Impacts of Subduction Earthquakes on Structures in Deep Sedimentary Basins

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Motivation

- Duration
- Basin Amplifications

Not Considered

Juan de Fuca Plate
M9 Subduction Eq. Possible

No Recordings
Effects Poorly Understood

North America Plate

Design Codes

Minimum Design Loads for Buildings and Other Structures

Motivation

No Recordings?
Not Considered
Effects Poorly Understood
M9 Project

M9 Cascadia Subduction Zone Simulation

Tsunami
Buildings & Infrastructure
Liquefaction
Landslides

Early Warning

Community Planning & Enhanced Resilience

Integrated Risk Maps

Community Engagement
M9 Simulations

Selecting Rupture Parameters

Seismic Wave Velocity Model

Finite-difference Simulations

Generate Broadband Motions

Puget Lowland Basin

Tualatin Basin
Duration

Simulated M9 CSZ

Typical FEMA P695 Ground Motion (Northridge)

$D_s \approx 80-120 \text{s}$

$D_s \approx 5-10 \text{s}$

$\approx 10 \times$ Longer
Acceleration Response Spectra

- MCE - Site Class C
- Snoqualmie - Real. 1
- Snoqualmie - Real. 2

Graph showing the acceleration response spectra with two realizations marked as Realization #1 and Realization #2.
Acceleration Response Spectra

- MCE - Site Class C
- Snoqualmie - Real. 1
- Snoqualmie - Real. 2
- Seattle - Real. 1

Key points:
- Damaging Spectral Shape
- Larger Spectral Shape
- Realization #1
- Realization #2
Inside vs. Outside Basin

Z_{2.5}, \text{km}

Up to 8km deep
Deep Basins in Japan

Velocity Profile from Koketsu et al. 2009
Deep Basins in Japan

Yufutsu Basin

Stiff-Soil or Rock Sites

2003 $M_w$ 8.3 Tokachi-Oki

Velocity Profile from Koketsu et al. 2009
Spectral Acceleration

Yufutsu Basin - Tokachi-Oki Eq.

\[ S_{a, g} \]

Increasing \( Z_{2.5} \)
Basin Amplification Factors

> Computed using GMPE **Residuals** that account for:
  - Local-soil effects
  - Attenuation with distance

> Computes Basin Amplification on $S_a$

$$B A F_{S_a} = \frac{S_{a,\text{inside}}}{S_{a,\text{outside}}}$$

- $Z_{2.5} > 3 \text{ km}$
- $Z_{2.5} < 1.5 \text{ km}$
Basin Amplification Factors

Period Dependent

Maximum $\text{BAF}_{\text{sa}}$ is at long-periods
Effects of Magnitude on BAF

Yufutsu Basin

- $M_w 8.3$ - Tokachi-Oki
- $M_w 7.4$ - Hokkaido
- $M_w 6.8$ - Hokkaido

Similar Trends
Comparison with $M_w 6.8$ Nisqually

$Z_{2.5}, \text{ km}$

2001 $M_w 6.8$ Nisqually
BAF_{sa} comparison with M_w 6.8 Nisqually

Yufutsu Basin

- M_w 8.3 - Tokachi-Oki
- M_w 7.4 - Hokkaido
- M_w 6.8 - Hokkaido
- M_w 6.8 - Nisqually

Similar trends and values at long-periods
Basin Effects on Significant Duration

Yufutsu Basin - Tokachi-Oki Eq.

\[ R^2 = 0.11 \]
\[ p-value = 0.01 \]

Positive Slope

High Variability
Basin Effects of Spectral Shape

> Spectral Shape Effects

![Diagram showing spectral shape effects with axes $S_a$ and $T_n$. The graph illustrates softening structures and a more damaging record at $T_1$.](image-url)
Measuring Spectral Shape

> Developed a Spectral Shape Intensity Measure (Marafi et al. 2016)

\[
SS_a(T_1, \alpha) = \frac{\int_{T_1}^{\alpha T_1} S_a(T_n) dT_n}{T_1 (\alpha - 1) S_a(T_1)}
\]
Measuring Spectral Shape

> Developed a Spectral Shape Intensity Measure (Marafi et al. 2016)

\[ S_a \]

\[ S S a < 1 \]

\[ S S a > 1 \]
Basin Effects on Spectral Shape

SS$_a$ computed from $T_1$ to $3.7T_1$

Spectral Shape increases with $Z_{2.5}$
Incremental Dynamic Analysis

\[ \mu = \frac{\delta}{\delta_c} \]

\[ S_a(T_n) \]

Collapse
Concrete Shear Walls

Boundary Elements

P-Delta Column

12-Stories

Designed for Seattle

Force-based Elements with 5-Integration Points

Fiber Section

Regularized material model based on crushing/fracture energy (Pugh et al. 2015)

Crushing Energy

Fracture Energy

Modelling Methodology
Calibrated to Experimental Data

Wall Archetype Designed by Pugh 2013
Collapse Fragilities

Archetype T73S12R60 - Yufutsu

Probability of Collapse

Collapse Capacity

Collapse Capacity

0.5

0.0

0.2

0.4

0.6

0.8

1.0

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

1.1

1.2

1.3

1.4

1.5

1.6

1.7

1.8

1.9

2.0

0.66

1.07
Combined Intensity Measure

> Dispersion of $S_{a,c}$ is due to spectral shape and duration.

$$IM_{comb} = S_a(T_n) \times D_{S,5-95\%}^{0.18} \times SS_{a}^{1.18}$$

The median collapse IMs are similar.

The variability in IM$_{collapse}$ is reduced.
Basin Design Factor

Amplifications in $S_a$ alone

Amplifications due to Duration and Spectral Shape

$$DF_{basin} = BAF_{S_a} \times \frac{\tilde{S}_{a,c,\text{outside}}}{\tilde{S}_{a,c,\text{inside}}}$$

= 1.35 $\times$ \frac{1.07}{0.66} = 2.2
What’s Next?

> Evaluating Effects on Other Structural Systems

Concrete Moment Frames

Concrete Core Walls

Steel Concentrically Braced Frame

> Quantifying Change in Collapse Risk due to Basin and Duration Effects
Conclusion

> An M9 CSZ earthquake could lead to poor structural performance due to:
  – Long-duration shaking expected during subduction events
  – Large $S_a$ and damaging spectral shapes observed in basins

> Current building codes do not explicitly account for the effects of basin and long-duration ground-shaking.

> Design strength amplification factors can account for these effects.
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