DEPARTMENT OF CIVIL ENGINEERING

IIT DELHI

Lec 2

INTRODUCTION TO STRUCTURAL HEALTH MONITORING

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READING MATERIAL FOR STUDENTS OF CVL 864, IIT DELHI

WHY STRUCTURAL MONITORING?

Similar reason that we go for regular health check-ups to hospital/ doctor.....

Silver bridge collapse in Ohio, December 1967 (USDT, 2003)

Mianus river bridge collapse in Greenwich, June 1983 (USDT, 2003)

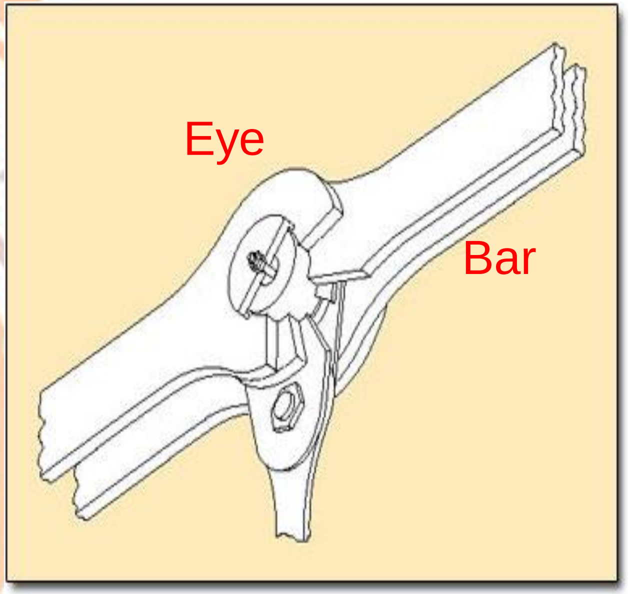
CAUSE OF COLLAPSE

Stress corrosion failure of an eyebar link.

CAUSE OF COLLAPSE

Hangar pin connection failure due to excessive corrosion accumulation, which remained undetected.

VULNERABLE COMPONENT: EYEBAR



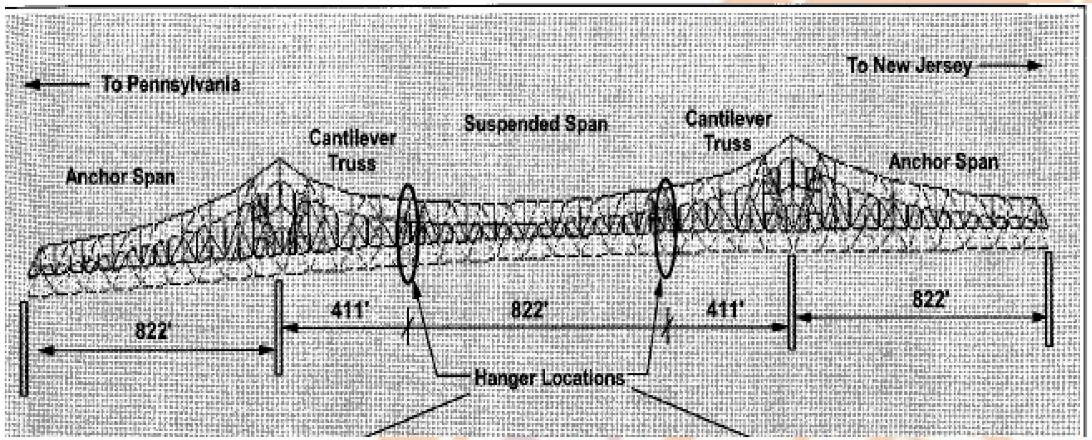
Silver bridge was built in 1928 as suspension bridge. It used eye bars and rigid hangers to support the deck. Each structural unit was a set of steel links held together laterally on a pin.

CAUSE OF COLLAPSE

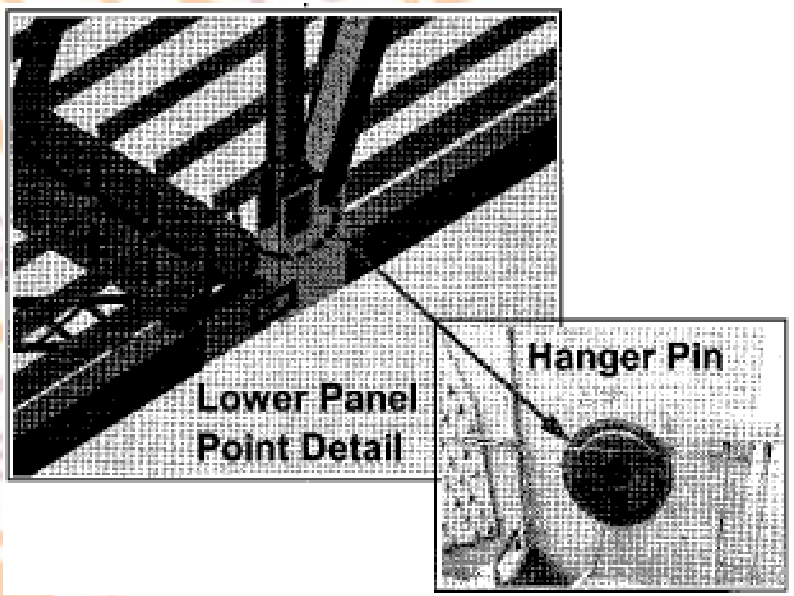
Stress corrosion failure of an eyebar link.

Source: http://open.jorum.ac.uk/xmlui/bitstream/handle/123456789/1025/Items/T357_1_section10.html

VULNERABLE COMPONENT: HANGAR PIN



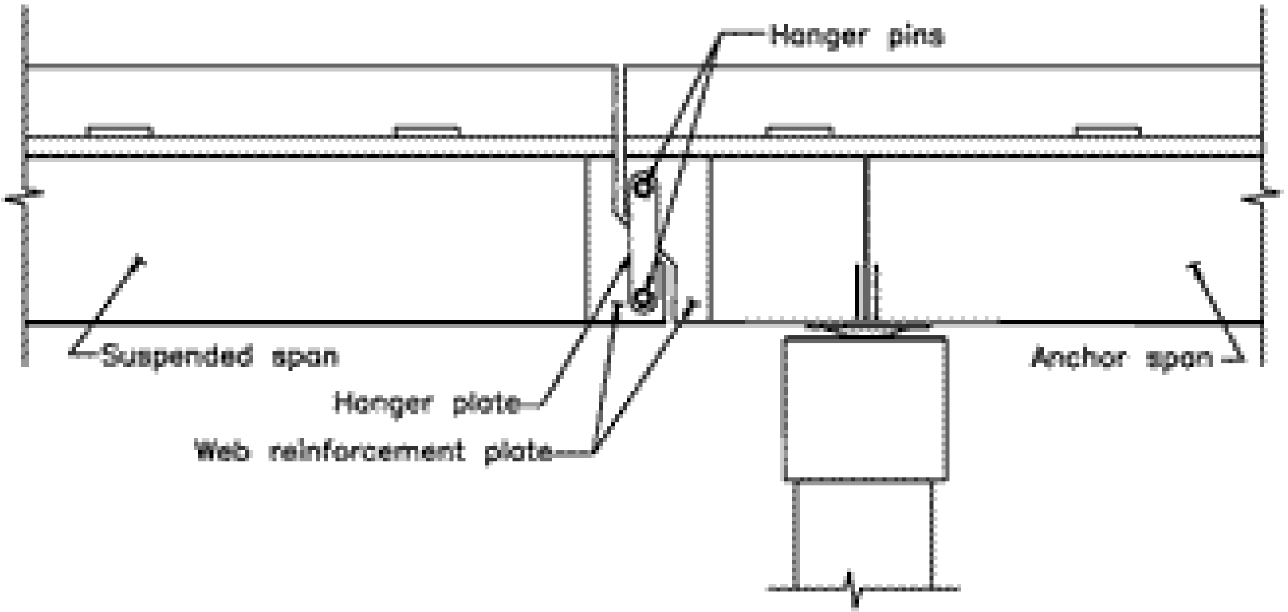
Long span cantilever truss bridge



Aktan et al. (2000):

Failure of any one of the four primary hanger elements may release such significant forces that the remaining elements may also fail due to the surge in their force levels.

VULNERABLE COMPONENT: HANGAR PIN

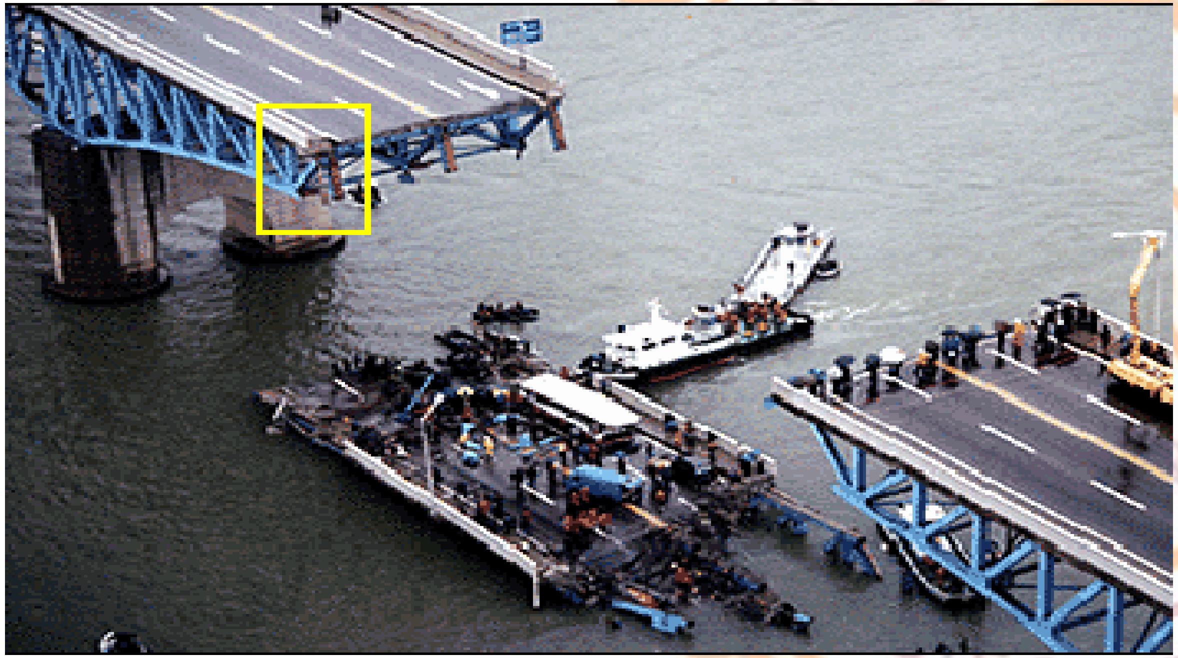


The primary function of a pin-and-hanger connection is to allow for longitudinal thermal expansion and contraction in the bridge superstructure. These connections are designed to support the transfer of shear forces from the suspended span into the anchor span.

http://www.fhwa.dot.gov/publications/publicroads/00nov/ultrasonic.cfm

VULNERABILITY OF DETERMINATE STRUCTURES

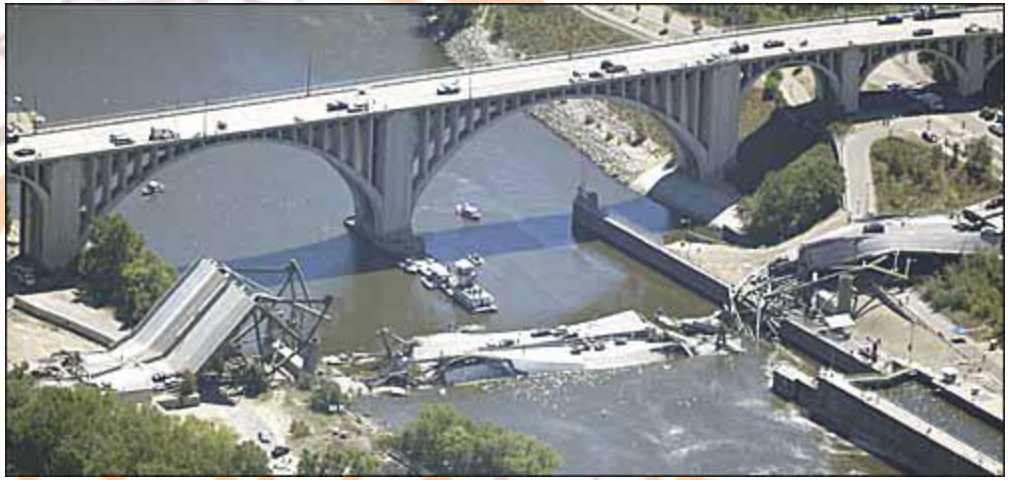
Collapse of Seongsu Bridge, Seoul, in 1994 (Park et al., 2006)



Vertical truss member

Fatigue cracks developed in welds connecting flange with web, causing failure of the member

I 35 BRIDGE IN MINNEAPOLIS
01 AUGUST 2007



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I 35 BRIDGE IN MINNEAPOLIS
01 AUGUST 2007

MAJOR DESIGN FLAW POINTED OUT BY EXPERTS

(Astaneh-Asl, 2008) http://www.ce.berkeley.edu/~astaneh

- Gusset plates were half the required thickness of 25mm.
- Corrosion further weakened the undersized gussets.
- Buckling of several gusset plates also went unnoticed.
- Situation further aggravated by piling of construction material on deck.

NICOLL HIGHWAY COLLAPSE SINGAPORE APRIL 20, 2004

Connection between struts supporting the retaining diaphragm walls gave way, triggering progressive failure from bottom up

INTERIM REPORT BY COMMITTEE OF INQUIRY

(Magnus et al., 03 September 2004):

"A NEW PILING TECHNIQUE WAS USED. BEING UNFAMILIAR CONSTRUCTION TECHNIQUE, MORE EMPHASIS SHOULD HAVE BEEN LAID ON REGULAR MONITORING……...."

NICOLL HIGHWAY COLLAPSE SINGAPORE APRIL 20, 2004

FINAL REPORT BY COMMITTEE OF INQUIRY (11 May 2005) (Magnus et al., 2005):

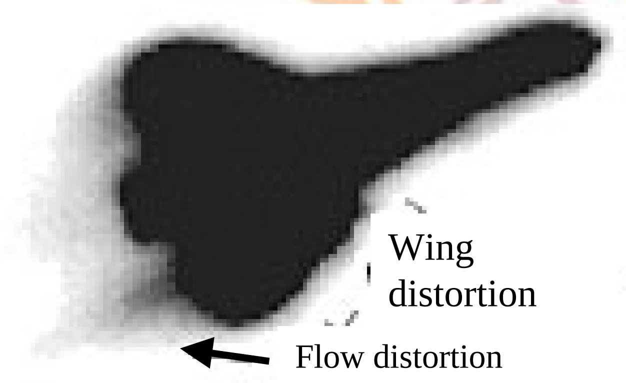
Soil strength was overestimated, forces on retaining wall were underestimated during design.

COMMITTEE REMARKED……….

"…………There should be appropriate instruments deployed. There should be proper use and management of the collated data. The monitoring system must determine the qualitative and the quantitative data sufficient to meet all design and construction needs. In particular, monitoring during construction must be meticulously undertaken with an eye to safety……………."

COLUMBIA SPACE SHUTTLE DISASTER (February 1, 2003)

- Shuttle was not equipped with any NDE system to evaluate the level of damage caused
- Based on computational analysis, ground team concluded that the wing was safe in spite of impact.



WHY STRUCTURAL MONITORING?

- Continuous monitoring to facilitate life-cycle management decisions in a smooth fashion.
- Design Validation. Design often based on parameters affected by statistical variation and uncertainty.
- Evaluation of structure after retrofitting.
- To overcome the constraints of visual inspections

SHM can facilitate generating a database of external loads, stress distributions, deflections etc., thereby facilitating greater understanding of structure.

UNFORTUNATELY....

Even a car costing only a few lacs is well equipped with sophisticated sensors which continuously monitor its operational performance.

However, we Civil Engineers seldom bother to validate designs or monitor structures after construction.

Traditional visual inspection is time and cost intensive

DEFINITION OF DAMAGE

Yao (1985):

"DAMAGE" IS ANY DEFICIENCY OR DETERIORATION IN THE STRENGTH OF A STRUCTURE, CAUSED BY EXTERNAL LOADING, ENVIRONMENTAL CONDITIONS OR HUMAN ERRORS.

CRACK, DELAMINATION, REDUCTION OF FLEXURAL RIGIDITY (EI) ARE SOME OF THE PHYSICAL MANIFESTATIONS OF DAMAGE

https://www.teachengineering.org/lessons/view/uoh_carbonfiber_lesson01

DEFINITION OF FAILURE

URUGAL AND FENSTAR (1995):

FAILURE IS AN INABILITY ON THE PART OF A STRUCTURE TO FUNCTION IN THE INTENDED MANNER.

FRACTURE, PERMANENT DEFORMATION, BUCKLING ARE SOME OF THE MODES OF FAILURE.

FAILURE RESULTS WHEN A PARTICULAR TYPE OF DAMAGE EXCEEDS ITS THRESHOLD VALUE, IMPARING FUNCTIONING OF STRUCTURE.

https://amtiss.com/blog/2019/09/03/3-types-of-machine-failure/

RUN-TO-FAILURE (RTF) MAINTAINENCE

Run-to-failure (TRF) maintenance, also known as reactive maintenance, is a strategy typically employed in production/ manufacturing, wherein the equipment/ machine is used till it fails, at which point major repairs or replacements are performed.

This doctrine is typically followed in case of Civil structures also.

https://www.je-bearing.com/news/run-failure/

PREVENTIVE MAINTAINENCE

Preventive maintenance is the act of performing regularly scheduled maintenance activities to help prevent unexpected failures in the future.

Petrol engine cars should have their oil changed every 3,000-6,000 miles or six months.

Structural Health Monitoring offers a very balanced maintenance approach for Civil Structures

https://www.machinerylubrication.com/Read/30787/oil-change-signs

STRUCTURAL HEALTH MONITORING (SHM)

Aktan et al. (2000):

Measurement of operating and loading environment and critical responses of a structure to track and evaluate the symptoms of operational incidents, anomalies, and/ or deterioration or damage indicators that may affect operation, serviceability or safety reliability

Kessler et al. (2002):

SHM denotes a reliable system with ability to detect and interpret adverse ‘changes’ in a structure due to damage or normal operation.

It implies acquisition, validation and analysis of technical data to facilitate life-cycle management decisions.

CONDITION ASSESSMENT

Periodic or one-time establishment of the current conditions, specifically aimed at assessing the fitness for purpose. This is a subset of SHM.

In contrast, SHM implies continuous monitoring so as to build up a database of the loading demand and to diagnose the onset of anomalies in structural behaviour and performance (Moyo, 2002).

https://serc.res.in/load-testing-arch-bridges

NON-DESTRUCTIVE EVALUATION (NDE)

Wide group of (experimental) analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage. These may aid in SHM.

Common NDE techniques include ultrasonic, magnetic-particle, dye penetration, radiography, eddy-currents etc.

SHM may use any one or more NDE techniques. SHM, however, emphasises on continuous evaluation.

https://www.inspection-for-industry.com/step-by-step-dye-penetrant-testing.html

https://www.advantecglobal.com/industrial/magnetic-particle-inspection-explained/

STRUCTURAL HEALTH MONITORING
VERSUS
STRUCTURAL AUDIT

Structural Audit is one time evaluation of a structure done by experts/ agencies primarily based on visual inspection aided with non-destructive evaluation, aiming to check compliance to codes and standards and looking at signs of structural damage, aging and wear and tear.

Structural health monitoring, on the other hand, is a data driven monitoring process relying on sensors……..

Structural health monitoring places emphasis on regular/ continuous monitoring…

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CAUSES OF DAMAGE IN STRUCTURES

- Environmental degradation
- Fatigue
- Excessive loads
- Natural calamities
- Vehicle impacts
- Prolonged intensive usage

Even a minor incipient damage carries the potential to grow and lead to either disruption of services or loss of lives and properties or both.

WHAT TO MONITOR

EXTERNAL LOADS

due to construction, occupancy, vehicle movement, blast / shocks or other factors) and the associated stresses and deflections

LHR= Load History Retrieval

OCCURRENCE OF DAMAGES

SHM, Structural Health Monitoring

SHM: WHERE ARE WE HEADING??

- Now very well recognized as a crucial element of overall structural management

- However, not part of codal requirements….but now included in contract for critical structures.

- No detailed benefit-cost analysis available

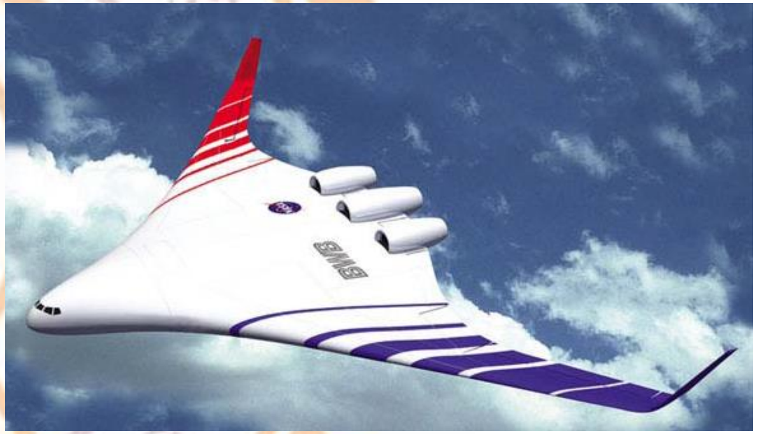
- No means of certification available

FUTURE FOR STRUCTURAL MONITORING

One of top 10 technologies that have the most potential for changing the aftermarket landscape in 2011 and beyond (Aviationweek, 2011).

Airplane Information Management System (AIMS)

Honeywell's airplane information management system (AIMS) is an integrated modular avionics system providing the Boeing 777 full cockpit integration – hosting technology including the primary flight-deck display system, the aircraft diagnostics and maintenance systems.



According to market research reports, the value of the SHM industry is to increase to nearly $ 6-8 billion by 2025.

LVL	TECHNOLOGY READINESS LEVEL (Roach and Neidigk, 2011)
1	Physical principles are postulated with reasoning
2	Application for physical principles identified but no results
3	Initial laboratory tests on general hardware configuration to support physical principles
4	Integration level showing systems function in lab tests
5	System testing to evaluate function in realistic environment
6	Evaluation of prototype system
7	Demonstration of complete system prototype in operating environment
8	Certification testing on final system in lab and/or field
9	Final adjustment of system through mission operations
	Roach, D. and Neidigk, S. (2011), "Does the Maturity of Structural Health Monitoring Technology Match User Readiness?", Proceedings of the 8th International Workshop on Structural Health Monitoring, 13-15 September, Stanford University, Stanford.

STRUCTURAL HEALH MONITORING

FUTURISTIC OPPORTUNITIES FOR INDIA & WORLD

- Worldwide market forecast till 2025: US $6-8billion.
- Technology Start-Ups
- Continuing Education and Manpower Training
- Development of Low-cost Sensors
- Integrating Structural Health Monitoring and Energy Harvesting
- Make/ Made-in-India
- Emphasis on Vocal for Local

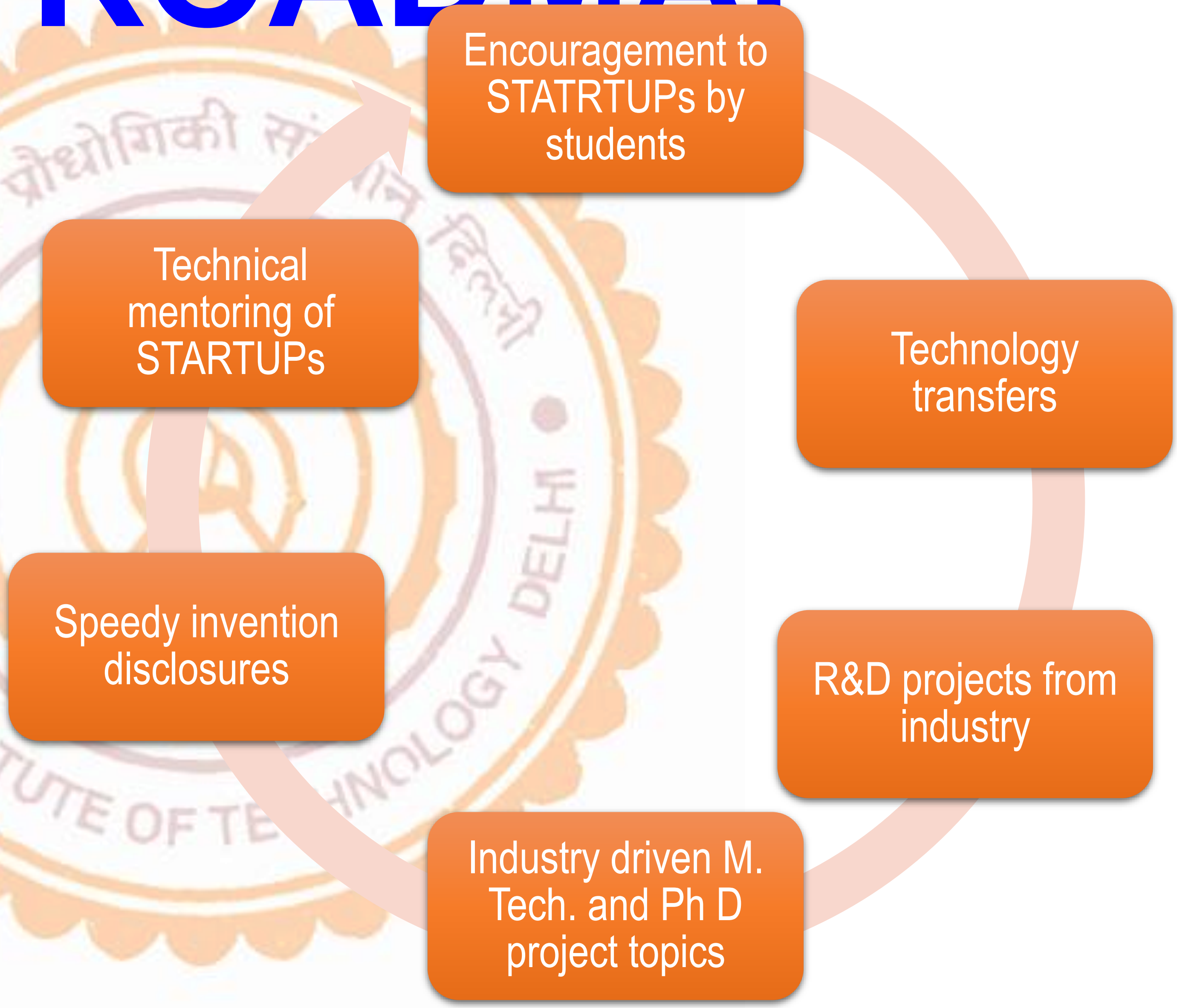
SUCEESS DRIVERS

- SHM techniques which are not heavily dependent on modelling
- Minimal baseline data requirement
- Reusable, rugged and long-life sensors
- Cloud & IOT enabled
- Self powered (solar/ wind/ structural vibrations)
- Integration with AI

The Internet of Things (**IoT**) describes the network of physical objects—“things”—that are embedded with sensors, software, and other technologies

INDIA'S ROADMAP

- Need SHM trained engineers
- Industry-academic joint research
- Ecosystem for academicians, Start-Ups, Industry
- Policy (initiate inclusion in codes of practice)



THANK YOU

Suggested reading:
Aktan et al. (2000)