# Methodology for Site Classification in TS 1170.5

An overview of the recommended methodology for site classification (details are not covered)

**OUTLINE**

1) Proposed site classes
2) Typical design spectra for different site classes
3) Methods for evaluation of $V_{s(30)}$ (principal site-classification parameter)
4) Uncertainty in $V_{s(30)}$ estimates (and implications)
5) Additional criteria for site classification
6) Site classification procedure (examples)

# The Role of Site Classification in Seismic Loading Standards

To incorporate site effects in design spectra,

in a comprehensive but simplified manner *(practical for application)*

- Organise site (ground) conditions into site classes
- Conditions within one site class produce similar response spectra
- Each site class has distinct set of design spectra
- Use small number of site classes *(to simplify application)* → 7 site classes
- Site classes collectively represent all relevant site conditions

Use few site parameters to achieve the above → $V_{s(30)}$

# Proposed Site Classes in TS 1170.5

$V_{s(30)}$ – principal parameter for site classification *(but not the only parameter used)*

$V_{s(30)}$ = time-averaged shear wave velocity from the ground surface to 30 m depth

| Site Class | Description | $V_{s(30)}$ range | Characteristic $V_{s(30)}$ value |
|---|---|---|---|
| I | Rock site | $V_{s(30)} > 750$ m/s | 750 m/s |
| II | Very stiff soil, very dense soil or soft rock | $450 < V_{s(30)} \leq 750$ m/s | 525 m/s |
| III | Stiff or dense soil | $300 < V_{s(30)} \leq 450$ m/s | 375 m/s |
| IV | Moderately stiff or medium dense soil | $250 < V_{s(30)} \leq 300$ m/s | 275 m/s |
| V | Soft or loose soil | $200 < V_{s(30)} \leq 250$ m/s | 225 m/s |
| VI | Very soft or very loose soil | $150 < V_{s(30)} \leq 200$ m/s | 175 m/s |
| VII | **Very soft or very loose soil** | **$V_{s(30)} \leq 150$ m/s** | - |

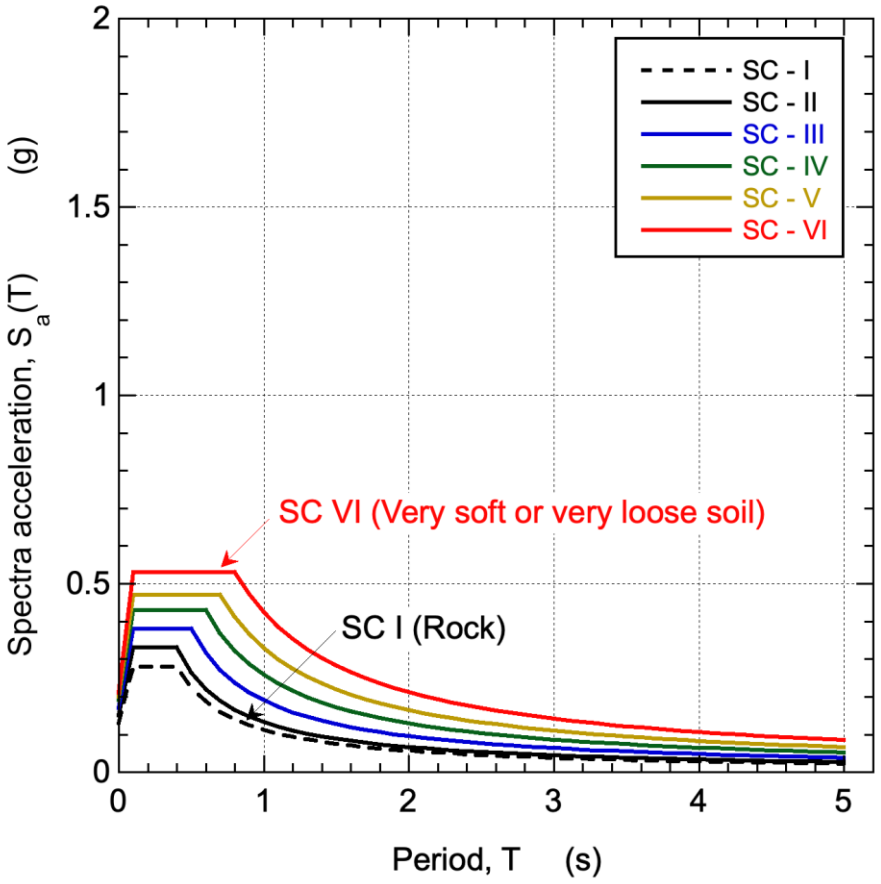
Design spectra

*Special considerations*

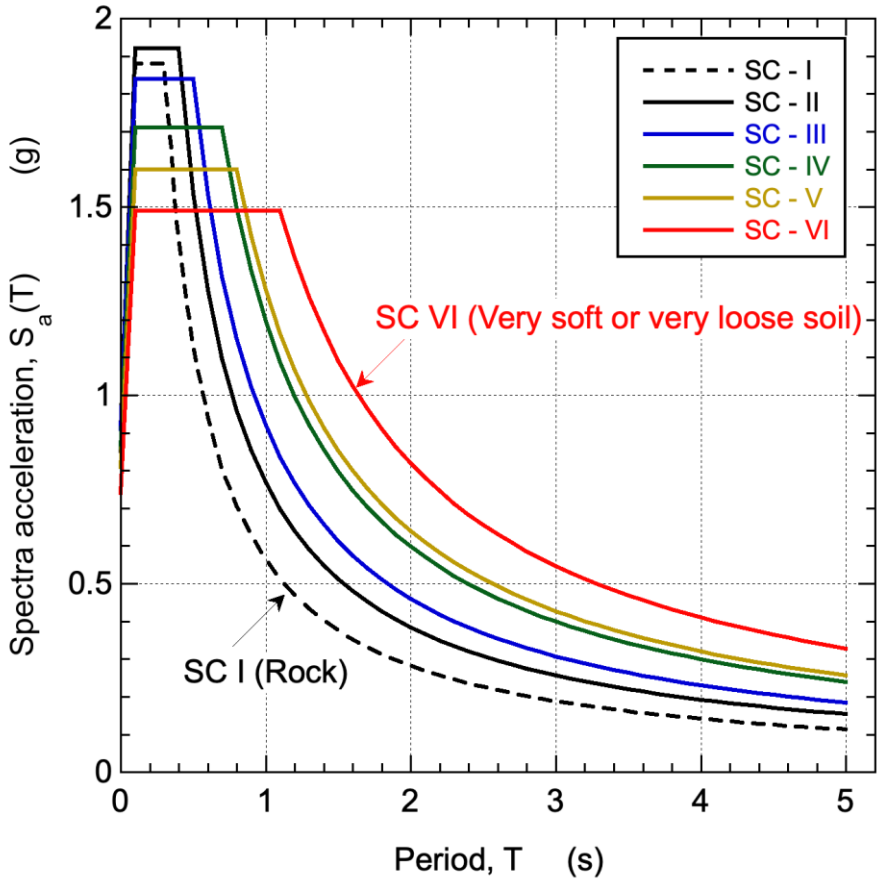
*Site response analysis*

# Design Spectra for Site Classes I to VI

*Low shaking intensity*



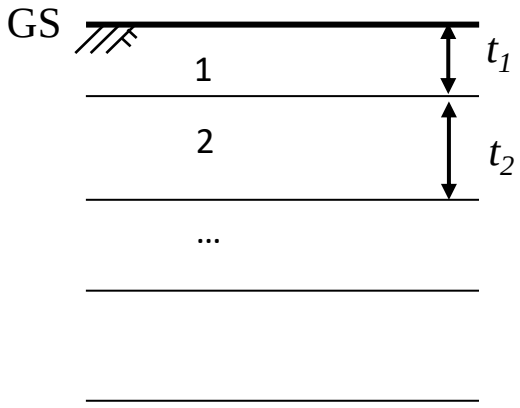

*High shaking intensity*

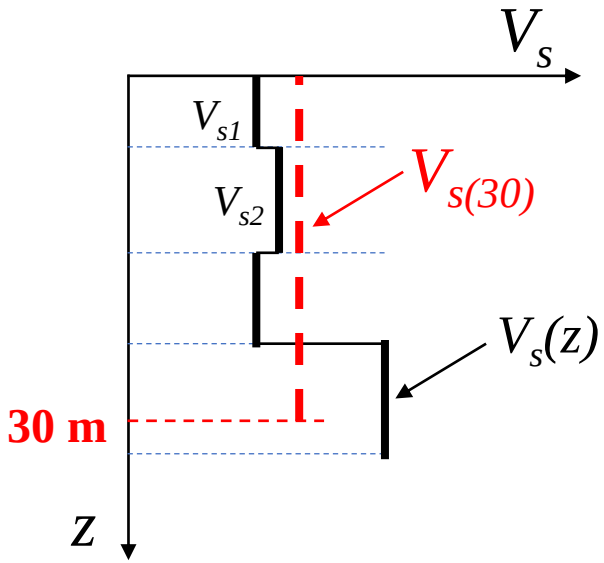



Smooth and gradual transition of the elastic spectra across different site classes

# Calculation of $V_{s(30)}$

$V_{s(30)}$ = time-averaged shear wave velocity from the ground surface to 30 m depth




$$V_{s(30)} = \frac{30}{\sum_{i=1}^{j} \frac{t_i}{V_{si}}}$$

Shear wave velocity profile $V_s(z)$ is required from the ground surface to 30 m depth

# Methods for Evaluation of $V_s$ Profile at the Site

| Method | Description | Procedure | Uncertainty in $V_{s(30)}$ *estimate* |
|---|---|---|---|
| **1** | **Measured $V_s$**<br>to 30 (25) m depth | • SCPT, Downhole, …<br>• SASW, MASW, … | **± 5%** |
| **2** | **Partially measured $V_s$**<br>to z ≥ 15 m, plus<br>use of empirical correlations | • $V_s$ measurements as for Method 1<br>• $V_{s(30)} – V_{sz}$ correlation<br>• CPT-, SPT- based correlations | **± 15%** |
| **3** | **Inferred $V_s$**<br>from empirical correlations | • CPT-$V_s$ correlation<br>• SPT-$V_s$ correlation<br>• Established geologic model | **± 30%** |

# Implications of Uncertainty in $V_{s(30)}$ Estimates

| Method | Uncertainty in $V_{s(30)}$ estimate |
|---|---|
| 1 | ± 5% |
| 2 | ± 15% |
| 3 | ± 30% |

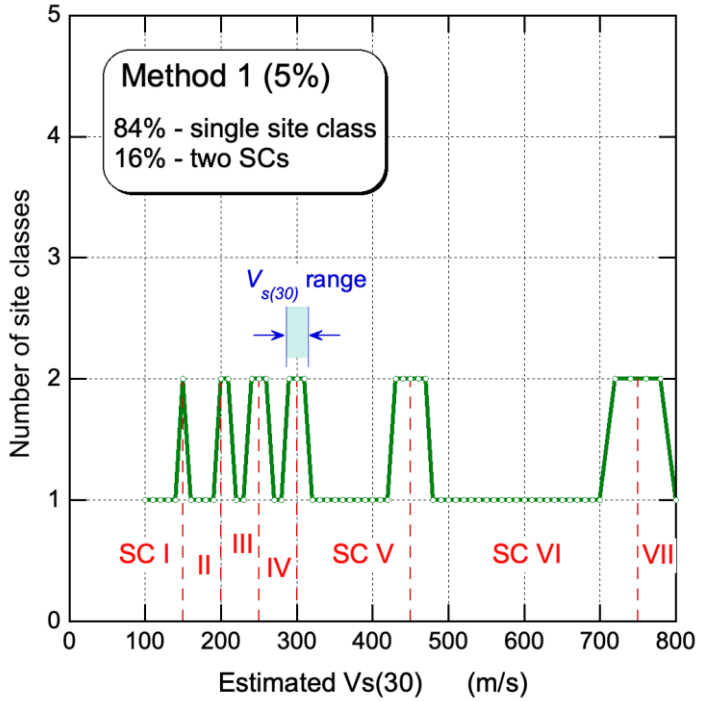
Estimated $V_{s(30)}$ ⇨

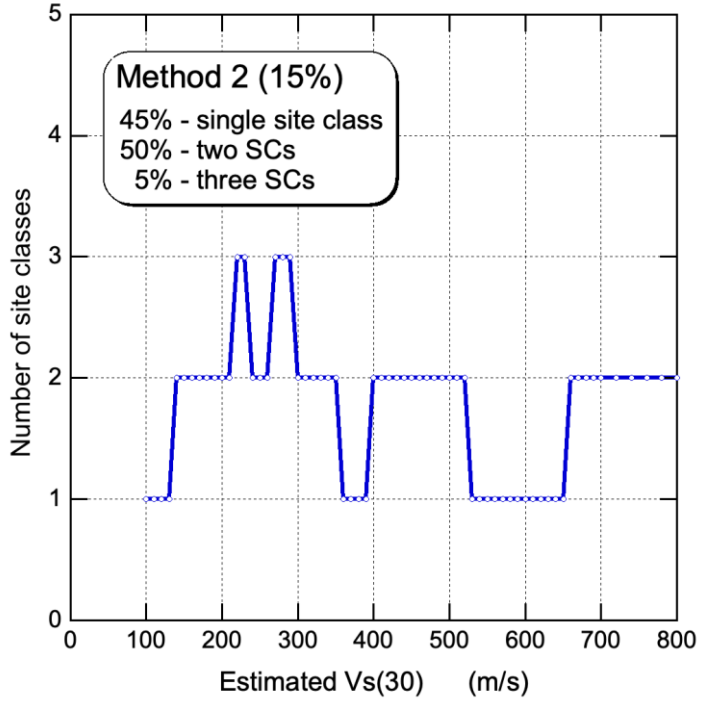
$$V_{s(30)-LB} = \frac{V_{s(30)}}{1.3}$$

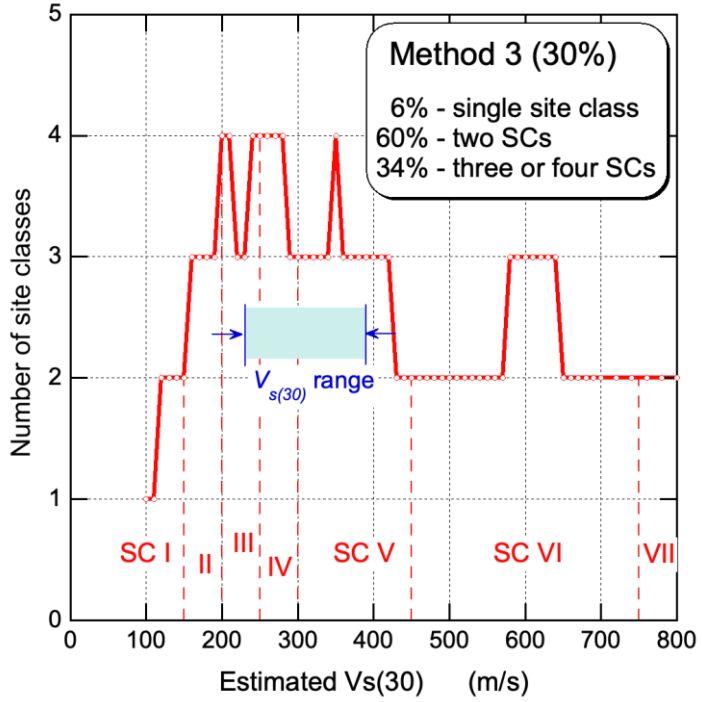
$$V_{s(30)-UB} = 1.3 \times V_{s(30)}$$

$V_{s(30)}$ range (Method 3)

## Number of site classes for a given estimate of $V_{s(30)}$



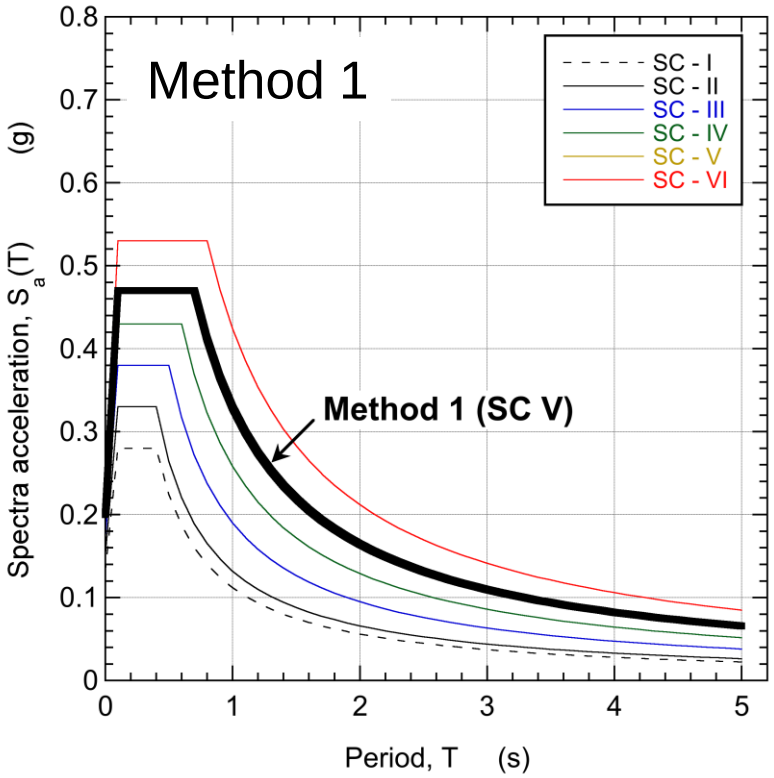



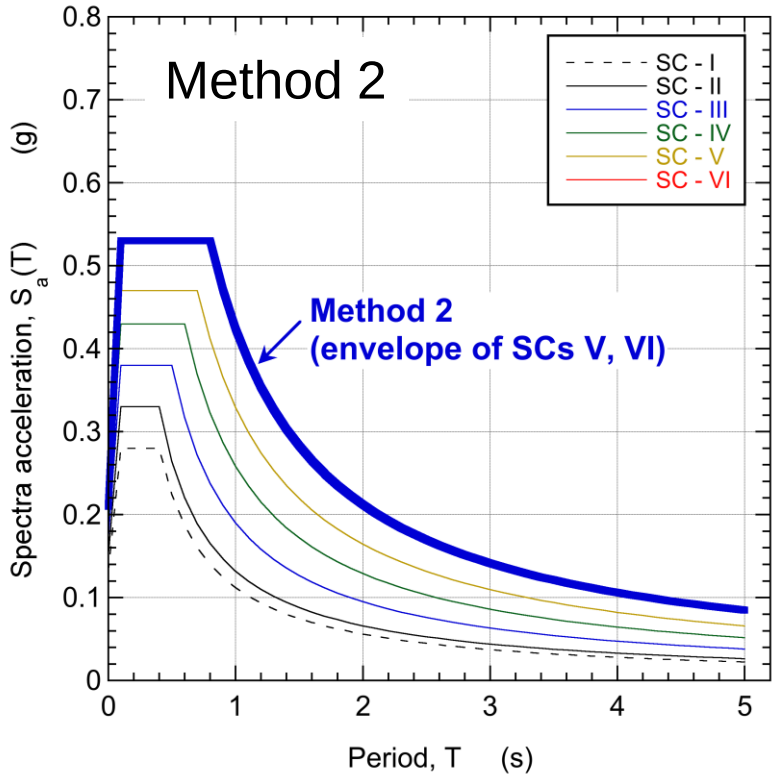

Clear benefits of using Methods 1 & 2

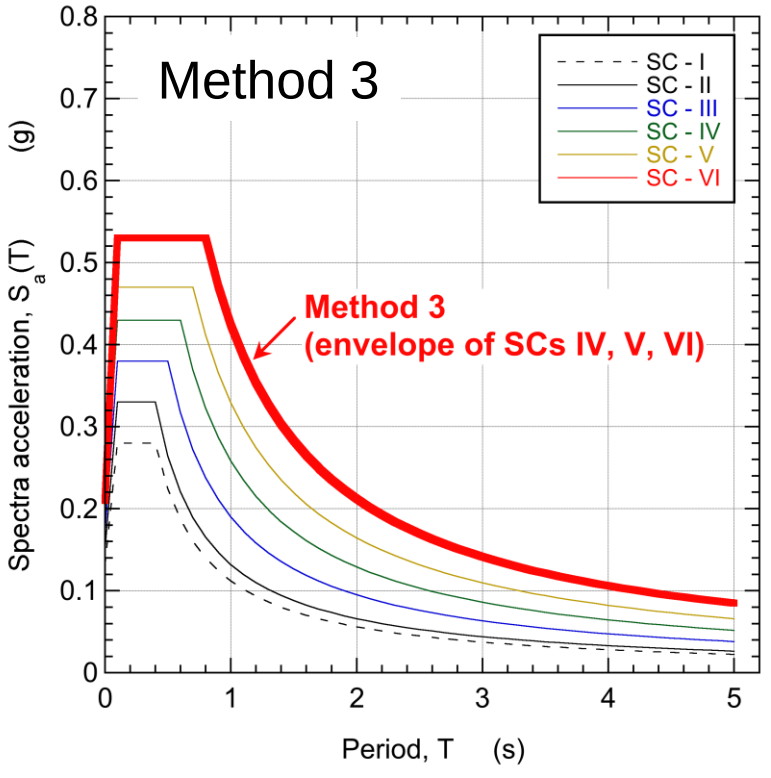
# Multiple Site Classes (low-moderate shaking intensity)

Implications of Uncertainty in $V_{s(30)}$ on Design Spectra

Estimated: $V_{s(30)}$ = 215 m/s



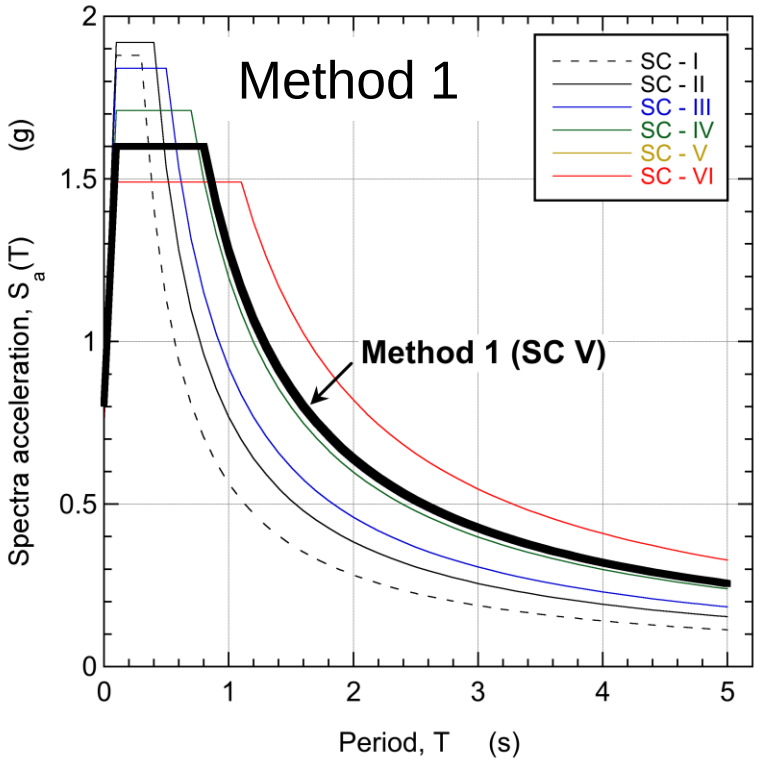



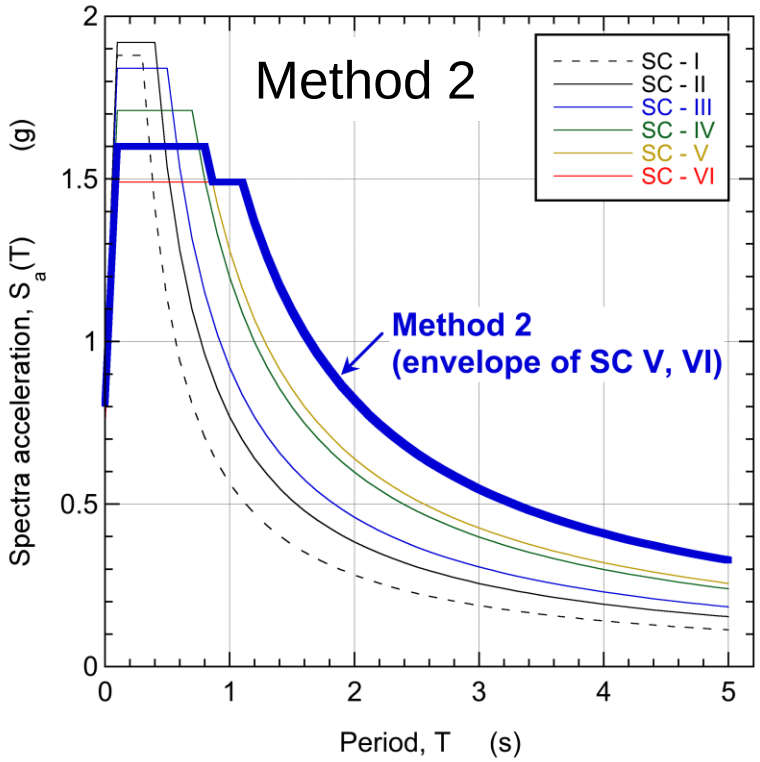



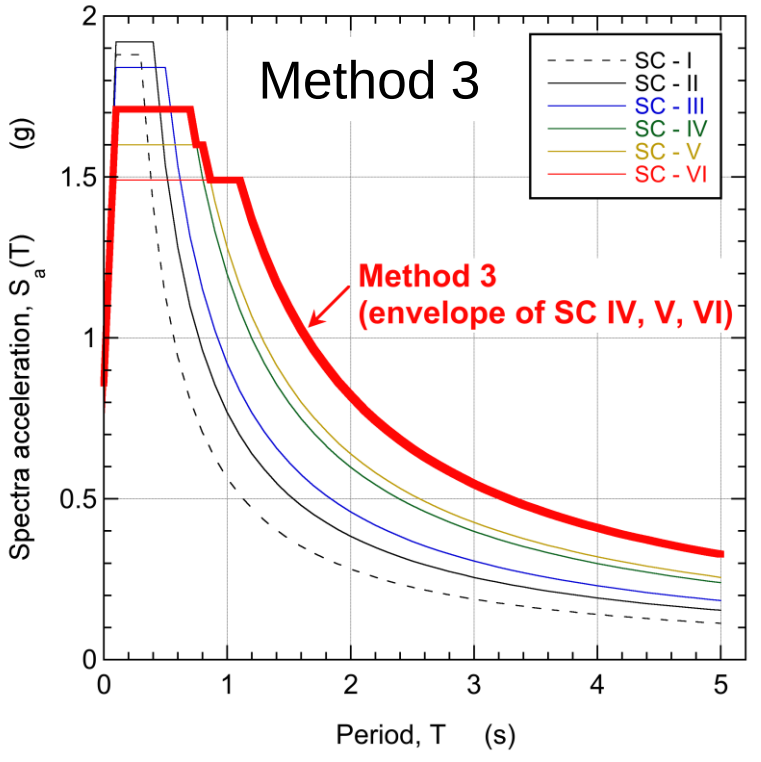
# Multiple Site Classes (high shaking intensity)

Implications of Uncertainty in $V_{s(30)}$ on Design Spectra

Estimated: $V_{s(30)}$ = 215 m/s



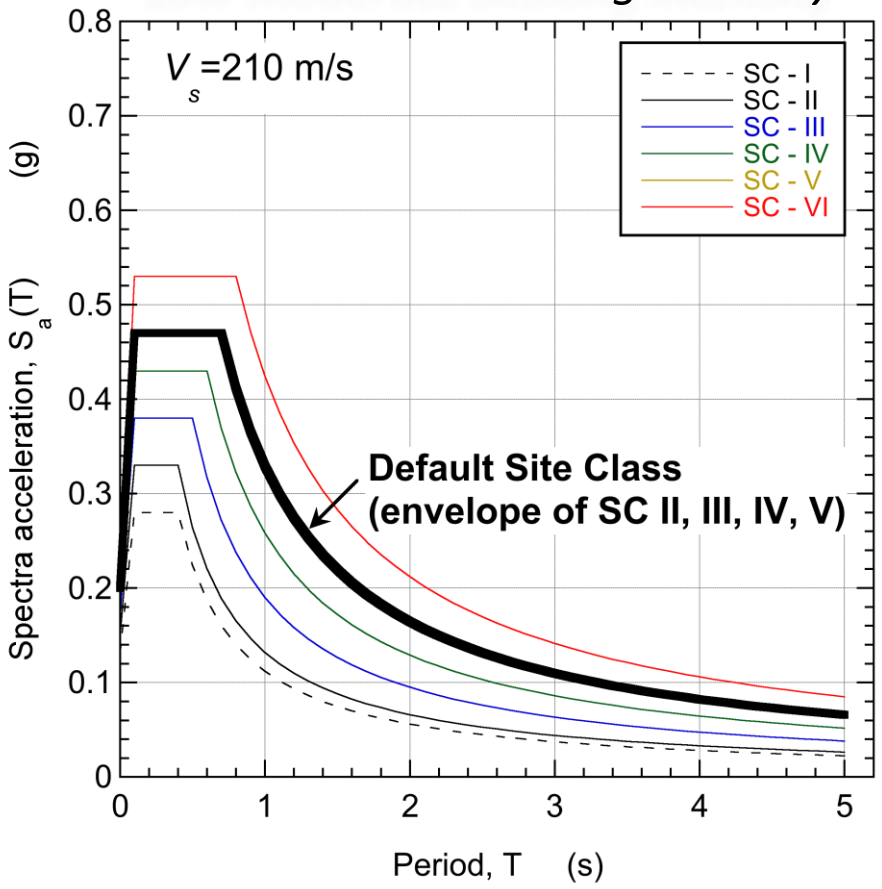



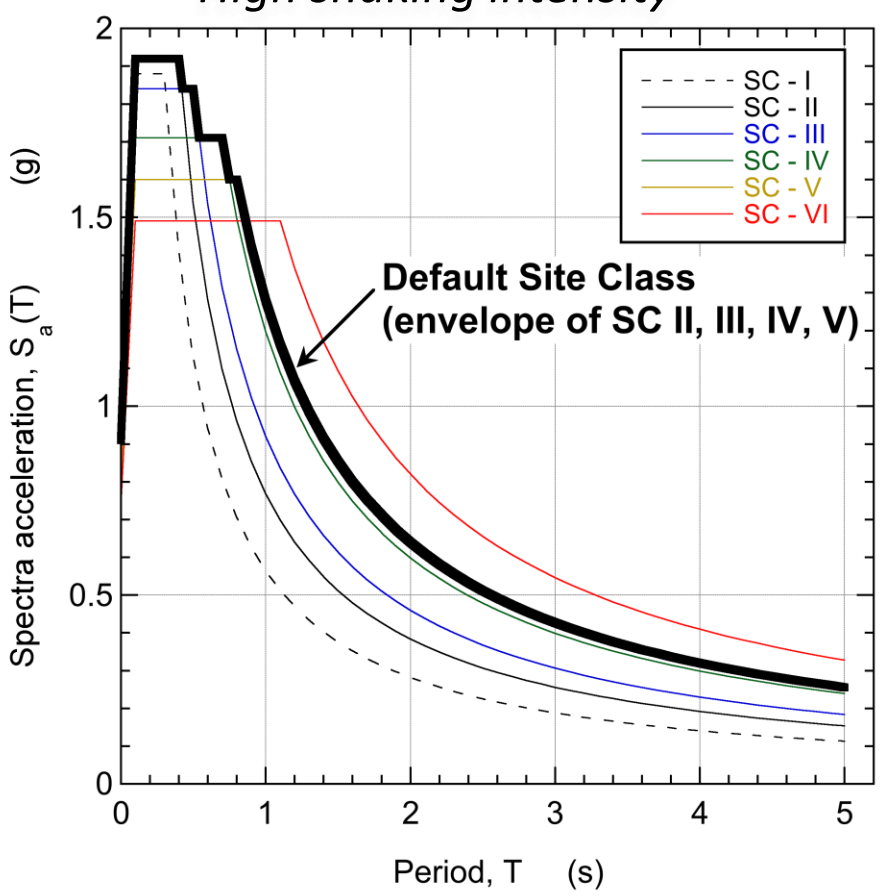
# Default Site Class

- In case of insufficient data to estimate $V_{s(30)}$, and
- Site Class VI or VII soils are not present at the site
- Envelope spectrum for site classes II - V

*Low-moderate shaking intensity*




*High shaking intensity*



# Site Classification for Elastic Site Spectra – Additional Criteria

| Site Class | Site Class Criteria |
|---|---|
| I | **Rock site with:**<br>a) Time-averaged shear wave velocity in the top 30 m, $V_{s(30)}$ > 750 m/s with the following additional requirements:<br>(i) The profile should not contain a shear wave velocity less than 600 m/s, and<br>(ii) There should be no more than 3 m of soil or highly-weathered rock between the bedrock and ground surface, unless excavated for a basement structure founded on rock. |
| II | **Very stiff soil, very dense soil or soft rock with:**<br>a) Time-averaged shear wave velocity in the top 30 m, 450 < $V_{s(30)}$ ≤ 750 m/s, and not underlain by materials having a shear wave velocity less than 300 m/s, or<br>b) Time-averaged shear wave velocity in the top 30 m, $V_{s(30)}$ > 750 m/s, with more than 3 m of soil or highly-weathered rock between the bedrock and ground surface, or underlain by materials having a shear wave velocity less than 600 m/s. |
| III | **Stiff or dense soil with:**<br>a) Time-averaged shear wave velocity in the top 30 m, 300 < $V_{s(30)}$ ≤ 450 m/s, or<br>b) Time-averaged shear wave velocity in the top 30 m, 450 < $V_{s(30)}$ ≤ 750 m/s, underlain by materials having a shear wave velocity less than 300 m/s |
| IV | **Moderately stiff or medium dense soil** with time-averaged shear wave velocity in the top 30 m, 250 < $V_{s(30)}$ ≤ 300 m/s |
| V | **Soft or loose soil** with time-averaged shear wave velocity in the top 30 m, 200 < $V_{s(30)}$ ≤ 250 m/s, and the following soil characteristics from the ground surface to 20 m depth:<br>(i) No more than 10 m of very soft soils with undrained shear strength less than 40 kPa, and<br>(ii) No more than 10 m of soils with SPT *N*-values less than 6, and<br>(iii) No more than 10 m of sandy soils or non-plastic silty soils with $q_c$-values less than 2.5 MPa, and<br>(iv) No more than 10 m of clayey soils or plastic silty soils with $q_c$-values less than 1.0 MPa, and<br>(v) No more than 10 m of soils with shear-wave velocities of 150 m/s or less, and<br>(vi) No more than 10 m combined depth of soils with properties as described in (i), (ii), (iii), (iv) and (v) above.<br>In the case of constructed fills, conditions (i) to (vi) shall be assessed over the larger depth of 20 m or the depth of the fill. |
| VI | **Very soft or very loose soil** sites with the following soil characteristics:<br>a) Time-averaged shear wave velocity in the top 30 m, 150 m/s < $V_{s(30)}$ ≤ 200 m/s, or<br>b) Time-averaged shear wave velocity in the top 30 m, $V_{s(30)}$ > 200 m/s, and any of the following soil characteristics from the ground surface to 20 m depth:<br>(i) More than 10 m of very soft soils with undrained shear strength less than 40 kPa, or<br>(ii) More than 10 m of soils with SPT *N*-values less than 6, or<br>(iii) More than 10 m of sandy soils or non-plastic silty soils with $q_c$-values less than 2.5 MPa, or<br>(iv) More than 10 m of clayey soils or plastic silty soils with $q_c$-values less than 1.0 MPa, or<br>(v) More than 10 m of soils with shear-wave velocities of 150 m/s or less, or<br>(vi) More than 10 m combined depth of soils with properties as described in (i), (ii), (iii), (iv) and (v) above.<br>In the case of constructed fills, conditions (i) to (vi) shall be assessed over the larger depth of 20 m or the depth of the fill. |
| VII | Sites with time-averaged shear wave velocity in the top 30 m, $V_{s(30)}$ ≤ 150 m/s. Refer to Clause 3.1.3.2. |

- $V_{s(30)}$ – based classification, with
- Additional criteria

***Why additional criteria?***

1) **To cover situations in which $V_{s(30)}$ alone is not sufficient for site classification**
2) **To facilitate site classification in practice**

# Additional Criteria for Site Classification

| Site Class | Site Class Criteria |
|---|---|
| I | **Rock site with:**<br>a) Time-averaged shear wave velocity in the top 30 m, $V_{s(30)}$ > 750 m/s with the following additional requirements:<br>(i) The profile should not contain a shear wave velocity less than 600 m/s, and<br>(ii) There should be no more than 3 m of soil or highly-weathered rock between the bedrock and ground surface, unless excavated for a basement structure founded on rock. |
| II | **Very stiff soil, very dense soil or soft rock with:**<br>a) Time-averaged shear wave velocity in the top 30 m, 450 < $V_{s(30)}$ ≤ 750 m/s, and not underlain by materials having a shear wave velocity less than 300 m/s, or<br>b) Time-averaged shear wave velocity in the top 30 m, $V_{s(30)}$ > 750 m/s, with more than 3 m of soil or highly-weathered rock between the bedrock and ground surface, or underlain by materials having a shear wave velocity less than 600 m/s. |
| III | **Stiff or dense soil with:**<br>a) Time-averaged shear wave velocity in the top 30 m, 300 < $V_{s(30)}$ ≤ 450 m/s, or<br>b) Time-averaged shear wave velocity in the top 30 m, 450 < $V_{s(30)}$ ≤ 750 m/s, underlain by materials having a shear wave velocity less than 300 m/s |
| VI | **Very soft or very loose soil** sites with the following soil characteristics:<br>a) Time-averaged shear wave velocity in the top 30 m, 150 m/s < $V_{s(30)}$ ≤ 200 m/s, or<br>b) Time-averaged shear wave velocity in the top 30 m, $V_{s(30)}$ > 200 m/s, and any of the following soil characteristics from the ground surface to 20 m depth:<br>(i) More than 10 m of very soft soils with undrained shear strength less than 40 kPa, or<br>(ii) More than 10 m of soils with SPT *N*-values less than 6, or<br>(iii) More than 10 m of sandy soils or non-plastic silty soils with $q_c$-values less than 2.5 MPa, or<br>(iv) More than 10 m of clayey soils or plastic silty soils with $q_c$-values less than 1.0 MPa, or<br>(v) More than 10 m of soils with shear-wave velocities of 150 m/s or less, or<br>(vi) More than 10 m combined depth of soils with properties as described in (i), (ii), (iii), (iv) and (v) above.<br>In the case of constructed fills, conditions (i) to (vi) shall be assessed over the larger depth of 20 m or the depth of the fill. |

**Site Classes I, II, III**

- In case of deeper soils with lower $V_s$ than $V_{s(30)}$
- Adopt the adjacent (softer) site class with lower $V_{s(30)}$

**Site Class VI**

- In case of > 10 m of very soft or very loose soils
- Adopt the adjacent *(softer)* site class with lower $V_{s(30)}$

# Step-by-Step Procedure for Site Classification

**Step 1**: Use geologic information and geotechnical data of the site, in conjunction with non-$V_{s(30)}$ criteria listed in Table 3.1 for Site Class VI, to either rule out or allow for possible presence of Site Class VI or VII soils at the site.

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**Step 9**: Check non-$V_{s(30)}$ criteria for Site Classes I, II, III, V and VI in Table 3.1 and modify, if necessary, the provisional site classification determined in Step 8 to satisfy all requirements stipulated in Table 3.1.

Comprehensive commentary covering various details and situations

# Recommended Empirical Correlations

1) Measured $V_s$ profile to a depth $z$ > 15 m (but less than 25 m)
   - Use measured $V_s$ data and empirical $V_{sz} - V_{s(30)}$ correlation to estimate $V_{s(30)}$

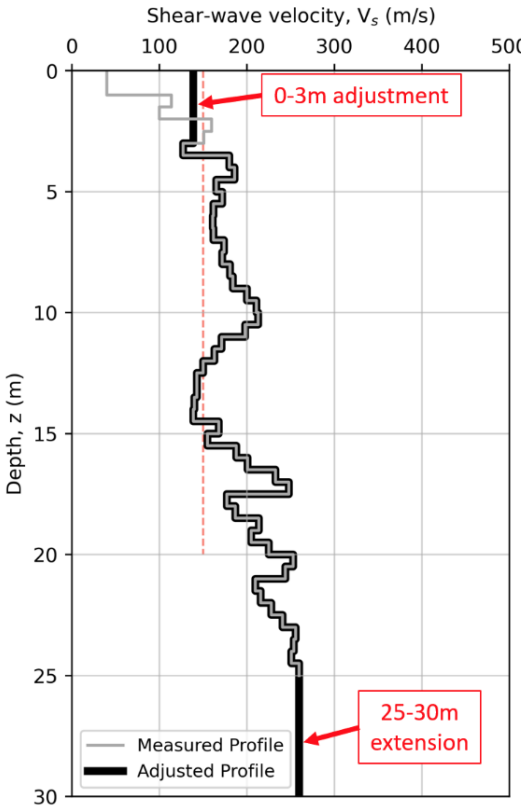
$$\log_{10} V_{s(30)} = a + b \log_{10} V_{sz}$$

2) Inferred $V_s$ profile (through the use of geotechnical data)
   - Available geotechnical data (CPT or SPT)
   - Use empirical CPT-$V_s$ or SPT-$V_s$ correlations
   - Different soil types, ground conditions, and age of deposits

# Examples of Site Class Identification

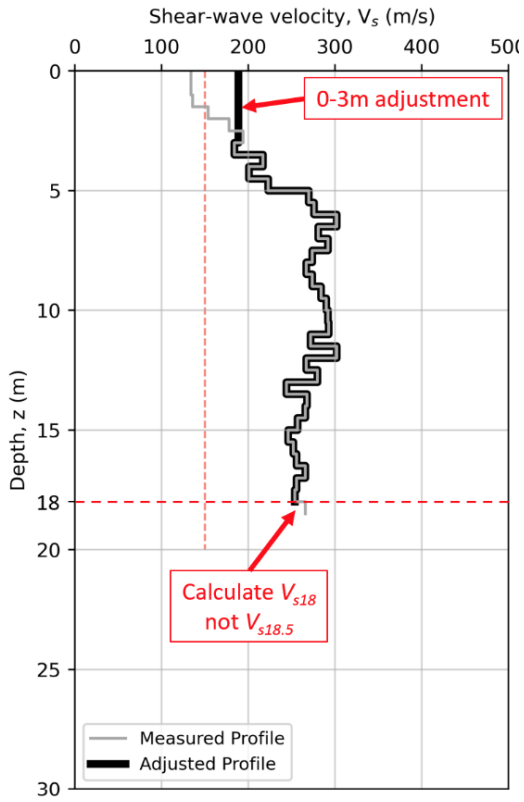
*Lee, Cubrinovski, Bradley (2024): Site classification methodology for TS 1170.5 design spectra, BNZSEE*

EX-1) Direct $V_s$ measurement (Method 1)



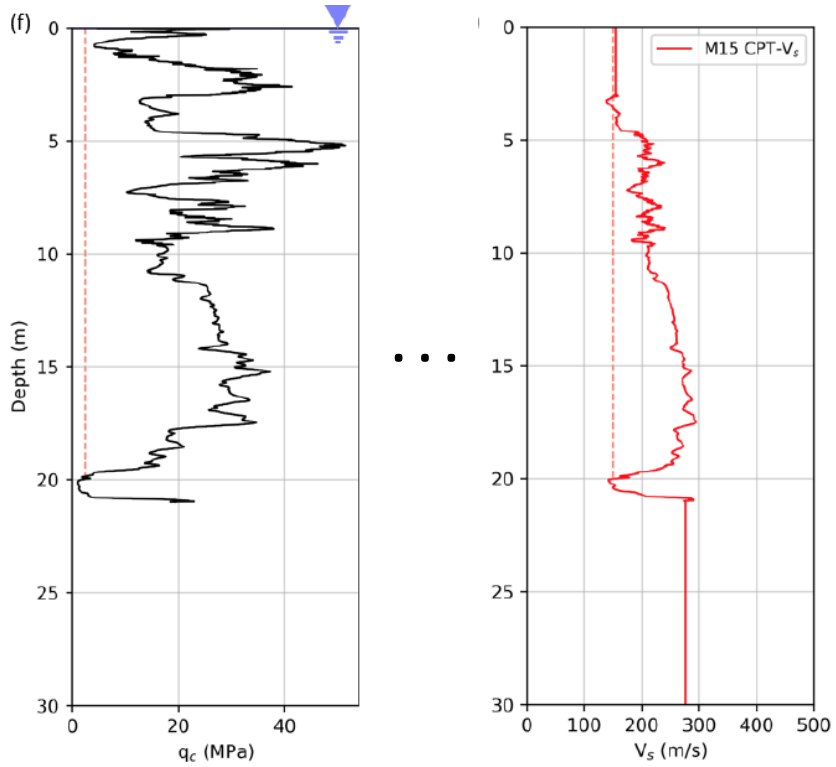

*Downhole $V_s$ data*

EX-2) Partial $V_s$ measurement (Method 2)




*Use of $V_{sz}$-$V_{s(30)}$ correlation*

EX-3) Inferred $V_s$ profile (Method 3)




*CPT-based calculation*

# Summary Remarks

1) Seven site classes, and design spectra for Site Classes I to VI
2) $V_{s(30)}$-based site classification (with additional criteria)
3) Three methods for evaluation of $V_s$ profile
   - *Measured $V_s$ profile*
   - *Partially measured $V_s$ profile*
   - *Inferred $V_s$ profile from geotechnical parameters (and geologic information)*
4) Treatment of uncertainties in the estimate of $V_{s(30)}$
   - *Multiple site classes*
   - *Default design spectra*
5) Step-by-step procedure, empirical relationships, additional geotechnical parameters, and detailed guidance are provided to facilitate implementation of the recommended methodology in practice


Balance between appropriate accuracy for design and appropriate simplicity for application to practice while accounting for key uncertainties