

36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

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The State of the Art and Science of Coastal Engineering

Probabilistic Tsunami Hazard Assessment (PTHA) And Damage Assessment (PTDA) of the Built Environment: Application to the Cascadia Subduction Zone and Seaside, Oregon

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Center for Risk-Based Community Resilience Planning A NIST-funded Center of Excellence



Risk = Hazard X Negative Probability X Consequence

2000's	P T HA	Probabilistic Tsunami Hazard Analysis	\rightarrow	P T DA	Damage Analysis Probabilistic Tsunami Damage Analysis
2010's	P ST HA	Probabilistic Seismic	→	P ST DA	Probabilistic Seismic
		Analysis			and Tsunami Damage Analysis

Methodology of PTHA, PTDA



Methodology of PTHA, PTDA



PSHA using conventional GMPE

1) Inversion model results

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4) Applying as input sub-faults in model



Flux, Arrival Time, and Duration Applied to Seaside, Oregon," Coastal Engineering, 117, 79-96

Bathymetry of two numerical models



- ComMIT/MOST(NOAA) A & B-Grid - COULWAVE Only C-Grid

Grid	Mesh number / size	Models
A-Grid	400 \times 400 / 1 min	ComMIT
B-Grid	800 × 800 / 3 sec	ComMIT
C-Grid	416 × 390 / 24 m	COULWAVE

- Following default setup for each models
- Default friction, n = 0.03.

Logic tree model



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Calculating annual exceedance probability (AEP) of IMs



Hazards map at Seaside, OR



Hazards map at Seaside, OR



Hazards map at Seaside, OR



Hazards map at Seaside, OR



Example: Duration time (T_D)

DOGAMI "M"

PTHA Comparison for Newport, Oregon

Park and Cox, 2017





Figure 7: Comparison of maximum extent of tsunami inundation in Newport, Oregon, for (a) present study with AEP = 0.0004, (b) ASCE Tsunami Design Geodatabase (TDG) for AEP = 0.0004, and (c) DOGAMI TIM, 'M' scenario (b and c are courtesy of ASCE TDG and Oregon Department of Geology and Mineral Industries).

2. Joint Distributions of IMs

- Correlation or relationship among h_{max} and other IMs



Methodology of PTHA, PTDA



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(6) Building classification

Three tools for building information at study area

1. Tax lot (Stat_Class, Year)



2. Pictures from Google map street view



3. Fields survey Rapid Visual Screening (RVS)

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FEMA BUILDING TYPE Basic Score Sovem Vertical Insput Moderaro Vertical Insput Moderaro Vertical Insput Sol Type E (-) Stotem Minimum Score, See FINAL LEVEL 1 SC EXTENT OF RE Extension Interfor: Drawings Raviewedd: Drawings Raviewedd:	E 0		21 5 M 8 8 8 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9	Dimon dam dam dam dam dam dam dam dam dam dam	(0.4 o (2 eee 5 COP W2 1.8 -0.9 -0.5	d/d 4 - T = T	14 0.7 0.4 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	RRS, AI S3 (M S S (M S	2017 4 Addition ND FIN 14 4 4 4 4 4 4 -0.7 -0.4 -0.2 -0.2 -0.2 -0.2 -0.2 -0.3 -0.5 5 Trigger A 5 Trigger A 5 5 5 5 5 5 5 5 5 5 5 5 5	31 Sketch AAL LI S5 UBB UBP 07 0.3 0.4 0.1 0.4 0.1 0.1 0.5 0.5	PC ess or com EVEL 1 CT 0.4 0.7 0.4 0.1 0.2 0.3 2.0 ACTII Detaile Vec	2 ments 5 5 5 5 5 5 5 5 5 5 5 5 5	Constru Ground urpose. RE, S, (08) 99 -0.5 -0.3 -0.3 -0.3 -0.3 -0.3 -0.3 -0.3 -0.3	te page (1 PC1 PC1 (1 PC1 PC1 PC1 PC1 PC1 PC1 PC1 PC	PC2 1.0 -0.7 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.7 -0.2 -0.4 -0.7 -0.2 -0.4 -0.7 -0.7 -0.4 -0.7 -0.7 -0.4 -0.7 -0	RM1 PC PC 1.1 1.7 0.4 -0.4 0.3 -0.2 0.3 -0.2 0.3 .0 0.0	RM2 (R0) (R0) (R0) (R0) (R0) (R0) (R0) (R0)	URM 0.8 0.6 0.3 0.3 0.1 0.0 0.0 0.0 0.0 0.2	N 1 N N N 0 0 0 0 0 0 7
FEMA BUILDING TYPE Basic Score Basic Score Score Pac Code Pac Code Pac Code Soil Type E (-3 score) Soil Type E (-3 score) FINAL LEVEL 1 SC EXTENT OF RE Exterior: Dravings Reviewed: Soil Type Source: Geologie Hazards So	E O why, V ₁ , clariby, V ₂ , clariby, V ₂ , correct, SL12 CORE, SL12 CO	9 SKE know	ETCH B 0.9 0.6 0.7 0.3 1.9 0.5 0.0 0.5 0.0 0.5 0.0 0.5 0.0 0.5 0.5	Dimensional Control Co	1.8 0.9 0.5 0.3 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4	d/ad / - d/ad / -	14 0.7 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.2 0.3 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	RS, AI 83 84 905 905 905 905 905 905 905 905	Addition ND FIN ND FIN 54 985 990 14 -04 -04 -04 -04 -04 -04 -04 -04 -04 -0	1 di sketch IAL LI 85 1080 112 -0.7 -0.3 -0.4 -0.1 -0.1 -0.5	es or com es or com	2 ments 5 5 5 5 5 5 5 5 5 5 5 5 5	Constru- Ground urpose.	ete page ete page (1 PC1 (7) PC1 (7) 1,1 1,7 -0,7 -0,2	PC2 1.0 -0.7 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.7 -0.2 -0.4 -0.4 -0.7 -0.2 -0.4 -0.7 -0.7 -0.4 -0.7 -0.7 -0.4 -0.7 -0.7 -0.4 -0.7 -0	RM1 I for co RM1 -0.7 -0.4 -0.2 -0.2 -0.2 -0.3 -0 -0.4 -0.2 -0.2 -0.2 -0.3 -0 -0.4 -0.4 -0.2 -0.3 -0.4 -0.4 -0.5 -0	RM2 (R01 1.1 -0.7 -0.4 -0.4 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2	URM 0.8 0.6 0.3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	A 4 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
PEMA BUIL.DING TYPE Basic Score Soven Verical Inoputa Moderare Verical Inoputa Manual Society Arc PaceSoce PaceSoce (1-3 society Manual Score, Sare FINAL LEVEL (-) a society Manual Score, Sare FINAL LEVEL (-) a society Interior: Drawings Reviewed: Geologic Hazards Source: Geologic Hazards Source: Geologic Hazards Source: Geologic Hazards Source:	E 0 why, V ₁₂ alarity, V ₁₂ alarity, V ₁₃ CORE, SL12 CORE, SL12 WIEW Partial None Yes None	9 SKE know SMm:	21 09 06 07 05 00 05 05	D7 HOR dam dam dam dam dam dam dam dam	18 -0.9 -0.5 -0.6 -0.3 2.0 0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.	add 4 - RE, MO 3487 -03 -03 -03 -03 -03 -03 -03 -03	14 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7	RS, A1 1.5 0.5 0.3 1.1 0.4 0.2 NA 0.5 0.3 1.1 0.4 0.2 NA 0.5 0.5 1.1 0.4 0.5 0.5 1.5 0.4 0.5 1.5 0.4 0.5 1.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0	Addition Port 4 Addition ND File Port 4 Port 4 P	34 sketch AAL LI 199 12 0.7 0.3 0.4 0.1 0.1 0.1 0.1 0.1 0.1 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	PC 485 or com EVEL 1 10 10 14 0.3 2.0 ACTI Detaile Yee No Dotaile	P P P P P P P P P P P P P P P P P P P	Constru Ground urpose. (NRE, S1 (NR) 0.9 0.9 0.9 0.3 0.0 0.9 0.3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	the page	PC2 1.0 -0.7 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.7 -0.4 -0.7 -0.4 -0.7 -0.4 -0.7 -0.4 -0	RM1 For co RM1 For 1,1 -0,7 -0,4 -0,4 -0,4 -0,4 -0,4 -0,4 -0,4 -0,4 -0,2 -0,3 -0,3 -0,3 -0,3 -0,3 -0,4 -0	RM2 RM2 (R0) 1.1 -0.7 -0.4 -0.4 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2	URM 0.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	N 1 N 0 0 0 0 0 0 7
FEMA BUILDING TYPE Basis Eccor Source Vertical Impulie Moderne Vertical Impulie Sol Type Code PaceBoectrast Sol Type (-) a toriest Minnum Score, -) a toriest Minnum Score, -) a toriest Minnum Score,	E D eity, V _c , elarity, V _b , corres, S _k = 2 CORE, S _k = 2 VIEW Partial None Yes Surce: ENING PI	SKE	21 0.7 0.7 0.7 0.5 0.0 0.4 0.7 0.5 0.0 0.4 0.7 0.5 0.0 0.7 0.5 0.0 0.7 0.5 0.0 0.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0	Dimony ASIC WIA 19 -0.9 -0.5 -0.7 -0.3 15 0.5 -0.2 -0.4 -0.7 -0.2 -0.4 -0.7 -0.2 -0.4 -0.7 -0.2 -0.4 -0.7 -0.5 -0.5 -0.5 -0.5 -0.5 -0.5 -0.5 -0.5	18 -0.9 -0.5 -0.6 -0.3 -0.6 -0.3 -0.6 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.7	defail (1	14 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7	RS, AII 53 64 15 05 05 05 05 05 05 05 05 05 0	Addition Additi	31 statch 43 statch 44 LLL 55 12 0.7 0.3 0.4 0.1 0.1 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	PC ess or com EVEL 1 1.0 0.7 0.4 0.1 0.1 0.2 0.3 2.0 ACTI Detailo Yes Vec Detailo Detailo PC	2 mments - SCC SCC SCC SCC SCC SCC SCC SC	Constru Ground urpose. On Reparso (MRE, Si (MR) 0.9 0.9 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3	the page	PC2 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	RM1 PC0 1.1 -0.7 -0.4 -0.4 -0.2 0.3 -0.4 -0.2 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.4 0.4 <td>RM2 RM2 <thr2< th=""> <thrm2< th=""> <thrm2< th=""></thrm2<></thrm2<></thr2<></td> <td>URM 0.9 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3</td> <td>N 1 N N 0 0 0 0 0 7</td>	RM2 RM2 <thr2< th=""> <thrm2< th=""> <thrm2< th=""></thrm2<></thrm2<></thr2<>	URM 0.9 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3	N 1 N N 0 0 0 0 0 7
FEMA BUILCONG TYPE Basic Score Sovem Verifical Insolution Moderara Vertical Insolution Press regulary, PL- PrecCode Decomposition, Plant Code Soil Type E (-3 activate) Minimum Score, Sue FINAL LEVEL 1SC EXTENT OF RE Exteriori Decemposition Score, Sue FINAL LEVEL 1SC EXTENT OF RE Exteriori Decemposition Score, Sue Contact Parence Contact Parence LEVEL 2 SCREED	E 0		21 09 06 07 03 19 05 00 0.0 0.0 0.0 0.0 0.0 0.0	D7mcOrr 0mr 0mr 0mr 0mr 0mr 0mr 0mr 0	(b) d o d b d o d b d o d c c c c c c c c c c c c c c c c c c c	contract of the second se	14 0.3 0.5 0.2 0.3 0.5 0.3 0.5 0.3 0.5 0.3 0.5 0.3 0.5 0.3 0.5 0.3 0.5 0.3 0.5 0.3 0.5 0.3 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	RS, AII RS, AII 18 0.8 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	Addition Port 4 Addition ND FIN S4 pro- pr	1 skeetch AL LI SBBM WF) 12 0.7 0.3 0.4 0.1 0.2 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	es or com evel 1 0.7 0.4 0.3 2.0 ACTI 0.3 2.0 ACTI 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3	P P P P P P P P P P P P P P P P P P P	Constru Ground urpose.	the page	PC2 1.0 -0.7 -0.4 -0.1 0.2 -0.1 0.2 -0.1 0.2 -0.1 0.2 -0.1 0.2 -0.1 0.2 -0.1 0.2 -0.1 0.2 -0.1 0.2 -0.1 0.2 -0.1	RM1 PC0 1.1 -0.7 -0.4 -0.2 -0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.3 -0.2 0.4 -0.2 0.3 -0.2 0.3 -0.2 0.4 -0.2 0.3 -0.0	RM2 RM2 <thr< th=""> <thrm2< th=""> <thrm2< th=""></thrm2<></thrm2<></thr<>	URM 0.5 0.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	1 5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
FEMA BUIL.DING TYPE Basic Score Sovern Vertical Insput Moderaro Vertical Insput Moreans Vertical Insput Sol Type E (-) Stored Minnum Score, Sier FINAL LEVEL 1 SC Bot Type E (-) Stored Minnum Score, Sier FINAL LEVEL 1 SC EXTENT OF RE Exterior: Interior: Drawings Reviewed: Source: Geologic Hazards So Contact Presons LEVEL 2 SCREE vertical Bazards'	E 0 Pity, V., Pity,		21 09 06 0.7 0.3 19 0.5 0.0 0.5 0.0 0.4 0.7 0.5 0.0 0.4 0.7 0.7 0.5 0.0 0.6 0.5 0.0 0.6 0.5 0.6 0.6 0.5 0.6 0.6 0.5 0.6 0.5 0.6 0.5 0.6 0.5 0.6 0.6 0.5 0.6 0.5 0.6 0.6 0.5 0.6 0.5 0.6 0.5 0.6 0.6 0.5 0.6 0.6 0.5 0.6 0.6 0.5 0.6 0.6 0.6 0.5 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6	Dimon ARSIC 4.19 -0.9 -0.7 -0.7 -0.3 -0.7 -0.7 -0.7 -0.2 -0.4 -0.7 -0.7 -0.7 -0.7 -0.7 -0.7 -0.7 -0.7	18 4.9 4.9 4.9 4.9 4.9 4.4 4.4 4.4	All A	H.p.= DIFIE 989 14 -0.7 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2 -0.2	RS, AI RS, AI 1.6 -0.5 -0.	Ib o 1 port +	4 sketch 4 sketch 12 0.7 0.4 0.1 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	PC BS or com Ser	P P P 2 mments - 9 SCC 2 5 mments - 0 5 -0.4 -0.5 -0.2 -0.3 -0.4 -0.5 -0.2 -0.3 -0.2 -0.3 -0.2 -0.3 -0.2 -0.3 -0.2 -0.3 -0.2 -0.3 -0.2 -0.3 -0.4 -0.5 -0.2 -0.3 -0.4 -0.5 -0.2 -0.3 -0.4 -0.5 -0.4 -0.5 -0.4 -0.5 -0.4 -0.5 -0.2 -0.5 -0.2 -0.5 -0.4 -0.5 -0.4 -0.5 -0.5 -0.2 -0.5 -0.5 -0.5 -0.5 -0.5 -0.5 -0.5 -0.5	Constru Ground urpose.	rte page rte page rte page (r PC1 1.1 4.7 4.4 6.5 4.2 1.5 6.3 4.2 U U E Valuation A buildin r out-off present E valuation A buildin researds i szards i bazards i	PC2 1.0 -0.7 -0.4 -0.4 -0.4 -0.1 -0.7 -0.4 -0.4 -0.1 -0.7 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.7 -0.4 -0.4 -0.7 -0.4 -0	RM1 P00 1.1 1.7 0.7 0.4 0.2 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3	R8M2 (80) 1.1 -0.7 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4 -0.4	URM 0.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	1 5 5 5 0 0 0 0 -{ 1 5 5 5 0 0 0 -{ 1 5 5 5 7 1 5 5 5 7 1 5 5 5 7 1 5 7 5 7



Building Classification



Example of building damage assessment (at AEP = 0.001)





Example of building damage assessment (at AEP = 0.001)



Example of building damage assessment (at AEP = 0.001)



Fragility curves (Suppasri et al., 2013) for collapse damage

Example of building damage assessment (at AEP = 0.001)





Photo taken by Hyoungsu Park, at Seaside Field trip (July, 14, 2015)

Example of building damage assessment (at AEP = 0.001)



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Probability damage at AEP = 0.001 (~1,000 year event) at CSZ with S2013 model (h_{max} , Collapse DS)



Methodology of PTHA, PTDA



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Merging Tsunami and Earthquake damage assessment

Can utilize FEMA Hazus methodology to combine damage from multi-hazard events -







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Direct loss Estimation Dollar Loss = Dollar value of building × Damage ratio





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6

"Over the past 5 years, debris removal accounted for approximately 27% of disaster recovery costs" FEMA 325 (2007)

Hazards and Disaster Debris types

Debris Forecasting

- 1. What is it?
- 2. How much is it?
- 3. Where is it?

From FEMA 325, Figure 6.2 – Typical Debris Streams for Different Types of Disasters

1		Natural)	Anthropogenic						
	Vegetative	Soil, Sand, Mud	Putrescence	Construction & Demolition	Household Hazardous Waste (HHW)	White Goods	Personal Property	Vehicles + Vessels	Hazardous Waste	
Hurricane	x	x	x	x	x	x	x	x	x	
Tsunami	x	x	x	x	x	x	x	x	x	
Flood	x	×	×	×	×	×	×	×	×	
Tornadoes	x		x	x	x	x	x	x	x	
Earthquake		x		x	x	x	x			
WUI Fire	x	x			x	x	x			
Ice Storm	x				x					

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Focus on critical facilities and lifelines





Debris Forecast Model: Quantification of debris at a single building

NS

EDF for structural damage

$$EDF_{S} = \int \left(\sum_{i}^{4} P_{S}(i) \cdot DF_{S}(i)\right) f_{S}(r) dr$$

EDF for non-structural damage

$$EDF_{NS} = \int \left(\sum_{i}^{4} P_{NS}(i) \cdot DF_{NS}(i)\right) f_{NS}(r) dr$$

EDF_{S}	Expected debris fraction from structural damage
i	Four damage states (slight, moderate, extensive and complete)
$P_{S}(i)$	Probability of structural damage at the 'i' damage state.
$DF_{S}(i)$	Structural debris fraction (percent) of unit weight at the 'i' damage states.

- $f_{S}(r)$ Structural debris fraction (percent) of unit weight at the 'i' damage states.
 - Subscription for non-structural damage variables.

Debris weight from structural damage

$$DW_{S} = (EDF_{S,F} \cdot W_{S,F} + EDF_{S,NF}W_{S,NF}) \cdot (SQ \cdot FL)$$

Debris weight from non-structural damage

$$DW_{NS} = (EDF_{NS,F} \cdot W_{NS,F} + EDF_{NS,NF}W_{NS,NF}) \cdot (SQ \cdot FL)$$

Total Weight of Debris $TDW = DW_S + DW_{NS}$

Disaggregation to floating or non-floating debris $TDW_F = EDF_{S,F} \cdot SQ \cdot W_{S,F} + DF_{NS,F} \cdot SQ \cdot W_{NS,F}$ $TDW_{NF} = EDF_{S,NF} \cdot SQ \cdot W_{S,NF} + DF_{NS,NF} \cdot SQ \cdot W_{NS,NF}$ *DW_s* Weight of debris from structural damage

- W_S Weights of debris per 1000 ft² of floor area from structural damage
- *SQ* Square footage of a building
- *FL* Number of floor levels (stories)
- *F* Subscript for floating debris
- *NF* Subscript for non-floating debris

Total Volume of Debris $TDV = TDW_F \cdot \rho_F + TDW_{NF} \cdot \rho_{NF}$

 , accurate and more subsection of the subsection										
Building		DF _{S,}	_F (%)		DF _{NS,F} (%)					
Туре	Slight	Moderate	Extensive	Complete	Slight	Moderate	Extensive	Complete		
	(i=1)	(i=2)	(i=3)	(i=4)	(i=1)	(i=2)	(i=3)	(i=4)		
W1	0.0	5.0	34.0	100.0	2.0	8.0	35.0	100.0		
W2	0.0	6.0	33.0	100.0	2.0	10.0	40.0	100.0		
C1	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0		

Table1. Floatable debris generated from structural and non-structural elements (in percent of weight)

Table2. Non-Floatable debris generated from structural and non-structural elements (in percent of weight)

Building		DF _{S,N}	_{NF} (%)		DF _{NS,NF} (%)					
Туре	Slight	Moderate	Extensive	Complete	Slight	Moderate	Extensive	Complete		
	(i=1)	(i=2)	(i=3)	(i=4)	(i=1)	(i=2)	(i=3)	(i=4)		
W1	0.0	3.0	27.0	100.0	0.0	0.0	0.0	100.0		
W2	0.0	2.0	25.0	100.0	0.0	10.0	28.0	100.0		
C1	0.0	5.0	33.0	100.0	0.1	8.0	28.0	100.0		

Table 3. Unit weight (tons per 1000 ft²) for structural and non-structural elements for building types

Building	Floatable (W	ood, Brick, and	Non-Floatabl	Non-Floatable (RC and Steel)				
Туре	otl	hers)			(Footage of			
	Structural	Non-structural	Structural	Non-structural	building/1000ft ²)			
W1	6.5	12.1	15.0	0.0	1.5			
W2	4.0	8.1	15.0	1.0	2.5			
C1	0.0	5.3	98.0	4.0	3.0			



Distribution of expected debris volume (m³) per unit area (hectare) for 1000 year event without advection. (a) Volume of total debris from EQ+TSU, (b) Volume of buoyant debris only from EQ+TSU.

Advection of buoyant debris from PSTDA at AEP = 0.0004 (2,500 yr)



Thresholds:

1 m, 0.3 m/s

0.5 m, 0.2 m/s





Cross-distribution of with and without advection debris at AA', BB', and CC'

No

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Discussion/Future work

PSTHA

- Uncertainty in tsunami inundation due to built environment
- New PTHA for each mitigation measure? (eg. seawall)

PSTDA

- How accurate are tsunami fragilities?
- Methodology to combine seismic and tsunami damage?
- Extending from damage to economic loss and loss of functionality

Debris

- Debris impact on building damage (cascading effects)?
- Debris interaction with fluid?
- Including natural debris (vegetation, sand) and other (vehicles, boats, etc.)
- Need for debris collision for large vessels

Thank you!