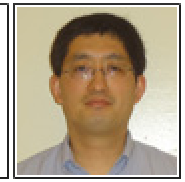
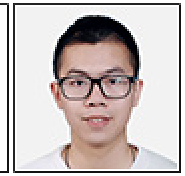
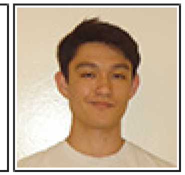
Collapse Simulations of Buildings Under Earthquake Conditions

ASPIRES SUMMER RESEARCH INTERNSHIP 2018

CIVIL ENGINEERING GROUP 1

Civil Engineering Group 1

Faculty Advisor	Dr. Cheng Chen	
Graduate Student Mentor	Yifeng Xu	
Team Leader	Alexander Carlson	
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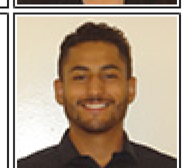
	Moises Vieyra	

Overview

- Introduction
- Background
  1. Earthquake Photo Collection
  2. Software
  3. Modified IMK Model
- OpenSees Simulation Structures
  1. Single Column Model
  2. 2-D Frame Model
- Optimization and Uncertainty Quantification
  1. Particle Swarm Optimization (PSO)
  2. Markov Chain Monte Carlo (MCMC)
- Analysis Results
- Summary & Conclusion

Earthquake Photo Collection: Loma Prieta Earthquake

- **Date:** October 17, 1989 at 5:04 P.M.
- **Lasted :** 15 seconds
- **Location**: Loma Prieta Peak (Santa Cruz Mountains)
- **Magnitude:** 6.9
- **Affected Area**: The San Francisco Bay Area
- **Damage Cost:** 10 billion USD
- **Casualties**: 63 earthquake fatalities, 3,000 injured

Credit: Lloyd Cluff/ Getty Images

Photo, Lloyd S. Cluff

Earthquake Photo Collection: Numerónimo 27F

Credit: El Mercurio Image

Credit: nachovalt Image

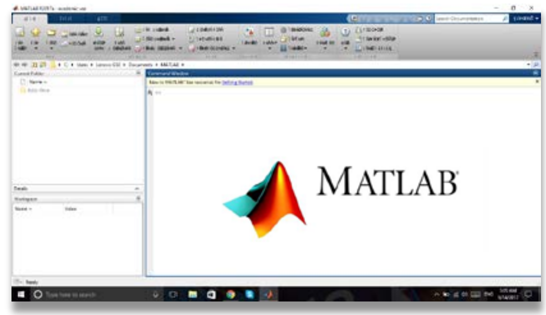
- **Date:** February 27, 2010 at 3:34 P.M.
- **Lasted:** approx. 4 Min
- **Location:** Ocean at about 150 km NE of Concepción, Chile, and 63km SW of Cauquenes, Chile
- **Magnitude:** 8.8
- **Affected Areas:** Valparaiso, Metropolitana de Santiago, Maule, Biobío y la Araucanía
- **Damage Cost:** 15-30 billion USD
- **Casualties:** more than 500 earthquake fatalities

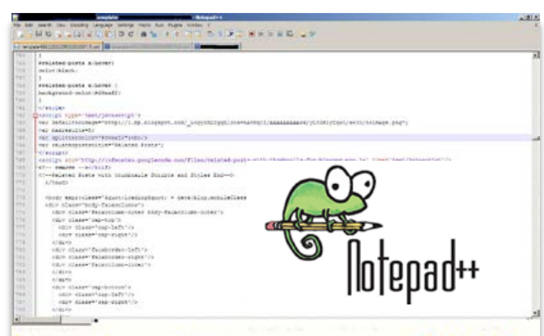
Goal

- Be able to predict structural response to seismic activity to improve building safety.

Tools Used

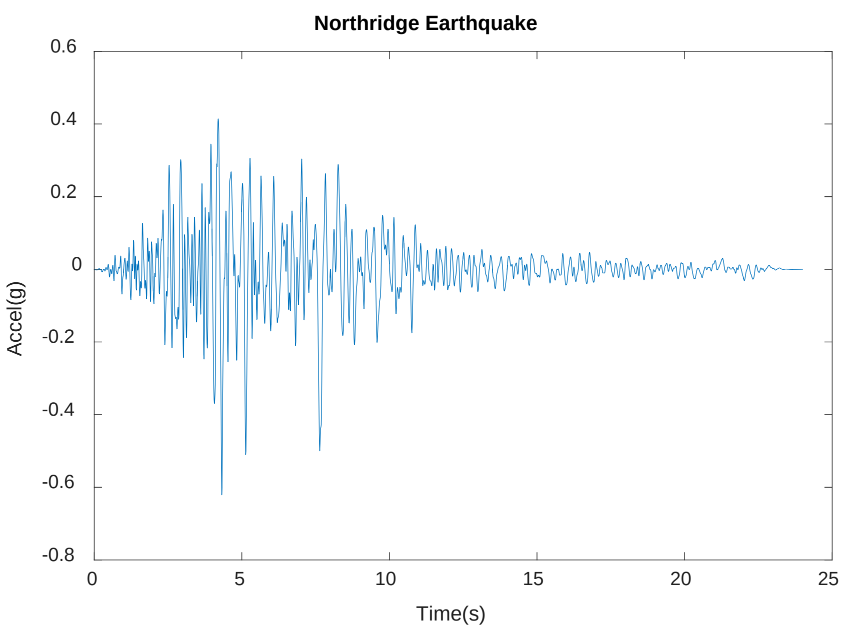
- **Matlab**: software for pre and post analysis processing
- **OpenSees**: platform for simulations
- **Notepad ++**: Text editor for coding process (saved as .tcl in OpenSees folder)

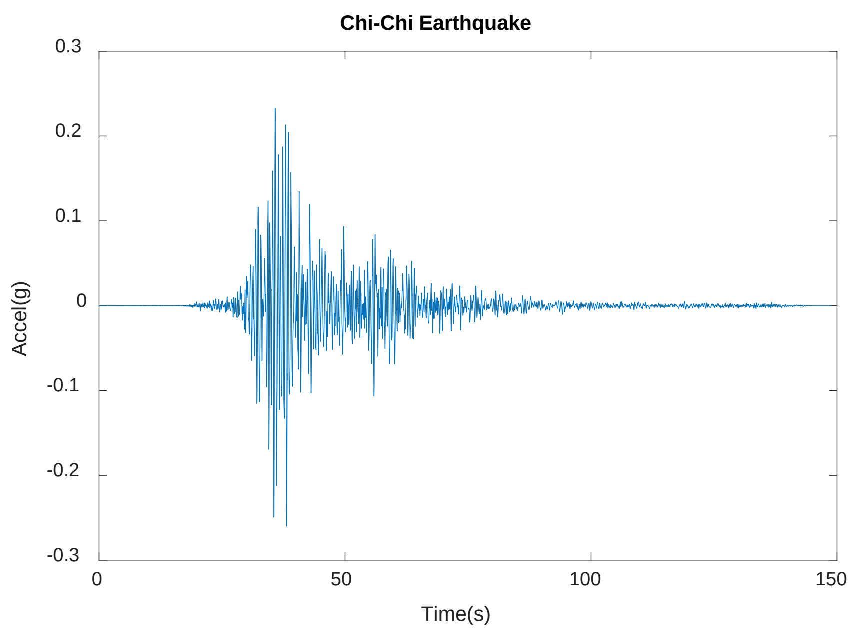




Research - Database

- Pacific Earthquake Engineering Research (PEER)
    - -Northridge Earthquake - Mag: 6.7
    - -Chi-Chi Earthquake - Mag: 7.6
- Dimitrios-Lignos Steel Database





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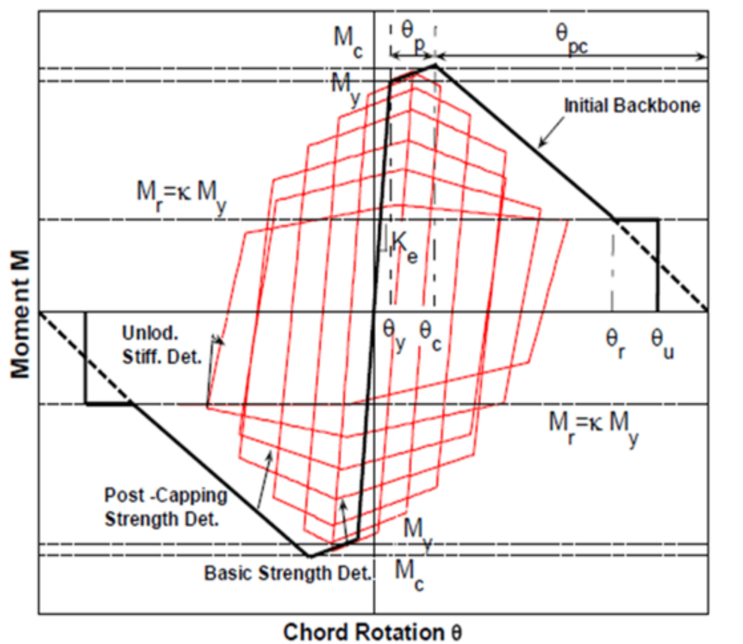
Ibarra-Medina-Krawinkler (IMK)

- Captures strength and stiffness deterioration
- Predicts structural response close to collapse



- Effective yield Rotation (M_y and θ_y)
- Effective Stiffness $K_e = \frac{M_y}{\theta_y}$
- Capping Strength and associated rotation for monotonic loading (M_c and θ_c)
- Pre-capping rotation capacity for monotonic loading θ_p
- Post-capping rotation capacity θ_{pc}
- Residual Strength $M_r = kM_y$
- Ultimate Rotation Capacity θ_u

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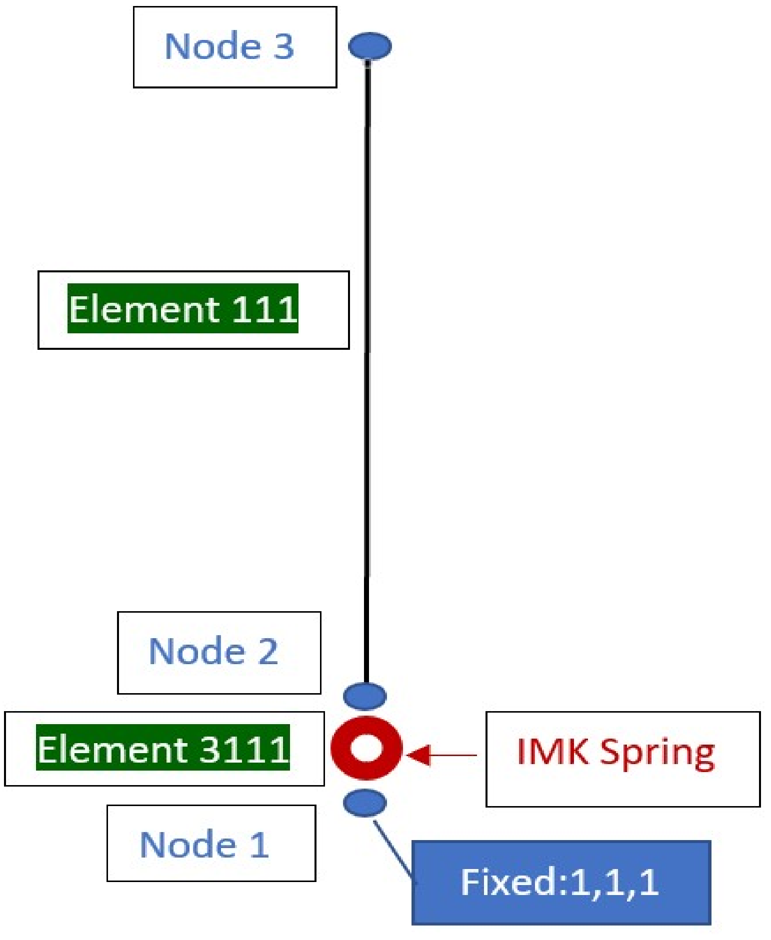
Single Column Model



Cyclic Analysis

- PSO: population based algorithm to determine the best position in the search space.
- MCMC: Method used for obtaining information about the distribution.

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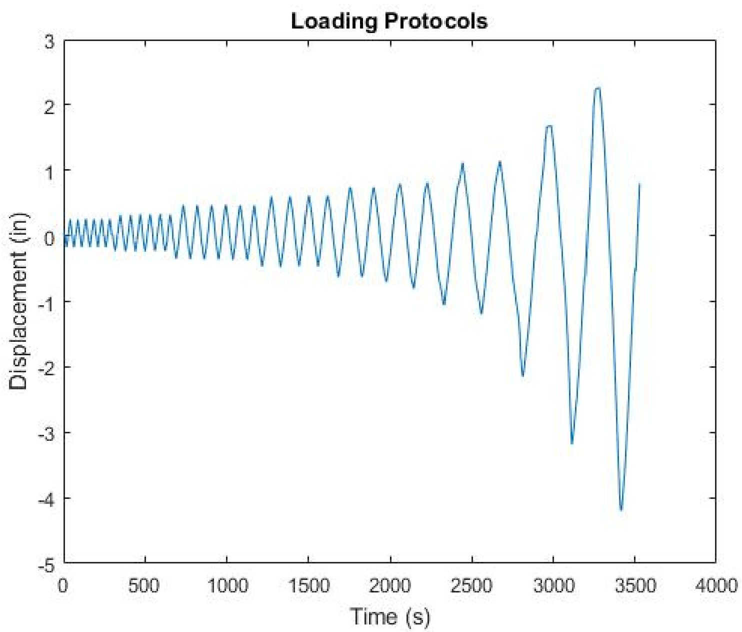
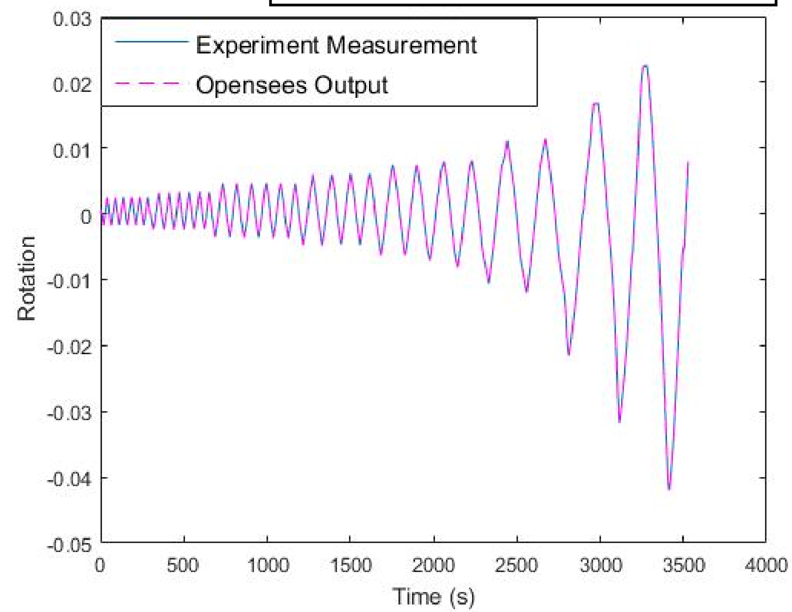
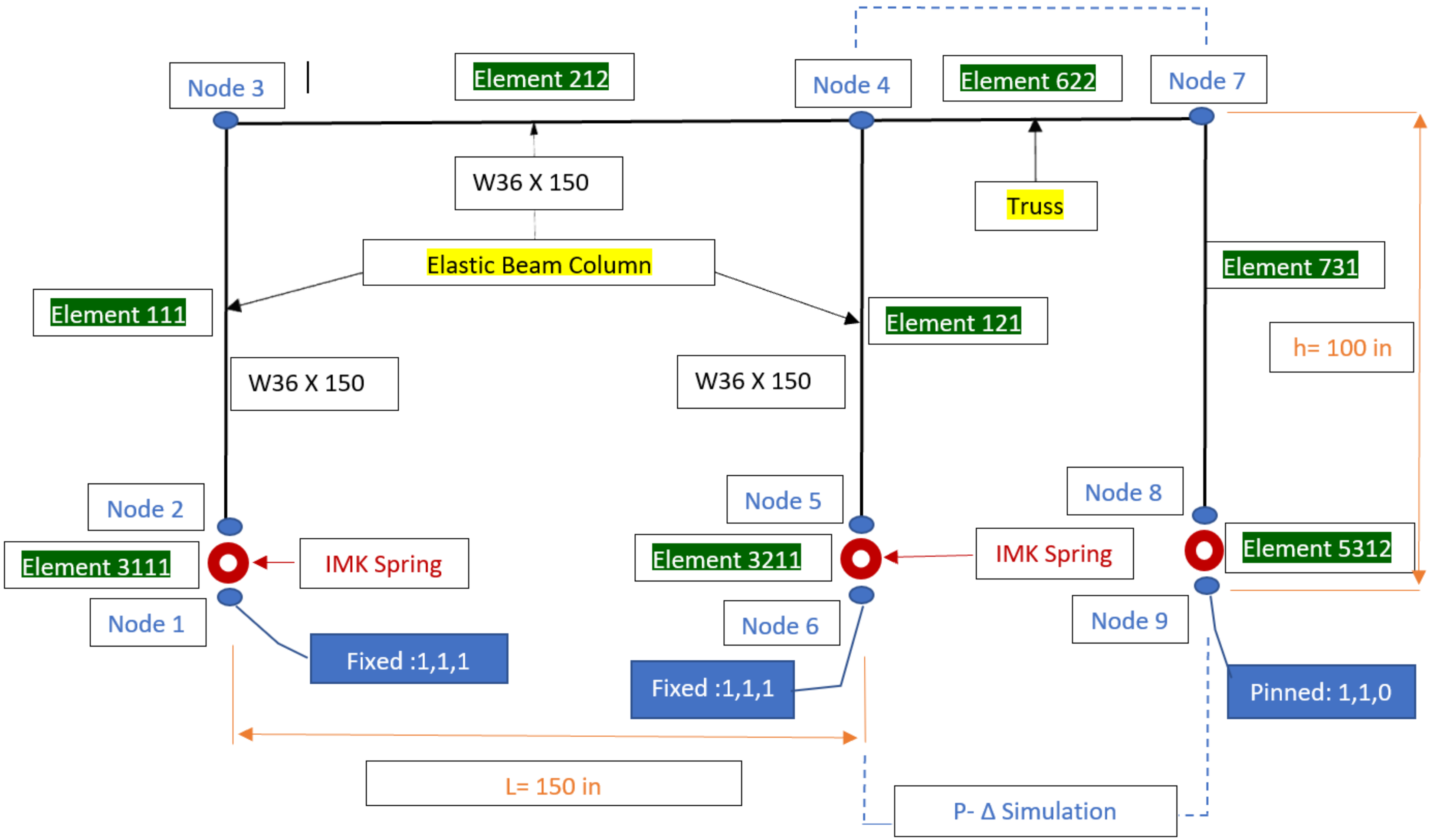
Cyclic Analysis

- Uses displacement control on point of interest of targeted structure.
- Allows for further optimization and uncertainty quantifications.

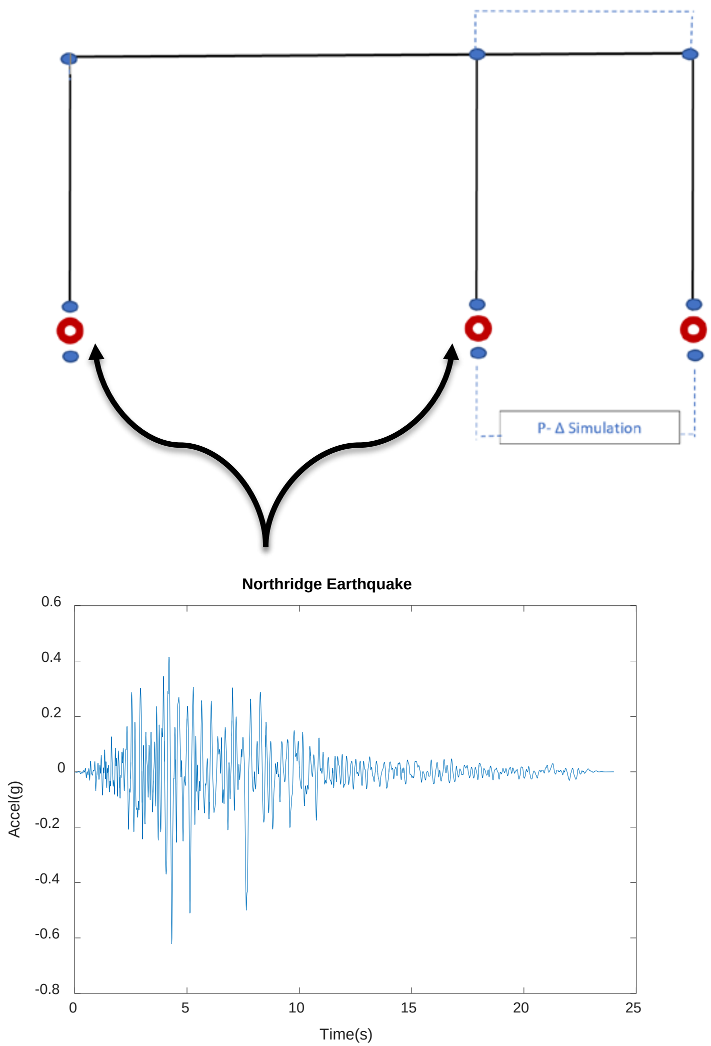




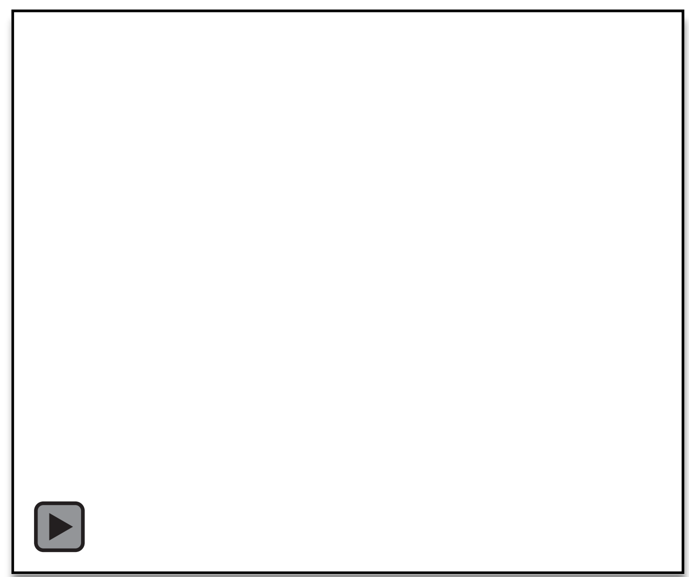
Steel Frame Model



Dynamic Analysis



- Further information about the structural response.



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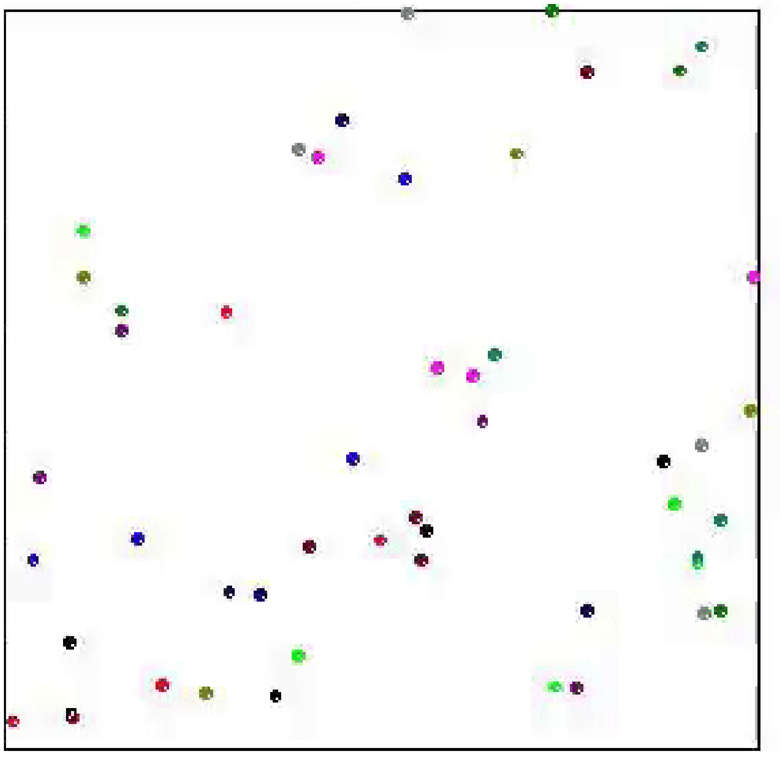
Particle Swarm Optimization (PSO)

- By James Kennedy & Russell Eberhart
- Iterative process in which particles move to obtain the global optimum
- Animation shows how PSO progresses in 2D scenario



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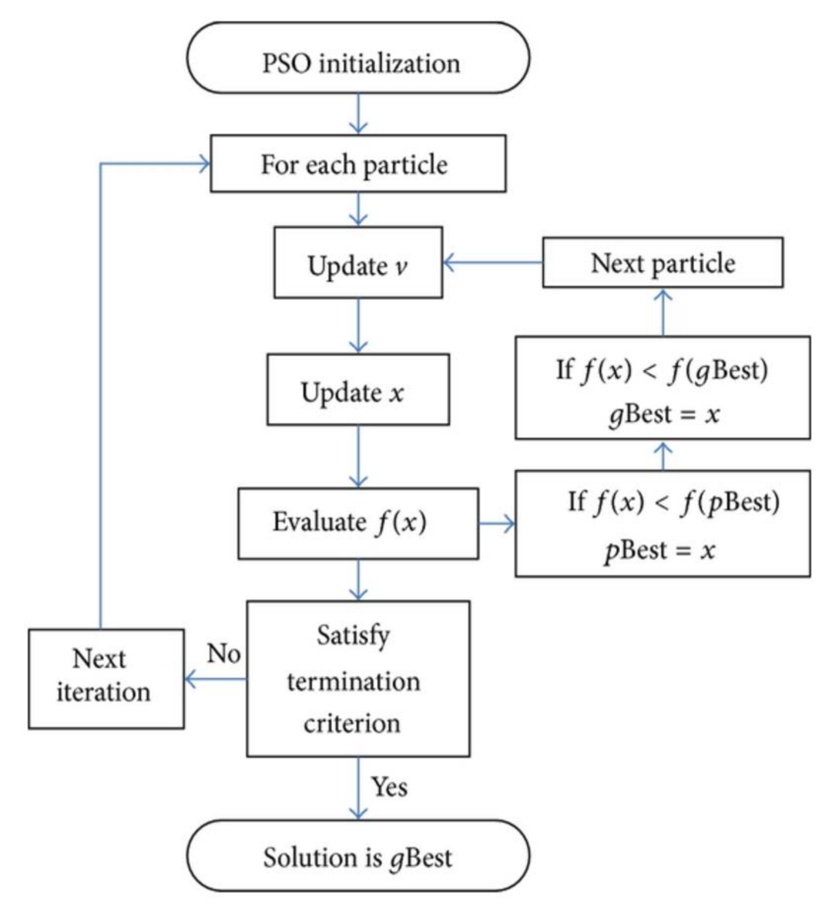
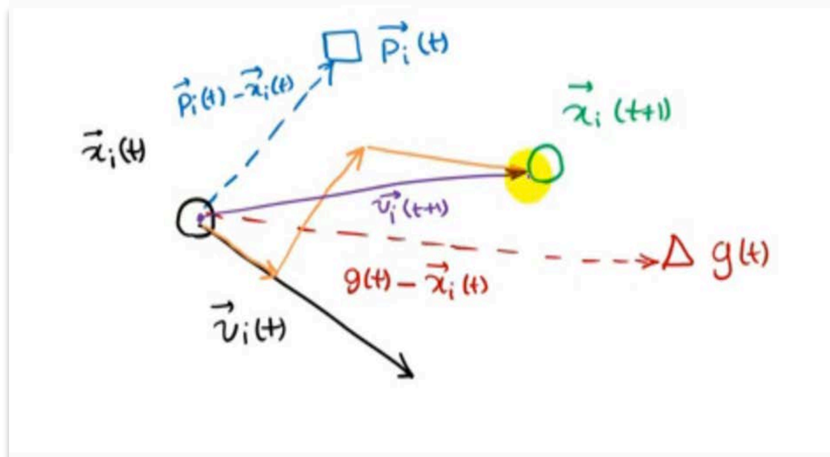
Particle Swarm Optimization (PSO)





- $x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) * 1$
- $v_{ij}(t+1) = wv_{ij}(t) + c_1 r_1 \left[P_{ij}(t) -\right.$

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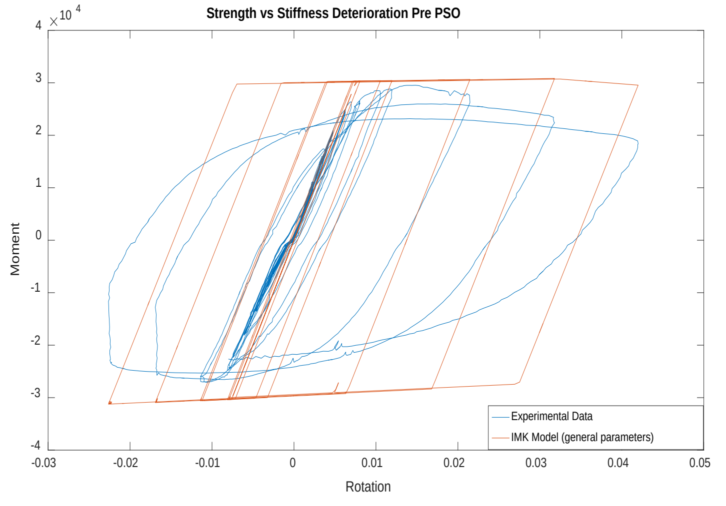
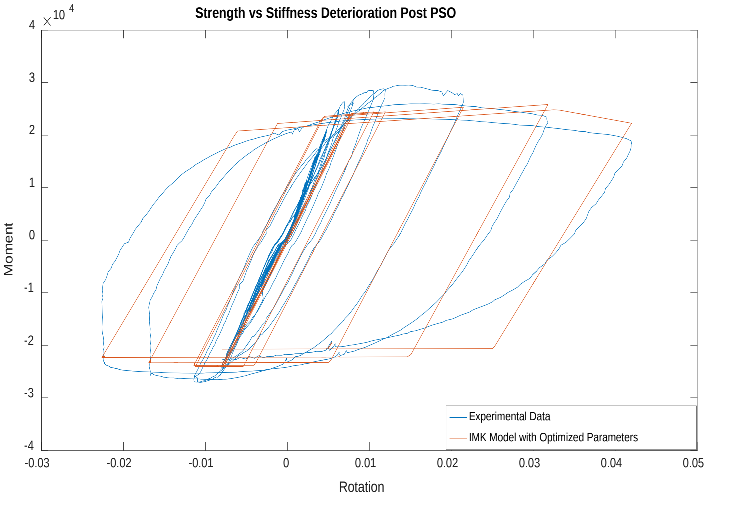
Particle Swarm Optimization (PSO)





Error Pre PSO: n*10e7

Error Post PSO: n* 10e6

	General Parameters	Optimized Parameters
McMyP	1.15	1.73
McMyN	1.05	1.28
MyP	30350	23378
MyN	-30350	-23378
K	4E+06	3E+06
th_p	0.025	0.022
th_pc	0.25	0.28
LS	10	1
ResP	0.4	0.6
th_u	0.4	0.4

Markov Chain Monte Carlo (MCMC)

- MCMC-statistical simulation using many algorithms that takes random samples from a probability distribution to produce uncertainty quantification

The Bayes Formula

$$P(\theta|y) = \frac{P(y|\theta)P(\theta)}{P(y)}$$

- $P(\theta|y)$-Posterior distribution
- $P(y|\theta)$-Likelihood Function
- $P(y)$-Single number
- $P(\theta)$-*Non-informative*
- y-IMK Parameters
- θ-Experimental Observation

Our Likelihood Function

$$P(y|\theta,\sigma^2) = (2\pi)^{\frac{-n}{2}}\sigma^{-n} \bullet e^{\{\frac{-1}{2\sigma^2}\bullet(\sum_{i=1}^{n}\left(y_i - f(x_i;\theta)\right)^2\}}$$

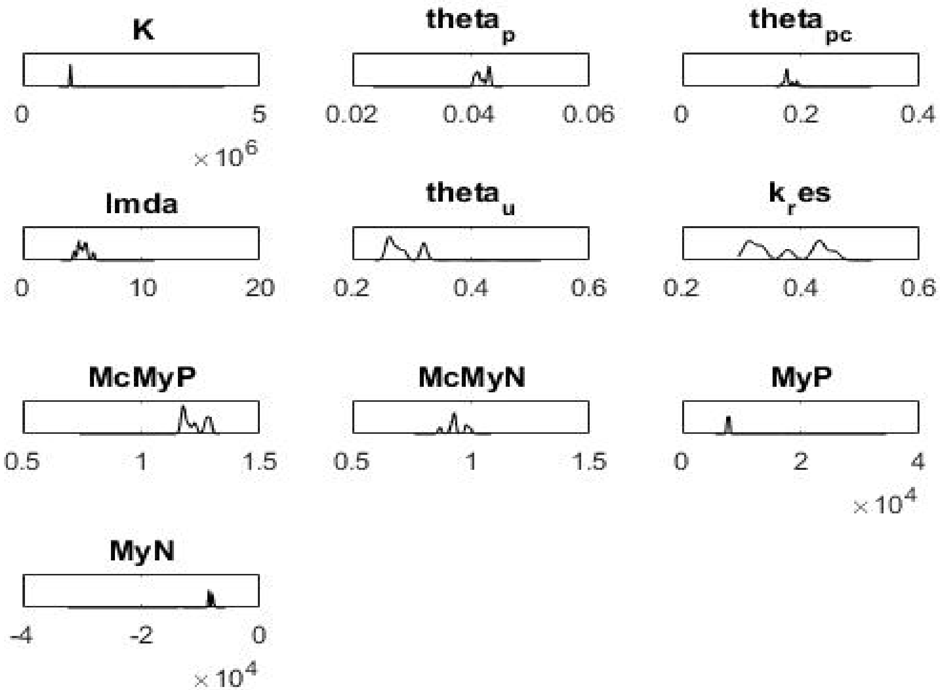
- σ^2-unknown variance
- n-number of individual observations
- π-target distribution

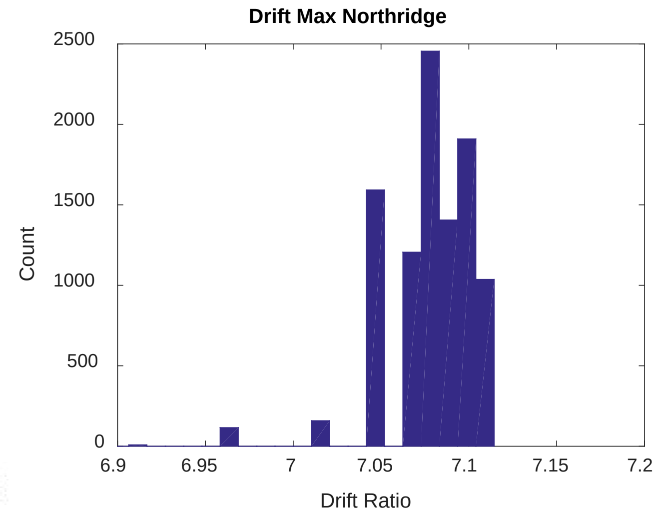
Metropolis-Hastings (MH) Algorithm

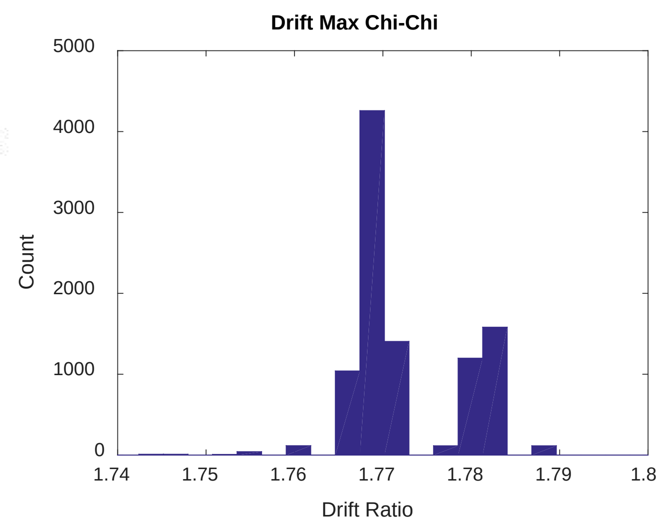
1) Start from the initial value θ^0, and select a proposal distribution.
2) At each step where the value is θ^{i-1}, it is correct to offer a candidate for a new distribution.
3) If the proposed value n is closer than the previous value θ^{i-1}, then it is accepted unconditionally.
4) If the new value is not closer than the previous value, θ^* is accepted as a new value with a probability function AKA the "delayed rejection" procedure.
5) If θ^* is not accepted, the chain remains as the current value $\theta^i = \theta^{i-1}$.
6) Repeat steps 2-6 until enough values are generated.

Analysis Results

- Small Graphs: PDF of model IMK Parameters
- Larger Graphs: distribution of story drift ratio from analysis







Summary

- Created a Photo Collection of structural damage due to earthquake conditions
- Conducted Literature Reviews
- Designed models in OpenSees for earthquake analysis
- Applied Particle Swarm Optimization to optimize IMK parameters
- Utilized Markov Chain Monte Carlo simulations to produce uncertainty quantifications for structural collapse

Conclusion

- Conduct simulations to reliably predict building responses to earthquake conditions
- Gain a greater appreciation for the multidiscipline research in Civil Engineering
- Teamwork
- Time management by meeting deadlines

Questions?

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