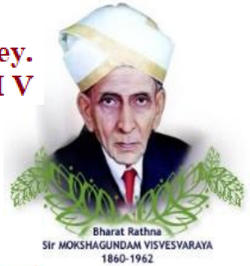
Dreams are not what you see in sleep,
it is the thing that doesn't let you sleep.

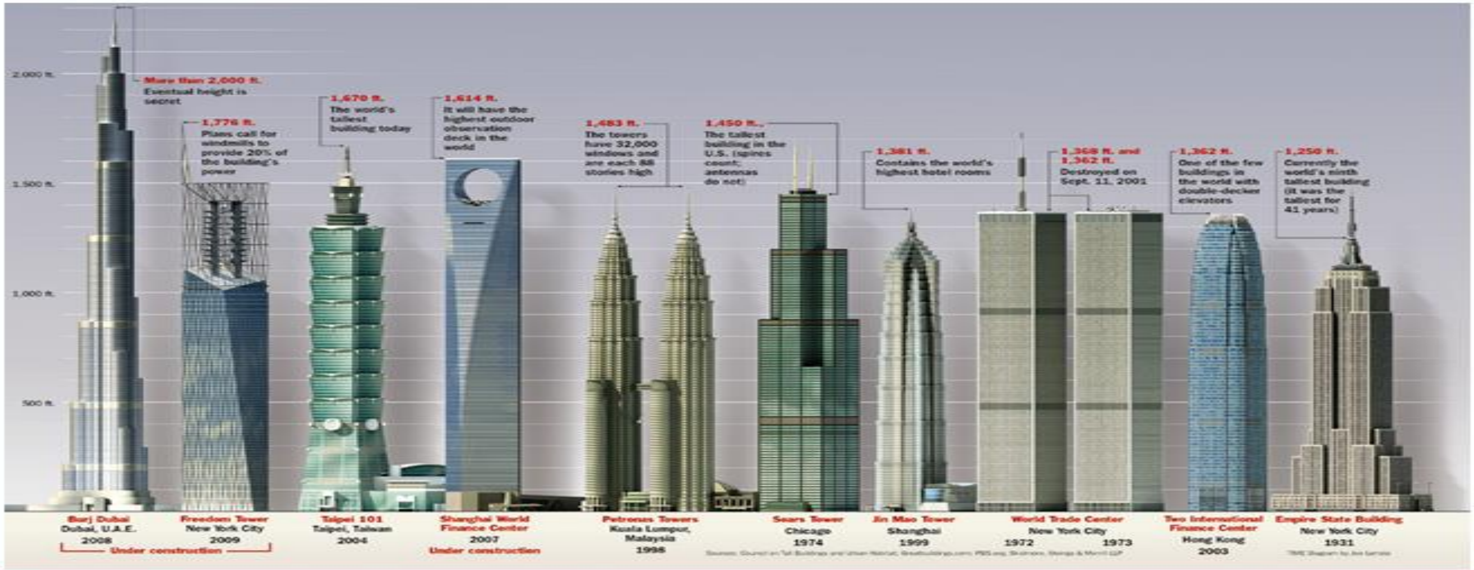
--- APJ Abdul Kalam

To give real service, you must add something
which can not be bought or measured with money.

-- Sir M V



Basics of Structural Engineering and Causes of failure of Structures



Dr. M. N. HEGDE

Contact: 97410 06095
email: mmmhegde@gmail.com

ME (Str. Engg), PhD (IISc)

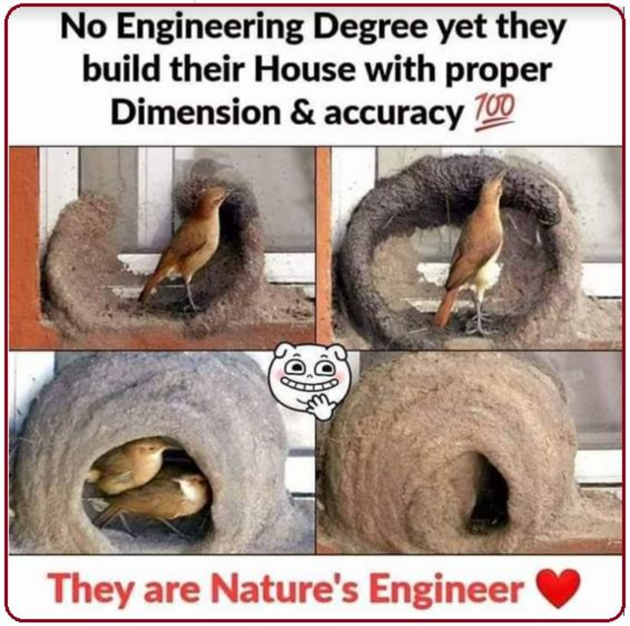
Professor: PG (Structural Engineering), Dr. AIT

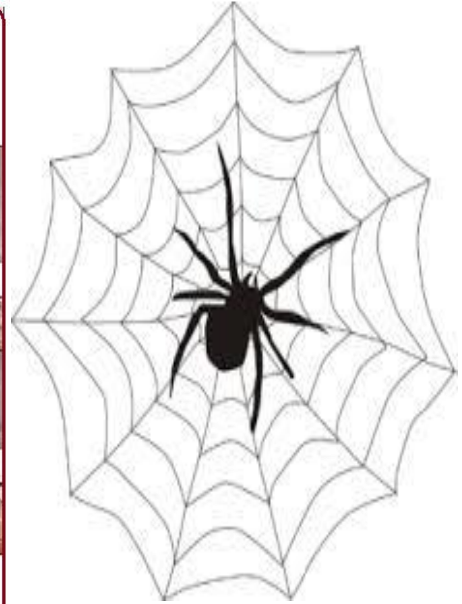
Formerly as:

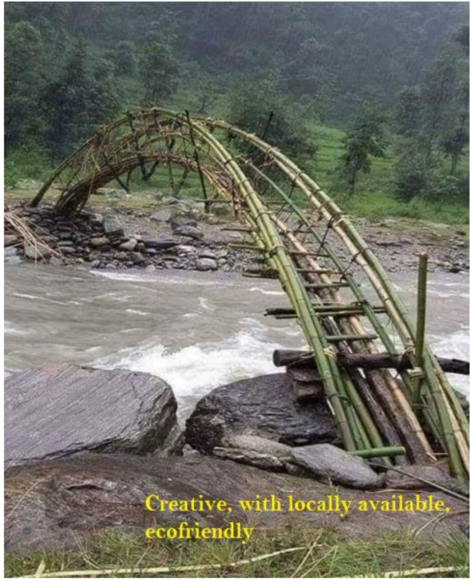
- Professor & Dean (Academic), Dr AIT, Bengaluru (1984 - 2020)
- Secretary, Indian Concrete Institute- ICI KBC (2003-2004, 2008-2011)
- Chairman, Association of Consulting Civil Engineers (India)- ACCE(I) BLC (2015-17)
- Executive Committee Member: ISET (2015-17, 2019-21), and IIScAA (2015-17, 2020-22)
- Member Governing Body: INSTRUCT (2017-19)

Content of the Presentation

- Developments in Structural Engineering & Construction
- **Basic principles of Structural Engineering**
- Environmental causes/Distress/Damage **for failure**
- Diagnostic procedures/Condition Assessment/ Structural Health Monitoring
- Need for Infrastructure sensing
- Conclusions

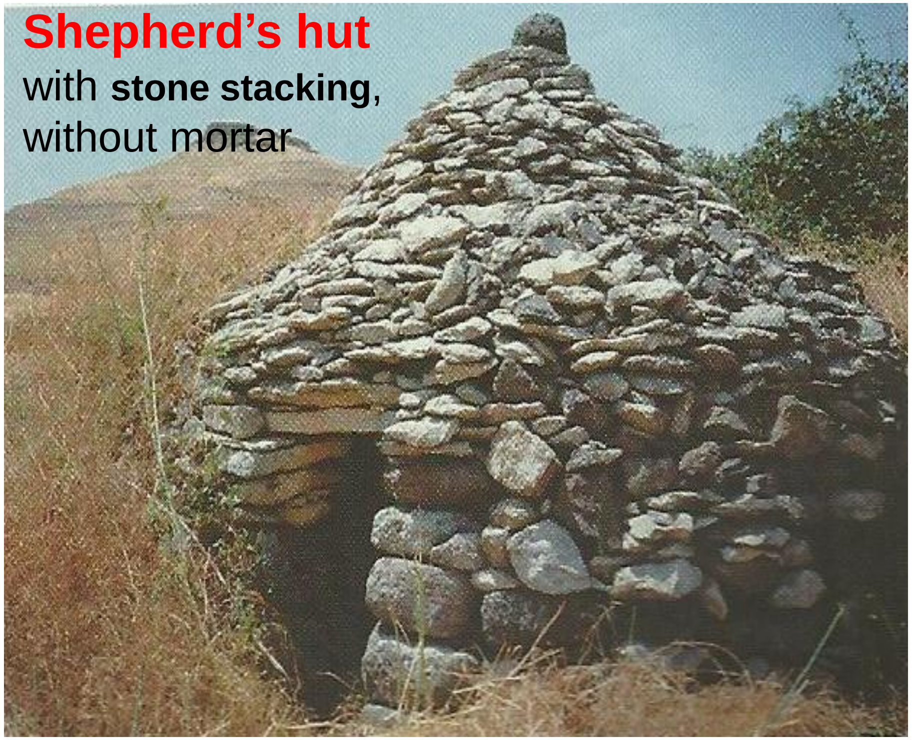

No Engineering Degree yet they build their House with proper Dimension & accuracy 💯
They are Nature's Engineer ❤



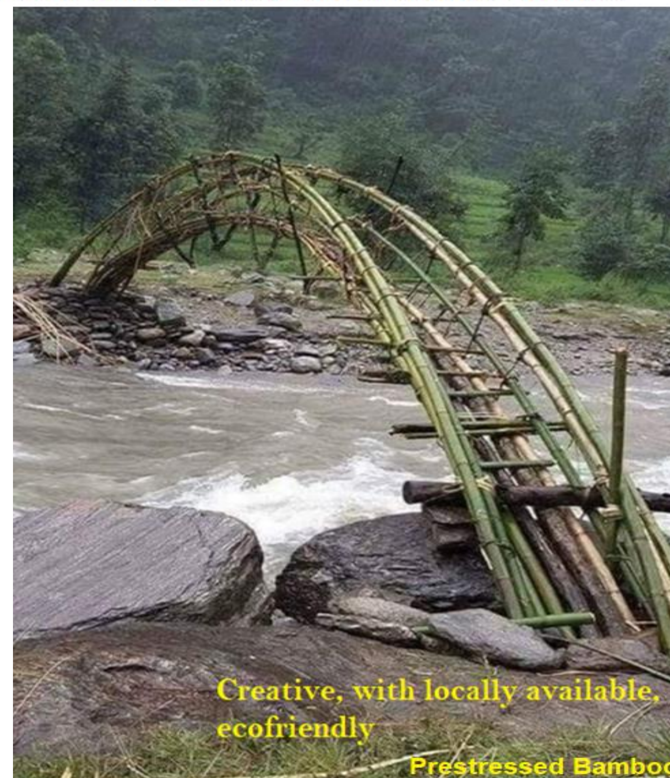

Creative, with locally available, ecofriendly


Potter Wasp Nests

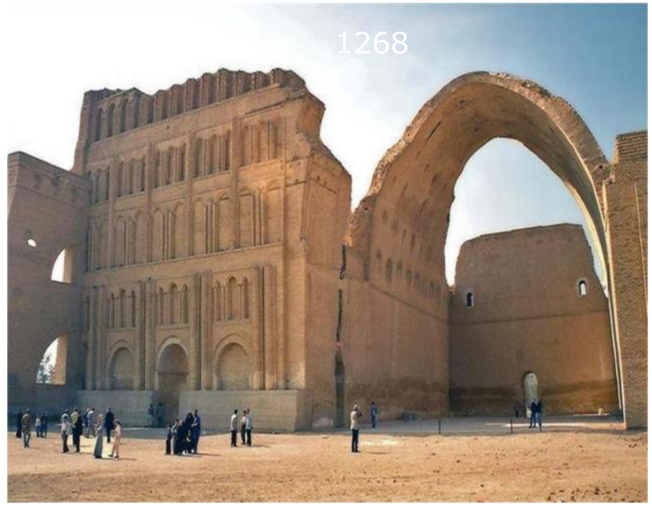
History



Built in 1300-1190 BC by Greeks
Oldest Arch bridges, still in existence and use



Colosseum, Rome, 70 - 80 AD

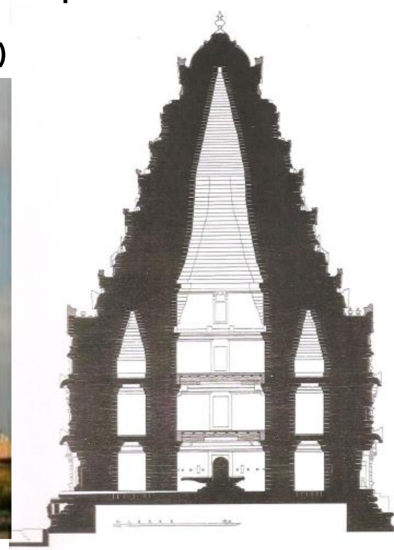


Massive mud brick wall, Ctesiphon Palace, Mesopotamia, 540 A.D

Hoysala Temples

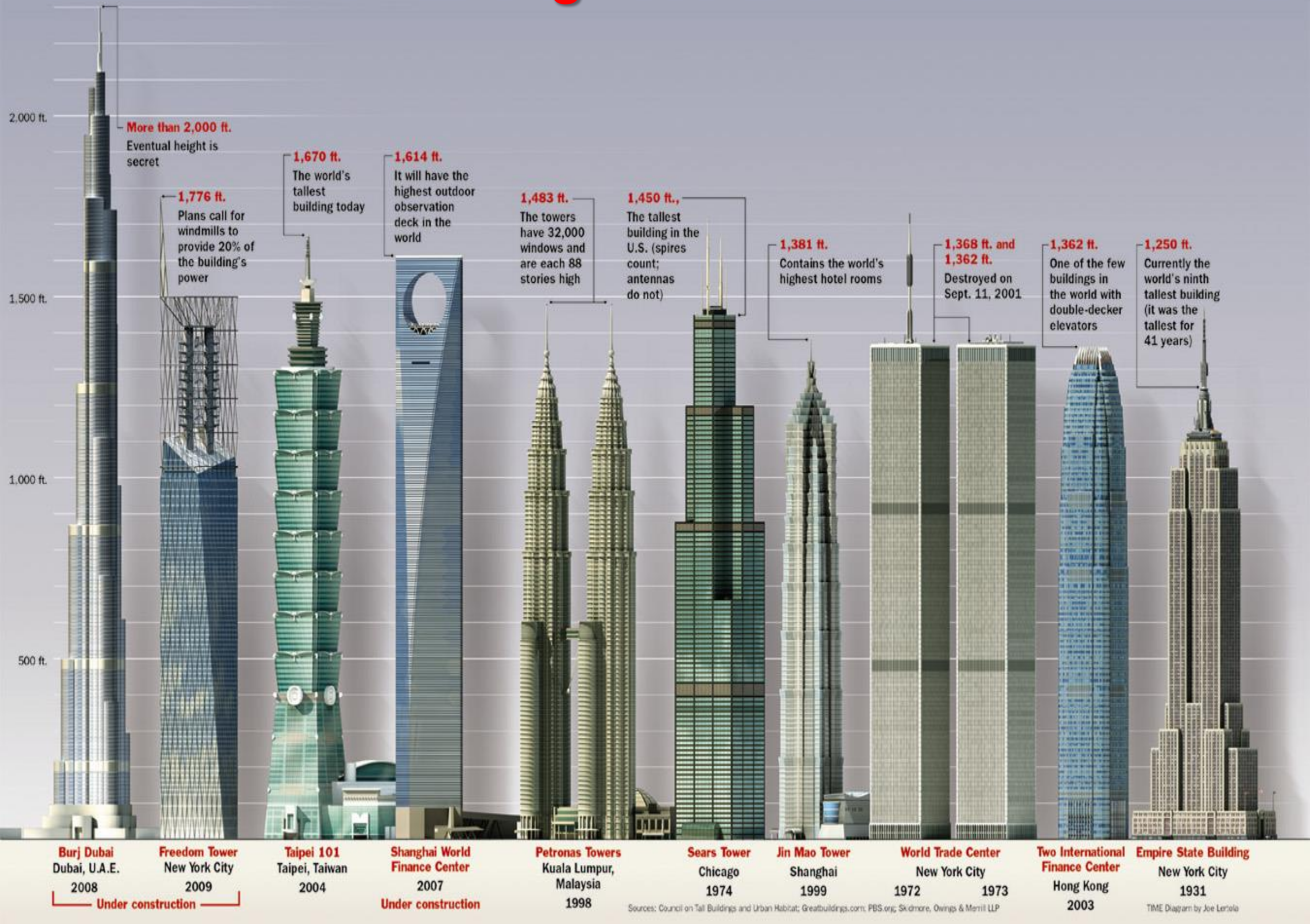
Tanjavore, India, 11 Century AD

(9th Century, 220 ft high)



Taj Mahal, India, 1632 - 1653

High Rise Structures

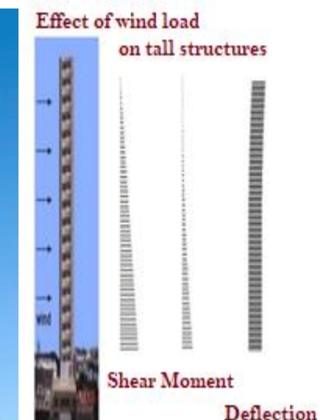


Developments of Infrastructures

Burj Khalifa 2010, in Dubai, UAE, the tallest tower in the world

Tokyo Sky Tree, 634 m, 2012

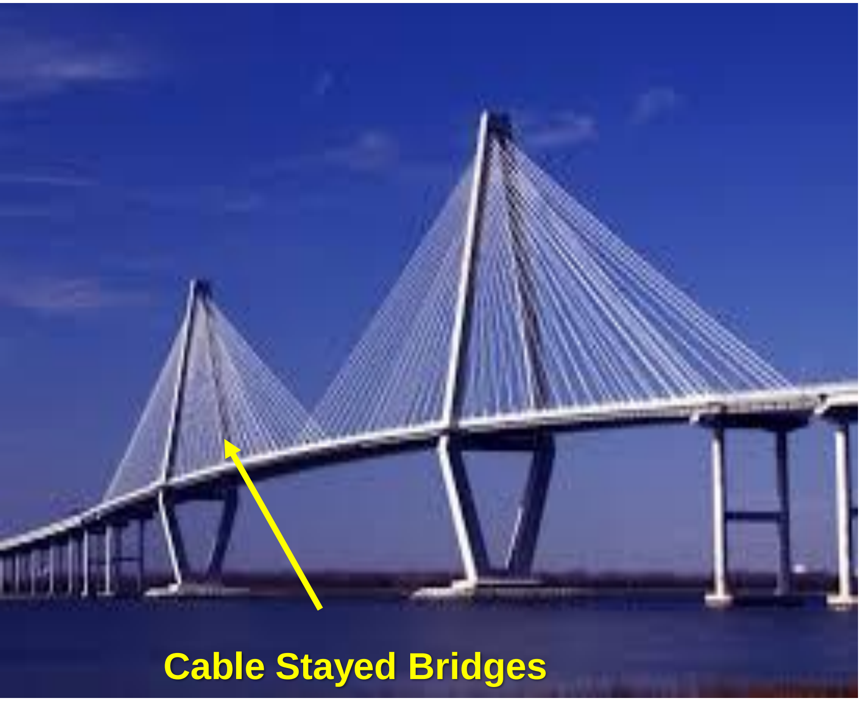
Engineering is awesome



LEED rated
Green Tall Structure
at Teipei101, 2010

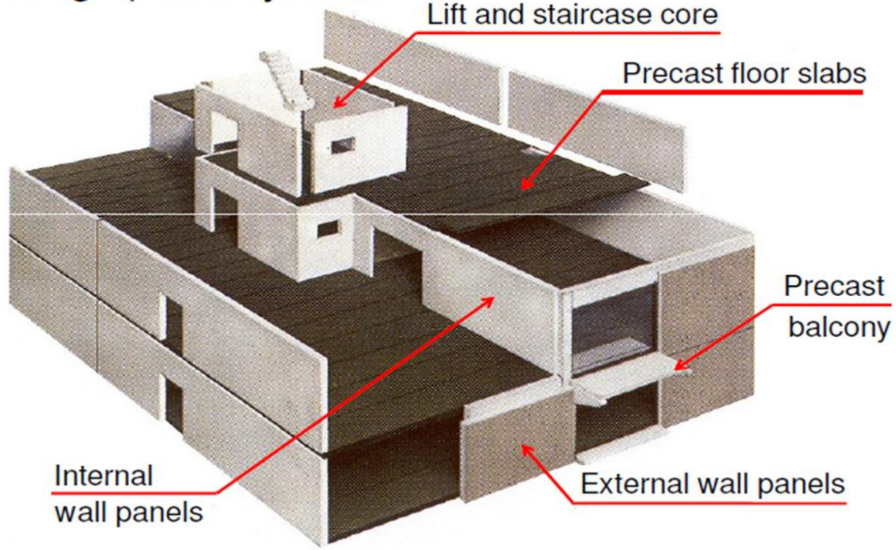

Steel structure:
Amusement facility


Suspension cable bridges


Cable Stayed Bridges


Stadiums

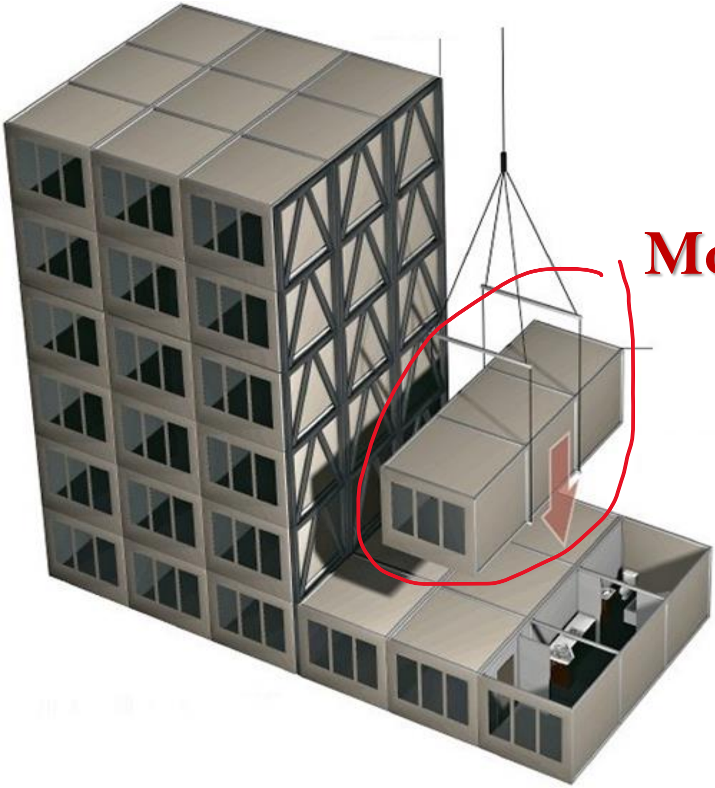
Large panel systems

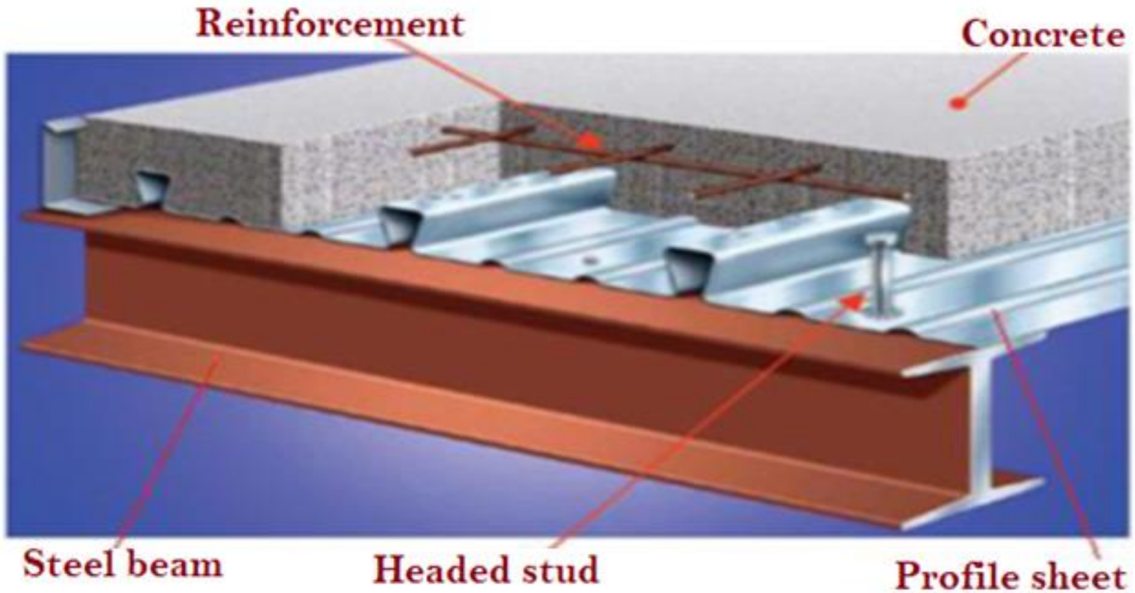


PRECAST CONSTRUCTION

Pre Fab Buildings

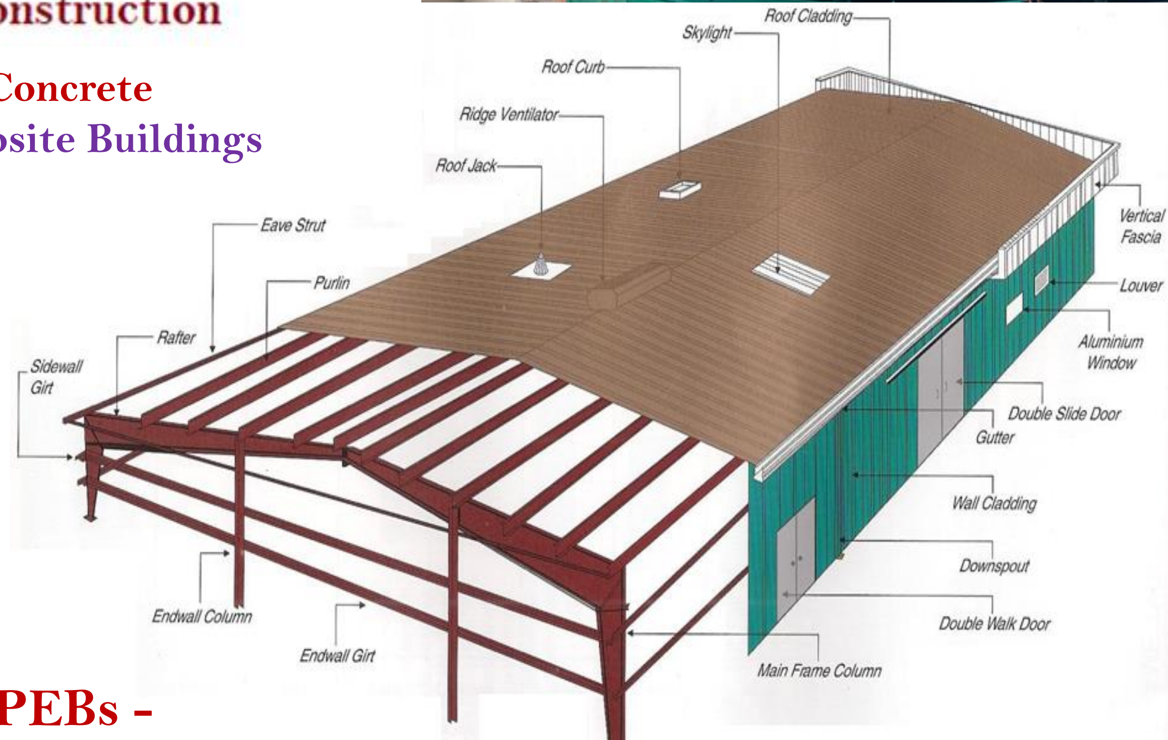
Modularization





Metal decking in a Floor construction

Steel-Concrete Composite Buildings



PEBs - Pre-Engineered Buildings

Fabric Tensegrity Structures

Tent and Tensile structures: fabric structures

Form-Finding of Funicular Geometries in **Spatial Arch Bridge**

Funicular surface structures

Parabolic Arches

Mechanization.......

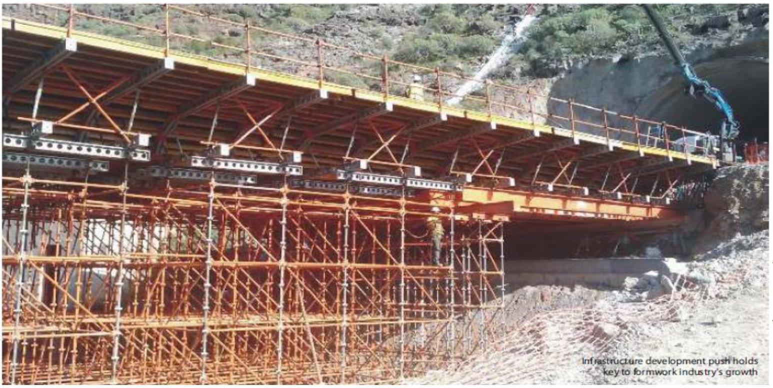
- More machines…
- Very few labourers
- Better Quality Control
- New Techniques/methods
- Speed, less time
- Cost
- Less pollution

Tell me, How hard is your Life?

Assembly of *Pre-Cast,* Hollow /Cellular Segments, and Prestressed Concrete Construction

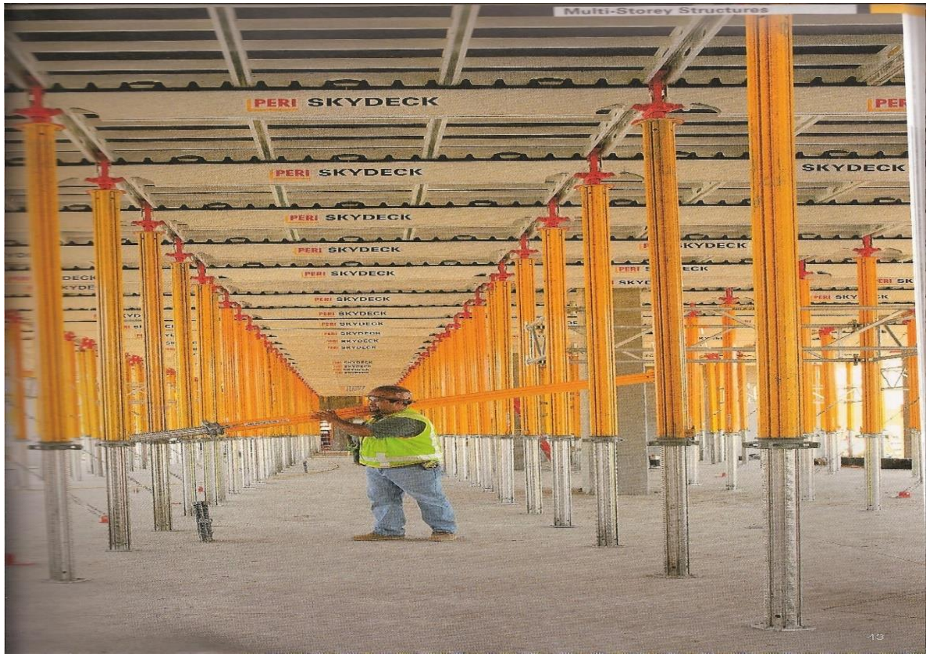
- Economic for large & repetitive projects
- Speed
- Quality Control
- Reduced labour
- Mechanisation
- No or less form work

Wood



Steel to
Aluminum

Development in Formworks




Plastic formwork

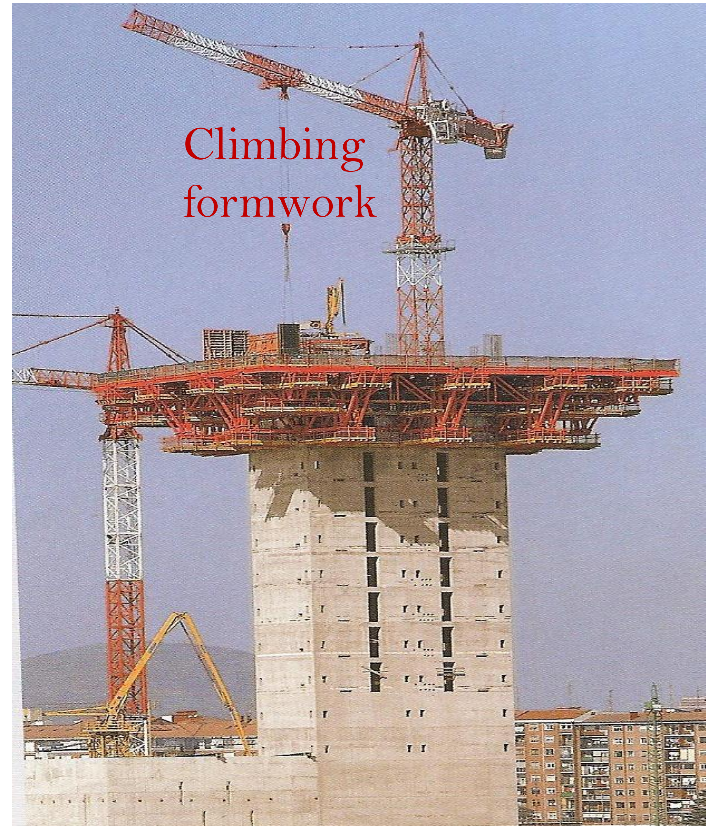

Wall formwork

No need to plaster

For Mass housing…..?

12/29/2021

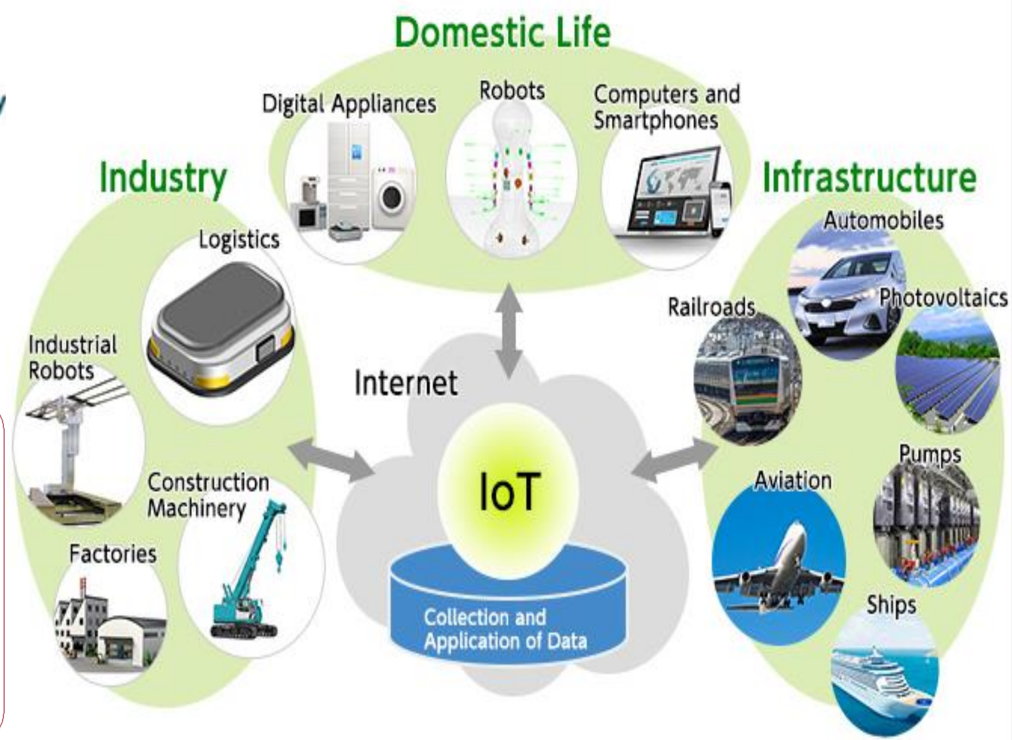
Mechanisation. Everywhere..?



Construction under greater risk

IoT (Internet of Things) devices and Sensors, Virtual & Augmented Reality, Digitalization, Cloud, big data and with knowledge based algorithms (AI, ML, DL) have changed the whole manufacturing industry in recent years.

Industry 4.0- Technological pillars



Cyber-Physical Systems (CPS) has five sequential scenarios:

- Data generation and acquisition (**Smart connection**: using intelligent sensors)
- **Digital twin**: (Ability to represent real time in a digital reality)
- Computation and aggregation of previously acquired data (**Data to information conversion**: value added information)
- finally decision support (**Cognition**: ability identify different scenarios and to support a proper decision making process)
- **Configuration**: (- provides feedback on physical reality from virtual reality for corrective action)

Three-storey building collapses in Wilson Garden, Bengaluru, on 27-9-2021

Next day

https://twitter.com/i/status/1446187027066589196

Collapse of Staircase passage of a three storey staff quarters building of Bengaluru Milk Union near diary circle on 28-9-2021

Three-storey Building Collapses in Bengaluru, Third Such Incident in Ten Days

https://www.youtube.com/watch?v=bQFhHrWZ9Ao

https://twitter.com/i/status/1447680569001738240

Collapse of 5- storey Residential Building in Kasturinagar, Bengaluru on 07-10-2021

(Official Permision for 3 storeys, No occupancy certificate)

https://twitter.com/ndtv/status/1446187027066589196?ref_src=twsrc%5Egoogle%7Ctwcamp%5Eserp%7Ctwgr%5Etweet

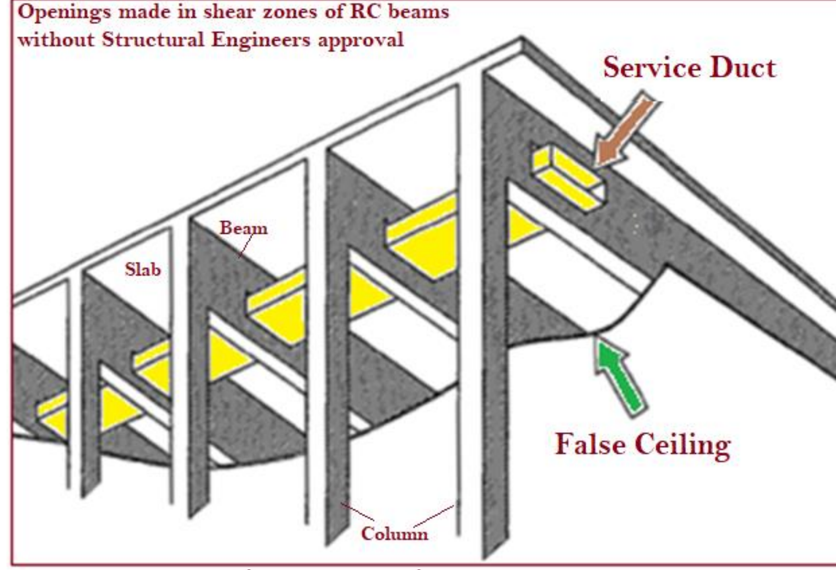
5-Storey Building Collapses In Bengaluru 7-10-2021 Kalyan nagar

Building collapsed due to heavy rain at Kamalanagar in Bengaluru 12-10-2021

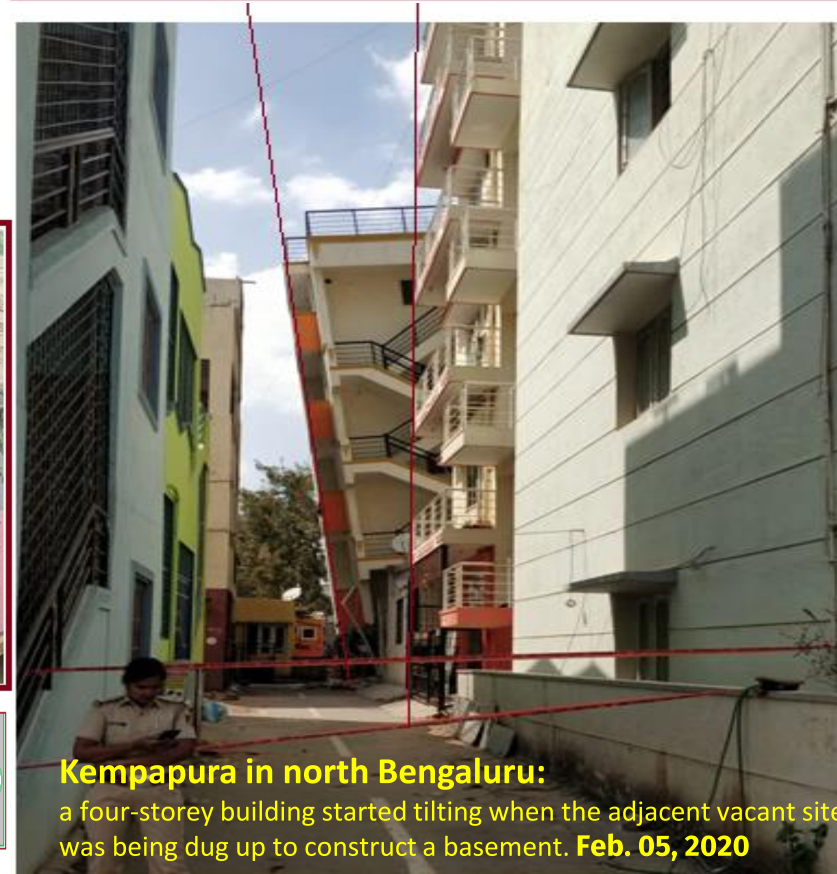
Most often

- Construction of extra floors or balcony in addition to the approved plan
- Structural aspects are not scrutinized.
- Owner & Mestri execute work without hiring or consulting the qualified engineer.
- Poor workmanship and materials

Damage due to fire accidents



Vulnerable Structures - Concerns



Kempapura in north Bengaluru:
a four-storey building started tilting when the adjacent vacant site was being dug up to construct a basement. **Feb. 05, 2020**

A four-storey residential **building collapsed** like a house of cards into a **newly dug canal** in Midnapore district, **West Bengal** on **13-6-2020**

Video

Three storey building behind the under construction site collapsed on **July 28, 2020**, **50 feet deep** basement in the adjacent site

Flyover, Under Construction, Collapses in Gurgaon, UP

August 23, 2020

3 beams of bridge under construction in Thalassery(Kerala) collapse.....August 26, 2020.

New bridge, collapsed **MP, August 30, 2020**

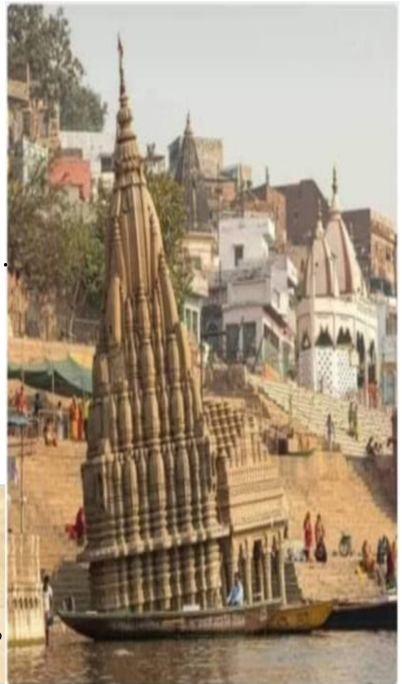
Residential Building Collapse, 2009, Shanghai, China

gas explosion

Demolition of unsafe structures

Ratneshwar temple, Manikarnika Ghat, Varanasi, UP

Leans by **9^0** and **74 m** high.



Famous Failures –

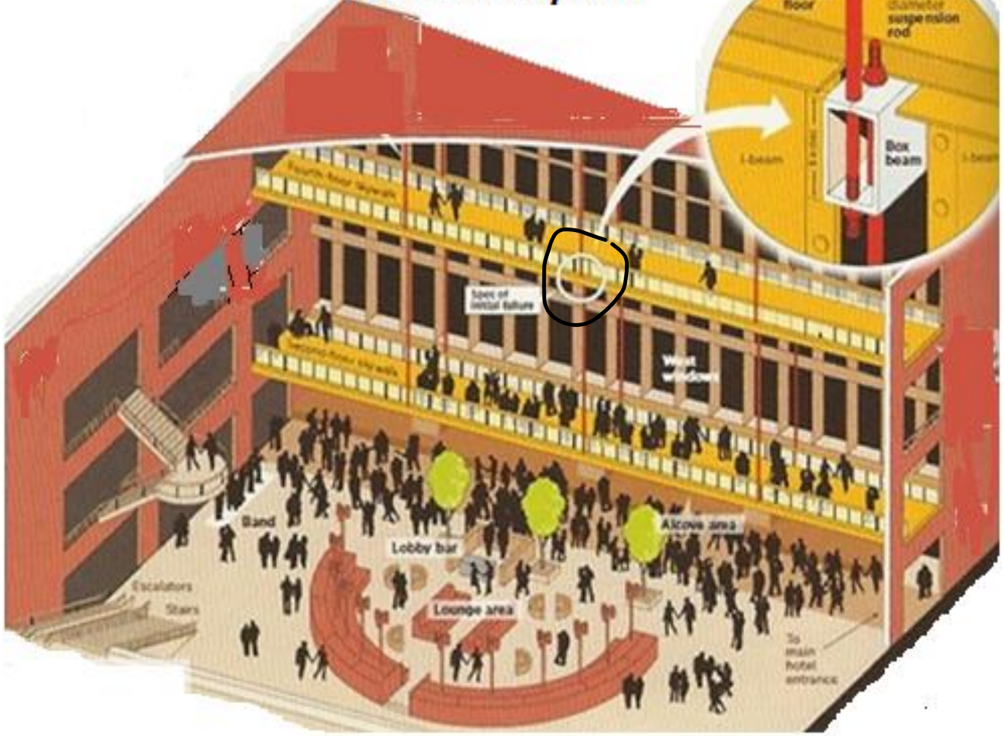
Leaning ***Tower of Pisa***

Europe 12th Century

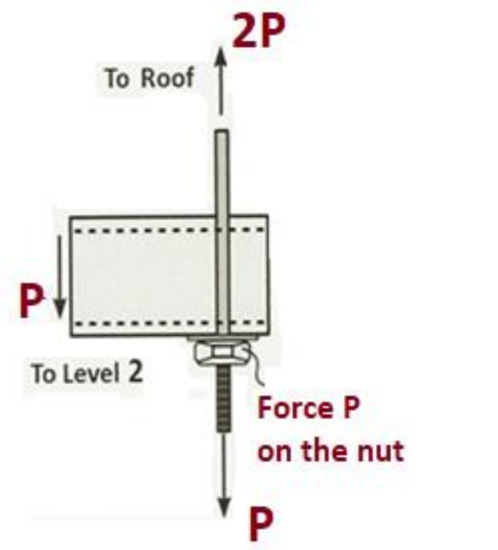
200 ft (**60 m**) tall, Inclined **5.5°**

Hyatt Regency Hotel, 1981, USA

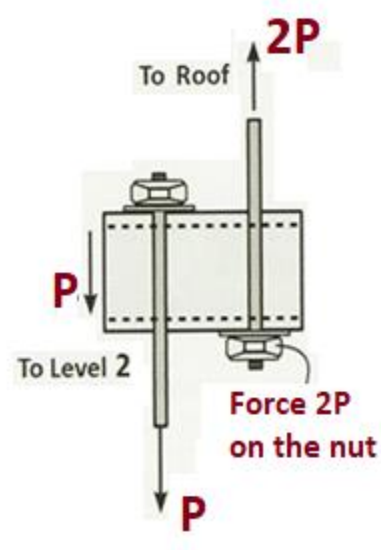
--- Failure of skywalk



.....Killed hundreds of people



a) Original Design



b) Actual construction

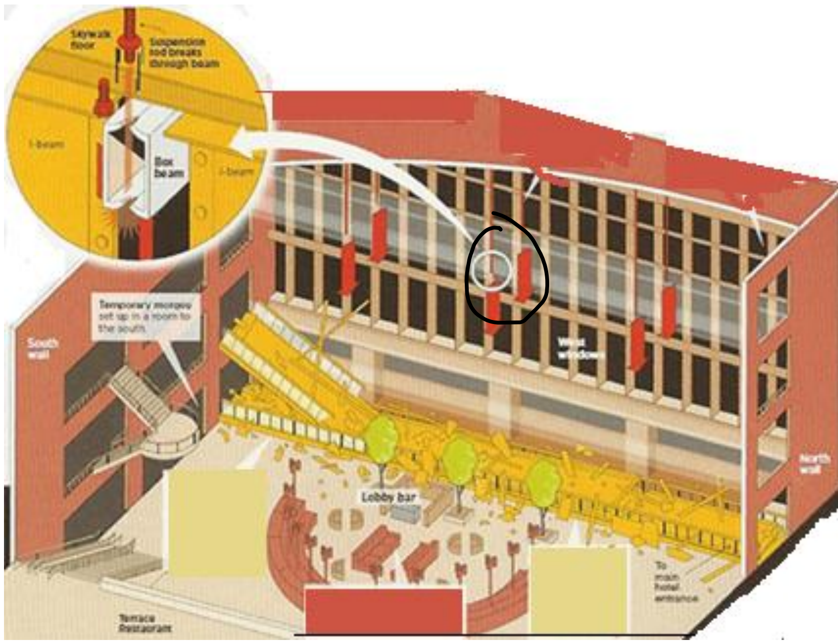
The Hyatt Regency Hotel Atrium (After the Collapse)

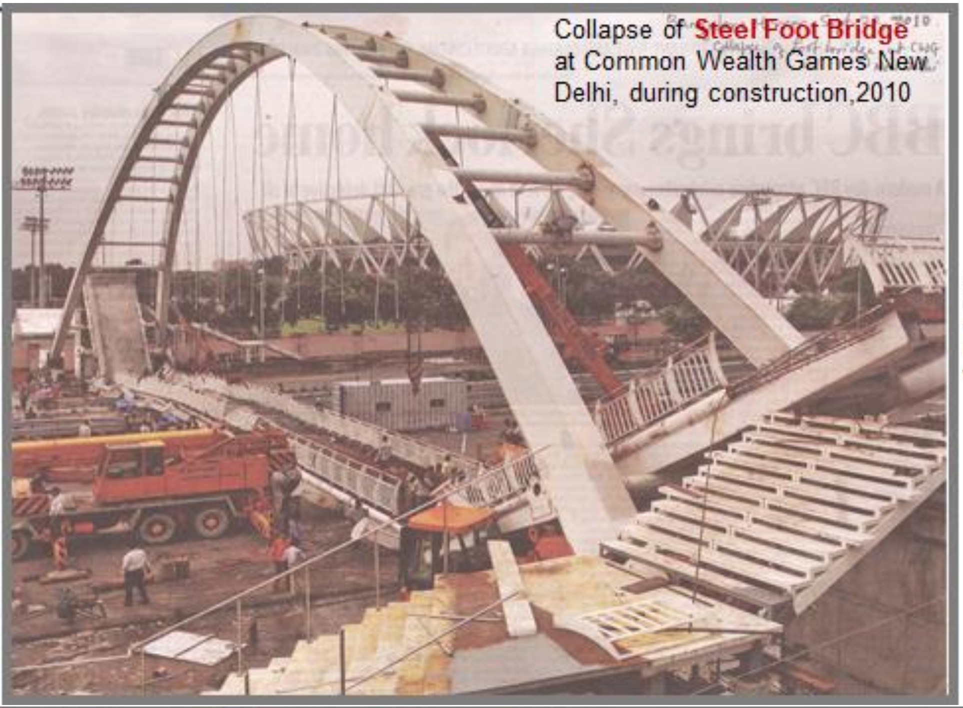
a) Before

b) After

Beam C/S

Debris

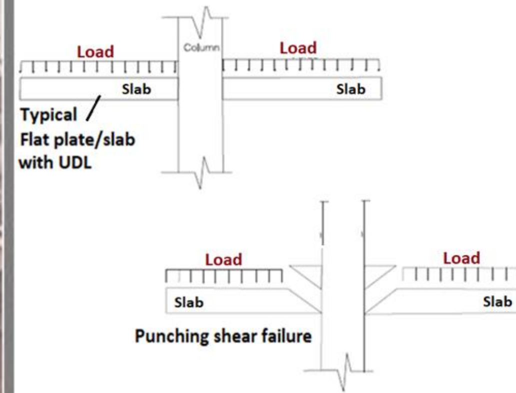




Progressive Collapse

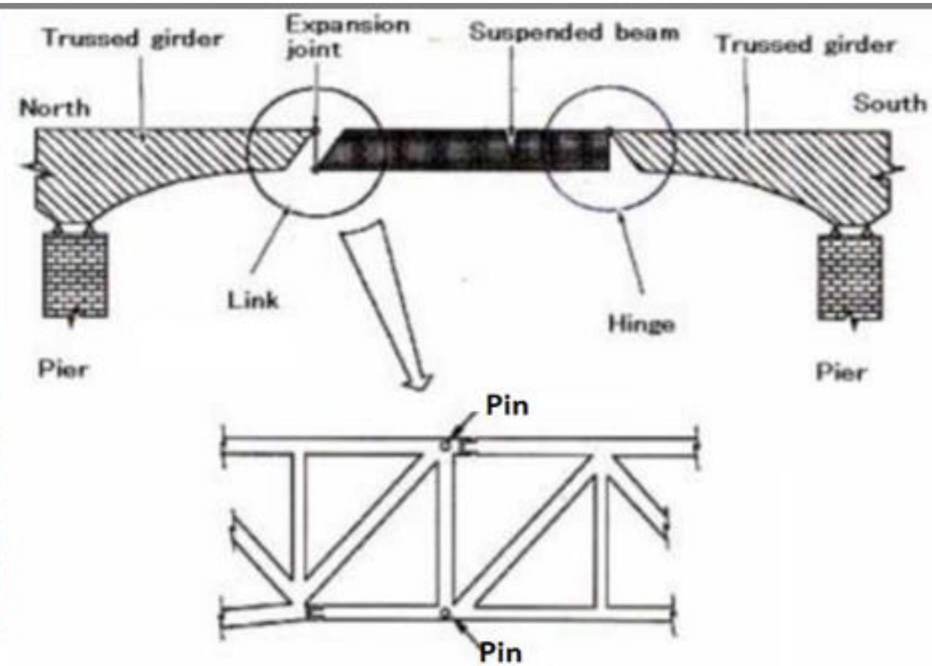
Prestige Shantiniketan Building Township project, Bengaluru, 2008

Collapse of 14 storeys-
Progressive Collapse….?
Early removal of Form work ..?



Seongsu Bridge after collapse **(Seoul, South Korea, 1994)**

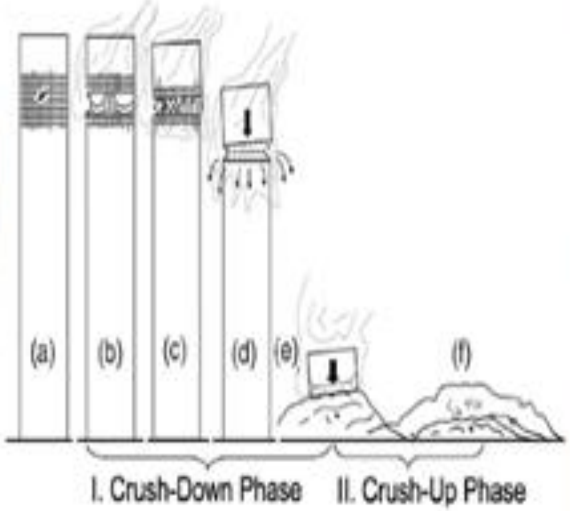
Han river: 6 cars fell, 32 killed, 17 injured



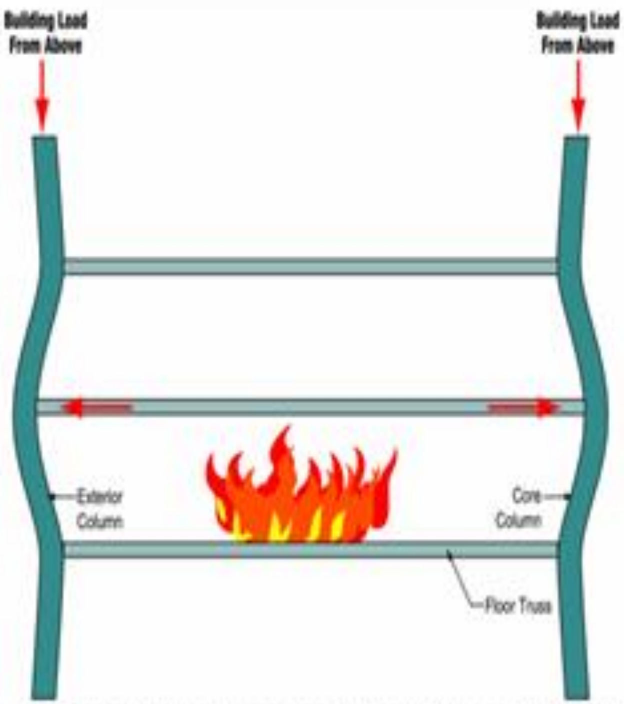
The Structure of Seongsu Bridge

Mechanism of progressive collapse

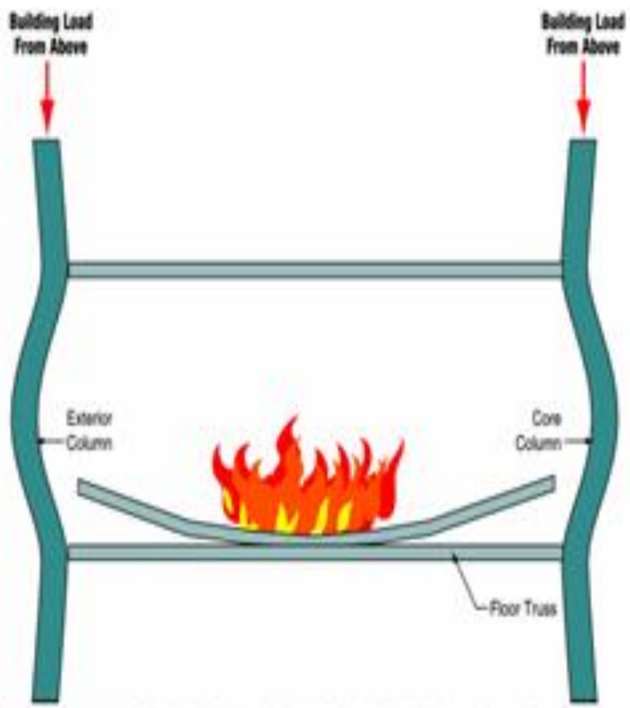
Pan Cake Effect



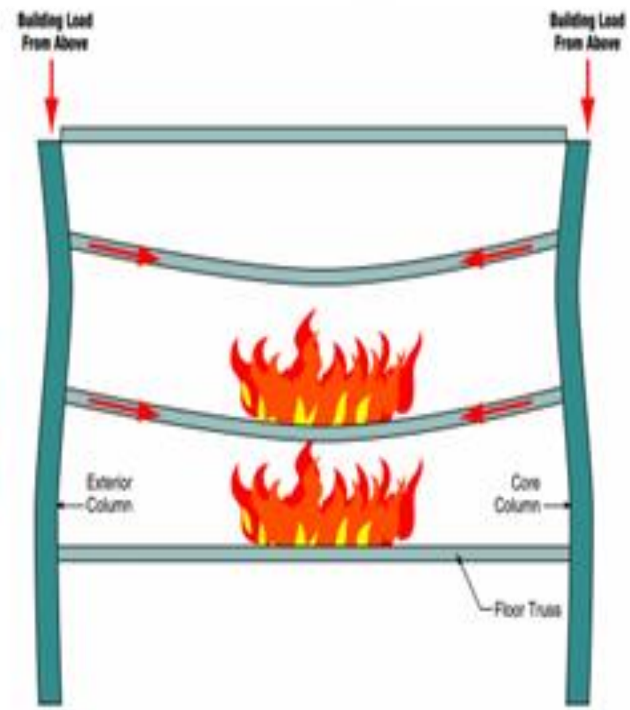
Scenario of progressive collapse
of the World Trade Center towers



Expansion of floor slabs and framing results in outward deflection of columns and potential overload.



Buckling of columns initiated by failure of floor framing and connections.



Catenary action of floor framing on several floors initiates column buckling failures.

Causes of Failures

…Mismatch between Construction Intent and Actual Condition

The primary causes of failures :

- ✓ **Human failures**: - includes ethical failure, negligence, accidents
- ✓ **Design failures**: - may be the result of unethical practices
- ✓ **Material failures**: - substandard, alternatives
- ✓ **Extreme or unforeseen conditions or environments**
- ✓ **Combinations of the above** – e.g., Construction Failure

Design deficiencies	**40- 60%**
Construction errors	**25- 30%**
Material defects	**10- 15%**
Maintenance deficiencies	**5- 10%**

Classification of Design life: (Ordinary design life: 50 years for buildings; 100 years for Civil Engg. Structures)		
Class 1	1-5 years	Special case temporary buildings
Class 2	25 years	Temporary buildings, e.g., stores buildings, accommodation barracks
Class 3	50 years	Ordinary buildings
Class 4	100 years	Special buildings, bridges, and other infrastructure buildings or where more accurate calculations are needed. e.g., for safety reasons
Class 5	Over 100 years	Special buildings, e.g., monuments, very important infrastructure buildings

Modern Construction Technology

Issues are: (**6Ms**)

- **Men** – Man power (– skilled/unskilled, availability, productivity, cost)
- **Money** (- available)
- **Materials** (- scarce, quality, alternatives)
- **Machinery** (- how to use them, increase of productivity)
- **Methods**/ Methodology
- **Management of projects….Monitoring**

The system has basically four units:

Client, Architect, Consulting Engineers, and **Contractors**

should take the responsibility for different phases and aspects of the project.

"Structural Engineers are the minds behind the safe and stable structures"

"Seeing what everybody has seen, and, thinking what nobody has thought"

It is a challenge for engineers to design efficient and cost-effective systems without compromising their integrity.

Whenever a failure occurs, a lot of people say

‘**The entire system is at fault**’.

- What ails the system?
- Are there no solution?
- Who will take the initiative?

Failure cost

1. Human life
2. Economic loss
3. Unavailability of service

Failure causes:

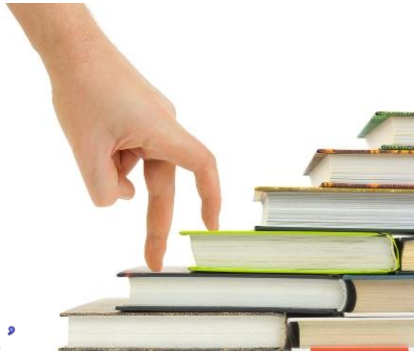
1. Improper material selection
2. Inadequate design
3. Processing

Today’s building practice has led to a lot of premature failure and lack of durability, which can cause serious safety, serviceability and functional problems.

The problem with the world is that

‘the intelligent people are full of doubts, while the stupid ones are full of confidence.’

‘ Begin with the END in mind ’



What has to be changed?

- From the costs and quality of construction phase **(into entire Lifetime)**
  - **Lifetime Value**
  - **Lifetime Quality**
  - **Lifetime Costs**

The fundamental questions arising are:
- **What?**
- **Why?**
- **How?**

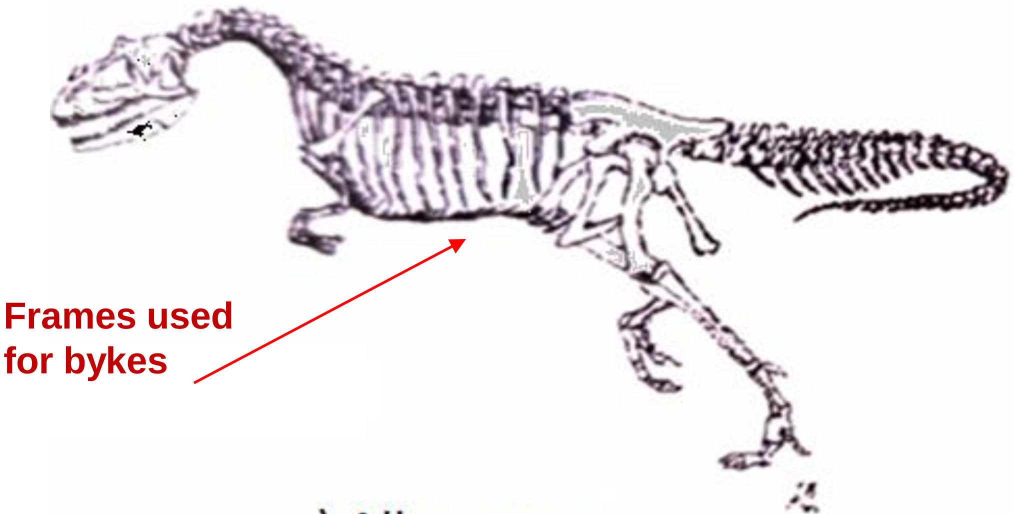
and
- **How much?**

Integrated Life Cycle Design of Structure (**ILCD**)

- Sustainable development and Optimization

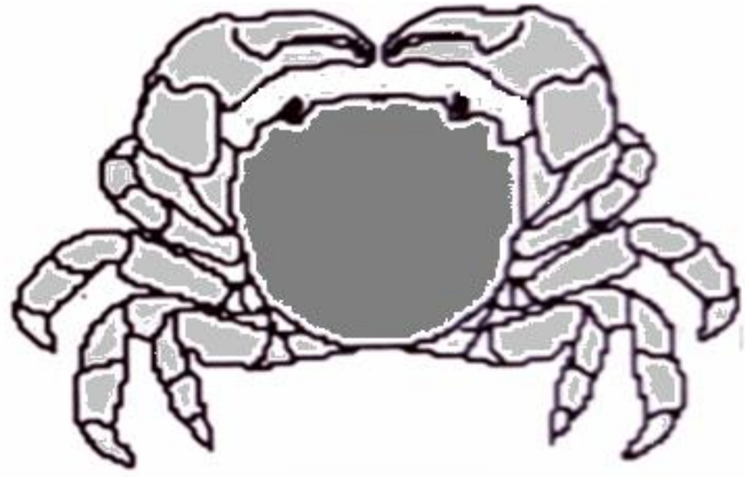
  (life cycle principle)
- Design must guarantee the
  - Performance (functionality and strength)
  - Durability (time - Service life)

A change in design philosophies - limit design to **performance based**, strength based to **durability based**, etc. is happening creating a need for a change in our codes of practice and practice itself.



a) Allosaurus

Endoskeletal Structure



b) Crab

Exoskeletal Structure

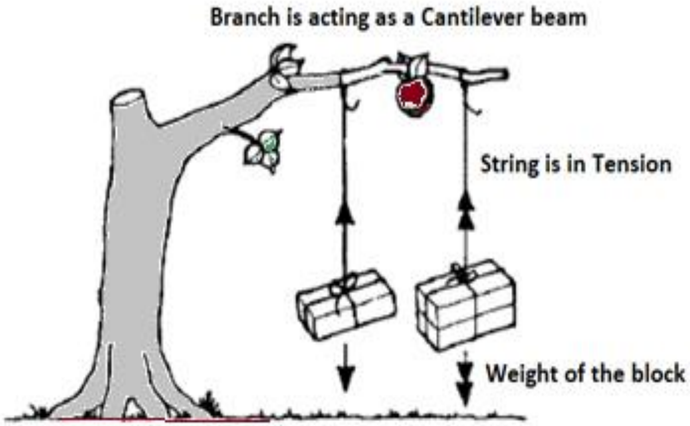
In biological objects, structure usually is classified as 'endo-skeletal' or 'exoskeletal'.

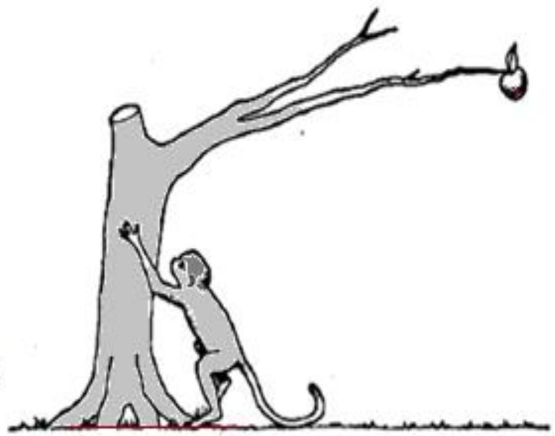
- **Endoskeletal structures** provide an 'internal skeleton' or a frame to which the rest of the object is essentially attached, like the bodies of humans and other vertebrates.
- **Exoskeletal structures** provide an 'external skeleton' or a shell within which the rest of the object is contained, like the body of a crab and other crustaceans.

Early automobile designs used a frame-chassis structure to which everything was attached.

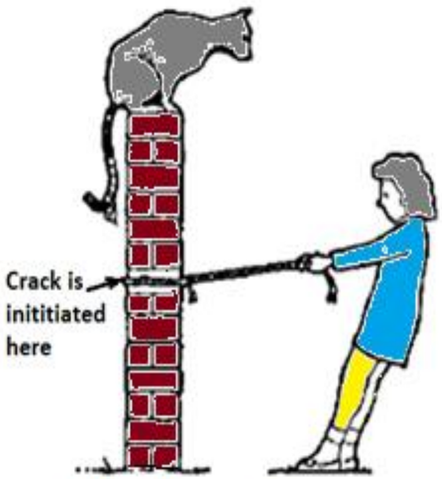
More recent designs use **a single** (unibody or monocoque) main shell structure, where as most recently a **return to endoskeletal structures is being explored**, combining metal frames with plastic or composite panels. The choice of the structure clearly depends on many factors, including material use and operating environments.

Biological examples for motivation to structural design



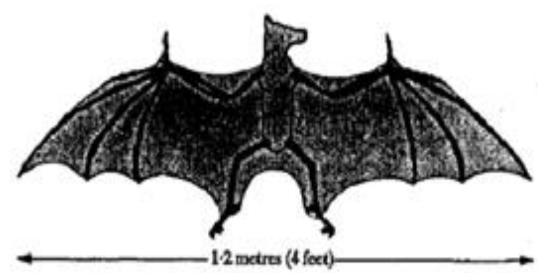


When a mechanical force is applied, the solid changes its shape.
Because of elastic property the solid will push back.
Upper surface is stretched and lower surface is compressed or contracted.



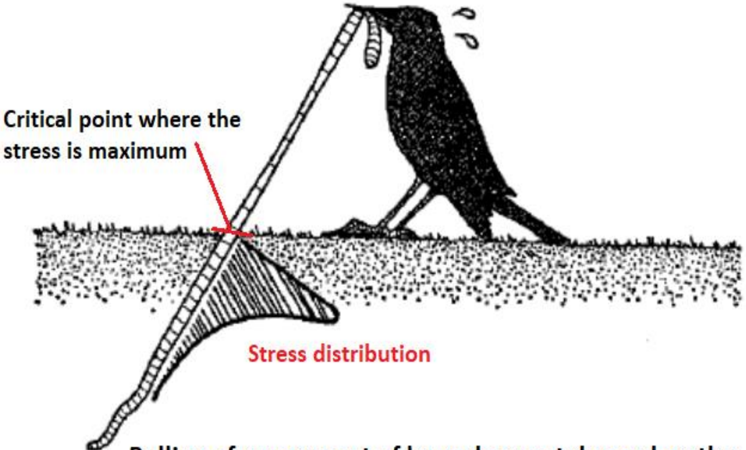
Wall is like a cantilever.
If the mortar is weak wall fails in tension.
Crack is initiated on outerface.

It does not make any difference whether Cat pulls or the child is pulling .... Tension or stetching of tail

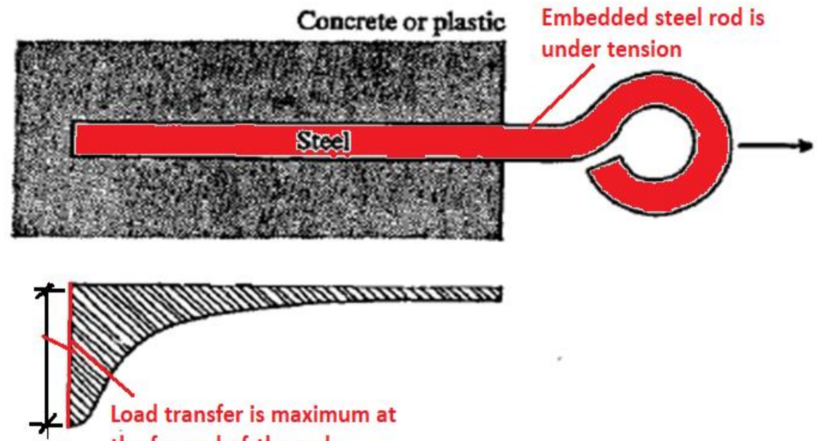


Bats wings are constructed by stretching a membrane of very flexible skin over a framework of long, thin bones (fingers of a hand)

Biological examples for motivation to structural design

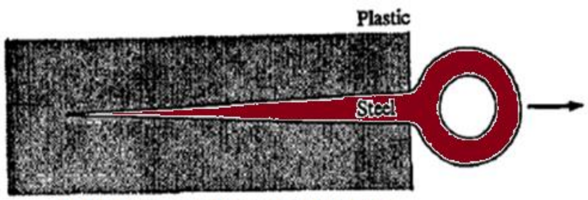


Pulling of a worm out of lawn does not depend on the length of the worm.
- a short worm is just as hard to extract as a long one

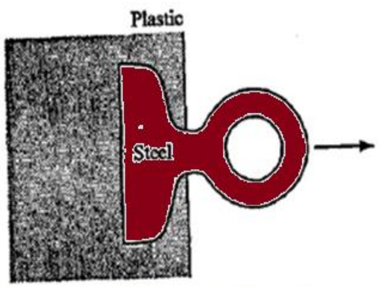


- Modulus of elasticity is higher in the rod than concrete

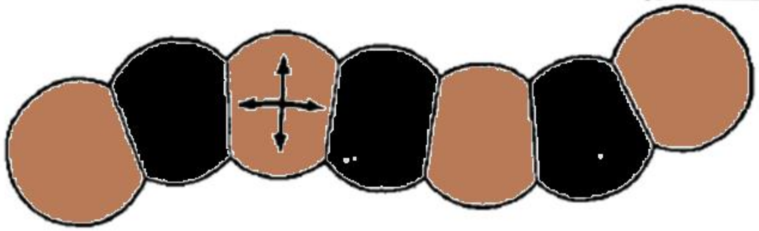
the stress concentration is more at the end of the rod.



Wrong shape for a steel insert.
This arrangement is weak.

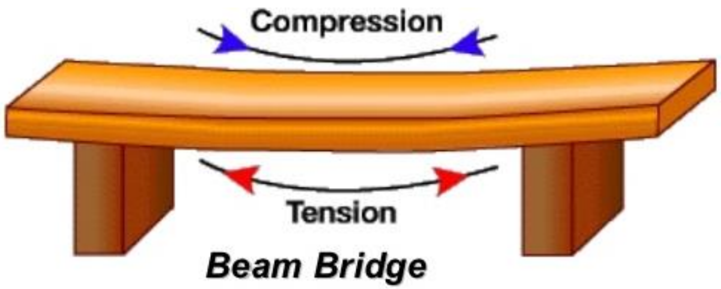


Right shape for a steel insert.
This is much stronger



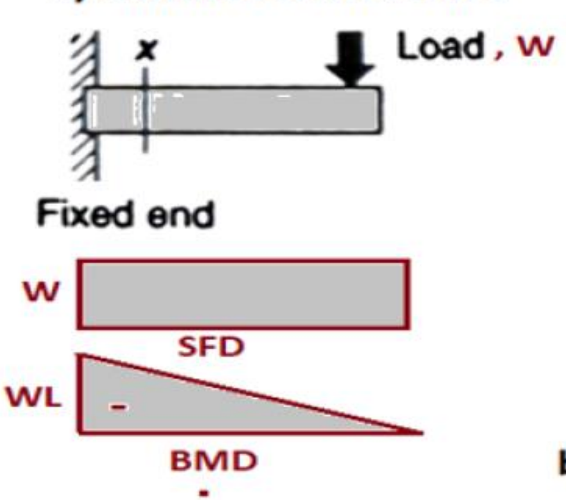
A segmental animal.

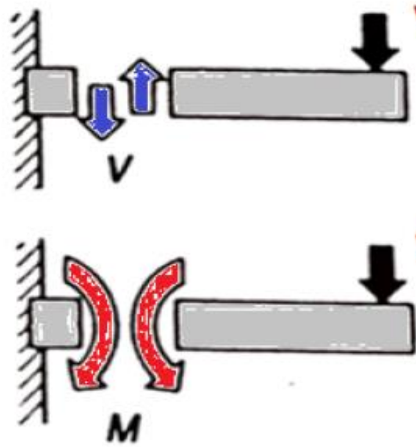
Stresses are equal in both directions in the surface



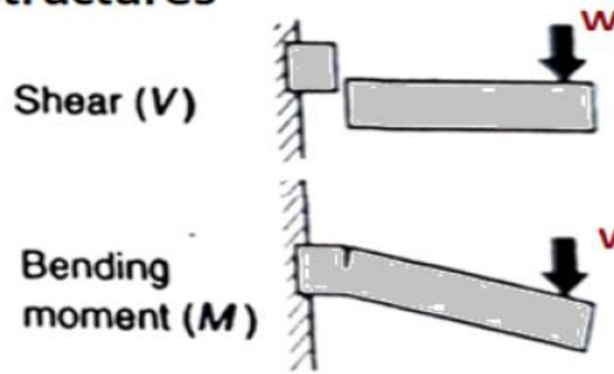
Shear and Moments in structures

a) Cantilever Structure

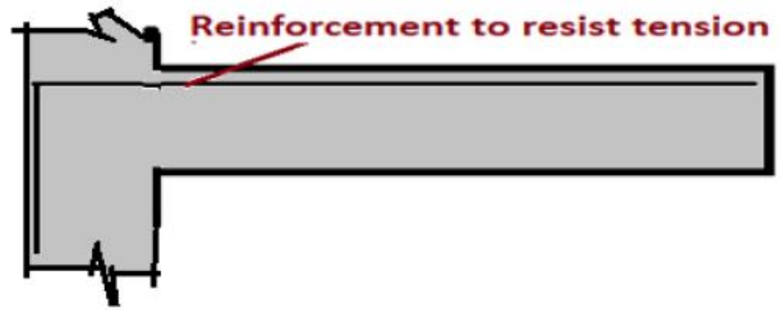




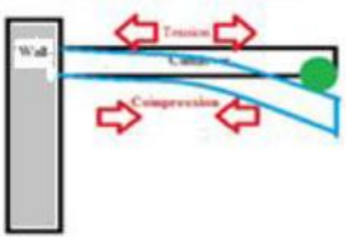
b) Internal forces, V and moments, M

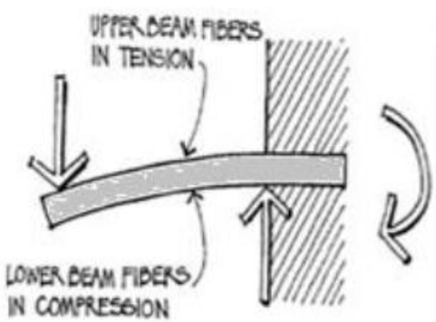


c) Possible failure modes:

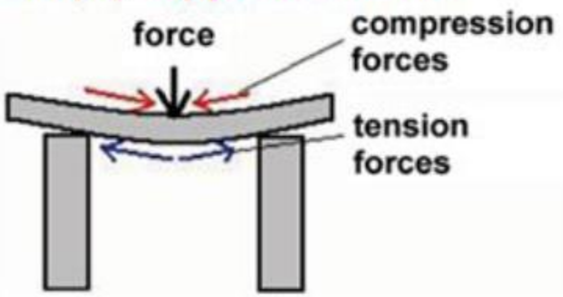


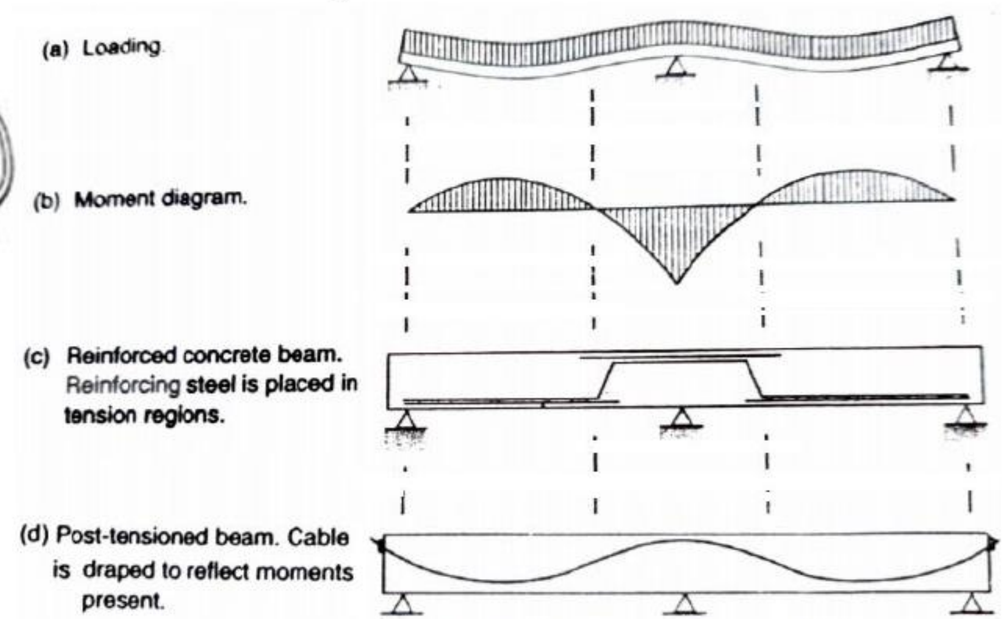
Cantilever beam





Simply supported beam



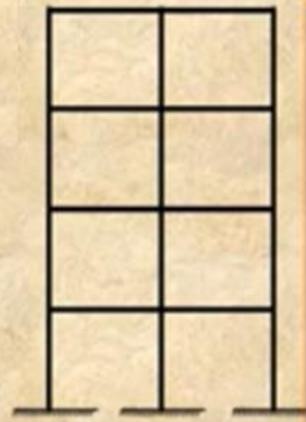


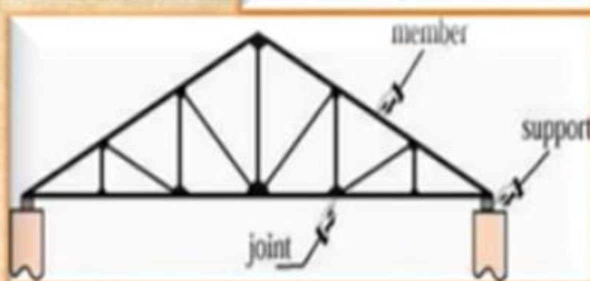
Reinforced Concrete Continuous beam

Structural Forms

Most commonly used structural forms for load transfer are

- **Beams**
- **Plane Frame**
- **Space Frame**
- **Plane Truss**
- **Space Truss**





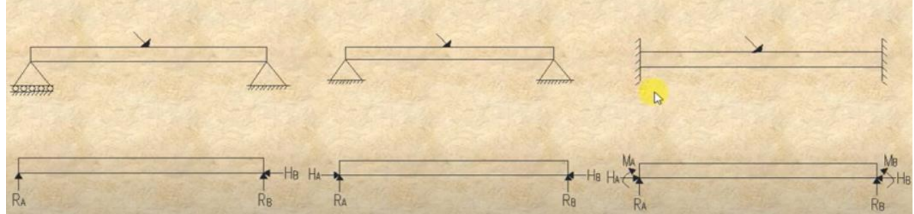
Beams

- *Beams are the simple structural elements that is capable of withstanding load primarily by resisting bending.*
- *Beams deflects in the same plane and it does not twist.*
- *All the forces acting on the beam [redacted] produce shear force and bending moment, that create internal stresses, strain and deflection of the beam.*

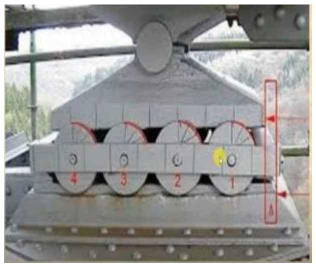
Simply Supported Beam

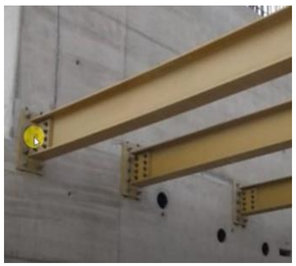
Continuous Beam

Roller Support | **Hinged Support** | **Fixed Support**



Reactions = 3 | Reactions = 4 | Reactions = 6



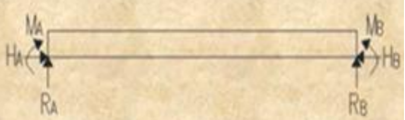


Fixed Support

- *A support which will resist vertical movement, horizontal movement and rotation. Such a support is known as fixed support.*

Reactions

- *There will be a horizontal reaction, vertical reaction and also a moment as it resists horizontal, vertical movement and rotation .*



Roller Support

- *A support which will resist vertical movement and allows horizontal as well as rotational movement. Such a support is known as roller support.*

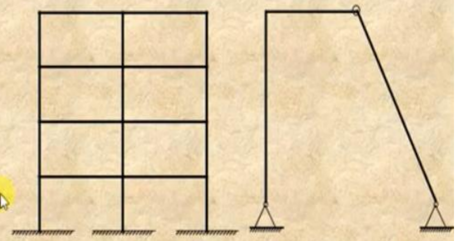
Reactions

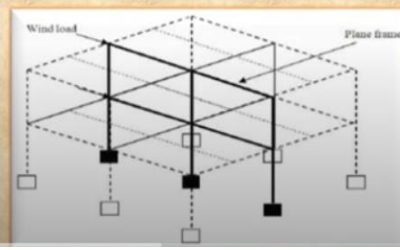
- *A roller support resists vertical movement and hence there will be a vertical reaction.*

- *There will not be a horizontal reaction and moment as it allows horizontal movement and rotation.*

Plane Frame

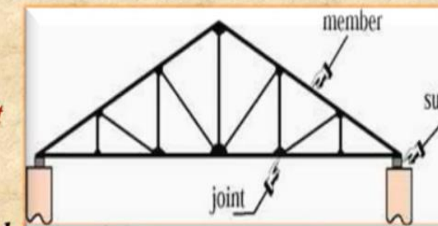
- *Plane frames are two dimensional structures constructed with straight elements(beams & columns).*
- *The internal forces at any cross section of the plane frames are shear force, bending moment and axial force.*
- *All members lie in the same plane and rigidly connected at joints.*





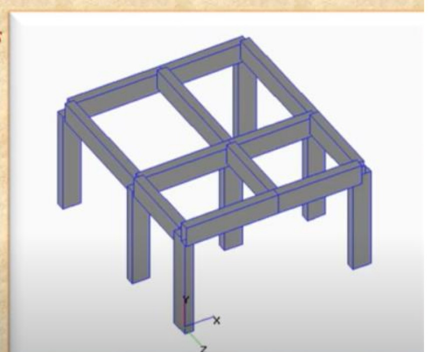
Plane Truss

- *A triangulated system of members that are connected by means of pin joint in such a way that they primarily transmit axial force.*
- *In plane truss all members are assumed to be in X & Y plane(two dimensional).*
- *Truss members could move either vertically or horizontally or combination of them.*



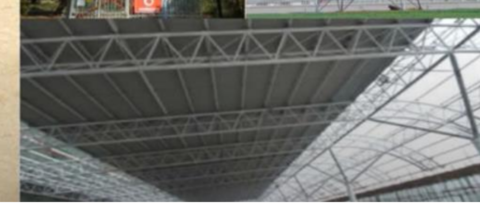
Space Frame

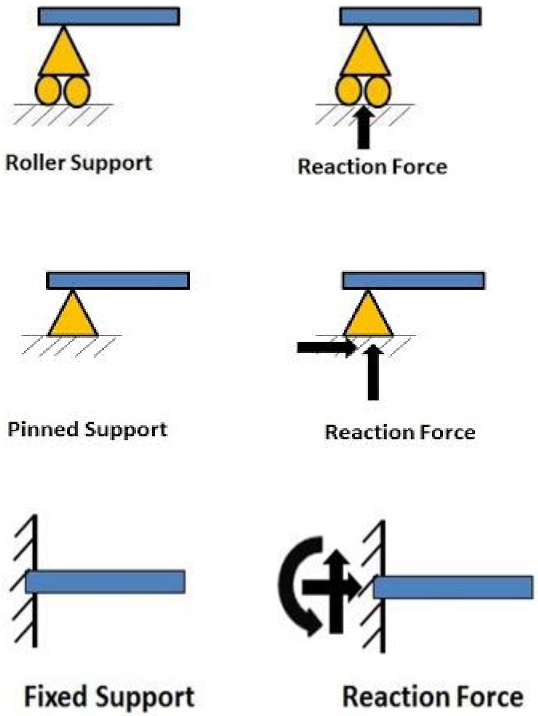
- *It is a structural system with three dimensional assembly of linear elements and the loads are transferred in a three dimensional manner.*
- *Loads are free to act anywhere on the frame.*
- *They are rigidly connected and generate shear force, bending moment and axial force in all the connected members.*

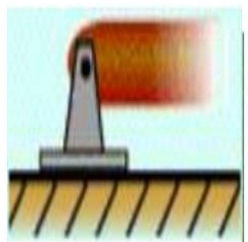


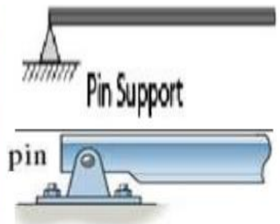
Space Truss

- *Members are oriented in all three directions(x,y,z).*
- *All members carry only axial compression or tension.*
- *Cranes, communication tower and power transmission towers are few examples for space truss.*

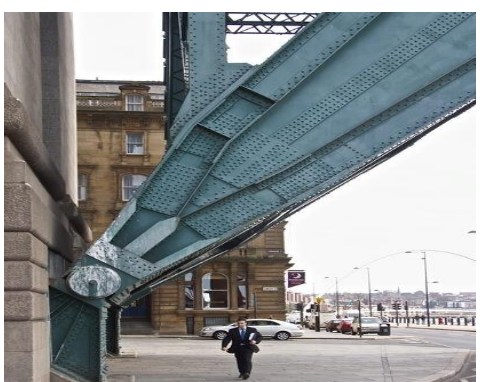


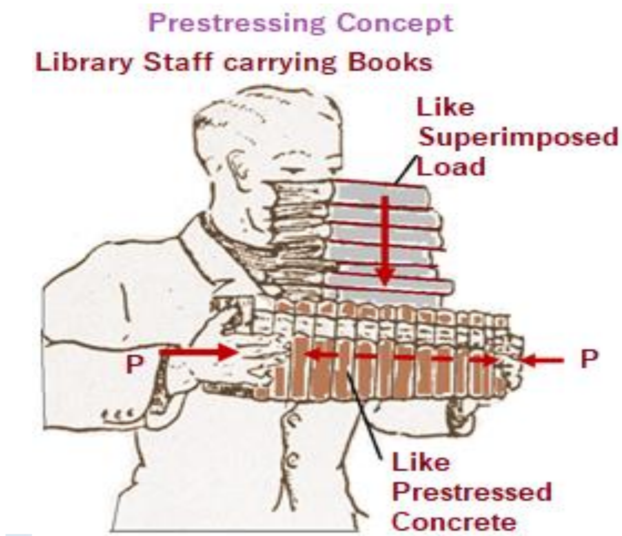

Roller Support
Reaction Force
Pinned Support
Reaction Force
Fixed Support
Reaction Force

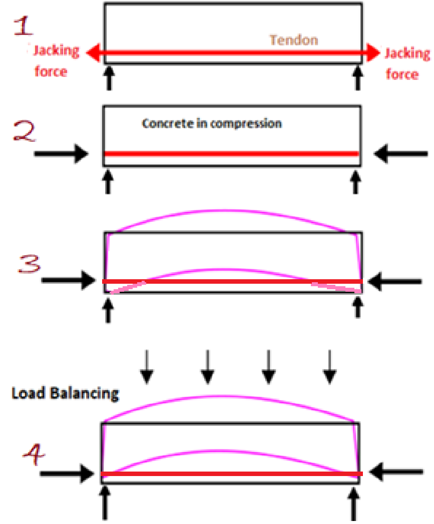



Pin Support
pin

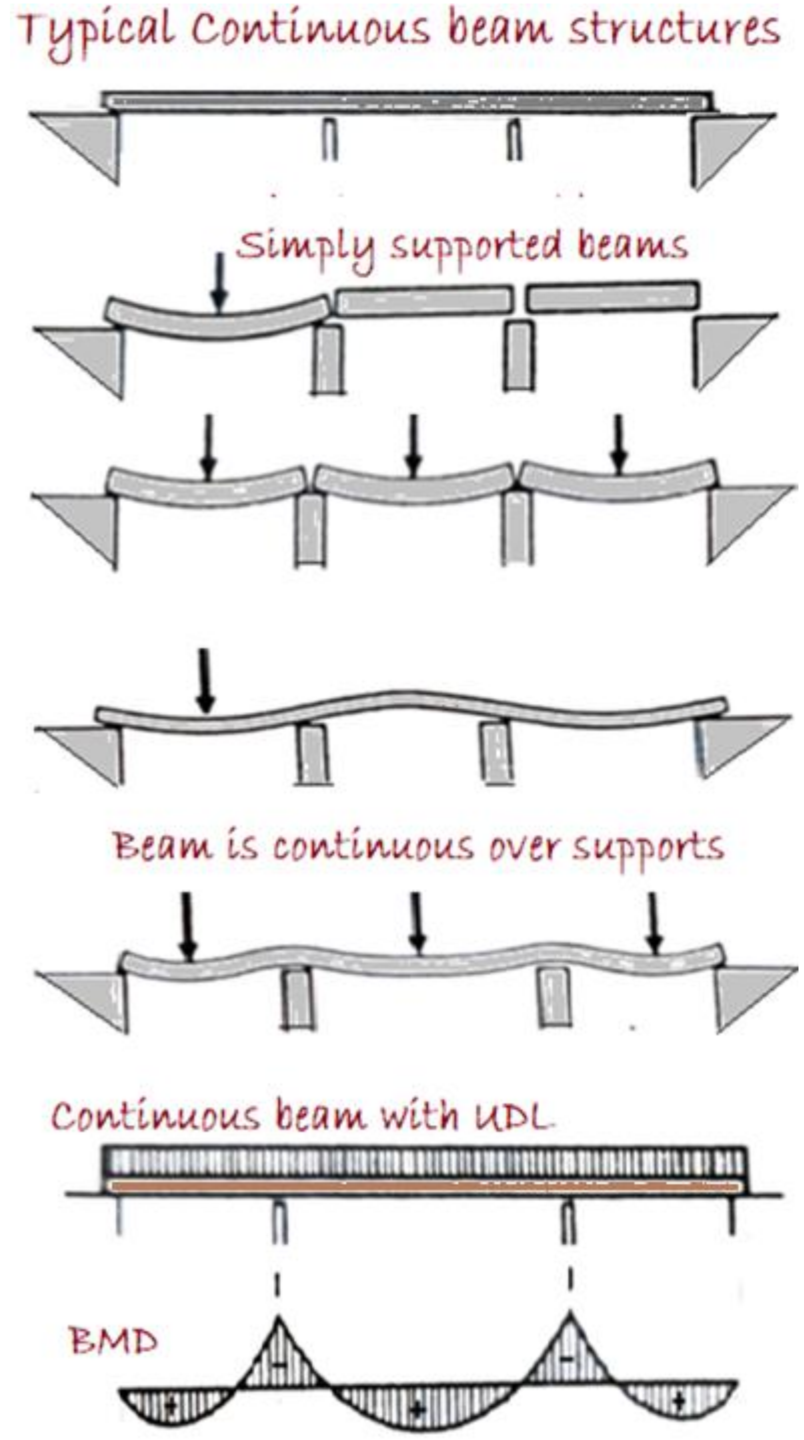

Rocker bearing




Prestressing Concept
Library Staff carrying Books
Like Superimposed Load
P
P
Like Prestressed Concrete

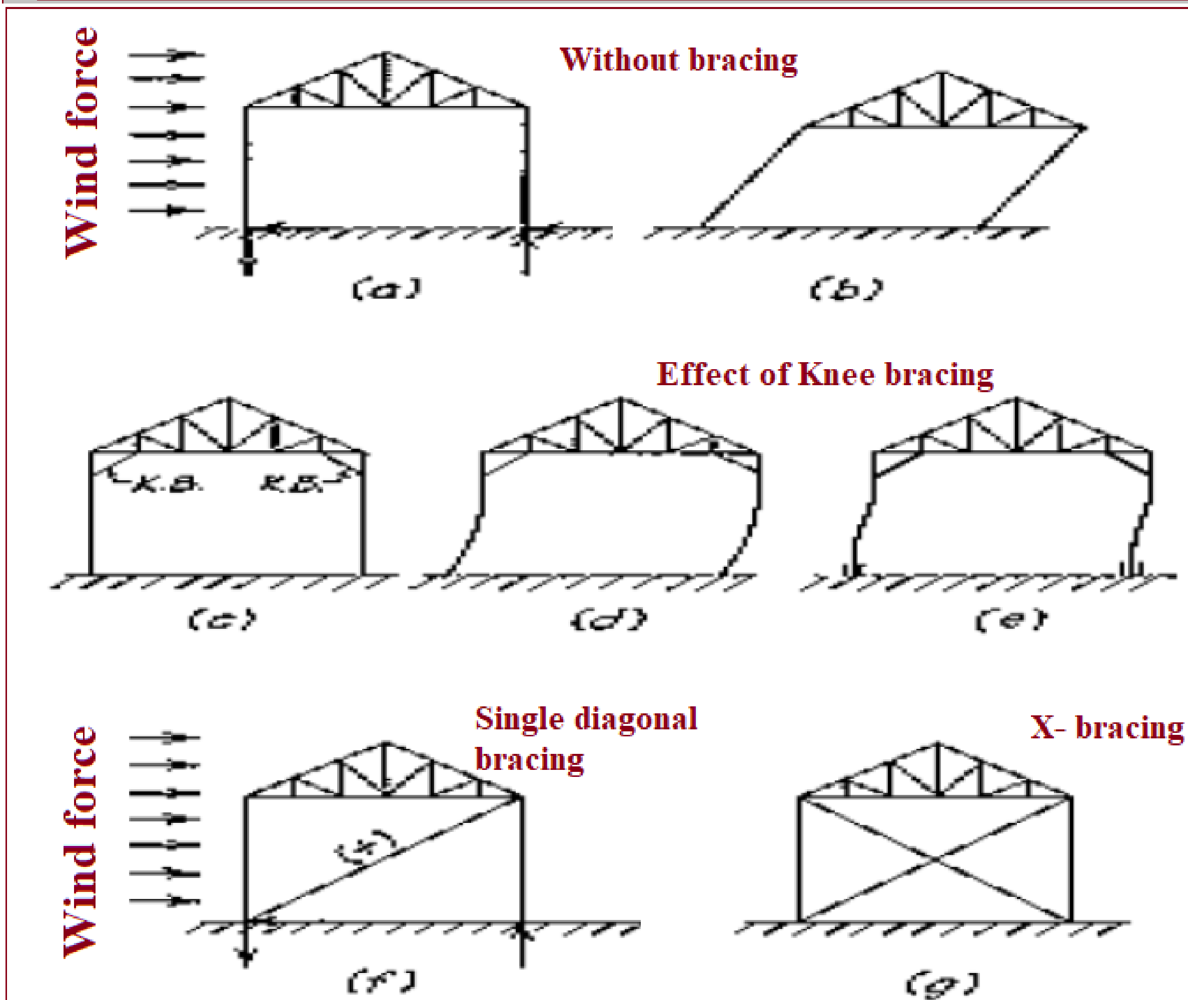

1
Jacking force
Tendon
Jacking force
2
Concrete in compression
3
Load Balancing
4

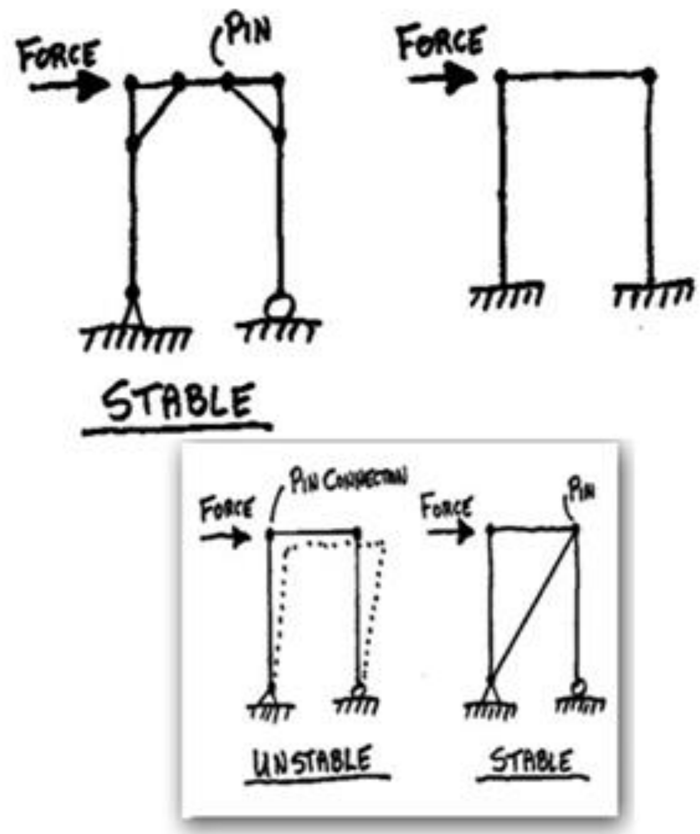

Simply supported Prestressed Concrete Box Girder

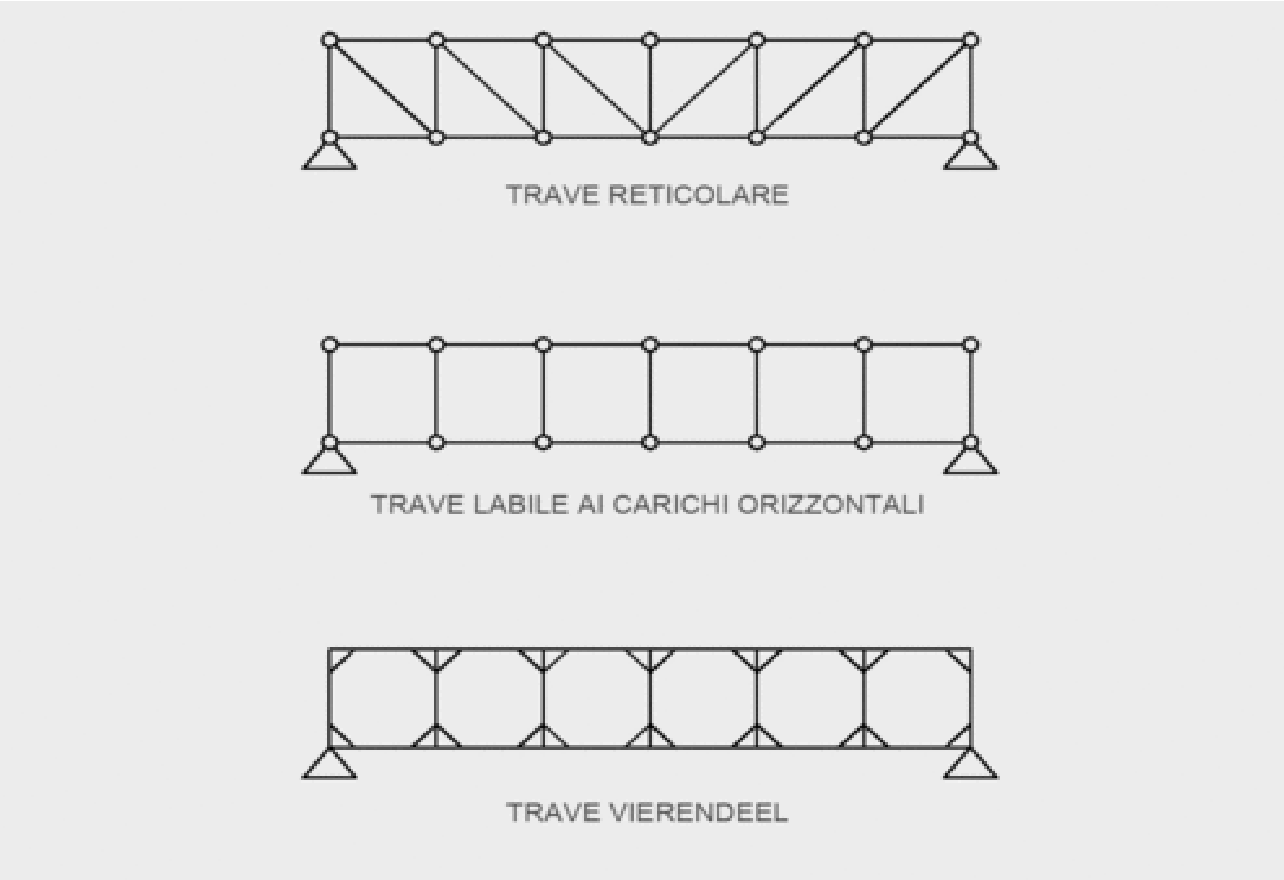

Typical Continuous beam structures
Simply supported beams
Beam is continuous over supports
Continuous beam with UDL
BMD

All structures deflect under the loads:

- How much deflection is 'too much'?
- How much sway may be permitted in a multi storey building under wind load?
- At what levels of vibration does the average person become uncomfortable and then alarmed?
- Should the designer cater for the most sensitive person or the average?



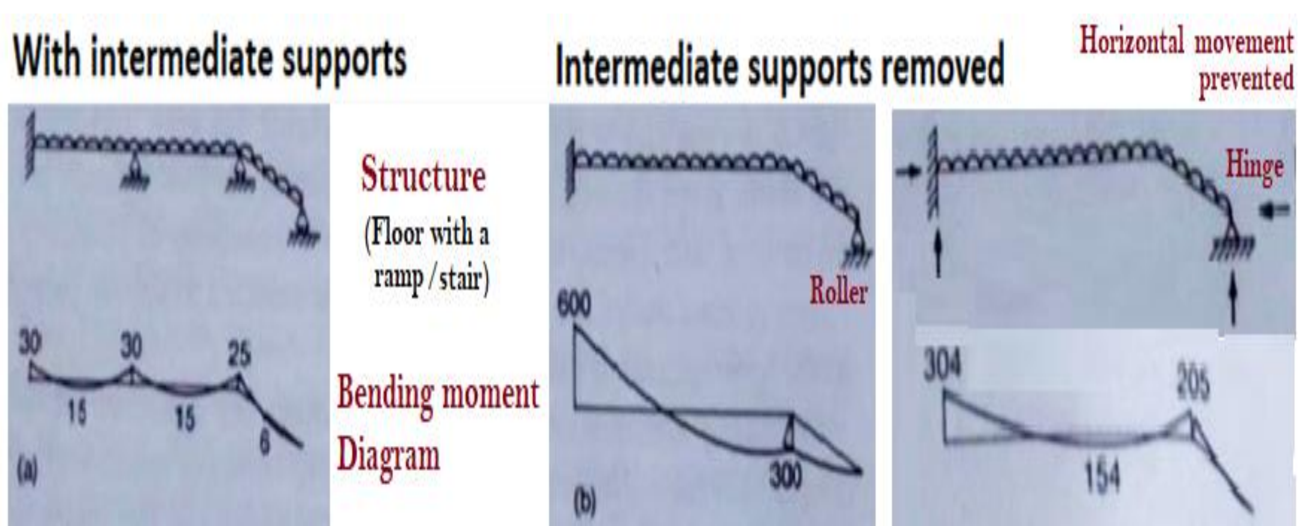


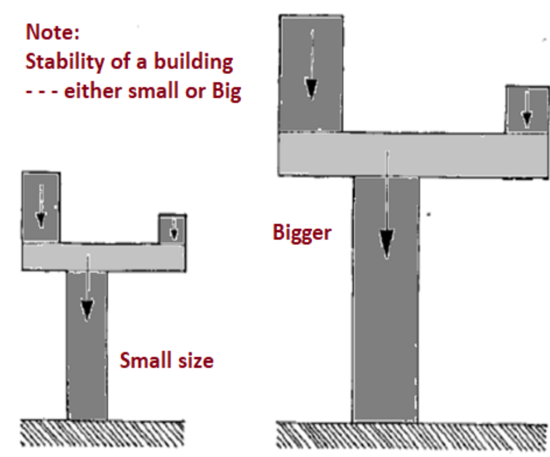


Stable: With inclined bracing

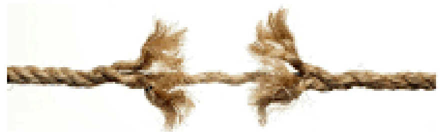
Unstable: without bracing

Stable: with knee bracing

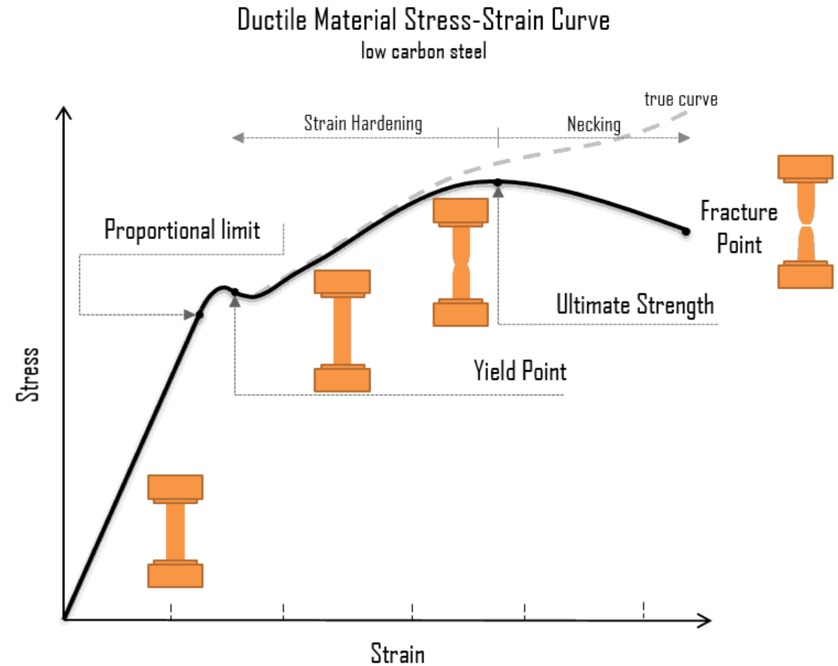


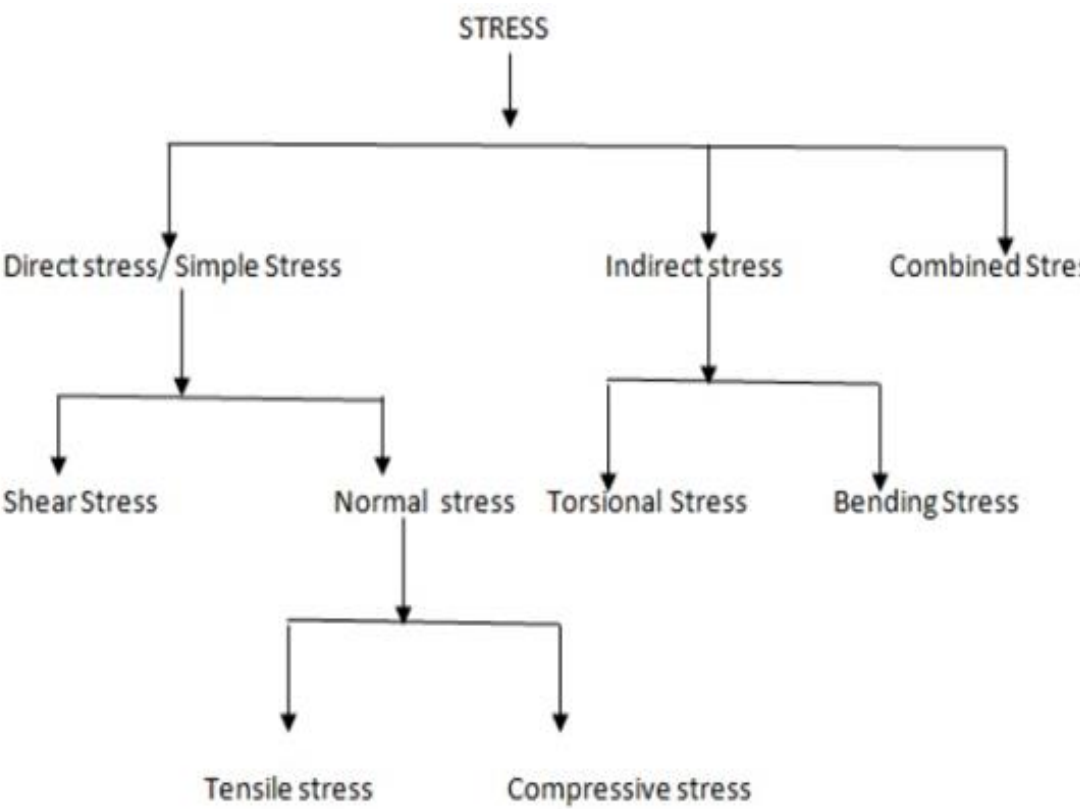


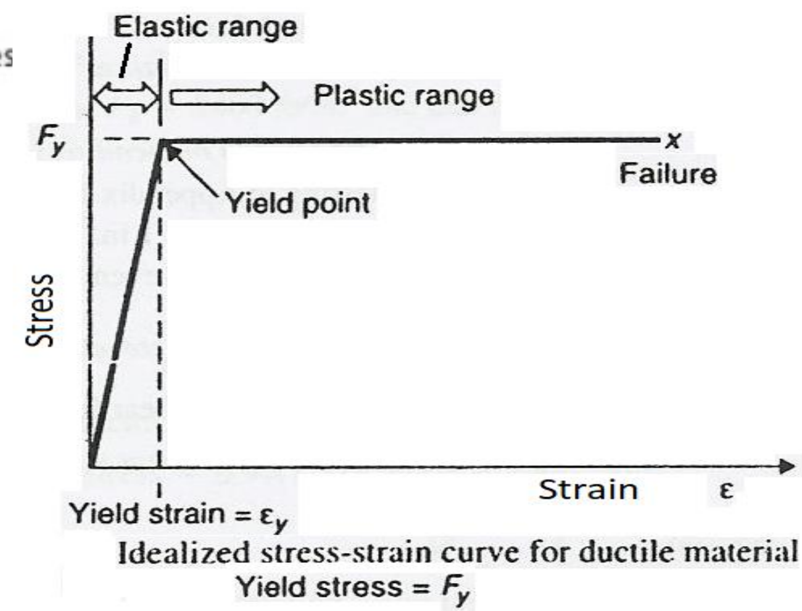
Strength of Materials



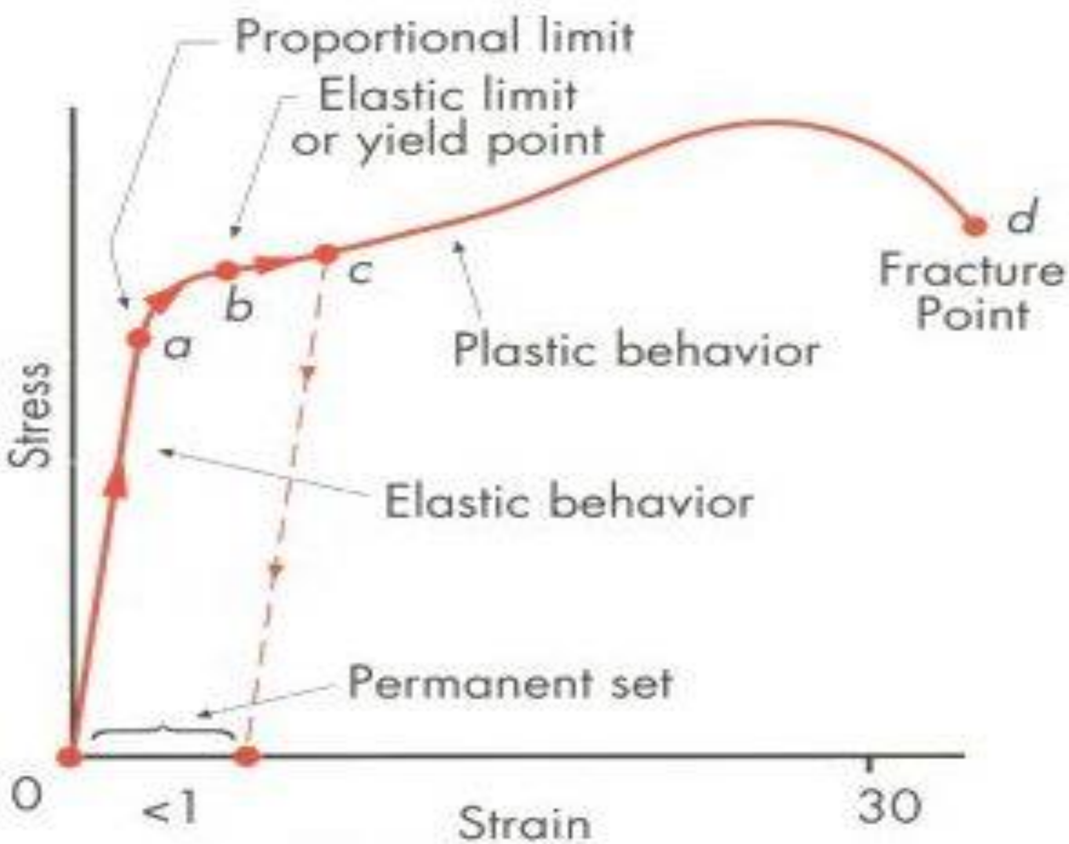
Stress and Strain

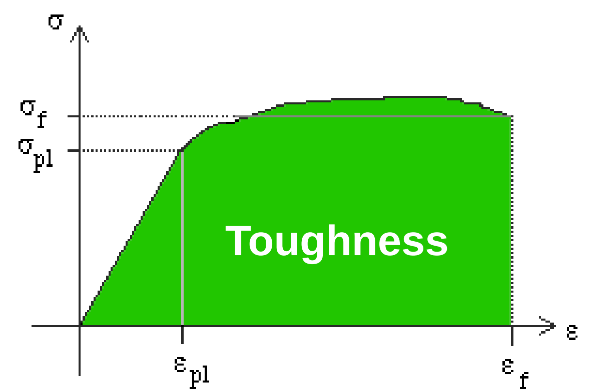


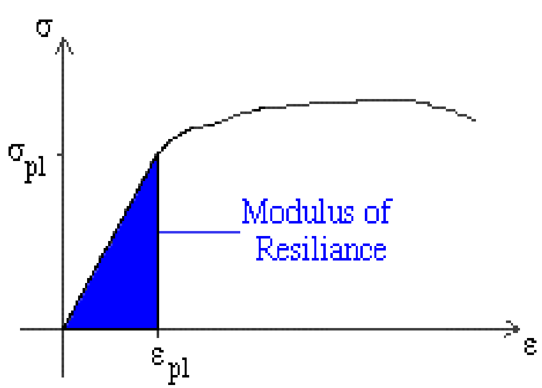


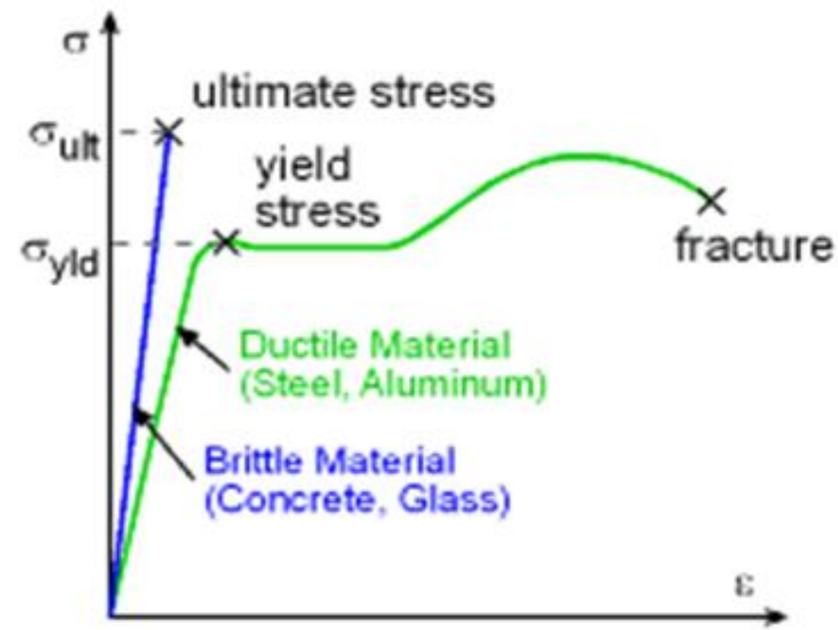


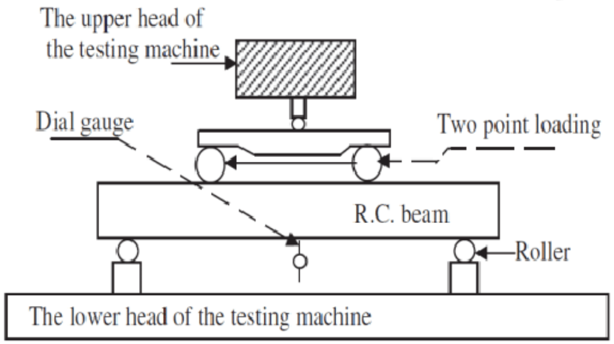
Understanding the performance & Selection of materials

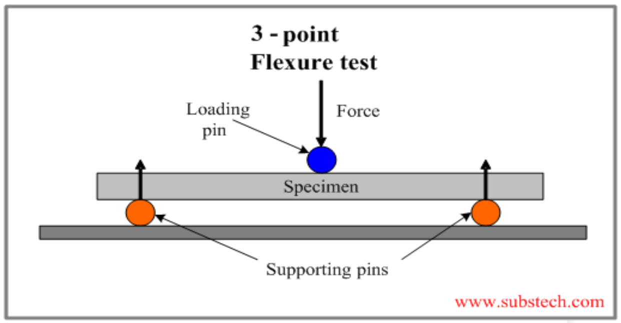


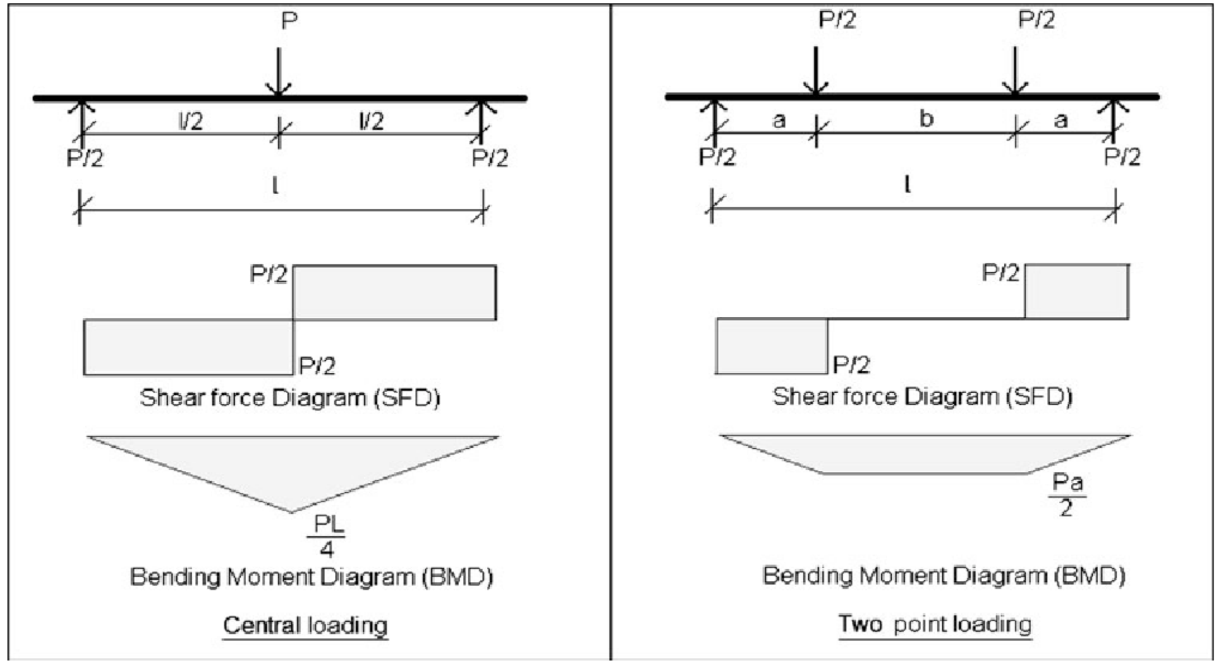


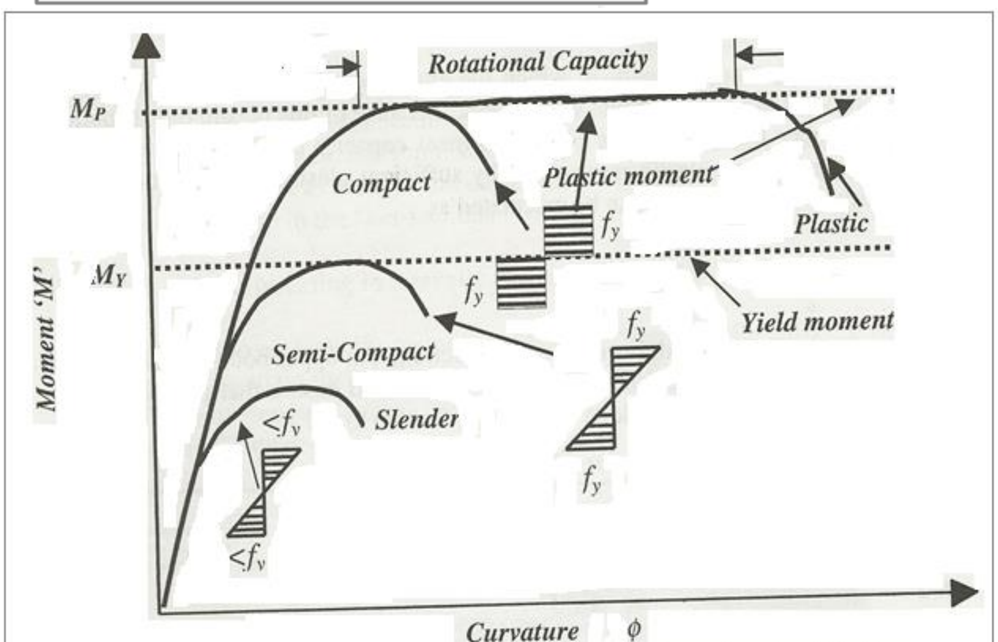




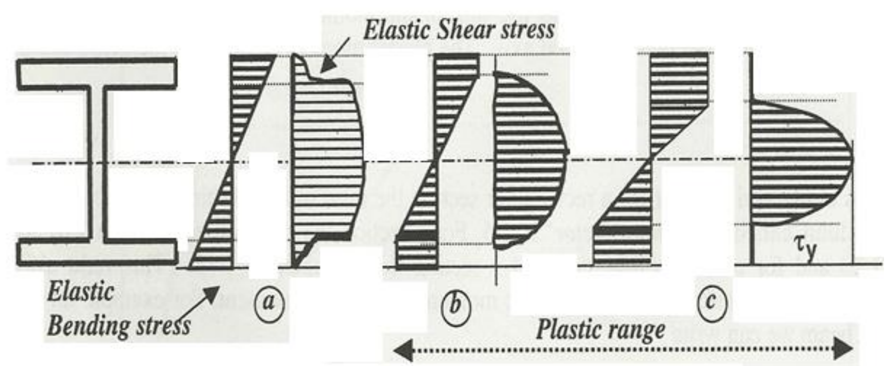






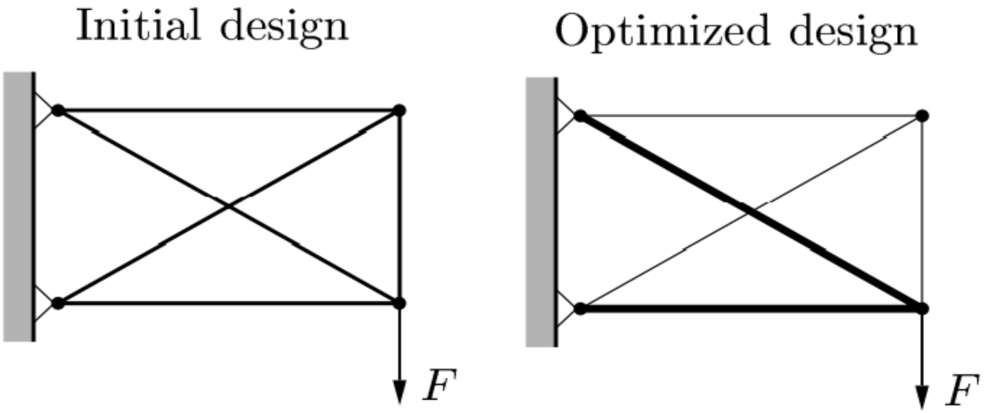


Flexural member performance using section classification

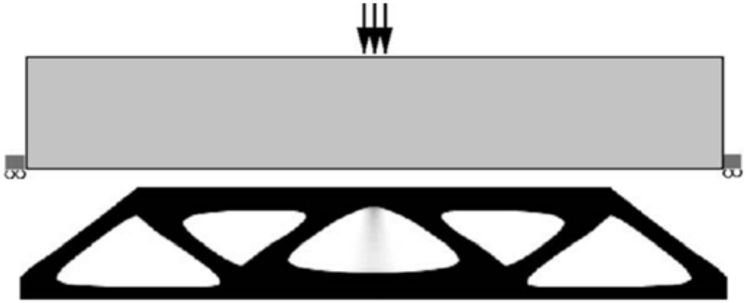


Combined bending and shear in beams

The fundamental questions arising in mechanics are: **Why?, How?, and How much?**



A sizing structural optimization problem

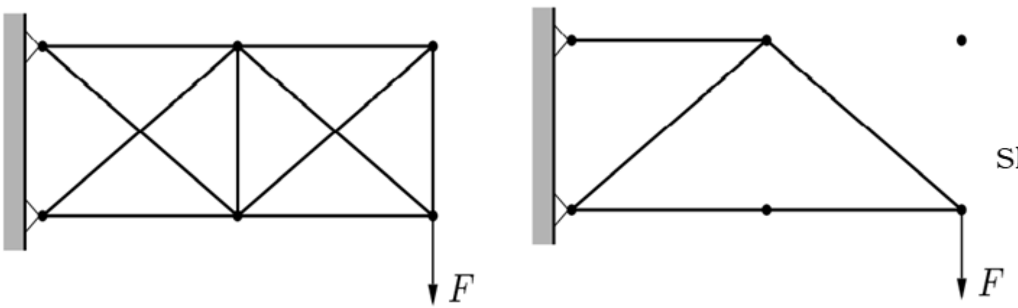


Two-dimensional topology optimization.

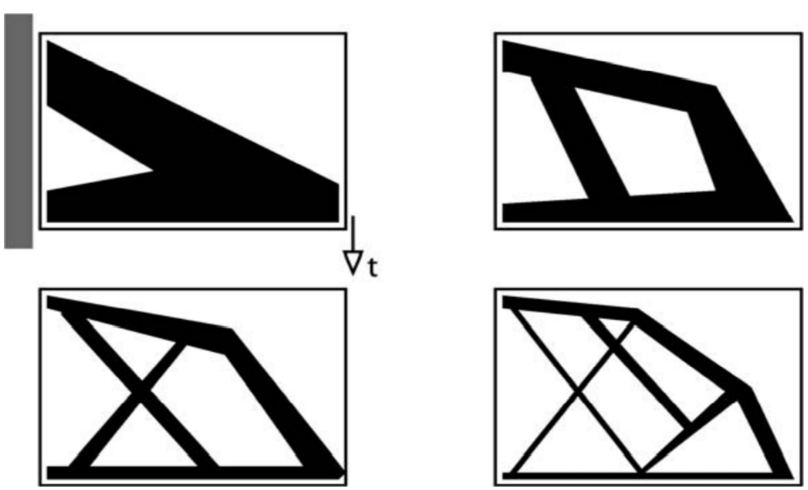
Types of structural optimization:

- **Sizing** optimization;
- **Shape** optimization;
- **Topology** optimization

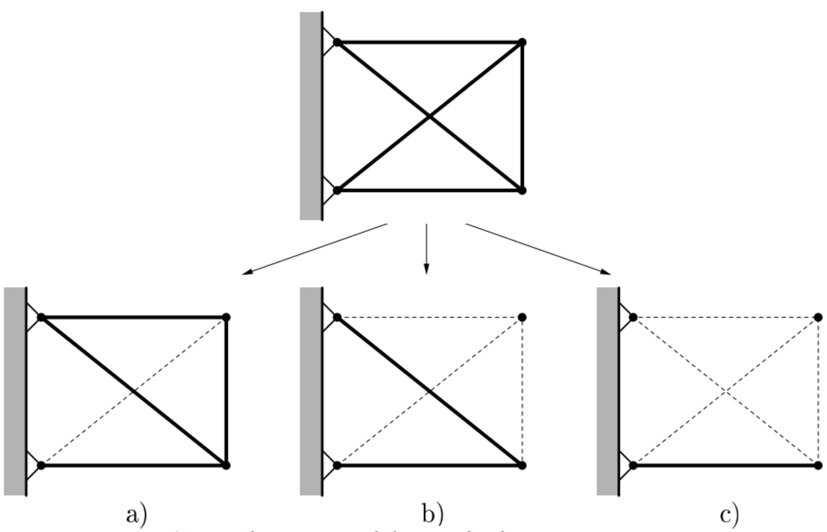
Shape optimization is a subclass of topology optimization



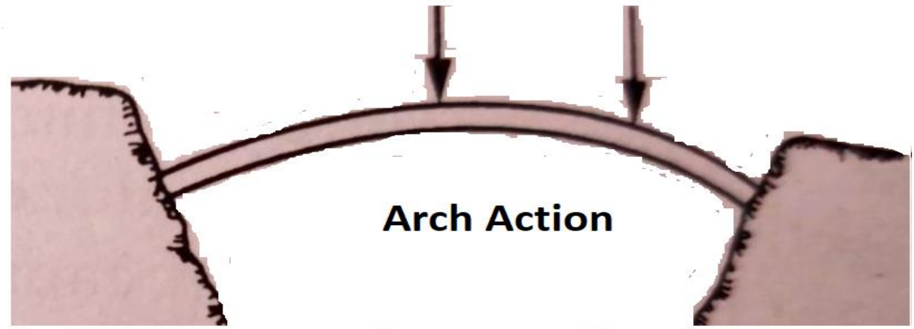
Topology optimization of a truss



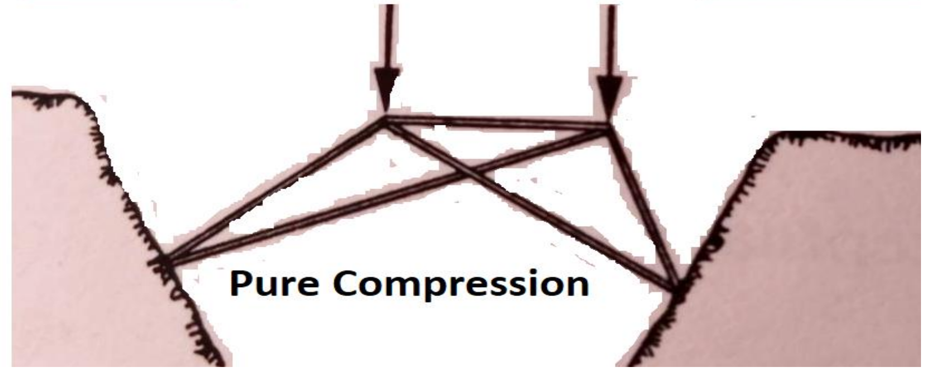
Introducing more and thinner bars gives a better objective function value, but there is no end to this process

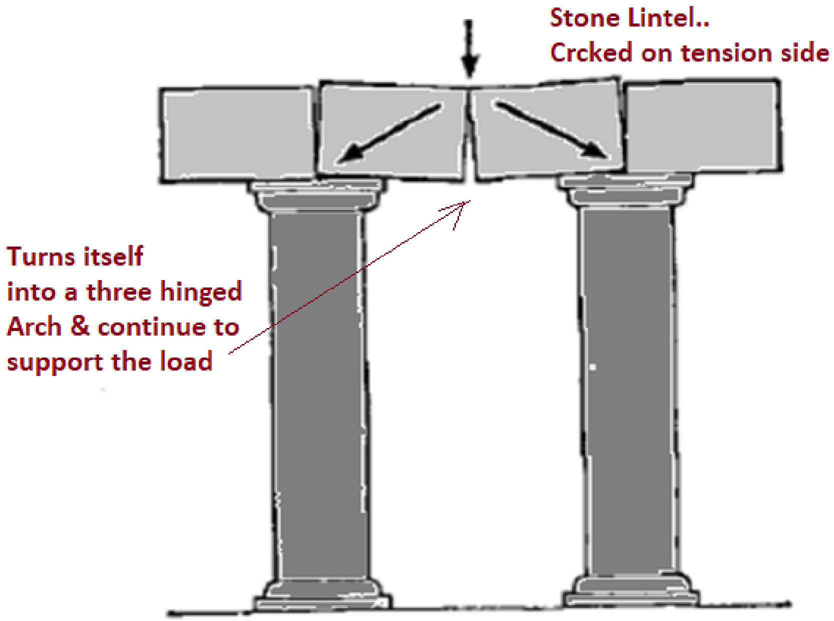


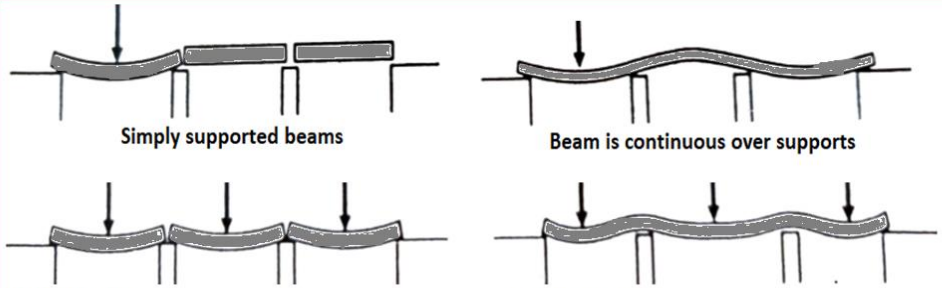
A ground structure and three optimal structures. *Dashed lines* correspond to bars with zero cross-sectional area



Alternative concepts of Structural action applied to the problem of supporting two loads across a gap







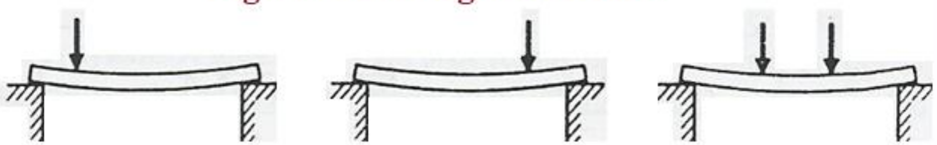
Simple beams:

- A load on one span causes curvatures and bending moments to develop in that span alone.
- No other span is affected.
- Only the member directly under the load is carrying the load.
- Each span deflects independently.

Continuous beam:

- A load on any one span causes curvatures and bending moments to develop in all spans.
- All spans share in carrying the load on any one span.
- Design moments get reduced.
- Member sizes can be smaller than those in a simply supported system.
- Reverse curvature, the system being stiffer, with smaller deflections.

Rigid and Non rigid Structures



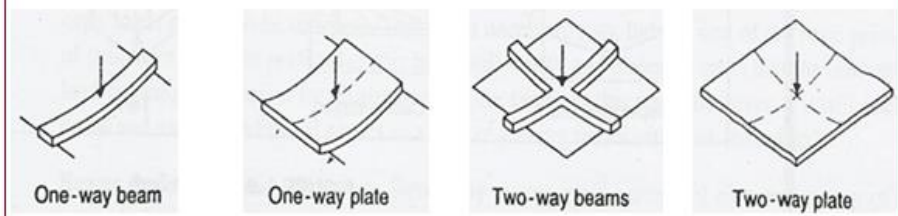
(a) Rigid structure (e.g., a beam). The structure is stiff and does not undergo appreciable changes in shape with changes in the loading condition.

(b) Nonrigid or flexible structure (e.g., a cable). The shape of the structure changes with changes in the loading condition.

Rigid- rigid elements are those that do not undergo appreciable shape changes under the action of a load or changing loads.

Flexible- such as cables, are those in which the element assumes one shape under one loading condition and changes drastically when the nature of the loading changes. Flexible structures maintain their physical integrity, however, no matter what shape they assume. Material: Steel may be rigid (steel beam) or flexible (cable or chain).

One way Structures Two way Structures



Type of Structural elements

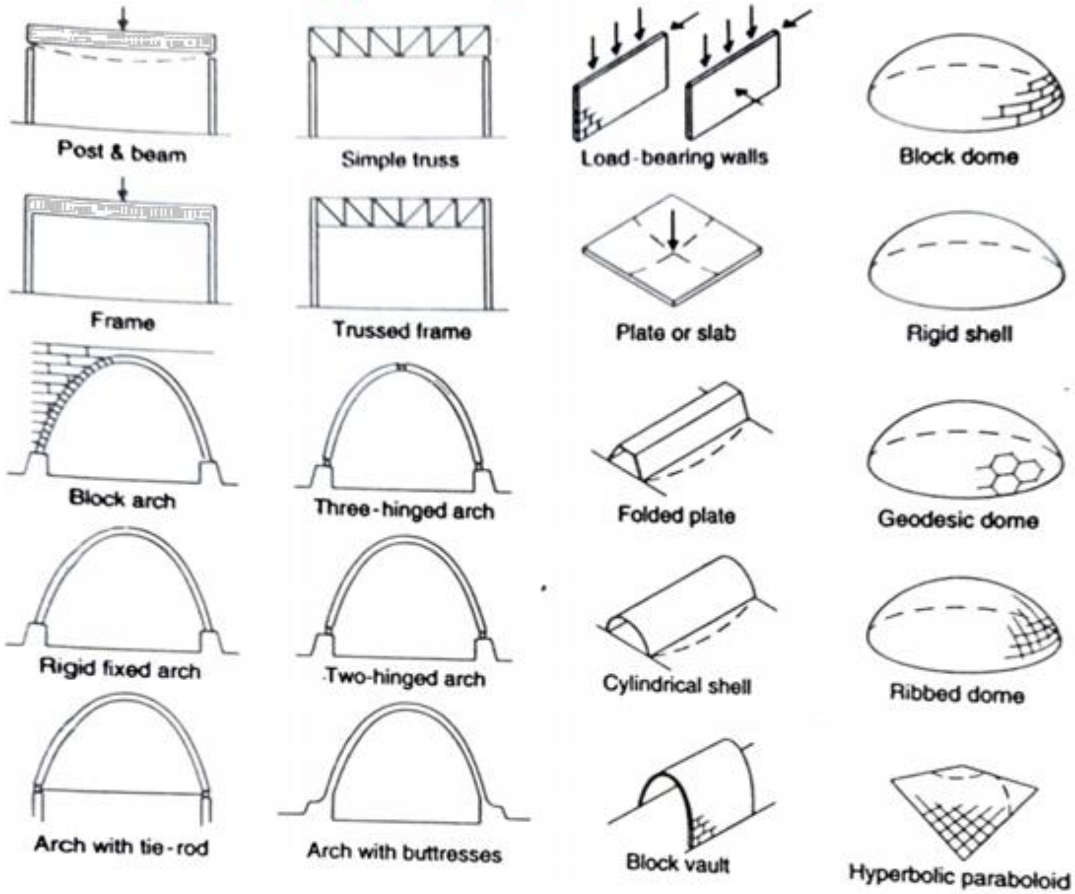
In **one way system**, the basic load transfer mechanism of the structure for channelling external loads to the ground acts in one direction only.

Ex: A linear beam spanning between two support points.

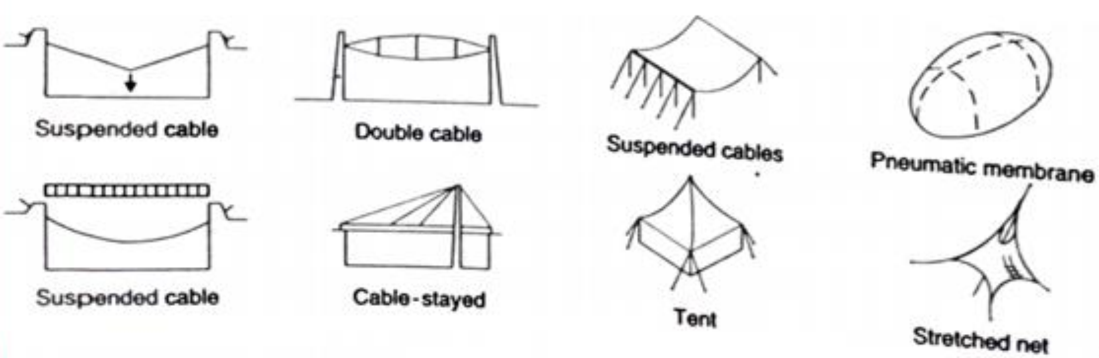
In a **two way system**, the direction of the load-transfer mechanism is more complex but always involves at least two directions.

Ex: A system of two crossed elements resting on two sets of support points not lying on the same line and in which both elements share in carrying any external load. A square, flat rigid plate resting on four continuous supports.

Typical Rigid Structures



Typical Flexible Structures



Primary structural elements

Elements - beams, columns or struts, arches, flat plates, singly curved plates, and shells having variety of different curvatures

Flexible elements include-

- cables (straight and draped)
- membranes (planar, singly curved, and doubly curved)

Structures derived: Frames, trusses, geodesic domes, nets, etc.

Beams and Columns – post-and-beam structures, where beams pick up loads that are transverse to their lengths and transfer them to vertical columns or posts. Columns loaded axially or eccentrically by the beams, transfer the loads to the ground. Beams: Single span or continuous beams

Frames – Beams and columns are connected rigidly offer resistance to both vertical and lateral loads.

Trusses – by assembling rigidly short, straight members into triangulated patterns; members only under axial compression or tension.

Arches – a curved, line forming structural member that spans between two points. Stacking rigid blocks or a rigid arch made of a continuous piece of rigid material.

Walls and Plates – rigid surface forming structures. Load bearing wall can be designed to support vertical loads and also resist lateral loads (wind or earthquakes). Flat Plate (made of RCC or steel) is typically used horizontally and carries loads by bending to its supports.

Cylindrical Shells and Vaults – singly curved plate structures, with curve perpendicular to the direction of the span. Vault is a singly curved structure that spans transversely (basically a continuous arch)

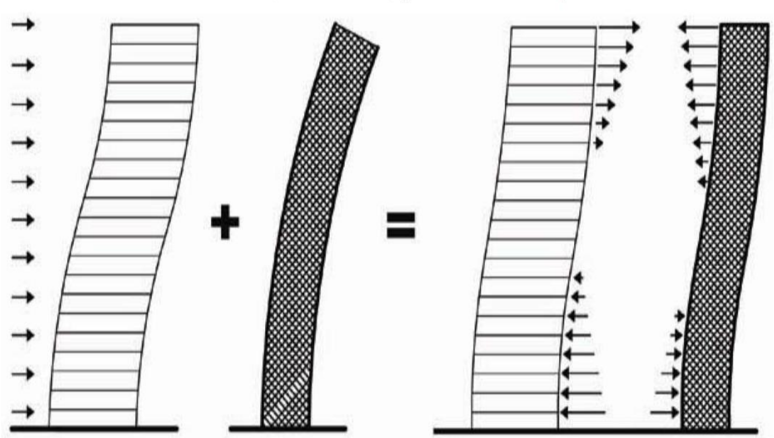
Spherical Shells and Domes – doubly curved surface structures/warped surfaces (e.g., the hyperbolic paraboloid). Domed structures can be made of stacked blocks or continuous rigid materials (RCC).

Cables – flexible structural elements, shape they assume under a loading depends on the nature and the magnitude of the load. Ex: Tie rod or catenary curve

Membranes, Tents, and Nets – membrane is a thin, flexible sheet; tent is made of membrane surfaces; and nets are three dimensional surfaces made up of a series of crossed curved cables.

Rigid frames may be combined with vertical steel trusses or reinforced concrete shear walls to create shear wall (or shear truss)-frame interaction systems. Rigid frame systems are not efficient for buildings over 30 stories in height because the shear racking component of deflection caused by the bending of columns and girders causes the building to sway excessively. On the other hand, vertical steel shear trusses or concrete shear walls alone may provide resistance for buildings up to about 10 or 35 stories, respectively, depending on the height-to-width ratio of the system. When shear trusses or shear walls are combined with MRFs, a shear truss (or shear wall)-frame interaction system results. The approximately linear shear-type deflected profile of the MRF, when combined with the parabolic cantilever sway mode of the shear truss or shear walls, results in a common shape of the structure when the two systems are forced to deflect in the same way by the rigid floor diaphragm

Shear wall (or shear truss)-frame interaction system.

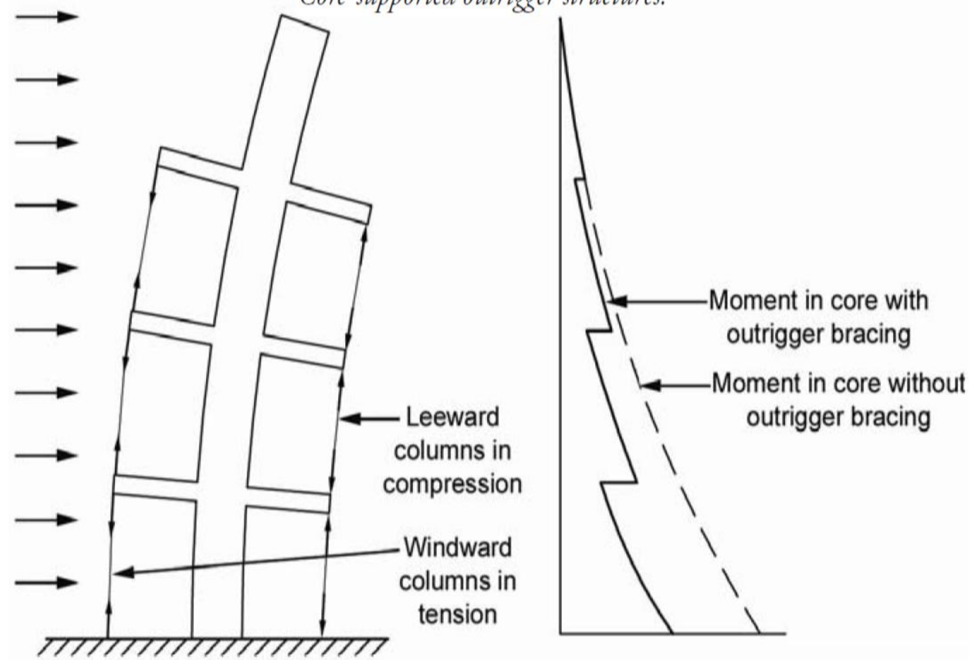


The upper part of the truss is restrained by the frame, whereas at the lower part, the shear wall or truss restrains the frame. This effect produces increased lateral rigidity of the building.

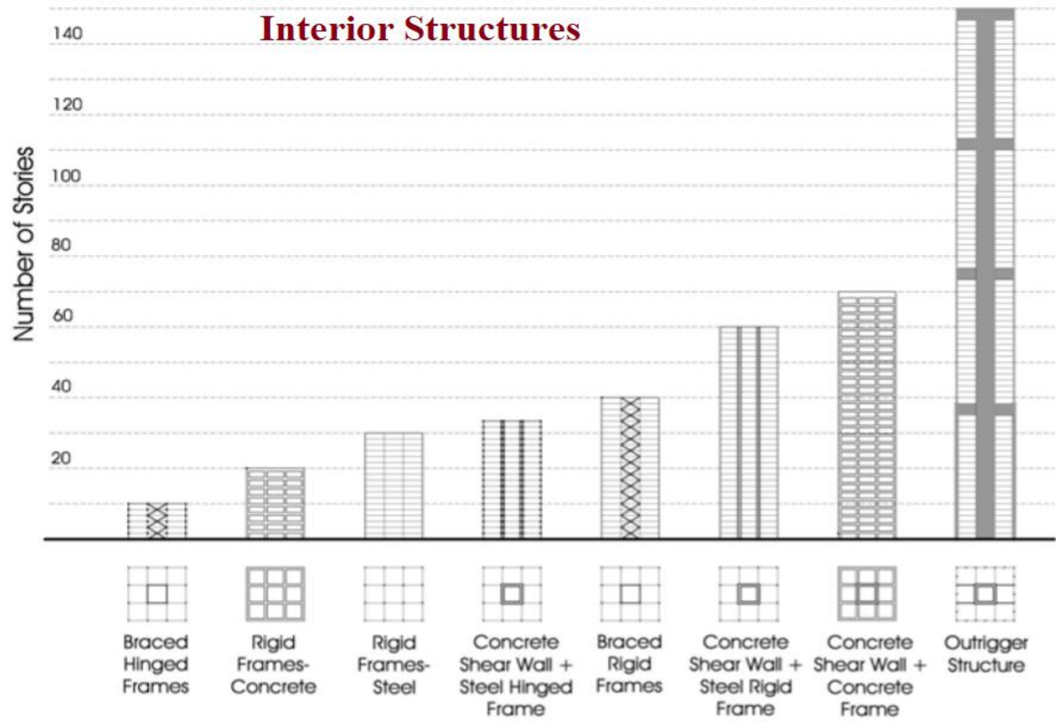
The core in a tall building is analogous to the mast of the ship, with outriggers acting as the spreaders and the exterior columns like the stays.

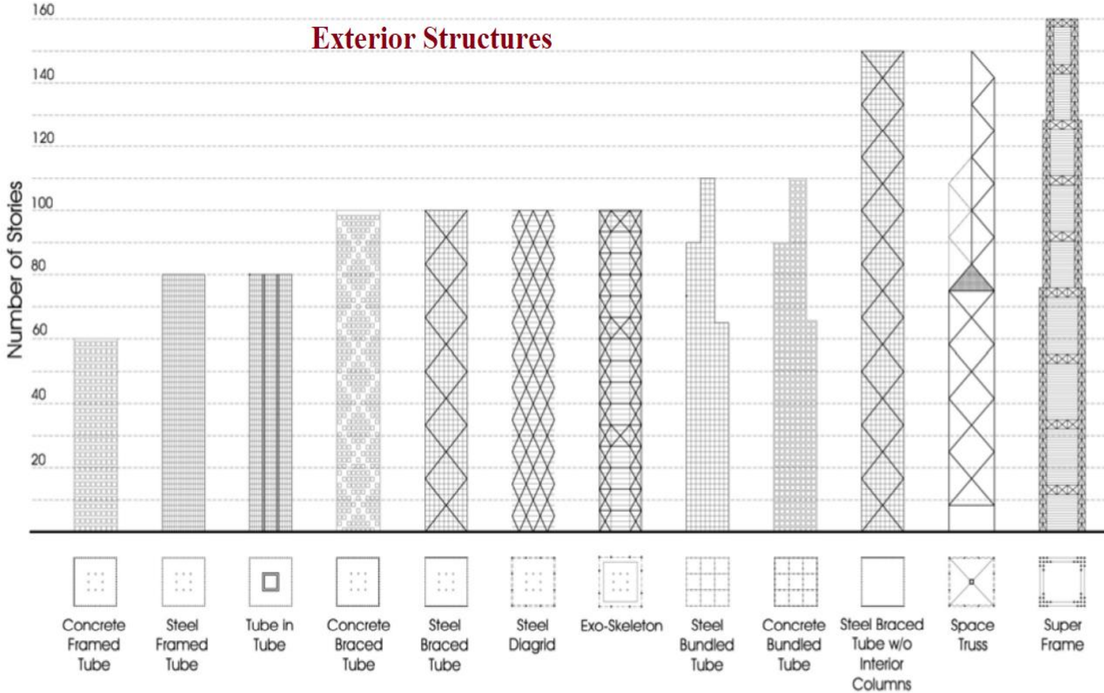
As for the sailing ships, outriggers serve to reduce the overturning moment in the core that would otherwise act as pure cantilever, and to transfer the reduced moment to the outer columns through the outriggers connecting the core to these columns

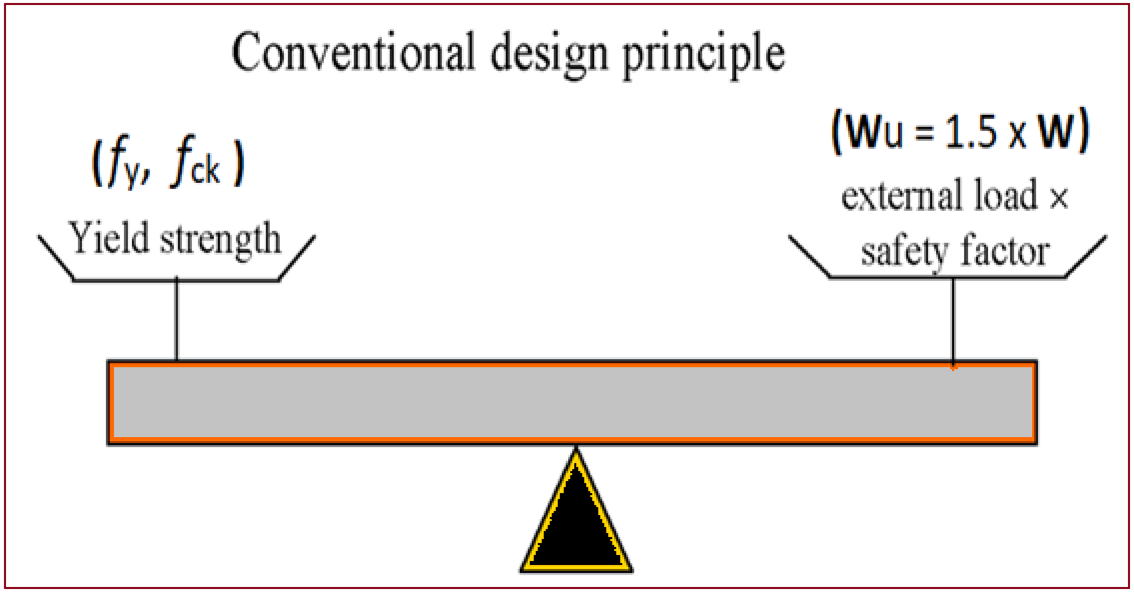
Core-supported outrigger structures.



High Rise Structures







$$\text{Safety factor} = \text{Factor of Safety (F.S)} = \frac{\text{Ultimate Load}}{\text{Service Load}} = \frac{\text{Ultimate Stress}}{\text{Allowable stress}}$$

Why buildings fall down...?

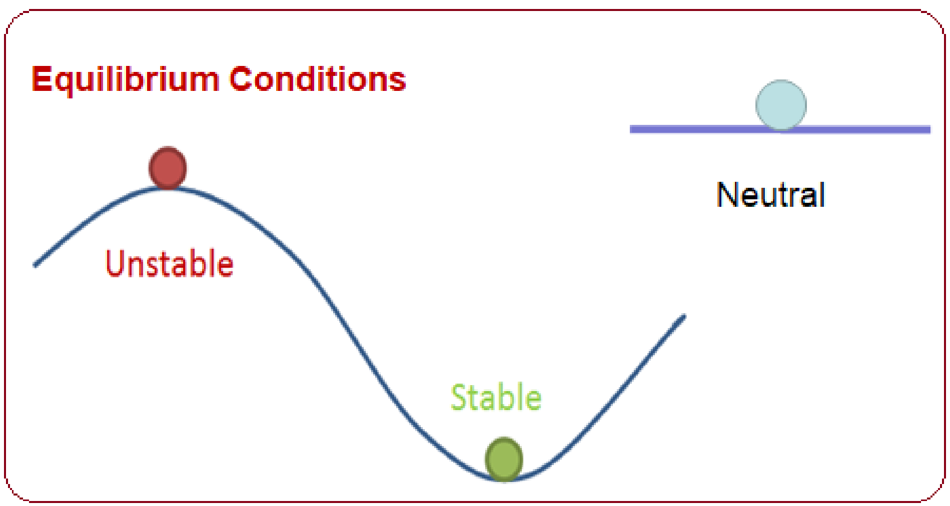
- Global Failure
- Local Failure

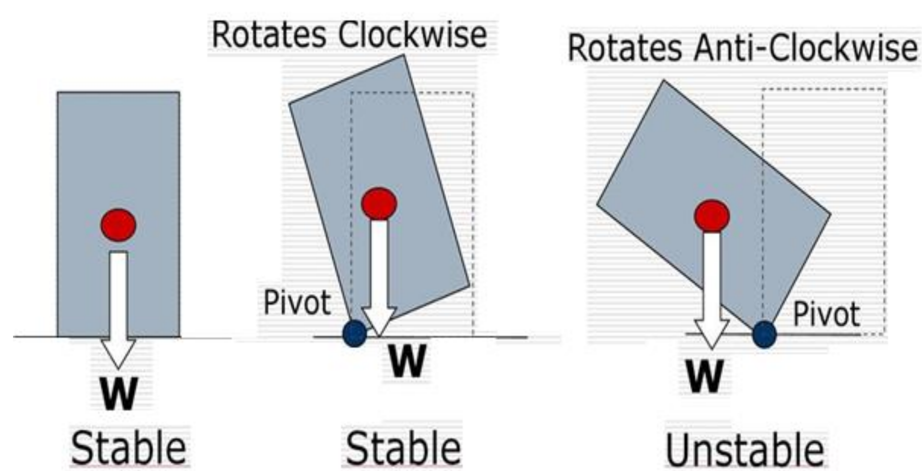
Building failure can be categorized into:

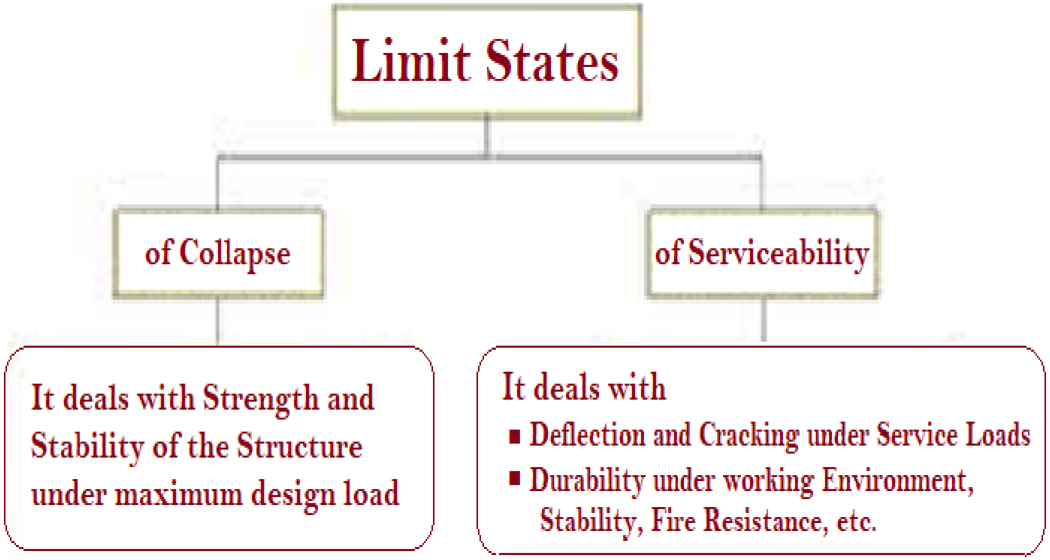
- **Physical (structural) failures** - due to loss of strength
- **Performance failures** – reduction in function below an acceptable limit.

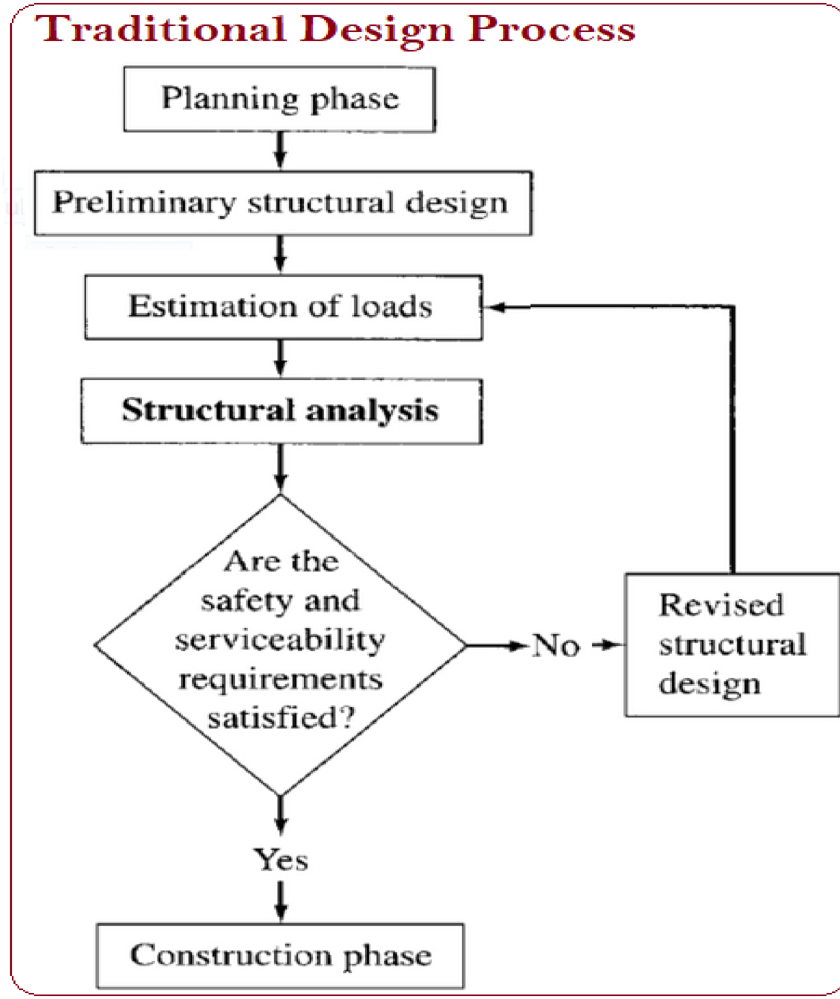
Structural failures – when they have reached limit states of

- **Collapse**
- **Serviceability (Cracking & Deflection)**



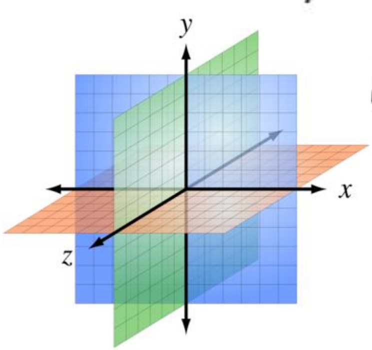


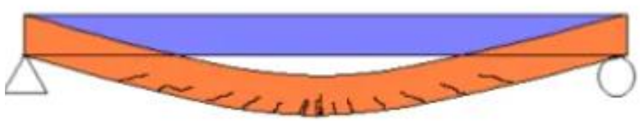


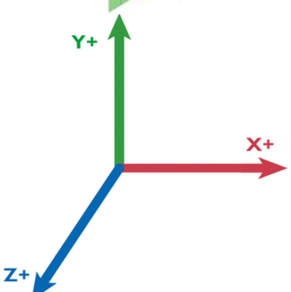


Serviceability Limit States:

- Cracking
- Excessive Deflection
- Buckling
- Stability



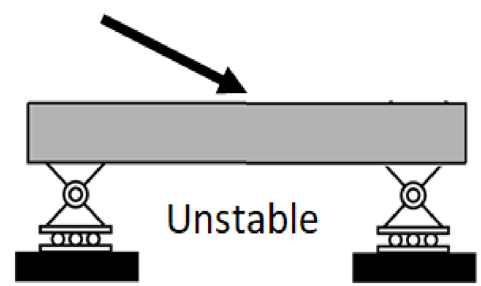




For equilibrium,

$$\sum H = \sum F_x = 0;$$

$$\sum V = \sum F_y = 0; \ \sum M_z = 0$$



Unstable under inclined or horizontal loads

$$\sum H \neq \sum F_x \neq 0; \quad \sum V = \sum F_y = 0; \quad \sum M_z = 0$$

For several reasons, structural design remains an important and challenging task.

- **One challenge**: Design a structure that meets not only behavioural criteria (load support and transfer) but also other requirements: accessibility, manufacturability, and aesthetics
- **Second challenge**: **Proper material** use; recognising that material properties often vary or are not precisely known.
- **Third challenge**: the dramatic variety of solutions a design problem can have in terms of the connectivity or topology of the structure (**structural configuration**)

Important concepts

- **Strength (Collapse)**
- **Stiffness**
- **Serviceability (Cracking & Deflection)- ductility**
- **Stability**

- **Equilibrium**
- **Compatibility**
- **Material obeying Hooke's law**

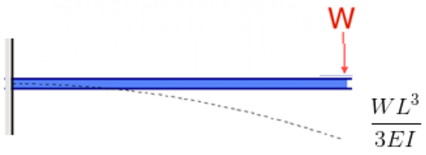
Basic Design parameters from analysis

- Bending/Flexure /Moment of resistance = MR = Mu = Max BM
- Shear force, Vu
- Torsion also produces shear
- Deflection

Design Solution:

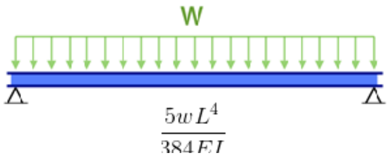
In RCC design

- Assume Width, determine the Depth required, **controls deflection** (Based on Span to depth ratio)
- Area of steel required to resist BM
- Stirrups or shear reinforcement to resist Shear force



In steel design,

- select steel section for a required plastic/ elastic section modulus
- Check for shear, deflection control, bearing, crippling/buckling



$< \textit{Allowable deflection}$

$$\delta l = \frac{WL^3}{3EI} = \frac{WL^3}{3E\frac{bd^3}{12}} = \frac{4WL^3}{Ebd^3} \alpha \frac{1}{bd^3}$$

Stiffness

$$\delta l \ \alpha \ \frac{1}{bd^3}$$

For a given b,

$$\delta l \ \alpha \ \frac{1}{d^3}$$

Strength

Plastic moment = Max. BM = Mu = Mp

$$M_p = \sigma_y Z_p = \sigma_y (SF \times Z_e)$$

$Z_e = \frac{I}{y}$ = Elastic sectional modulus

$Z_p = \frac{A(\bar{y}_1 + \bar{y}_2)}{2}$ = Plastic sectional modulus

$\sigma_y = \textit{yield stress of steel}$

$$V_p = \frac{A_v f_{yw}}{\sqrt{3}}$$

A_v = shear area, and

f_{yw} = yield strength of the web.

Stability:

- **Equilibrium Conditions are met**
- **Boundary conditions**

Compatibility:

Continuity in reinforcement

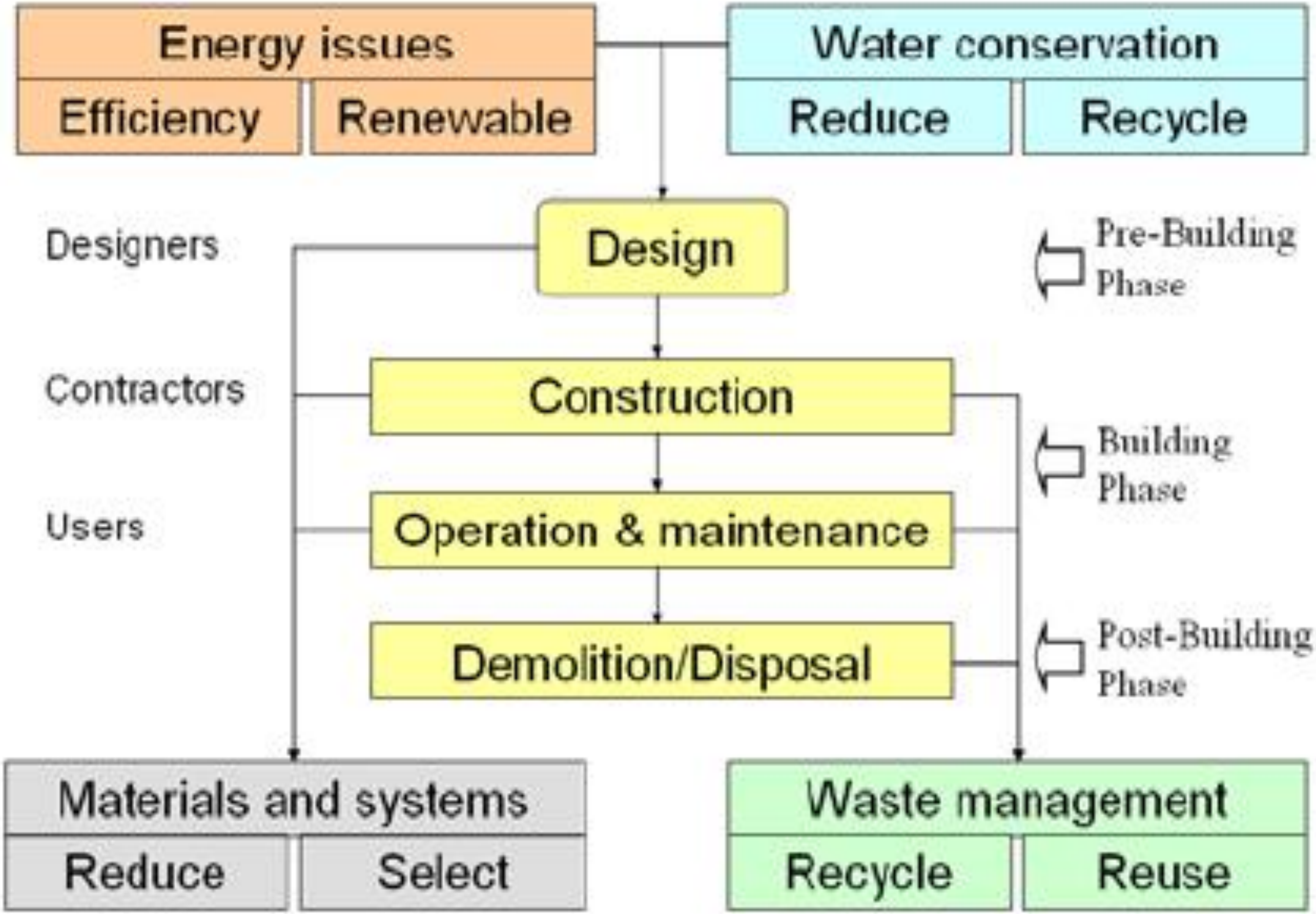
The Philosophy of design:

- The Materials
- the shape and dimensions
- No. of structural elements
- the weight
- the cost (optimization)

Safety against yield failure is the basic requirement of any design and taught in all courses on Strength of Materials.

Structural Health is a prediction of the ability of a structure **to survive** or **meet performance requirements** in the future.

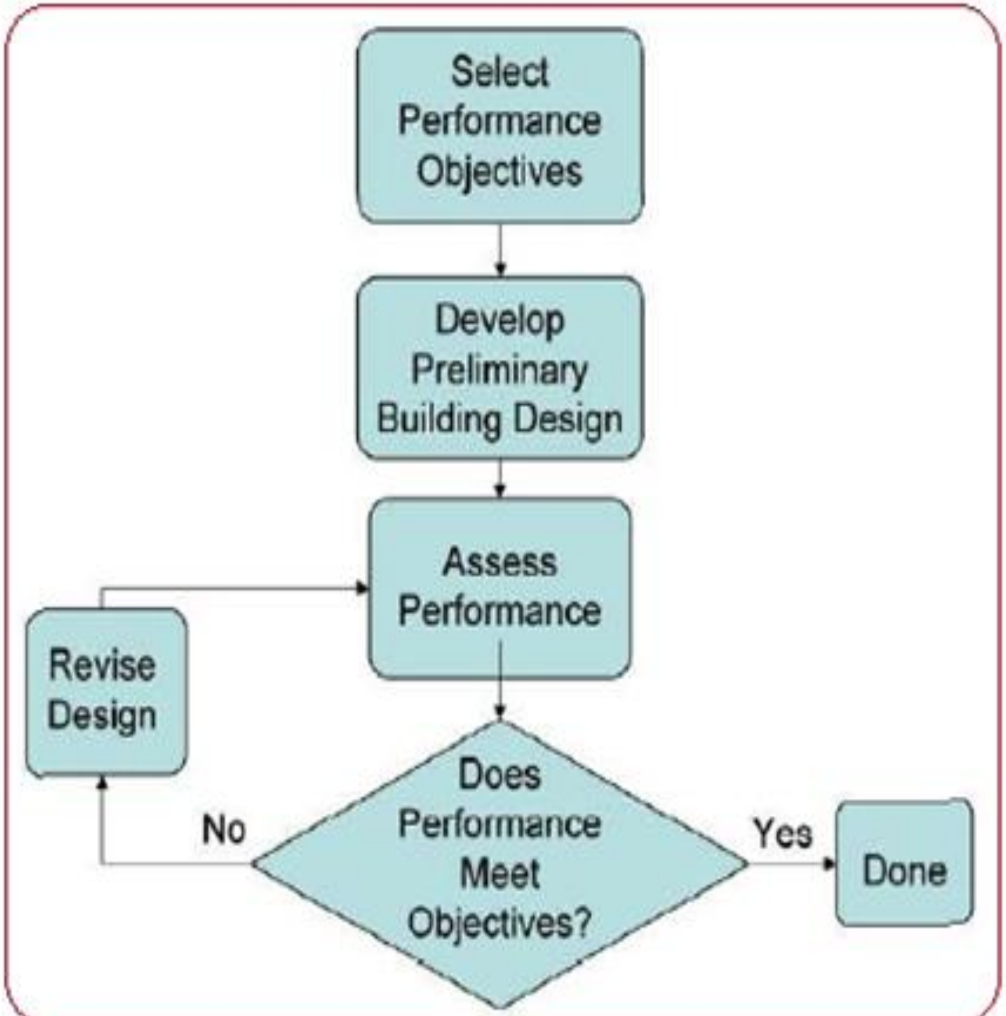
We must be able to analyze designs to make further decisions.



Building life cycle and sustainable construction

Performance based Design

Design for Performance is the process whereby **a developer or owner commits to design, build and commission** a building.

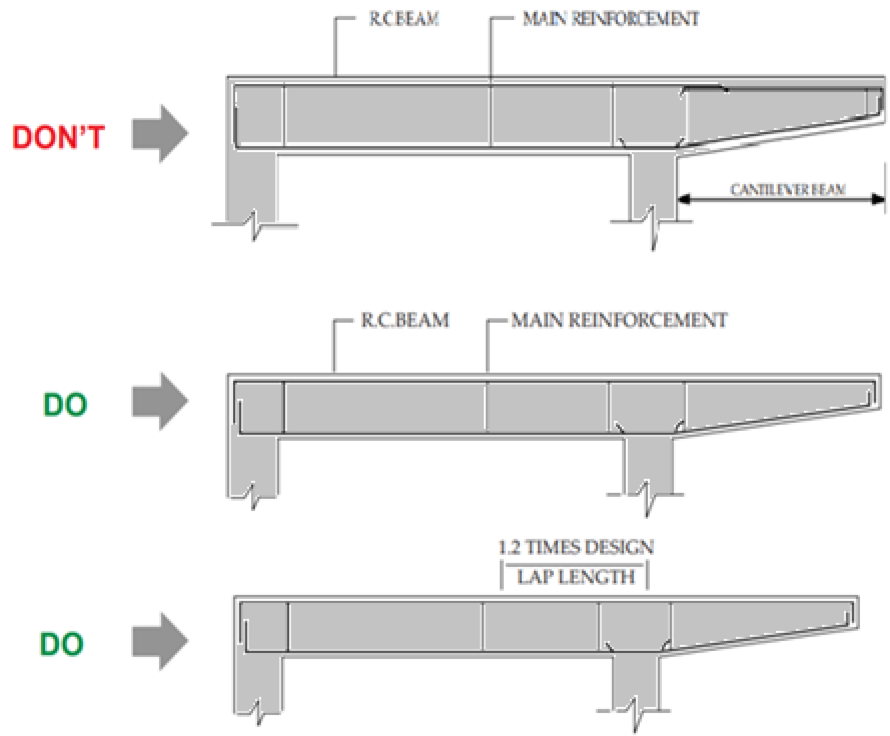


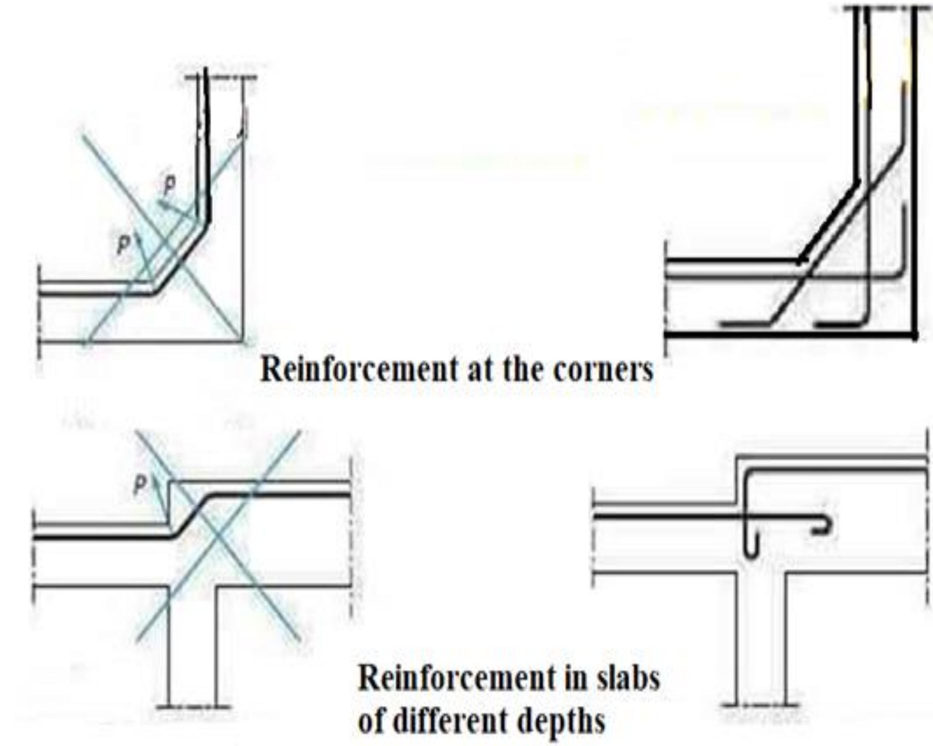
Performance Objectives

- **Fully operational**
- **Operational**
- **Immediate Occupancy**
- **Life Safety**
- **Collapse prevention**

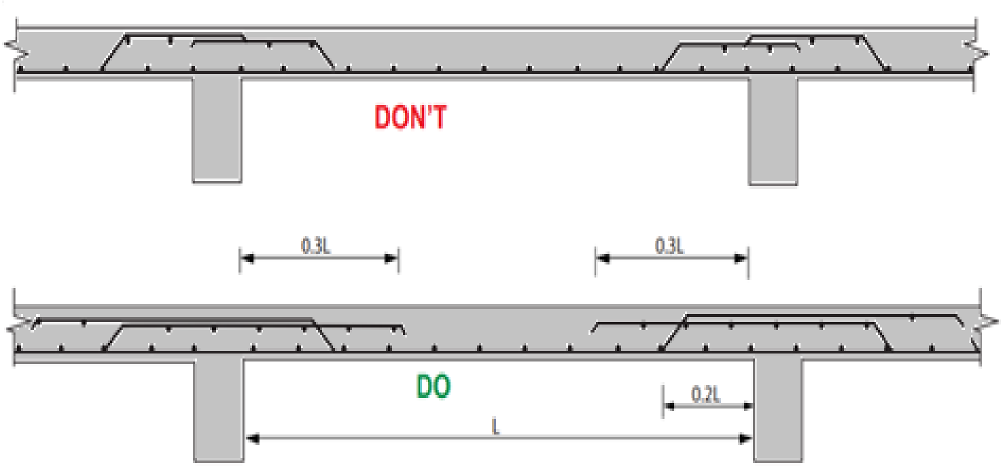
Dos and Don'ts

LAPPING OF BARS IN CANTILEVER BEAMS

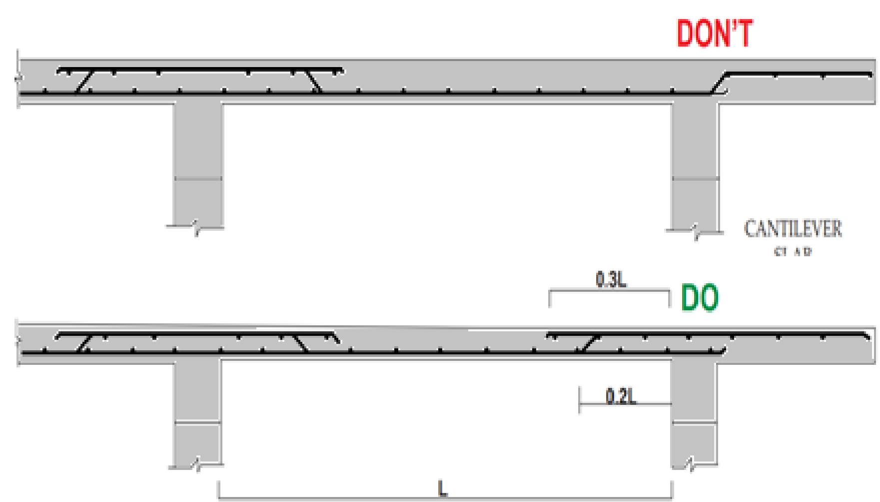




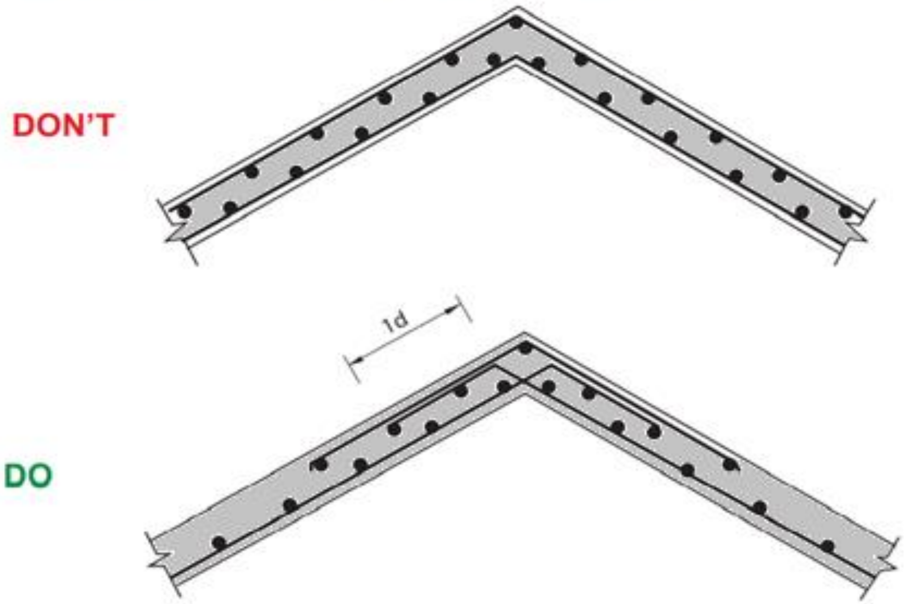
PLACEMENT OF BARS AT SLAB SUPPORT



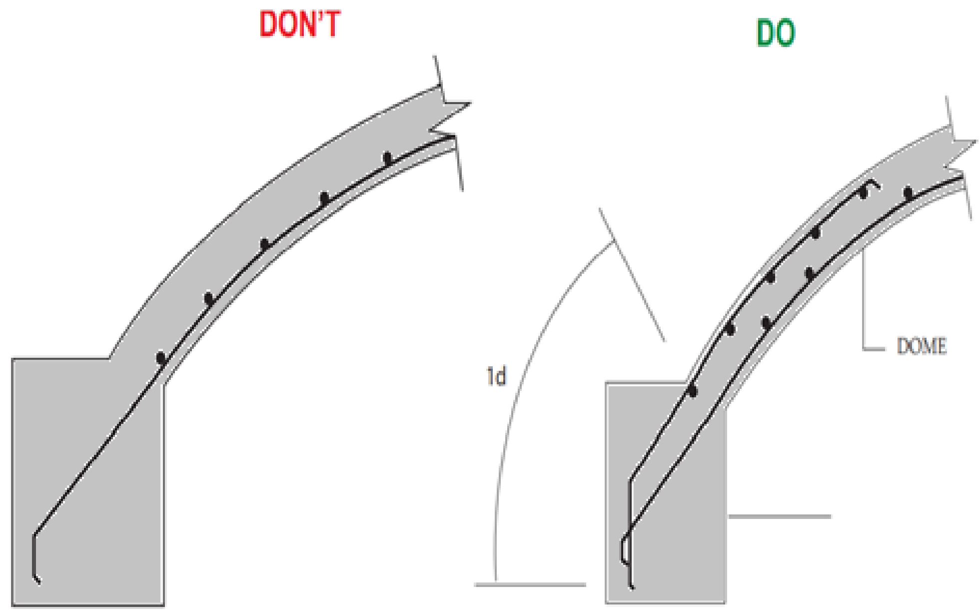
BAR PLACEMENT IN CANTILEVERED SLAB



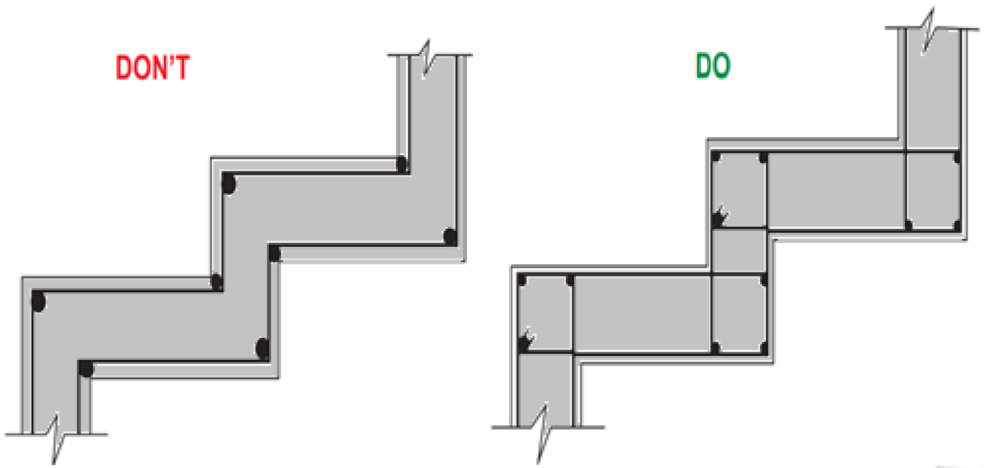
REINFORCEMENT DETAILING IN GABLES



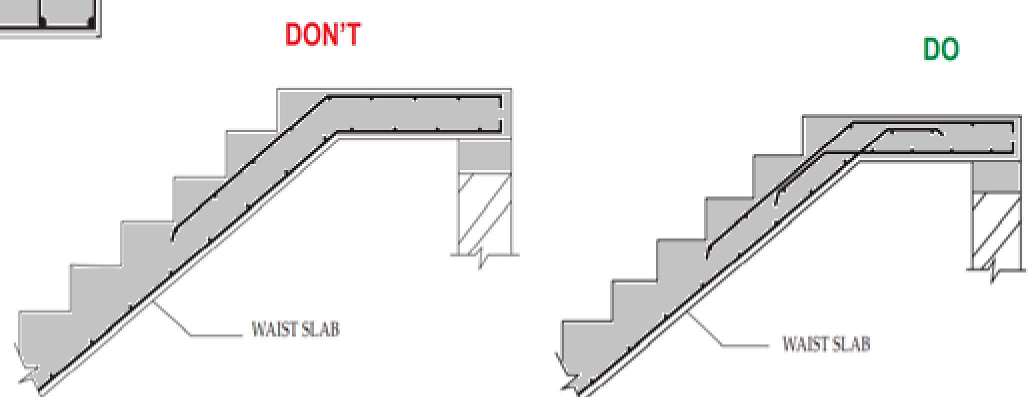
REINFORCEMENT DETAILING IN LARGE DOMES

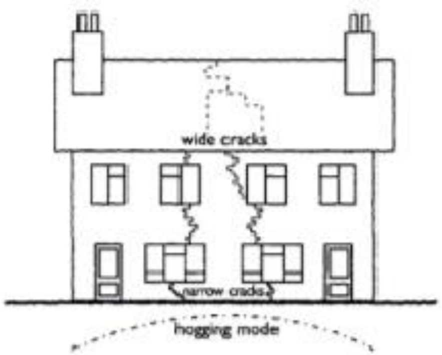


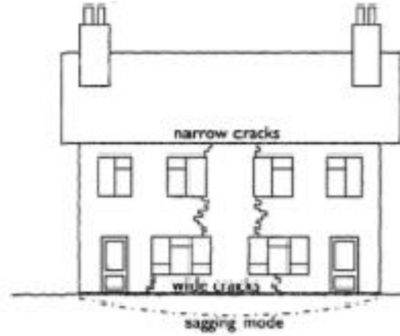
REINFORCEMENT IN FOLDED STAIRCASE

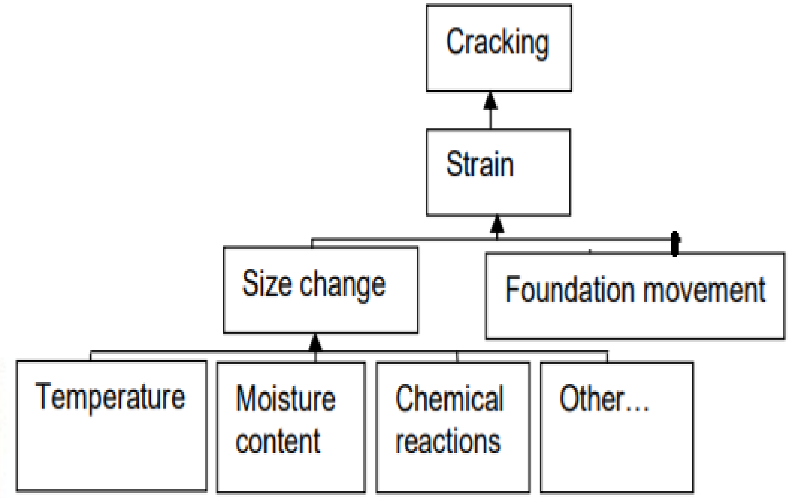


PLACEMENT OF BARS IN WAIST SLAB

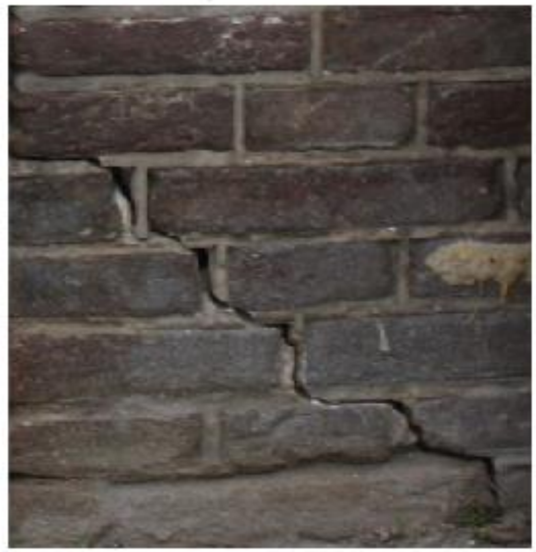






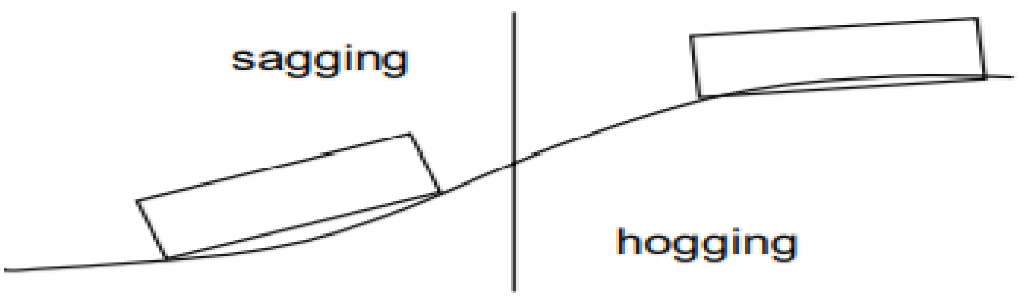


Several causes of cracking

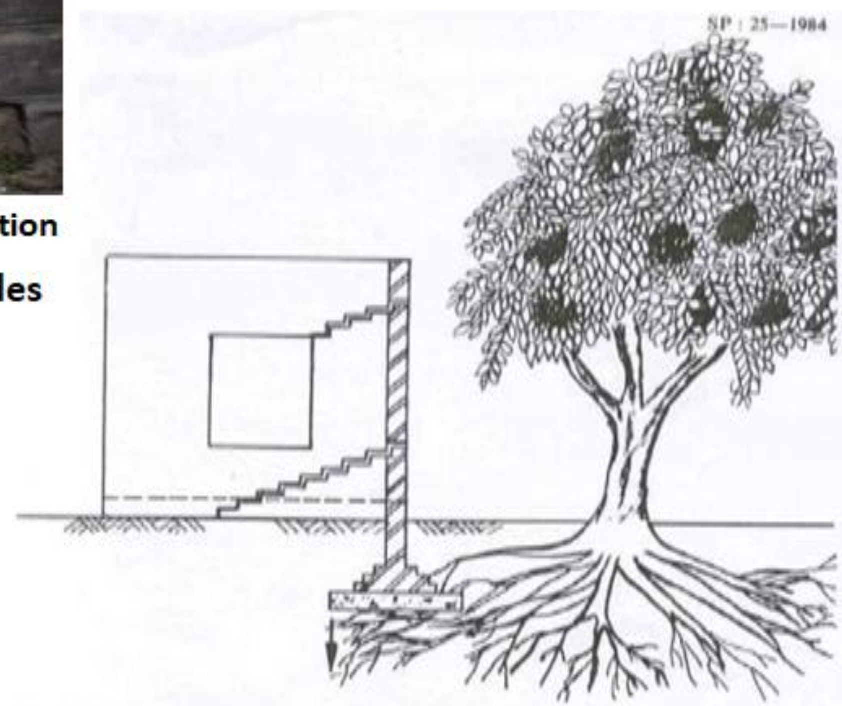


Cracks due to shear deformation

Cracks patterns due to different deformation modes



Sagging and hogging deformation modes

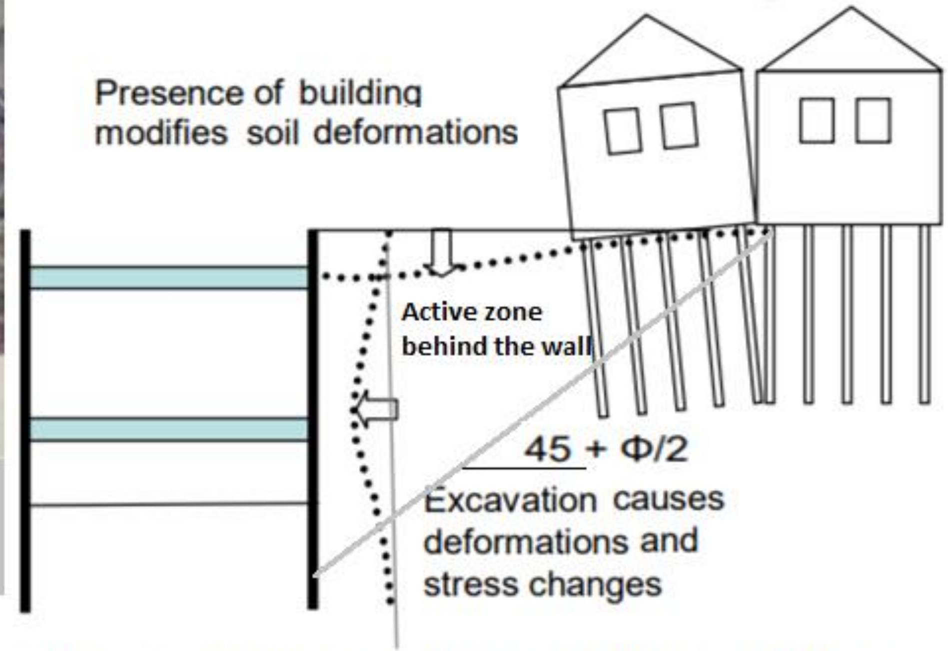


Larger span with no proper load transfer mechanism

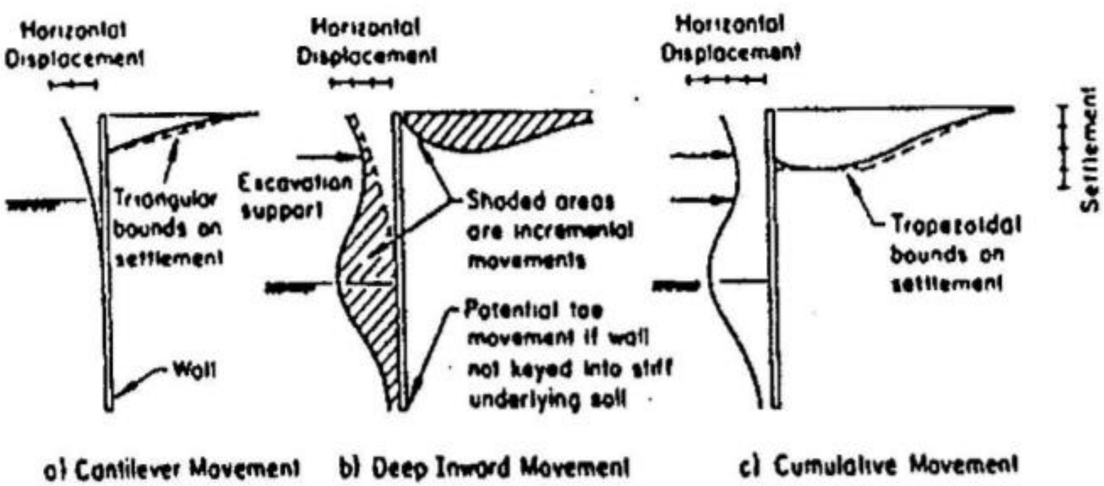
Differential Settlement

Nicoll Highway collapse, Singapore August 2004

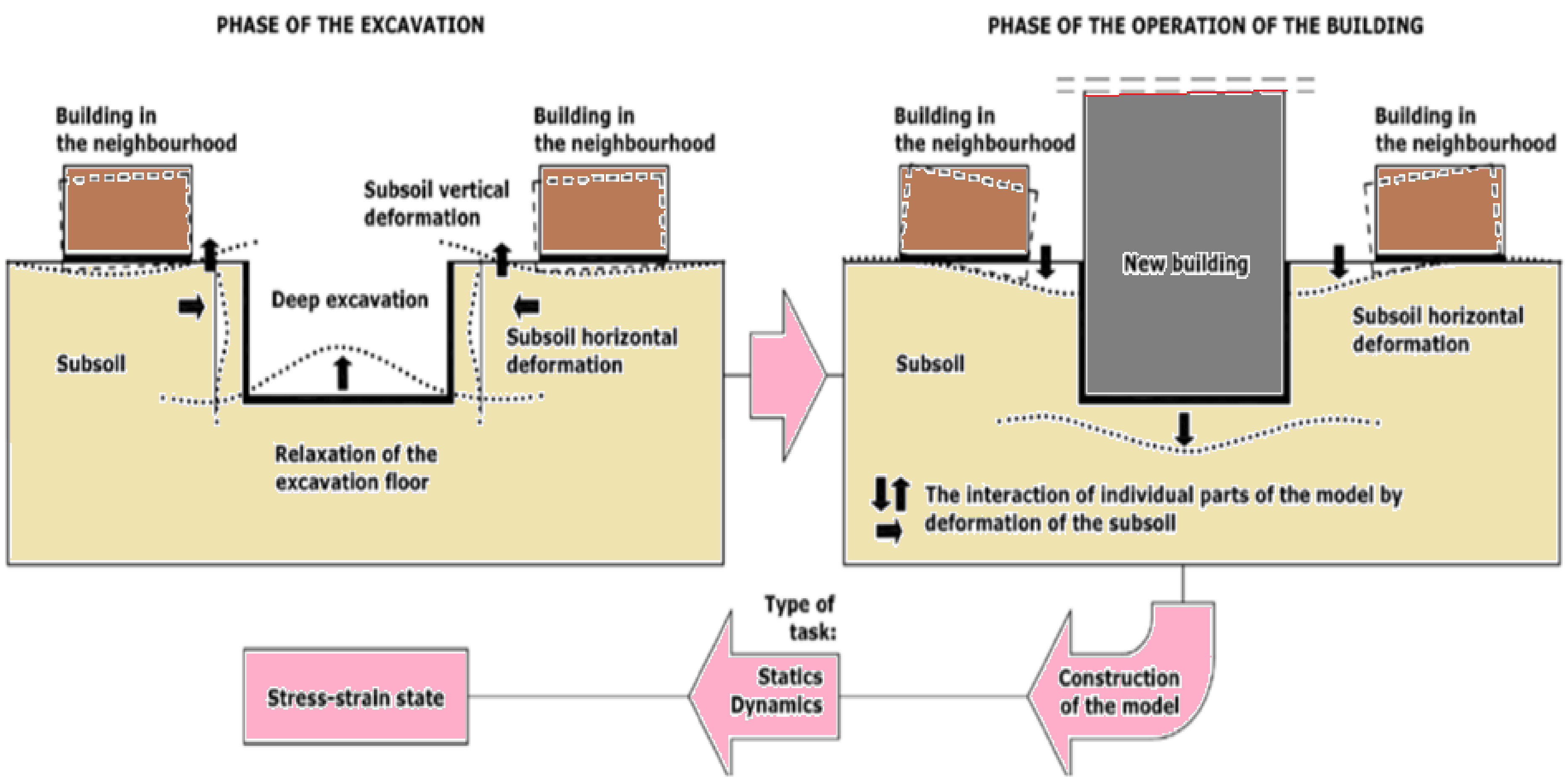
Deep excavation under construction tunnel



Interaction between excavation and adjascent buildings

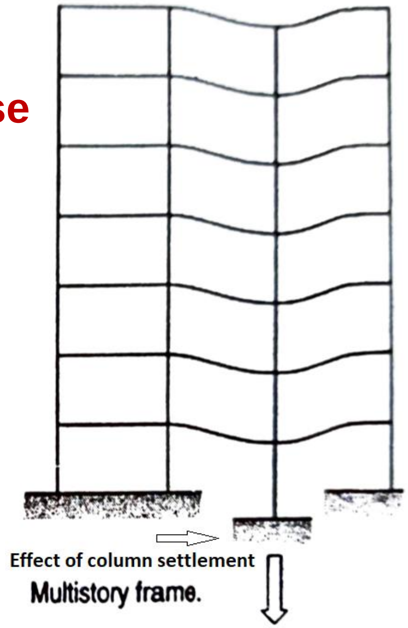


Typical profiles of movement for braced and tied-back walls

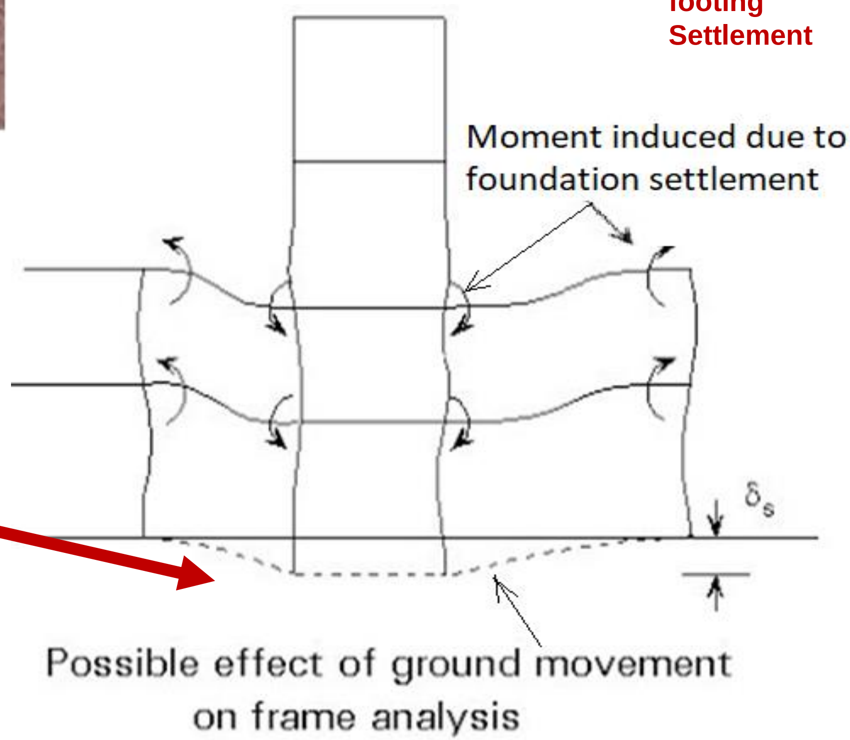


Impact of deep foundation of the building on adjcent buildings

Tall / High Rise building

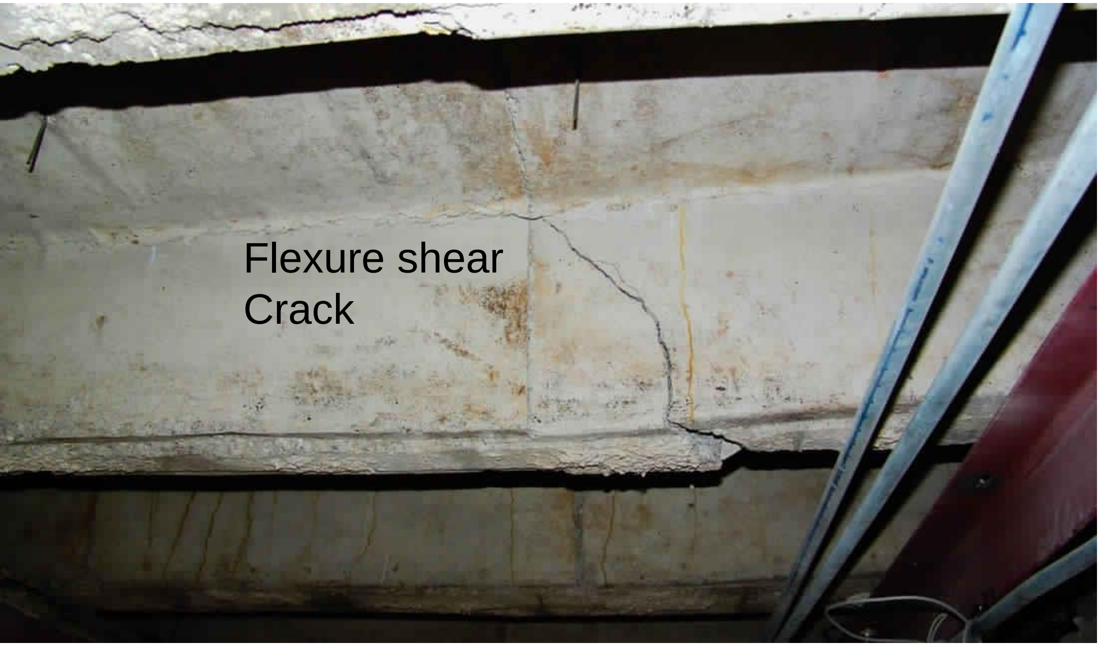


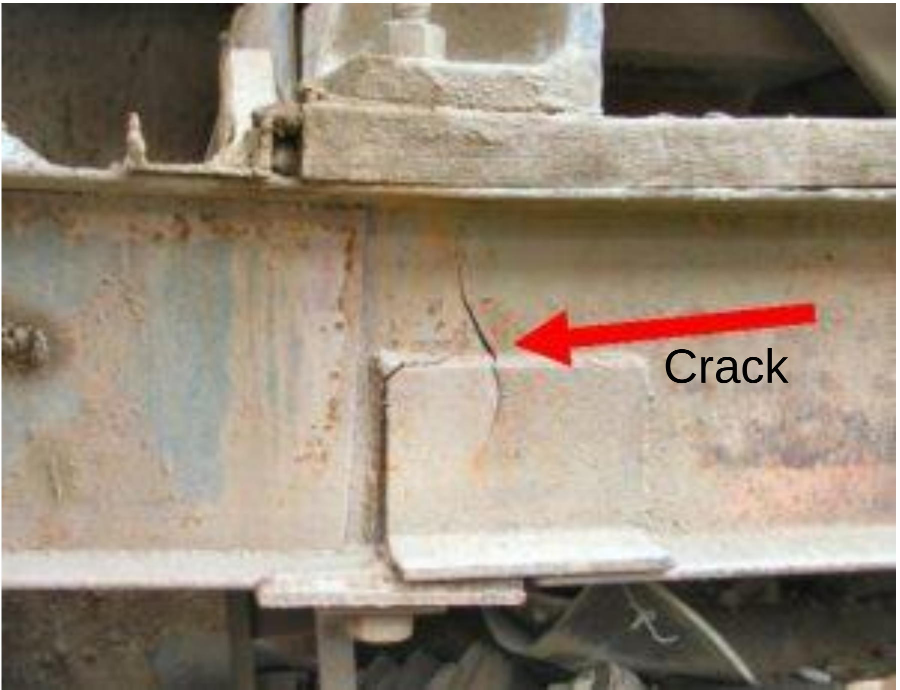
Column footing Settlement



Sudden sinking, Filled up open well / bore hole

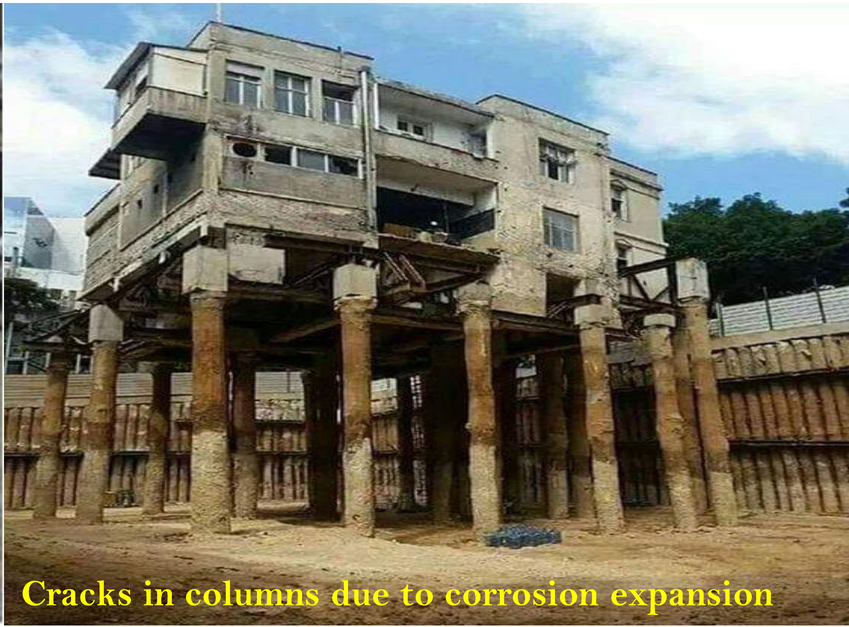
Component failures



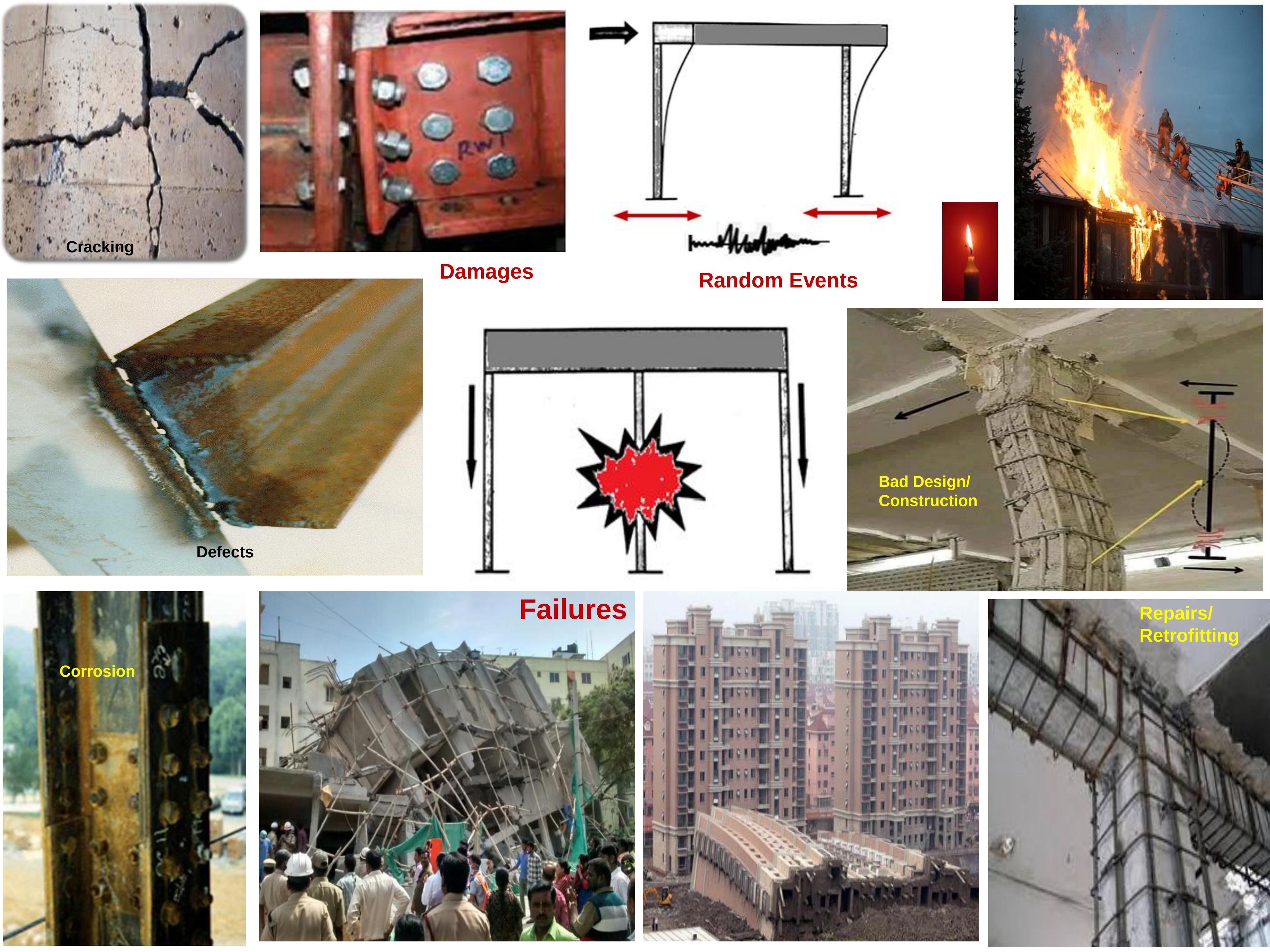


Distress due to degradation Corrosion

Corrosion is a **chronic** degenerative condition/ degradation like cancer.
Its Impact is a **acute** injury.

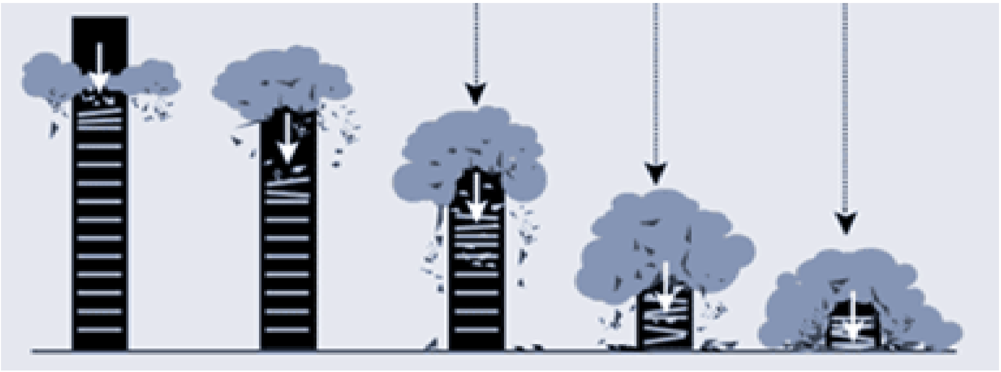


Cracks in columns due to corrosion expansion

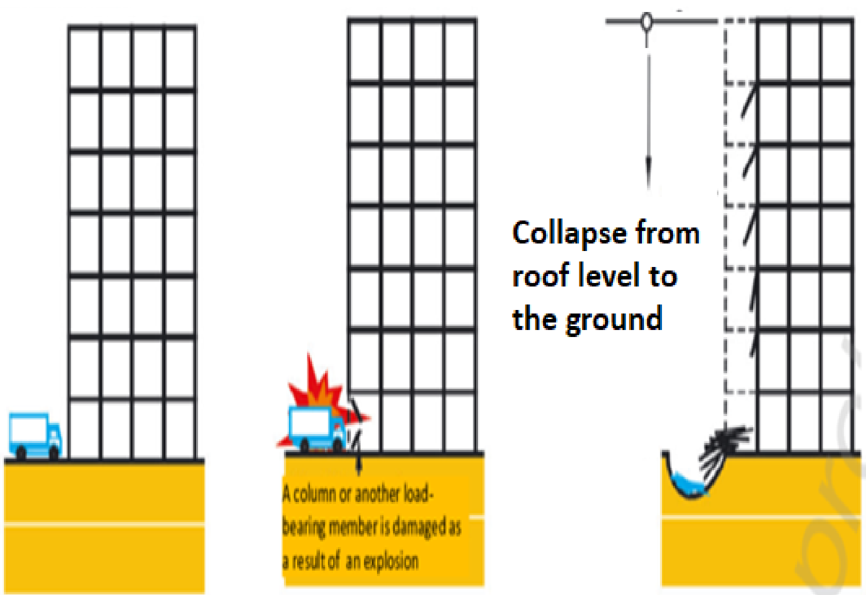

Cracking
Damages
Random Events
Defects
Bad Design/
Construction
Corrosion
Failures
Repairs/
Retrofitting

Damage due to **blast or Impact** or **terrorist attack**

Progressive Collapse

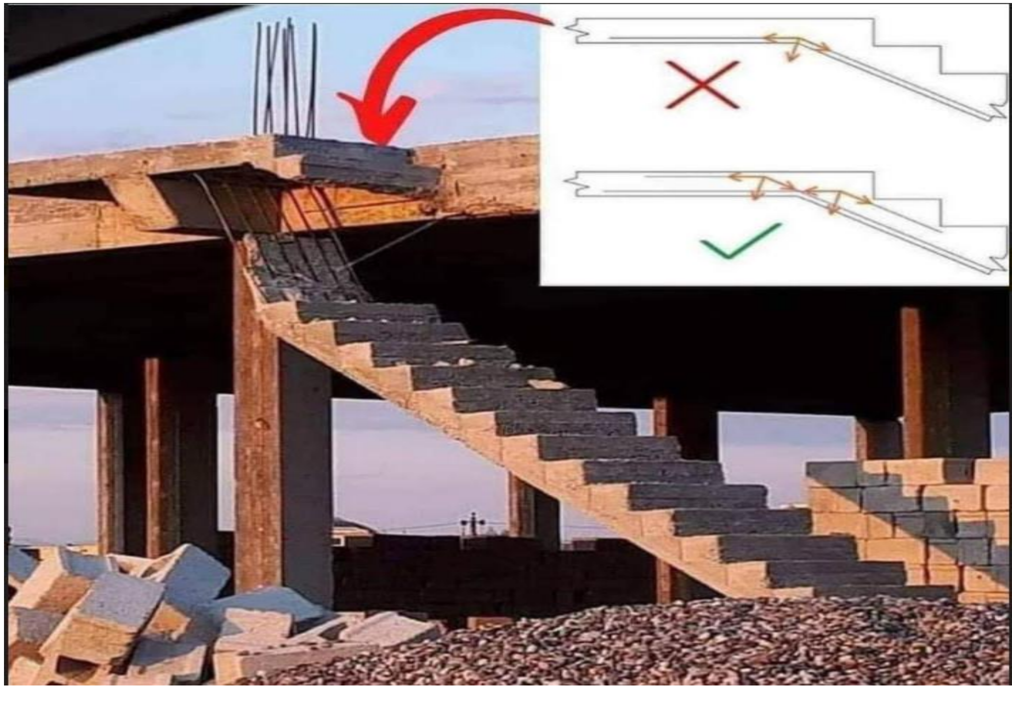


After the failure of column systems, the buildings' floors appeared to fall nearly straight down in a floor-by floor collapse



Damage to primary structural member
-- progressive collapse due to localised damage

Construction mistakes/ Human errors/blunders




HydNewsTezz
Steel bracing

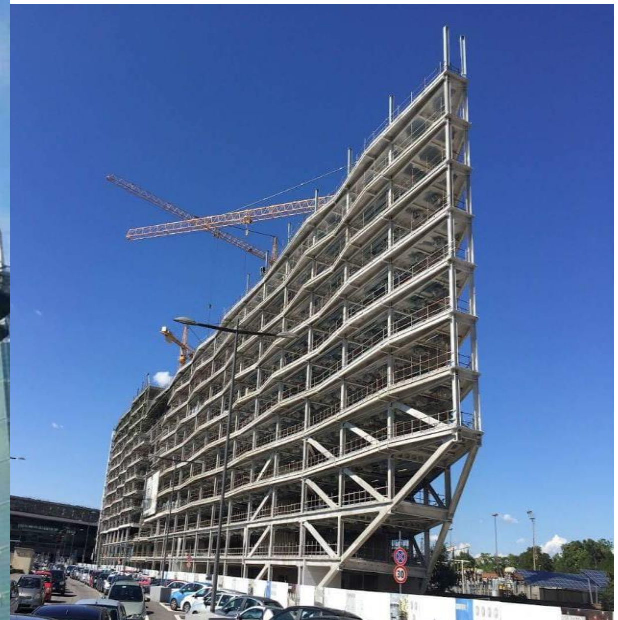

Column alignment...?
Splash
auto wash
Collapse of the Hotel New World, in Singapore in 1986.
Chinese Engineer designed and responsible for it.

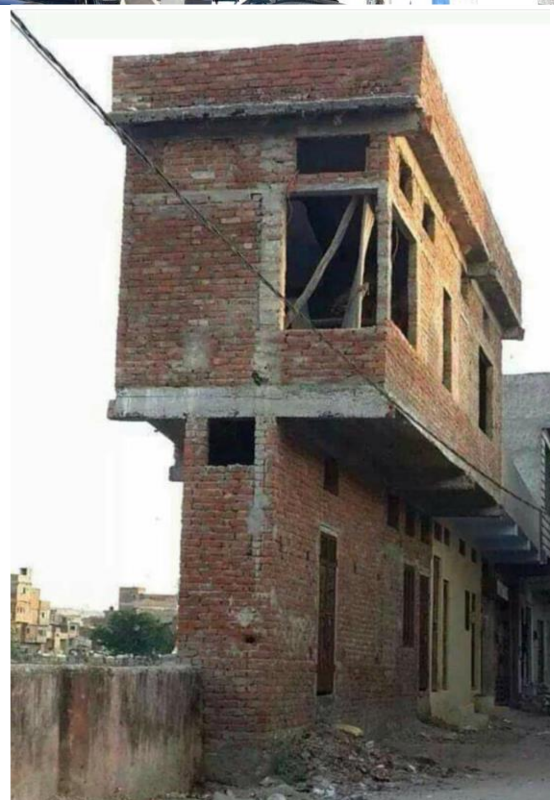
Excavation under the compound wall

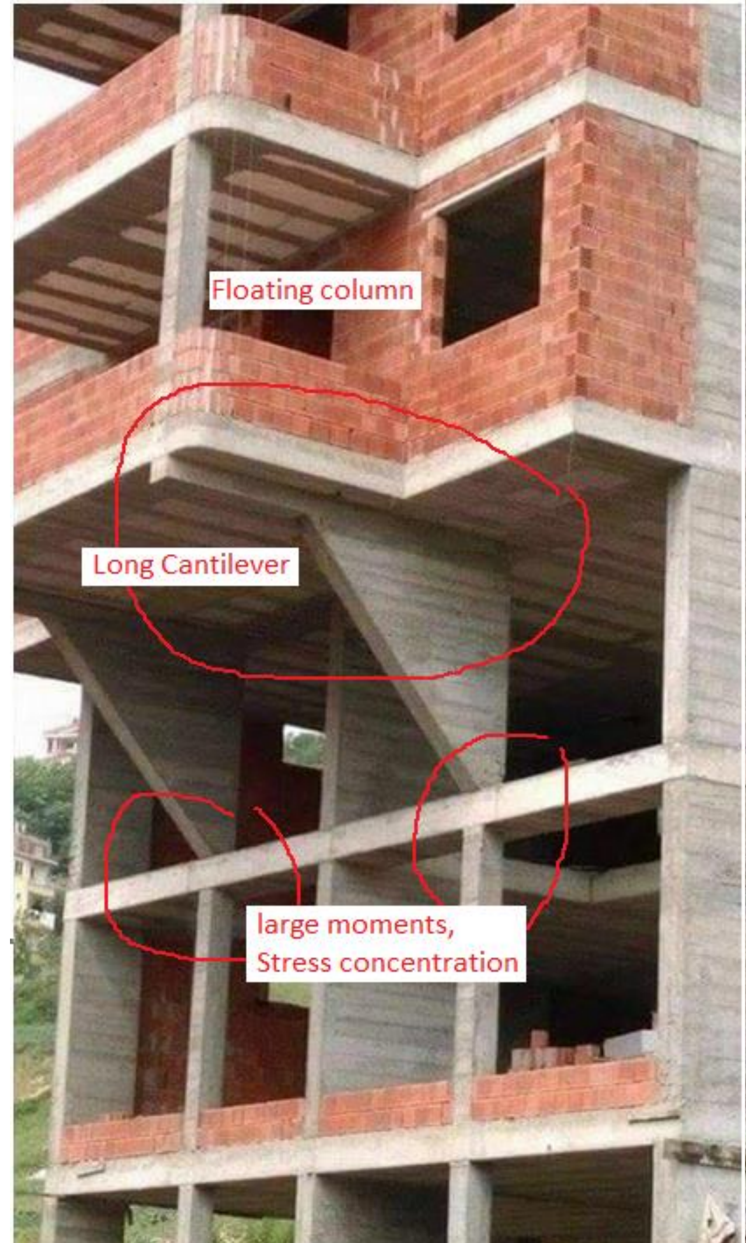
In 2019, Bengaluru **Collapse of sump tank wall**

Plumber's Interventions

Vulnerable Buildings

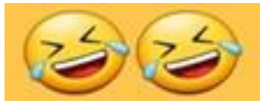




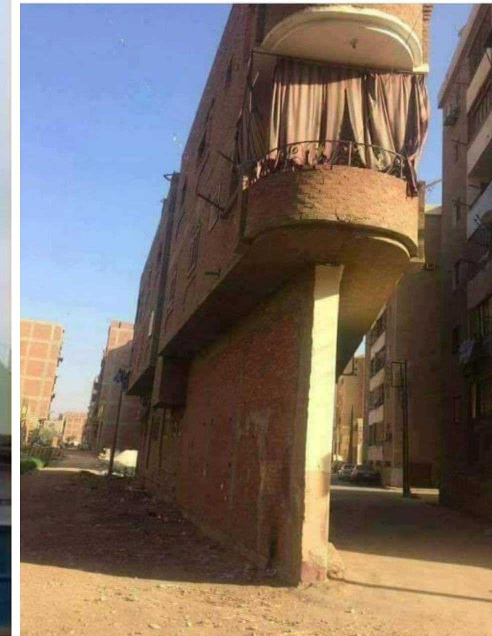


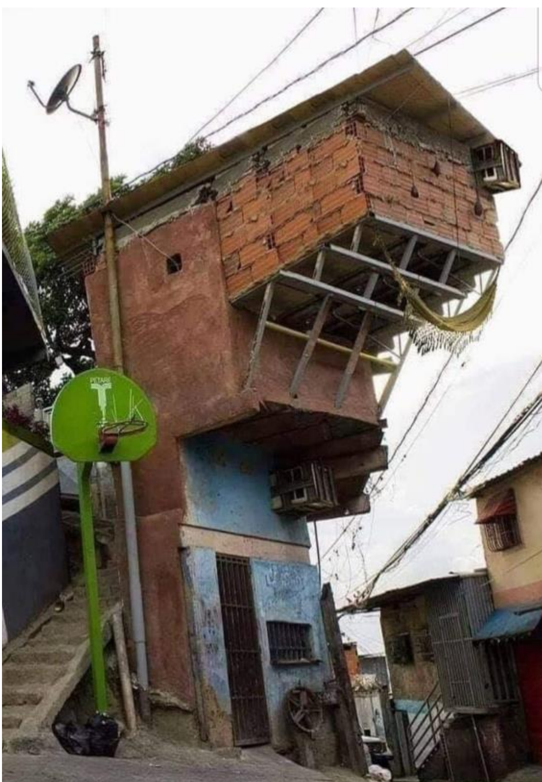
Vulnerable Buildings

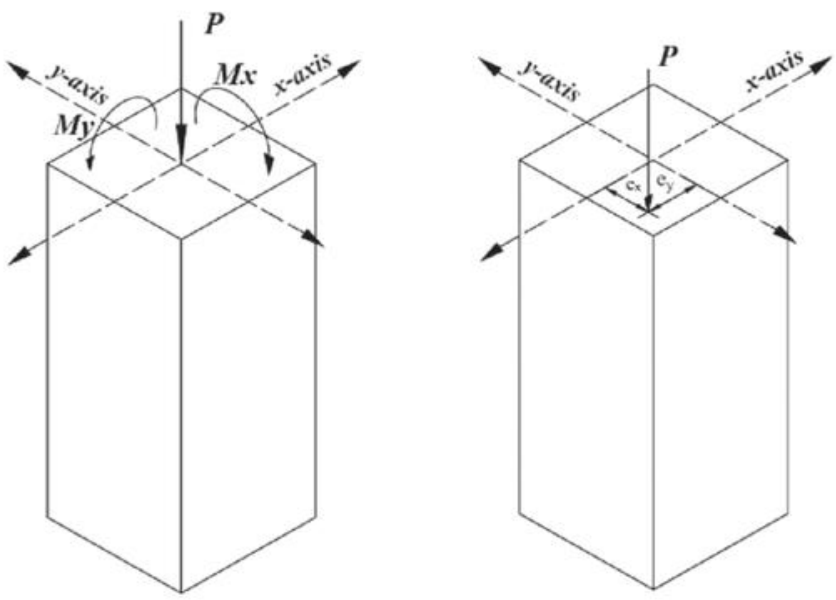
Searching for the Engineers of these buildings…?

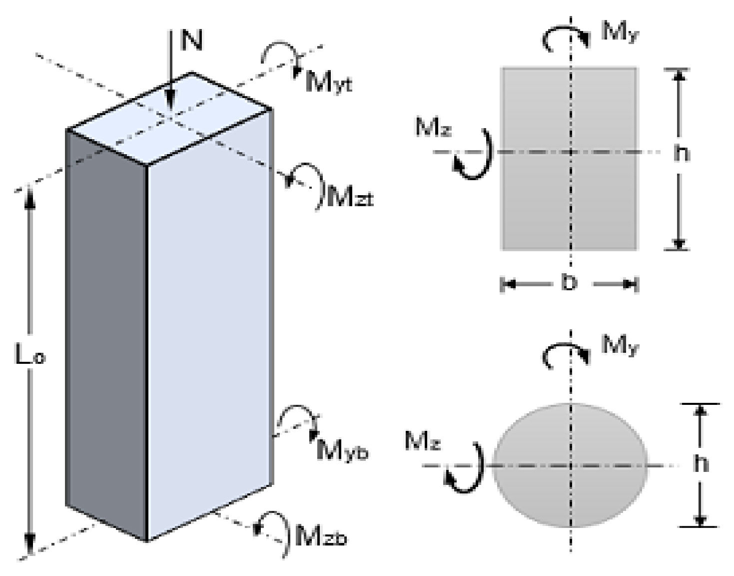


beyond imagination,






P
y-axis
Mx
x-axis
My
P
y-axis
x-axis
e_x
e_y


N
Myt
Mzt
Lo
Myb
Mzb
My
Mz
h
b
My
Mz
h

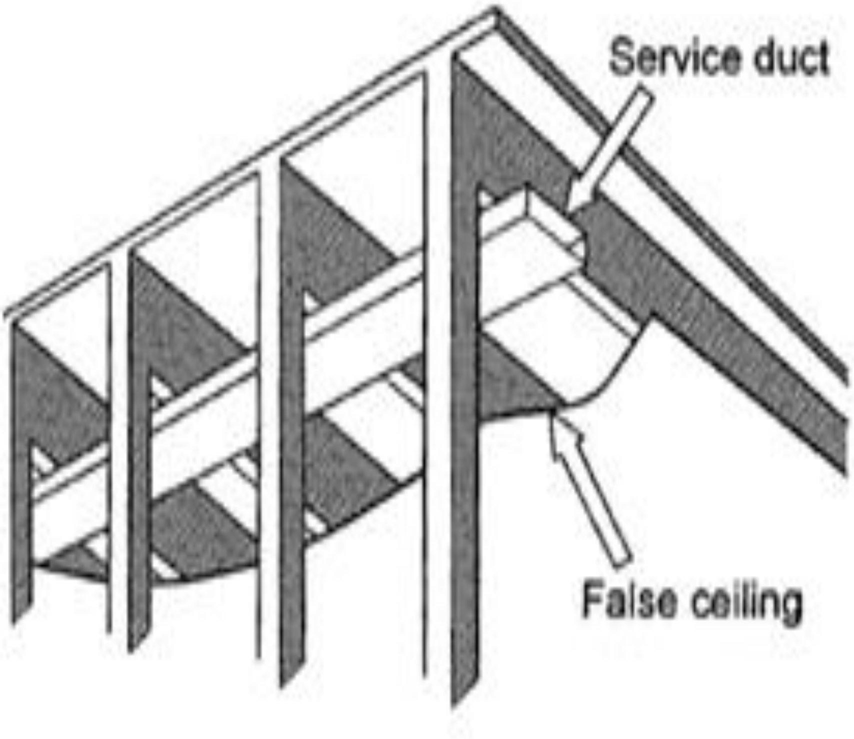
Vulnerable Buildings

Vulnerable Buildings

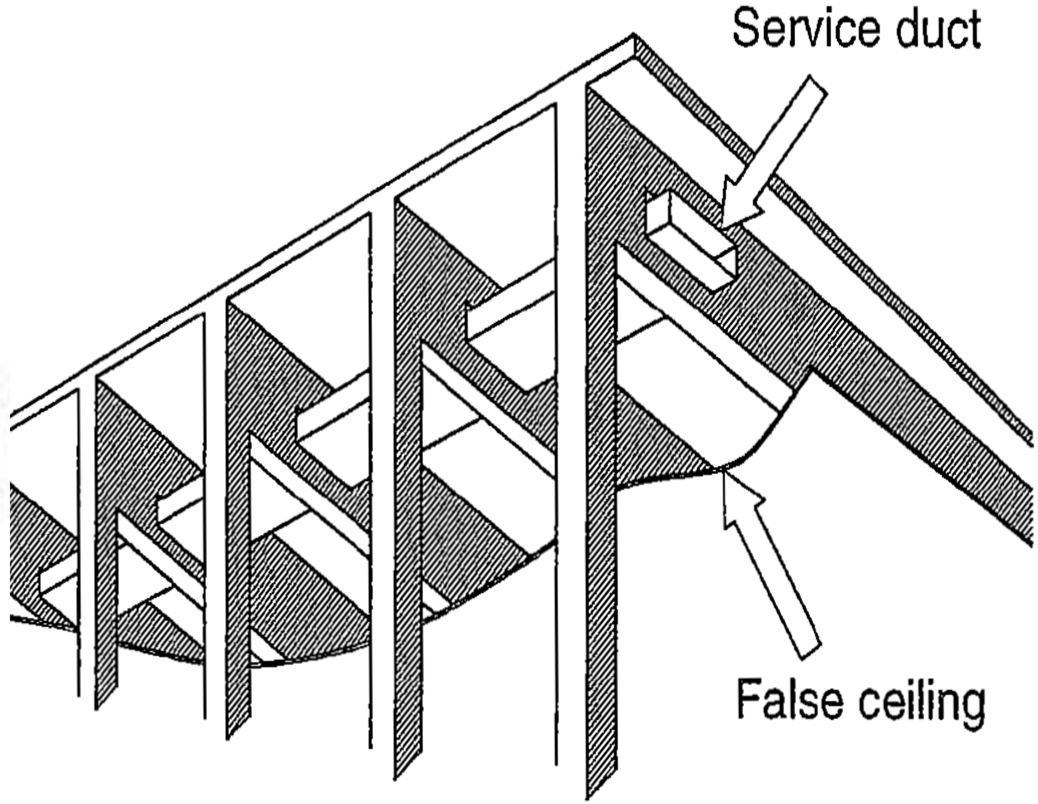
Photoshoping trick?...

When construction goes wrong..!!

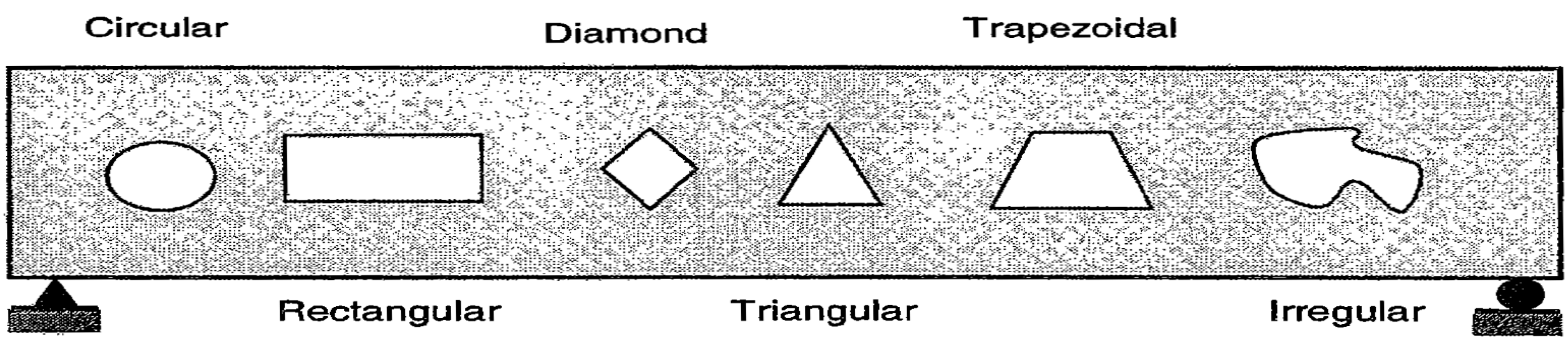
Vulnerable Buildings and Towers



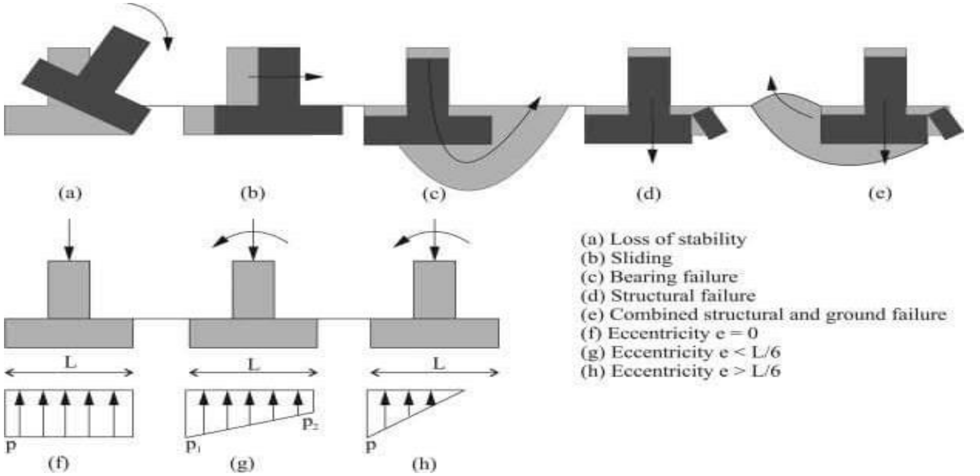
Ducts passing outside the beam



Ducts passing through the beam



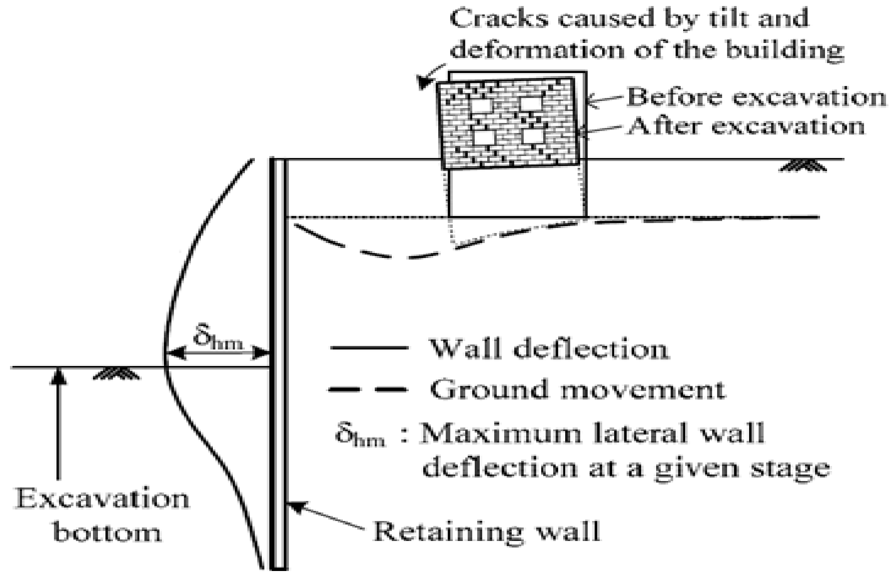
Types of openings in common practical application



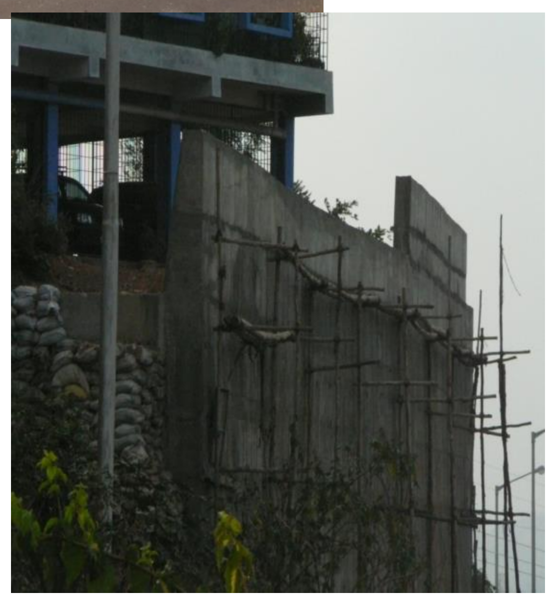
Going deeper for basements, G - -

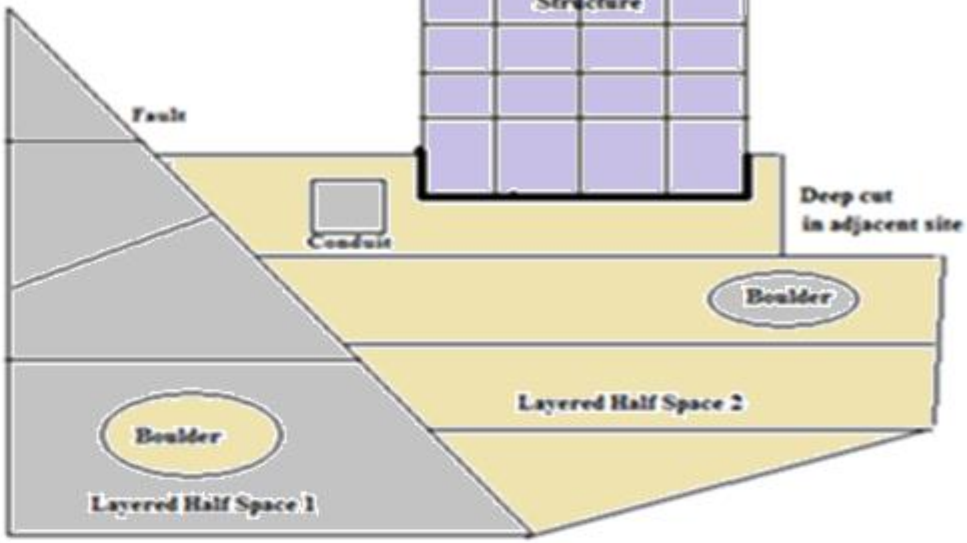
who cares for safety of adjacent buildings..?


Retaining wall with
no base slab
(by BDA on Ring Road)
PLINTH BEAM
COLUMN FOOTING
6m HEIGHT


Cracks caused by tilt and
deformation of the building
Before excavation
After excavation
δ_{hm}
Wall deflection
Ground movement
δ_{hm} : Maximum lateral wall
deflection at a given stage
Excavation
bottom
Retaining wall

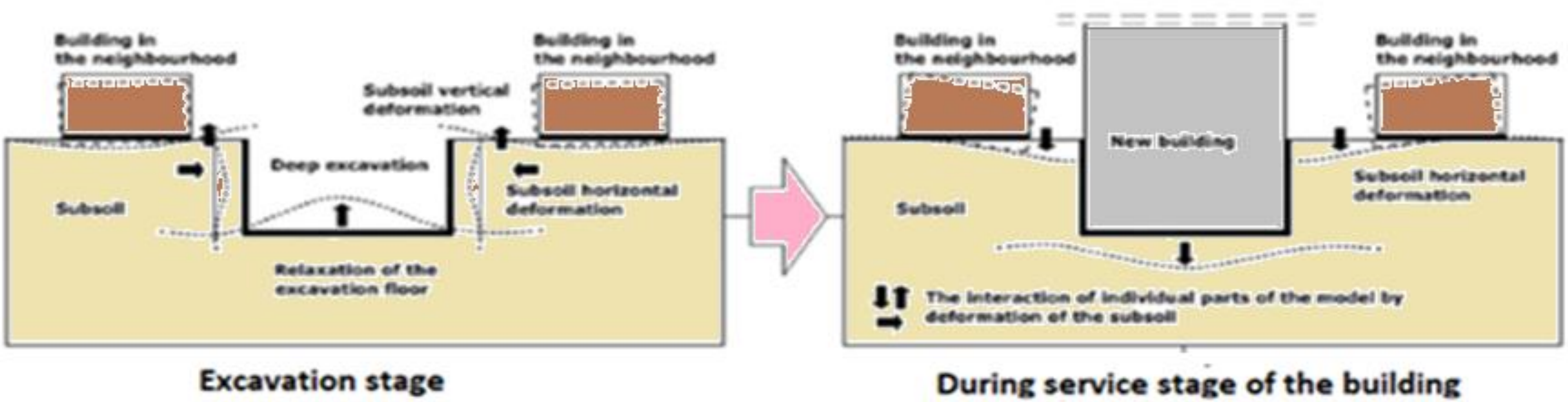

NO BASE SLAB





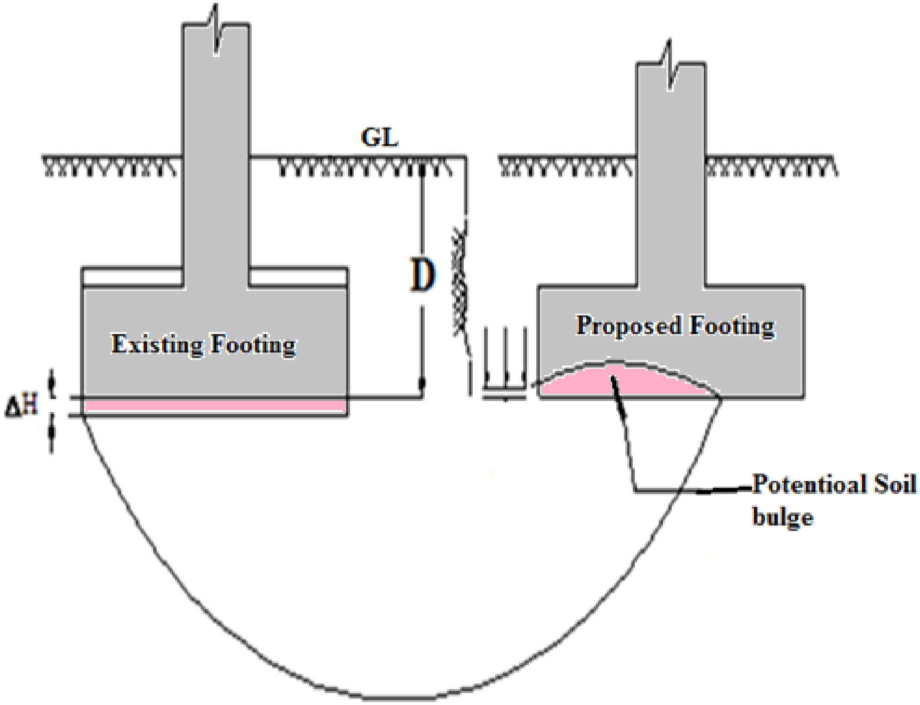
a) Types of problems encompassed

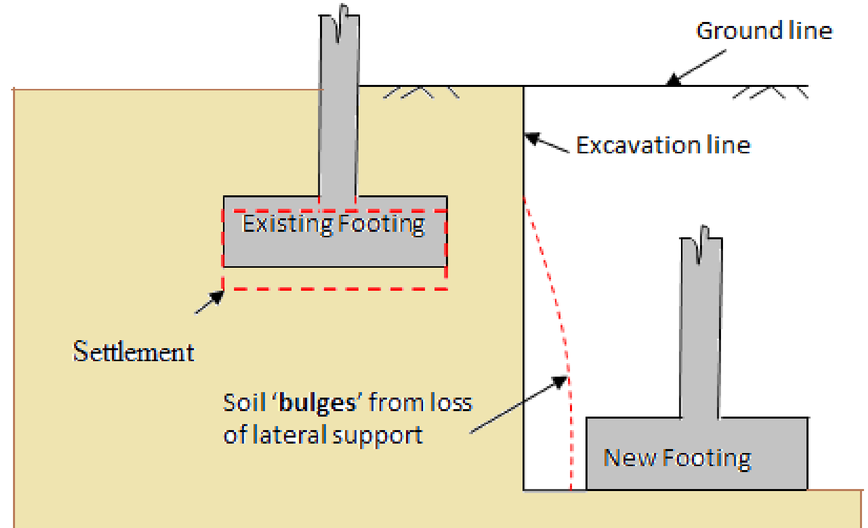
b) View of an existing structure



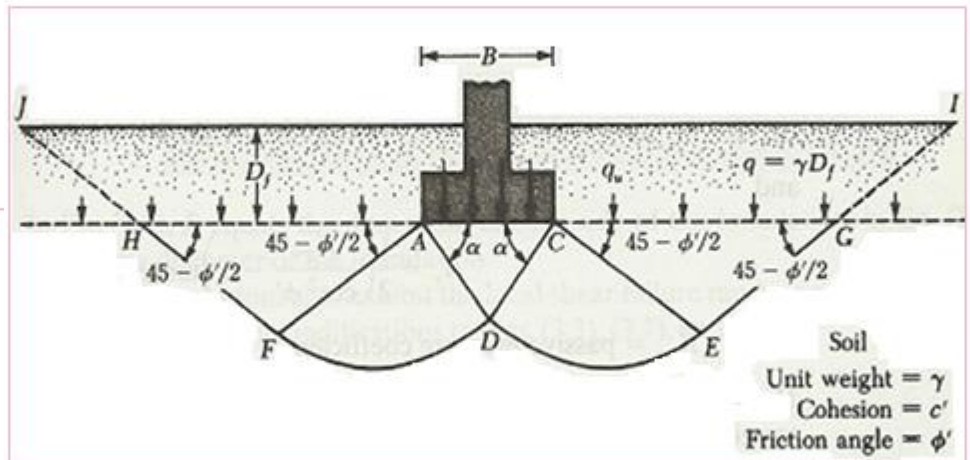
c) Possible settlement of existing footing because of loss of lateral support of soil wedge beneath existing footing

(Source: Bowles, 1997)





Possible settlement of existing footing because of loss of lateral support of soil wedge beneath existing footing (Source: **Bowles 1997**)



Case 1: Structure without any adjacent excavation

Terzaghi's bearing capacity equation,

$$q_{ult} = cN_c s_c + \bar{q}\, N_q + 0.5\gamma N_\gamma s_\gamma$$

Case 2: If the excavation for the foundation of the new structure is too close to existing building.

Lost

$$q_{ult} = cN_c s_c + \bar{q}\, N_q + 0.5\gamma N_\gamma s_\gamma$$

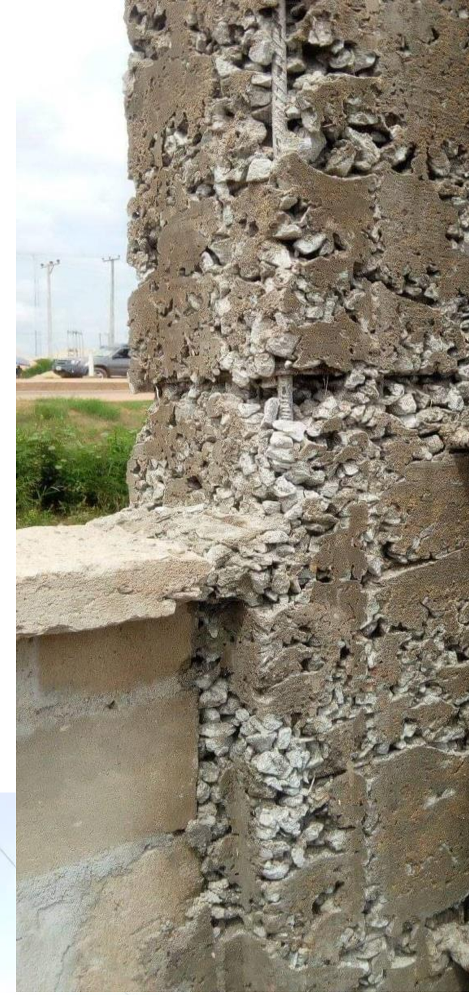
$$q_{ult} = cN_c s_c + 0.5\gamma N_\gamma s_\gamma$$


Erosion/ Flow of sub soil


Foto: James Ramirez Gtz

Design mistakes

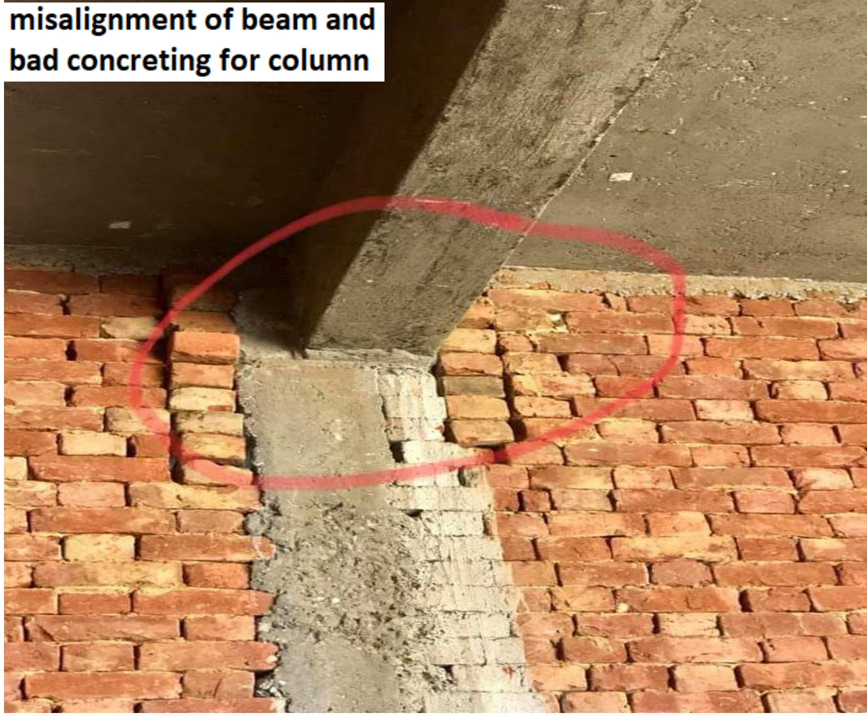
Bad concreting, no proper Cover to column reinforcement..?



Honeycombing…?

Bad concreting at critical zones
- Shear zone, compression zone


Column misaligned...
poor substitute

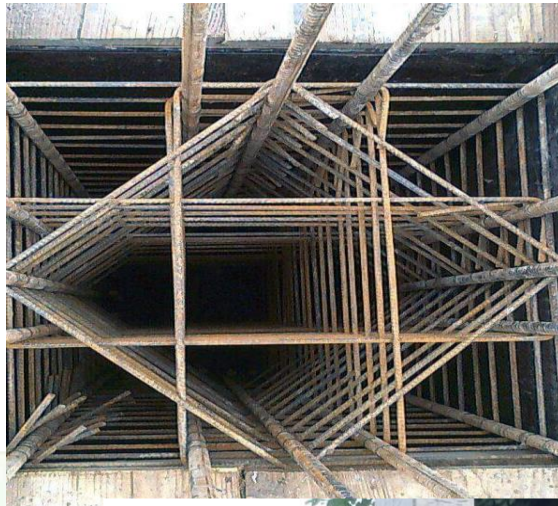

misalignment of beam and
bad concreting for column


What
is
the
Mistake
here?


Concrete cracking &
mialignment
of upper flight
26 17:27

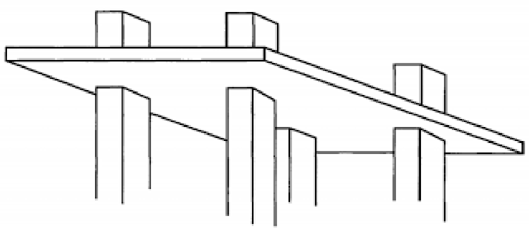

Long cantilever..
liable for over crowding

No proper cover to reinforcement



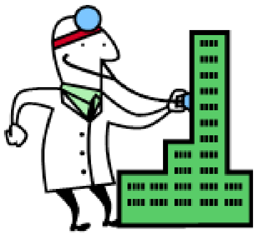
Misaligned columns unexpected eccentric load on lower column

Flat Slab Vs Flat plate Slab

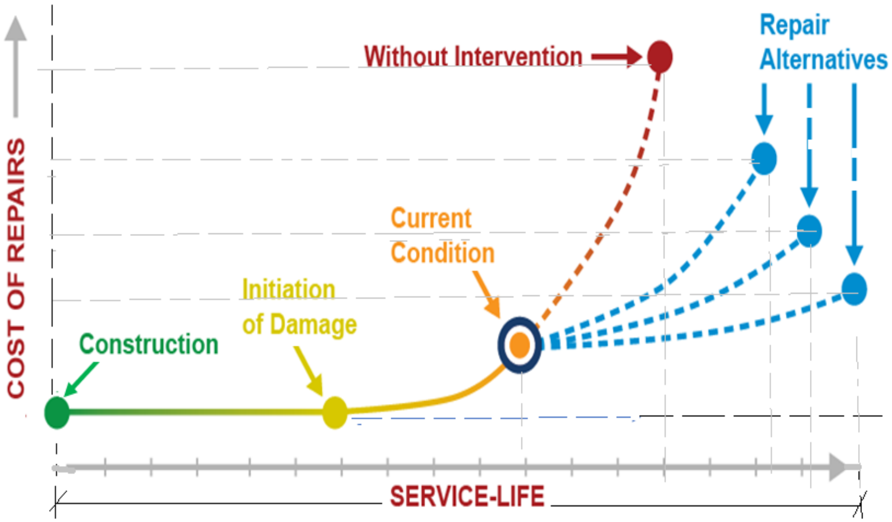


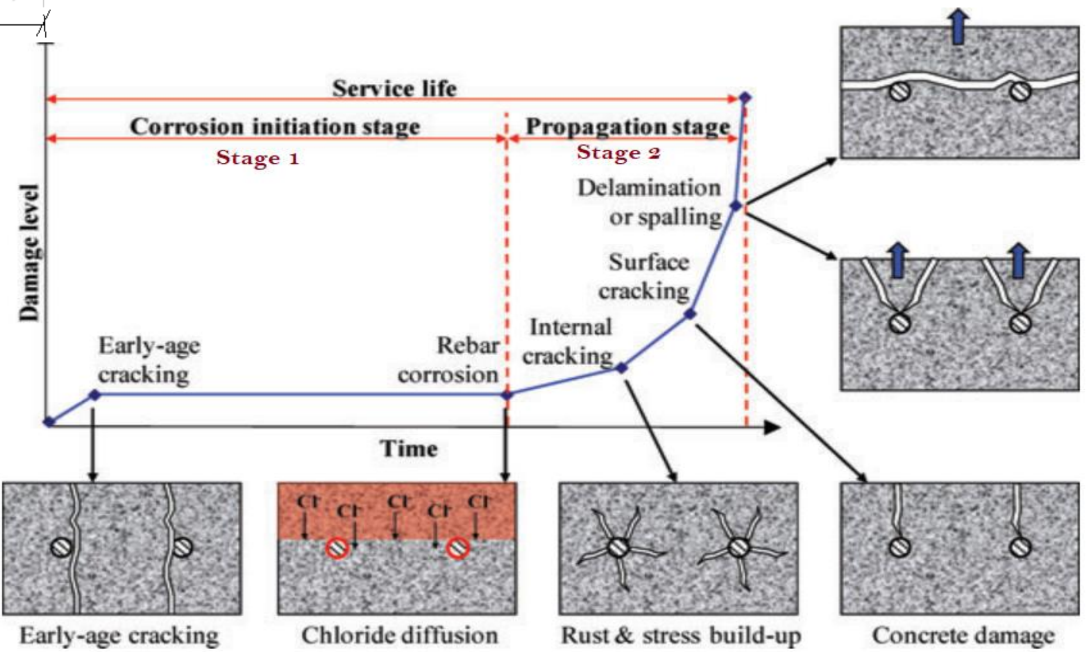
Flat slab or plate slab/beamless slab – **punching shear mitigation**..?

Service life/ Residual Life/Remaining life of Structures

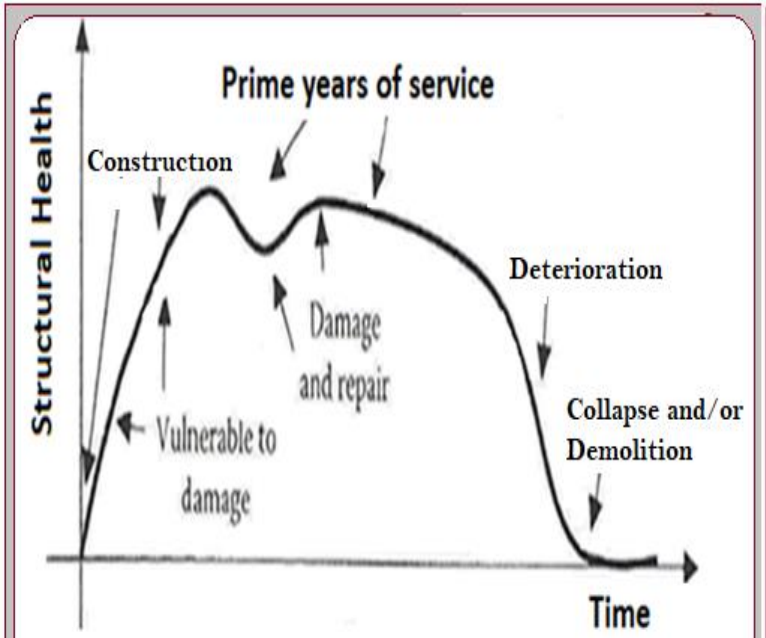


The **service life** is defined as the time from inception to the time of appearance of first visible crack.

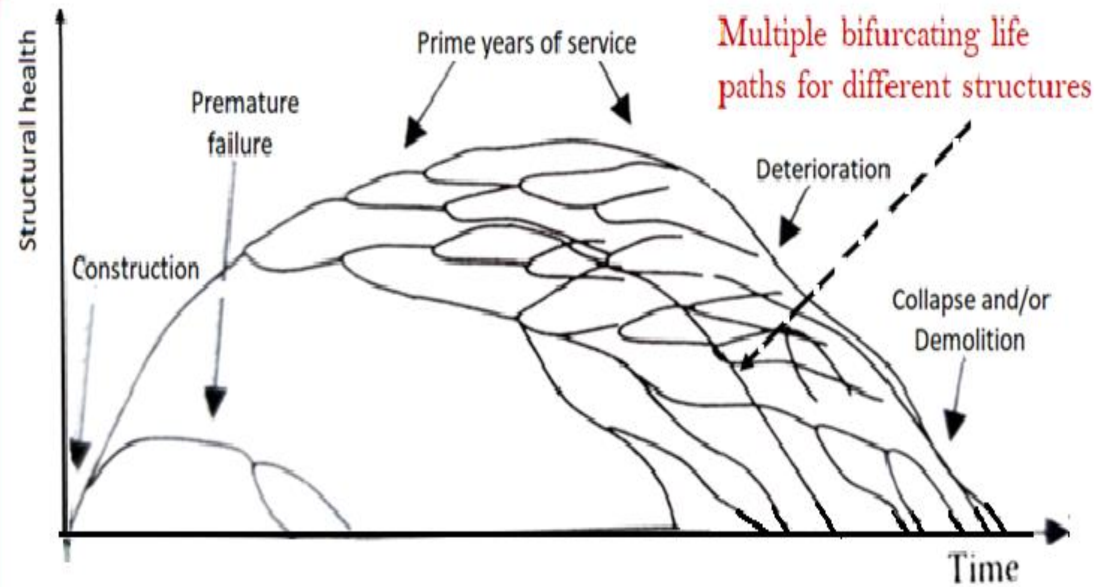




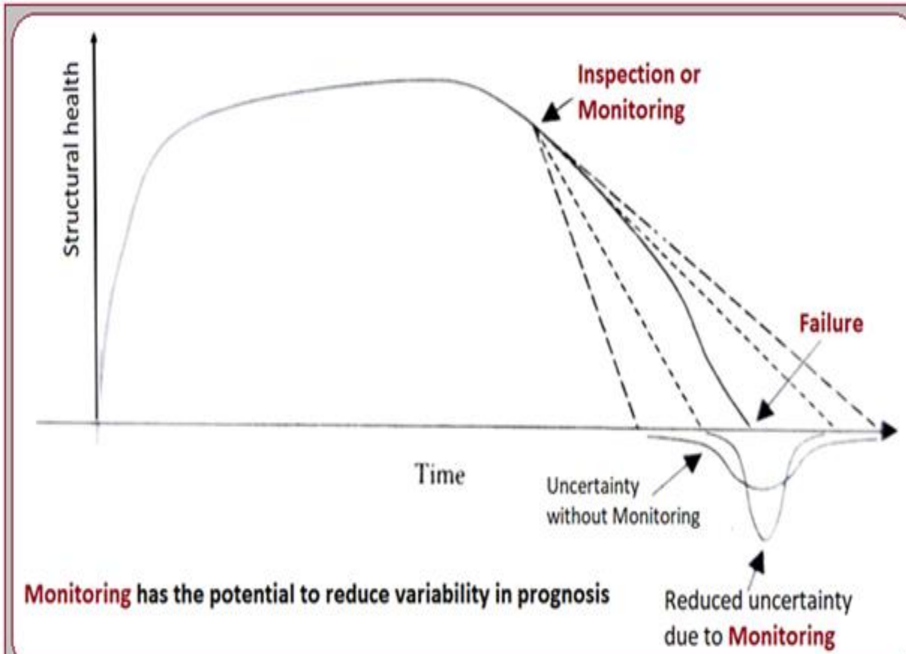
Schematic description of the service life model.



Possible Structural health life cycle



Tree of possible life paths and health functions for the structure



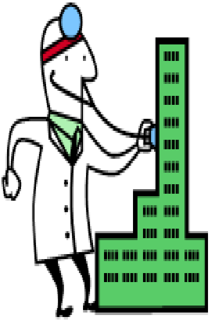
Monitoring has the potential to reduce variability in prognosis

Monitoring-
Reduces the variability of structural prognosis

All infrastructures are **ageing**, need

- **monitoring**
- **assessment**
- **maintenance**
- **periodic repair**

Under construction building collapses



Damage Diagnosis Vs Prognosis

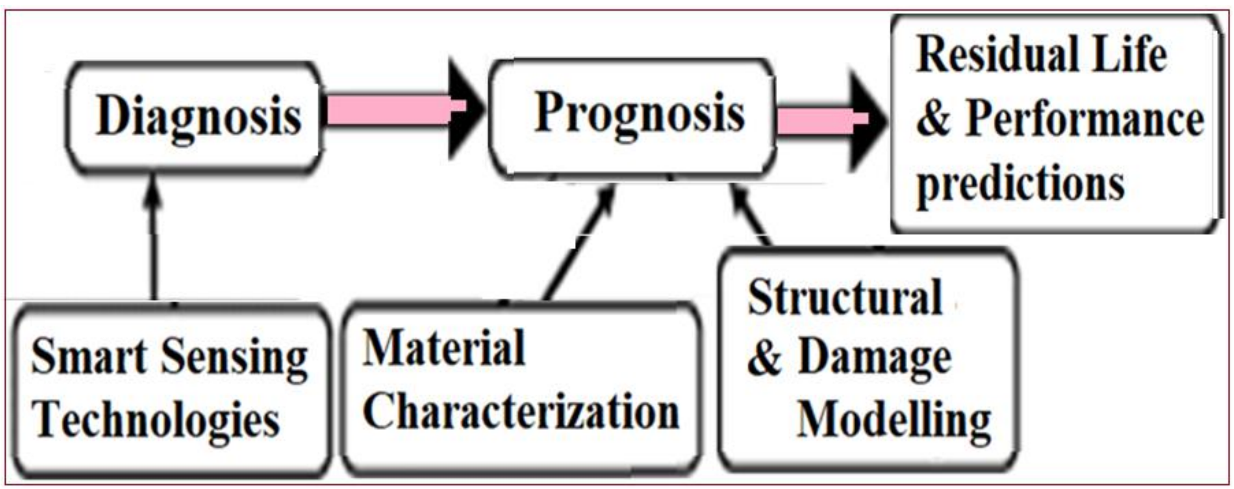
Prognosis *means* - **a judgement that a doctor makes about an ill person's chance of becoming healthy after diagnosis**

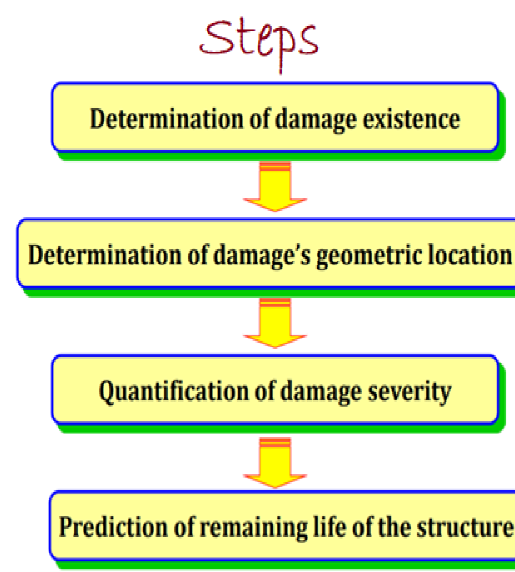
– *an opinion about the future of someone or something.*

People sometimes confuse *diagnosis* and *prognosis.*

- ***diagnosis*** is used to **identify a present disease, illness, problem**, etc., by examination and observation (of signs and symptoms);
- ***prognosis*** refers to **predicting the course** of the diagnosed disease, illness, problem, etc., and determining treatment and outcome/result.

Damage prognosis- To estimate a system's remaining useful life



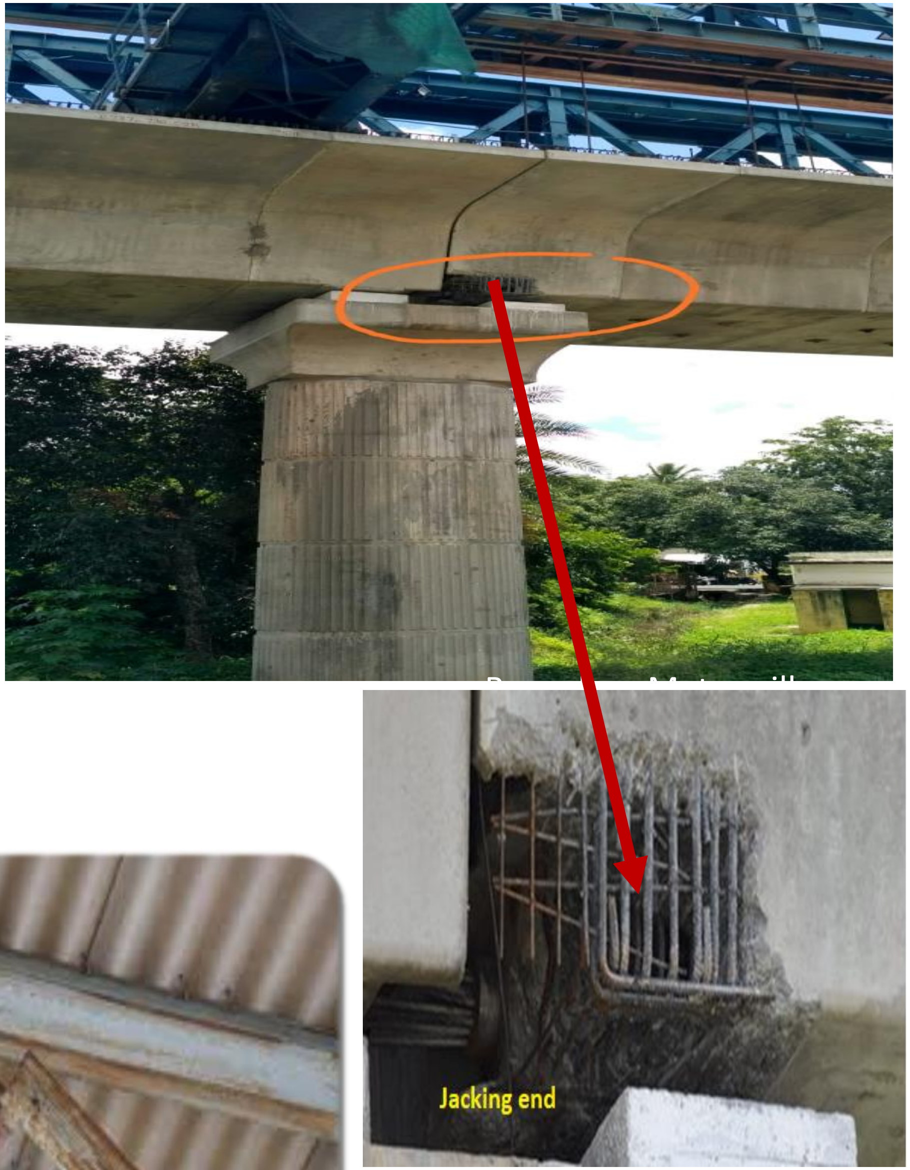


Key element in damage prognosis is **Structural Health Monitoring**

Monitoring- Reduces the variability of structural prognosis

Damage: -- surface level or internal

- **Damage** can be defined as changes introduced into a system that adversely affects its current or future performance.
- **Damage** can accumulate **incrementally over long periods of time** that associated with fatigue or corrosion damage accumulation.



Damage is commonly encountered in civil infrastructure due to creep, corrosion, shrinkage, fatigue and scour.

Structural Condition Assessments

Damage assessment techniques

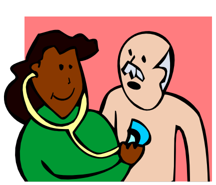
- Signal based
- Model based

Methods of diagnosing buildings and building materials

- **Destructive Methods**
  - Methods of assessing strength and its changes over time
  - Load tests
- **Semidestructive Methods**
  - Methods of assessing strength and its changes over time
  - Methods of assessing properties other than strength
- **Non-destructive Methods**
  - Methods of assessing strength and its changes over time
  - Methods of assessing properties other than strength

Non-Destructive Testing (NDT)

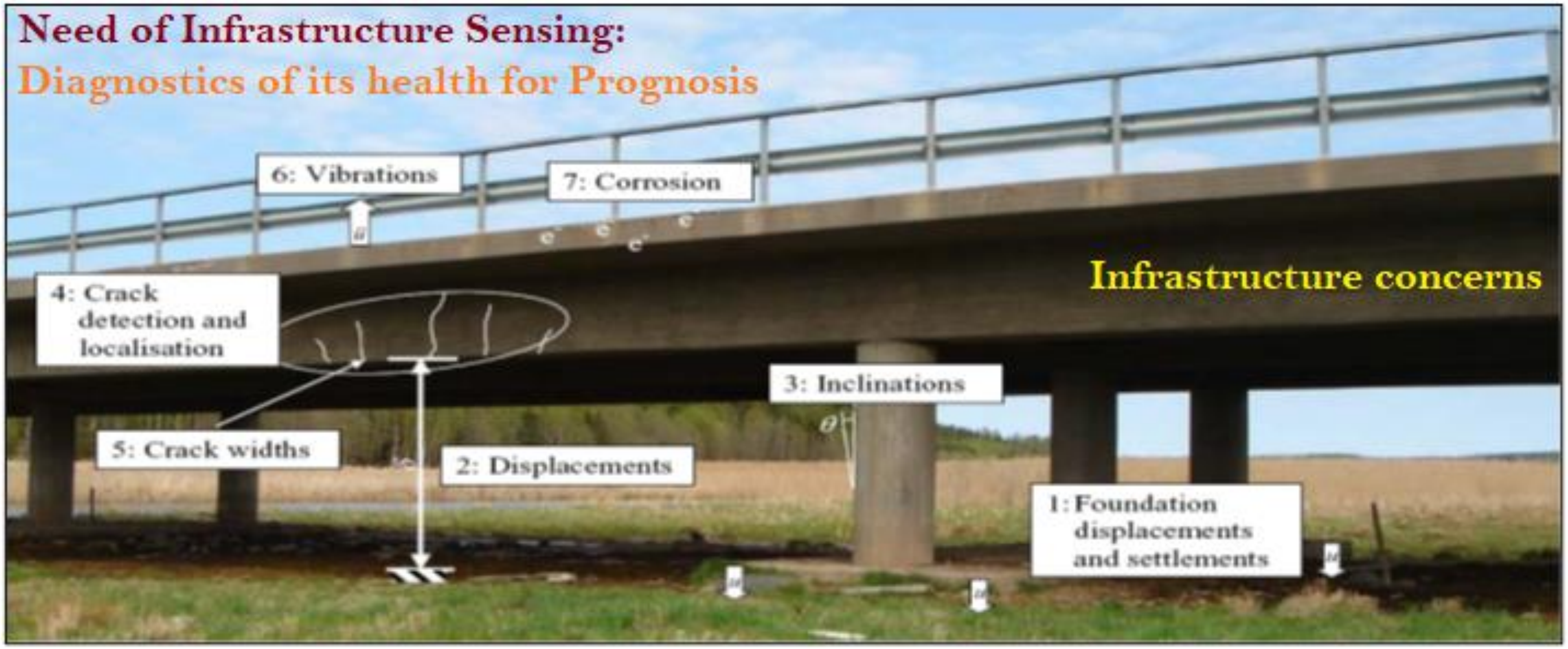
- Visual inspection
- Rebound hammer
- Ultrasonic Pulse Velocity meter
- Penetration resistance
- Pull out strength
- Cover meter
- Carbonation depth
- Corrosion mapping
- Maturity meter
- Permeability Test
- Radiography



- **Non-Destructive Testing**: (NDT)
- **Non Destructive Evaluation using Sensors**: (NDE)
- **Vibration Based Techniques**:
  - (Experimental/Analytical –FEM based- Sensitivity analysis)
    - **Modal Analysis**: **Sensitivity** of Eigen values and Eigenvectors- - Changes in frequencies and mode shapes
    - **Modal Assurance Criteria** (MAC)
    - **Frequency Response Sensitivity** (FRF Sensitivity)
- **Probabilistic Approach / Uncertainty Quantification** - Stochastic Finite Element Method (SFEM)
- **Other analytical methods**

Crack detection using Soft computing Techniques

- Wavelet Analysis /Signal Processing
- System Identification using Internet of Things
- Artificial Neural Networks - Pattern Recognition
- Fuzzy Inference method
- Big Data Analytics
- Machine Learning and Deep Learning
- Genetic Algorithm
- MANFIS (Multiple Adaptive Neuro Fuzzy Inference System) method
- Hybrid methods:
  - i. Neuro-Fuzzy Technique
  - ii. Genetic-Fuzzy Technique
  - iii. Genetic-Neural Technique
  - iv. Genetic-Neural-Fuzzy Technique



Sensing technologies for Infrastructure Sensing

Types of Sensors used

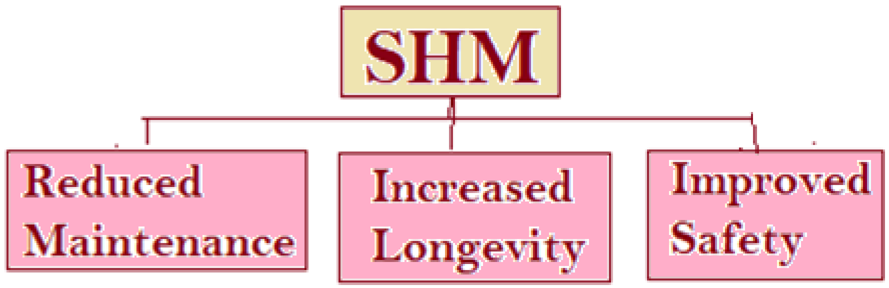
- Fiber Optic sensors (FOS)
- Optical Fiber Bragg Grating sensors (FBGS)
- Linear Variable Differential Transformer (LVDT)
- Piezoelectric Sensors
- Magnetostrictive sensors
- Self-diagnosing fibre reinforced **structural** composites
- Accelerometers, Load Cells and Strain Gauges
- Humidity Sensors

Structural Health Monitoring (SHM) & Technologies

Civil infrastructure is a valuable asset, which keeps the economy and people's life running.

SHM – is **to detect and diagnose damage in the structure, to analyse future risk**.

Structural Health is a prediction of the ability of a structure **to survive** or **meet performance requirements** in the future and to guide maintenance/repair actions.



SHM is expected to provide an efficient and effective tool for management of infrastructure.

Data Acquisition

- number of sensors.
- types of sensors
- selecting their excitation methods
- data storage techniques

COMPONENTS:

- Structure
- Sensors
- Data acquisition systems
- Data management
- Data transfer
- Data interpretation and diagnosis

Parameters to be monitored

- ✓ Deflection
- ✓ strain
- ✓ rotation
- ✓ temperature
- ✓ acceleration
- ✓ corrosion
- ✓ pre stressing force, etc

IoT system is used for **checking** and **controlling** operations of Urban and Rural infrastructure, Tall buildings, Railway tracks, Bridges, Flyovers, Towers, on-and offshore platforms, wind farms, Dams. – to assess changes in basic conditions and safety.

Monitoring Metrics

Measure:

- **Acceleration**
- **Strain**
- **Climatic Conditions**
- **Curvature**
- **Displacements**
- **Load**
- **Tilt/Slope**
- **Scour**

Identify

- **Corrosion**
- **Cracking**
- **Strength**
- **Tension**
- **Location of rebar/delaminations**

Testing categories of SHM

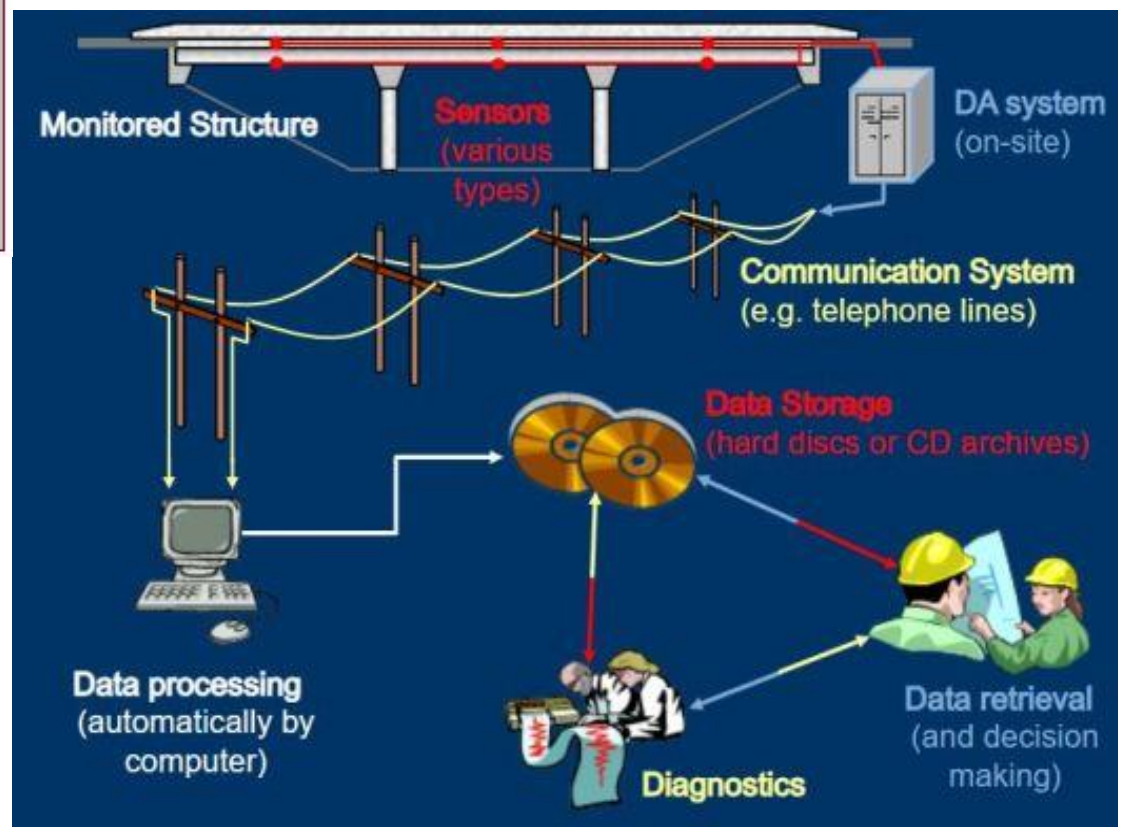
Based on a timescale of monitoring:

1. Continuous testing
2. Periodic testing

Based on the manner the response is invoked

1. Static load
2. Dynamic load
3. Ambient vibrations

Components and Related Tasks



Sensor

A sensor is **a converter** which converts **parameters of a physical nature** to an **electronic signal**, which can be interpreted by humans or can be fed into an autonomous system.

These signals for conventional sensors, amongst others, include **light, pressure, temperature, humidity, moisture** and a variety of other parameters.

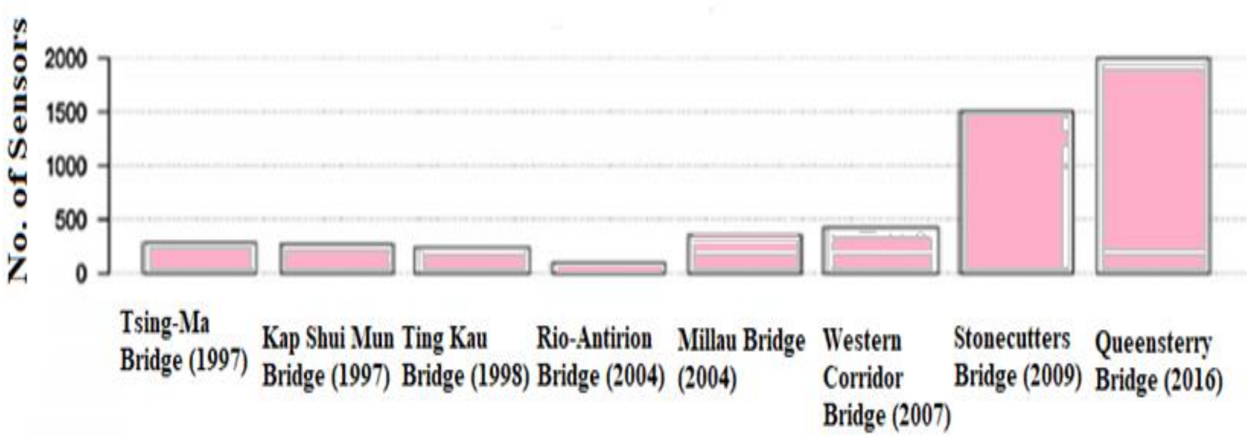
Sensor systems based on level of damage:

– **Surface Damage level**
  - Acoustic sensor system- pulse echo method
  - Electro-mechanical system- LVDT sensors
  - Optical systems- CCD cameras

– **Internal Damage level**
  - Embedded sensors- PZT Piezo-electric sensors

Applications of Sensors:

- Structural Health Monitoring (SHM)
- Inspections for fatigue cracks
- Seismic damage identification



Evolution of the number of sensors during the past 10 years in major monitored bridges

Output of **a large number of sensors** becomes a variety of big data source: **Big data analysis**

Emerging Sensor technologies for **Infrastructure Sensing**:

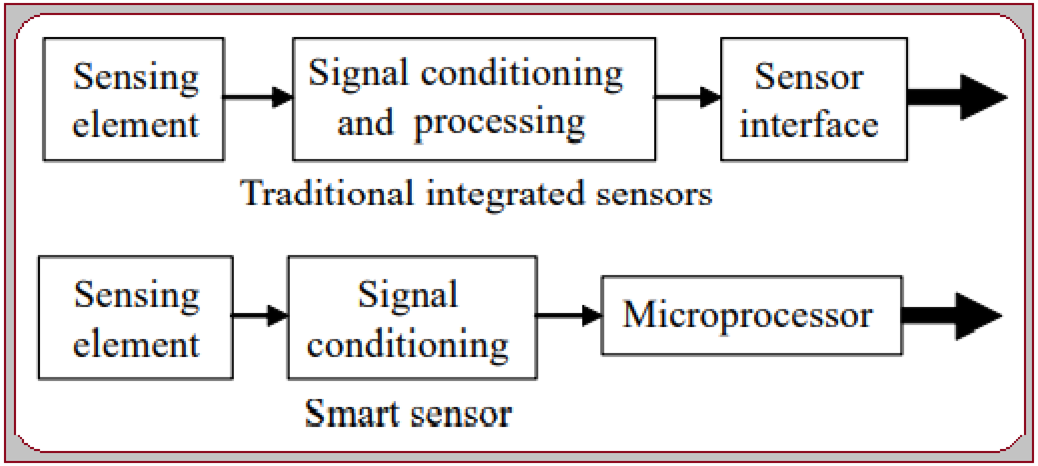
Smart Sensing technologies for Infrastructure Sensing

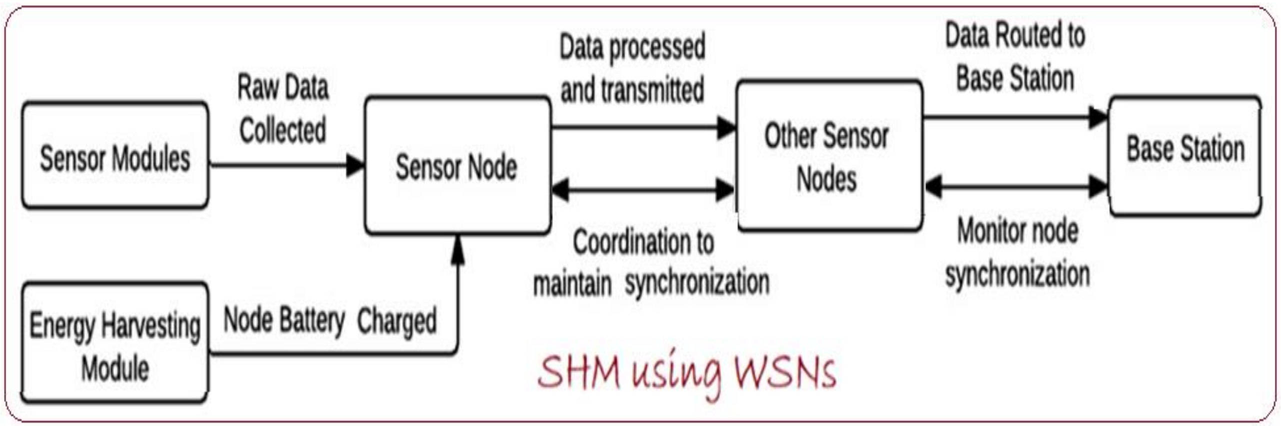
- Distributed Fiber Optic Sensing (FOS)
- Time Domain Reflectometry (TDR)
- Low power miniature/ Micro Electro Mechanical System (MEMS)
- Particle Image Velocimetry (PIV)
- Acoustic Emission (AE)
- Energy Harvesting for continuous monitoring
- Computer Vision & Robotic inspections
- Wireless Sensor Networks (WSNs)
- Satellite images
- Citizens as sensors

Sensor systems need to be either **long-life** or **adaptable for replacement**.

These Smart materials/sensors, possess very important capabilities of **sensing** various **physical** and **chemical parameters** related to the **health of the structures**.

"Smart" sensors with **embedded microprocessors and wireless communication** links have the potential to change fundamentally the way **Civil Infrastructure Systems** are monitored, controlled, and maintained.

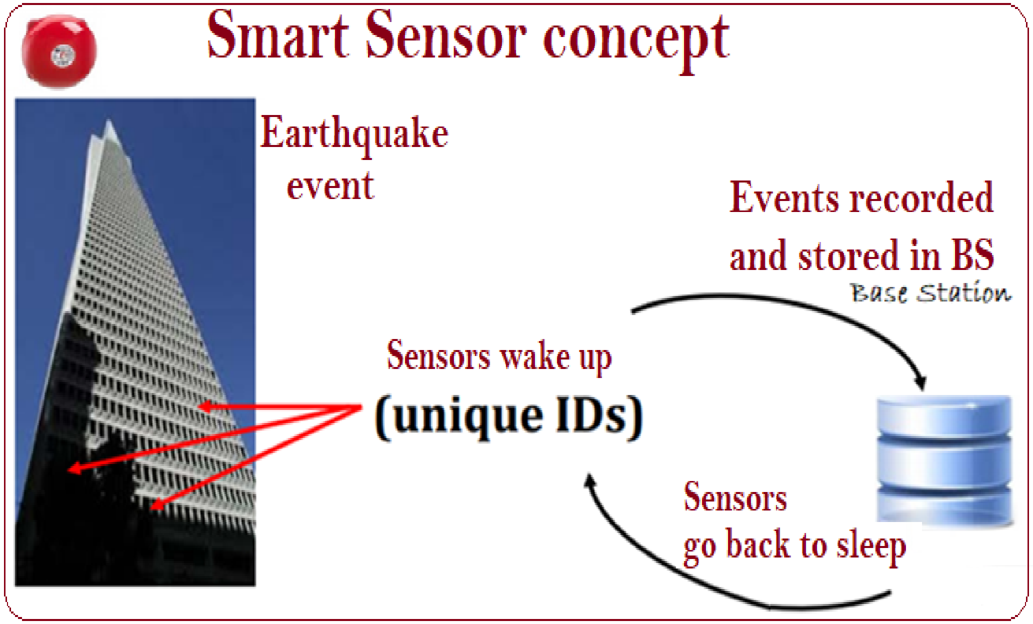




The on-board microprocessor is typically included for digital signal processing, analog-to-digital or frequency-to-code conversions, calculations, and interfacing functions, all of which can facilitate self-diagnostics, self-identification, or self-adaptation (decision-making) functions (its intelligence capabilities).

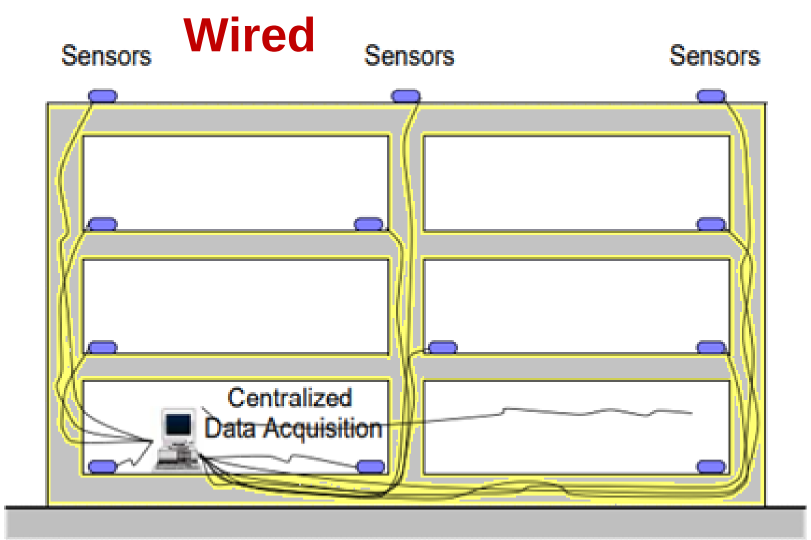
Essential features of a smart sensor:

1. on-board microprocessor (CPU)
2. sensing capability
3. Wireless communication (RF, widely used)
4. battery-powered & small size
5. low cost

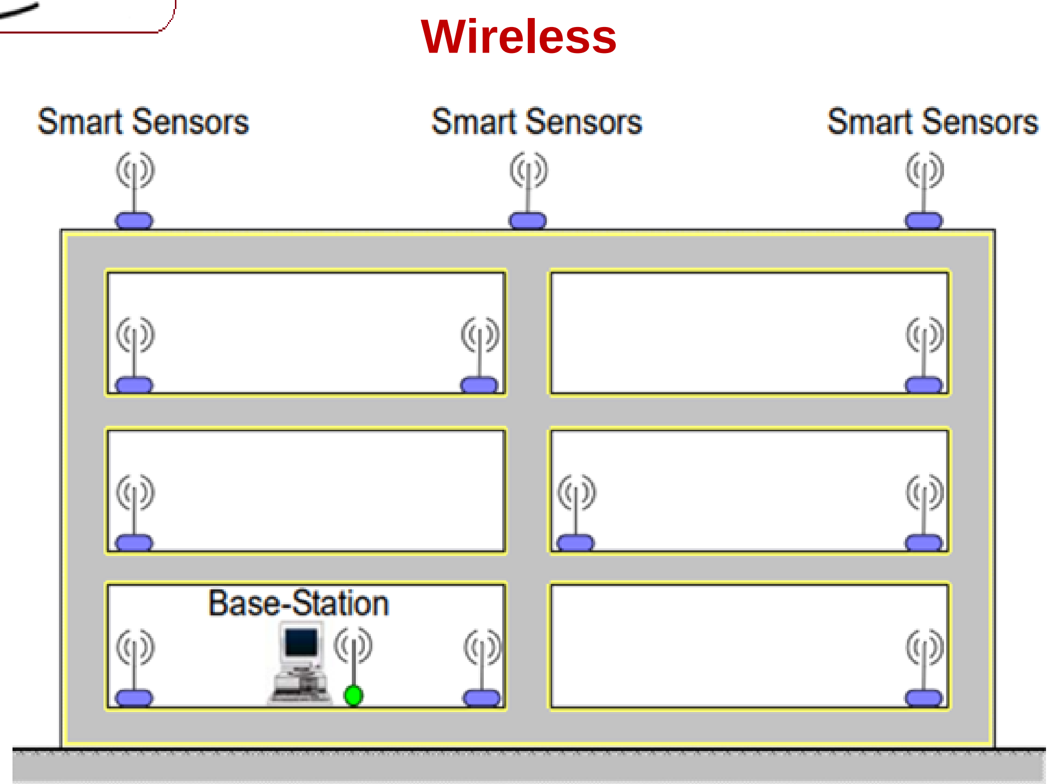


Wireless communication appears to be attractive. **'Smart' sensors** can **locally process** measured data and **transmit only** the important information through wireless communication.

More sophisticated sensors include **accelerometers** which can be used to **measure acceleration and vibration**.

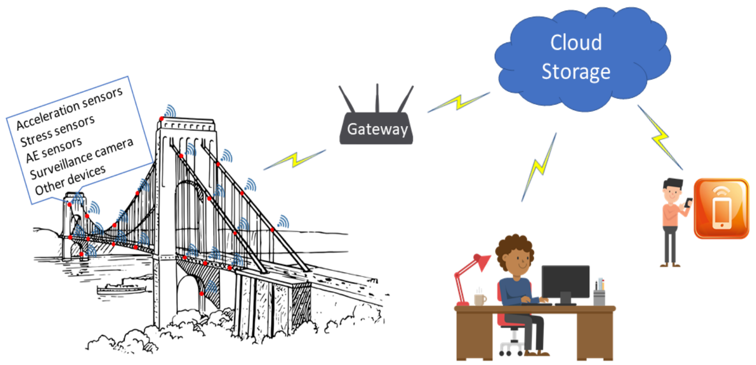


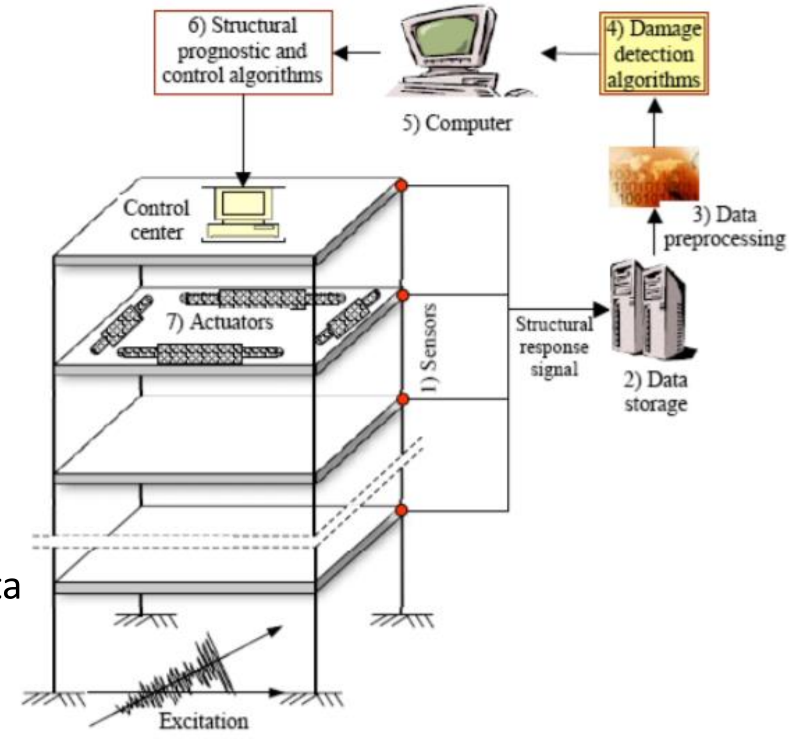
Traditional SHM system using centralized data acquisition.



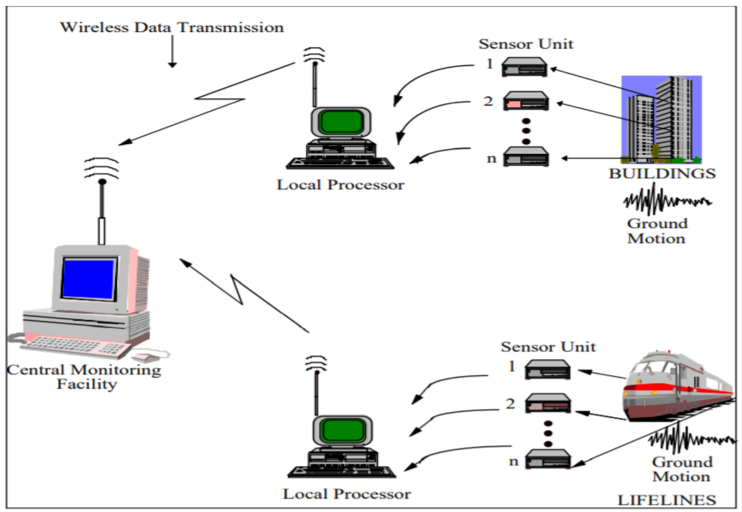
SHM system with smart sensors.

Components of a **Prognostics and Health Management** (**PHM**) system

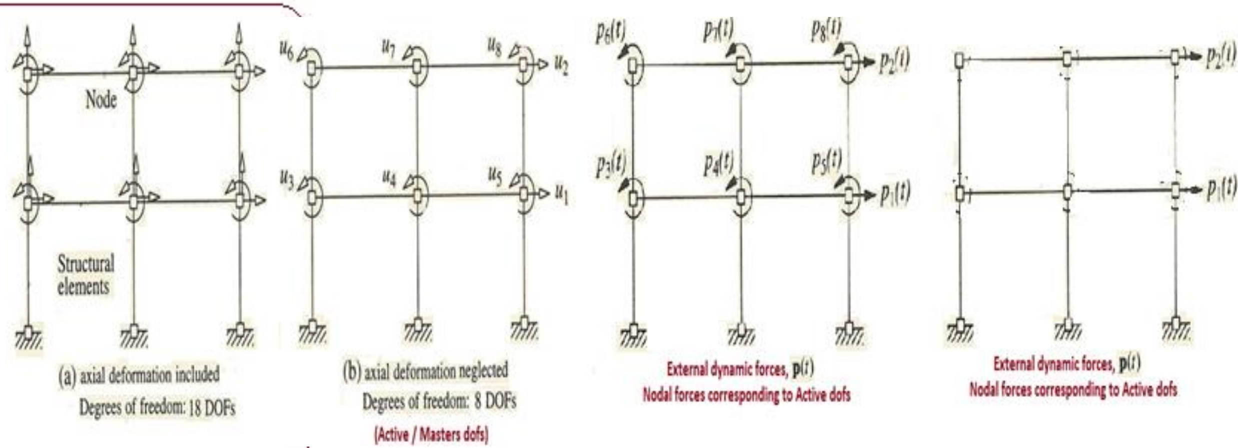




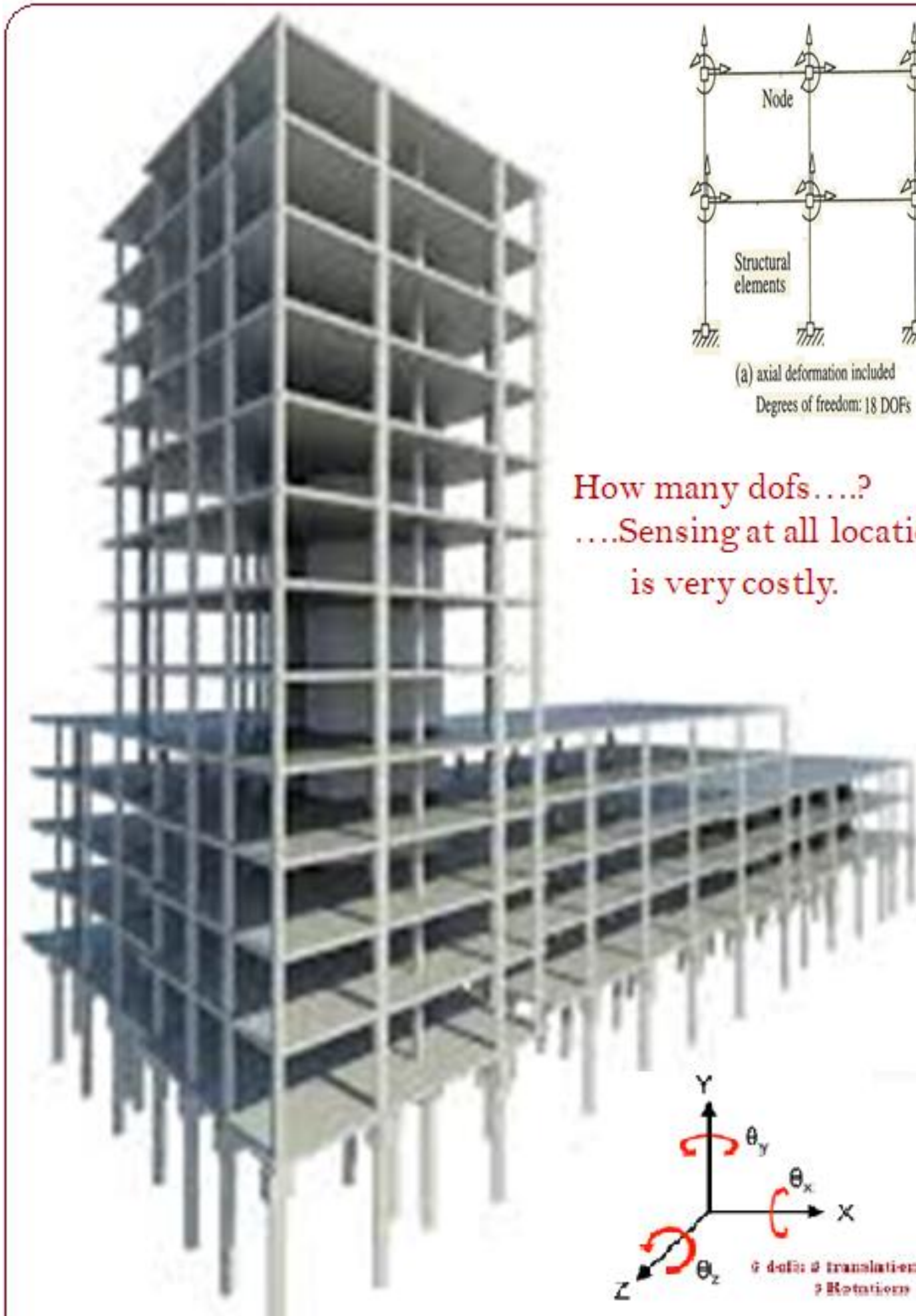
1. **Sensors** to acquire system response signals
2. **Media** (including disks, flash, RAM, ROM, and any other solid state memory devices and the like) to store sensor data
3. **Data pre-processing** to validate, clean, and interpret the collected data
4. **Damage detection models/algorithms** to assess the health status of the system
5. **Computer** to provide central control/communication between damage detection and prognosis results
6. **System prognostics and control algorithms** to provide decision support for the preventative maintenance activities
7. **Actuators** to enforce control forces on the engineering structure for damage reduction and risk mitigation



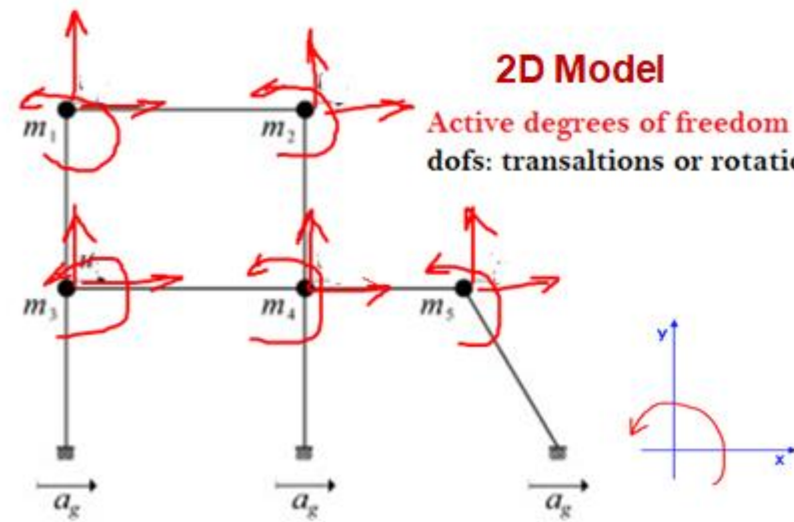
Conceptual Structural Monitoring System.



How many dofs….?
….Sensing at all locations
is very costly.



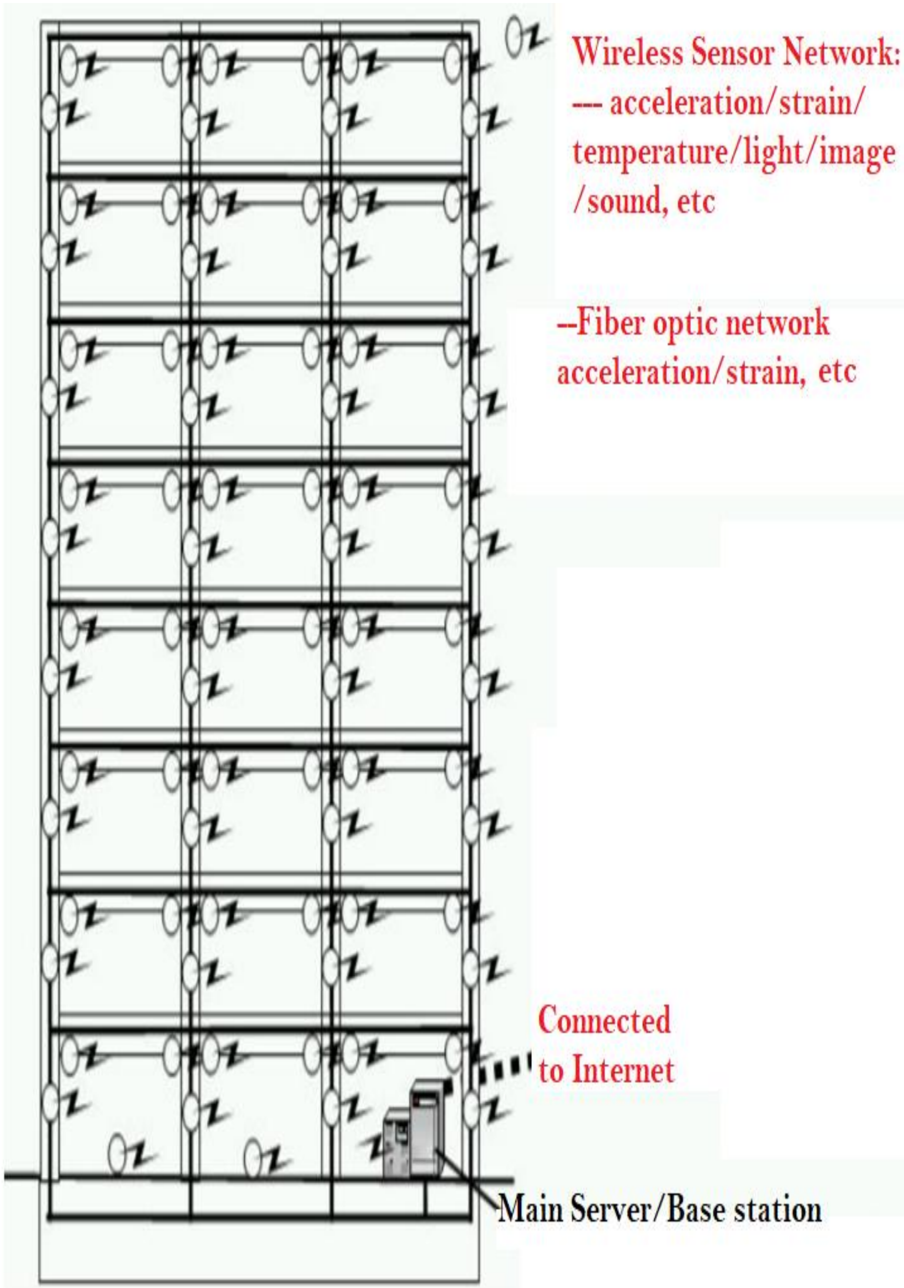
A building frame (Skeleton) 3D- model



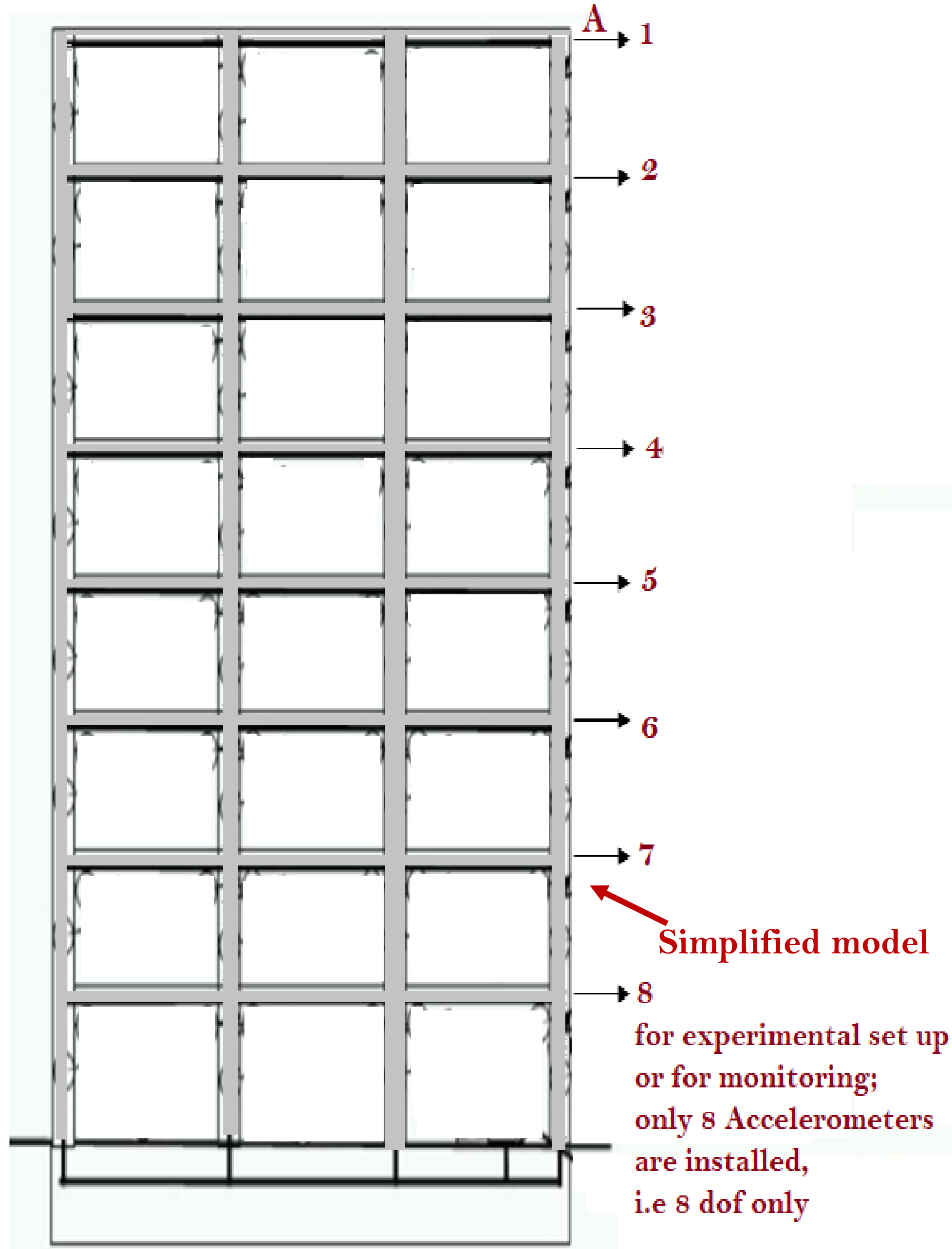
Earthquake / seismic excitations
a_g = acceleration (horizontal component)

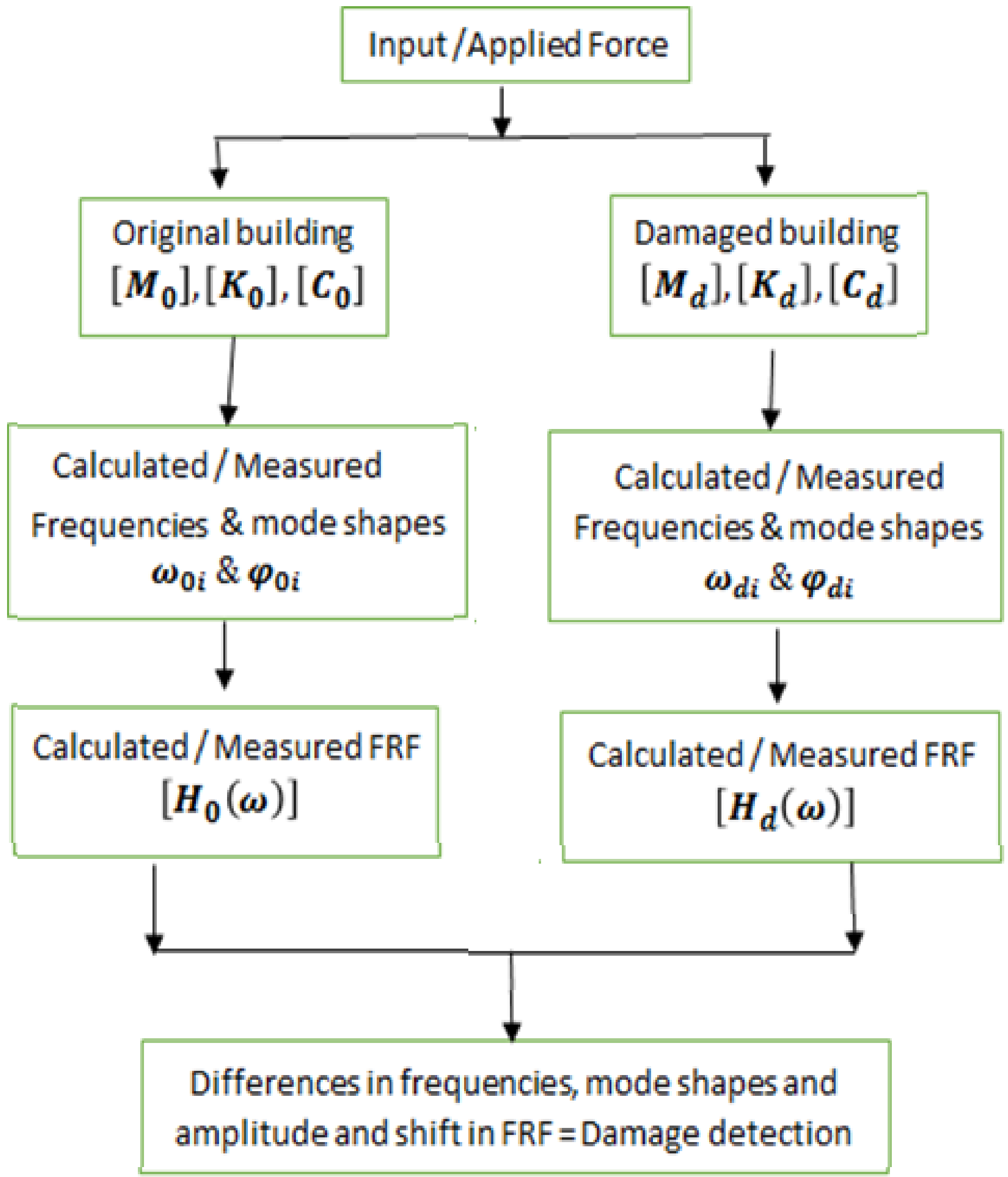
Rotational dofs are usually not measured and some dofs will be inaccessible.

For each type of sensor : 32 nodes with 3 dofs = 96 Nos.

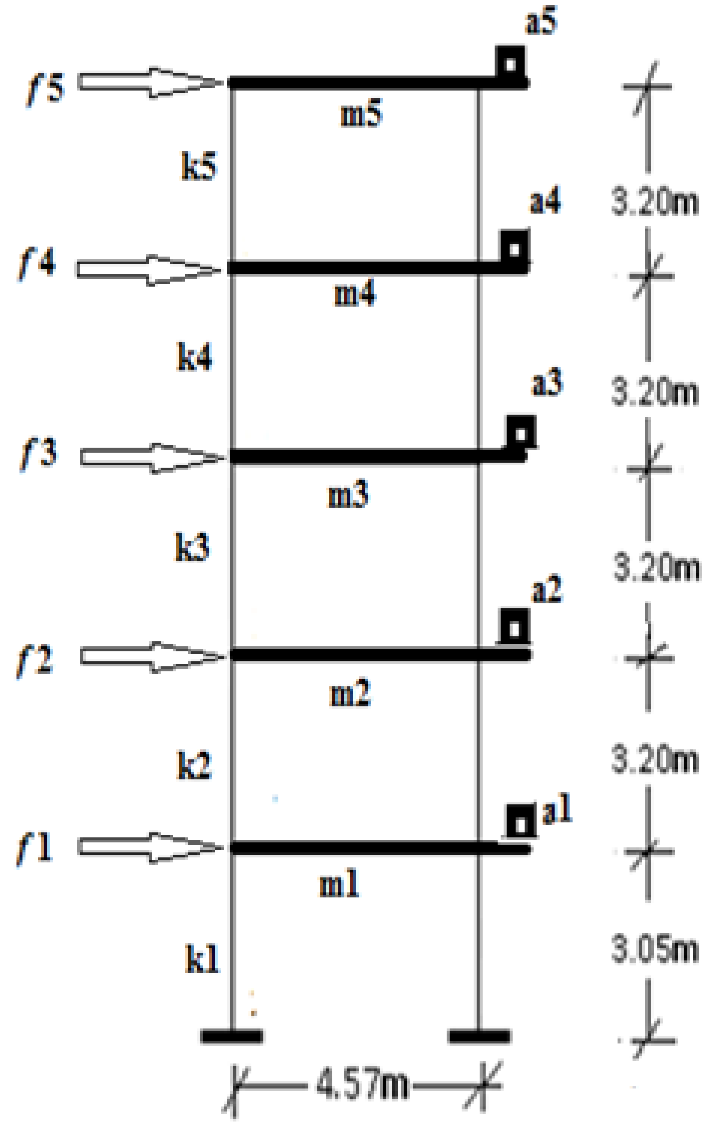


A building frame (Skeleton)



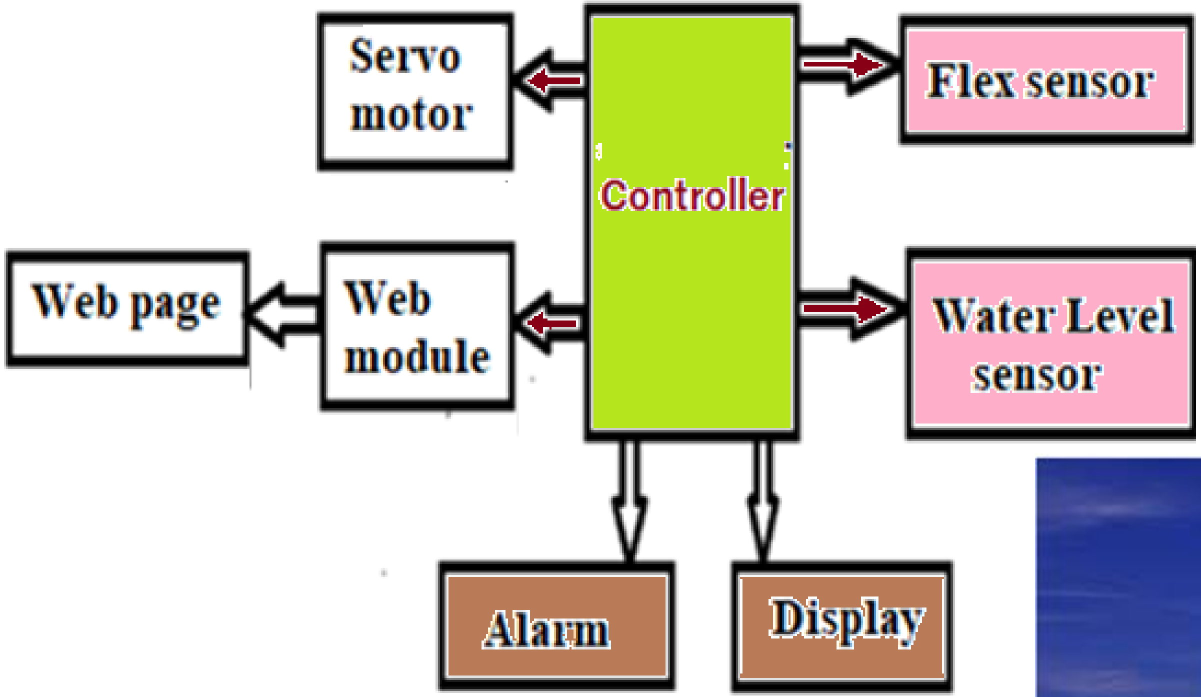


Flow chart of the proposed damage detection method



Shear building model

where $f1, f2, f3, f4$ & $f5$ excitations at floors
a1,a2,a3,a4 & a5 accelerometers/sensors
m1,m2,m3,m4 & m5 lumped masses
k1,k2,k3,k4 & k5 stiffnesses



BMS block diagram

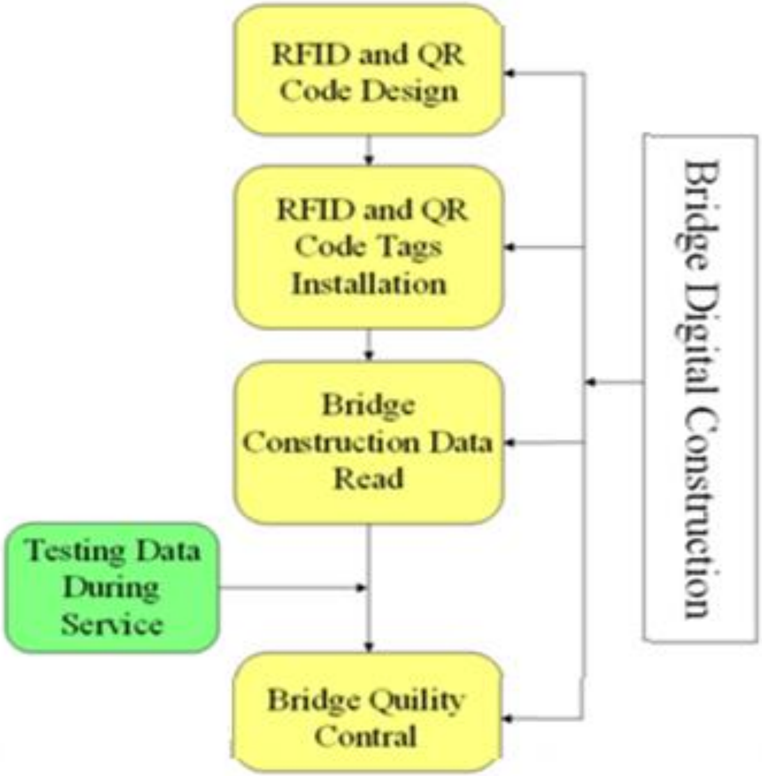
Smart Bridge

Bridge Monitoring System (BMS)-

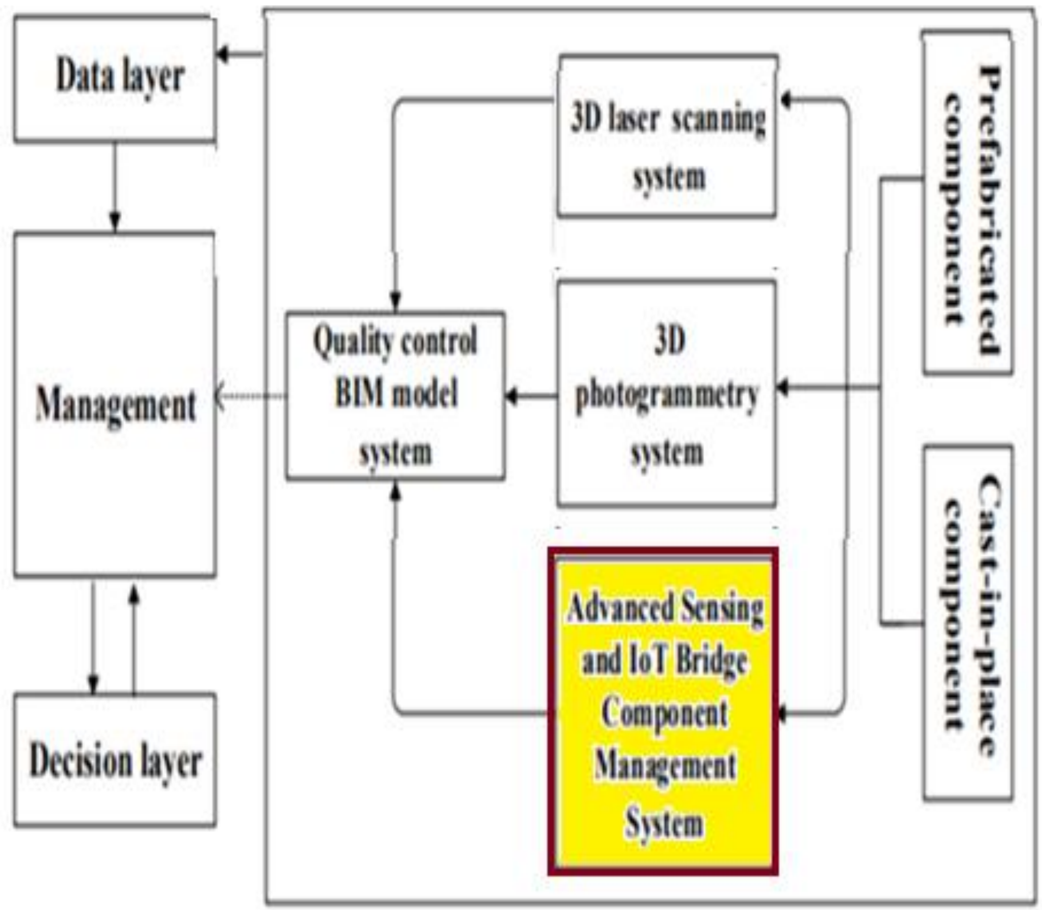
- to assess structural condition and possible damage

The **Flex sensor** measures the angle of tilt of the bridge as well as cracks.
The **water level sensor** will be placed below the bridge and within the gaps.
When the **water touches the sensor** it will give **alertness** and the **alarm** will beep.

IoT facility contains **Unmanned Aerial Vehicle** (**UAV**) equipped with camera and 3D laser, as well as sensors and QR codes installed on the component, which can timely grasp the quality status of the physical bridge including it visual appearance, geometric size, stress and strain.

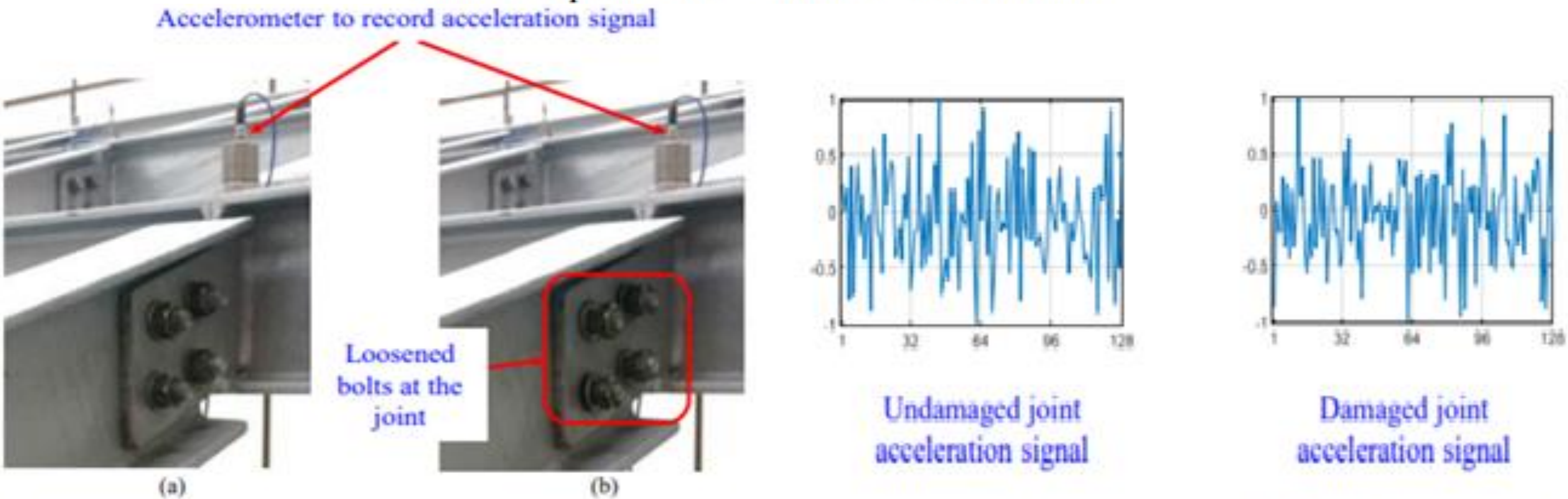


Bridge digital construction and maintenance



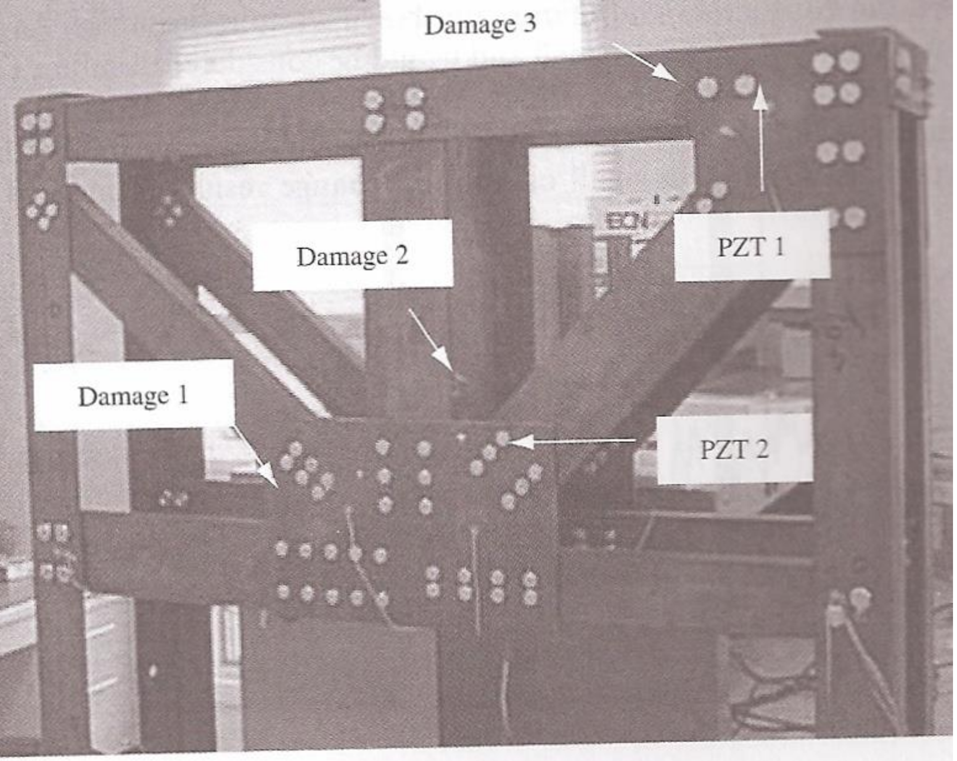
Bridge quality control system integrates BIM and IoT technologies

The test setup and wireless sensors used in Avci et al.

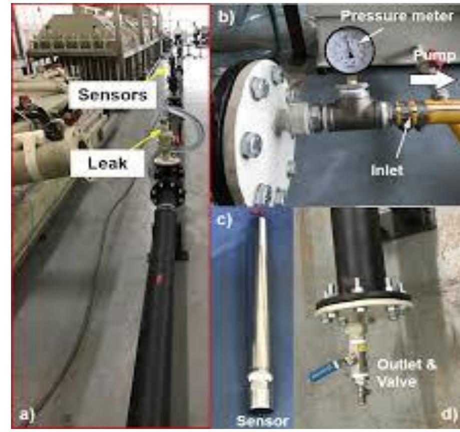


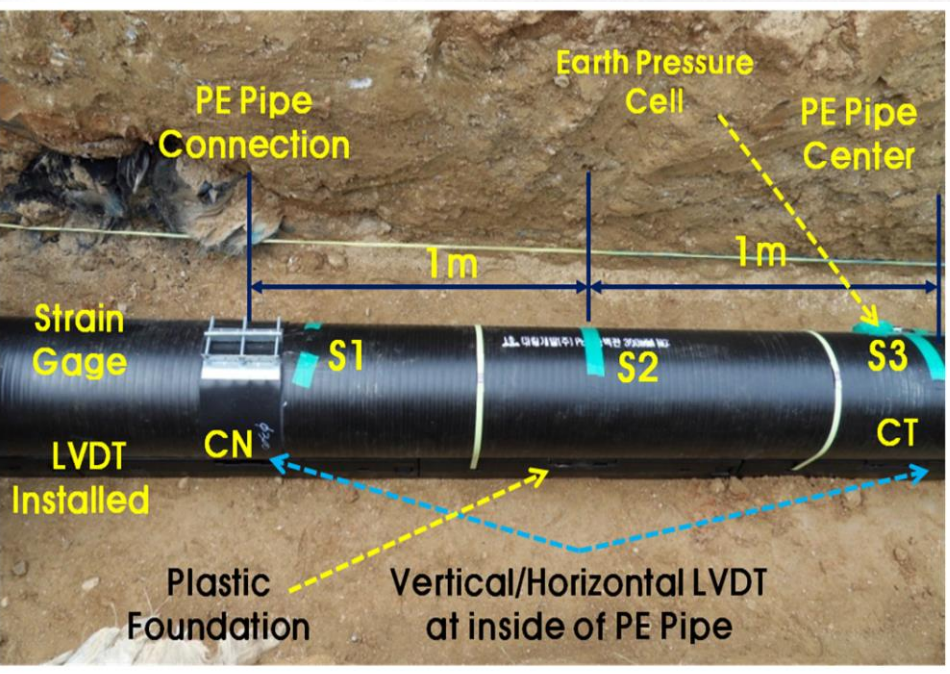
Damaged and undamaged vibration signals measured at the joints in Abdeljaber et al.

Even with a slight stiffness change such as **loosened bolts,** all the damaged joints were detected.



SMARTape installation in gas pipeline





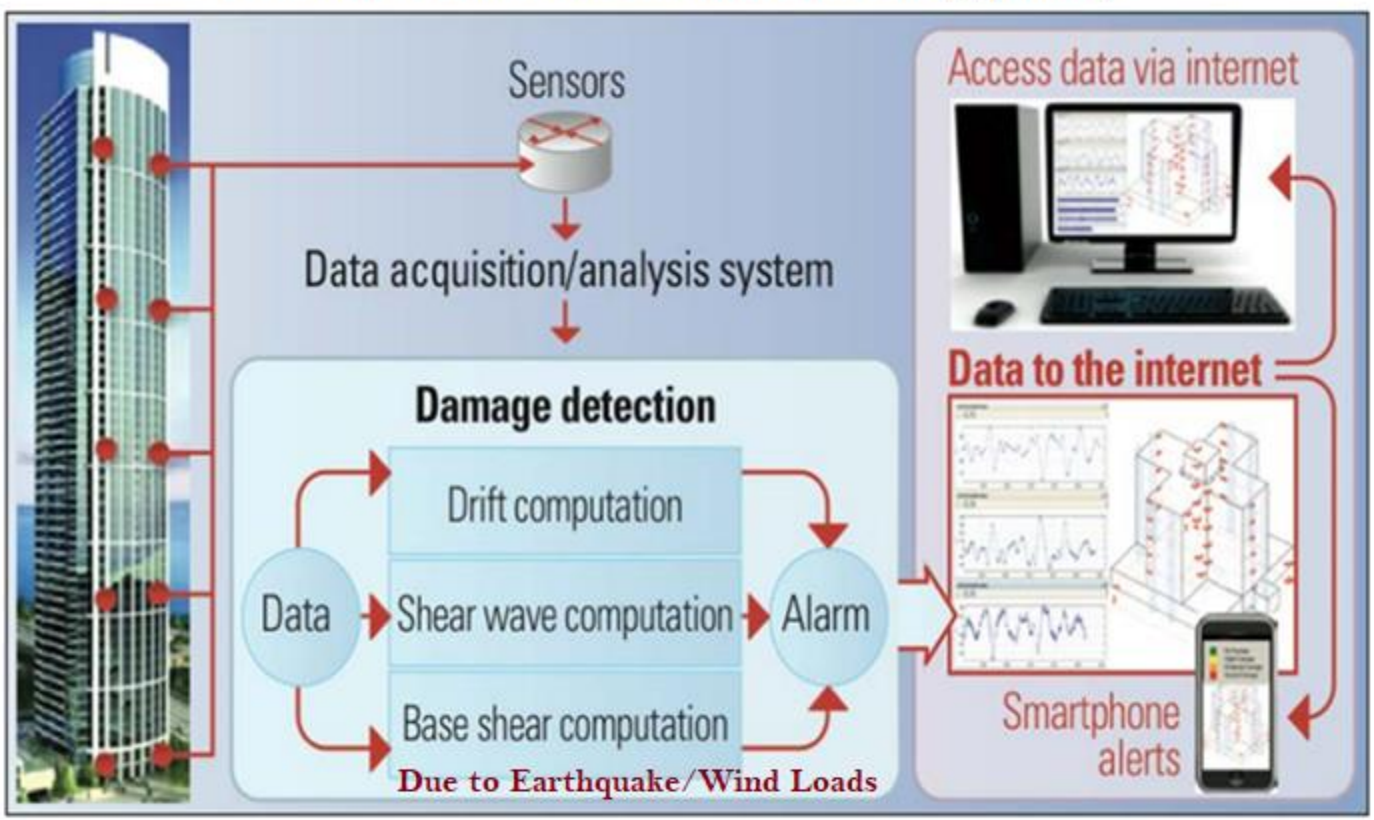
Monitoring the collapse process of Building during an Earthquake

Application of maintenance and management of Civil Infrastructures

Earthquake alarming system

Traffic induced vibration sensors in the houses

Future of Structural Health Monitoring (SHM)



Citizens as sensors

Our understanding of **mobility in a city** can be improved by

better **tracking of where and how people move in space and time.**

Integrating such infrastructure information will lead to **better management** and **operation**, and allow cutting-edge technologies to be tested.

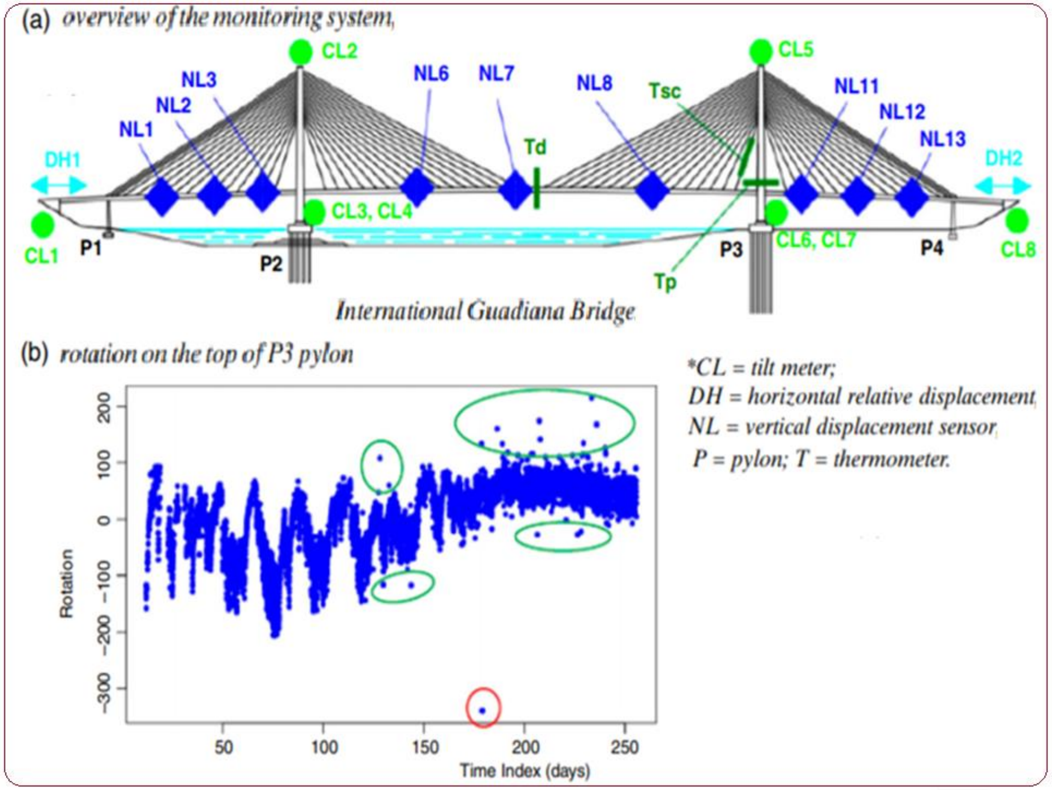
The rich information provided will act as a catalyst for new design, construction and maintenance processes for **integrated transport service systems** linked directly with **user behaviour patterns**.

As transport volume and therefore density increases, transport speed will reduce in order to safely manage the increased volume.
It is now possible to **crowdsource travel journey times** from GPS-enabled phones in addition to conventional traffic count data from the automated traffic counter system. **-- 'citizens as sensors' crowdsourcing aspect of citizen science**.

Examples include **monitoring** and **measuring** of real-time data using **smart phones/watches** from occupants and customers that provide data on how they feel about the usage of infrastructure.

If large quantities of data can be collected for **real-time understanding of human activities**, the **outputs of the models** can inform **infrastructure owners about people movement and use of space, and provide guidance on future usage and efficiency.**

Monitoring Bridge Structure



A Review of Vibration-Based Damage Detection in Civil Structures: From Traditional Methods to Machine Learning and Deep Learning Applications:

Onur Avci, Osama Abdeljaber, Serkan Kiranyaz, Mohammed Hussein, Moncef Gabbouj, Daniel J. Inman (2020)

Monitoring structural damage is extremely important for sustaining and preserving the service life of civil structures.

While successful monitoring provides resolute and staunch information on the health, serviceability, integrity and safety of structures; maintaining continuous performance of a structure depends highly on monitoring the occurrence, formation and propagation of damage.

Damage may accumulate on structures due to different **environmental and human-induced factors**.

Numerous monitoring and detection approaches have been developed to provide practical means for early warning against structural damage.

With the present computing power and sensing technology, **Machine Learning (ML)** and **especially Deep Learning (DL) algorithms** have become more feasible and extensively used in **vibration-based structural damage detection**.

Vibration-based Structural Damage Detection methods based on Machine-Learning

ML-based SDD methods are categorized into **parametric** and **nonparametric methods**

A large portion of parametric and nonparametric ML-based SDD systems perform the two common tasks:

- **feature extraction**
- **training**

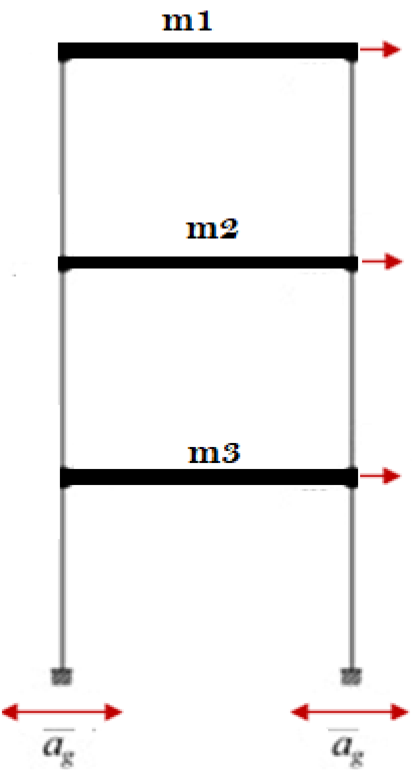
Then the trained ML system is utilized to identify the **presence and location of structural damage** by performing classification.

ML methods for parametric vibration-based SDD

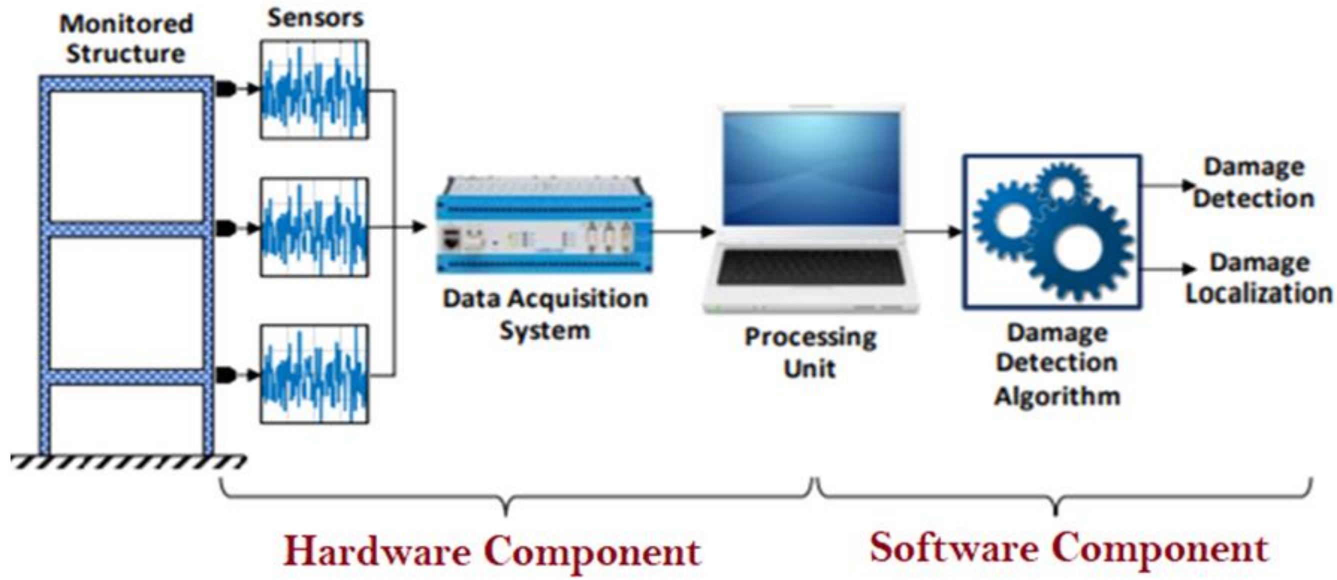
The **feature extraction process** is carried out by simply identifying certain modal parameters from the structural systems using input-output or output-only modal identification techniques.

A **well-trained ML classifier** is then used to process the extracted modal parameters to assess the structural integrity.

The most commonly used parametric ML-based approaches are those that rely on modal characteristics such as **natural frequencies and mode shapes** as extracted features along with the **feed-forward, fully-connected, multi-layer Artificial Neural Networks** (ANNs) or the so-called **Multi-layer Perceptrons** (**MLPs**) as classifiers.

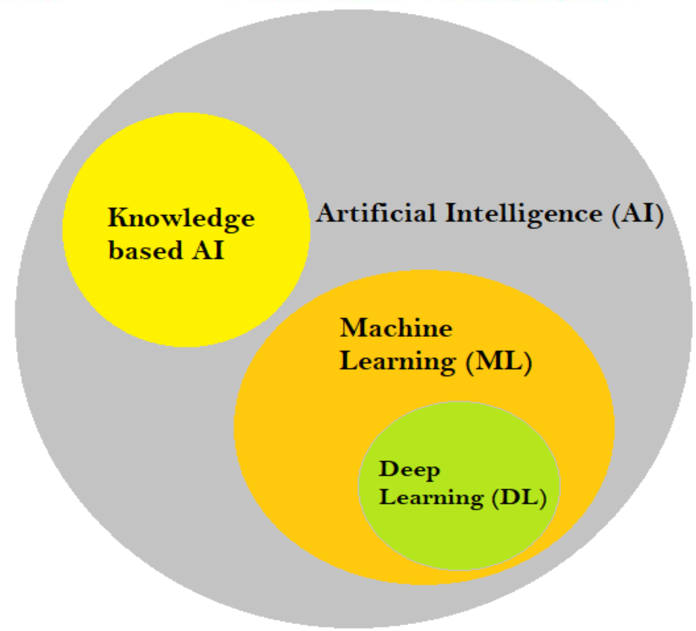


Main components of Structural Damage Detection systems



The **hardware part** is composed of the **sensing and data acquisition interface** used to collect measurements which may usually include accelerometers, velocimeters, strain-gauges, load cells, or fiber optic sensors along with data acquisition modules.

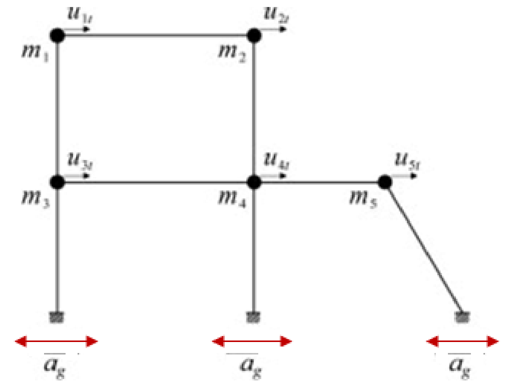
The **software component** of a damage detection system is an arsenal of **signal-processing and pattern recognition algorithms** designed to translate the signals acquired by the **sensing interface** into essential information that **reflects the condition of the structure being monitored**.



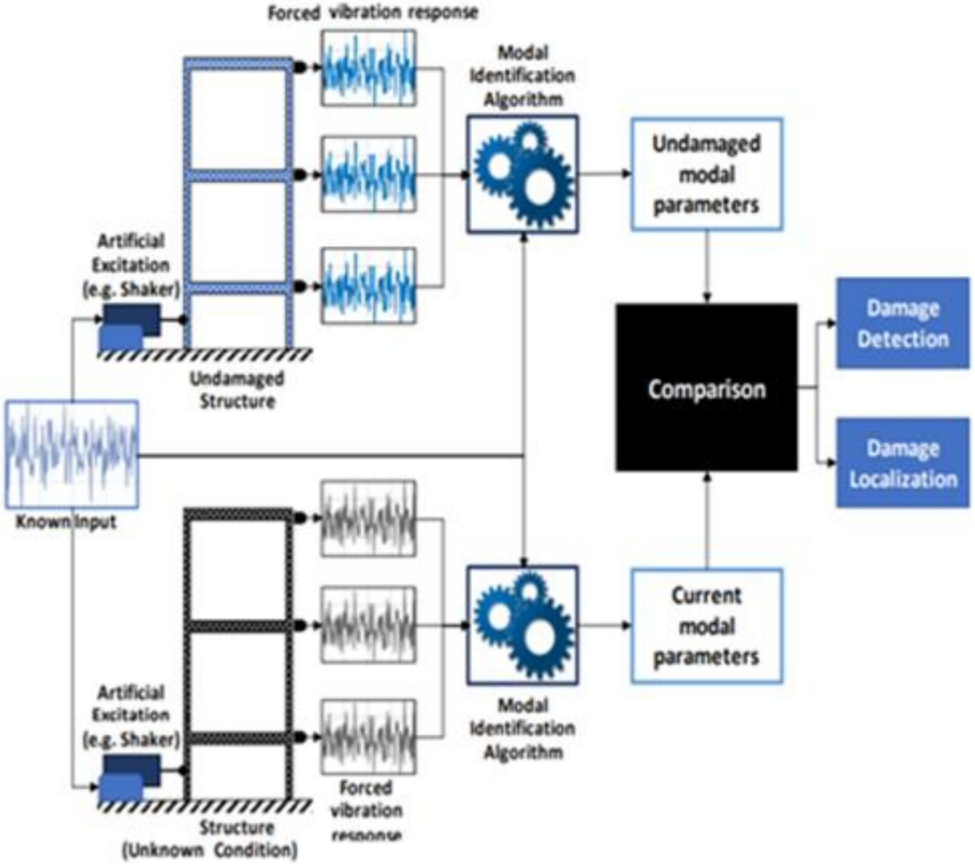
Venn Diagram presenting the relationship among different AI systems

Artificial Intelligence (**AI**) is aiming at developing machines that exhibit human-like intelligence in solving problems and performing tasks

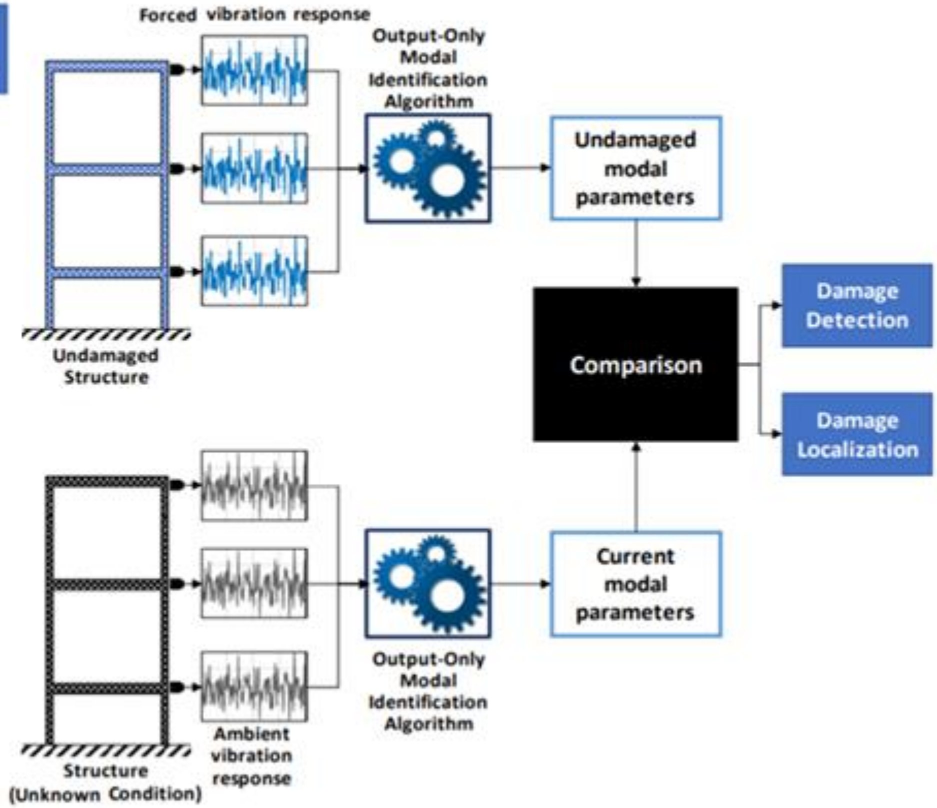
Parametric Vibration Based Damage Detection methods



Based on both Input Output



Based only on Output



Machine Learning (ML) algorithms

- **Unsupervised algorithms**
- **Supervised algorithms**

Supervised algorithms require a dataset consisting of **human-labeled data for training**.

As such, the primary purpose of the supervised learning is to discover the optimal mapping from the inputs to the desired (or target) outputs. Therefore, supervised algorithms **require a human "supervisor" to assign each data** sample by a correct label or target before running the training.

Unsupervised learning algorithms, on the other hand, require input-only data without any labeling.

The objective of unsupervised learning is to investigate the distribution of the data in order to obtain useful information regarding its underlying structure

The tasks performed by ML systems can be summarized as:

- **Classification**: The objective of this task is to determine which category the input belongs to. (The medical diagnosis system serves as an example of classification task since the input to the system is classified into either "cancer" or "no cancer" categories.)
- **Regression**: In this task, the goal is to model the relationship between a numerical output and a number of inputs.

  The only difference between regression and classification is the format of the output.
- **Prediction:** Prediction is a special type of regression in which the objective is to foresee the future values of a given time series.
- **Clustering:** The target of clustering is to divide the input dataset into clusters with similar examples.

Deep Neural Learning or Deep Neural Network methods

In order to avoid the **hand-crafted features** in complex ML applications, Deep Learning (Deep Neural Learning or Deep Neural Network) methods have been introduced.

DL is indeed a **subset of ML** within AI context that has networks capable of learning unsupervised from unstructured data.
DL, also known as **representation learning**, are a special type of ML methods capable of extracting the optimal input representation **directly from the raw data** without user intervention.
In other words, DL algorithms can learn not only to correlate the features to the desired output, but also to carry out the feature extraction process itself.
Therefore, a DL system with proper training can indeed find the direct mapping from the raw inputs (e.g. the images in the previous example) to the final outputs without the need to extract features in advance.

DL is then able to explain high-level and abstract features as a hierarchy of simple and low-level learned features. This ability allows DL algorithms to deal with complex tasks by breaking them down into a large number of simple problems.

Recent studies have revealed that relying on learned features instead of hand-crafted ones results in much better performance in challenging tasks such as object detection, image classification, and classification of electrocardiogram (ECG) beats.

Big Data Analytics in Online Structural Health Monitoring,

Guowei Cai , Sankaran Mahadevan, International Journal of Prognostics and Health Management, ISSN2153-2648, 2016 024

-- Investigated **infrared thermal images** for structural damage diagnosis.

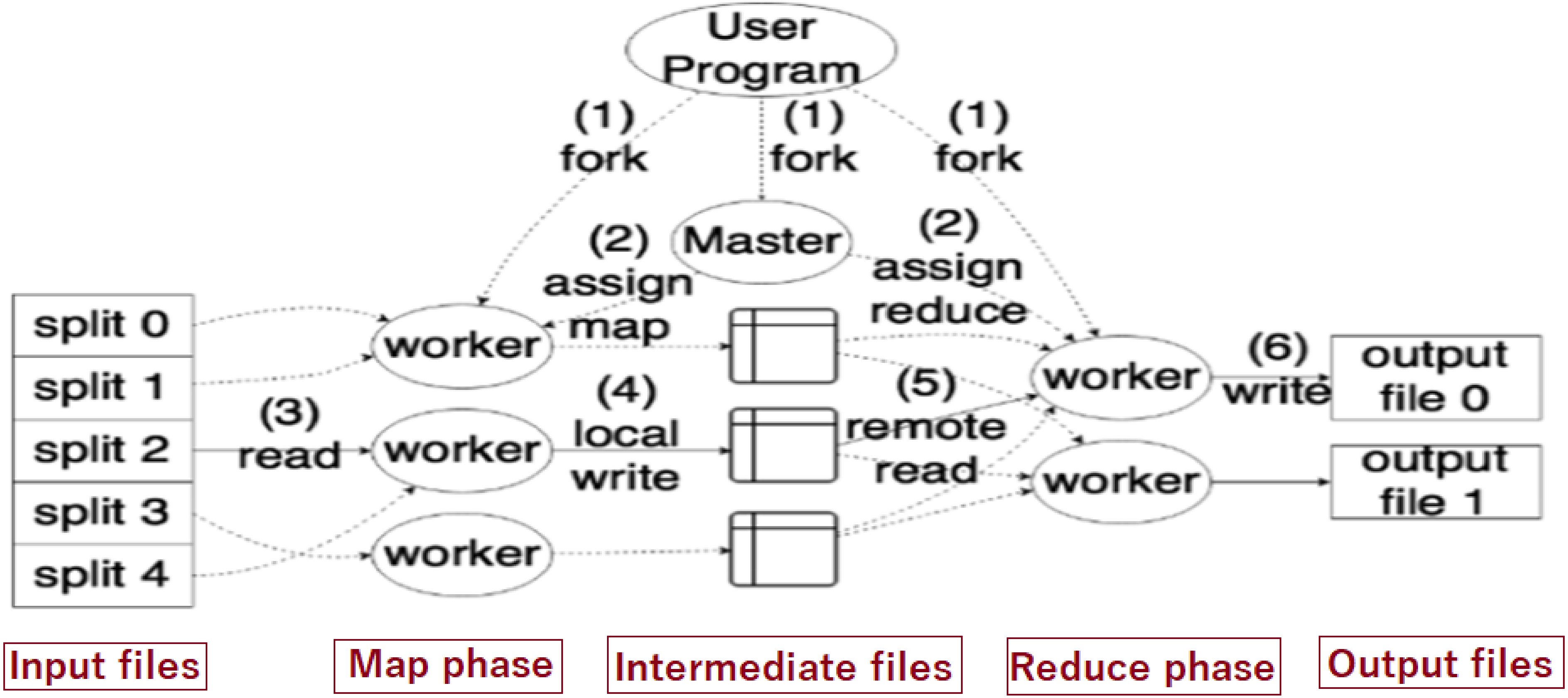
-- illustrated using actual experimental data on concrete slabs, with induced damage

As **smart sensor technology** is making progress and low cost online monitoring is increasingly possible, **large quantities of highly heterogeneous data** can be acquired during the monitoring.

- big data techniques to handle the **high volume data** obtained.

MapReduce technique to **parallelize the data analytics** and efficiently handle the high volume, high velocity and high variety of information.

MapReduce is implemented with the Spark platform, and image processing functions such as uniform filter and Sobel filter are wrapped in the mappers.

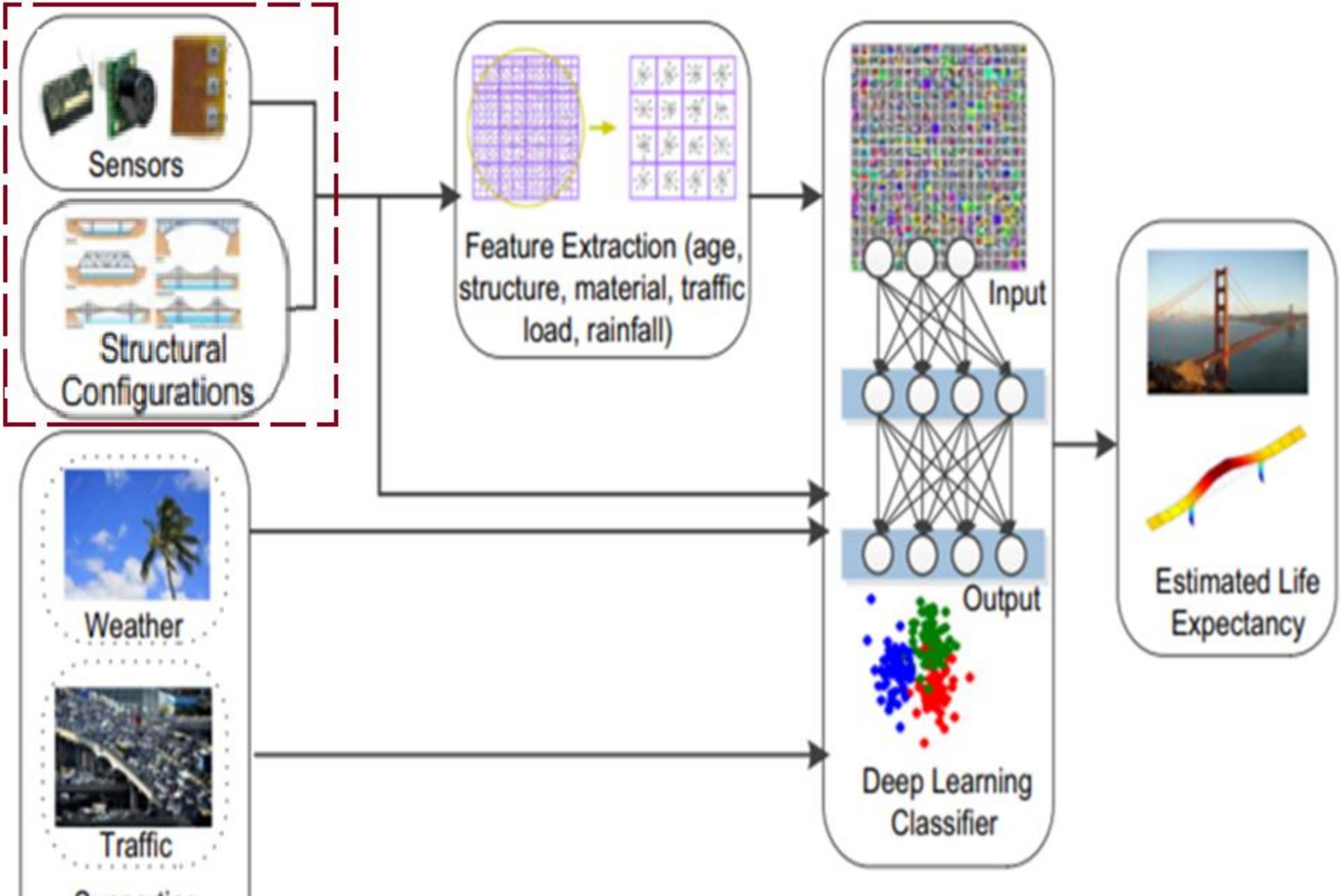


Overview of MapReduce execution

The MapReduce framework is split into two steps: **Map** and **Reduce**

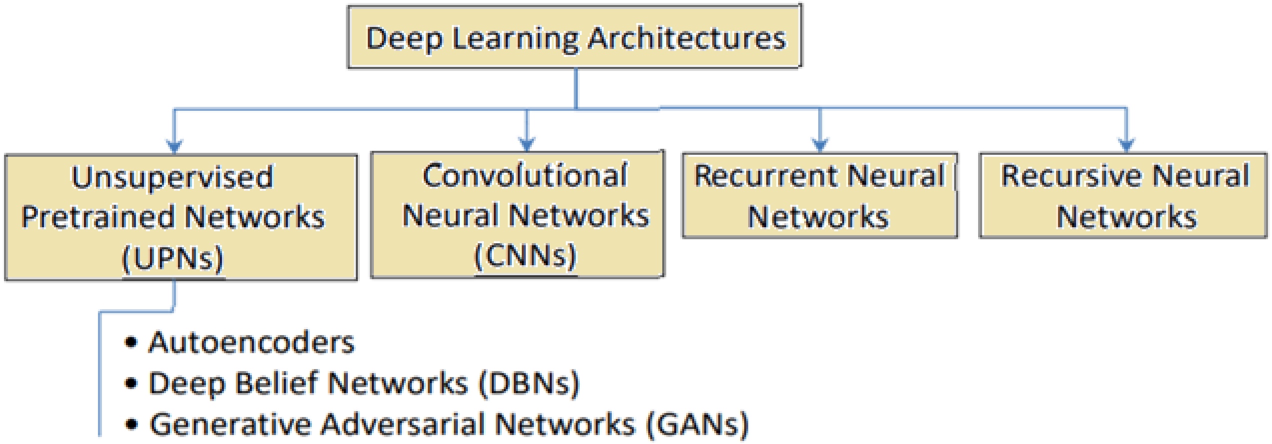
-- the input is written as the **key/value pair** (**k1, v1**) will then be input to the **Map function,** which will generate the intermediate key/value pairs (**k2, v2**).

Then the **intermediate key/value pairs** are passed to the **Reduce function**, which **merges together** these values to form a smaller set of values.



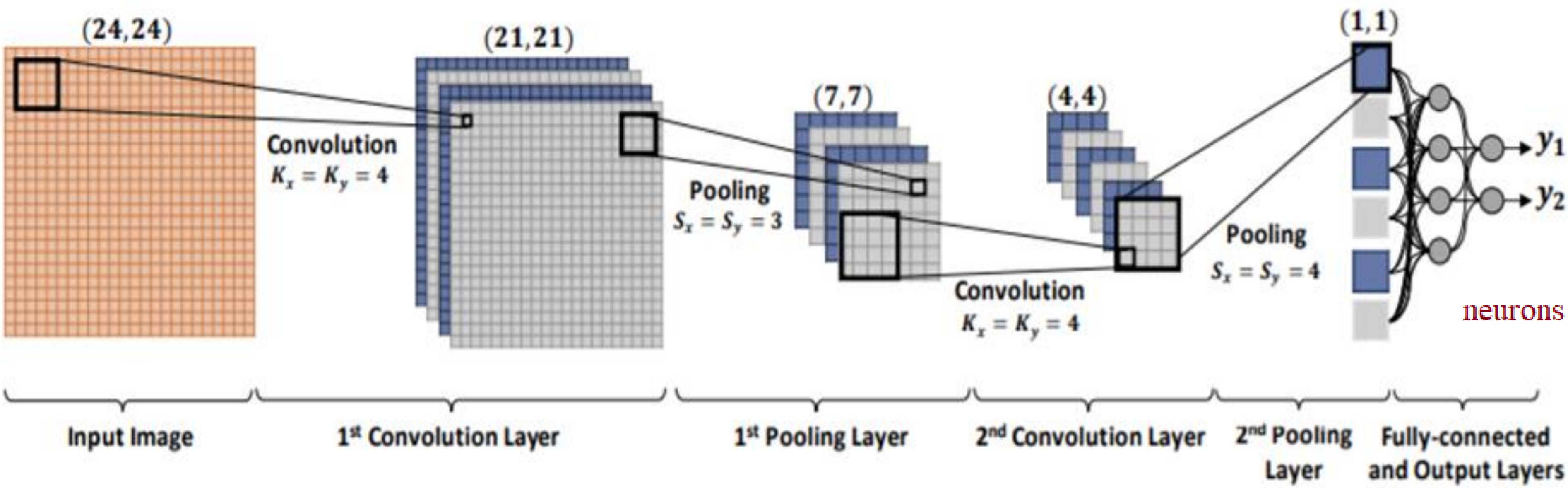
Flow chart of the Deep-Learning-centric nationwide bridges survey in USA

Vibration-based Structural Damage Detection (SDD) by Deep-Learning (DL)



In DL, multiple abstract layers communicate with each other.

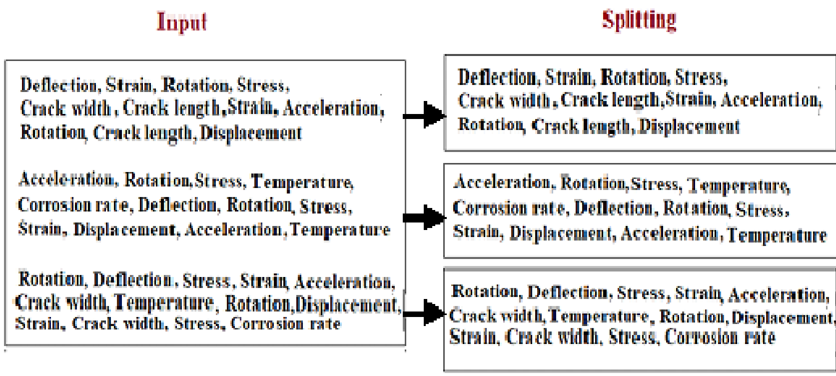
are trained principally in a supervised manner by a stochastic gradient descent method, or by backpropagation (BP) algorithm.

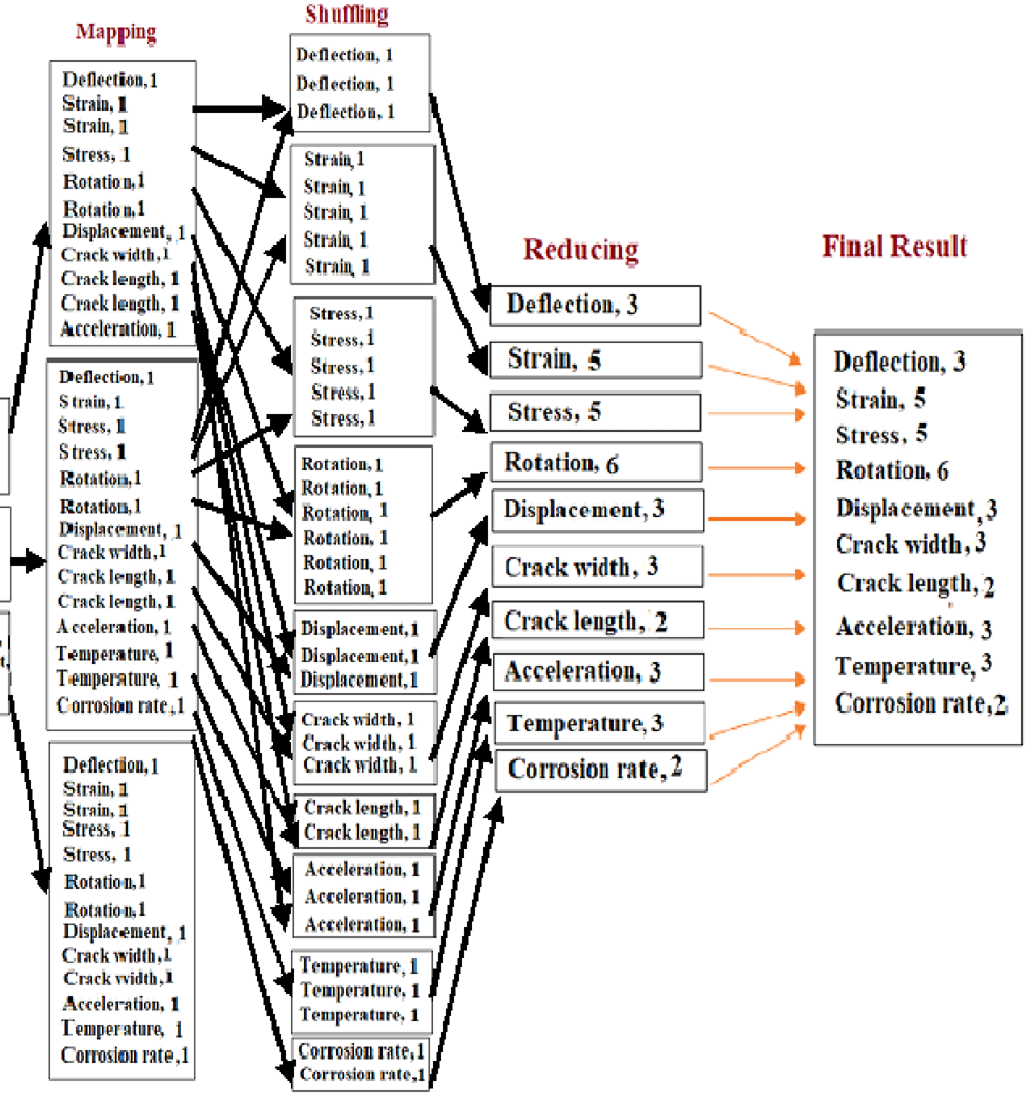


A sample CNN with 2 convolution and one fully-connected layers.

24×24-pixel grayscale image into two categories.
The network consists of two convolution and two pooling layers

K for kernel sizes and S for subsampling factors





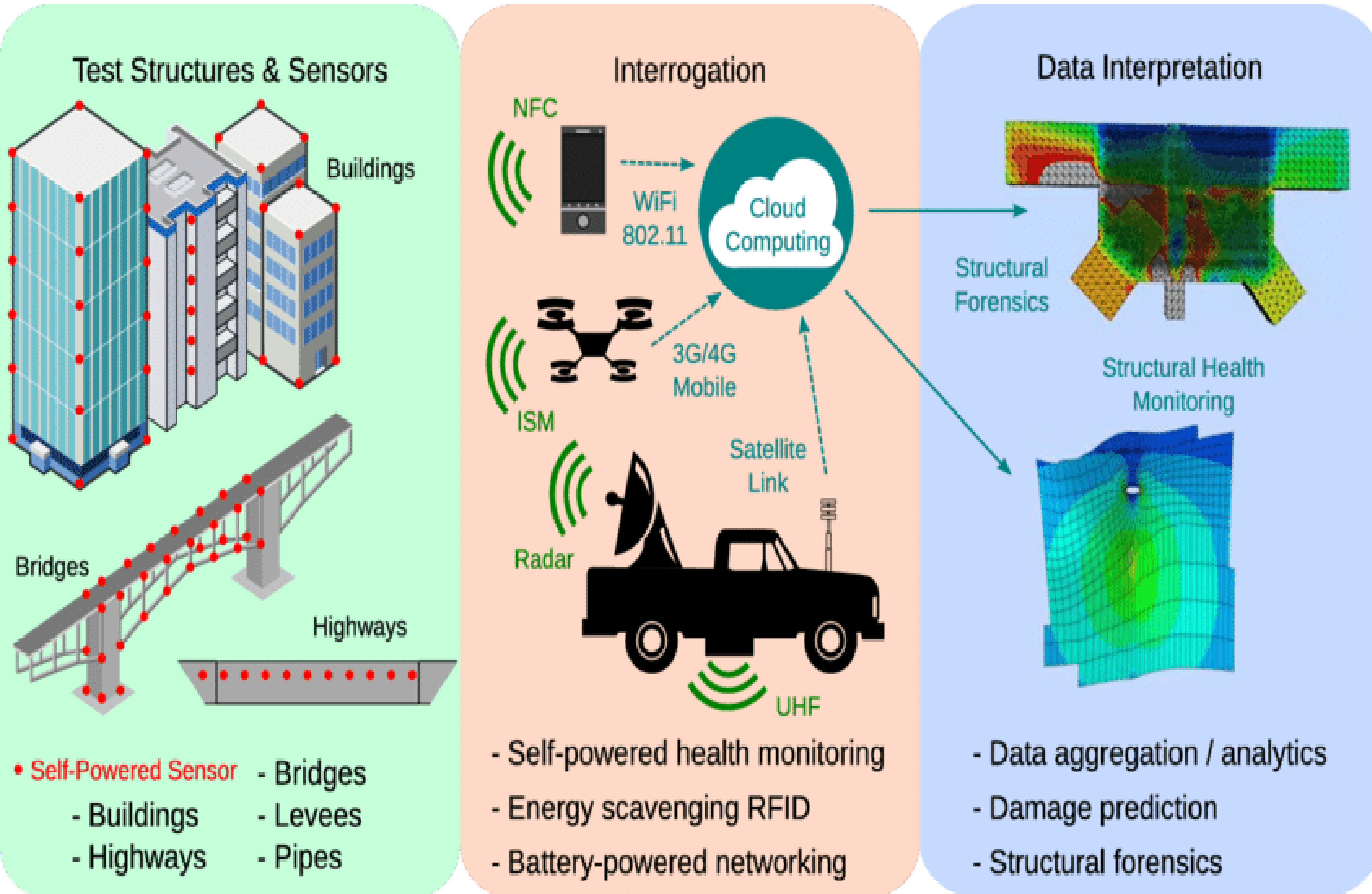
Sensor data

Hadoop/ MapReduce data processing

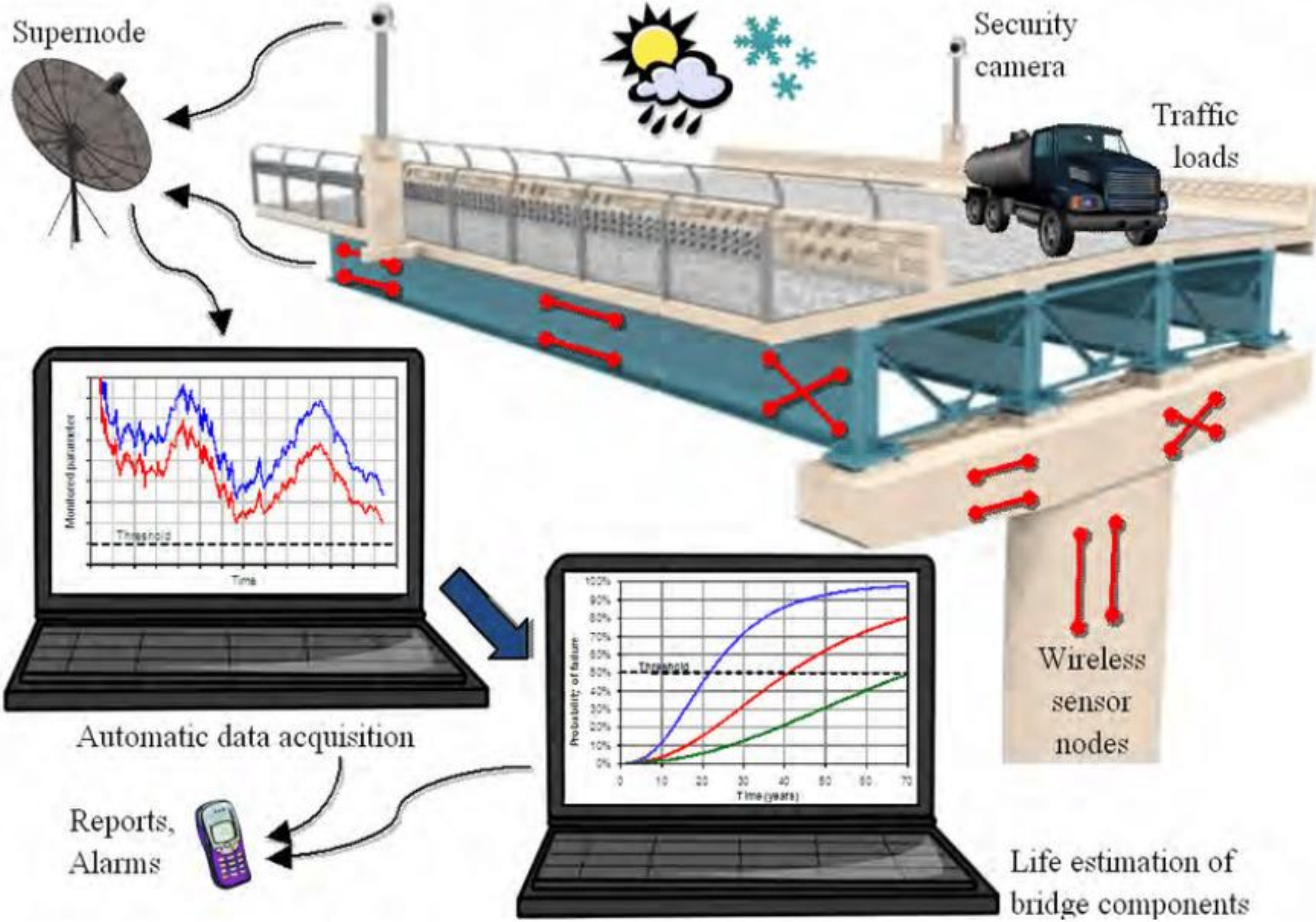
Big Data Analysis

Voluminous data handling/processing require latest techniques to convert them into useful information for diagnosis and prognosis … Hence **Big Data Analysis**

Framework of Infrastructural Internet of Things (IoT)



-- with self-powered sensors shown as red dots



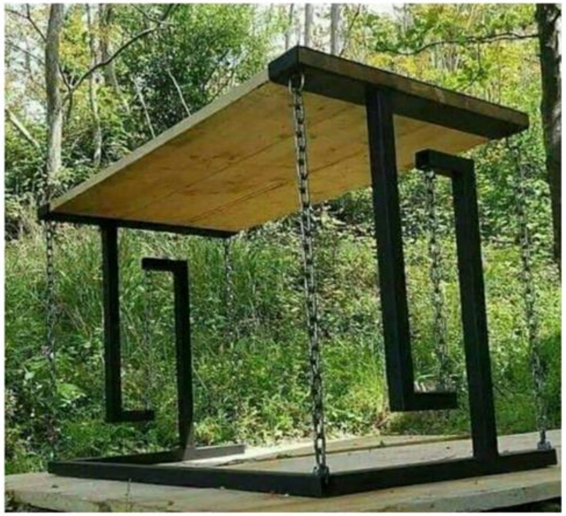
Concept of structural health monitoring of bridge structures.

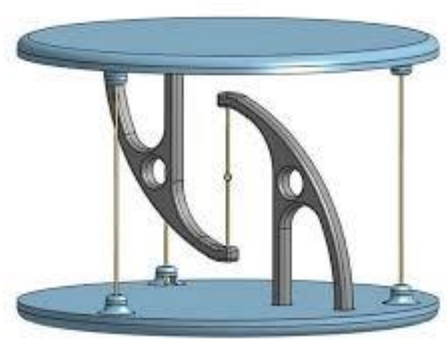
Conclusion

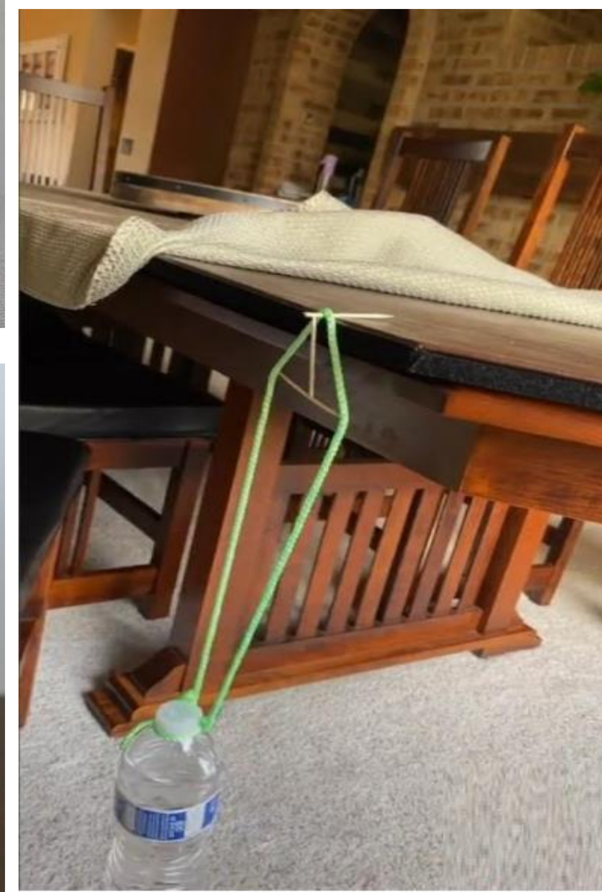
- New Sensor Technologies integrate Machine Learning, Deep Learning, and Artificial Intelligence for structural health monitoring and fault detection.
- Sensors are used for the dynamic measurement, in the structural elements, buildings, bridges, dams and tanks.
- **Real time Information** obtained from sensors helps to predict Strength, Integrity, Service life and Safety of the structure
- Sensor systems need to be either **long-life or adaptable for replacement**. The development of **'smart' infrastructure** means true realization of **performance-based design and maintenance**.
- Early detection of structural damage could save human and animal lives.

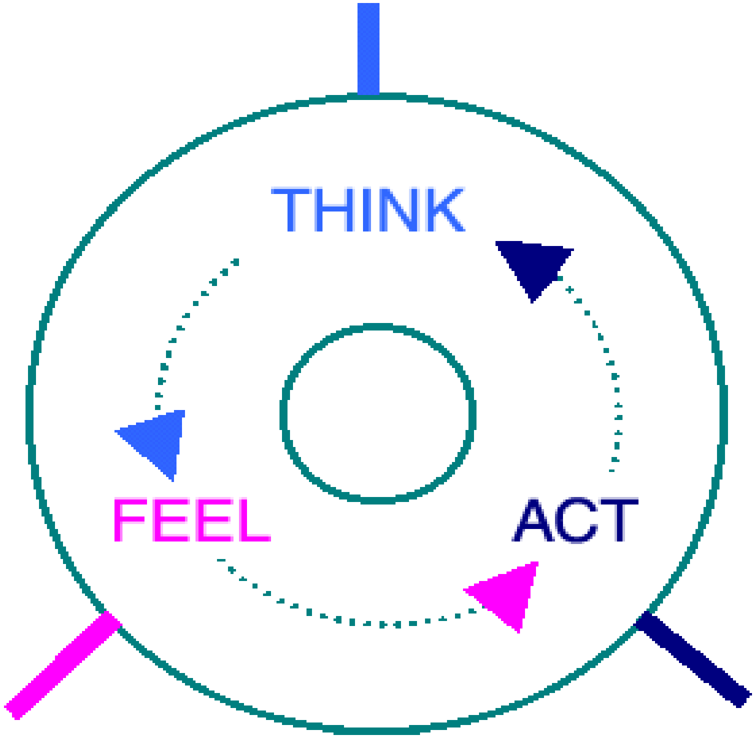
Modest amount of **routine inspection** and **monitoring** combined with routine **maintenance** activities, along with keeping operational loads to within specified limits, can lead to long standing structures.

Tensogravity structure..








THINK
FEEL
ACT


Thank you