CV5100 – MUDE
Modeling, Uncertainty, and Data for Engineers

Course instructors:

Prof. Phanisri Pradeep Pratapa

Prof. Prakash Singh Badal

Prof. Sudheendra Herkal

Department of Civil Engineering

Indian Institute of Technology Madras

1 August 2025

Outline

- Introducing the instructors
- Motivation & Interaction
- Course overview
  - Unifying theme (Flowchart showing 3x3 modules)
  - Course content
- Course objectives & outcomes
- Course plan & logistics

Instructor background

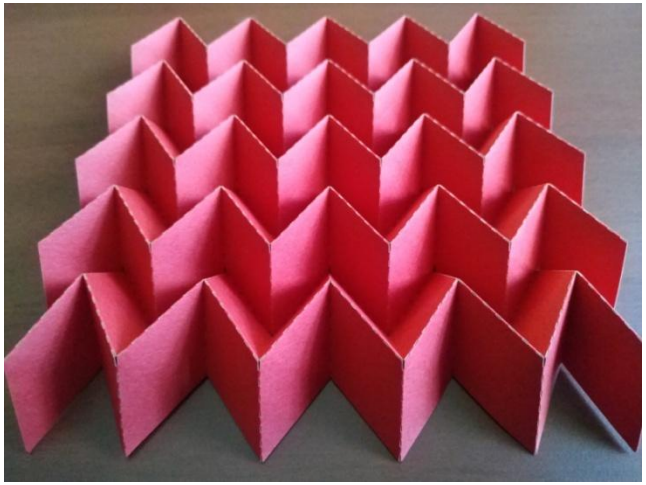
Dr. Phanisri Pradeep Pratapa
(www.pppratapa.com)

Education

- Ph.D., Georgia Tech, 2016
- M.S., UT Austin, 2011
- B.Tech., IIT Madras, 2010

Research

- Metamaterials
- Origami engineering
- Lattice structures
- Concrete 3D printing



Instructor background

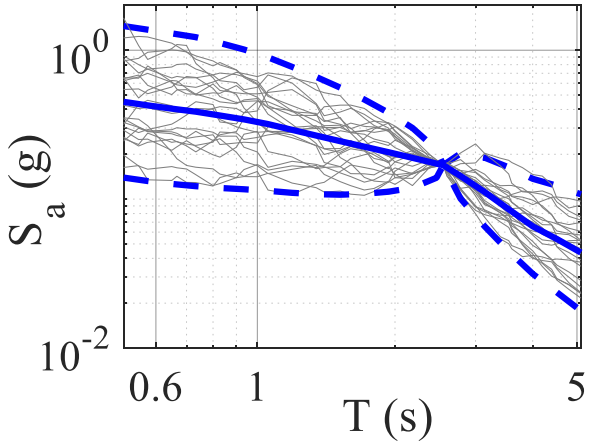
Dr. Prakash Singh Badal
sites.google.com/view/Prakashbadal

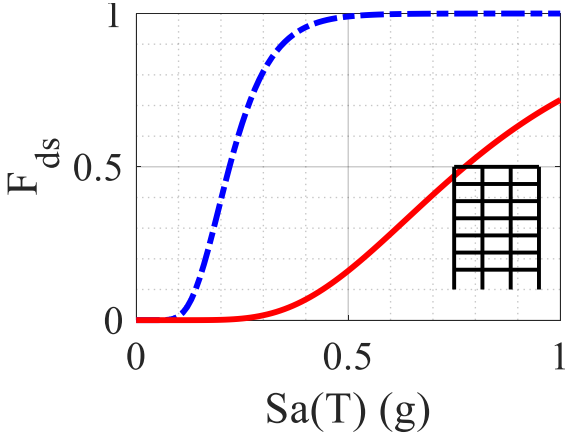
Education

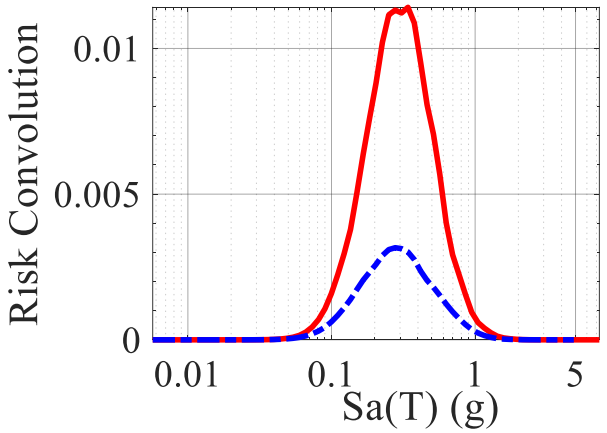
- Ph.D., IIT Bombay, 2020
- B.Tech., IIT Bombay, 2011

Research

- Earthquake Engineering
- Seismic Risk and Resilience
- Multihazard Engineering
- NP-Hard Rank Aggregation







Instructor background

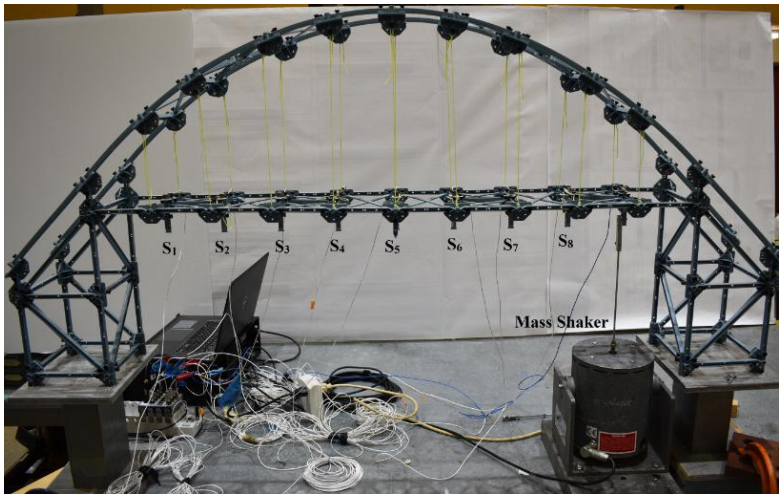
Dr. Sudheendra Herkal (www.linkedin.com/in/sudheendra-herkal)

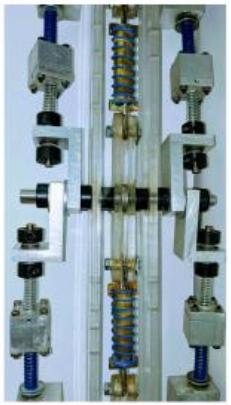
Education

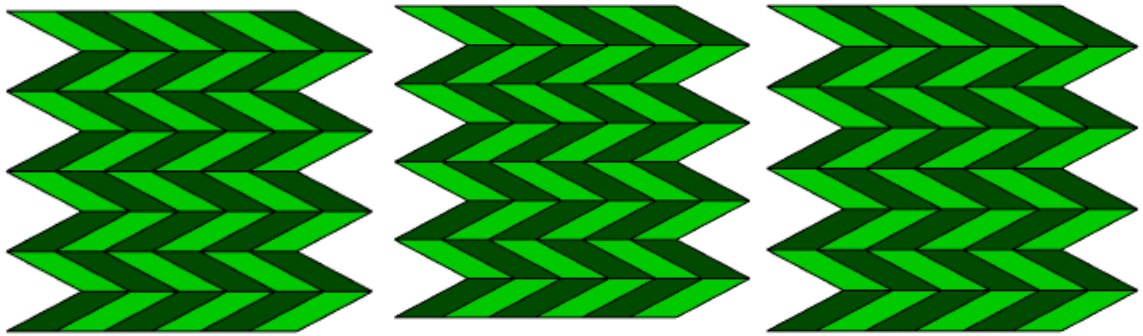
- Ph.D., Rice University, 2023
- B.Tech. and M.Tech., IIT Madras, 2018

Research

- Seismic Protection
- Structural Dynamics
- Structural Health Monitoring
- Origami Engineering







Motivation & Interaction

Numerical Modeling, Linear Algebra, Optimization

Can you solve Ax=b?

If $A \in R$ and $b \in R$,
Then $x = b/A$.

e.g.

$2x = 3 \Rightarrow x = 3/2$

If $A_{2\times2}$ and $b_{2\times1}$ are matrices,
then $x = (A_{2\times2})^{-1} b_{2\times1}$

e.g.

$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{bmatrix} 5 \\ 6 \end{bmatrix}$$

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \frac{1}{-2} \begin{bmatrix} 4 & -2 \\ -3 & 1 \end{bmatrix} \begin{bmatrix} 5 \\ 6 \end{bmatrix} = \begin{pmatrix} -4 \\ 4.5 \end{pmatrix}$$

What if $A_{n\times n}$ and $b_{n\times 1}$ are very large matrices ($n \gg 1$)?

$$\begin{bmatrix} A_{11} & \dots & A_{1n} \\ A_{21} & \dots & A_{2n} \\ \vdots & \ddots & \vdots \\ A_{n1} & \dots & A_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}$$

Use Computing Machines!

What are computer models made of?

Numerical problem

$$\begin{bmatrix} A_{11} & \dots & A_{1n} \\ A_{21} & \dots & A_{2n} \\ \vdots & \ddots & \vdots \\ A_{n1} & \dots & A_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}$$

Algorithm/ Solution procedure

While $i < i_{max}$ and $\delta_{new} > \varepsilon^2 \delta_0$ do
- $q \Leftarrow Ad$
- $\alpha \Leftarrow \frac{\delta_{new}}{d^T q}$
- $x \Leftarrow x + \alpha d$
- If i is divisible by 50
  - $r \Leftarrow b - Ax$
- else
  - $r \Leftarrow r - \alpha q$
- $\delta_{old} \Leftarrow \delta_{new}$
- $\delta_{new} \Leftarrow r^T r$
- $\beta \Leftarrow \frac{\delta_{new}}{\delta_{old}}$
- $d \Leftarrow r + \beta d$
- $i \Leftarrow i + 1$

Data/ Inputs

Given inputs A, b.

Code/ Software

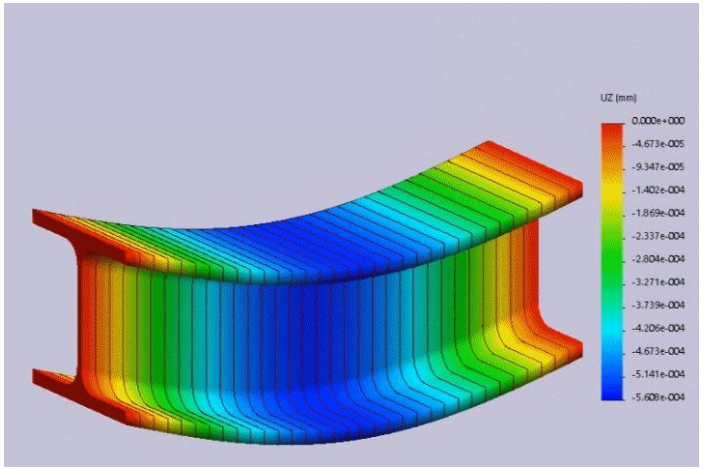
```
% loop over maxit iterations (unless convergence or failure)

for ii = 1 : maxit
    if existM1
        y = iterapp('mldivide',m1fun,m1type,m1fcnstr,r,varargin{:});
        if ~all(isfinite(y))
            flag = 2;
            break
        end
    else % no preconditioner
        y = r;
    end

    if existM2
        z = iterapp('mldivide',m2fun,m2type,m2fcnstr,y,varargin{:});
        if ~all(isfinite(z))
            flag = 2;
            break
        end
    else % no preconditioner
        z = y;
    end

    rho1 = rho;
    rho = r' * z;
    if ((rho == 0) || isinf(rho))
        flag = 4;
        break
    end
    if (ii == 1)
        p = z;
    else
```

Visualization/ Graphics/ "Animations"



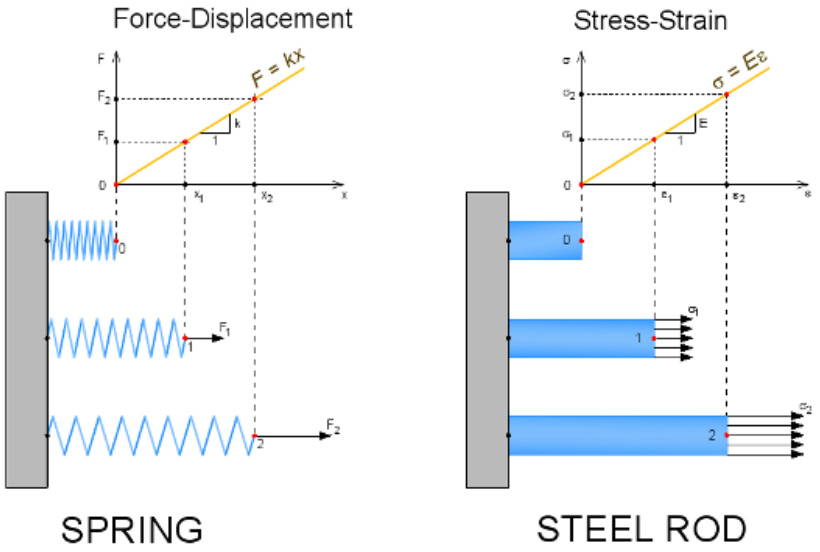
Ref:https://grabcad.com/library/animated-fem-simulation-of-a-beam-1

Hooke's Law (Theoretical model)

Consider a bar subjected to a force.

Input variable is: **Force** (f)

Output measurement is: **Elongation** (x)



Theoretical/ Mathematical model based on experiments is:

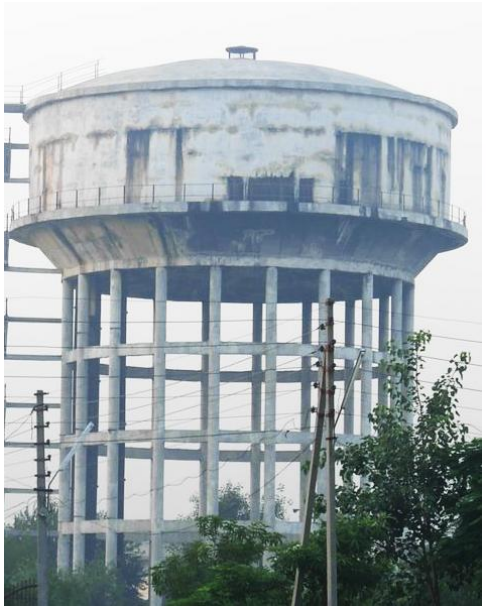
$$Kx = f$$

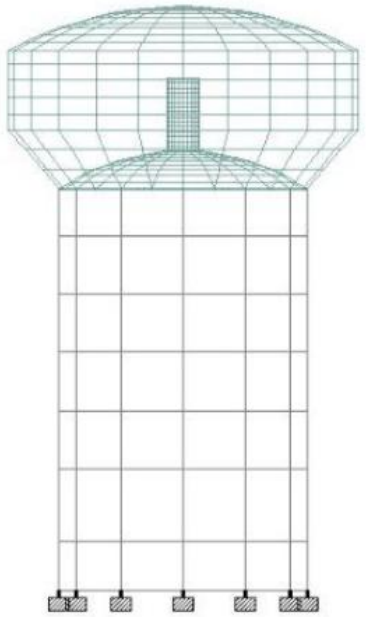
$$\Rightarrow x = f/K$$

Ref: http://infinitepower3.com/1/hookes-law/

Hooke's Law (Numerical model)

Consider a structure APPROXIMATED to be a connected network of many bars subjected to external forces.





Input variables are:
Forces $(f_1, f_2, f_3, \ldots)$

Output measurements are:
Elongations $(x_1, x_2, x_3, \ldots)$

$$\boldsymbol{K_{full}x = f} \quad ??$$

Numerical model based on "Finite Element" Approximation:

$$K_1 x_1 = f_1$$
$$K_2 x_2 = f_2$$
$$K_3 x_3 = f_3$$

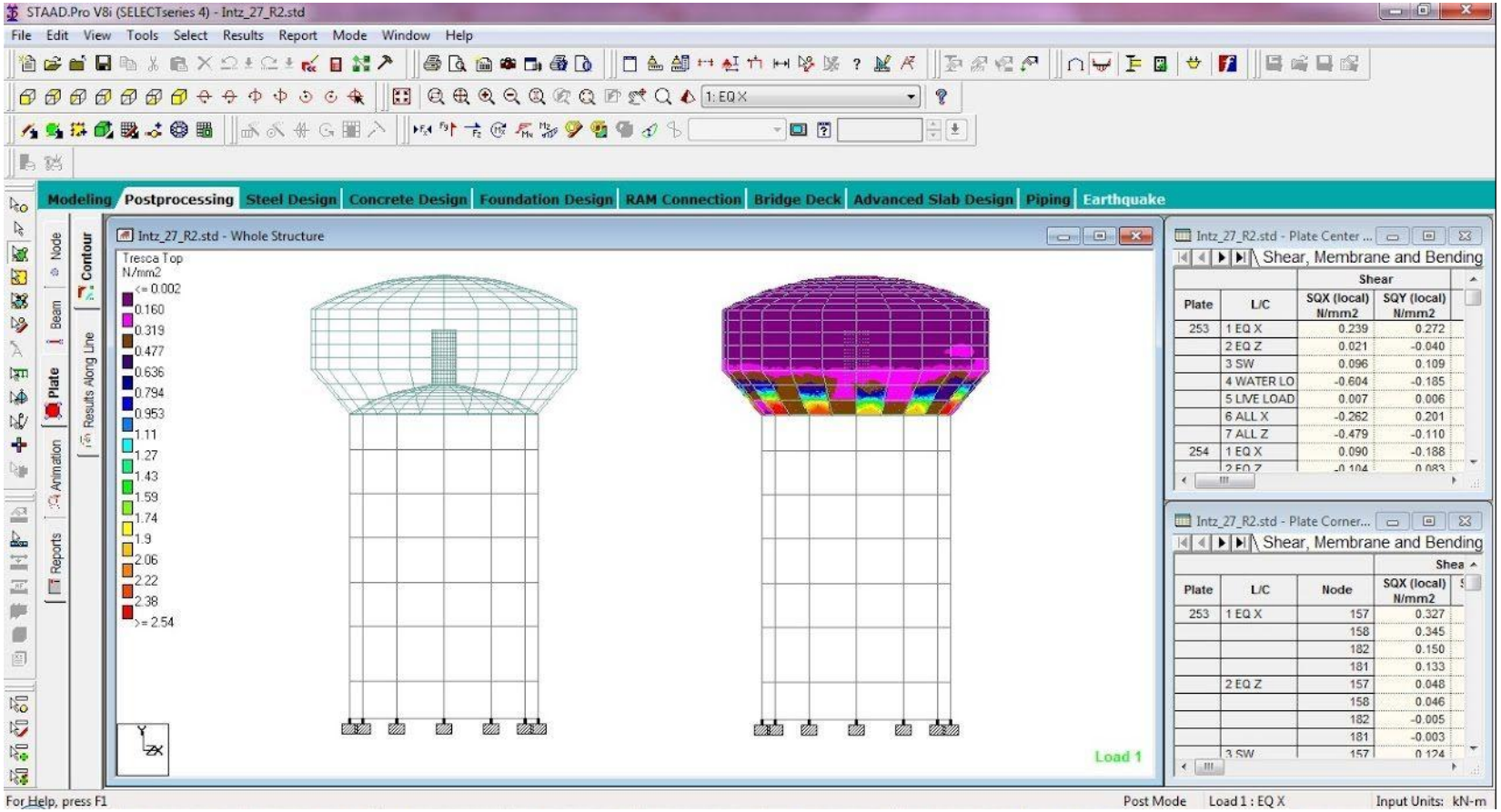
$$\begin{bmatrix} K_{11} & \cdots & K_{1n} \\ K_{21} & \cdots & K_{2n} \\ \vdots & \ddots & \vdots \\ K_{n1} & \cdots & K_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix}$$

Ref: https://i.pinimg.com/originals/1e/39/fc/1e39fca4fb2a73d41a80a053d1e5a356.jpg
https://mapio.net/images-p/27523359.jpg

Hooke's Law (Computational model)

Computational model is obtained by solving a numerical model on a computer.

$$\begin{bmatrix} K_{11} & \dots & K_{1n} \\ K_{21} & \dots & K_{2n} \\ \vdots & \ddots & \vdots \\ K_{n1} & \dots & K_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix}$$



Ref: https://i.pinimg.com/originals/1e/39/fc/1e39fca4fb2a73d41a80a053d1e5a356.jpg

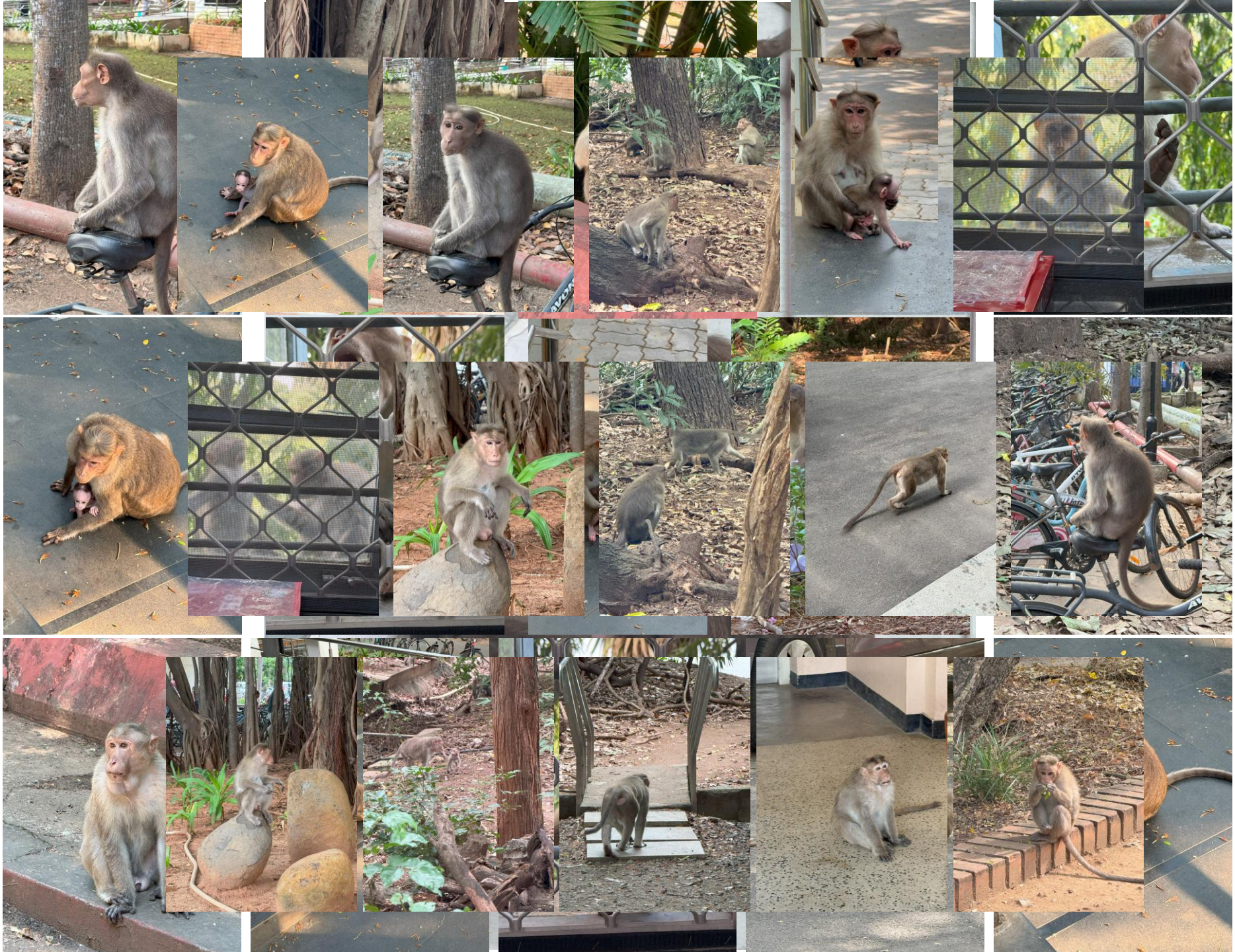
Motivation & Interaction

Uncertainty, Probability Distributions, Risk Analysis

IIT Madras Campus

Name one thing on IITM campus that has caught your attention?

Mor ys ...



Should you be afraid of monkeys?

- How can we know?
- Fear varies with person.
- Associated risk

$$Risk = Exposure \times Probability \times Impact$$

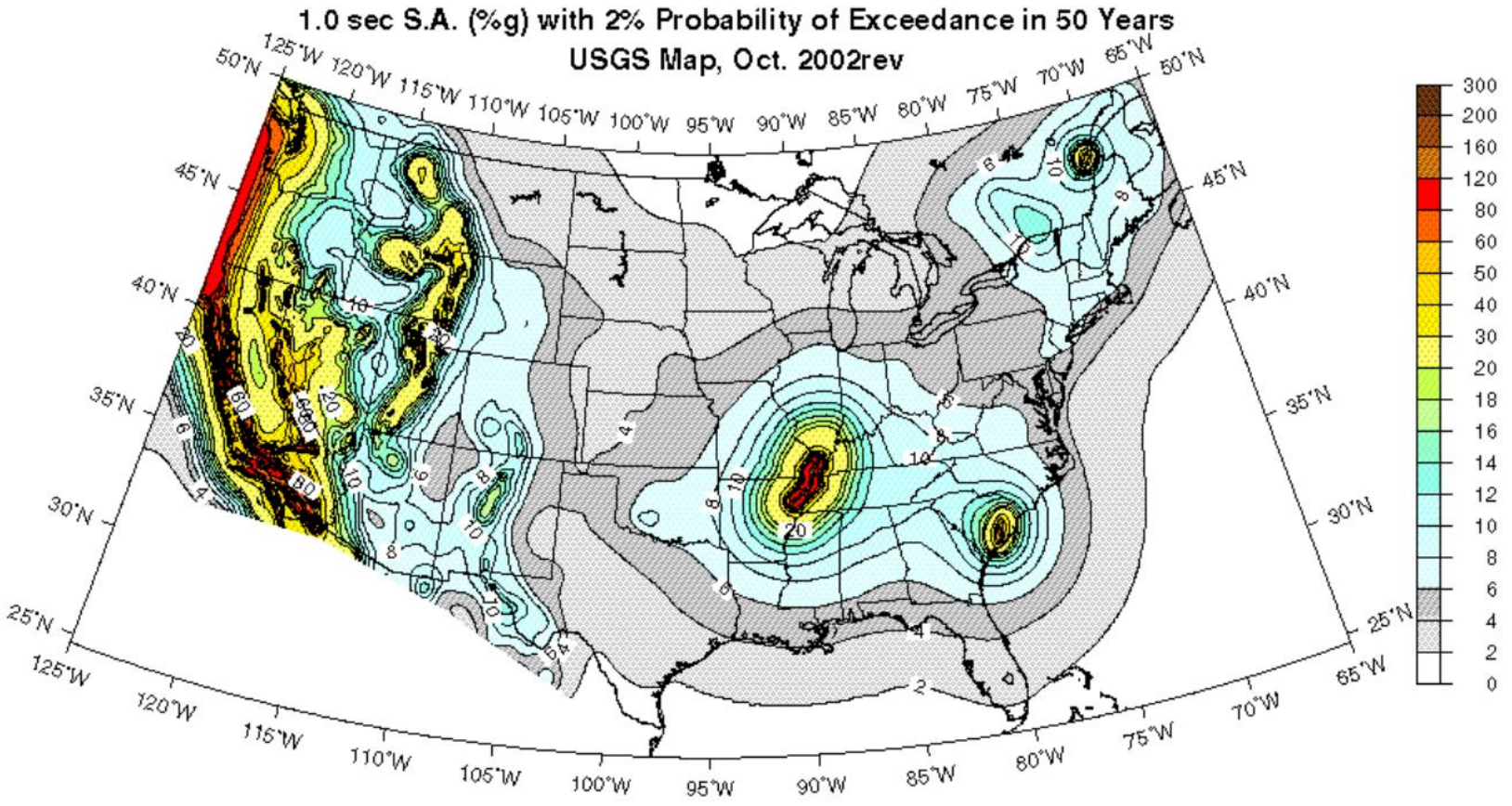
Exposure: The extent of monkey attack that you are subjected to.

Probability (likelihood): The chance that the threat will occur.

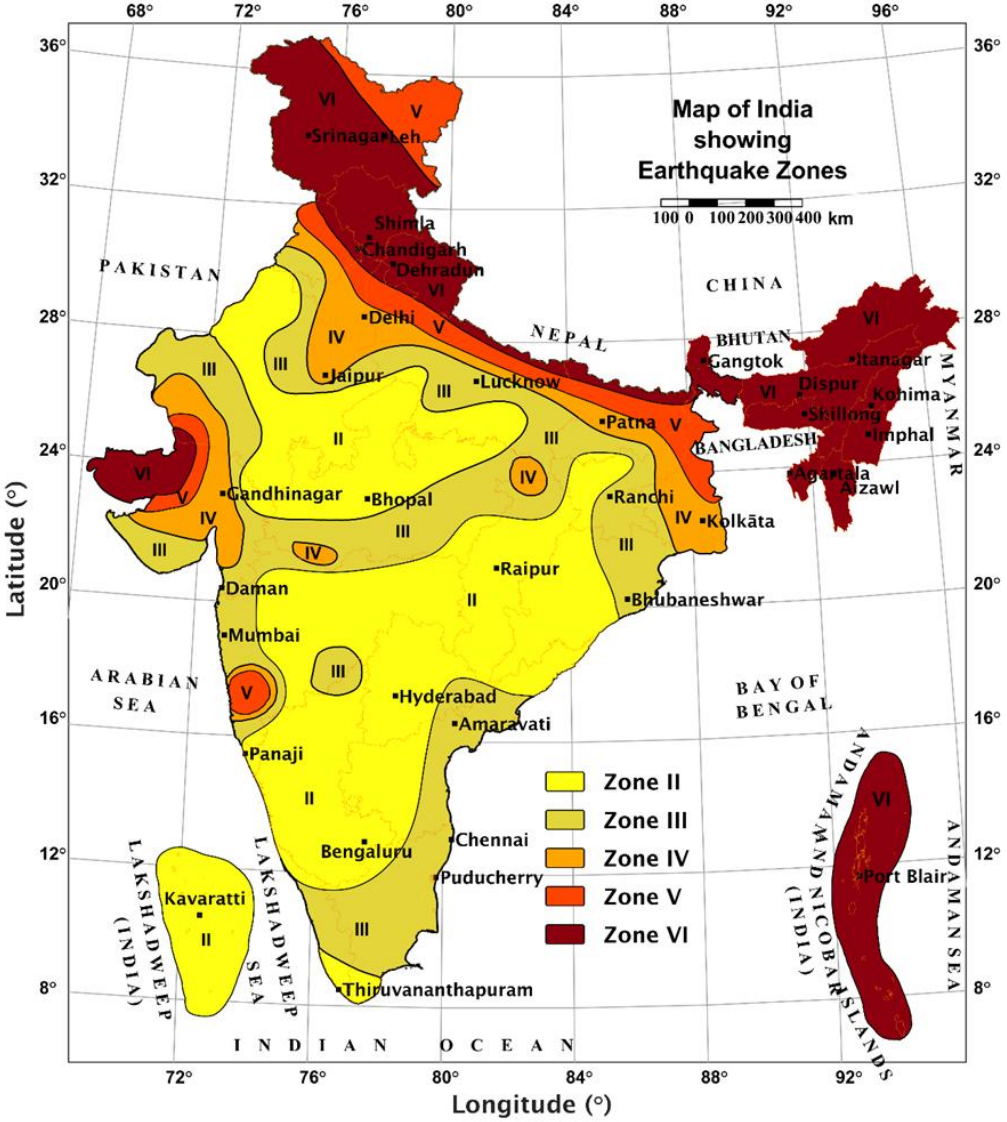
Impact (Consequence): Potential severity of the outcome if the threat occurs.

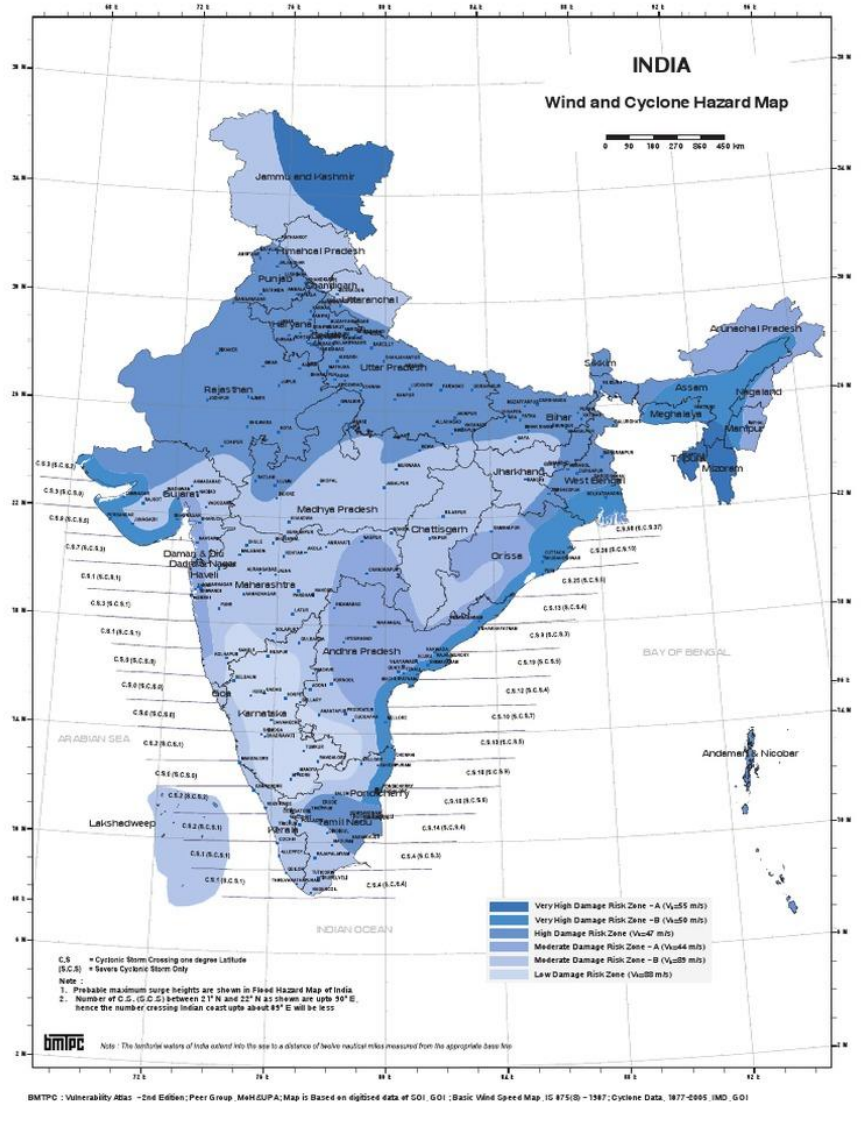
Probabilistic Analysis (Hazard and Risk)

- Decision-making for low-probability high-consequence events



Probabilistic Analysis (Hazard and Risk)





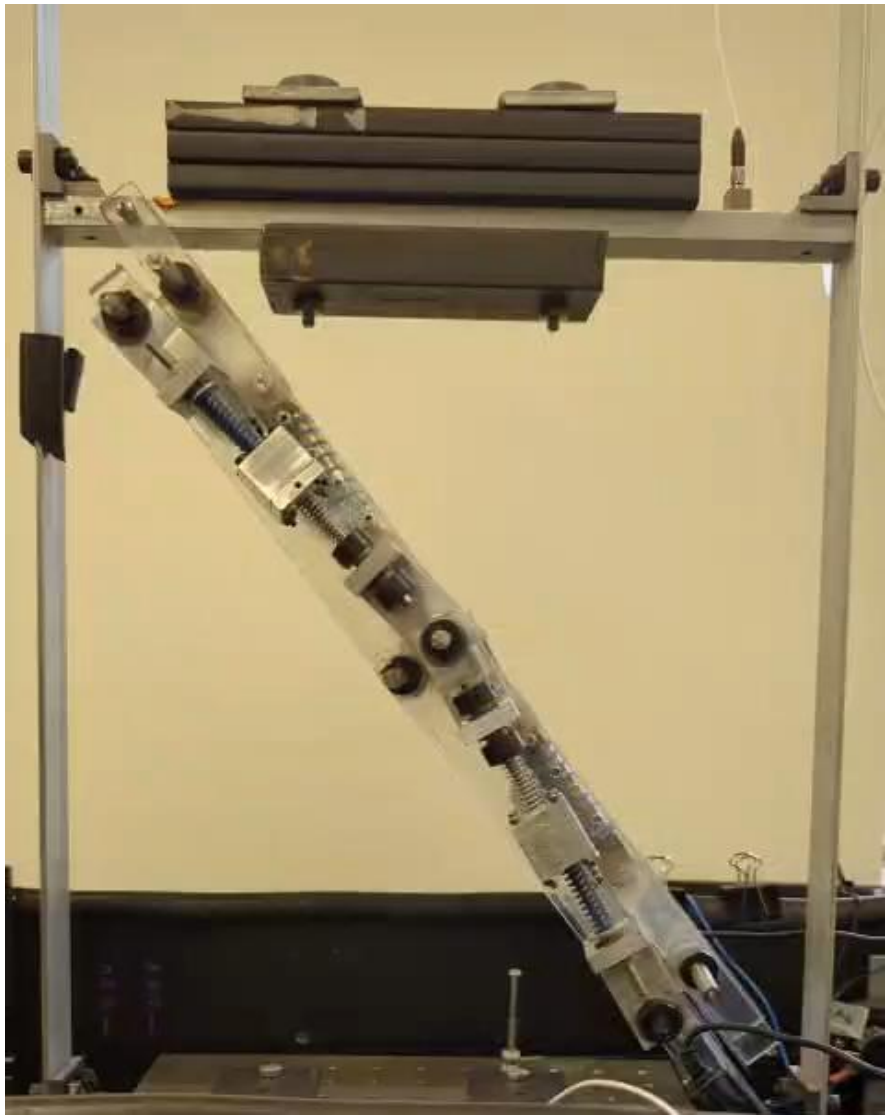
Topics

- Distributions
  - PDF, CDF
  - Discrete random variable (rv), probability, continuous rv
  - Gaussian, uniform, exponential, lognormal, Gumbel
- Uncertainty and Estimation
  - Random variables, covariance, correlation
  - Propagation laws, least-squares
  - Confidence intervals, MLE, hypothesis testing
- Risk Analysis
  - Extreme value, return period
  - Design life, peak over threshold
  - Risk and reliability

Motivation & Interaction

Signal Processing, Time Series, Machine Learning

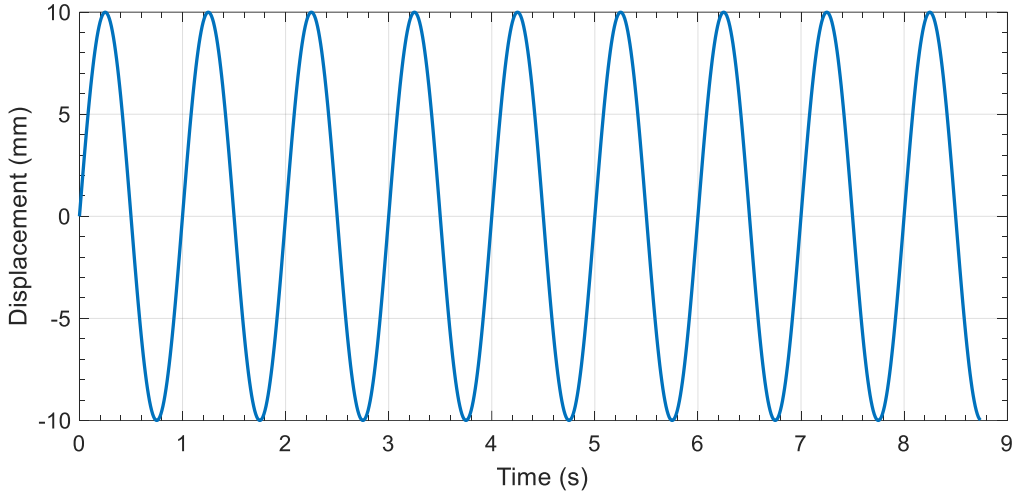
Let’s do an experiment!



- You did the experiment!
- You recorded some data!

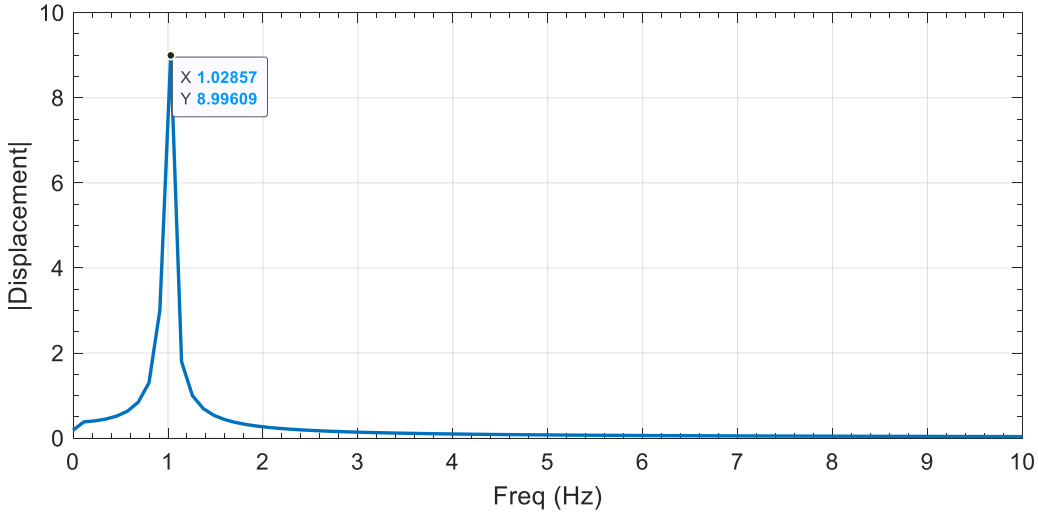
- Now let us look at the data…

Frequency Content



- What is the amplitude and frequency of data?
- Amp = 10 mm
- Freq = 1 Hz

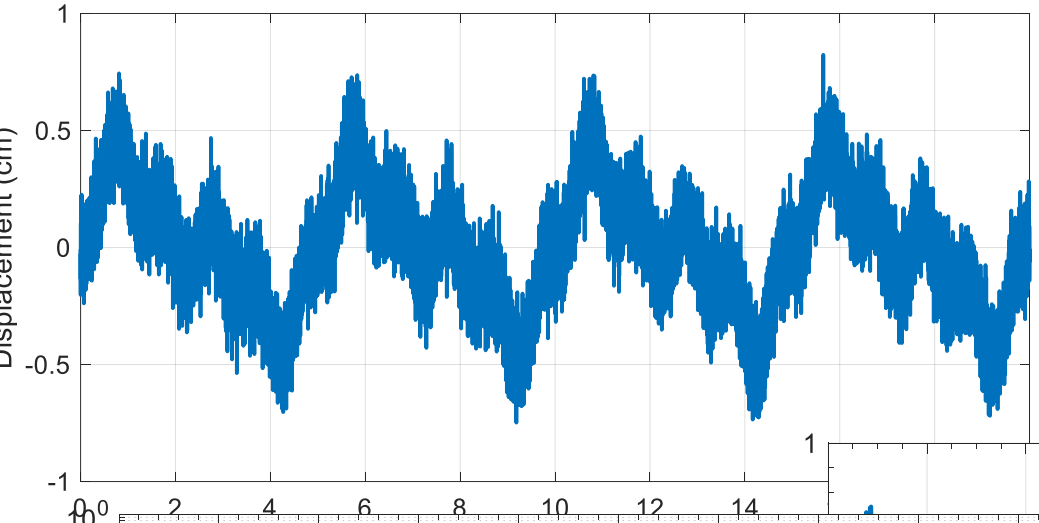
Get Frequency Content Using a MATLAB Function



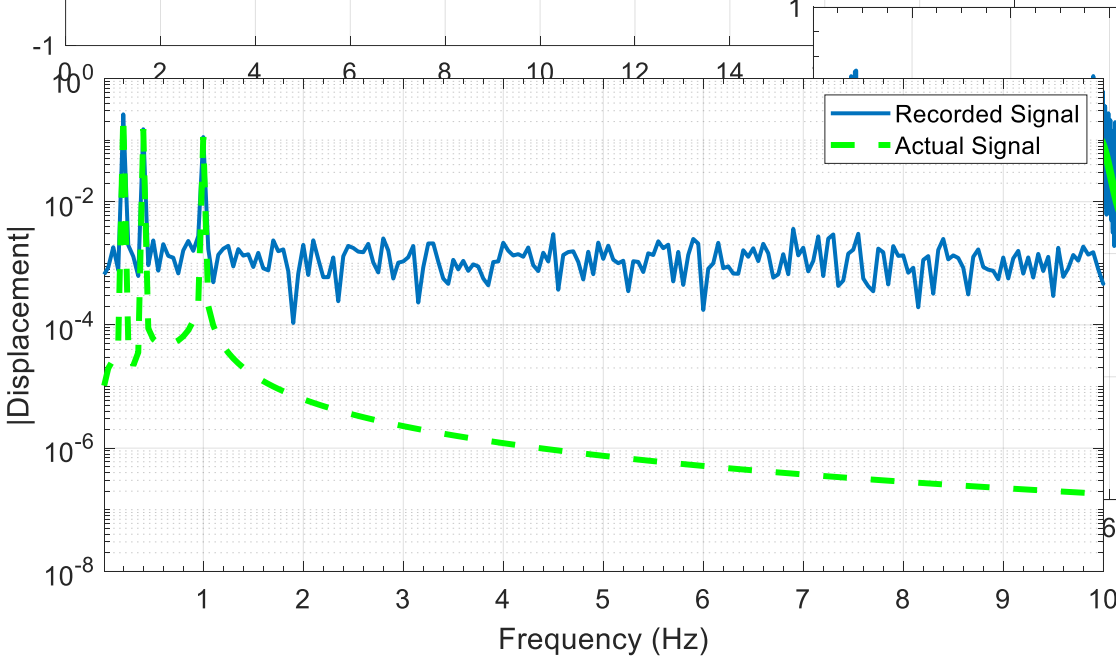
Why are amplitudes and frequency contents not what they should be?

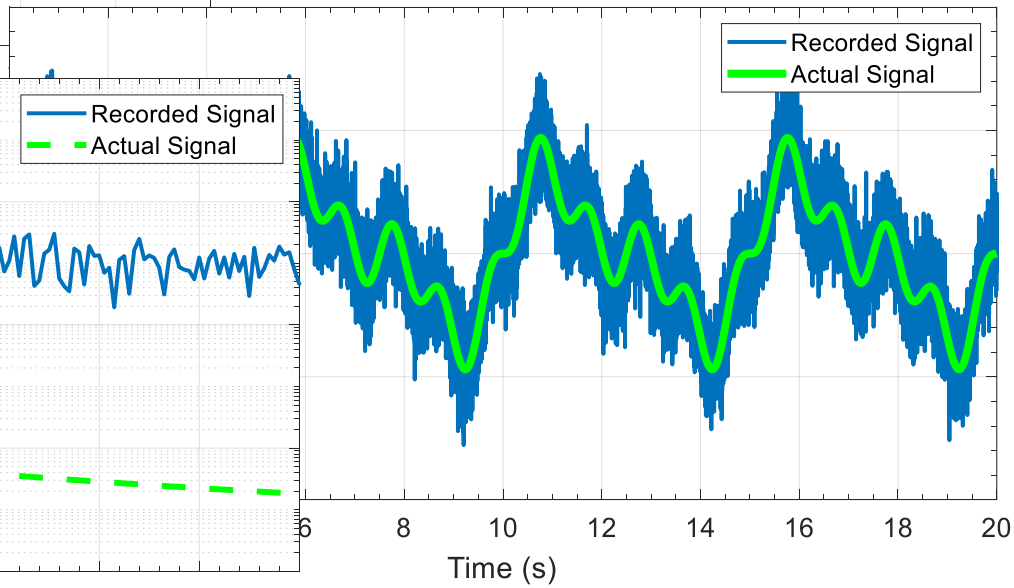
You should be able to answer this question by the end of the course!

Signal Processing and Time-series analysis



Some tools, techniques, and processing!





How to get the actual signal?

You should be able to answer this question by the end of the course!

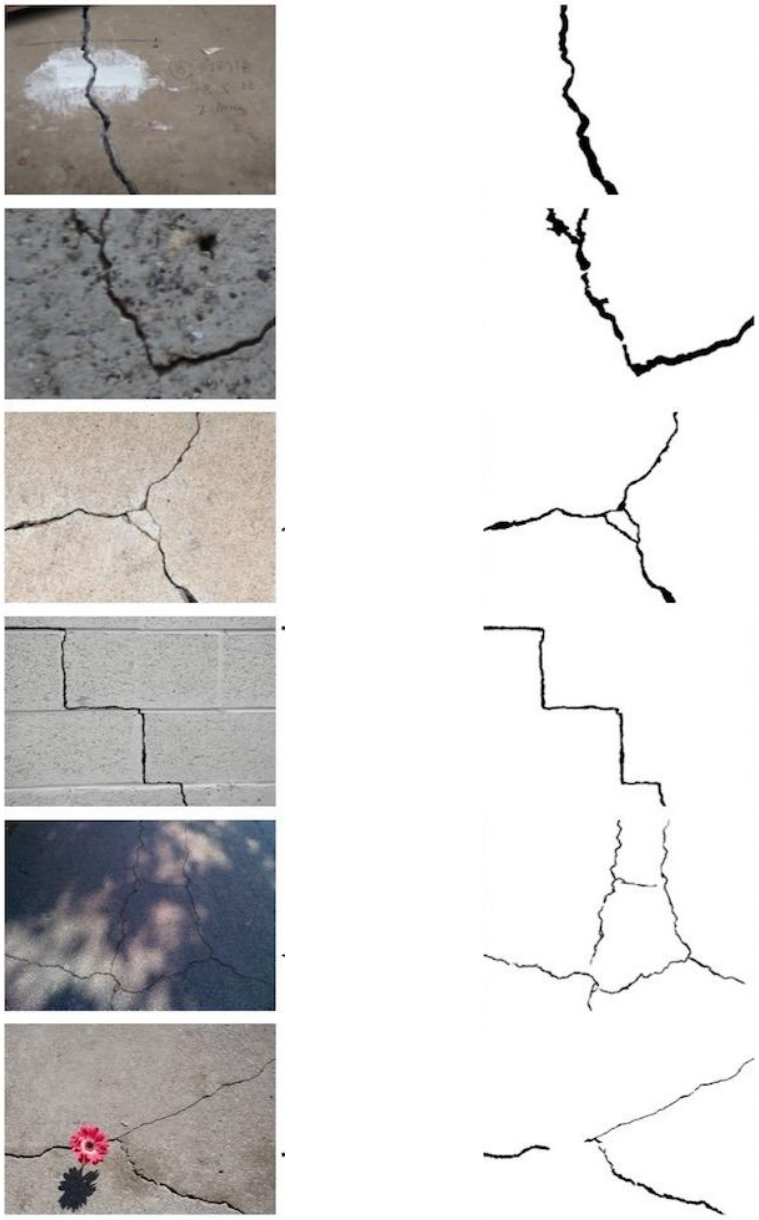
Let us visit an aging bridge!

https://en.riebotech.com/wp-content/uploads/2025/06/Manual-bridge-inspection-and-maintenance-1024x576.jpeg

- What do you prefer?
- Drones -> Do not put lives of people at risk! But capture thousands to lakhs of pictures!
- How to process and infer from so many images?

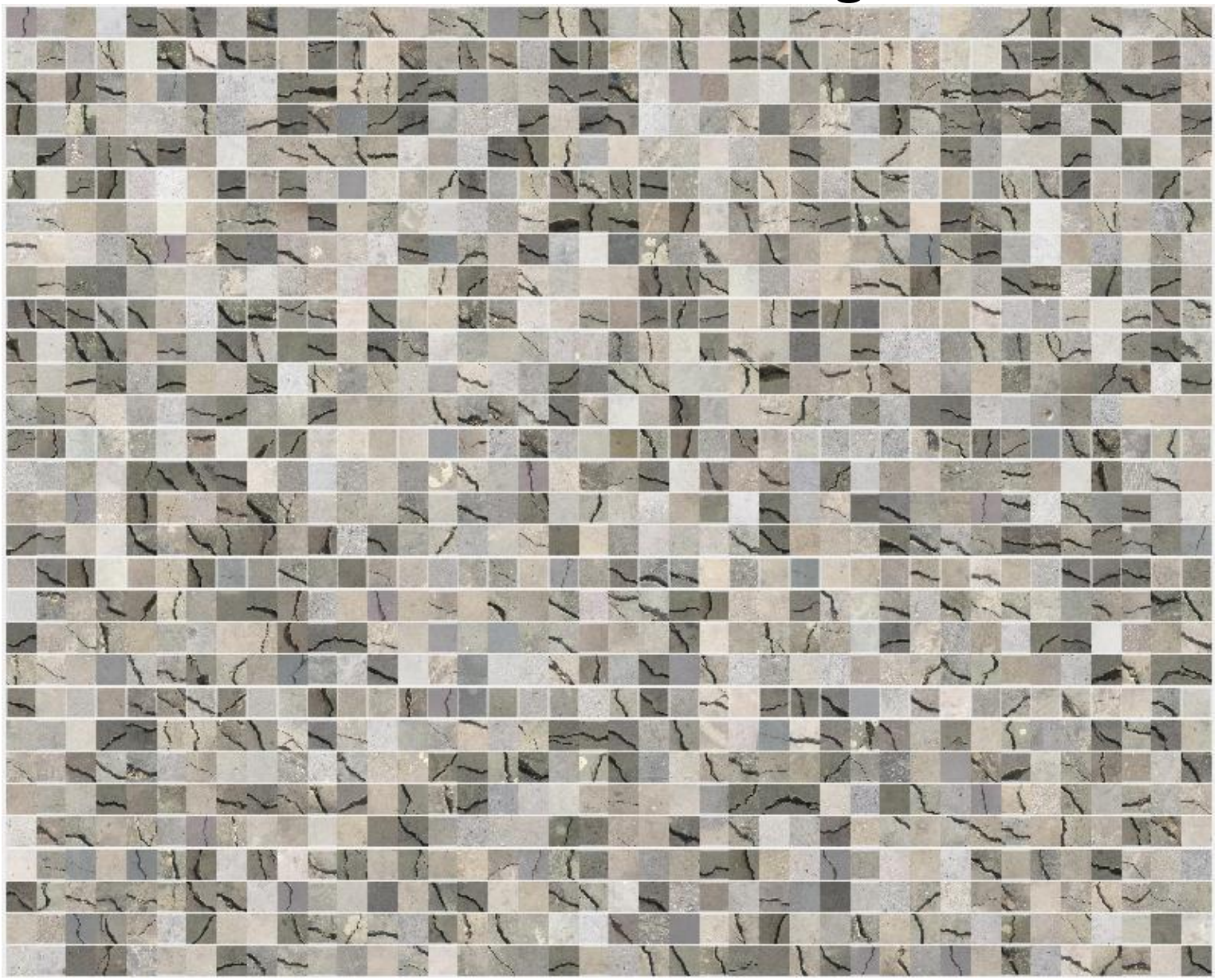
https://en.riebotech.com/wp-content/uploads/2023/11/Field-inspection.jpg

Machine Learning



https://github.com/yhlleo/DeepCrack

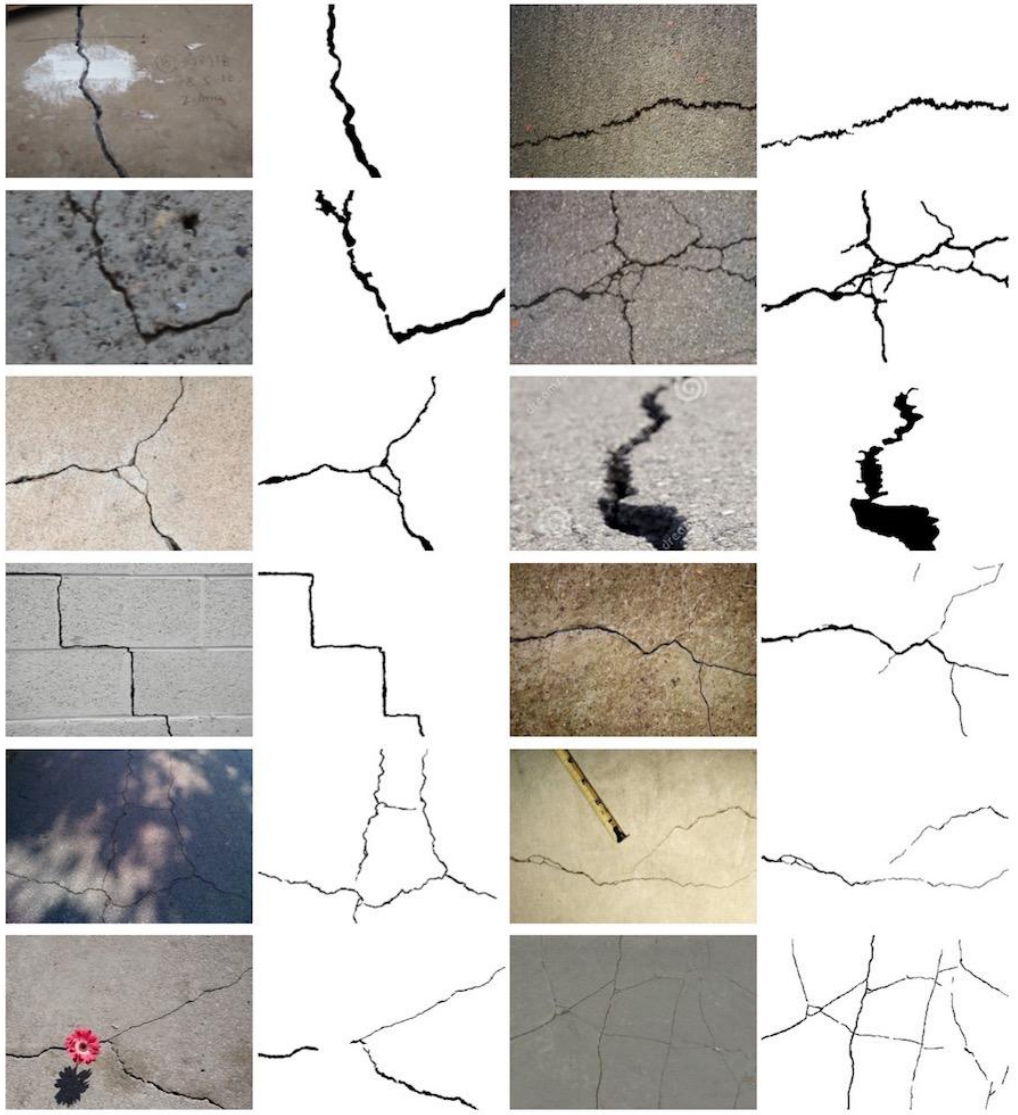
Machine Learning



https://www.kaggle.com/datasets/arnavr10880/concrete-crack-images-for-classification?resource=download

Machine Learning

- Process millions of images within hours!
- More accurate than humans or even traditional algorithms!
- You should be able to implement machine learning algorithms to do this yourselves by the end of the semester!



https://github.com/yhlleo/DeepCrack

Course plan & logistics

Weekly plan

- Monday morning: Upload the assignment
- Monday afternoon (P-slot in DCF): Tutorial session
- Friday end of the day: Assignment due (online submission)
- Friday 8am-9am: Help session (by TAs)
- Classes in F-slot on Tue, Wed, Thu in STR 301

For M.Tech. / M.Sc. / M.S. / Ph.D.

Days	8.00 - 8.50	9.00 - 9.50	10.00 - 10.50	11.00 - 11.50	12.00 - 12.50		14.00 - 15.15	15.30 - 16.45	17.00 - 17.50
Mon	A	B	C	D	G		P		J/J3
							H/H1	M/M2	
Tue	B	C	D	E	A		Q		F
							M/M1	H/H2	
Wed	C	D	E	F	B		R		G
							J/J1	K/K2	
Thu	E	F	G	A	D		S		H/H3
							L/L1	J/J2	
Fri	F	G	A	B	C		T		E
							K/K1	L/L2	

Lunch recess 12.50 am - 14.00 pm

Grading pattern

- Assignment – 40%
- Quiz-1 – 15%
- Quiz-2 – 15%
- EndSem – 30%
-

- Assignment – 30%
- MidSem – 20%
- EndSem – 30%
- Project – 20% (finalize topics)