UNIT 3

Static Field Testing

Static field testing is the most commonly used method to determine the load carrying capacity of a structure, and provides data about a structure's behaviour and ability to sustain live loads.

Types of Static Tests:

1. Behaviour Tests
   - The aim of a behaviour test is to study the mechanics of a structure's behaviour and/or to verify the methods of analysis that should be used on similar types of structures.
   - The test is carried out using loads that are less than or equal to the maximum allowed service load on the structure.
   - Results of a behavior test show how a load is distributed throughout a structure, but no information is provided about the load capacity of the individual structural components
2. Diagnostic Tests
   - The method used to carry out a diagnostic test is the same as that used for behaviour tests; however, the goal of diagnostic testing is to determine if the response of a particular component of a structure is hindered or helped by another structural component.
   - By understanding the interactions between structural components (the effects of the interaction may be either detrimental or beneficial to the behaviour of the component concerned), the engineer can take appropriate action to fix a detriment or utilize a benefit.
3. Proof load test:
   - Proof tests are used to study the load-carrying capacity of a structure by inducing proof loads on the structure.

- Proof loads are usually static loads which are greater than the maximum service loads and are defined as the maximum load of a given configuration that a structure has withstood without suffering any damage.
- During the course of a proof test, loads are gradually increased until the limit of linear elastic behavior is reached – extreme care must be taken to ensure that a proof loaded structure is not permanently damaged by excessive loading.
- Care should be taken to ensure that all calculations are correct, all safety precautions are taken, and that the structure is continuously monitored during testing.
- It should also be noted that subjecting a structure to a sufficiently high proof load is not always a confirmation of its load carrying capacity.
- Supporting analysis based on sound engineering reasoning is essential for determining if there is reason to believe that a structure can be relied upon to carry the required loads for the foreseeable future

Simulation Methods

Simulation methods use computational and experimental techniques to replicate the behavior of structures under static loads. These methods aim to predict structural responses without direct field testing, saving time and resources.

1. Finite Element Analysis (FEA):
    - A widely used computational approach where a structure is divided into smaller elements, and mathematical models simulate how it reacts to static loads.
    - FEA evaluates stress, strain, and deformation, helping identify weak points or areas of high stress.
    - It is especially useful in designing complex structures like bridges, buildings, and Aircraft.

2. Analytical Modeling:
    - Uses mathematical equations to model structural behavior.

- While less detailed than FEA, it provides quick approximations for initial Assessments.

3. Material Property Simulation:

- Considers the behavior of different materials under static loads, such as concrete, steel, or composites.
- Simulations account for material nonlinearity, fatigue, and environmental factors.

Loading Methods

Static load testing involves applying a constant or gradually increasing load to a structure to
measure its response. The loading methods can vary based on the type of structure and the
goals of testing:

1.Point Load Application:

- Loads are applied at specific points on the structure to simulate concentrated forces, such as the weight of vehicles on a bridge.
- Hydraulic jacks or actuators are commonly used to apply and control these loads.

2. Distributed Load Application:

- Uniform or varying loads are applied over a surface to simulate distributed forces, like wind pressure or the weight of occupants in a building.
- This method often uses sandbags, water-filled bladders, or distributed hydraulic systems.

3. Incremental Loading:

- Loads are applied in increments to observe the structural response at different stages.
- This method helps identify the structure's elastic and plastic behavior, as well as its ultimate load-carrying capacity.

4. Dead Weight Loading:

- Uses physical weights (e.g., concrete blocks or steel plates) to apply static loads.
- Though labor-intensive, this method is straightforward and ensures precise load application.

5. Hydraulic Loading:

- Hydraulic systems apply controlled loads with high accuracy and are ideal for dynamic and static testing.
- These systems can mimic real-world scenarios like pressure variations or force distribution.

Sensor Systems and Hardware Requirements for Static Field Testing

Static field testing in Structural Health Monitoring (SHM) focuses on evaluating structural response to constant or slowly varying loads, contrasting with dynamic testing which analyzes responses to rapid load changes. This section details the sensor systems and hardware essential for conducting effective static field tests.

Sensor Systems

The selection of appropriate sensors is paramount for accurate data acquisition in static testing. The following sensor types are commonly employed:

- **Strain Gauges:** These are fundamental for measuring material deformation under load. They operate on the principle that the electrical resistance of a wire changes with strain.

    - *Electrical Resistance Strain Gauges:* These gauges measure changes in electrical resistance proportional to the applied strain. They are widely used due to their cost-effectiveness and versatility in various applications.

    - *Fiber Optic Strain Gauges:* These gauges utilize optical fibers to measure strain based on changes in light transmission characteristics within the fiber. They offer advantages such as high accuracy, immunity to electromagnetic interference, and suitability for long-distance monitoring and harsh environments.
- **Load Cells:** These transducers directly measure applied forces or weights. They are crucial for quantifying the loads acting on the structure during testing. Different types of load cells exist, including strain gauge-based, hydraulic, and piezoelectric.

- **Displacement Transducers:** These sensors measure the linear or angular displacement of specific points on the structure.

    - *Linear Variable Differential Transformers (LVDTs):* These provide highly accurate measurements of linear displacement based on the principle of electromagnetic induction.
    - *Potentiometers:* These offer a simpler and more economical method for measuring displacement, although with generally lower accuracy compared to LVDTs.
- **Tiltmeters/Inclinometers:** These devices measure the angle of inclination or tilt of a structural element with respect to gravity. They are particularly useful for monitoring settlement, rotation, or deformation in foundations, retaining walls, and slopes.

Hardware Requirements

Effective static field testing requires a robust and reliable hardware setup. The key components are as follows:

- **Data Acquisition System (DAQ):** The DAQ is the central component for collecting, digitizing, and storing sensor data. Important specifications include:
    - *Number of Channels:* The DAQ must have a sufficient number of input channels to accommodate all the sensors being used in the test.
    - *Sampling Rate:* While high sampling rates are typically not required for static testing, the rate should be adequate to capture the slow variations in the measured parameters.
    - *Resolution and Accuracy:* The DAQ's resolution and accuracy determine the precision of the measurements. High resolution is essential for capturing small changes in strain or displacement.
    - *Data Storage Capacity:* Sufficient storage capacity is necessary to accommodate the data collected during the testing period.
- **Signal Conditioning:** This stage involves processing the raw sensor signals before they are input to the DAQ. This may include:
    - *Amplification:* Increasing the signal amplitude to improve signal-to-noise ratio.
    - *Filtering:* Removing unwanted noise or interference from the signal.
    - *Excitation:** Providing a stable excitation voltage or current for certain sensors, such as strain gauges.
- **Power Supply:** A stable and reliable power supply is essential for powering the sensors, signal conditioning units, and the DAQ system.

- **Cabling and Connectors:** High-quality cabling and connectors are crucial for ensuring reliable signal transmission and minimizing signal loss or interference.

- **Environmental Protection:** In field testing scenarios, the equipment may be exposed to harsh environmental conditions. Appropriate enclosures and protective measures are necessary to protect the sensors and hardware from moisture, dust, temperature extremes, and other environmental factors.

- **Calibration Equipment:** Regular calibration of sensors and the DAQ system is crucial for maintaining measurement accuracy and ensuring reliable results. Traceable calibration standards should be used.

Specific Considerations for Static Field Testing

- **Long-Term Stability of Sensors:** Sensors used in static tests must exhibit long-term stability to accurately capture slow changes over extended periods. Drift and other long-term variations in sensor readings should be minimized.
- **Temperature Compensation:** Temperature variations can significantly influence sensor readings, particularly for strain gauges. Temperature compensation techniques, either through hardware or software, are often necessary to achieve accurate measurements.
- **Sensor Installation and Mounting:** Proper installation and mounting of sensors are paramount. Incorrect installation can lead to inaccurate readings or even damage to the sensors. Manufacturer's guidelines should be strictly followed.

By carefully considering these sensor and hardware requirements and addressing the specific challenges of static field testing, engineers can obtain reliable data for accurate structural health assessment.

Static Response Measurement in SHM

Static response measurement in Structural Health Monitoring (SHM) focuses on the structural behavior under sustained or slowly varying loads. This contrasts with dynamic measurements, which capture responses to rapidly changing loads.

1. Definition and Scope

Static response refers to the structural behavior under loads that remain constant or change gradually over time. These loads include:

- **Dead Loads:** The permanent weight of the structure itself, including structural elements, finishes, and fixed equipment.
- **Sustained Live Loads:** Loads due to occupancy, stored materials, or other sustained usage patterns.
- **Slowly Varying Environmental Loads:** Loads that change gradually, such as temperature variations, long-term settlement, or slow creep effects.

Static response measurements capture the resulting long-term structural behavior, including:

- **Deformation:** Changes in the shape or dimensions of the structure, such as beam deflection, column shortening, or shell deformation.
- **Strain:** The deformation of a material under stress, representing the change in length per unit length.
- **Stress:** Internal forces within the material resisting the applied loads.
- **Displacement:** The movement of specific points on the structure relative to their original positions.
- **Tilt/Inclination:** Changes in the angular orientation of structural elements.

2. Objectives of Static Response Measurement

The primary objectives of measuring static response in SHM are:

- **Assessment of Long-Term Performance:** To evaluate the long-term stability and performance of the structure under sustained loading conditions.
- **Damage Detection:** To identify damage that manifests as permanent deformation or changes in structural stiffness, such as cracks, yielding, or connection failures.
- **Evaluation of Load Capacity:** To verify if the structure can safely carry the intended design loads and assess its remaining load-carrying capacity.
- **Monitoring of Foundation Settlement:** To monitor the settlement of foundations, which can induce significant stresses and deformations in the superstructure.

3. Measurement Techniques and Instrumentation

Static response measurements typically involve the following:

- **Sensors:** Common sensor types include:
  - *Strain Gauges:* Measure strain in structural members.
  - *Load Cells:* Directly measure applied forces.
  - *Displacement Transducers (LVDTs, Potentiometers):* Measure linear displacement.
  - *Tiltmeters/Inclinometers:* Measure angles of inclination.
- **Data Acquisition:** Data is collected using data loggers or Data Acquisition Systems (DAQs) at relatively low sampling rates due to the slow nature of the changes being measured.
- **Data Analysis:** Analysis involves examining changes in measured quantities over time, comparing them to design values or baseline measurements obtained

from the undamaged structure, and identifying any deviations or trends that indicate potential problems.

4. Key Characteristics of Static Response Measurements

- **Focus on Long-Term Behavior:** Measurements capture sustained responses to constant or slowly varying loads.
- **Low-Frequency/DC Signals:** The signals of interest are typically very low frequency or DC.
- **Emphasis on Accuracy and Stability:** High accuracy and long-term stability of sensors and instrumentation are crucial.
- **Sensitivity to Environmental Factors:** Measurements can be influenced by temperature, humidity, and other environmental conditions.
- **Measurement of Fundamental Quantities:** Focus on strain, stress, displacement, and tilt/inclination.
- **Relevance to Specific Damage Types:** Particularly relevant for detecting damage causing permanent deformations or changes in stiffness.
- **Data Analysis Focus:** Monitoring changes over time and comparing to design/baseline values.

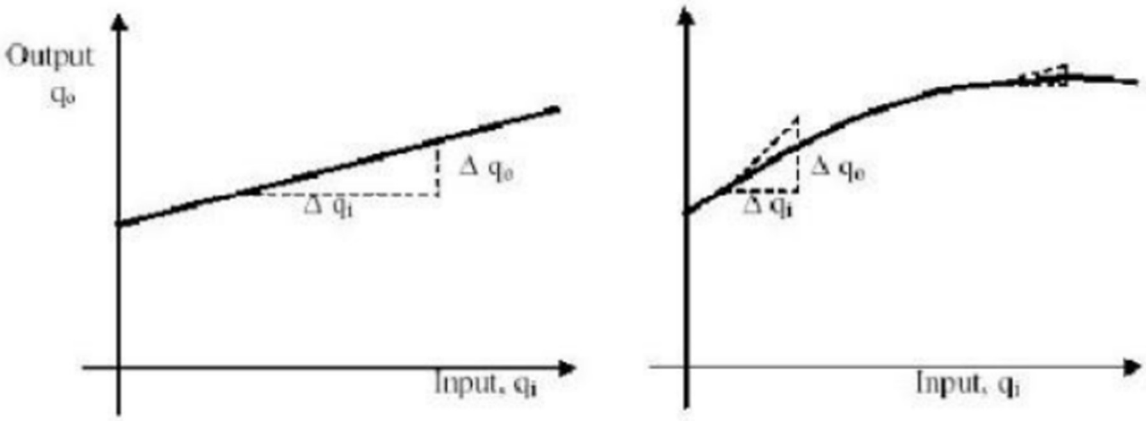
Static response measurement provides valuable insights into the long-term health and performance of structures, contributing to improved safety and reliability.

Static characteristics

The set of criteria defined for the instruments, which are used to measure the quantities which are slowly varying with time or mostly constant, i.e., do not vary with time, is called ‘static characteristics’.

The various static characteristics are:

1. **Accuracy**: It is the degree of closeness with which the reading approaches the true value of the quantity to be measured.
2. **Sensitivity**: The sensitivity denotes the smallest change in the measured variable to which the instrument responds. It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured. Mathematically it is expressed as,



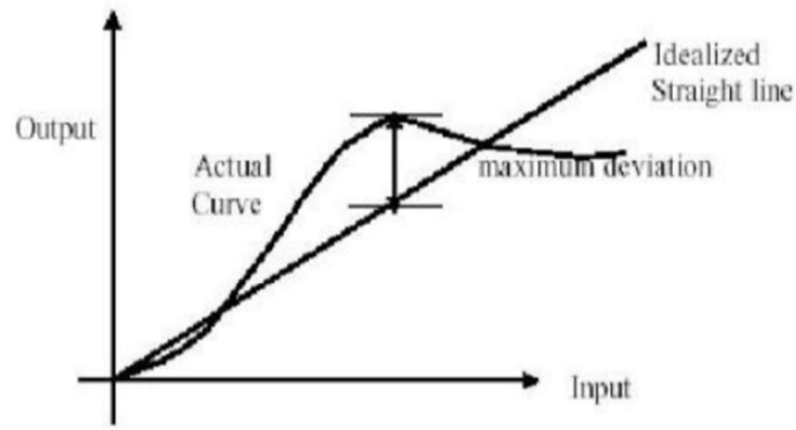
$$\text{Sensitivity} = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

$$= \frac{\Delta qo}{\Delta qi}$$

Thus, if the calibration curve is liner, as shown, the sensitivity of the instrument is the slope of the calibration curve. If the calibration curve is not linear as shown, then the sensitivity varies with the input. Inverse sensitivity or deflection factor is defined as the reciprocal of sensitivity. Inverse sensitivity or deflection factor = 1/ sensitivity

Linearity:

The linearity is defined as the ability to reproduce the input characteristics symmetrically & linearly. The curve shows the actual calibration curve & idealized straight line.



$$\% \text{ non-linearity} = \frac{\text{Max. deviation of output from idealized straight line}}{\text{Full scale reading}}$$

3.
4. **Reproducibility:** It is the degree of closeness with which a given value may be repeatedly measured. It is specified in terms of scale readings over a given time
5. **Repeatability**: It is defined as the variation of scale reading & random in nature.
6. **Resolution**: If the input is slowly increased from some arbitrary input value, it will again be found that output does not change at all until a certain increment is exceeded. This increment is called resolution
7. **Threshold**: If the instrument input is increased very gradually from zero there will be some minimum value below which no output change can be detected. This minimum value defines the threshold of the instrument.
8. **Stability**: It is the ability of an instrument to retain its performance throughout is specified operating life.
9. **Tolerance**: The maximum allowable error in the measurement is specified in terms of some value which is called tolerance.

10. **Range or span**: The minimum and maximum values of a quantity for which an instrument is designed to measure is called its range or span.

Semester: VII						
INTEGRATED HEALTH MONITORING OF STRUCTURES **Category: Institutional Elective** **(Theory)**						
Course Code	**:**	21CV75IF		**CIE**	**:**	**100 Marks**
Credits: L:T:P	**:**	3:0:0		**SEE**	**:**	**100 Marks**
Total Hours	**:**	42L		**SEE Duration**	**:**	**3Hours**

Unit-I	**08 Hrs**
Structural Health: Factors affecting Health of Structures, Causes of Distress, Regular Maintenance, Importance of maintenance **Structural Health Monitoring**: Concepts, Various Measures, Analysis of behavior of structures using remote structural health monitoring, Structural Safety in Alteration.	
Unit – II	**08 Hrs**
Materials: Piezo–electric materials and other smart materials, electro–mechanical impedance (EMI) technique, adaptations of EMI technique, Sensor technologies used in SHM **Structural Audit**: Assessment of Health of Structure, Collapse and Investigation, Investigation Management, SHM Procedures, SHM using Artificial Intelligence	
Unit –III	**08 Hrs**
Static Field Testing: Types of Static Tests, Simulation and Loading Methods, sensor systems and hardware requirements, Static Response Measurement.	
Unit –IV	**08 Hrs**
Dynamic Field Testing: Types of Dynamic Field Test, Stress History Data, Dynamic Response Methods, Hardware for Remote Data Acquisition Systems, Remote Structural Health Monitoring.	
Unit –V	**08 Hrs**
Remote Structural Health Monitoring: Introduction, Hardware for Remote Data Acquisition Systems, Advantages, Case studies on conventional and Remote structural health monitoring **Case studies:** Structural Health Monitoring of Bridges, Buildings, Dams, Applications of SHM in offshore Structures- Methods used for non-destructive evaluation (NDE) and health monitoring of structural components	

https://virtual-labs.github.io/exp-electro-mechanical-impedance-iitd/images/piezo.pdf