path, and site uncertainty	0.47
Including source, path, and site uncertainty	0.50
95 th Confidence Interval; $\pm 2\sigma$ Range (sec)	
Excluding source, path, and site uncertainty	0.0024 – 0.0148
Including source, path, and site uncertainty	0.0023 – 0.0154

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Conclusions

- Reference rock velocity
 - $V_{s,ref} = 3,000 \text{ m/s}$ (2,700 -3,300 m/s)
 - $V_{p,ref} = 5,500 \text{ m/s}$ (5,000 -6,100 m/s)
- Local attenuation
 - $K_{0,ref} = 0.006 \text{ sec}$
 - Log-normal distribution
 - Log standard deviation = 0.43
 - Recorded motions will be incorporated once they become available

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