STRUCTURAL HEALTH MONITORING

(BSTB07)

M.TECH I SEMESTER

Prepared by

Mr. N Venkat Rao

Associate Professor

Department of Civil Engineering

UNIT I

STRUCTURAL HEALTH

FACTORS AFFECTING HEALTH OF STRUCTURES:

- External factors and loads influence and impact the life and quality of structures and buildings.
- Forces of nature are some of the harshest tests that these structures are subjected to.
- From different kinds of wind loads to seismic loads, effects of corrosion and solar radiation – there are many factors to consider in the engineering and design of buildings and structures:

Wind Effects On Structures

- Wind is a powerful force that has a great deal of effect on structures. There are two broad types of effects of wind on structures: static and dynamic.
- The static load mainly leads to elastic bending and twisting of structure. Dynamic analysis of wind is required for skyscrapers, taller, long-span and slender structures.
- This is because gusts of wind cause fluctuating forces on the structure that induce large dynamic motion, including oscillations.

Fig.1 Air pollution

Effects

- In contemporary architecture, tall buildings and skyscrapers have increasingly complex design and scale that puts them at a greater risk to wind effects and induced forces on the structure. How various structures respond to wind depends on the characteristics of wind.

- With taller structures that have high aspect ratios, it is vital to analyze the unsteady vortex shedding because this can cause oscillating cross wind forces with a certain frequency.

- And if this coincides with the natural frequency of the structure then it could lead to a lot of damage or even structural failure.

Architectural use

The architectural, civil and structural design engineers must create a safe, sustainable and cost-efficient design with the help of wind engineering skills and studies. Wind engineering is an industry standard and is used to first review the dynamic impact of wind on structures and also understand the ways in which design can be optimized to mitigate the effect.

Effects of corrosion

- Mitigate the effect.
- Impact of Corrosion on Structural Integrity
- Put simply, corrosion is the damage to metals over a period of time because of their reaction with the environment.
- For civil and structural engineers, corrosion is not simply an aesthetic issue; it causes severe damage and deterioration to buildings, bridges, equipment and pipelines.
- While the metal components on the exterior of the building are more prone to atmospheric damage and corrosion, the effect of corrosion on all the metal elements especially within the building – like foundation and structural walls – is equally bad.

Effects of corrosion

- If suitable corrosion control and prevention measures are not applied, corrosion can lead to irreparable structural damage and serious problems in the long-term.

- Whilst most corroded elements and structures can be salvaged or replaced, the cost is prohibitive. This is mainly why best practice recommends contractors to exercise a preventive approach.

- During project planning and design stages, structural engineers must look into the site data sheets or environmental studies documents and specifications along with the metal components and coating systems' survivability given the environment factors.

corrosion in buildings

Corrosion in building structures:

can diminish the overall value of various buildings because it can result in:

- Thinning of metals used, leading to loss of mechanical strength, damages and ultimately failure.
- Environmental damage: leaking pipes, fuel tanks and vessels can have grave consequences on public health and the entire ecosystem.
- Corrosion Of Steel In Concrete.
- Concrete is a secure protective layer for steel and prevents corrosion and rusting of steel.

Environment

- Owing to high initial alkalinity, a thin passive film of ferric oxide is automatically formed on the steel surface. It is this layer, however thin, that protects steel from corrosion.
- However, once the environment loses its alkalinity, the layer is no longer effective and the steel starts corroding.
- To maintain the alkalinity of the environment, the concrete needs to be impermeable. The following preventive measures can be taken to mitigate corrosion

Ensure of reinforcement

- Ensure reinforcement is not heavily congested specifically at the intersection of beams and columns.
- Prevent steel from coming in contact with soil, wood, bricks and other porous non-alkaline substances.
- Use materials sensibly, avoiding those that promote the corrosion process that is aggregates with high salt, water containing high salt etc.
- Best-in-class structural design practices with provision of cover
- Giving cathodic protection to reinforcements.
- Corrosive resistant surface coatings with paints, tars, asphalts, etc.
- Using high grade, impermeable concrete.
- Correct water-cement ratio.

Solar radiation

- Solar Radiation
- Solar radiation or UV rays are the energy from the sun. The quantity of solar radiation on a particular site depends on the location – that is latitude and sunlight hours in that area.
- Effect Of Solar Radiation On Buildings
- UV radiation impacts the durability of many building materials. The paints fade, plastic-based materials become brittle, timber twists and moves, and expansion and contraction owing to heating and cooling causes stress on various materials, so UV radiation is an important consideration in the building's sustainability.

Introductory Definitions

Repair: Process of reconstruction and renewal of the existing buildings, either in whole or in part

Renovation: Process of substantial repair or alteration that extends a building's useful life.

Remodeling: Essentially same as renovation – applied to residential structures.

Rehabilitation: An upgrade required to meet the present needs – being sensitive to building features and a sympathetic matching of the original construction.

Introductory Definitions

Repair: Process of reconstruction and renewal of the existing buildings, either in whole or in part

Renovation: Process of substantial repair or alteration that extends a building's useful life.

Remodeling: Essentially same as renovation – applied to residential structures.

Rehabilitation: An upgrade required to meet the present needs – being sensitive to building features and a sympathetic matching of the original construction.

Introductory Definitions

Restoration: More restrictive term than rehabilitation – suggests replicating the structure as originally built (Ref. Historical buildings)

Retrofit: Upgrading certain building systems such as electrical, mechanical, or structural to improve performance or appearance.

Refurbishment: Replacement of certain components and using whatever is alright.

UNIT II
STRUCTURAL HEALTH MONITORING

Social Benefits

Societal Benefits of Structural Health Monitoring (SHM)

- The monitoring and maintenance of structures that mark modern society has long been considered to be crucial. Applying effective approaches to the regular upkeep of bridges, skyscrapers, roads, and other structures is essential.

- In addition to the need to keep buildings and infrastructures running smoothly, maintaining safety and public health is also of great importance.

- Today, new technological developments and methods are being utilized as part of a process now referred to as Structural Health Monitoring (SHM).

Social Benefits

- Proponents of this emerging capability understand the importance of successfully maintaining civil infrastructures.
- Recently, various automated tools and systems have emerged to improve inspection processes and structural analysis for the benefit of society.
- In addition, government regulations for building and construction, required maintenance, and new mandates surrounding data collection applications have also contributed to the development of SHM.

Social Benefits

- This emerging trend has a number of benefits, from improving safety standards and reducing risks, to discovering new opportunities to reduce costs, and safety.
- Increased Safety
- Greater efforts to improve SHM ultimately work to improve overall public safety. These efforts include everything from new guidelines and policies that help ensure building and construction safety, to the development of new technologies that make achieving safety simpler.

Social Benefits

- Federal mandates requiring municipalities to repair or replace pipes that contain lead or corrosive damage, is just one example of how greater attention to SHM is helping improve public health.

- In the case of technology, new instruments are monitoring and analyzing digital information about the integrity of bridges, buildings, and other structures.

- This has made it easier to determine whether a structure is in good or fair condition, or is unsafe.

Advanced SHM methods

Advanced SHM methods:

- Using sensors, data collection, and analysis—have greatly improved the ability of engineers to contribute to public safety.
- This is particularly important with aging structures. The SHM process could involve testing the faltering strength of old buildings, or analyzing the corrosion levels of older pipes that transport water or fossil fuels.
- New structures can also benefit from advanced SHM technologies.
- Continual monitoring and analysis helps pinpoint design flaws, and works to recognize environmental factors.

Safety risks

Detecting Early Safety Risks:

- In addition to helping engineers recognize poor structural conditions and other safety issues, advances in SHM also help professionals determine potential future risks to safety.

- This has been particularly useful in preventing water and flood damage caused by failed dams, dykes, pipelines, and other similar structures.

- In this context, built-in sensors are able to monitor changes in water levels and detect minor leaks in water infrastructures early on—enabling engineers to help prevent more significant damage down the road.

Safety risks

- New monitoring technologies can also be used to track the geotechnical details of foundations for roads, buildings, and other structures.

- This provides engineering professionals with the ability to detect ground movement early on, enabling them to prevent or mitigate catastrophic risks involved with earthquakes, landslides, and other disasters.

.

Longer Life spans

Longer Life Spans:

Naturally, performing regular preventative and emergency maintenance on civil infrastructures helps increase their longevity. Various technologies and new approaches using SHM give engineers the tools to build and maintain longstanding structures like never before.

- Installing proper sensing technology not only provides greater details about structural health, but also helps account for human error.
- Traditional methods of visual monitoring and analysis could often overlook design flaws or immediate safety risks.

Longer Life spans

- New instrumentation and methods now provide for greater accuracy by using digital data collection and analysis.

- Furthermore, automated inspection systems, and the increasing use of smart technology that provides real-time analytical details, allow for more frequent, more accurate monitoring and risk analysis.

- These have vastly improved the efficiency of inspections and detection, and have increased the effectiveness of maintenance procedures that reduce the likelihood of catastrophic structural failures and damage.

Cost Efficiency:

- In addition to improving safety and ensuring longer life spans for structures, SHM can also greatly reduce long- and short-term costs related to structural maintenance.
- Of course, reduced costs are inherent in improved safety measures that reduce the risk of catastrophes as well as structural and environmental damage.
- Likewise, maintaining structural integrity for longer periods of time reduces overall costs related to demolition and rebuilding.

Assessment

- Additionally, SHM technology reduces the need to halt profitable operations for large-scale safety inspections, and to perform unnecessary maintenance on structural components that are still in good condition. This reaps economic benefits for business and industry.

- As the monitoring and assessment capabilities of SHM become more sophisticated, and the list of benefits they provide continues to expand, the application of SHM technology will become more prominent.

Assessment

- Safety accountability and expectations for property owners, governments, and builders are likely to continue to increase.

- This means that more policies will be put in place to ensure that innovative SHM methods are being put to greater use.

- The end goals are to reduce costs related to inspection labor, mitigate the impact of structural disasters, reduce unneeded repairs, and improve public safety for us all.

Assessment

- Of course, there are some challenges with SHM in terms of standardizing policies, given the diversity of new and old structures as well as the range of construction methods.

- Still, advances in SHM continue to improve in the face of these challenges—and more professionals are recognizing the range of benefits to implementing SHM methods.

Recommended Readings:

- The Managerial Aspects of Construction Contracting

- The Basics of Temporary Traffic Control

- Bridge Scour Protection & Preventing Bridge Failure

Structural stability during alteration, demolition and dismantling

What you need to do

The law says that all alteration, demolition and dismantling work should be carefully planned and carried out by competent people to avoid unplanned structural collapse.

- The law requires commercial clients to provide contractors with relevant information about a building's structure, including stability and structural form and any significant design assumptions, suggested work methods and sequences.

- The contractor must then use that information to plan and carry out the work safely.

Key requirements are:

- Survey and assessment
- Preventing structural collapse
- Arrangements for demolition
- Consulting building control departments

What you need to know

- Workers and passers-by can be injured by premature and uncontrolled collapse of structures, and by flying debris.
- Survey and assessment

A competent person should do a thorough structural survey and assessment before any potentially load- bearing parts of a structure are altered.

The structural survey should consider:

- The age of the structure;
- previous use;
- type of construction; and
- any nearby buildings or structures.

This information should be used to determine the steps required to prevent any collapse.

Preventing structural collapse

- A competent person should decide the method and design of temporary supports. Temporary support provided must be designed, installed and maintained to withstand foreseeable loads and structures should never be overloaded.
- Arrangements for demolition
- Demolition or dismantling arrangements should be written down before the work begins.
- This safe system of work may be in the form of a safety method statement identifying the sequence required to prevent accidental collapse of the structure.

- In addition to the design and method of temporary supports a safe system of work may include:
- Establishing exclusion zones and hard-hat areas, clearly marked and with barriers or hoardings;
- covered walkways;
- using high-reach machines;
- reinforcing machine cabs so that drivers are not injured; and
- training and supervising site workers

Factors contributing to corrosion

Factors contributing to corrosion:

External factors:

Availability of oxygen and moisture at rebar level

- Carbonation and entry of gaseous pollutants that reduce the pH of concrete
- Ingress of chloride ions
- Stay currents
- Relative humidity and temperature

Factors contributing to corrosion

Internal Factors:

Cement composition- Adequate amount of cement helps to maintain the pH of concrete in the range of 12.5 and 13

Impurities in aggregate- Aggregates containing chloride salts

Impurities in mixing or curing water

- Water/cement ratio- It has no direct bearing, but permeability is the function of w/c ratio.
- Increase in w/c ratio increases the permeability of concrete which in turn increases the penetration depths of chlorides, carbon dioxide and oxygen diffusion in concrete.

Factors contributing to corrosion

Aggregate size and grading- large sized aggregate increase permeability.

Coarse aggregate and fine aggregate must be appropriately proportioned in order to have a compact mass.

- Poor construction practices
- Use of admixtures like $CaCl_2$
- Inadequate cover to reinforcement.

UNIT III
STRUCTURAL AUDIT AND STATIC FIELD TESTING

Structural audit

Structural health monitoring (SHM) technology has various applications in different engineering fields.

The technology of setting up sensors, the sensors type, and the assessment procedures are key elements for damage detection and material characterization.

- Studies that incorporate the effect of loads on SHM are still limited. The latest development in the sensors' quality and the monitoring systems has triggered new ideas in the existing SHM methodologies.

Fig. 3 Deteriorated structure

- The building audit (building structure audit) is the process by which a building is tested / evaluated to reveal its quality worth.
- There are three types of tests during this evaluation process:
  A. Visual Inspection – before you go hardcore and set the proper milestones of testing, the construction should be visualized in order to:
- recognize the structural defects;
- identify the signs of material deterioration;
- identify structural distress or deformation;
- identify extra alteration / addition in the structure that can lead to overloading

- Any crack, stress mark, damp spot or an unusual touch up on a surface, when carefully observed, these apparently minor indicators can sing a song to an expert, revealing the health of a building.
- Non Destructive (NDT) and Destructive Testing (DT) – these tests are of great importance in order to determine the strength and quality of concrete, to determine the damage to construction structures subjected to corrosion, chemical attack, fire or other reasons.

Concrete strength tests:

- Rebound Hammer Test: to measure surface hardness of concrete;
- Ultrasonic Pulse Velocity Test: to assess homogeneity of concrete, to assess strength of concrete qualitatively, to determine structural integrity;
- Core Sampling and Testing: to measure strength, permeability, density of concrete

Chemical attacks

B2. Chemical attacks:

– Carbonation Test: to assess depth of carbonation and pH of concrete;

– Chloride Test: to assess total water/acid soluble chloride contents;

– Sulfate Test: to assess total water/water soluble sulfate contents of concrete

Corrosion Potential Assessment:

- **Corrosion Potential Assessment:**
  – Cover Meter: to measure cover of reinforcement, diameter of reinforcement and spacing of reinforcement;
  –Half Cell Method: to assess probability of corrosion in the embedded steel;
  – Permeability Test: to assess permeability of concrete due to water and air
- Homogeneity and integrity Assessment
  – Ultrasonic pulse velocity: for determination of cracks and discontinuities

Types of testing

- **Core Testing:**
  This method is hard testing the concrete strength. In this method cylindrical core samples are taken from existing structures. The cores are visually inspected and tested in laboratory to check its comprehensive strength.

- **Overload Testing:**
  The easiest type of testing that can be used to ascertain the strength of a concrete roof is to load it with weights and check the degree of variation that it undergoes under that load on different building levels and floors.

Need for Evaluation of Reinforced Concrete Structures:

The different types of deterioration get noticed in different forms like cracking, spalling, staining etc. These visual forms indicate the presence of problem. The symptoms alone are not enough to find the correct solution, the reason being there could be more than one cause responsible for the particular symptom.

- It is imperative to determine and eliminate the cause of the original damage because any repair that is made on the basis of an incorrect estimation of the cause is likely to damage the repaired concrete also, resulting in larger and expansive repair of repairs

Condition and evaluation of concrete structures:

- Condition evaluation is generally carried out under any of the given circumstances
- Change in resistance of structure due to deterioration owing to time-depending processes such as corrosion or fatigue.
- Structural damage due to accidental loadings like earthquake, tsunami, fire, blasts, etc.
- Structures subjected to change in use, operational changes or increased load where it is necessary to check the adequancy of the structure to resist additional loads.

Condition assessment

Condition assessment generally leads to two major findings:

- Condition of the structure is satisfactory and requires no further intervention
- Structures require any of the following

  Preservation: The process of maintaining a structure in its present condition and arresting further deterioration

  Rehabilitation: The process of repairing or modifying the structure to its desired useful condition.

Repair: The process of replacing or correcting deteriorated, damaged, or faulty materials, components, or elements of a structure.

Restoration: the process of re-establishing the materials, form, and appearance of the structure.

Strengthening: The process of increasing the load-resistance capacity of a structure or portion.

Retrofitting: the process of strengthening the structure along with structural system.

Objectives of condition assessment

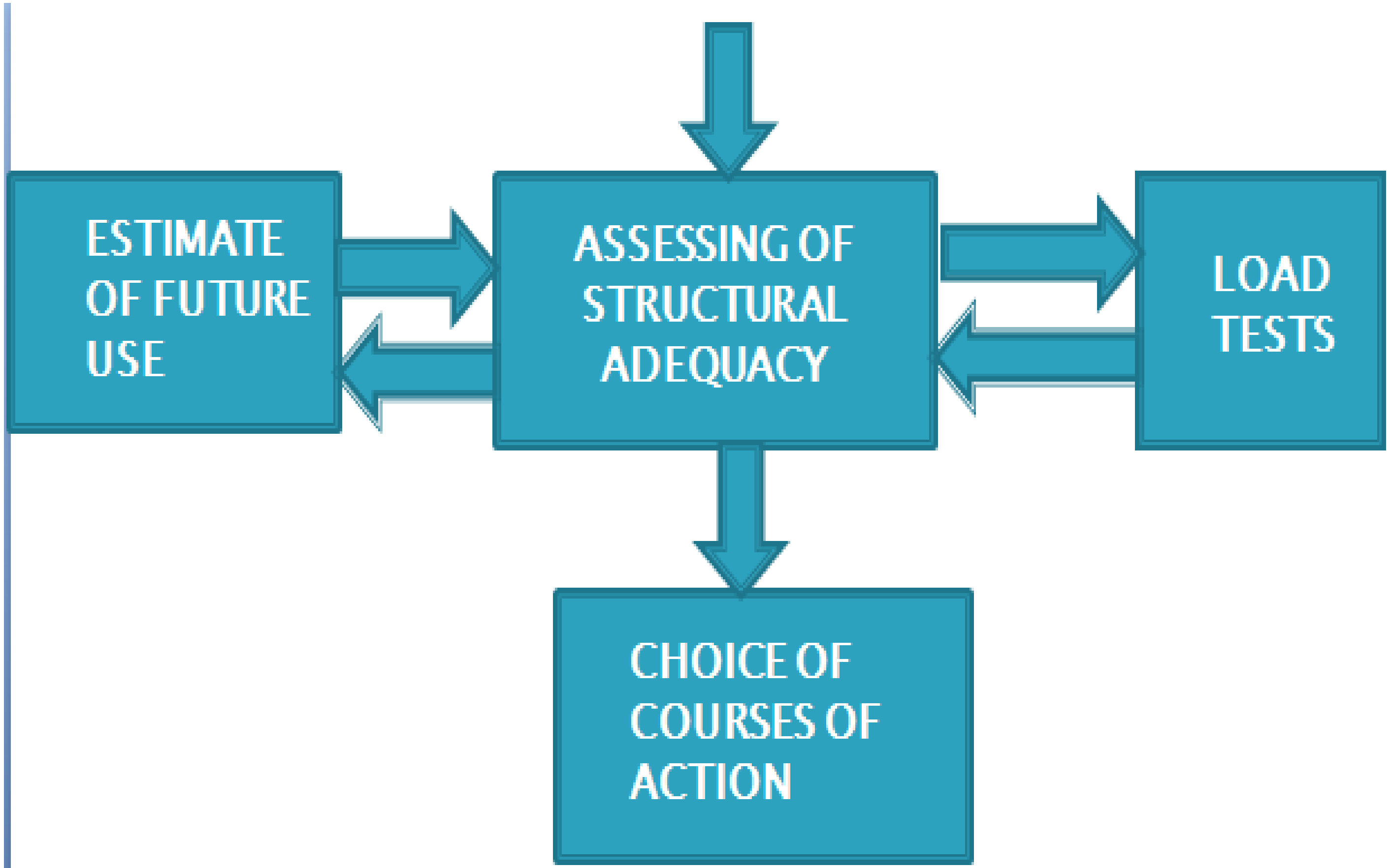
Condition assessment of the structure is the systematic and logical examination of the structure to identify the area and cause of distress:

The objectives of condition assessment include the following:

- To provide insight into the current condition of the structure i.e. to identify the cause & source of observed distress.
- To assess the extent and development of the deterioration.

- To assess the influence of the deterioration on the safety and life expectancy of the structure i.e. determining the residual strength of structure and its possibility of being repaired.
- To accurately assess the scenario of concrete in structure in terms of its physical, chemical and electro-chemical properties.
- To prioritise the repair of the distressed elements in order of the seriousness of the deterioration.
- To chart out an effective and economically feasible concrete-repair program.


PHYSICAL INSPECTION
MATERIAL TESTS
STUDY OF DOCUMENTS
ESTIMATE OF LOAD ACTING
ESTIMATE OF ENVIRONMENTAL EFFECTS
DIAGNOSIS
RETROSPECTIVE ANALYSIS
IS DIAGNOSIS CONFIRMED


ESTIMATE OF FUTURE USE
ASSESSING OF STRUCTURAL ADEQUACY
LOAD TESTS
CHOICE OF COURSES OF ACTION

Stages of conditional assessment

Stages of conditional Assessment:

- Preliminary investigation
- Detailed investigation

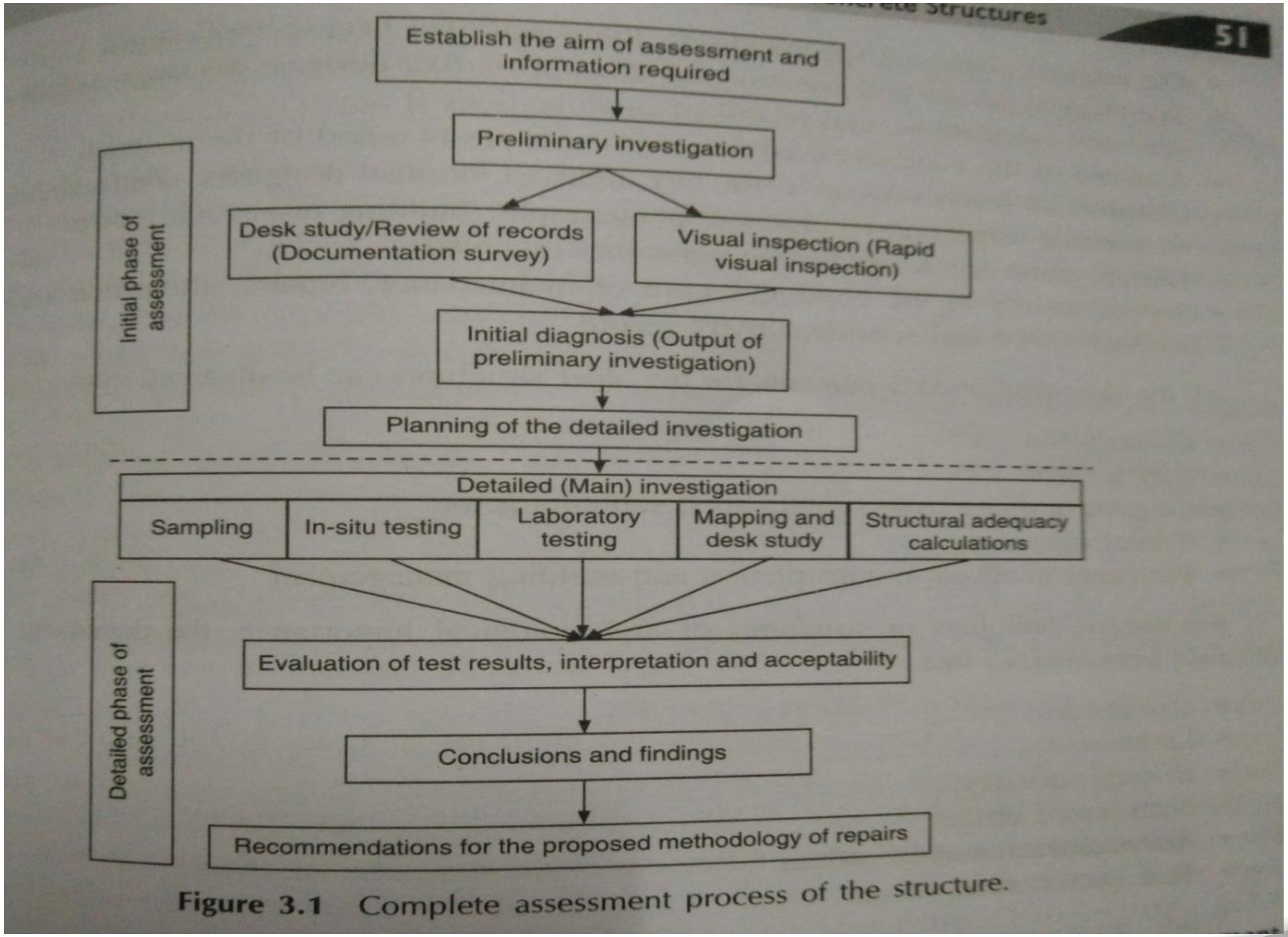


Figure 3.1 Complete assessment process of the structure.

Preliminary investigation

Preliminary investigation: It helps to understand the past record of the structure in terms of the distresses and repair carried out if any. It is also helps to assess the apparent physical condition, robustness, structural integrity and strength of structure.

- The main objective of preliminary investigation include
- To obtain the initial information regarding the condition of structure by studying past records based on the information obtained from the owners, occupants of the buildings and general public.

- To understand the type and the seriousness of the problems affecting the structure
- To determine the feasibility of performing the required repairs and rehabilitation works.
- To identify the need for detailed investigation
- To plan the necessary site preparations, procurement of the required field-testing equipment and tools for sampling.

Preliminary investigation can be broadly classified into two headings: Review of records, Condition survey.

Review of record: A thorough review of all pertinent data related to design, construction and service life of the structure is assessed in evaluating the condition of structure.

- The list of records which should be gathered includes:
- The original plans & specifications.
- The original design and construction documents like design, drawings, specifications, structural calculations, and record of modification if any.

- A record of materials used in construction-tests reports of the material
- Building inspection records
- Design construction and testing personnel involved such as
- Service history of building-record of maintenance,
- repairs,
- alterations,
- settlement,
- weather record and
- seismic-activity record

- Things one must look for while carrying out the visual inspection
- Verification of information collected during desk study, i.e., to verify if the on-site conditions are in conformance to the available designs and drawings.
- Record of the existing condition of concrete, i.e., note of construction faults like bug holes, cold joints, honey combing, exposed reinforcement, corrosion etc.
- Presence of cracking (location, depth, width, nature of cracking, the surface appearance of the cracks, current state of activity, physical state of concrete when the cracking occurred)

- Surface appearance of cracks (pattern of cracks, length of cracks, short cracks or interconnected)
- The surface appearance of concrete (texture, discolouration, staining, spalling, delamination and erosion)
- Sources of leakage or seepage due to concealed services, through joints or cracks, inadequate systems of rain water disposal, improper terrace slope or absence of rain water pipes, ponding of water and discolouration due to dampness must be noted.

- Movements of structures in the form of excessive deflections, heaving or settlement.
- Damage to structural elements & finishes like blistering membranes and coatings.

Overall building assessment:

- In overall building assessment, the inspector must look for any abnormal deformation or deflection. Check for any leaning of the building, soil displacement under foundations, load bearing wall or settlement of the floor.
- Water leakage, ponding areas, areas of poor drainage or other indications of water problems must be noted.
- Evidence of any type of chemical deterioration on the building must also be noted.

Component assessment

Component assessment:

- The inspector needs to focus on specific building elements for presence of any kind of defects or deterioration.
- The component assessment has to be properly documented along with sketches showing particular distressed structural member, location, classification and extent of distress, besides the photographic record of defects like cracks, spalls and other surface defects, honey combing, corrosion of reinforcement, loss of c/s, deflections and other misalignments.

Output of preliminary investigation

Output of preliminary Investigation

The major inferences that can be drawn after the preliminary investigation include the following:

Description of the actual condition of the existing structure including the location, extent and nature of the deterioration or distress.

A quality classification of the components or the whole structure and the repair/rehabilitation option based on condition and degree of damage.

Is there any need for detailed investigation

Unit -IV

STATIC FIELD TESTING

What is SHM

What is Structural Health Monitoring (SHM)

"The process of implementing a damage detection and characterization strategy for engineering structures"

SHM Involves:

- Health monitoring
- Operational Evaluation
- Data Feature Extraction
- Statistical Models Development

Objectives of SHM

Objective of Structural Health Monitoring:

- Performance enhancement of an existing structure
- Monitoring of structures affected by external factors
- Feedback loop to improve future design based on experience
- Assessment of post-earthquake structural integrity
- Decline in construction and growth in maintenance needs
- The move towards performance-based design philosophy

Determination of damage existence

↓

Determination of damage's geometric location

↓

Quantification of damage severity

↓

Prediction of remaining life of the structure

Infrastructure	2005	2013
Aviation	D+	D
Bridge	C	C+
Dams	D	D
Drinking Water	D-	D
Energy	D	D+
Hazardous Waste	D	D
Inland Waterways	D-	D-
Ports	C-	C
Public Parks and Recreation	C	C-
Rail	C-	C+

Grade	Implication
A (fit for the future)	Exceptional
B (adequate for now)	Good
C (requires attention)	Mediocre
D (at risk)	Poor
E (unfit for purpose)	Failing

	2005	2013

Roads	D	D
Schools	D	D
Solid Waste	C+	B-
Transit	D+	D
Waste Water	D-	D

Estimated Investment needed	1.6 trillion (by 2010)	3.6 trillion (by 2020)
Overall Condition	D	D+

How to do SHM practice

How to Do SHM in practice?

Visual Inspection

- Fully experience-based
- Subjective/Non-quantitative

Non-Destructive Evaluation (NDE)

- Various technologies for different purposes
- Demands a high degree of expertise
- Time consuming and costly
- Usually requires *a priori* knowledge of the potentially damaged region
- Works only in accessible regions of the structure
- Interruption and downtime
- Labour intensive and risky

Static-Based SHM

Based on the premise that damage will alter the static properties of the structure.

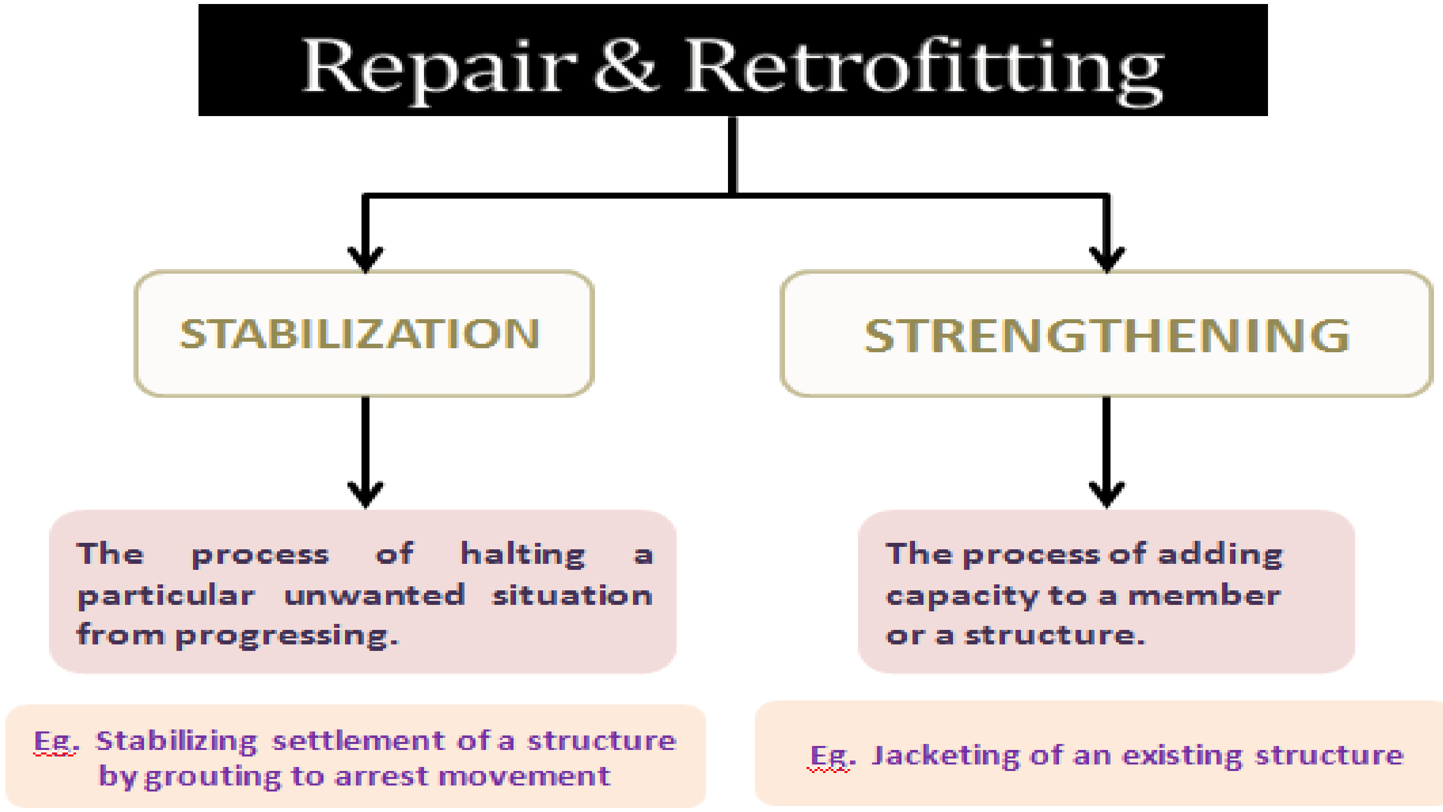
e.g. displacements, rotations, Drawback

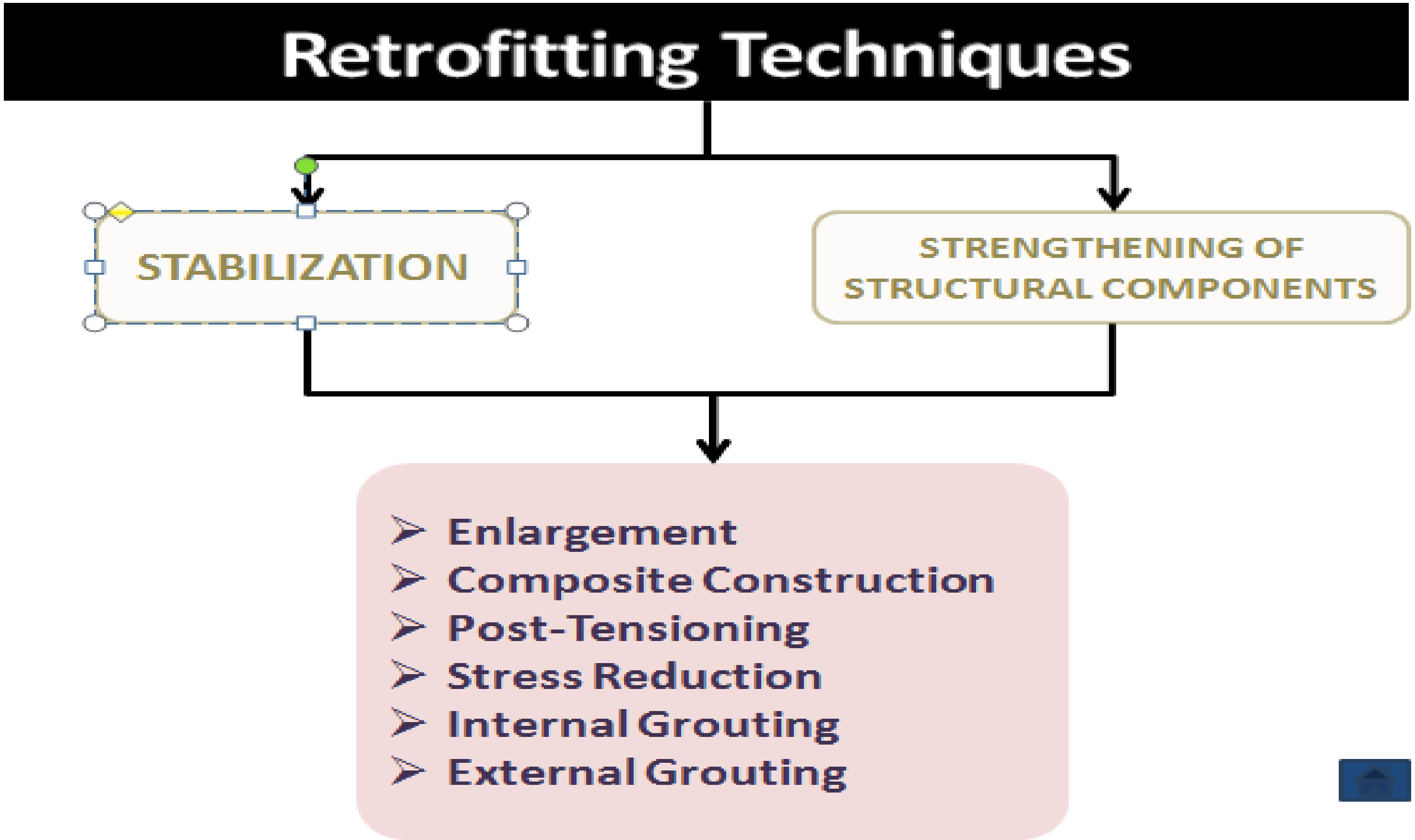
- Considerable static deflection requires large amount of static force Vibration-Based SHM
- Based on the premise that damage will alter the dynamic properties of the structure.

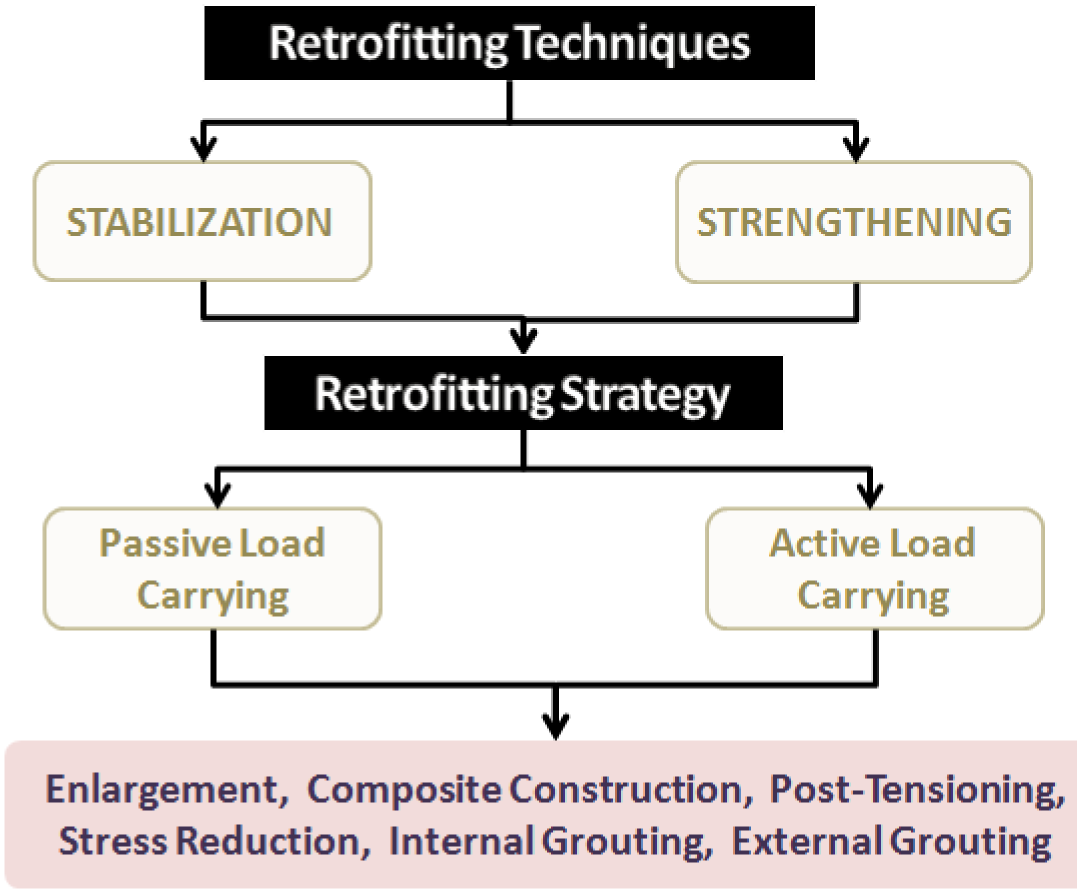
e.g. structural response, frequencies, mode shapes, damping or modal strain energy change

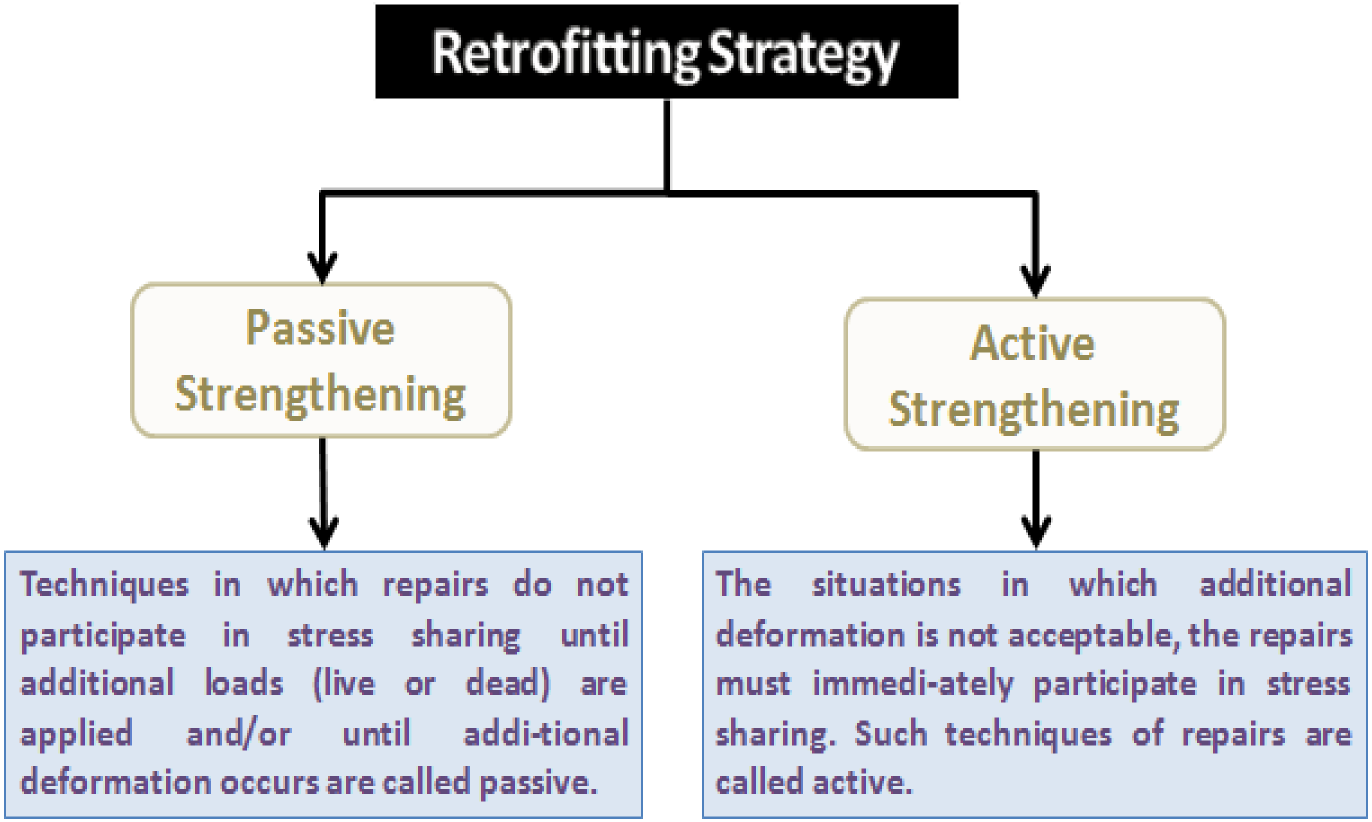
- By measuring the structural response by means of sensors strategically placed on the structure, and intelligently analyzing these measured responses,
- it is possible to identify damage occurrence.
- It can be done either in modal domain or physical domain

BROAD CLASSIFICATION




Retrofitting Techniques
STABILIZATION
STRENGTHENING OF STRUCTURAL COMPONENTS
Enlargement
Composite Construction
Post-Tensioning
Stress Reduction
Internal Grouting
External Grouting


Retrofitting Techniques
STABILIZATION
STRENGTHENING
Retrofitting Strategy
Passive Load Carrying
Active Load Carrying
Enlargement, Composite Construction, Post-Tensioning, Stress Reduction, Internal Grouting, External Grouting


Retrofitting Strategy
Passive Strengthening
Active Strengthening
Techniques in which repairs do not participate in stress sharing until additional loads (live or dead) are applied and/or until addi-tional deformation occurs are called passive.
The situations in which additional deformation is not acceptable, the repairs must immedi-ately participate in stress sharing. Such techniques of repairs are called active.

UNIT-V

INTRODUCTION TO REPAIRS AND REHABILITATIONS OF STRUCTURES

VIBRATION BASED SHM: SENSORS

Different forms of dynamic structural response:

- Displacement, Velocity,
- Acceleration, Strain.
- Which ones to measure depends on monitoring conditions and objectives.Sensing technology: an ever emerging field of study

Based on what to measure, different sensors available:

- Laser Displacement Sensors (LDS)
- Velocity Transducers
- Seismometers
- Piezoelectric Accelerometers
- Strain Gauges

- Most of these sensors can be wirelessly connected


6

Types of sensors

Pros and cons of various types of sensors:

Bandwidth:

- displacement sensors capture low frequency modes
- acceleration sensors capture high frequency modes

Global vs. Local:

- strain gauges capture local dynamics better accelerometers/displacement sensors measure global dynamics. Based on a model (e.g. F.E.) of the monitored structure.

Methods of optimization

Optimization based methods:

- An initial model is updated using measured structural response. Also called FE model updating
- Optimization algorithms are run by iteratively changing the values of some structural properties (e.g. Young's modulus), so that the FEM parameters match measured parameters.
- Measured parameters: Measured responses or some parameters obtained from measured responses (e.g. modal properties).
- Usually require repeatedly solving the forward problem.

Alternatively, inverse problem solution approach:

- Identify modal parameters using some system identification method.
- Use identified modal parameters to obtain physical parameter (mass, damping, stiffness) matrices.

- Does not require repeatedly solving the forward problem, but is more complicated

PROS:

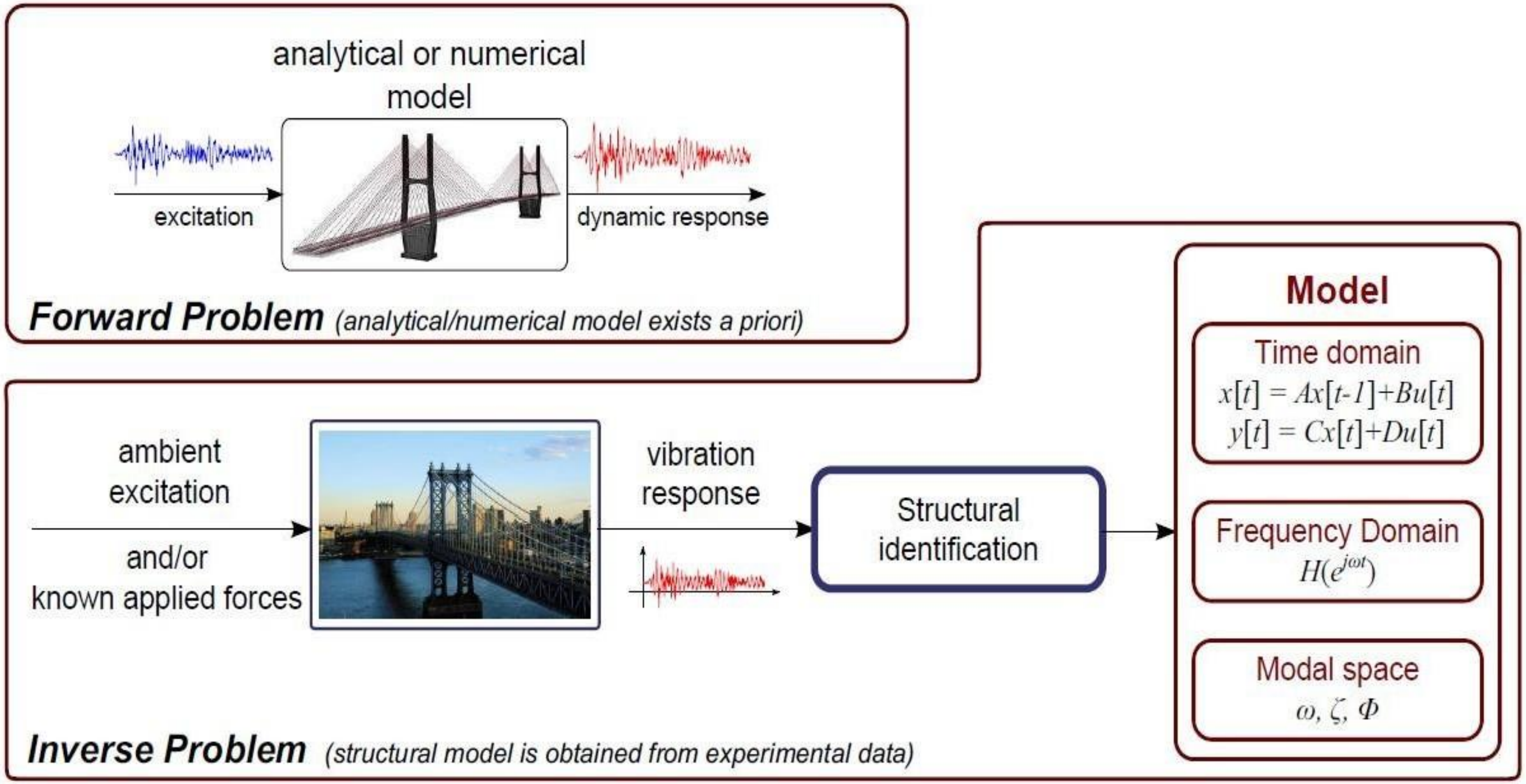
Allow damage detection, as well as damage location and extent estimation. May even be used to assess the damage type and to estimate the structure's remaining life, though research is still at its onset in this regard

CONS:

- Require high user expertise
- Affected by modeling assumptions (e.g. boundary conditions, number of DOFs, material properties, etc.)
- Often too many unknowns
- Usually computationally expensive

- Data-Based techniques are based on statistical, rather than physical models of the structure.
- These methods are called data-based because the features extracted from the structural response are obtained by simple operations performed on the response time histories itself, and do not require any physical model assumptions.
- These approaches are often said to “let the data speak by themselves

- PROS
- Do not require high user expertise.
- Often coined using machine learning knowledge: highly computationally efficient and ideal to be automated.
- Take into account uncertainties inherently present in SHM.
- Free from modeling assumption induced errors.


analytical or numerical model
excitation
dynamic response
Forward Problem (analytical/numerical model exists a priori)
ambient excitation
and/or known applied forces
vibration response
Structural identification
Model
Time domain
x[t] = Ax[t-1]+Bu[t]
y[t] = Cx[t]+Du[t]
Frequency Domain
H(e^{jωt})
Modal space
ω, ζ, Φ
Inverse Problem (structural model is obtained from experimental data)

- CONS
- Without a physical model, can at most reach the second level of the damage detection hierarchy (damage location).
- Being based on a statistical model of the features, they require sufficient data to be available.
- Many sources of uncertainty in the different stages of SHM: During data acquisition:
- Measurement noise,
- Environmental effects (different temperature, humidity levels),
- Unknown and non stationary inputs (traffic, wind, earthquake; may excite different frequency regions).

- Missing data (not every point on the structure observed).

During feature extraction/modeling/identification:

- Modeling assumptions,
- Errors associated with any numerical method,
- Non-unique identification (many models may fit the measured data equally well).

Structural Monitoring Challenges

Structural Monitoring Challenges:

Infrastructure is expected to provide:

- reliable service for long periods of time,
- Undergoing major technology changes,
- spanning several generations and experiencing dramatic evolutions

Develop Wireless Sensor Networks:

- Reliable
- Energy aware
- Smart

Barriers in SHM

Some Barriers in SHM up today

- Conventional cables
- High installation costs
- Vulnerable to ambient signal noise corruption
- Vulnerable to earthquake conditions
- Size and complexity of large structures require a large number of sensing points to be installed.

Applications of SHM

Application of SHM in ‘Housing for All’ Project

- North-East India is prone to earthquake hazards
- So monitoring is important to reduce seismic hazard
- Proposed Idea: One house will be properly instrumented among a colony of houses
- Sensor data will be taken once in a year and the health of that colony can be estimated
- Visual inspection and NDTs will be done in a regular basis
- This will also be used for post-earthquake health assessment and validate retrofitting operations