Specifications For Building Instrumentation

Derek A. Skolnik
Robert L. Nigbor and John W. Wallace

DAS SPECIFICATIONS

SMIP Specifications

- Recommended specifications for civil structures (buildings)
- Based on qualitative assessment and experience

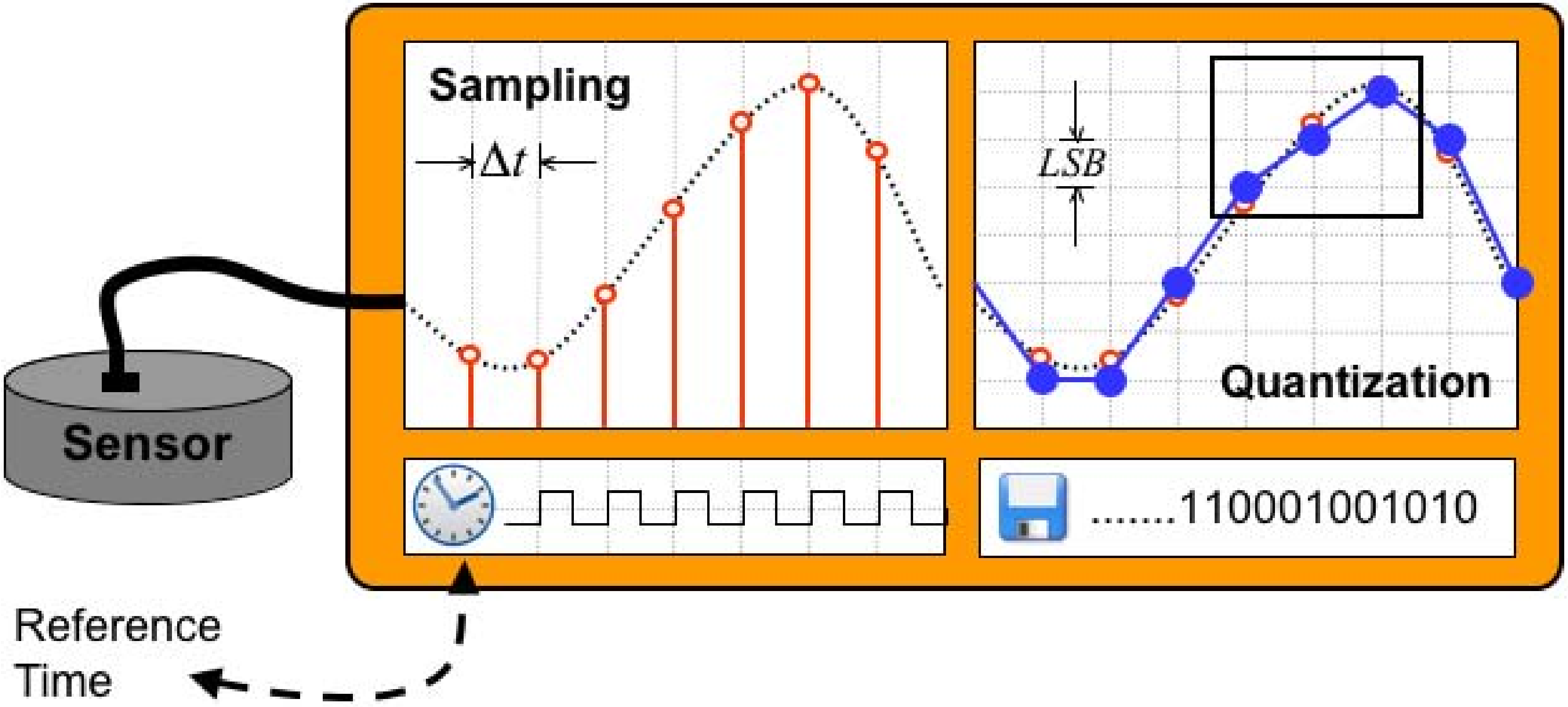
Recommended Specification	ANSS (USGS 2005)	CSMIP (CGS 2007)	
Sensor Range	±4g	± 4g	R (bits/g)
ADC Resolution	16bits	18bits	
Sample Rate	200sps	200sps	S (sps)
Sample Sync	1% Δt	0.2ms	T_{se} (ms)
Reference Time	1.0ms	0.5ms	
Clock Stability	0.1ppm	1min/month	

Guideline for ANSS Seismic Monitoring of Engineered Civil Systems, USGS Report 2005-1039

Integrated Tri-Axial Accelerograph, CGS/DGS SYSREQ 2007-TR

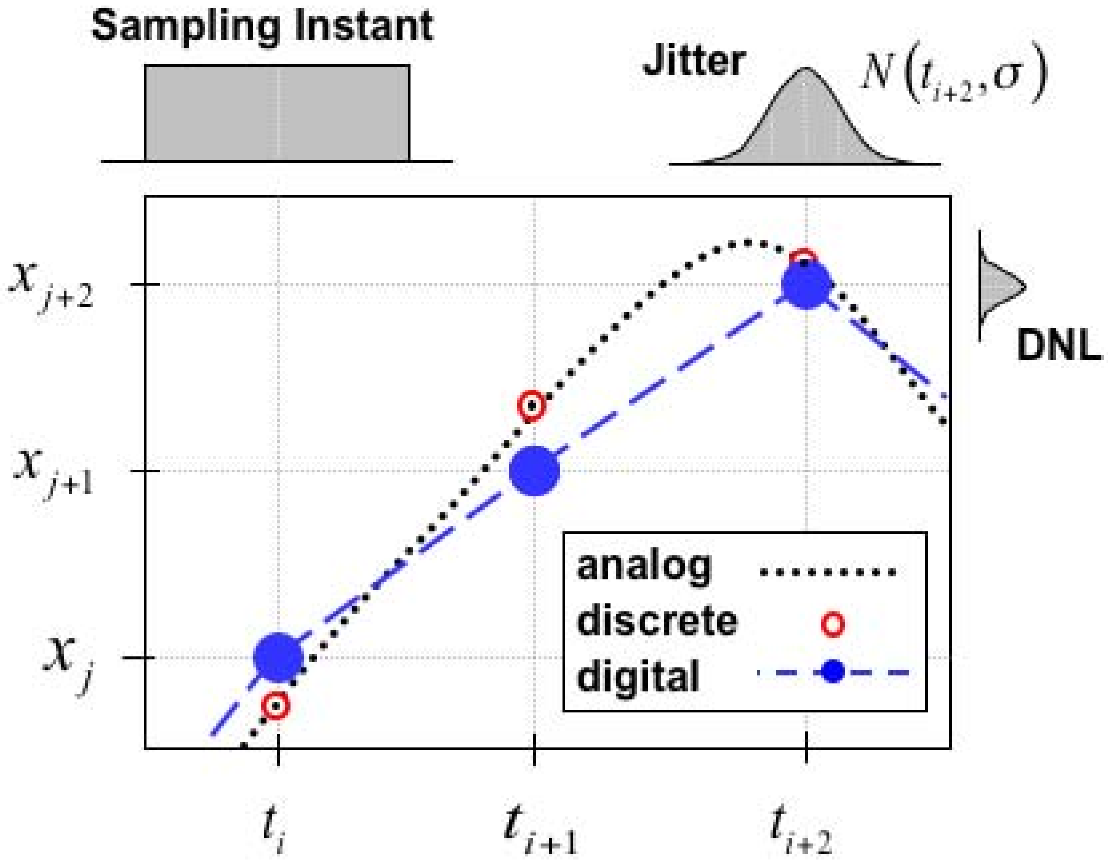
Data Acquisition Systems (DAS)

- Sampling – sample rate ($sps = 1 / \Delta t$)
- Quantization – resolution ($LSB = Range / 2^{Bits}$)
- Time stamp for synchronization of multiple channels



Data Acquisition Errors

- Sampling – initial sampling instant and clock jitter
- Quantization – Differential Non-Linearity (DNL)

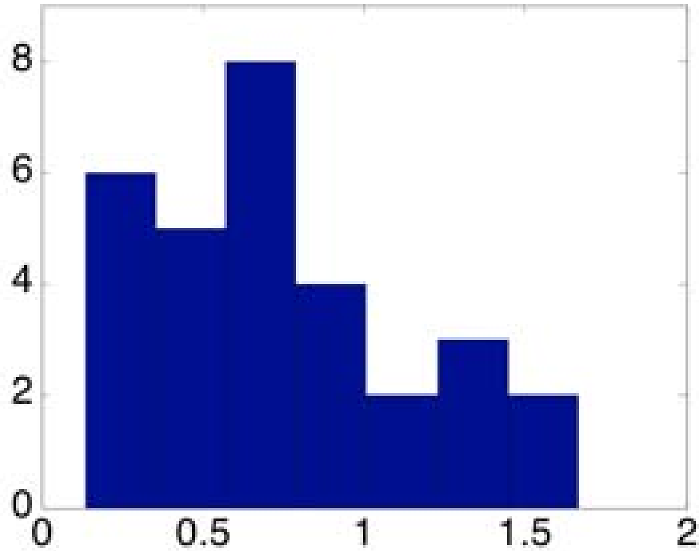


OUTLINE

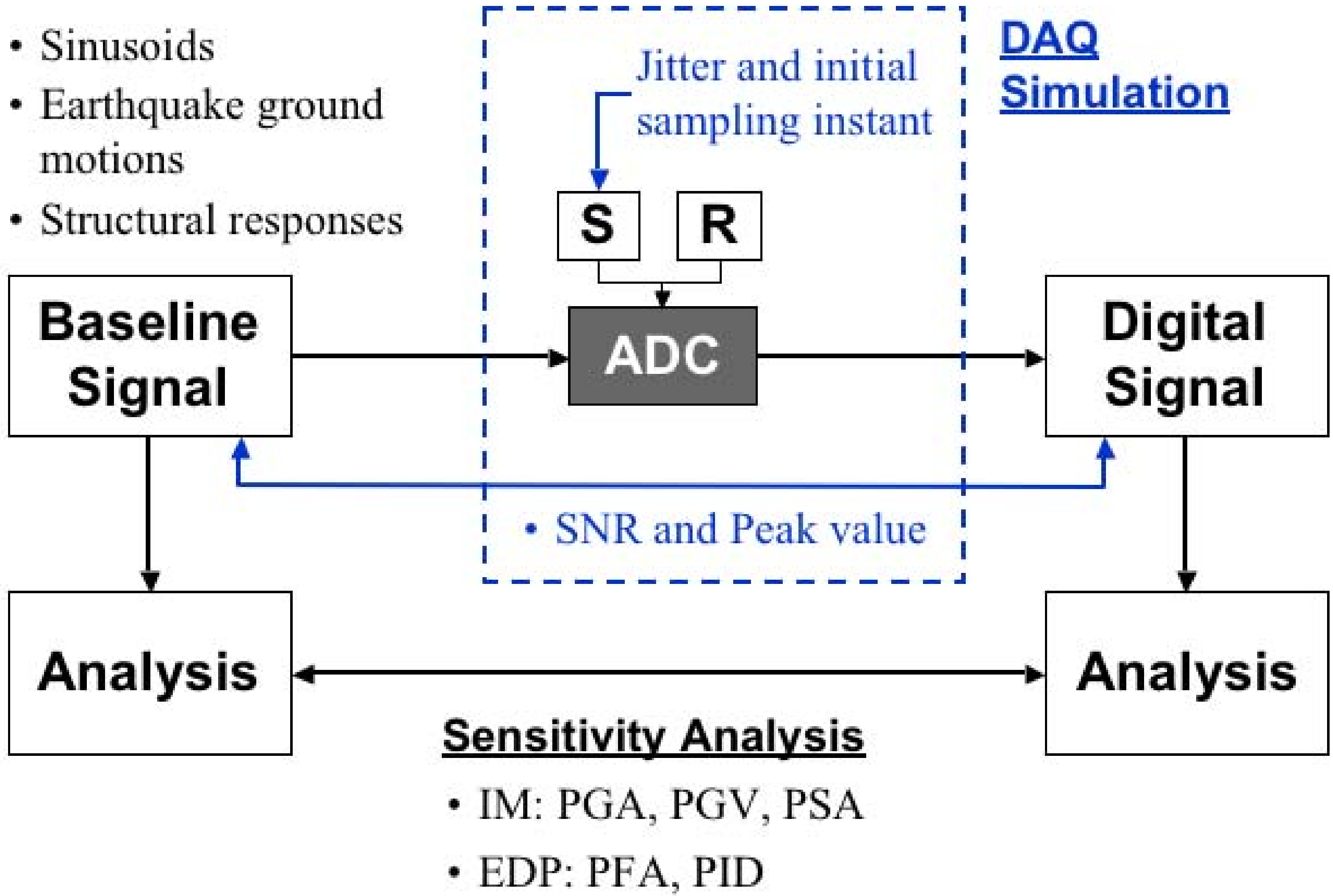
- Introduction
- DAS Specifications
- **DAQ Simulation**
- Sensitivity Studies
- Conclusions

Baseline Earthquake Record Set

- 30 EQ records downloaded from PEER, NCESMD, K-Net, KiK-Net, COSMOS
- Selected to capture broad nature of earthquakes
- Digitally enhanced to increase resolution: resample to 2kHz, zero-pads for filtering, band-pass filter 0.1-50Hz



DAQ SIMULATION



Clock Jitter

- Independent of sample rate
- Can be neglected

100sps

0.1 Hz

1 Hz

50 Hz

Sinusoidal Signal

$$X(t) = A\sin\left[2\pi f t\right]$$

Sampled Signal

$$x_i = A\sin\left[2\pi f t_i\right]$$

$$t_i = i\,\Delta t$$

Jittery Sampled Signal

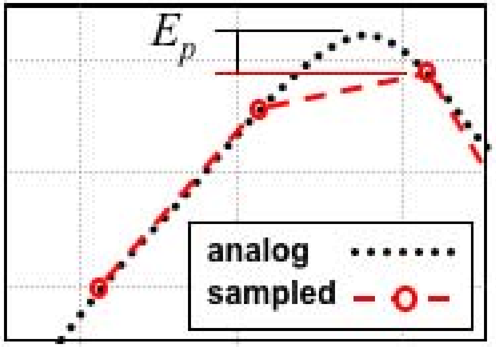
$$\bar{x}_i = A\sin\left[2\pi f \tau_i\right]$$

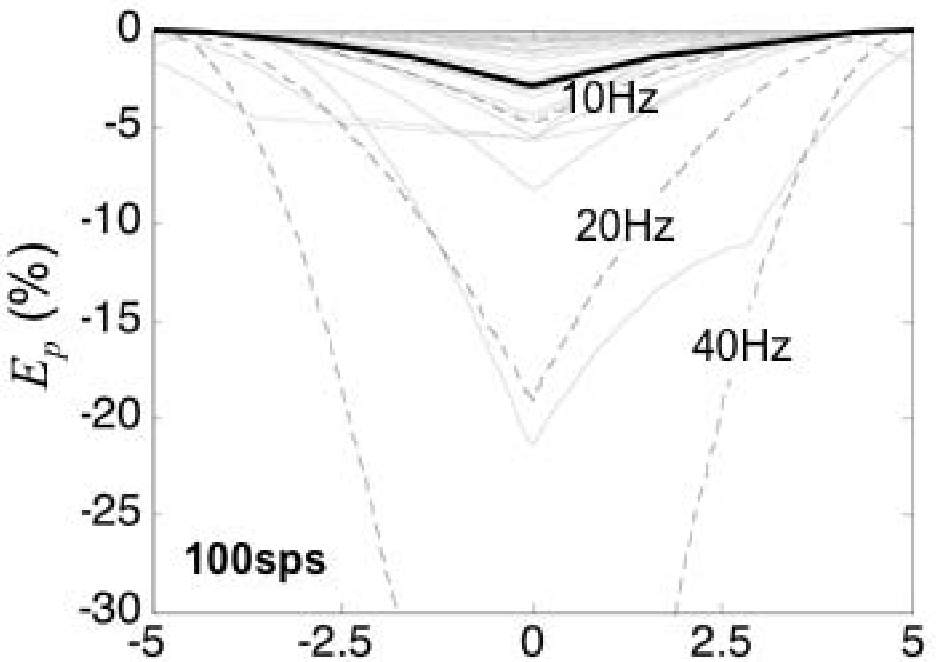
$$\tau_i \sim N\left(t_i, \sigma\right)$$

Initial Sampling Instant

- Depends on sample rate
- Biased error – always negative

Error in peak value (E_p)



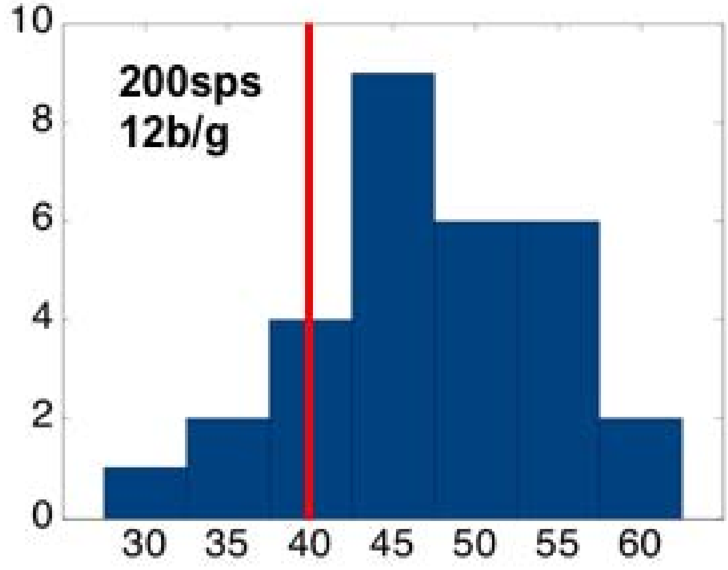


DAQ SIMULATION

X = EQ record

1. $t_0 \sim U(0,\Delta t)$
2. $t_i = t_0 + i \cdot \Delta t$
3. $x_i = interp(X\ @\ t_i)$
4. $x_i = round(x_i / res) \cdot res$

- S = [50-500] sps → $\Delta t = 1/S$
- R = [6-24] bits/g → $res = g/2^R$



SNR

30 **40dB** **50dB**

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- DAQ Simulation
- **Sensitivity Analysis**
- Conclusions

OBJECTIVE

Determine minimum requirements for specifications of sample rate, resolution, and time synchronization

STRATEGY

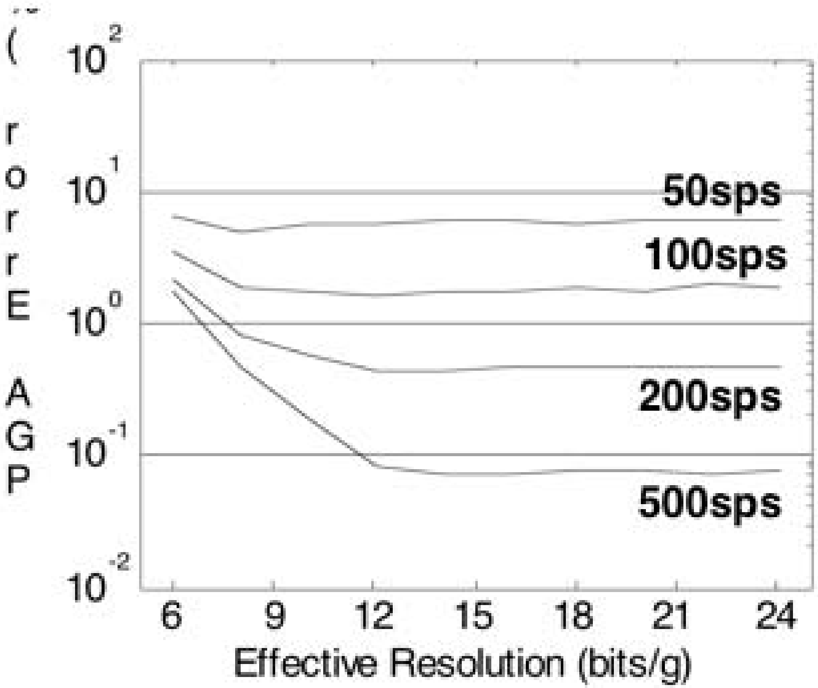
Quantify the sensitivities of ground motion intensity measures and engineering response quantities to DAQ

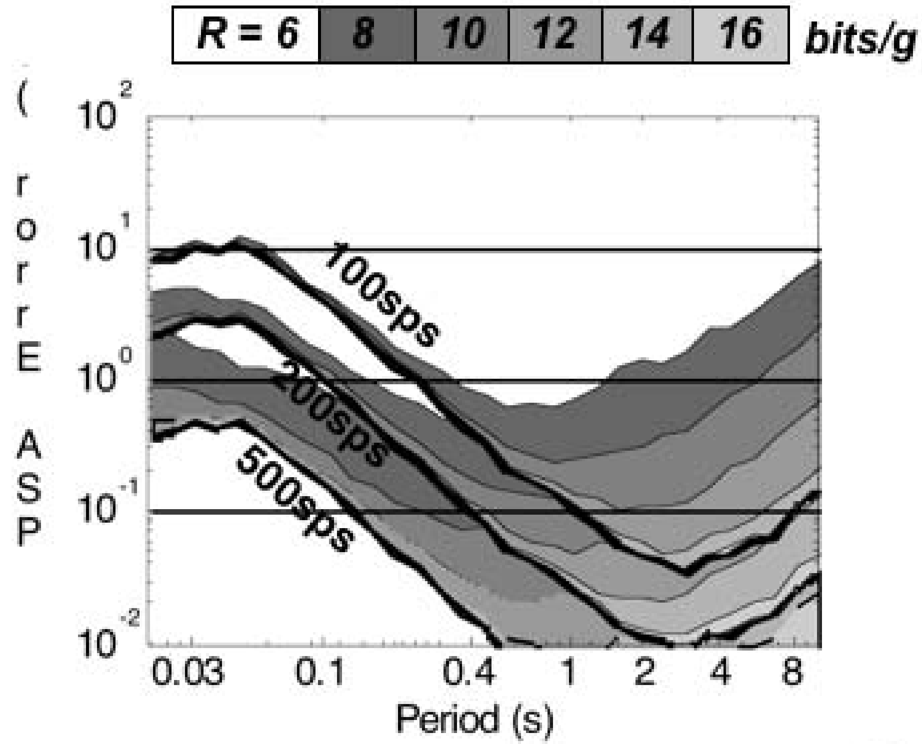
APPROACH

1. Understand how engineers use strong-motion data
2. Simulate the *noisy* DAQ process
3. Perform sensitivity analyses

Intensity Measures

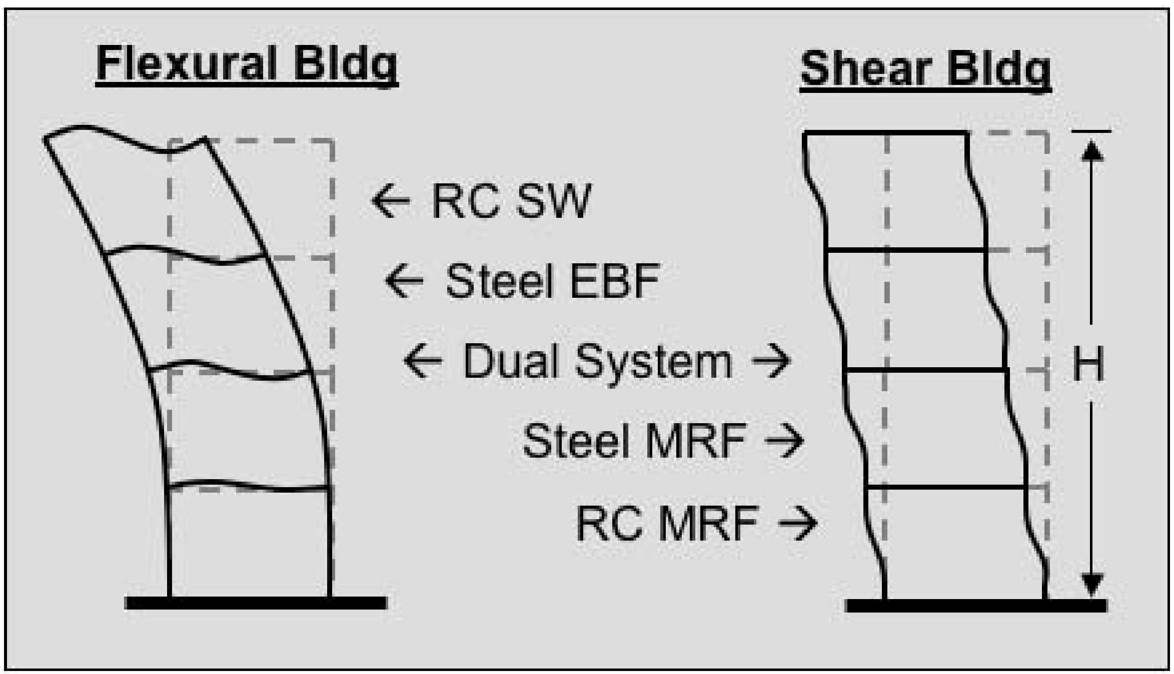
- PGA – 100sps, 6bits/g for error less than 5%
- PGV – 50sps, 8bits/g for error less than 5%
- PSA – 200sps, 8bits/g for error less than 5%





Baseline Building Response Set

- Simulate responses to baseline EQ record set by superimposed first few modal responses
- Assumptions: bounded by flexural & shear idealizations, uniform mass and stiffness, ζ_n = 5%



$$\phi_n(x) = \sin\left[\frac{2n-2}{2}\frac{\pi x}{H}\right]$$

$$T_n = \beta_n T_1$$

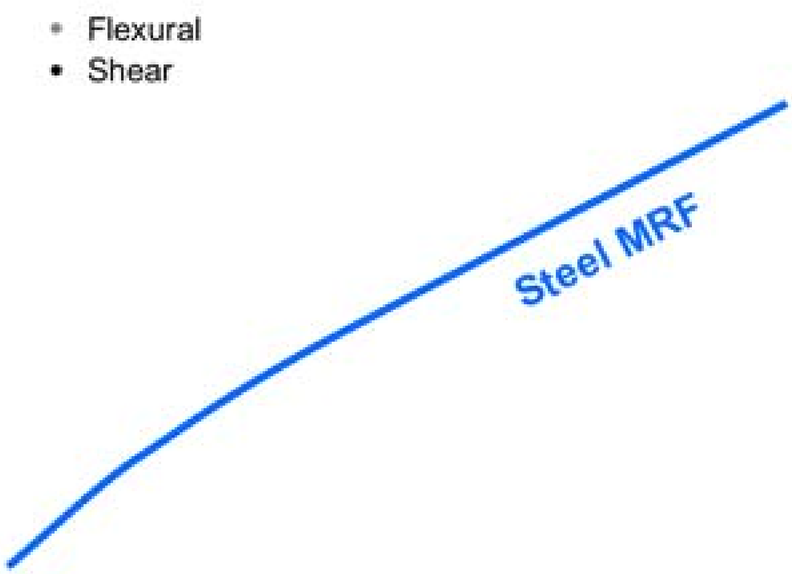
$$\Gamma_n = \frac{\int_0^H m\phi_n(x)dx}{\int_0^H m(\phi_n(x))^2 dx}$$

$$a_i = a_g + \sum_{n=1}^{N} \Gamma_n \phi_{ni} a_n$$

SENSITIVITY ANALYSIS

Fundamental Period

- Depends on building structure and height... sort of
- Based on real data from instrumented buildings
- Empirical conventions in code (ASCE 7) are lower bounds



$$T_s = 0.68 + 0.11N$$

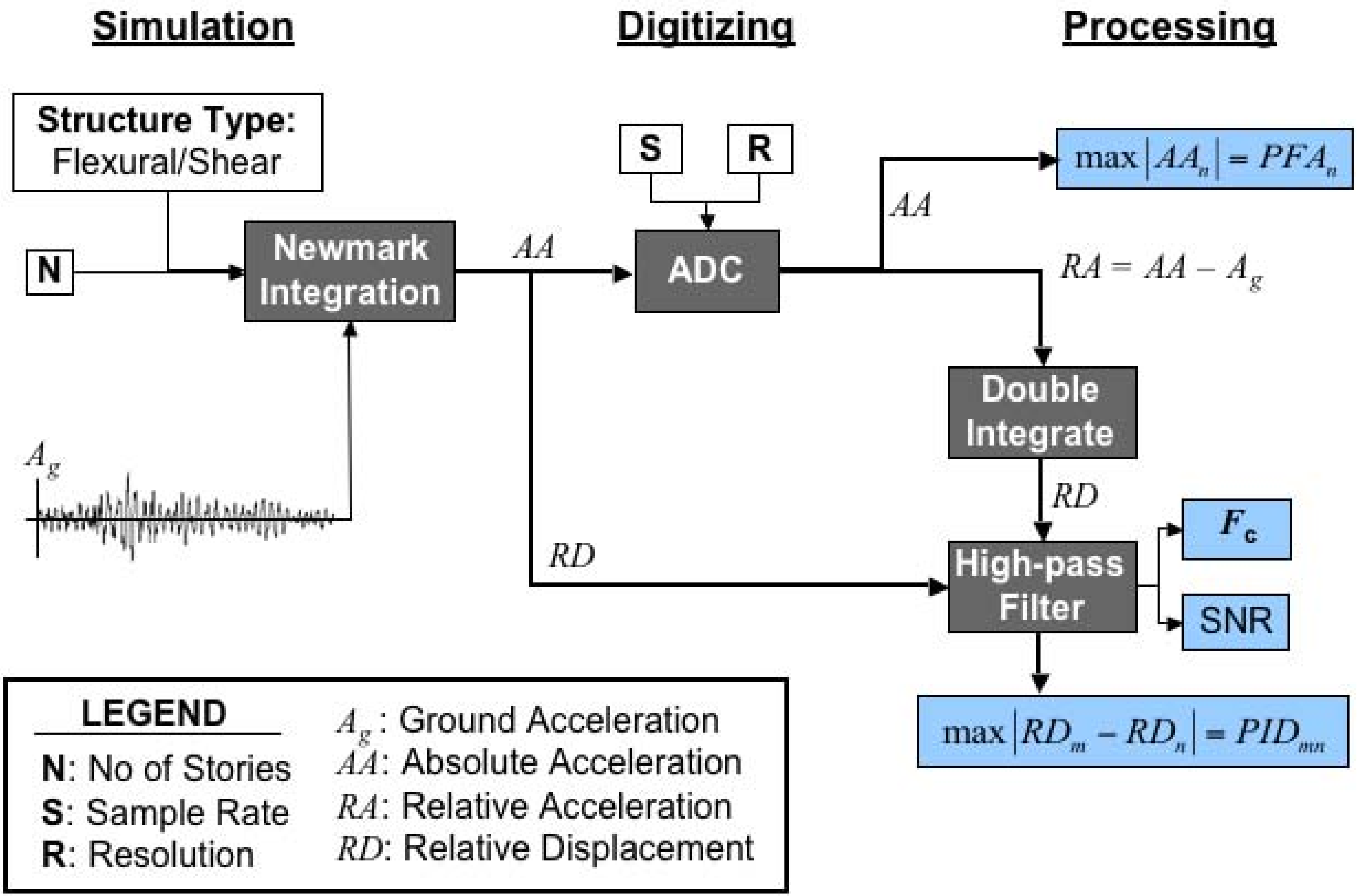
$$T_f = 0.46 + 0.03N$$

ASCE 7-05 S12.8.2.1

$$T_a = C_t h_n^x$$

(Goel and Chopra 1997-98, Naeim 1998)

SENSITIVITY ANALYSIS



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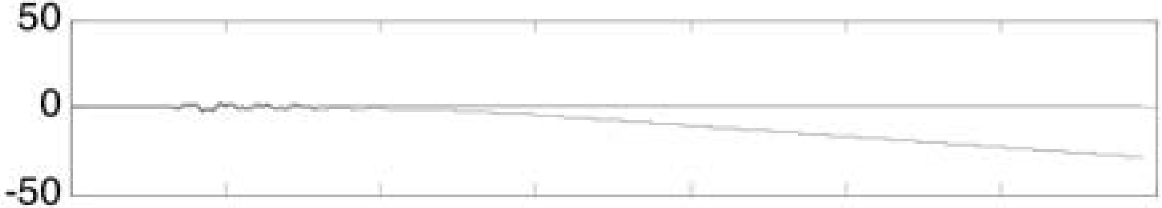


Displacement (in)

No correction
SNR = -31dB

Detrend
SNR = -16.3dB

F_c = 0.01Hz
SNR = -8.9dB

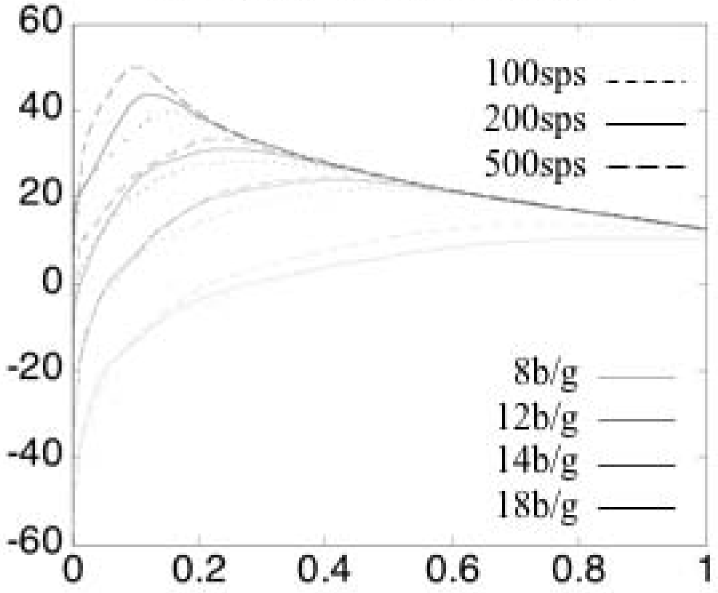
F_c = 0.1Hz
SNR = 20.5dB

F_c = 1.0Hz
SNR = 1.25dB

Optimizing Frequency Cutoff

- High-pass 4th order acausal digital Butterworth filter
- A single floor of a 10-story bldg to one earthquake
- Resolution is important which corroborates Boore's (2003) findings of ADC quantization being a source of numerical drifts

Shear: f_n = [1.5, 9.3, 26] Hz

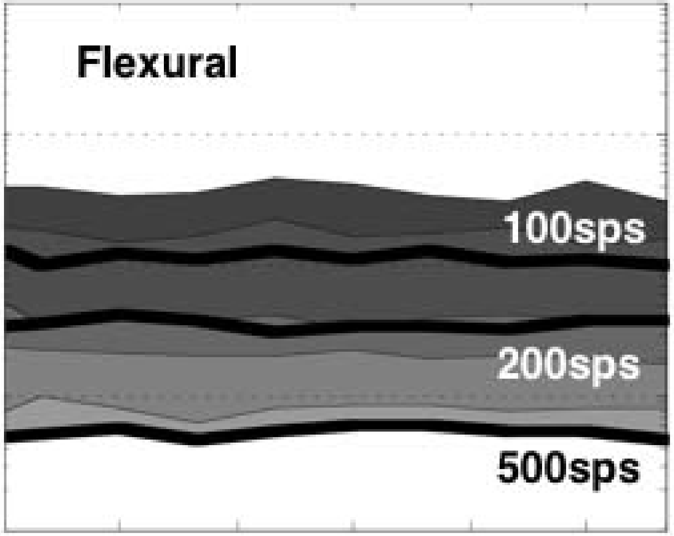


Flexural: f_n = [0.4, 1.2, 1.9] Hz

Engineering Demand Parameters

- PFA – 100sps, 8b/g for error less than 5%
- PID – 100sps, 14b/g for error less than 5%

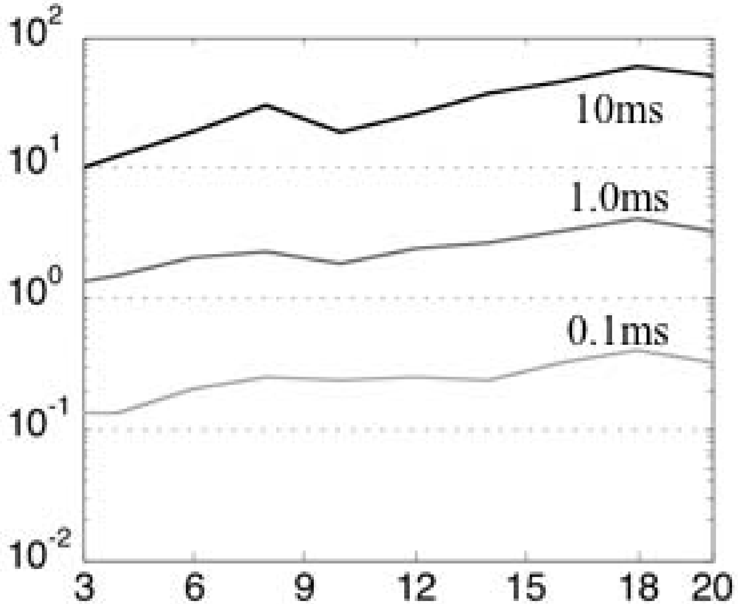
8	10	12	14	16	18	20	bits/g



Shear

Time Synchronization Error

- Sync errors are additional to digitizing error
- PID – 200sps, 16b/g and sync to 1.0ms for total error < 5%



10ms

1.0ms

0.1ms

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CONCLUSIONS

Specification	ANSS (USGS 2005)	CSMIP (CGS 2007)	Recommend (Skolnik 2009)
Range ADC Resolution Sample Rate	±4g 16bits 200Hz	±4g 18bits 200Hz	±4g 20bits 200Hz
Sample Sync Reference Time	0.05ms 1.0ms	0.2ms 0.5ms	1.0ms

Potential Improvements

- Other specifications – frequency response, dynamic range, cross-axis sensitivity, sensor layout
- Improved simulations – non-uniform stiffness; vary damping ratios, combo flex-shear shapes, non-linear responses
- Other engineering analyses – system identification

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NSF

CENS
CENTER FOR EMBEDDED NETWORKED SENSING

nees@UCLA
Earthquake Engineering Mobile Laboratory

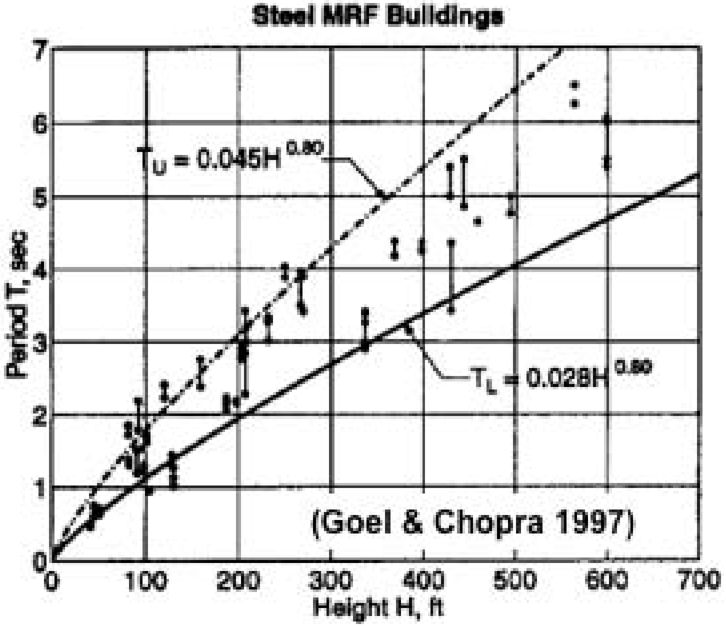
Future Publications

BSSA: A quantitative basis for strong-motion instrumentation (12/09)

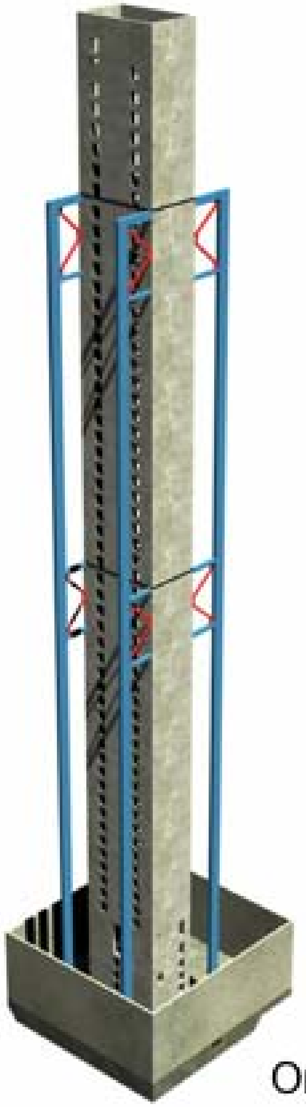
EQS: A quantitative basis for building instrumentation

Engineering use of Strong-Motion Response Data

- Traditional – validate modeling assumptions and develop code provisions: fundamental period approximation formulas
- Modern – tall building issues, structural health monitoring (SHM)



Tall Building Construction



- Alternative designs citing Chap 16 of ASCE 7
- NDA of 3D FEM w/ suite of motions & peer review
- Exposed fundamental issues: ground motion selection, modeling guidelines, acceptance criteria
- LA-TBSDC publish document for LA-DBS (2008)
- Since 1965 LA requires accelerographs at base, mid-level, and roof
- UCLA, LA-DBS & CSMIP update requirements
- Deployment approval by peer review panel

Stories	Channels
10 – 20	15
20 – 30	21
30 – 50	24
> 50	30

One Rincon Hill - MKA

Structural Health Monitoring (SHM)

- Assess health of instrumented structures from measurements
- Detect damage before reaching critical state and allow for rapid post-event assessment
  - Potentially replacing expensive visual inspection which is impractical for wide spread damage in urban areas


Arabdrill 19, UAE


I-35W Bridge 2007


Steel Joint Damage
1994 Northridge

Strong Motion Instrumentation Programs (SMIP)

- CSMIP (CGS), ANSS & NSMP (USGS), K-net/KiK-net (Japan), Taiwan Seismology Center (CWB)
- Provide real-time ShakeMaps and data for engineers and scientists to improve hazard mitigation
- Since early 20th century with focus on ground monitoring
- Uniform structural instrumentation specifications are lacking

650 ground
170 buildings

762 ground
133 buildings

92 ground
51 buildings

Intensity Measures (IM)

- PGA – Peak Ground Acceleration
- PGV – Peak Ground Velocity
- PSA – Peak Response Spectral Pseudo-Acceleration
- MMI – Modified Mercalli Intensity

Engineering Demand Parameters (EDP)

- PFA – Peak Floor Acceleration
- PID – Peak Interstory Drift

Advanced Engineering Analyses

- SID – System Identification, Model Updating
- SHM – Structural Health Monitoring

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