Comparison Between V_{S30} and Site Period as Site Parameters in Ground-motion Prediction Equations for Response Spectra

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Conclusion

Is V_{S30} a good site parameter?
Definitely not!

Does V_{S30} work in a GMPE ?
Definitely yes, well for *most* sites!

Rational

Why can a bad parameter work well ?

The nature/data is too bad !

**The large variability in GMPE
buries the *bad side* of V_{S30} &
obscures the *good sides* of other parameters**

Little we can do about the large variability!

Introduction

In theory, complete shear-wave velocity profile and impedance ratio, *at least*, are required to model site effect

In reality, the detailed variation of shear-wave velocity profile and impedance ratio are *buried* by ground motion variability

Introduction

Site period T_{site} is an ideal site parameter as:

- **Dominant peak response spectral amplification normally occurs at T_{site}; and**

- **At a given spectral period, site amplification ratios can be described well by a simple function of T_{site}**

Site parameter – why site period

Peak response spectral amplification ratio *usually* occurs at T_{site} – real data
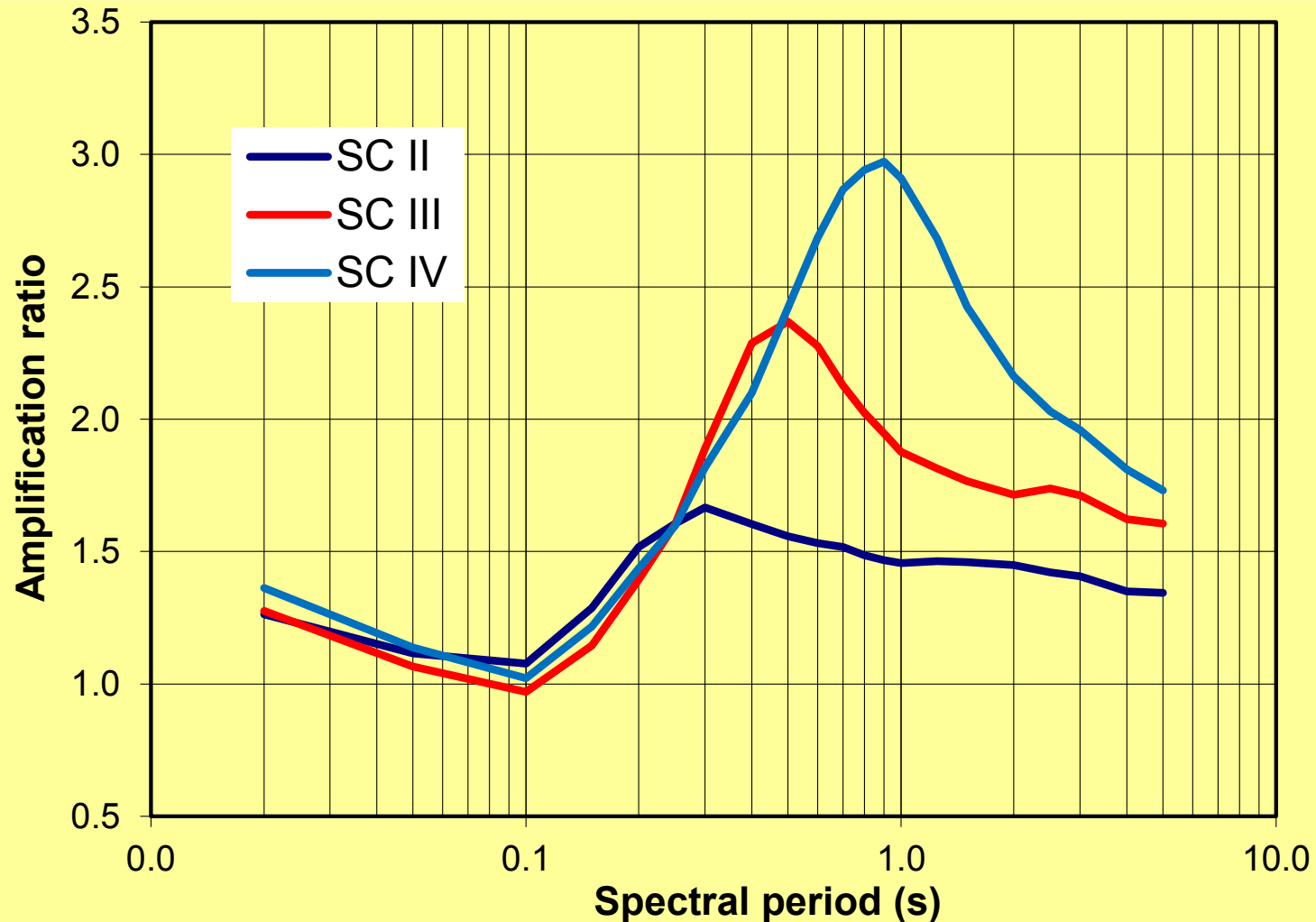
V_{S30} ⟷ site period T_{site}

In theory, V_{S30} is an *incomplete* site parameter

With the usual large variability in GMPEs, is V_{S30} a reliable site parameter?

Is site period a better alternative?

Validation of V_{S30}

So far, the examination and validation have been *curtailed* by the small number of records

Need to have a lot of high-quality strong-motion records used for GMPEs

Need to have reliably measured site parameters

The best data is from Kik-net in Japan

Can we use borehole data?

Not directly in GMPE!

Why to use surface and borehole records

Variability from source and path effects can be *minimized*

If a site parameter can model surface/ borehole amplification ratios well, *it can also be a good site parameter in GMPEs*

How to use

Amplification ratios between surface and borehole records from Kik-net stations

to verify a site parameter for GMPE

$$A_{site}(T_s, T_{SP}) = A_{SB}(T_s, T_{SP}) / A_{SB}(T_{rock}, T_{SP})$$

A_{site} – *Surface soil / surface rock*

A_{SB} – Response spectral ratio: surface / borehole

T_s – Site parameter: site period T_{site} or T_{VS30}

T_{SP} – Spectral period

"Site period" from V_{S30}

To facilitate a simple comparison, we use

$$T_{VS30} = 120 / V_{S30}$$

where V_{S30} is in m/s and T_{VS30} is in seconds

When bedrock is reached at 30m depth, $T_{VS30} = T_{site}$

Correlation between T_{VS30} and T_{site} for Strong-motion stations in Japan

$\sigma_{ln(T)} = 0.266$

T_{VS30} (s) (vertical axis)

Site Period (s) (horizontal axis)
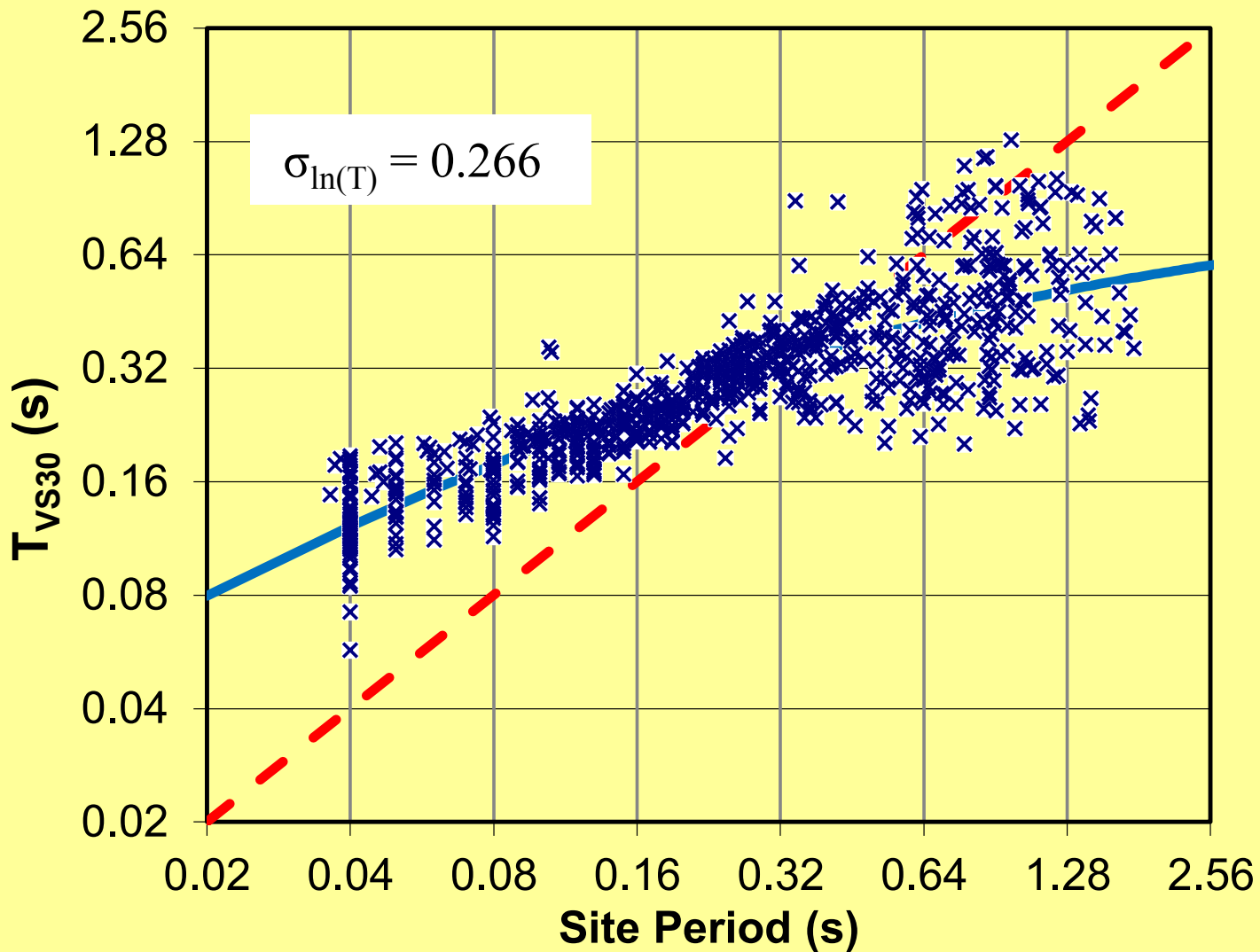
Kik-net strong-motion records
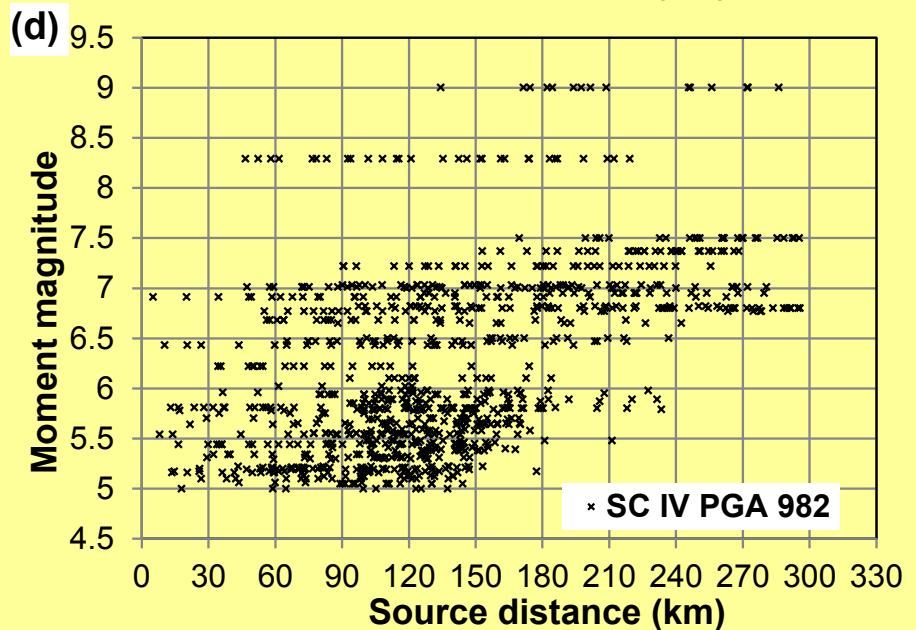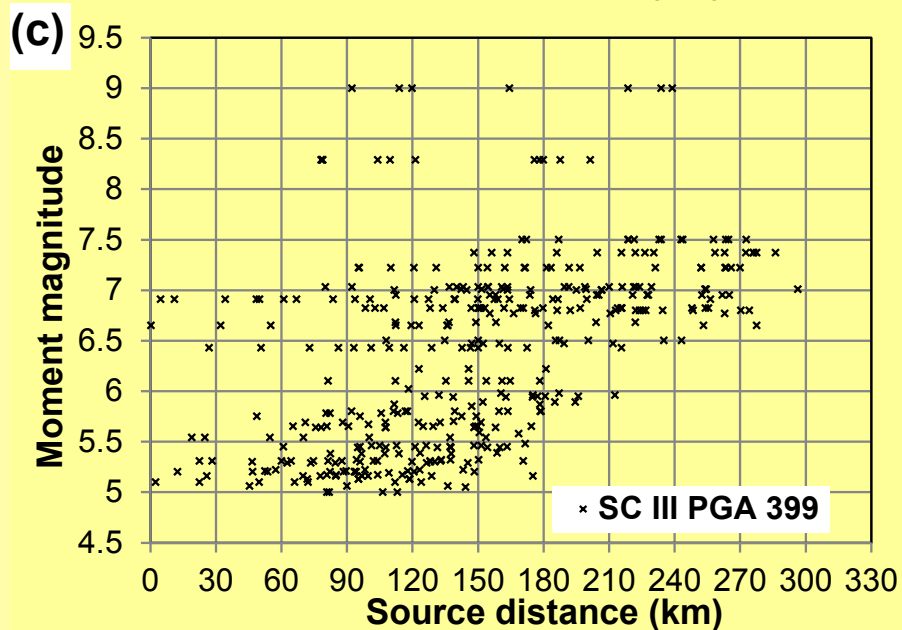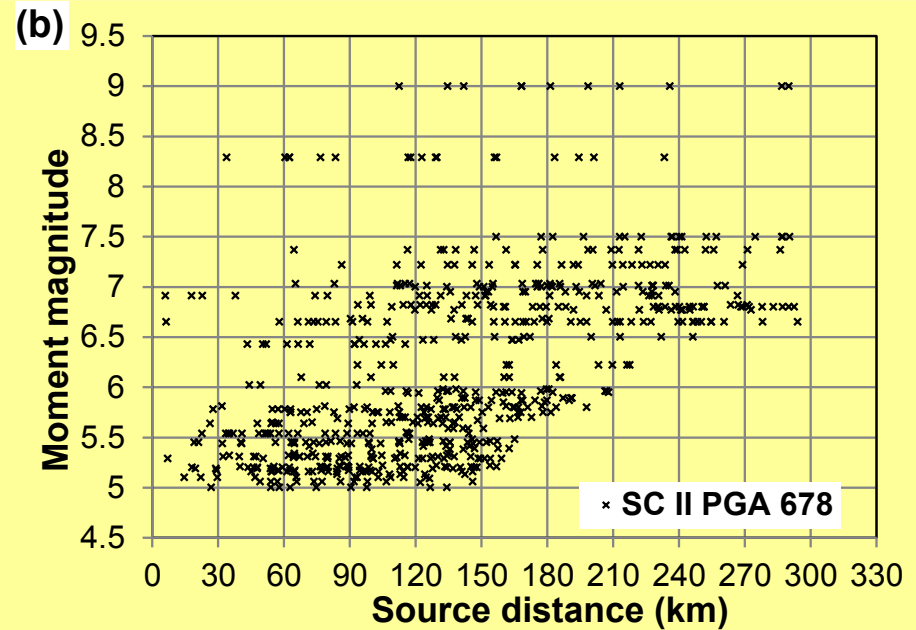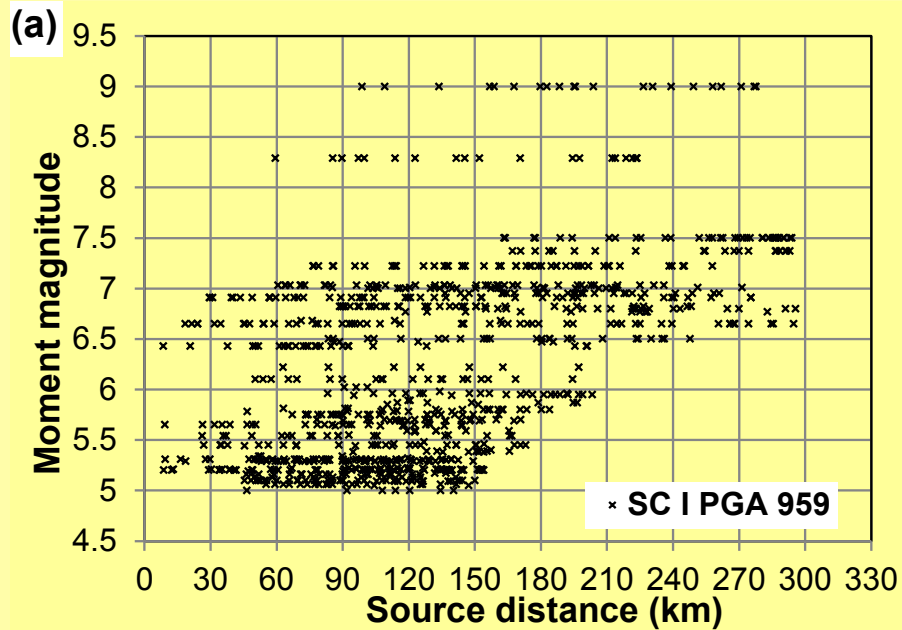
Approximate separation of variability associated with site effect

Inter-site variability τ_s from:

the variability for the empirical functions fitted to the average amplification ratio for each site

Intra-site variability σ_s from:

the difference *between* each record at a given site *and* the site average

Approximate separation of variability associated with site effect

In theory,

τ_s to measure the **appropriateness** of a site parameter

σ_s to measure the effect of all other factors: **interaction** among the effects of **source, and path,** the variability from one record to another from the same site

Amplitude-independent models

Among the data, only a very small number of records experience nonlinear-soil response

A amplitude-dependent model is used

The nonlinear-soil response will not affect the model standard deviation

Nonlinear model can not be *appropriately* accounted for unless *source and path effects* on amplification ratios are *corrected*

Methodology

Take average amplification ratios for each site to minimize the *effect* from source and path effects

For each spectral period, fit a simple function to the site average amplification ratios

$$\ln(A_{SB}) = a_{SB}\,T + b_{SB}\ln(T) + c_{SB}\,[\ln(T)]$$

where *T* is either the site period T_{site} or T_{VS30}

Statistically significant terms used

Methodology

Compute the residuals & standard deviations from the empirical functions of T_{site} or T_{VS30} (*inter-site variability*)

F-test is used to see if the residuals from the two empirical models have identical standard deviations

Magnitude-dependent amplification ratios for response spectra

σ_s & τ_s : constant ratio for each site class

Amplification ratios as a function of T_{site} or T_{VS30}

Amplification ratios as a function of T_{site} or T_{VS30}

Amplification ratios as a function of T_{site} or T_{VS30}

(a) 2.0s $\tau_s = 0.24$

(b) 2.0s $\tau_s = 0.31$

(c) 4.0s $\tau_s = 0.25$

(d) 4.0s $\tau_s = 0.30$

Axis labels: Amplification ratio, Site period (s), T_{VS30} (s)
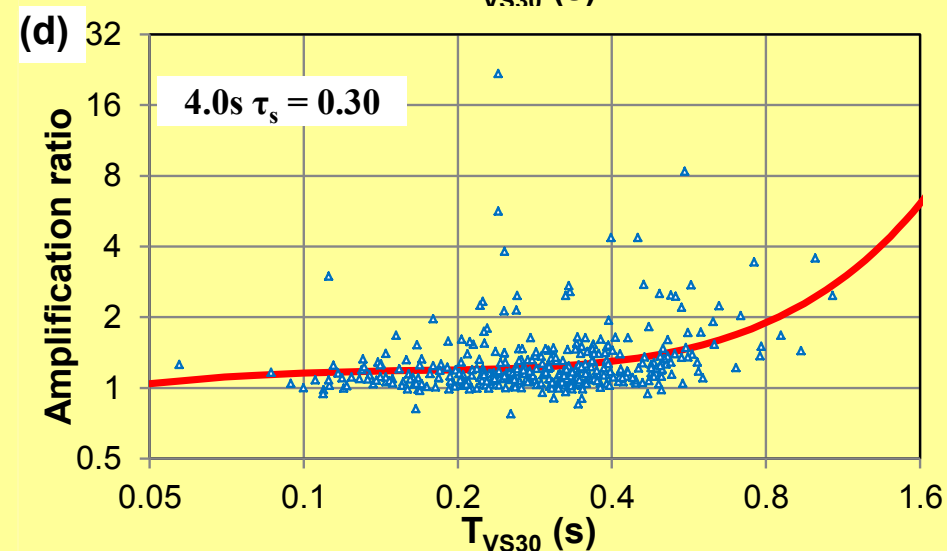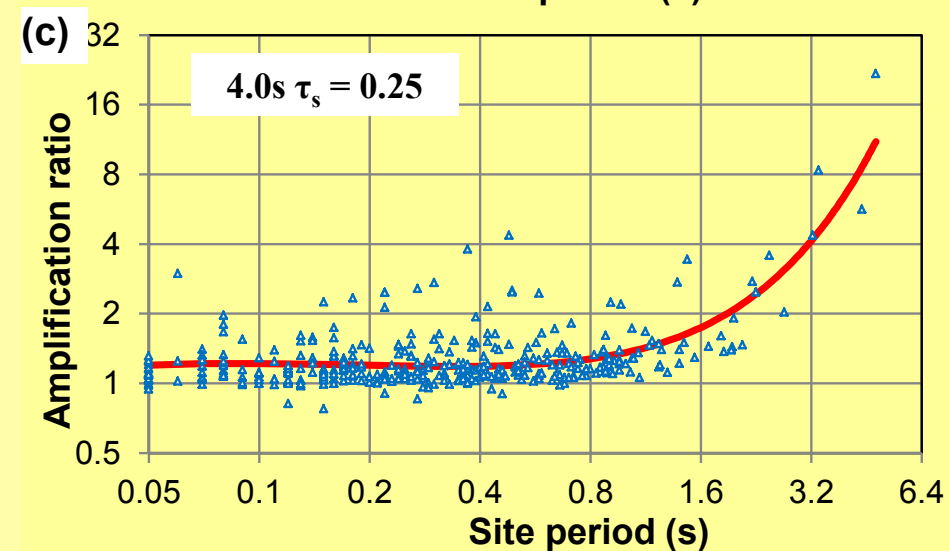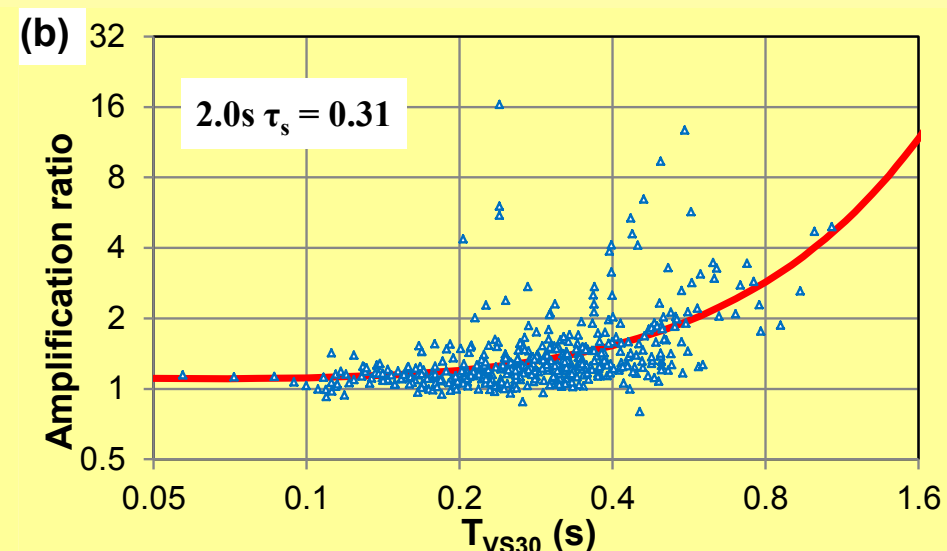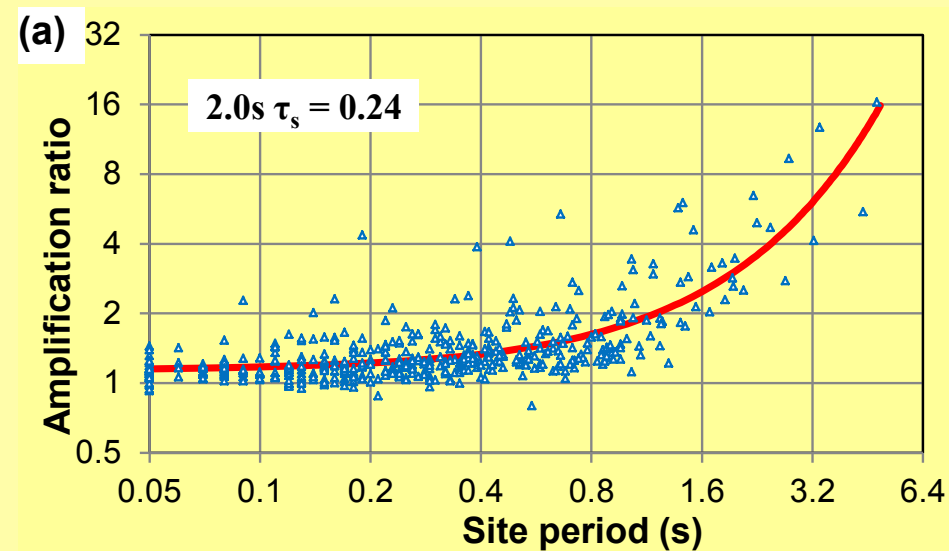
Inter-site standard deviation and *F-test* probability
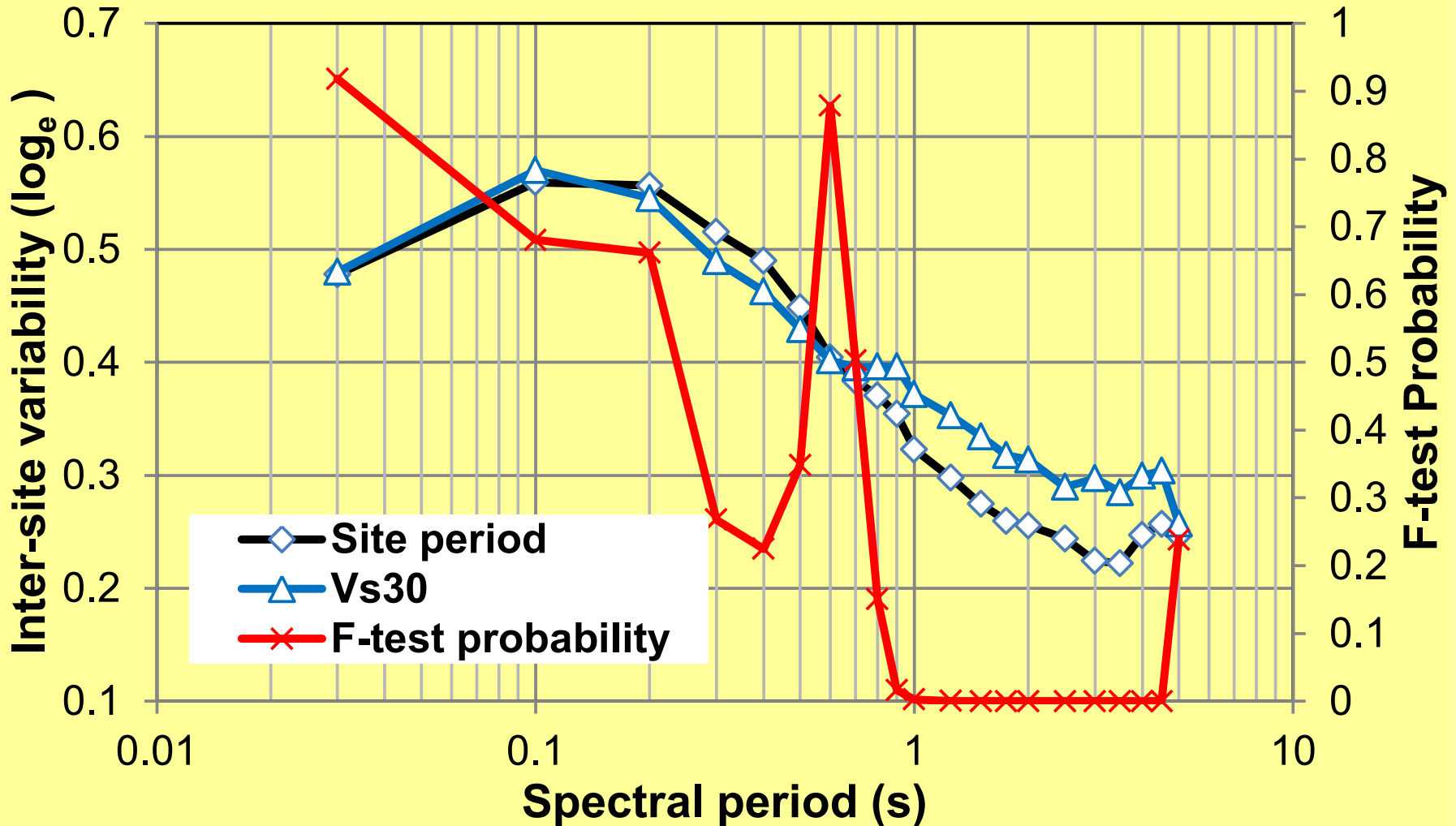
Inter-site standard deviation for each site class (rock and stiff soil)
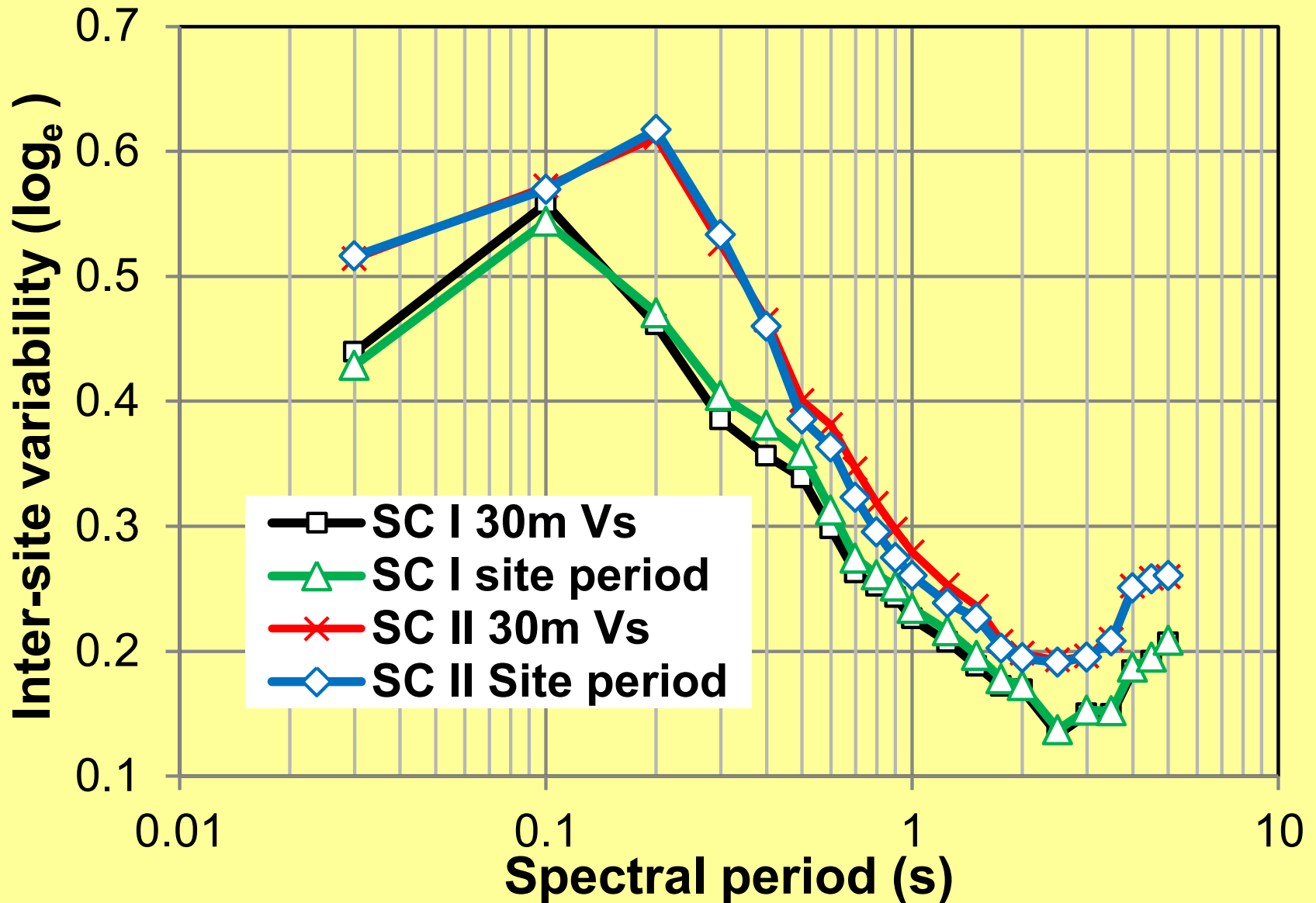
Inter-site standard deviation for each site class (medium soil)
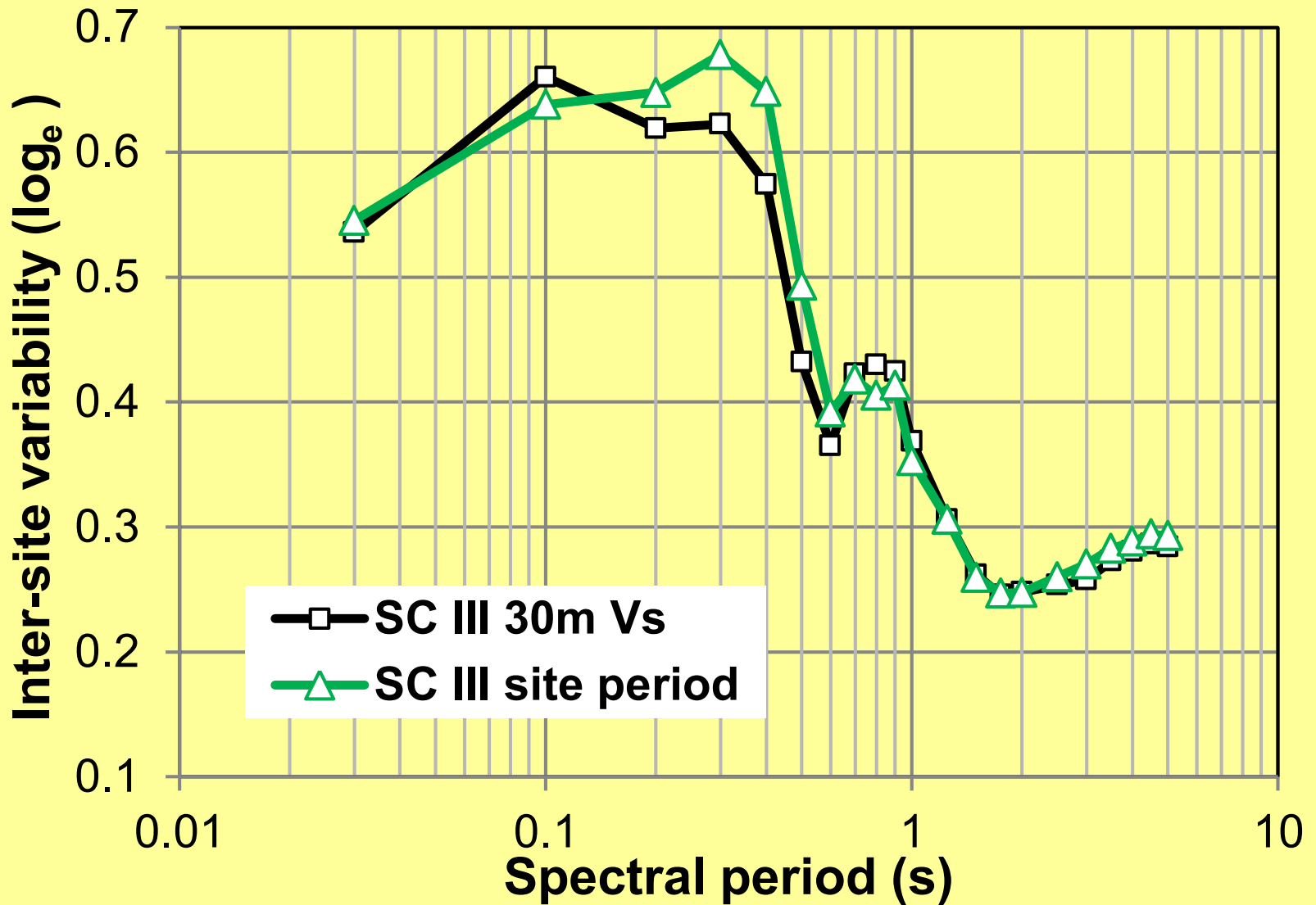
Inter-site standard deviation for each site class (soft soil)
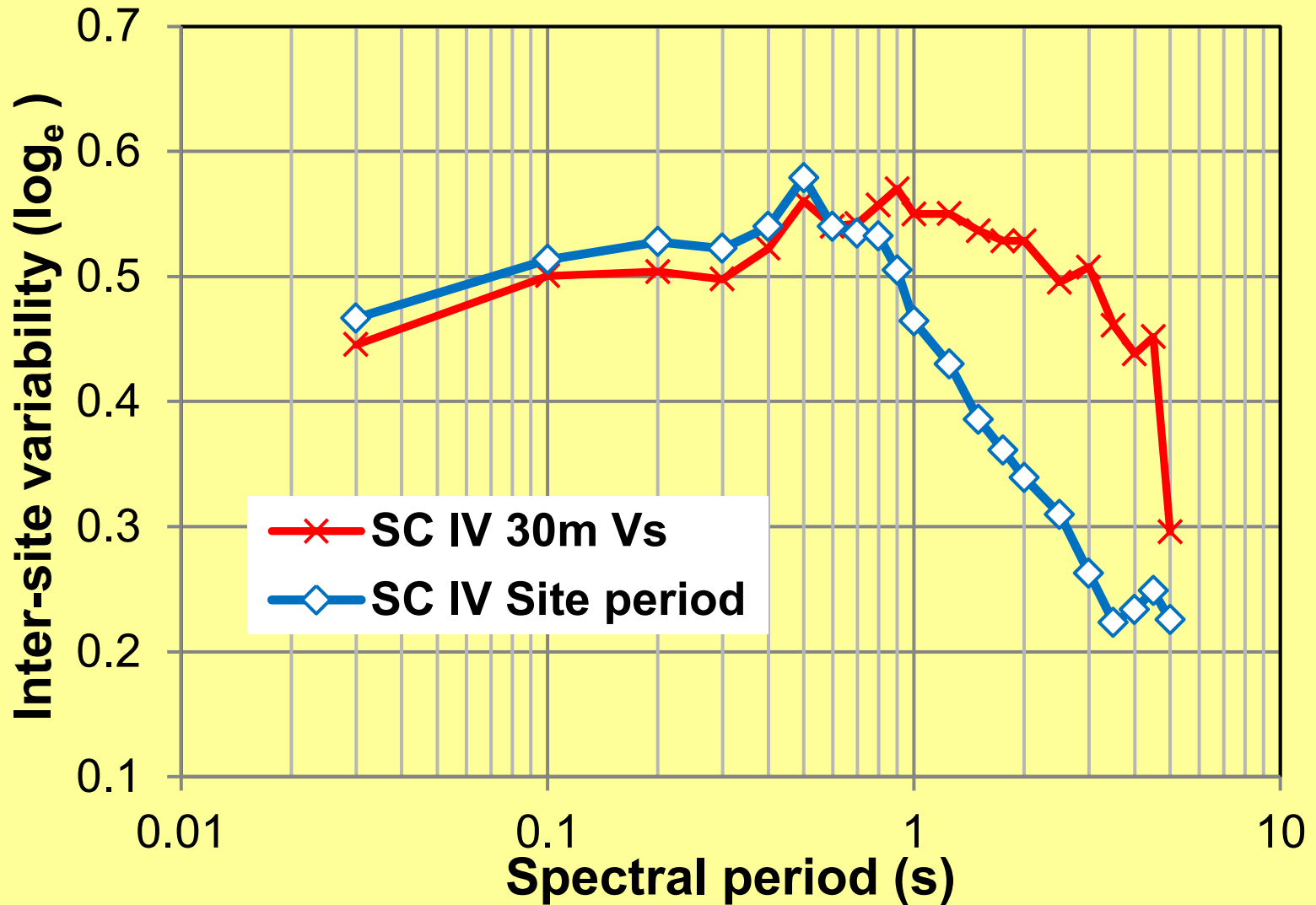
F-test probability for each site class for residuals using T_{site} or T_{VS30}
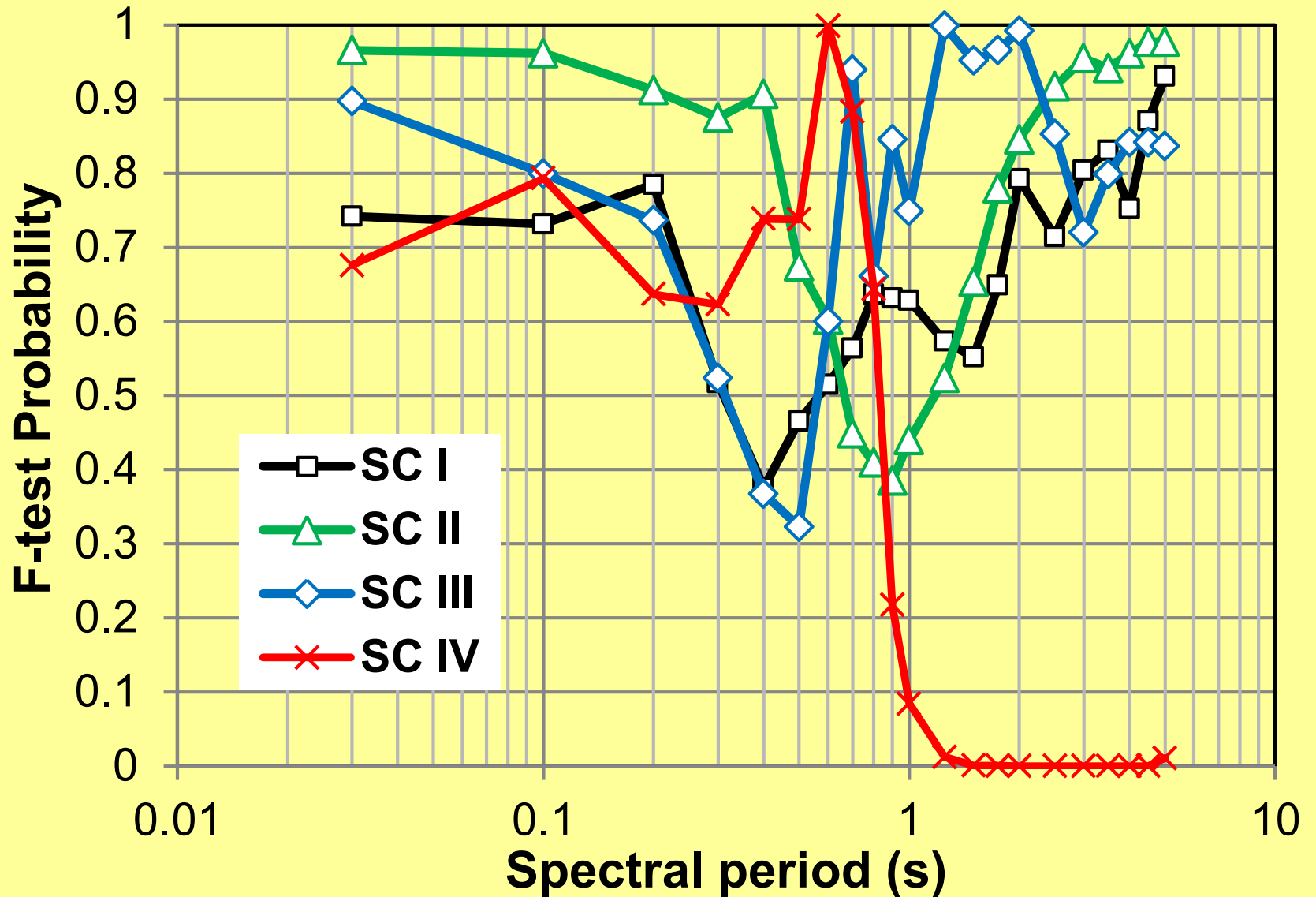
Site amplification ratios with respect to a site having T_{site}=0.1s

Legend:
- Site period 0.3s
- Site period 0.5s
- Site period 1.0s
- Site period 1.5s

Y-axis: Spectral amplification ratio

X-axis: Spectral period (s)
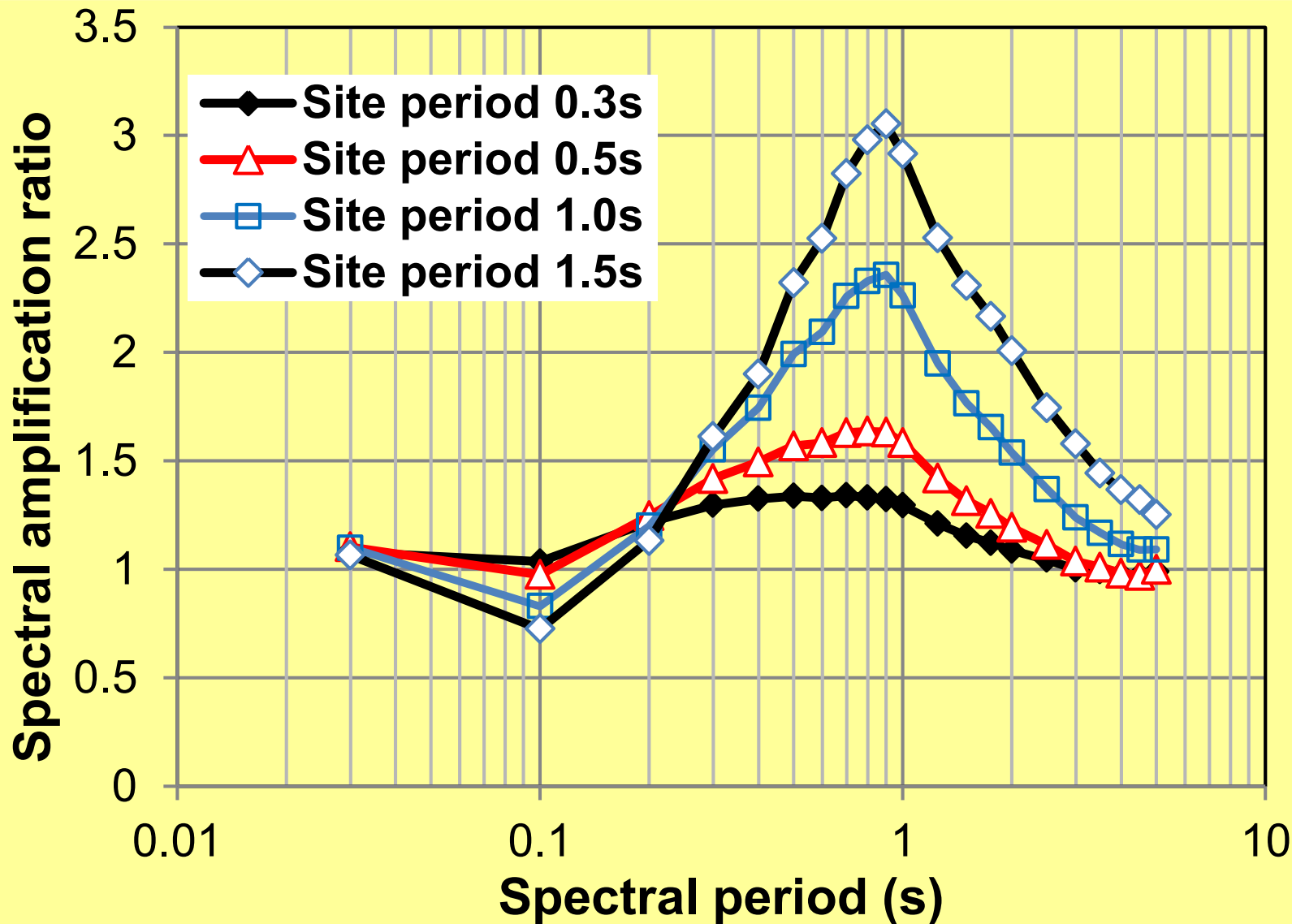
Site amplification ratios with respect to a site having T_{VS30} = 0.1s
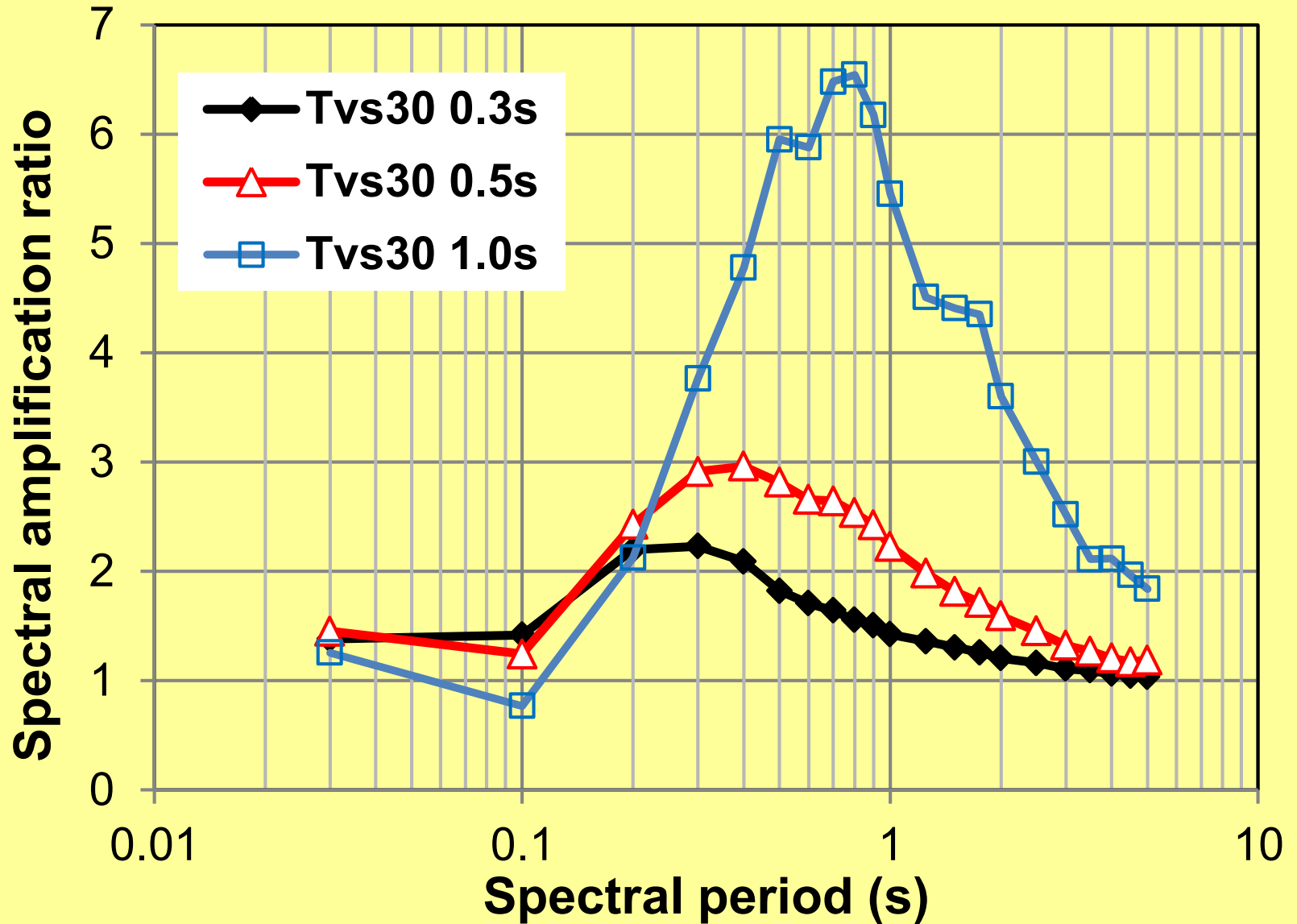
Inter- and intra-site variability for site amplification ratios

Inter-site variability is computed assuming a constant amplification ratio in each site class
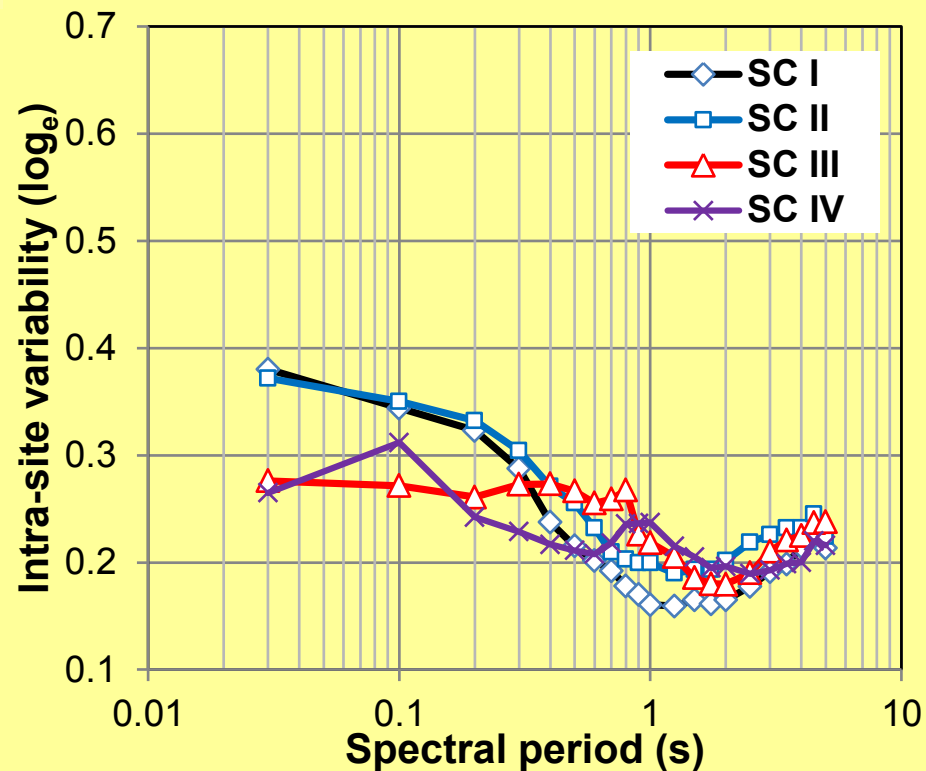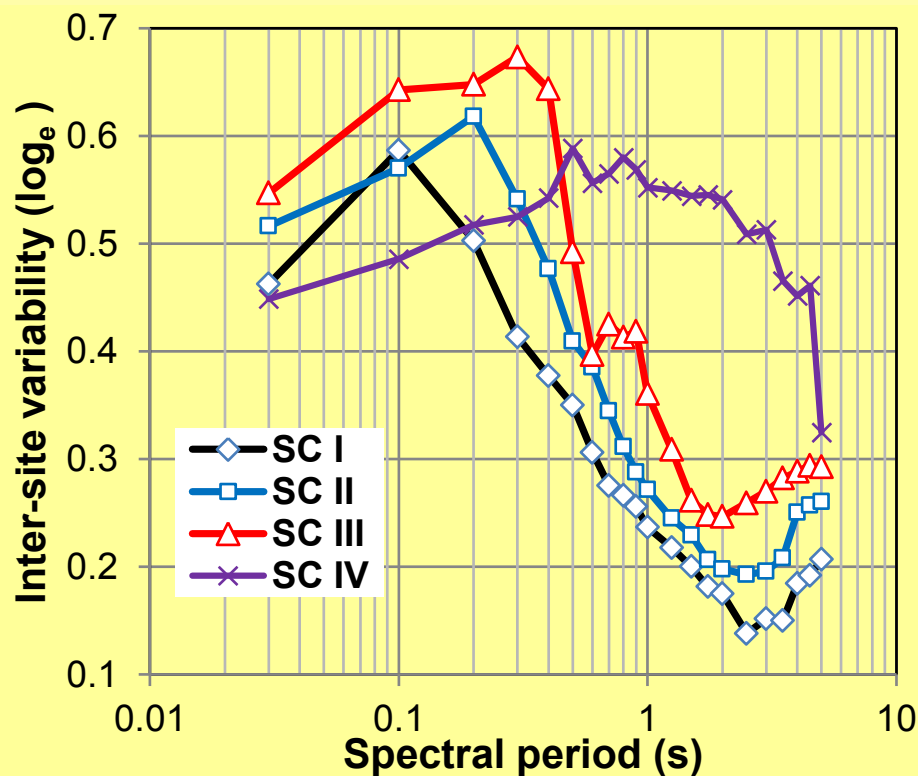
Site terms plus intra-event residuals from GMPE (Zhao 2010 and Zhao 2011)

In theory:

Inter-event residuals are due to variability associated with source terms

Intra-event residuals are due to variability associated with path and site effects

Implications of relatively small intra-site variability

Higher probability of repeated amplification ratios at a same site than at two sites with identical shear-wave profiles

Small single station σ is likely a result of low intra-site variability

Site modelling is really worthwhile (*if you get it right*)

Strong-motion records
Partial data from Zhao (2010 and 2011)
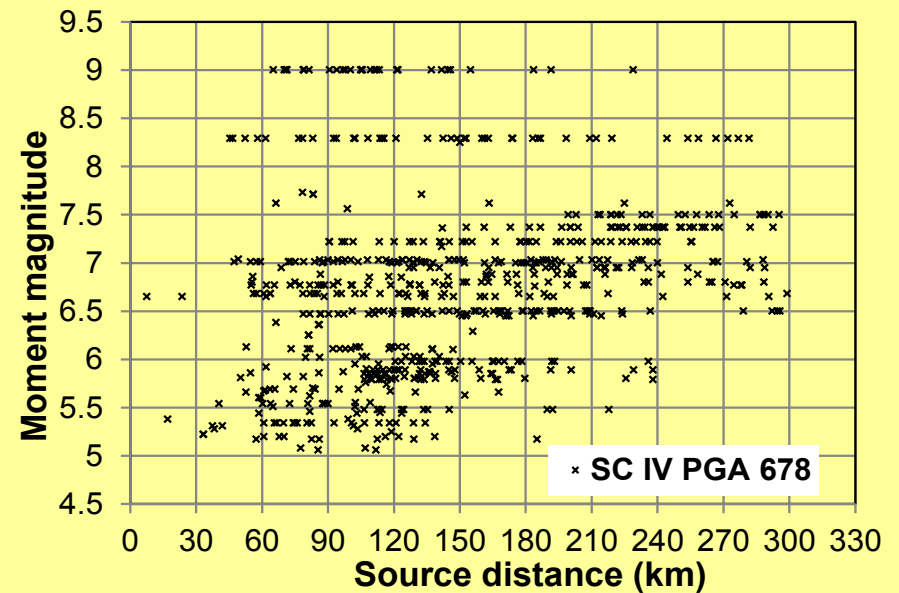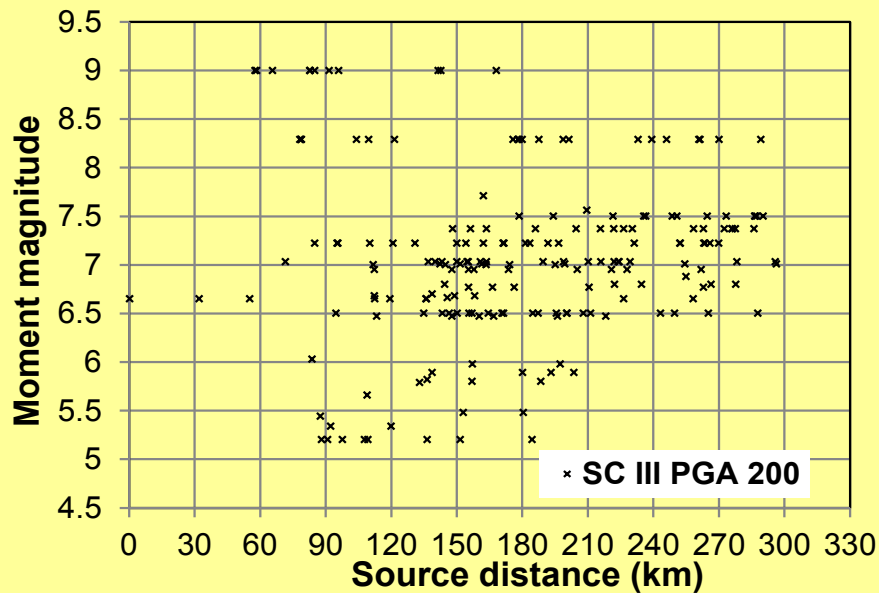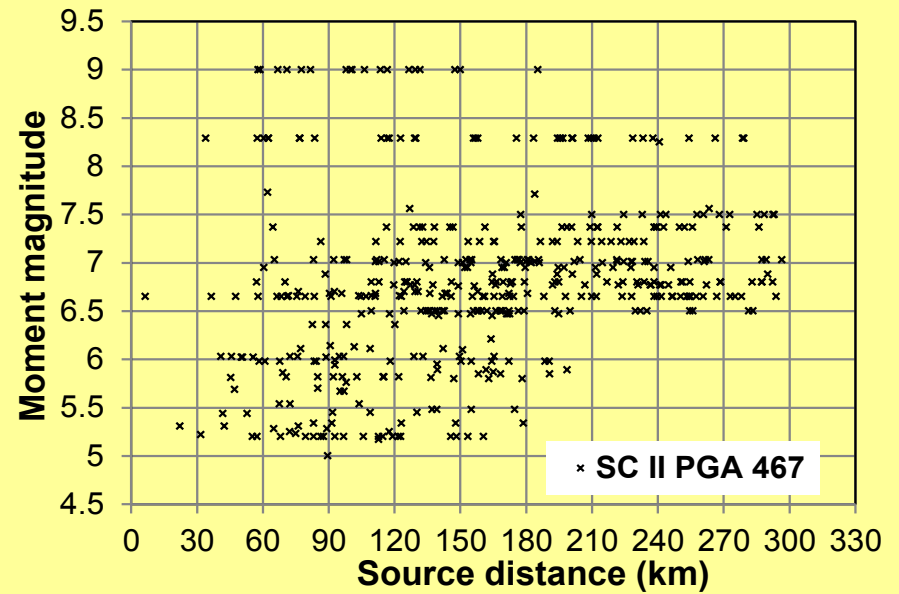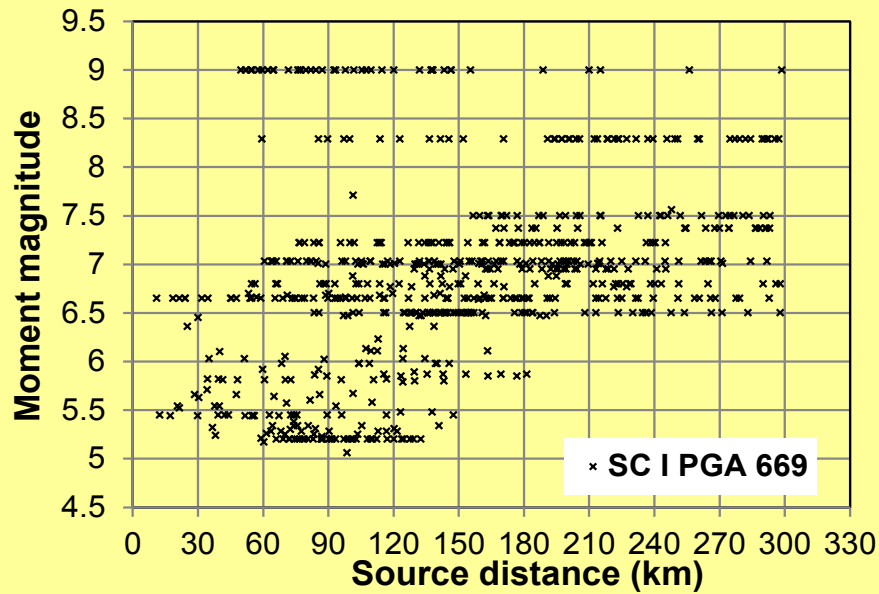
Intra-event residual + site terms
Variation with magnitude
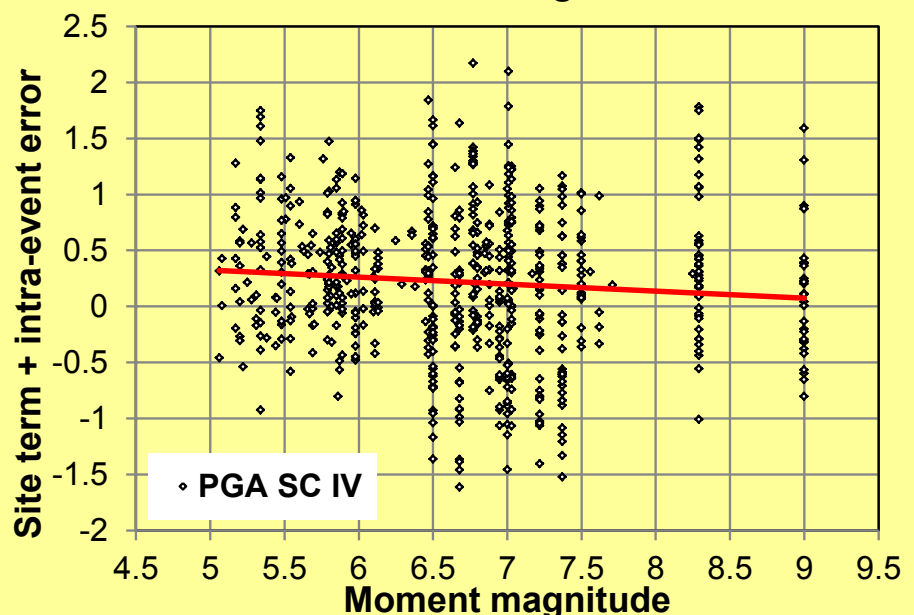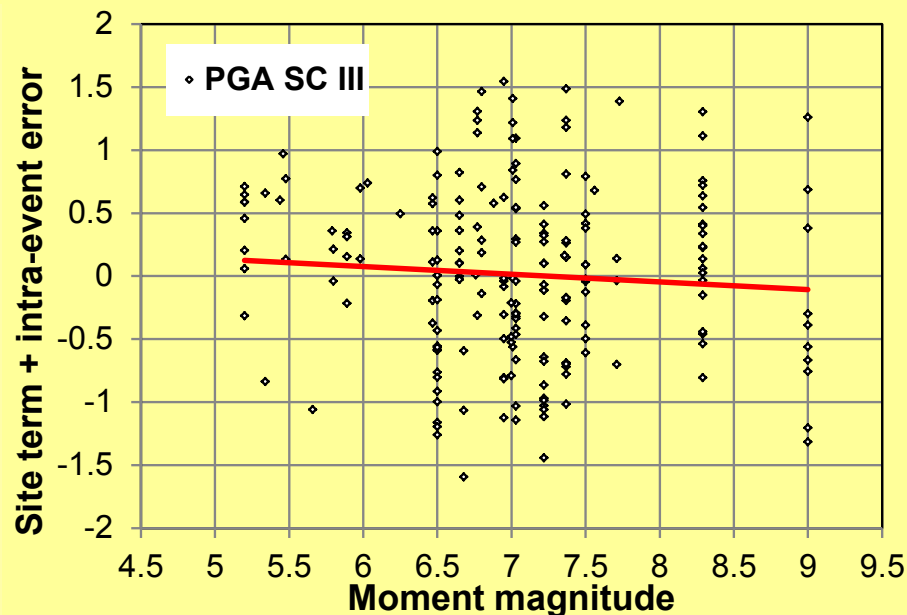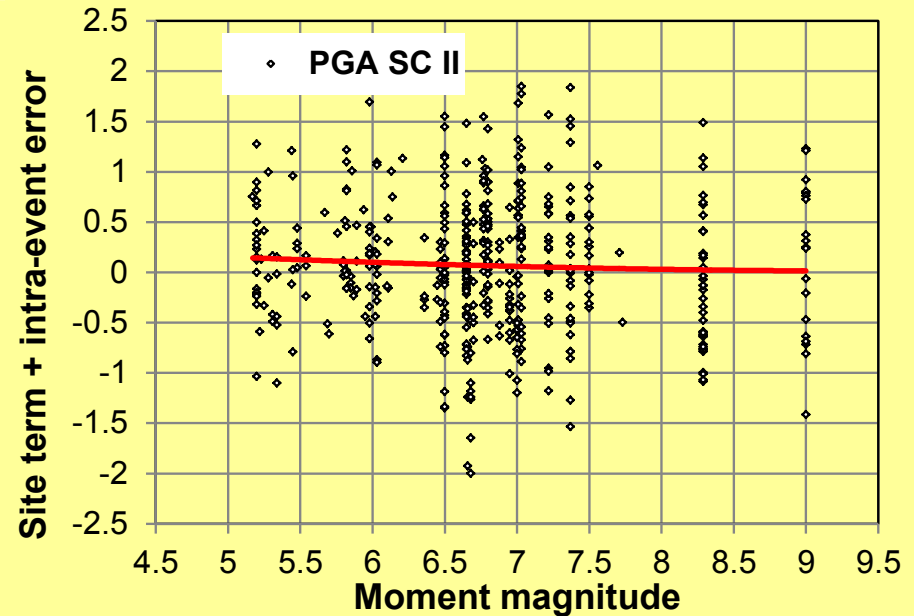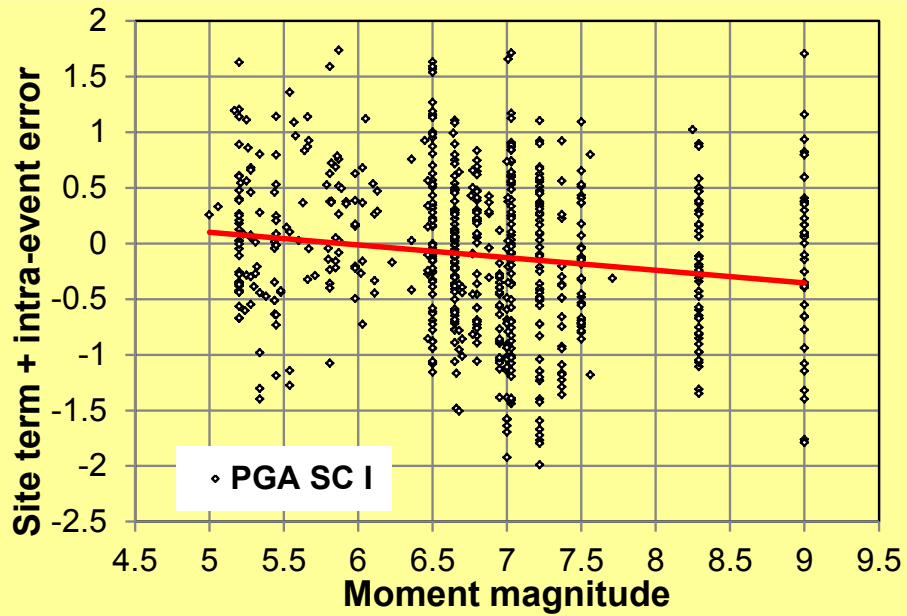
Site effect factor
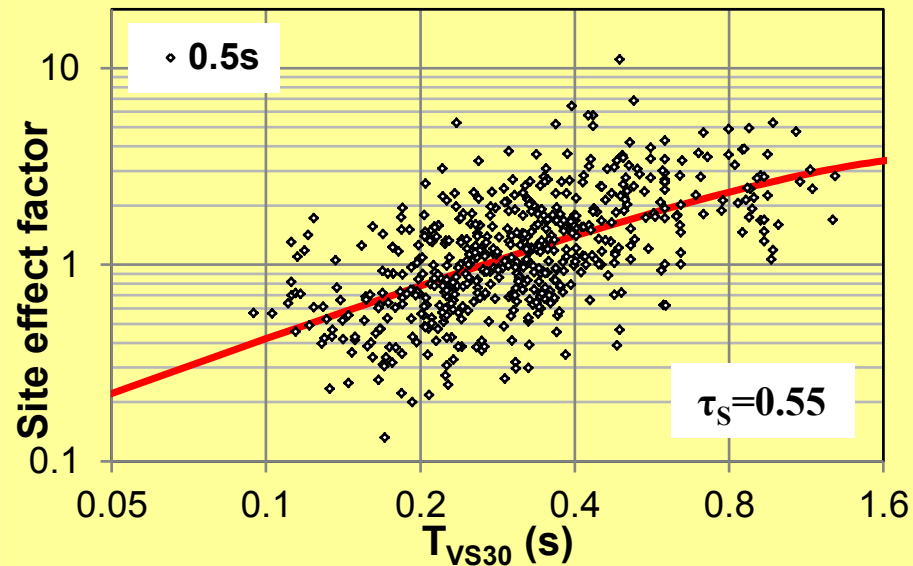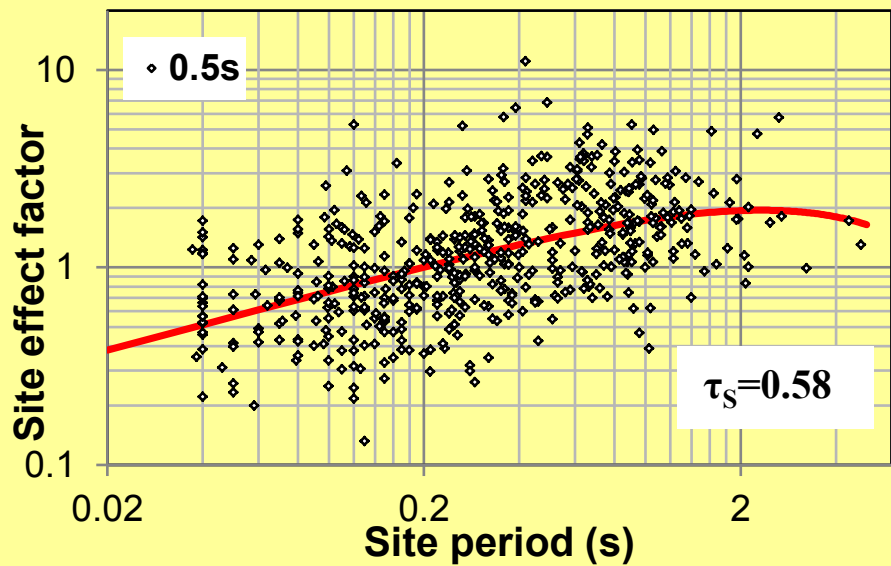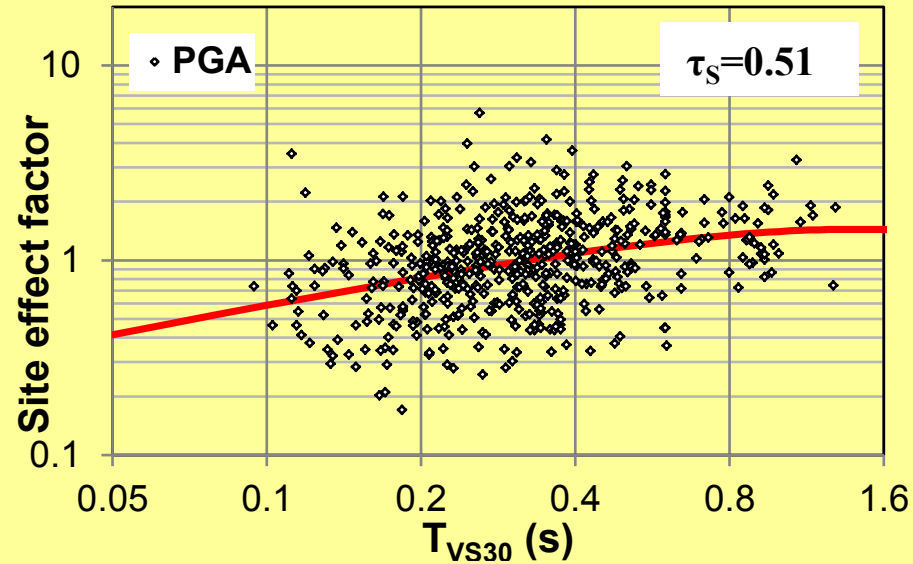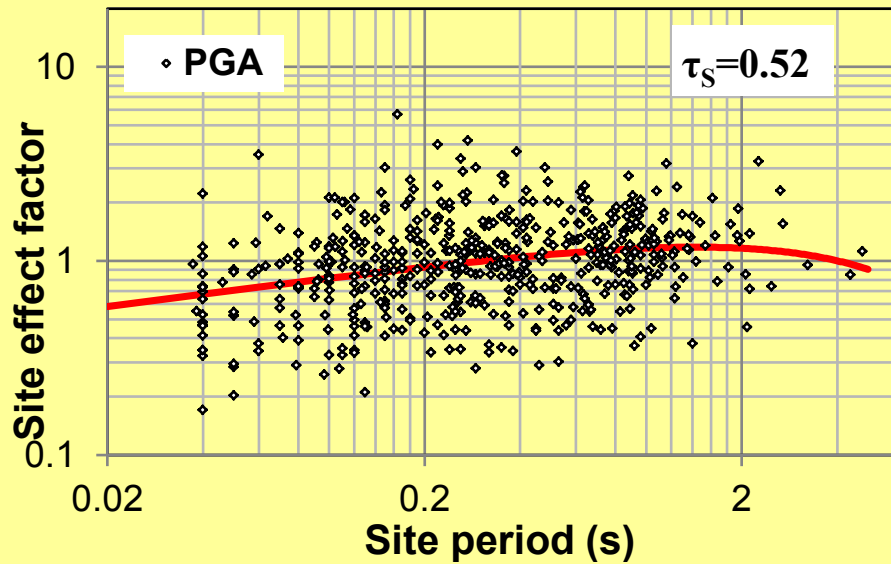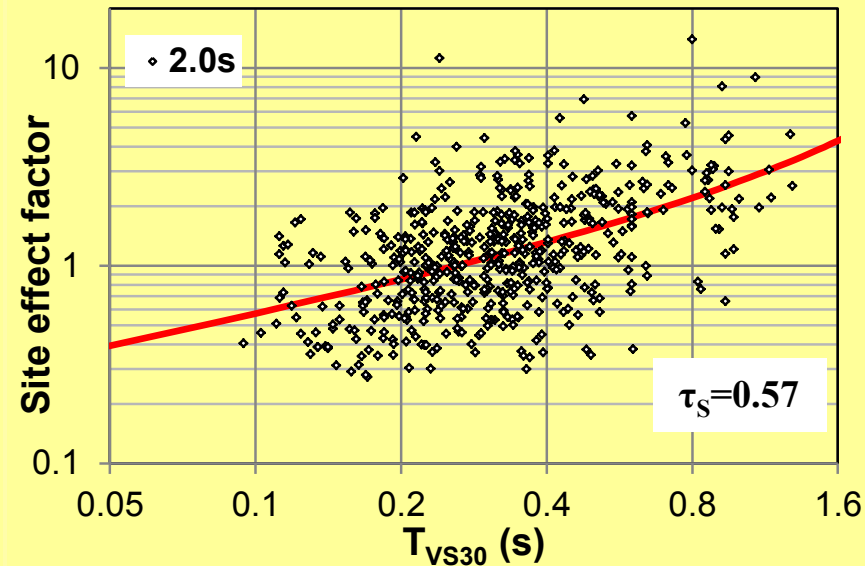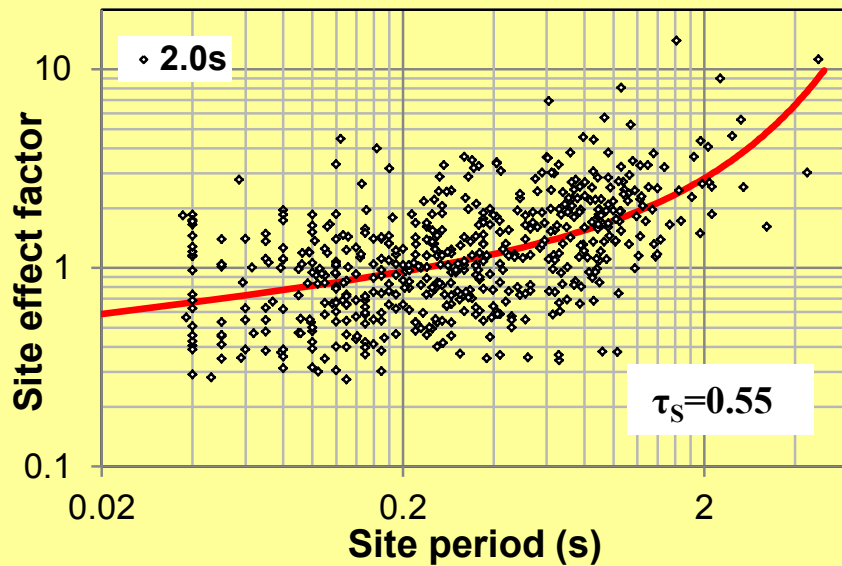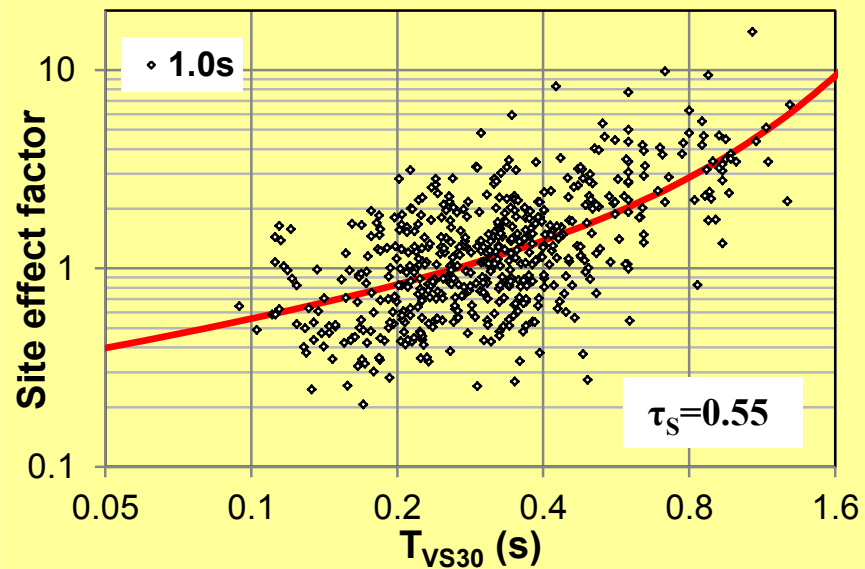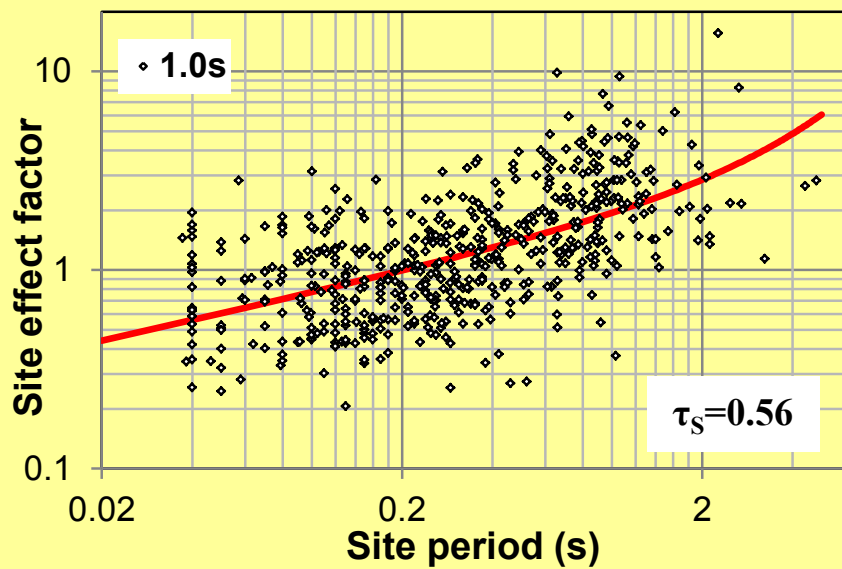
Site effect factor

Site effect factor
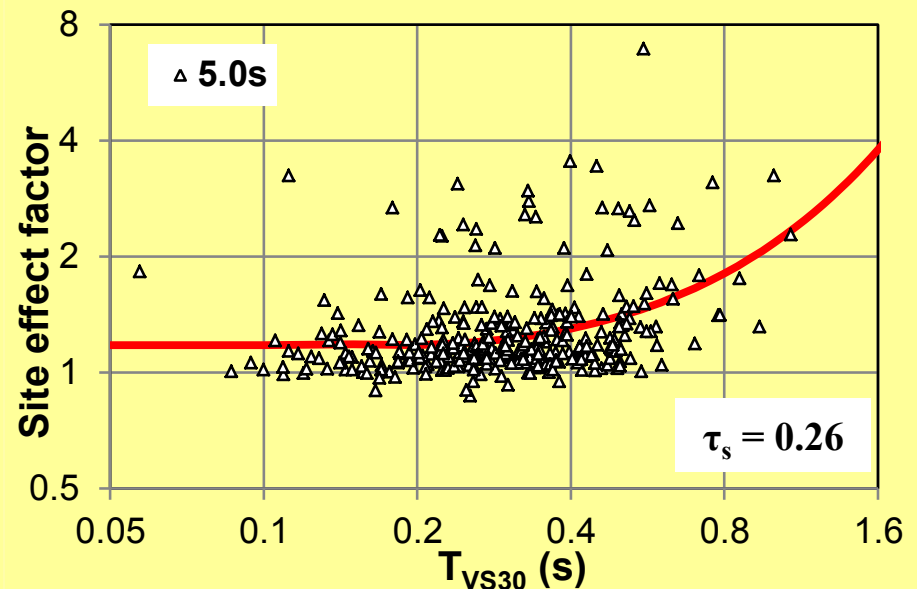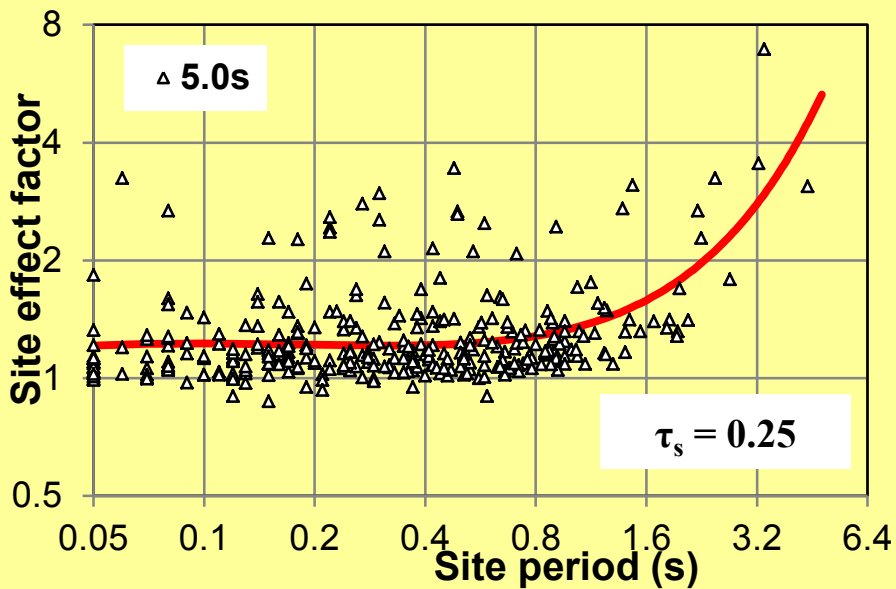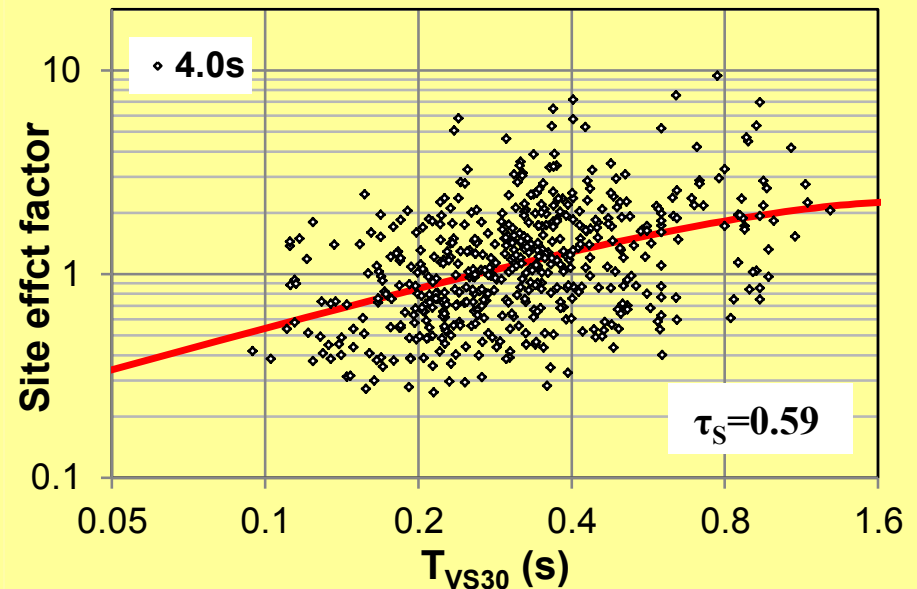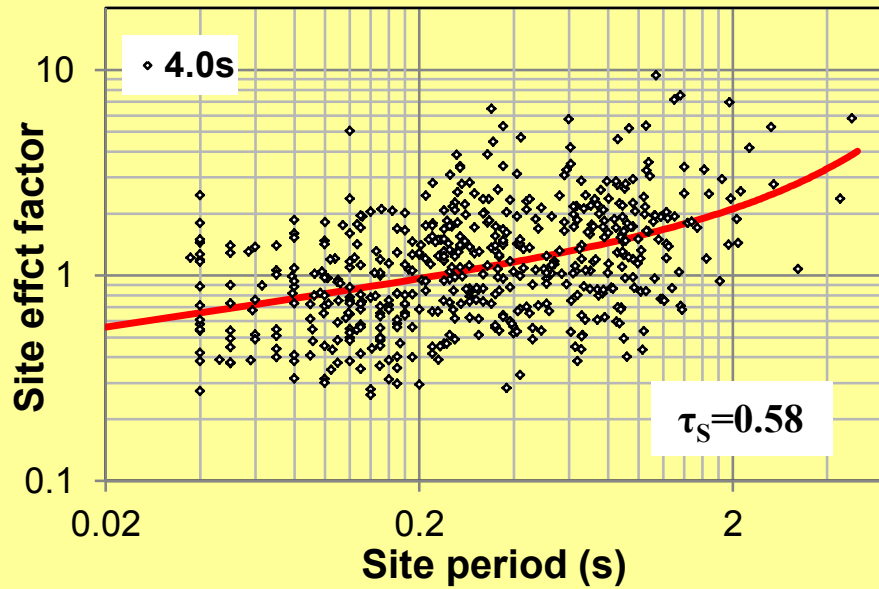
Inter-site variability
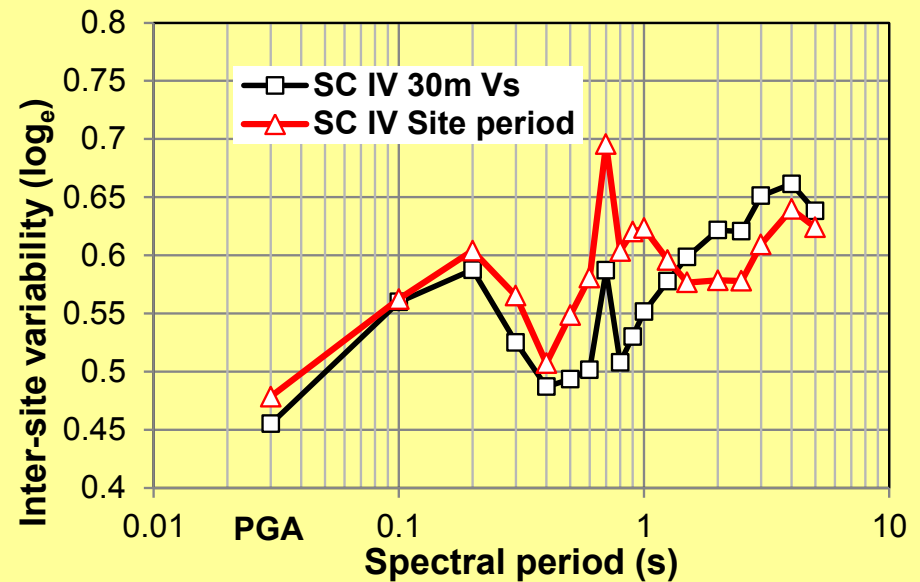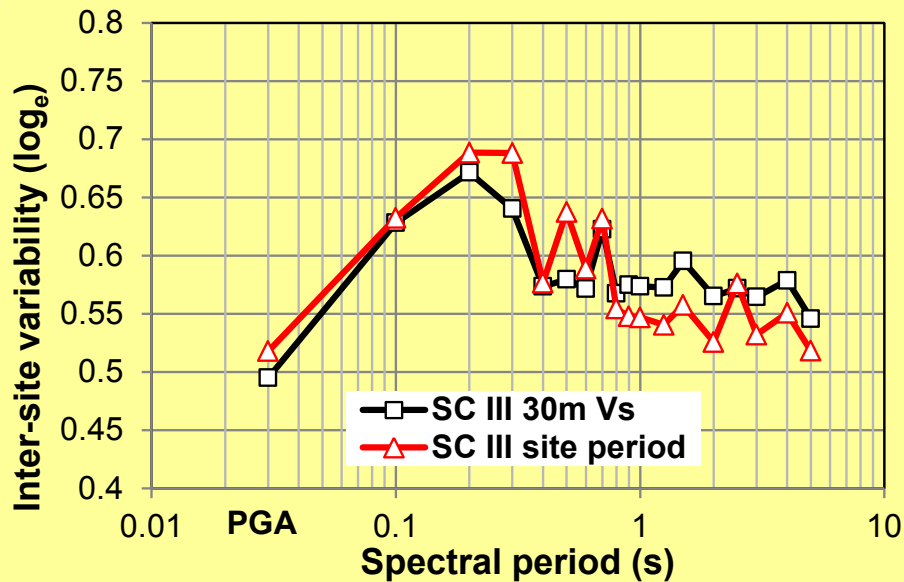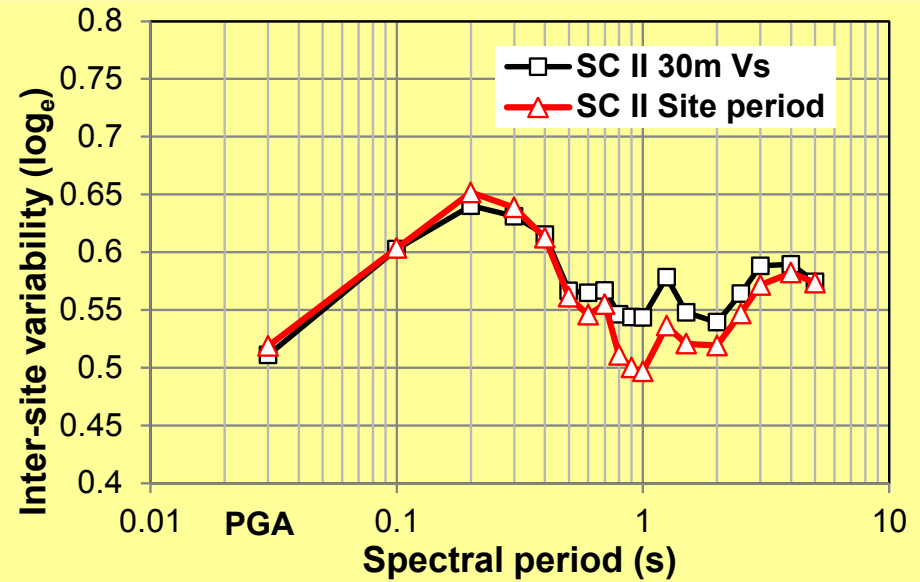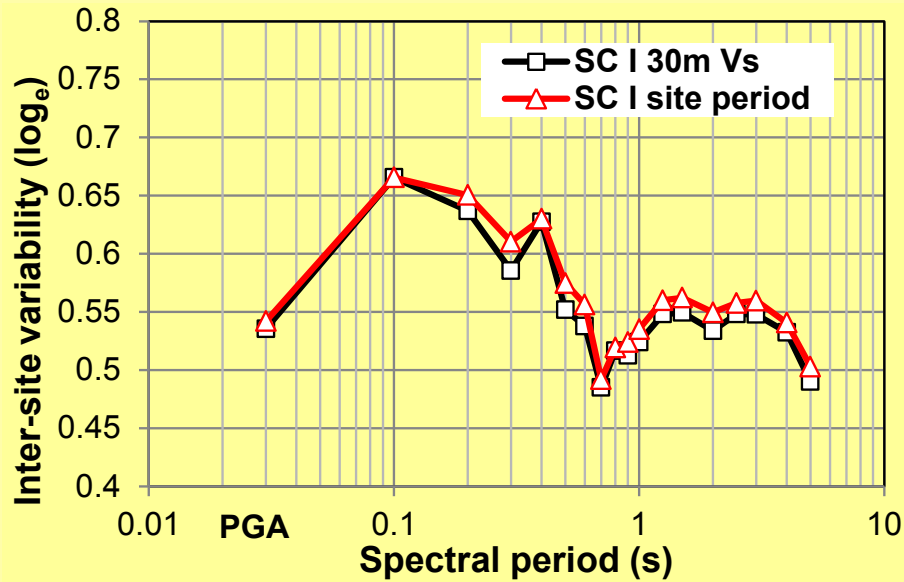
F-test probability for site period and T_{VS30}
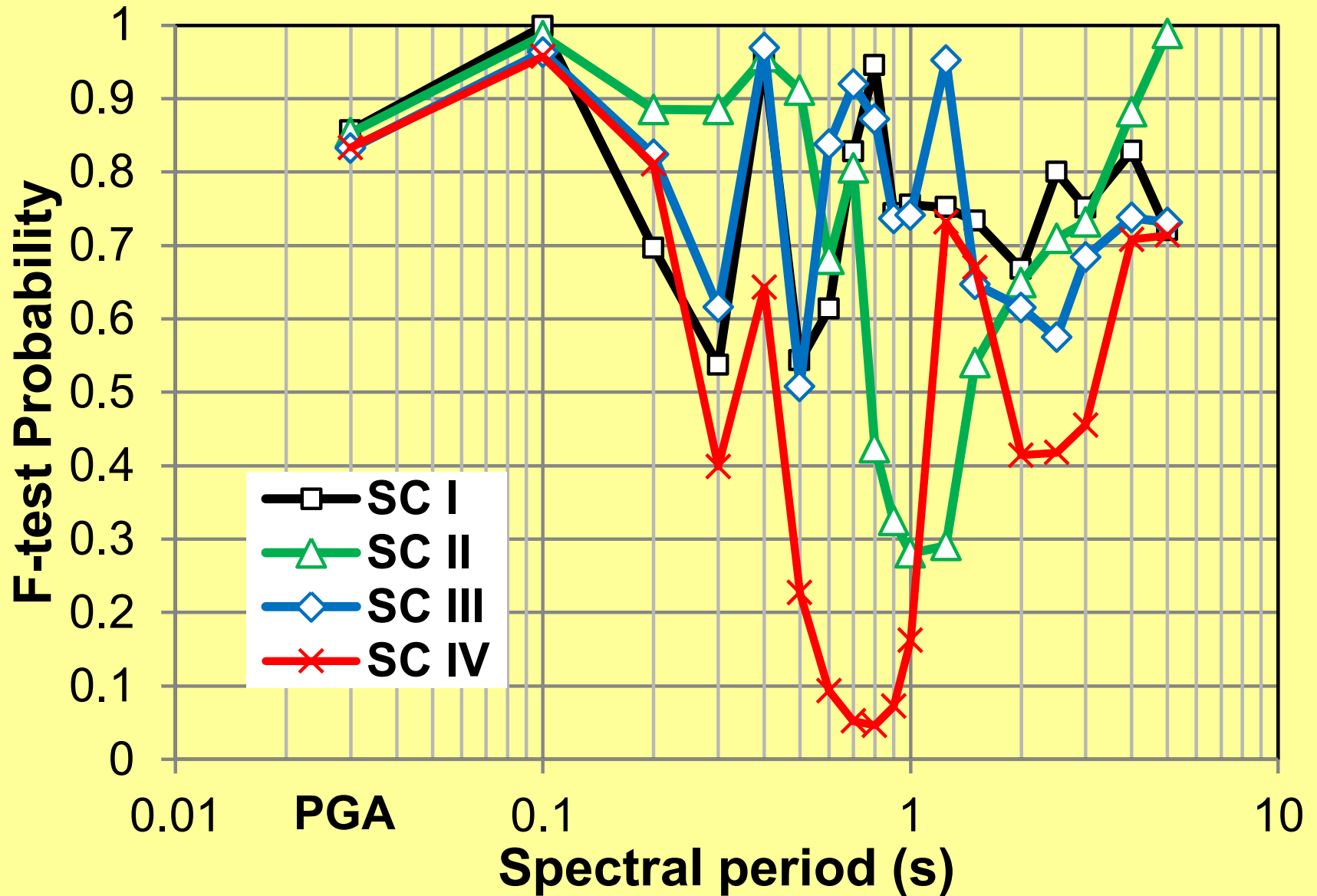
Site effects - more complex than we consider at present

The calculation of response spectrum is a nonlinear operation

$$SA(T) = max[\int_{0}^{T} \, peak \quad a(\tau)h(t-\tau)d\tau \,]$$

The ratio of two response spectra *does not cancel* source, and path effect contained in *a(t)*

Site effects - more complex than we consider at present

Response spectral amplification ratios depend on *frequency contents*

The best physical parameters to represent frequency contents are *magnitude, source distance and earthquake types*

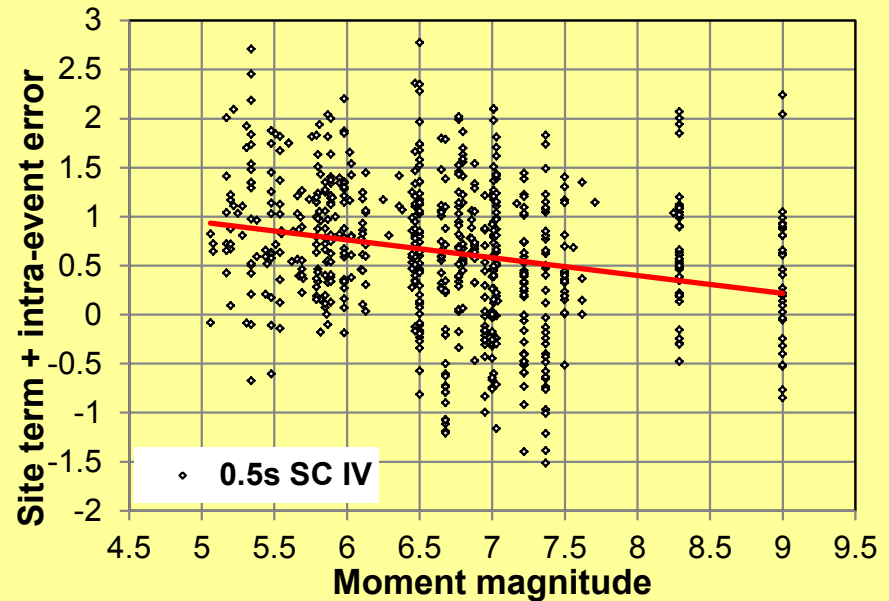**Magnitude-, source distance-, & earthquake type-dependent *amplification ratios***

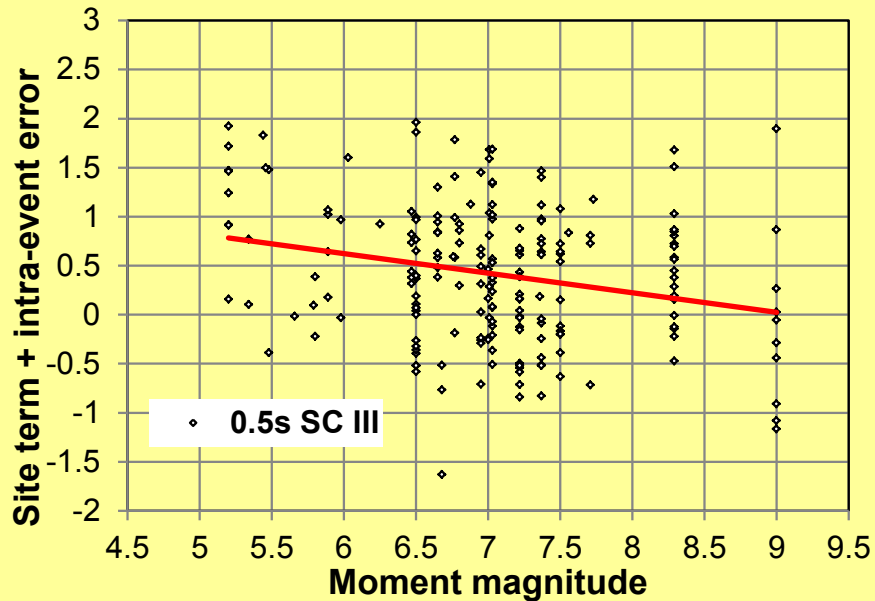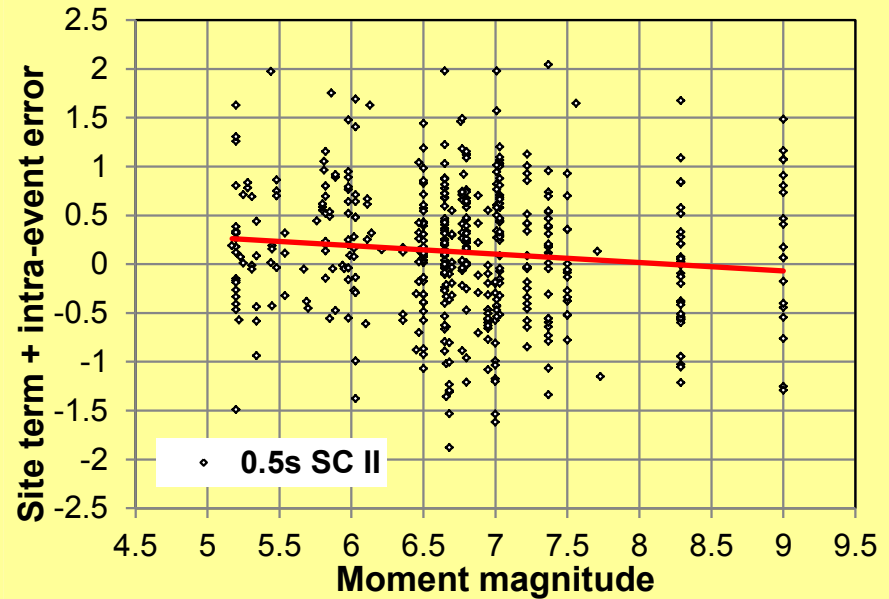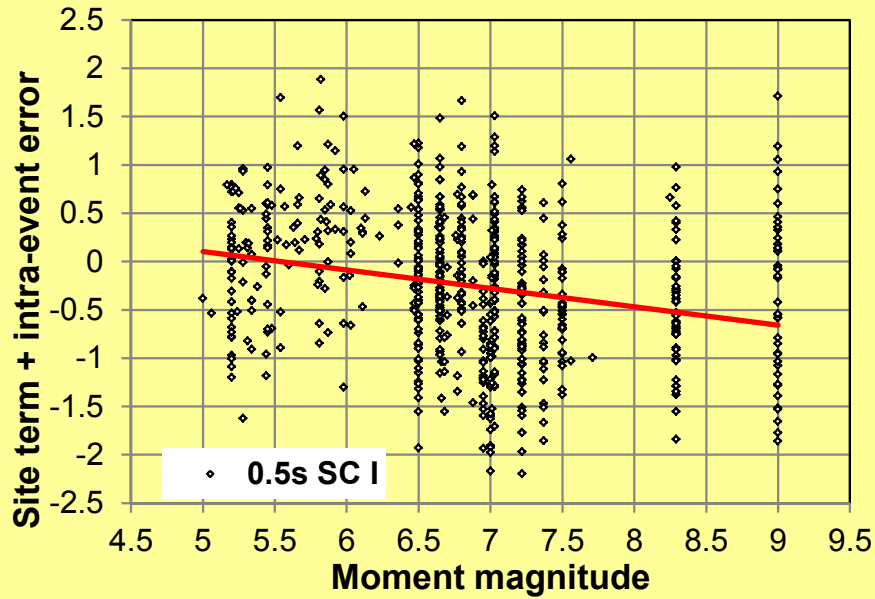# Magnitude-dependent amplification ratios for response spectra

σ_s & τ_s : constant ratio for each site class
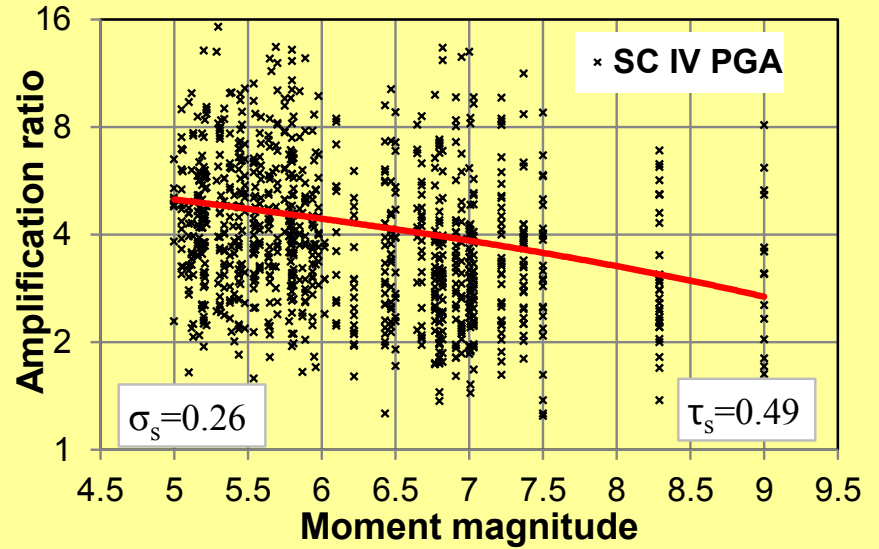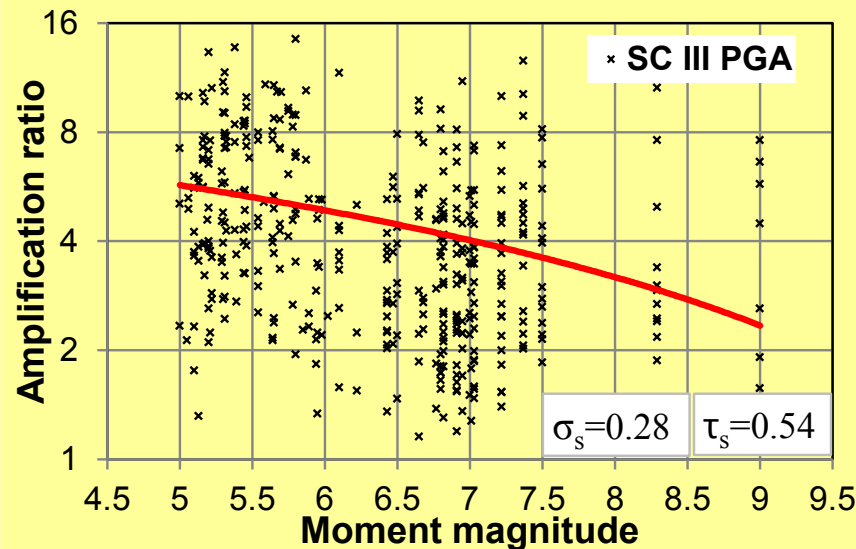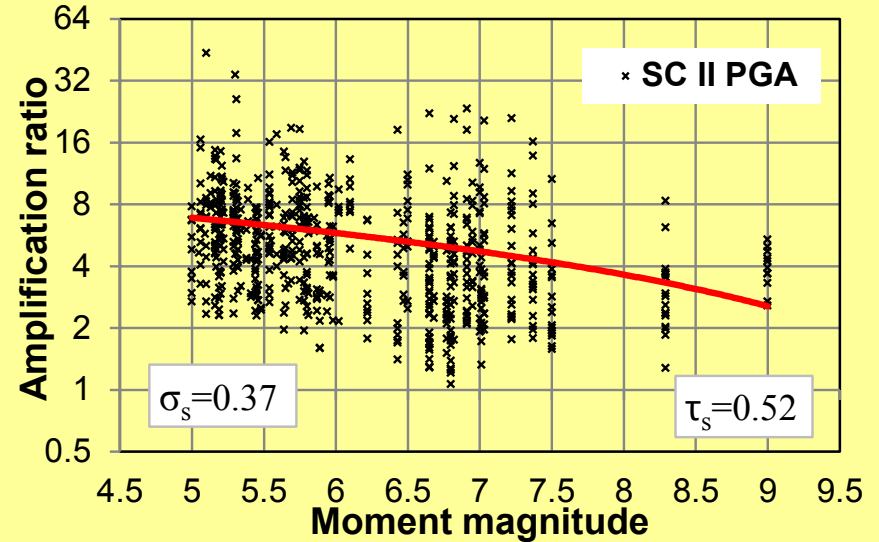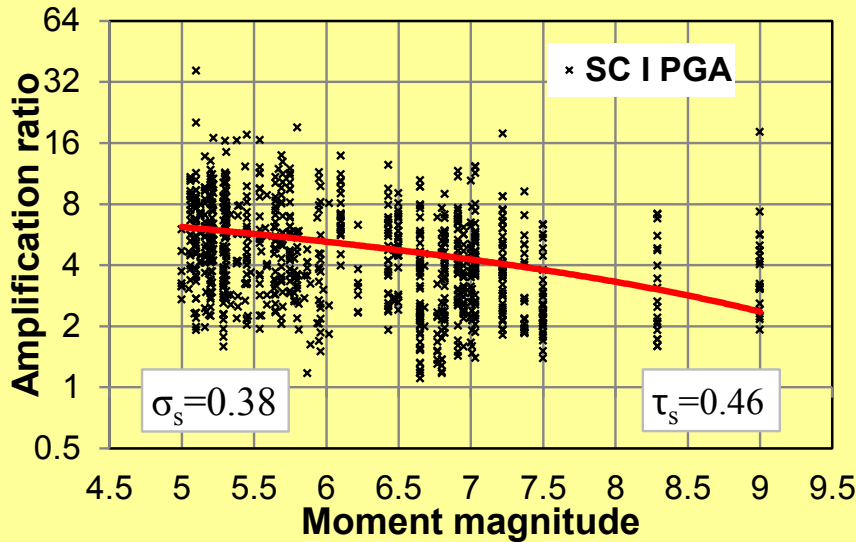
Magnitude-dependent amplification ratios for response spectra – Kik-net data
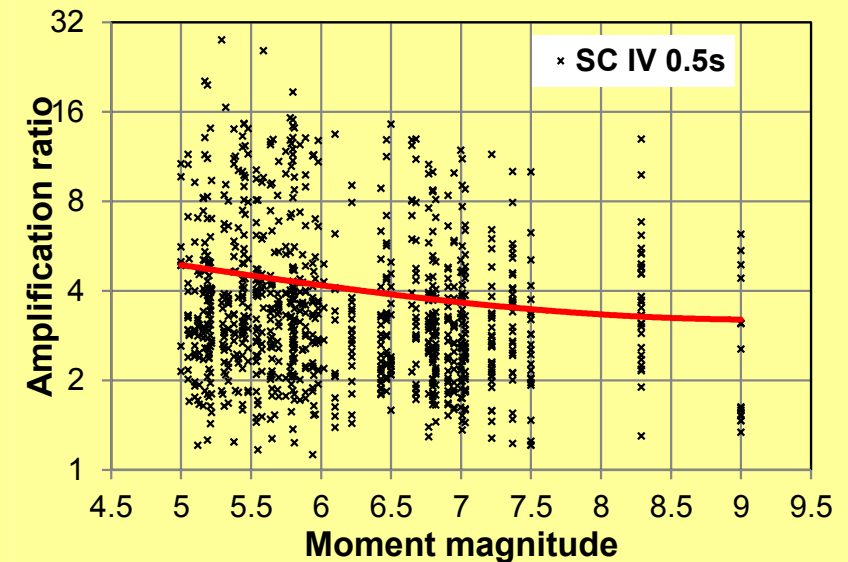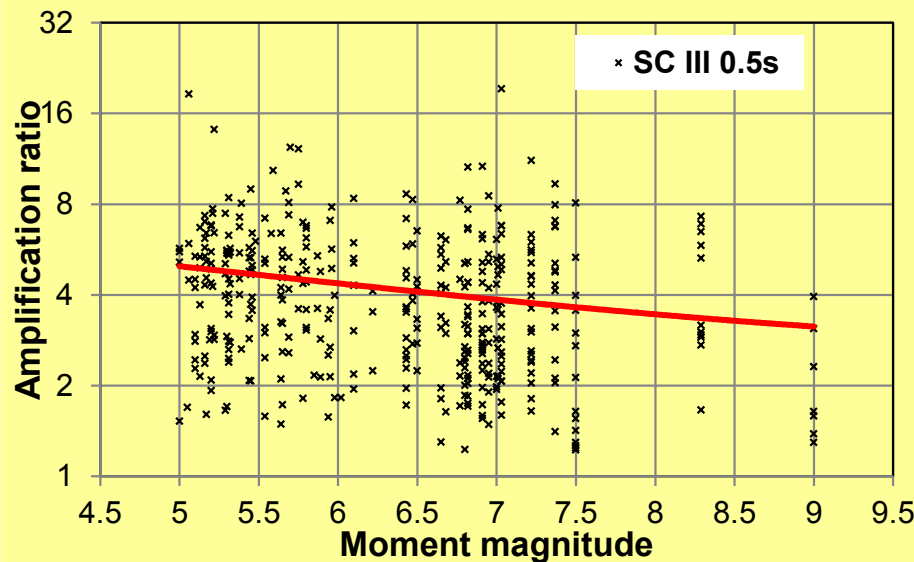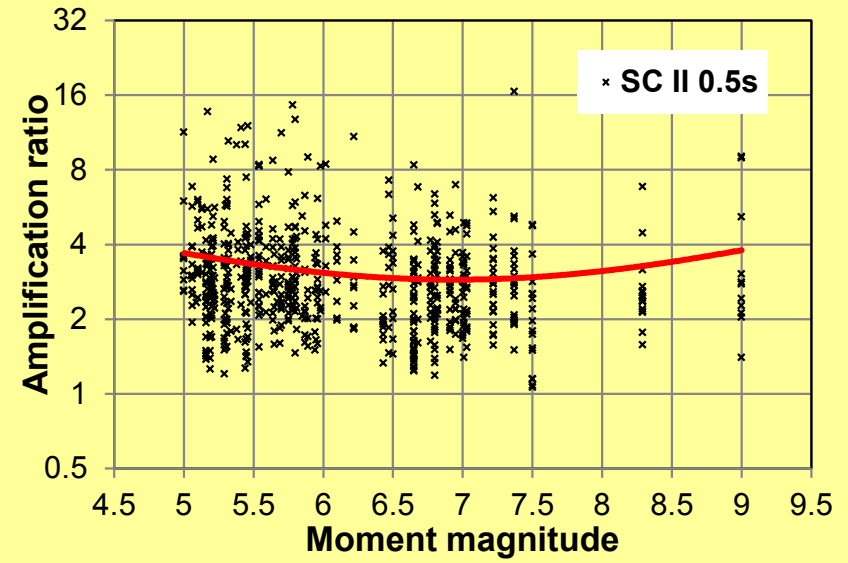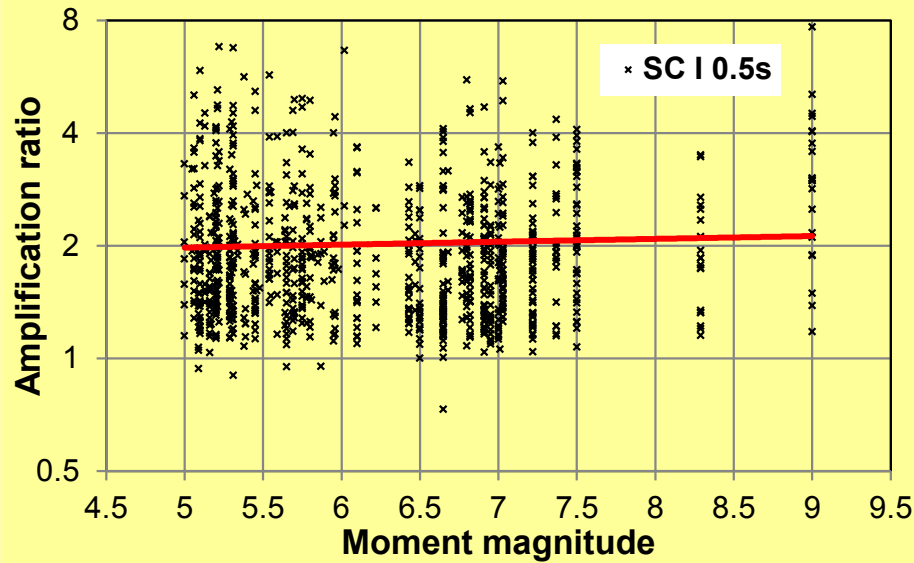
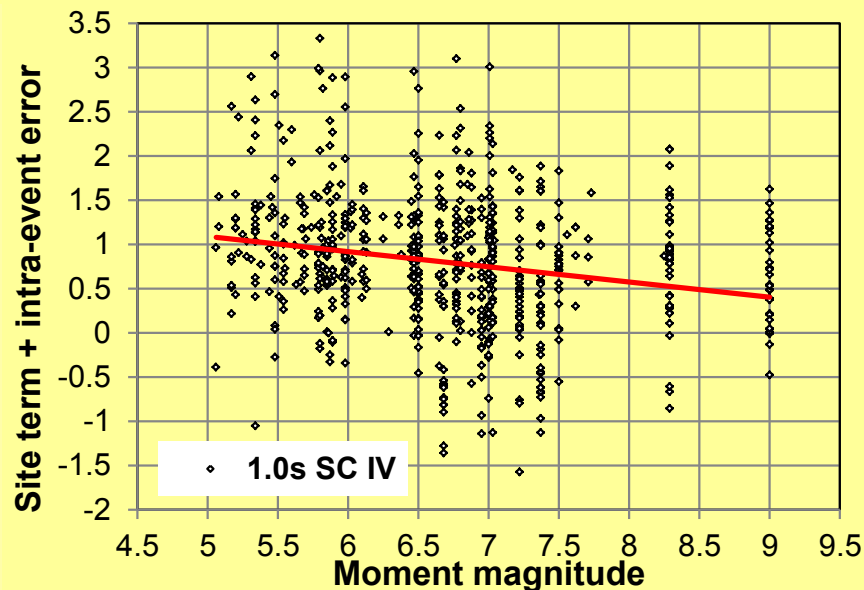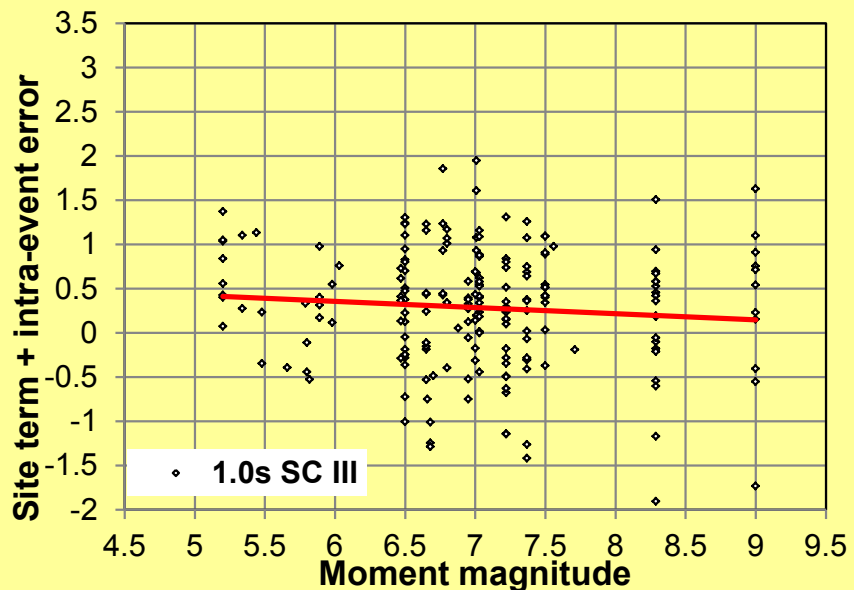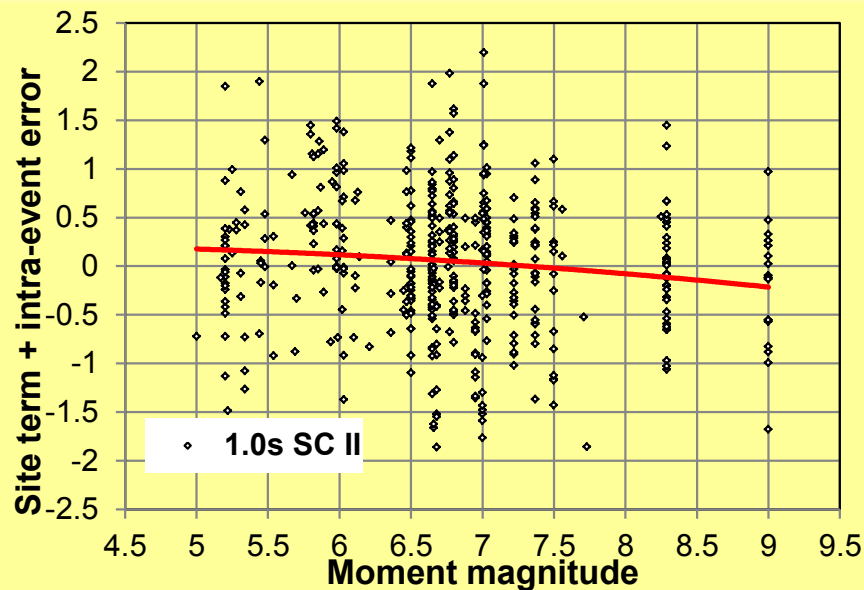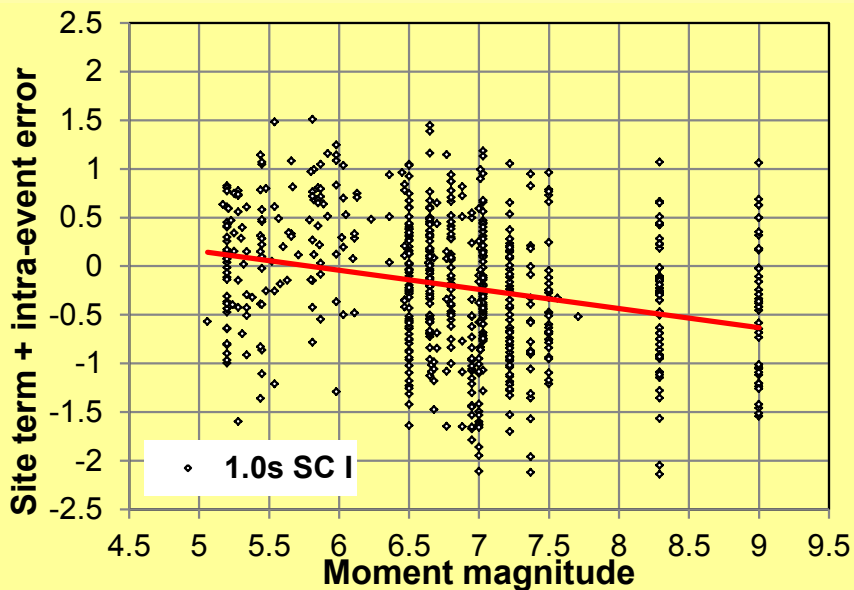# Magnitude-dependent amplification ratios for response spectra – Kik-net data
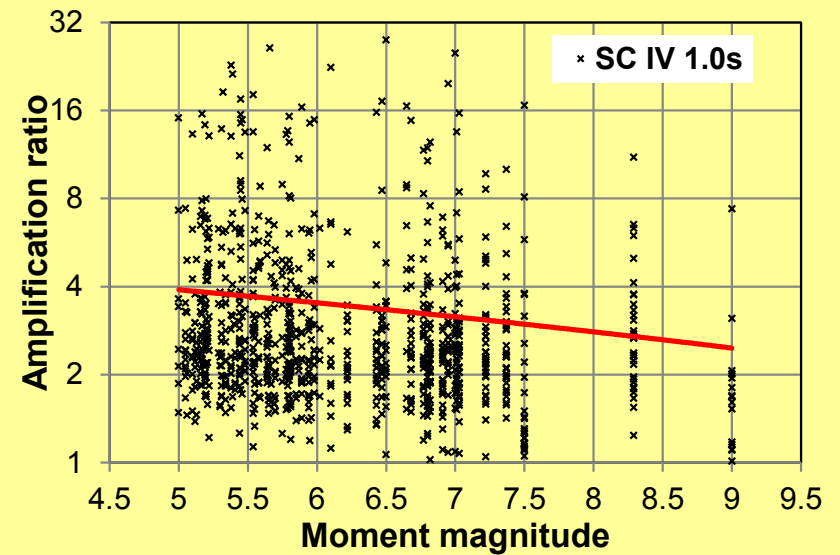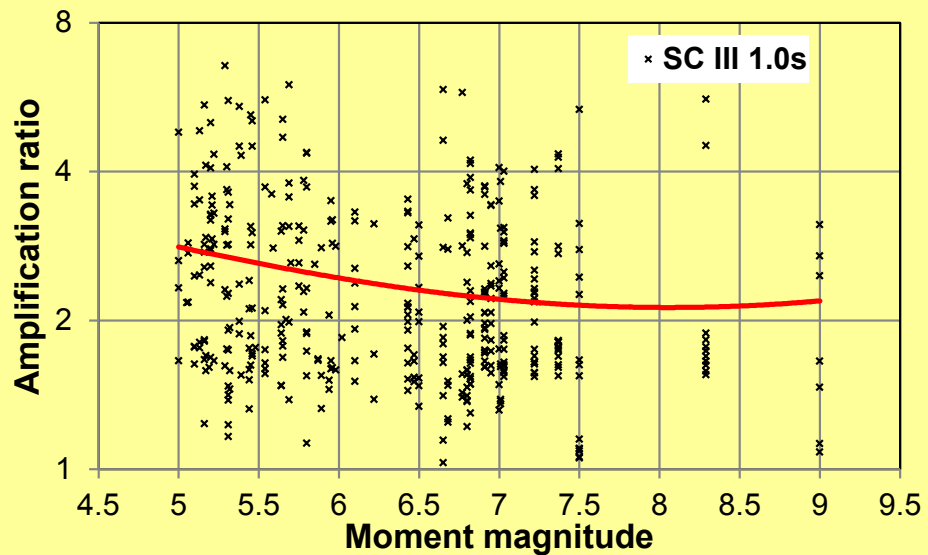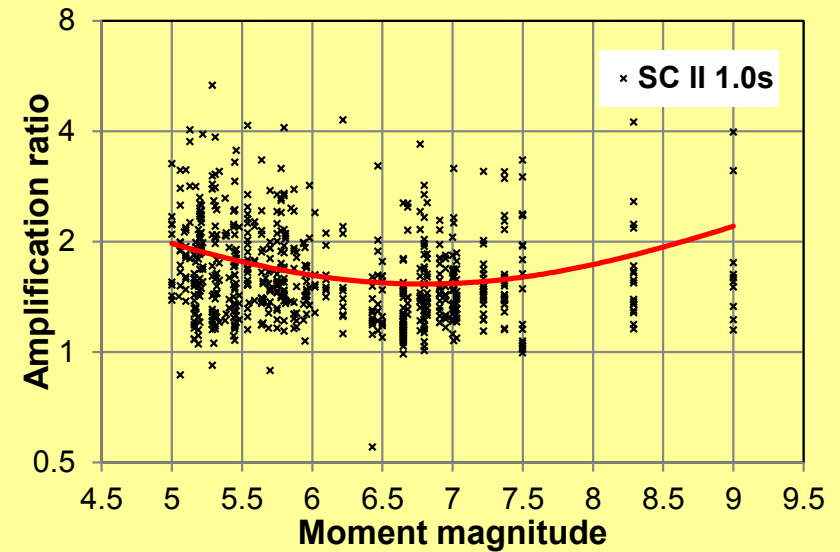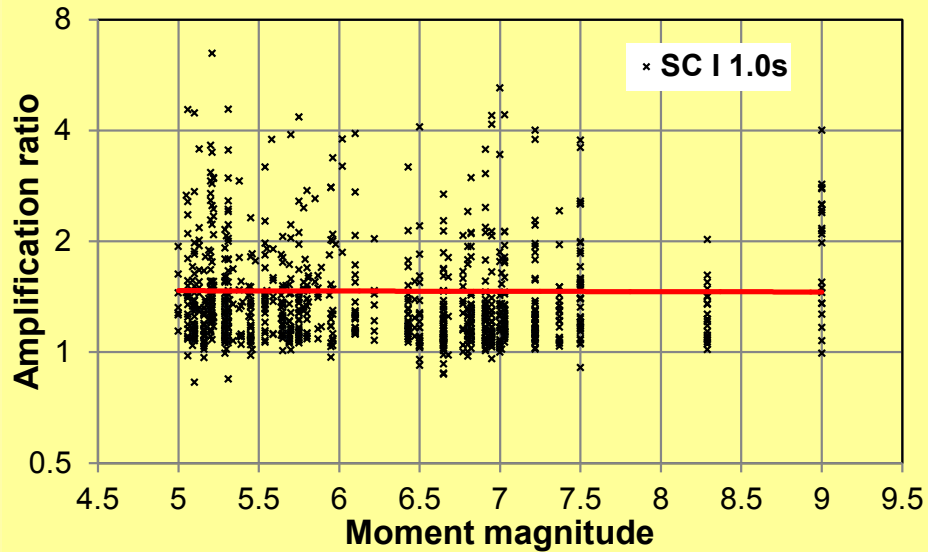
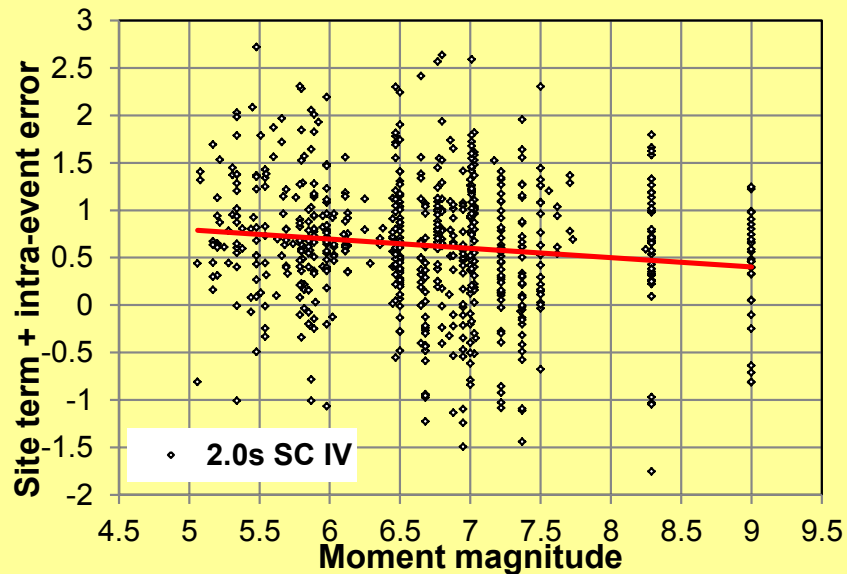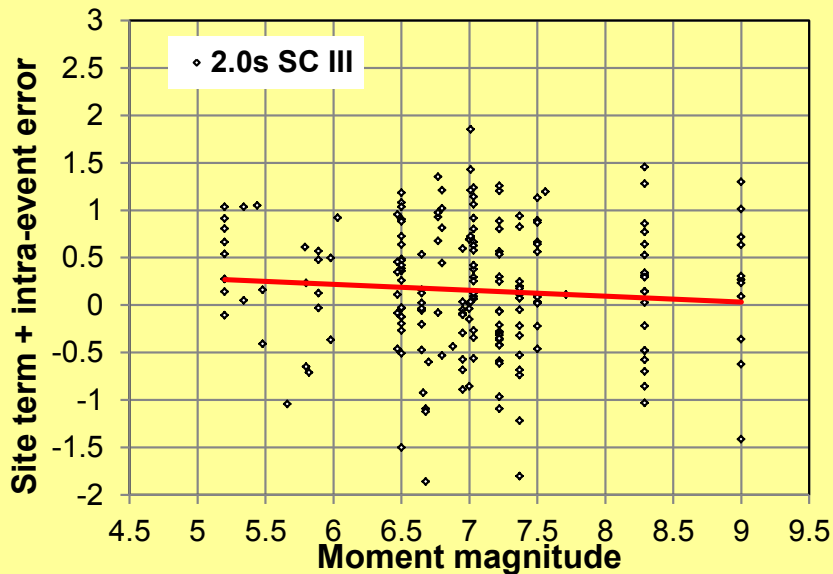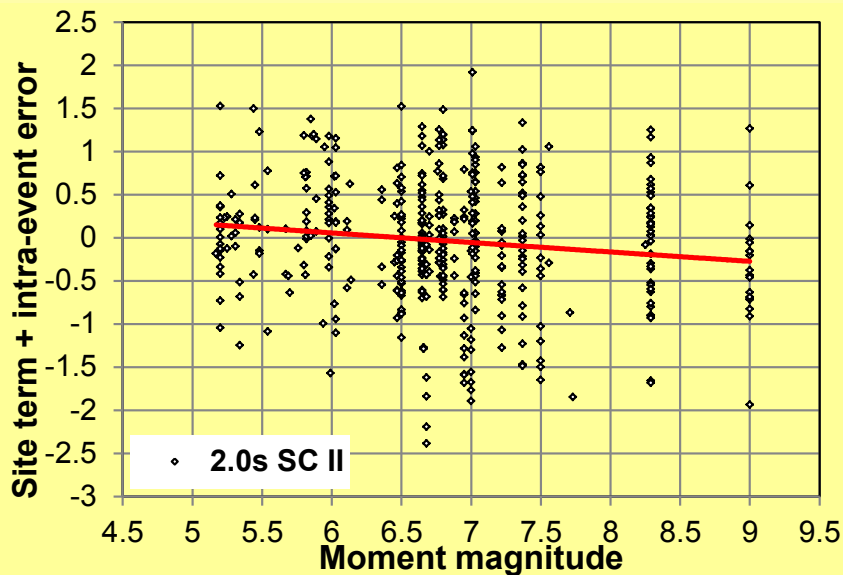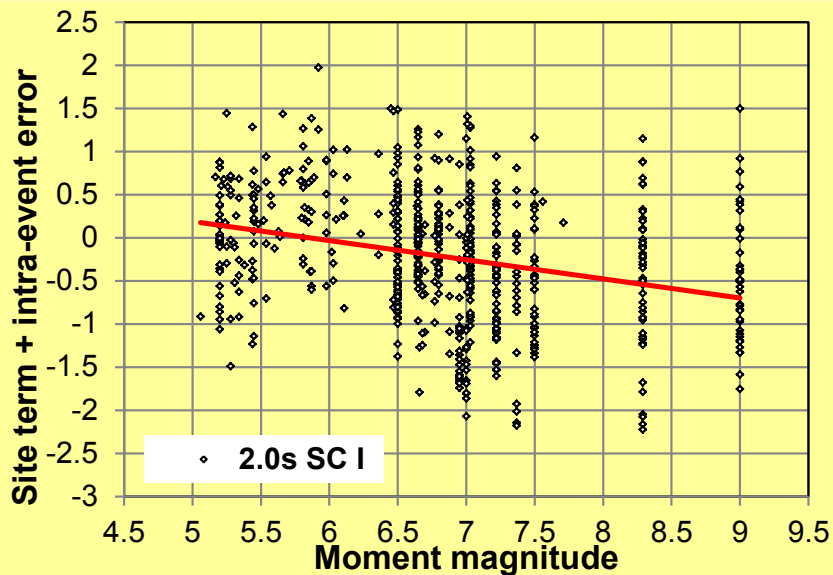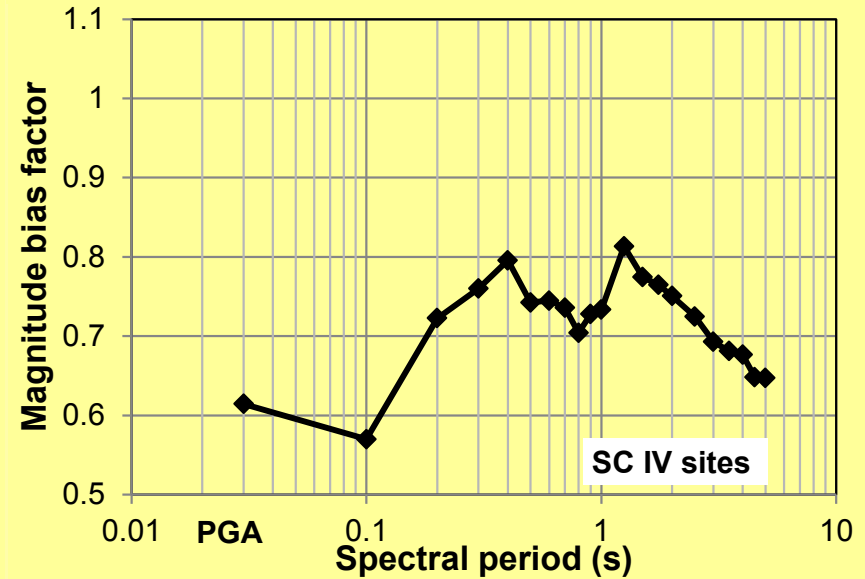# Distance-dependent amplification ratios for response spectra – Kik-net data
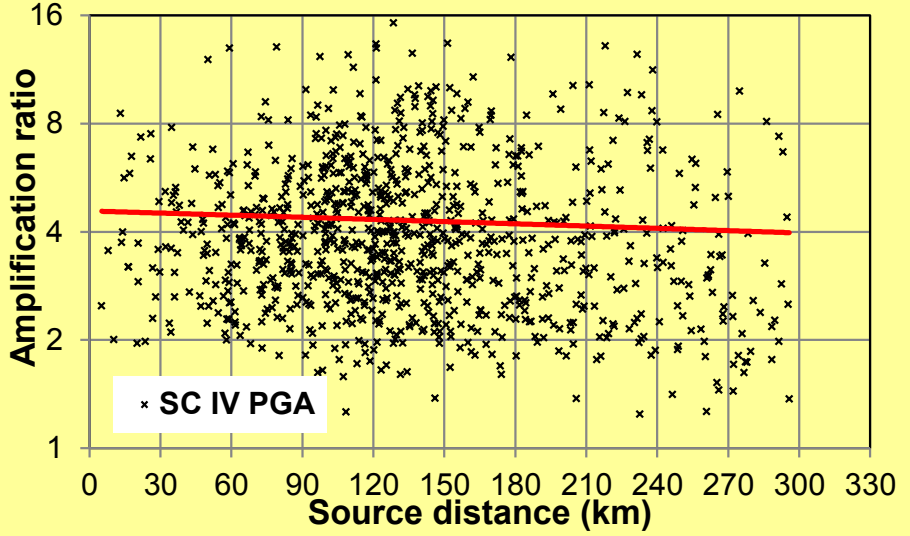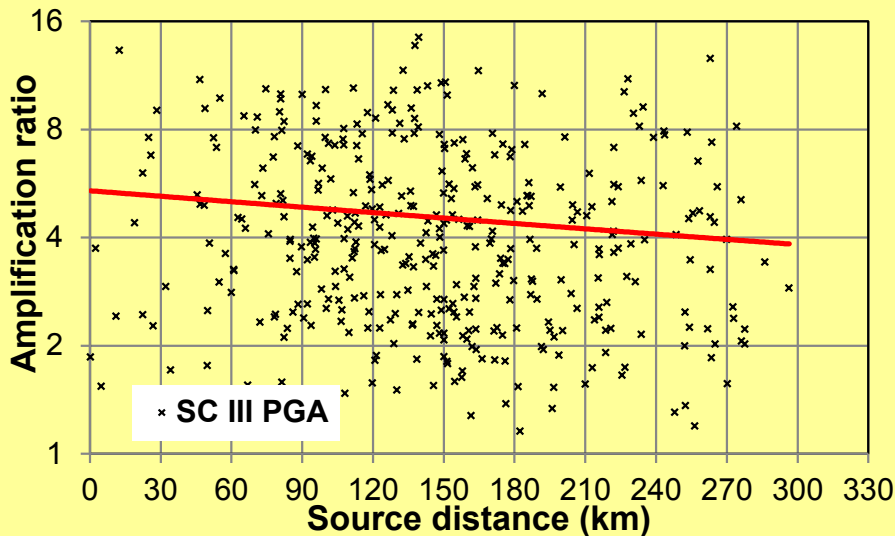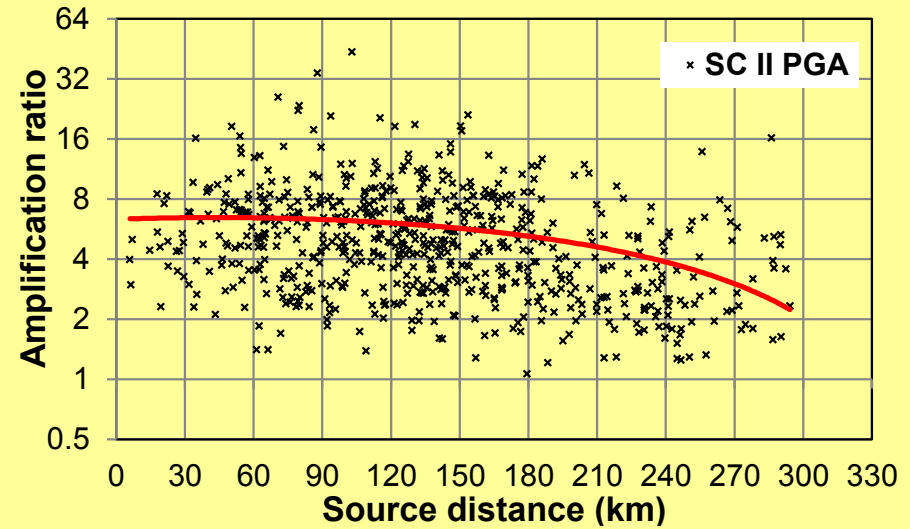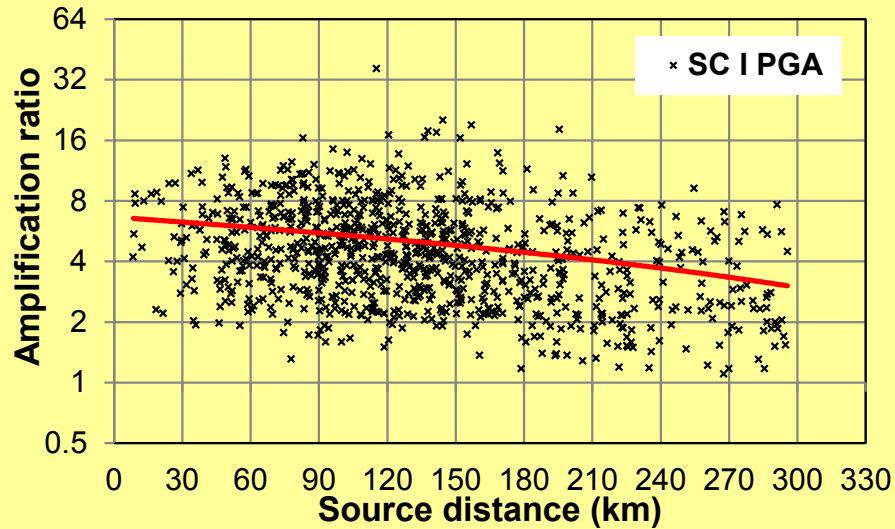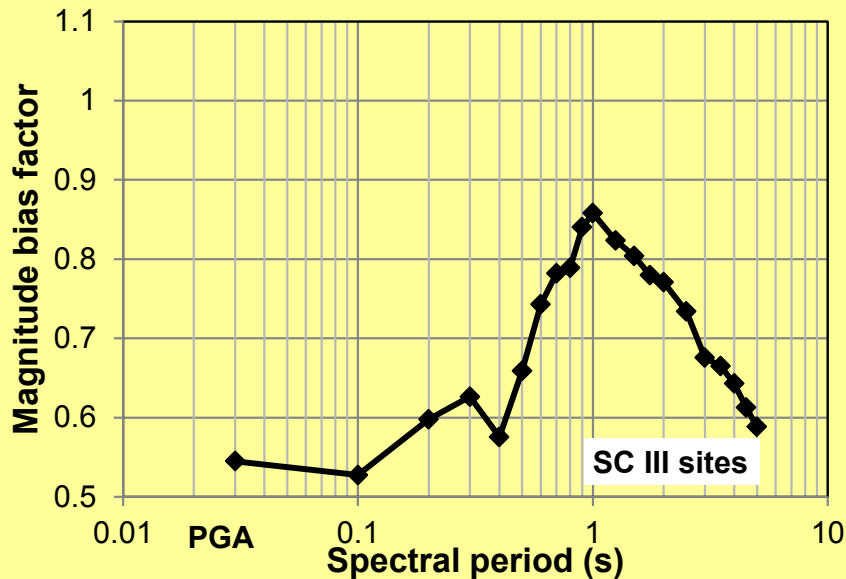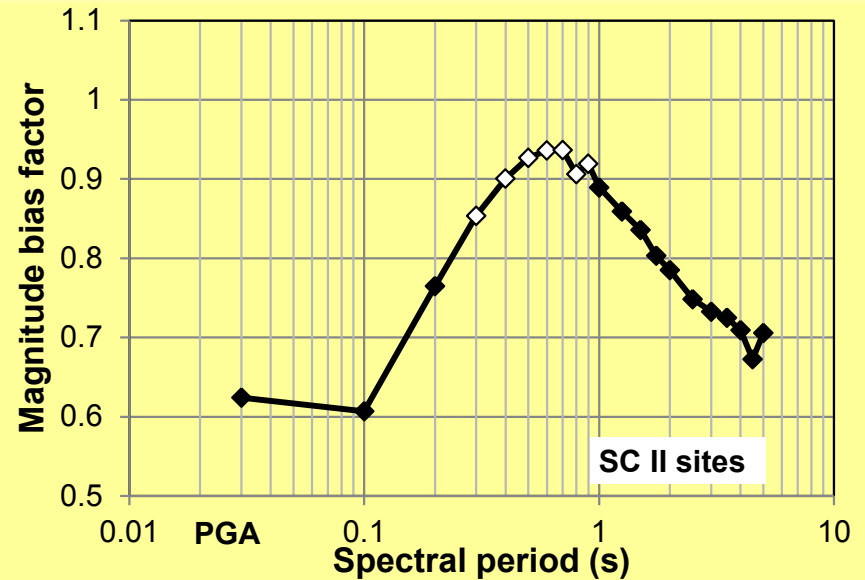
Intra-event residual + site terms Variation with magnitude (Zhao 2010 and 2011 data)

Intra-event residual + site terms Variation with magnitude (Zhao 2010 and 2011 data)
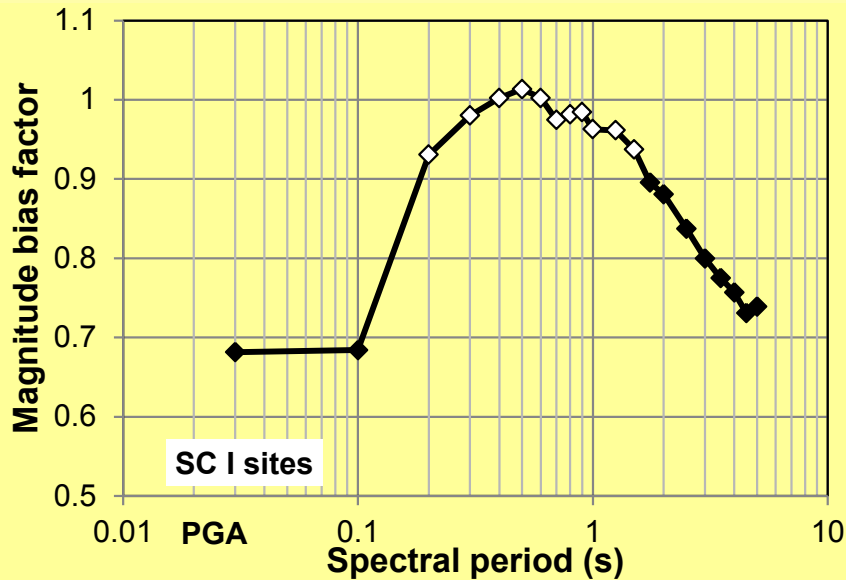
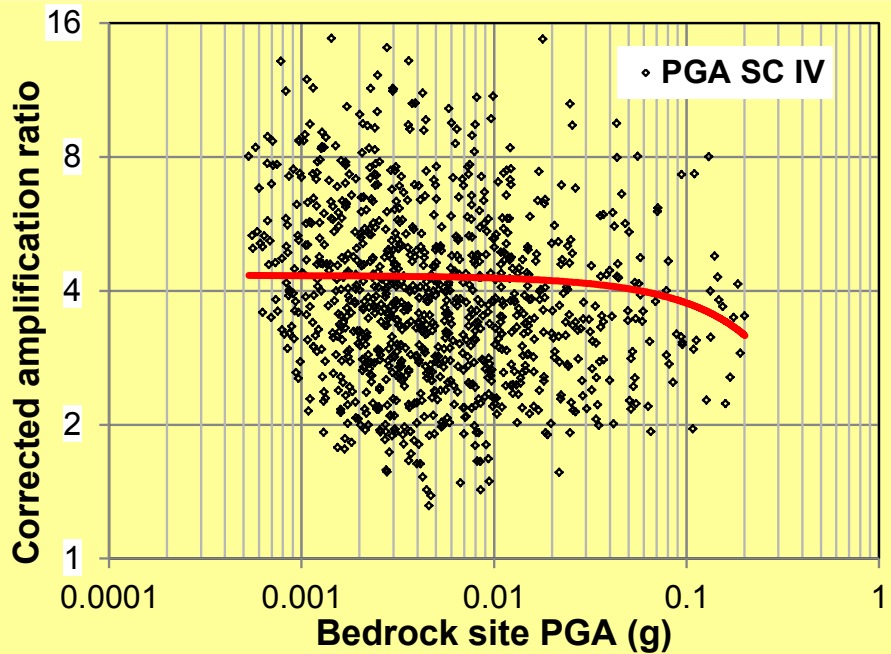# Intra-event residual + site terms Variation with magnitude (Zhao 2010 and 2011 data)
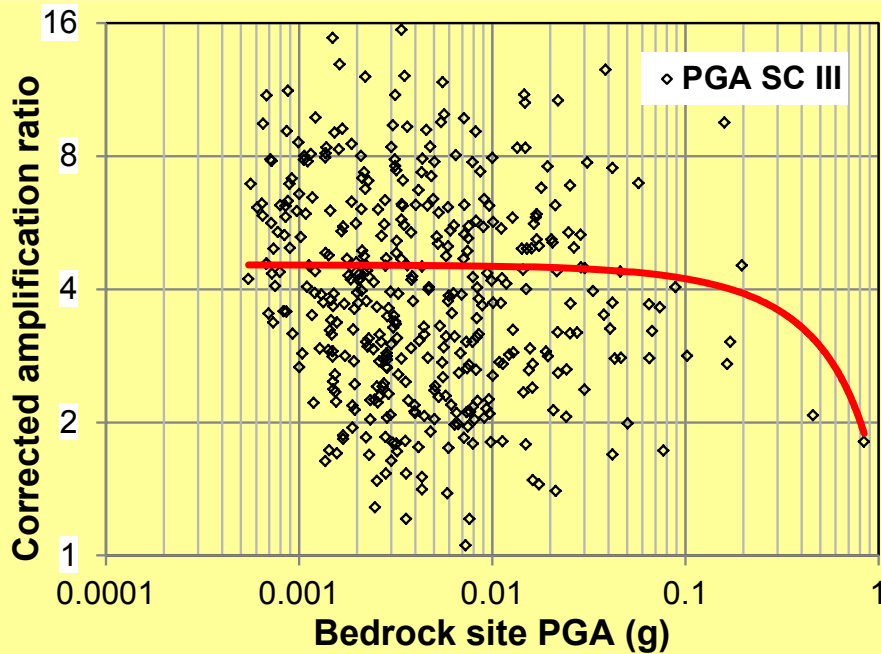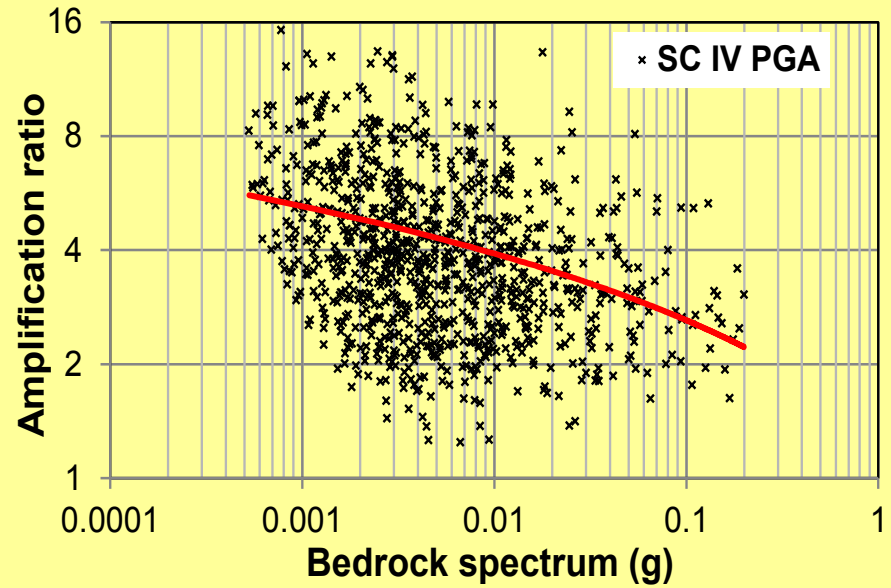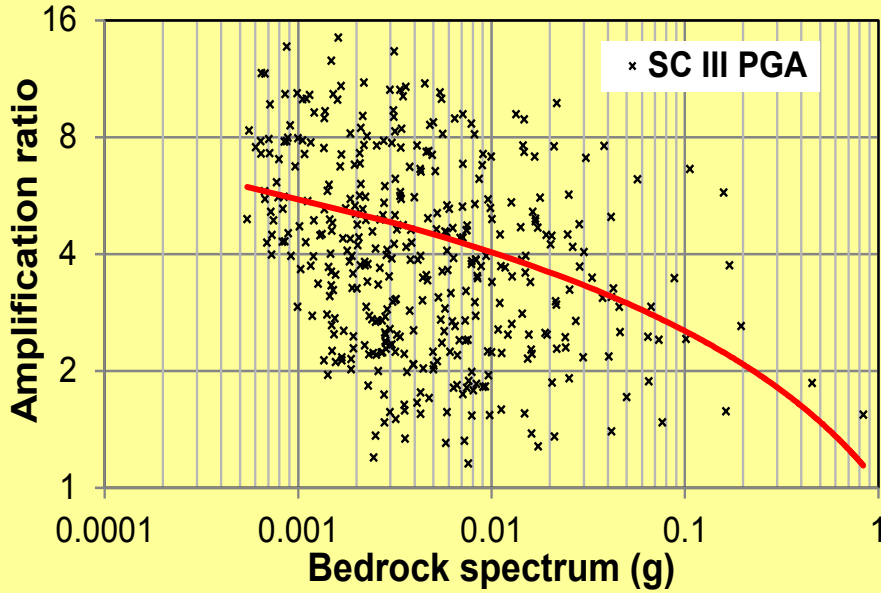
Amplification ratio for $M_W=8$ / $M_W=5$

Open diamond – not statistically significant – Kik-net data

Kik-net data: Nonlinear soil response ?

Conclusions

Real data shows *magnitude*- and *source distance*-dependent amplification ratios for response spectra

Thank you