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Advisor to the Custodian of the Two Holy Mosques & Governor of Makkah Region

CONFERENCE OMAINTEC 2025 FM EXHIBITION

المؤتمر الدولي الثاني والعشرون لإدارة الأصول والمرافق والصيانة
The 22nd International Asset, Facility & Maintenance Management Conference

Digitization - Excellence - Sustainability

Predicting Failures of Buildings, Roads and Bridges Utilizing Artificial Intelligence and Machine Learning

Prof. Mufid Samarai,
Senior Advisor, Sahara GCC, UAE

26-28 January 2025
The Ritz-Carlton Jeddah, Kingdom of Saudi Arabia

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WORKSHOP OUTLINE

PART 1: CONCRETE TECNOLOGY AND ARTIFICIAL INTELLIGENCE

PART 2:INSPECTION, EVALUATION AND TESTING OF CONCRETE STRUCTURES

PART 3: MAINTENANCE AND REPAIR OF STRUCTURES

PART 4: CODES, CASE STUDIES AND REFERENCES

PART 1:

CONCRETE TECNOLOGY AND ARTIFICIAL INTELLIGENCE

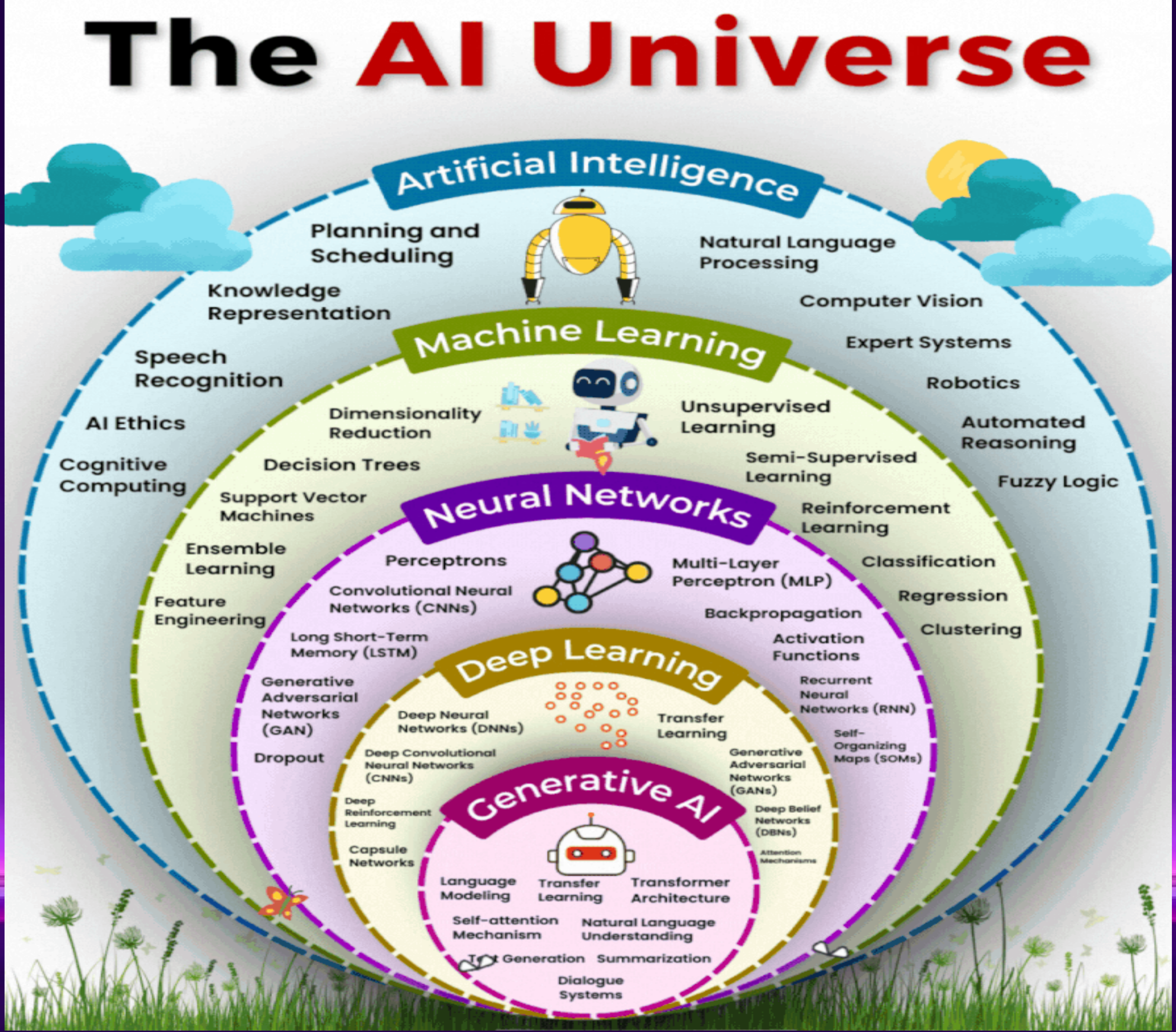
التعرف على الصور
معالجة اللغة الطبيعية
أخلاقيات الذكاء الاصطناعي
التعرف على الكلام

التصنيف
التعليم الذاتي
التجميع

الذاكرة طويلة المدى
الإدراكات
الخرائط ذاتية التنظيم

التعلم العميق
التعلم الانتقالي

نمذجة اللغة
التوليد
فهم اللغة الطبيعية



الذكاء الاصطناعي

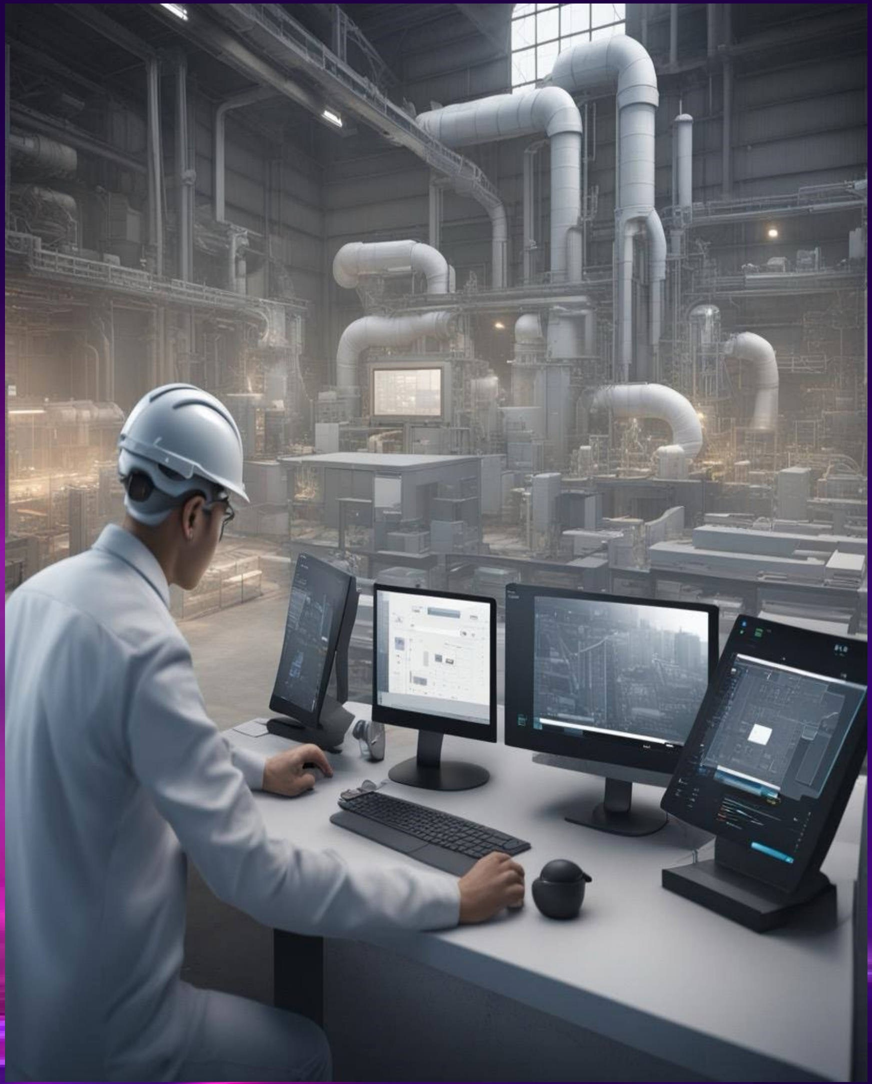
التعلم الآلي

الشبكات العصبية

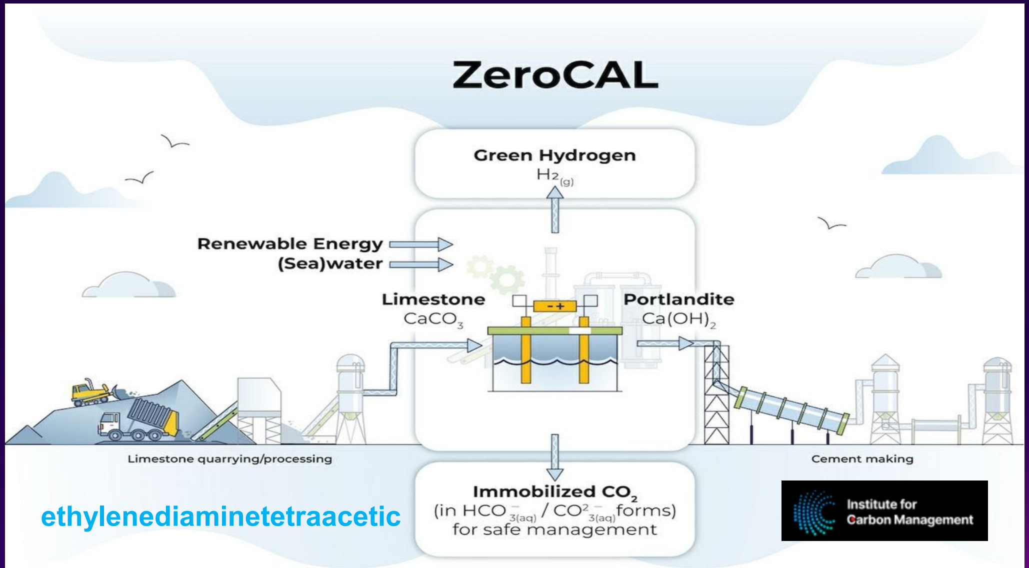
التعلم العميق

ذكاء اصطناعي توليدي

AI can significantly enhance the manufacturing process of Portland cement in various ways



1. Process Optimization
2. Predictive Maintenance
3. Quality Control
4. Supply Chain Management
5. Energy Management
6. Carbon Emission Reduction
7. Simulation and Modeling
8. Training and Skill Development



AL JOUF CEMENT CO TO USE ITS GREEN CEMENT IN NEOM PROJECT

- Reduction of CO_2 emissions by 30 percent, making it an environmentally friendly cement. low heat of hydration, s enhanced concrete durability, longevity, reduced water absorption, reduced permeability, and is highly resistant to chloride penetration and sulphates. Resistant to sulphate and chloride salts and upports heat insulation and is fire-resistant.

FAILURE CASES OF STRUCTURES

- There are many causes for the failures of concrete and concrete structures and in most cases, it does not mean the complete collapse of the structural element, but that it is no longer, in a proper way, serving the purpose for which it was designed. It is believed that the most common causes of failure and the percentage of its occurrence are as follows:

- Damages due to Compounds of concrete 40%
- Damages due to the manufacture of concrete 22%

- Damages due to structural design 12%
- Damages due to excessive loads 8%

- Damages due to foundations 7%
- Damages due to fire, etc. 4%
- Damages due to the collapse of structure 5%

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ROADS

PAST, PRESENT AND THE FUTURE

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Background on Asphalt Production

- Asphalt is considered a national wealth as well-maintained roads are the key to networking and an efficient transportation system
- World use of asphalt is approximately **102 million tons per year**
- **WORLD PAVED ROADS ARE APPROXIMATELY 23 MILLION Km. 95% ASPHALT**

MACHINE LEARNING IN CONCRETE TECHNOLOGY

- **Machine Learning uses algorithms and models that enable computers to learn and make decisions from data.**
- **Instead of being programmed to perform a specific task, Machine Learning has the ability to predict outcomes based on previously learned data**

Data Input → Modelling and Learning Process → Prediction and Decision Making

Data Input	Modelling and Learning Process	Prediction and Decision Making
Get introduced to the data set that contains Inputs and Outputs	Identify trends and Patterns to train the model	Find patterns in new data and make educated guesses based on its training

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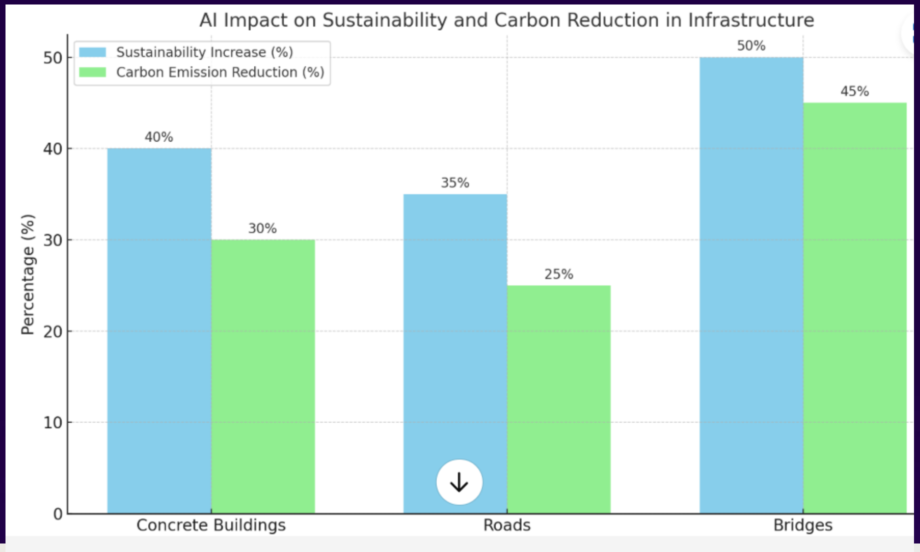
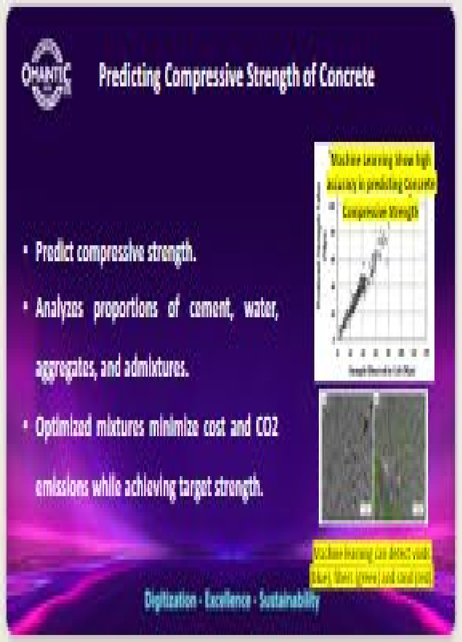
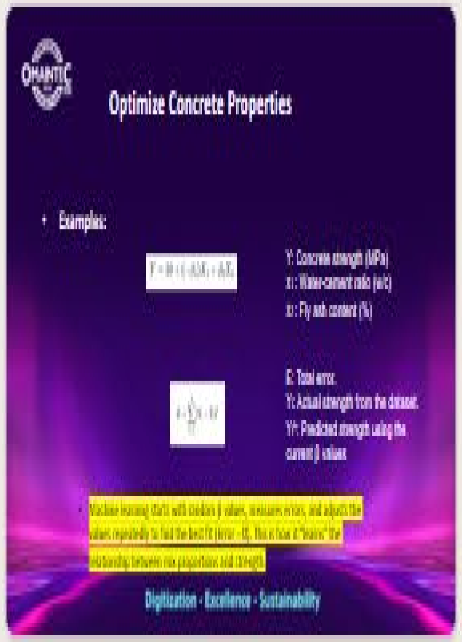


Machine Learning Softwares

Many software can apply machine learning including MATLAB, TensorFlow, and Python

TensorFlow





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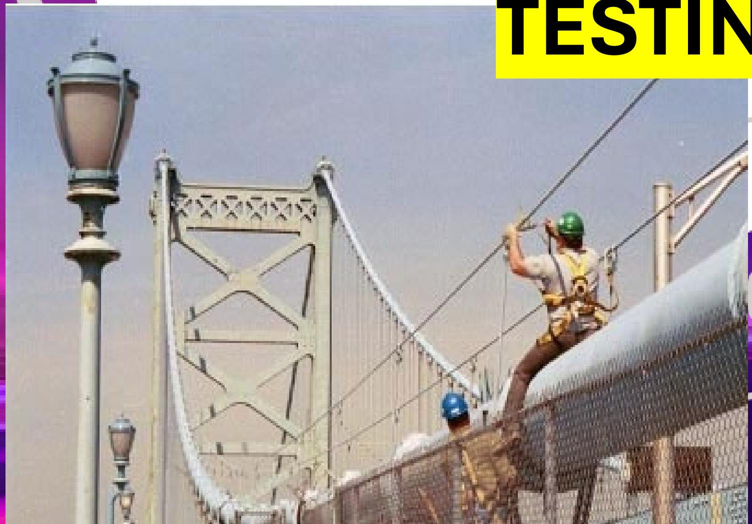
PART- 2

INSPECTION, EVALUATION AND TESTING OF CONCRETE STRUCTURES



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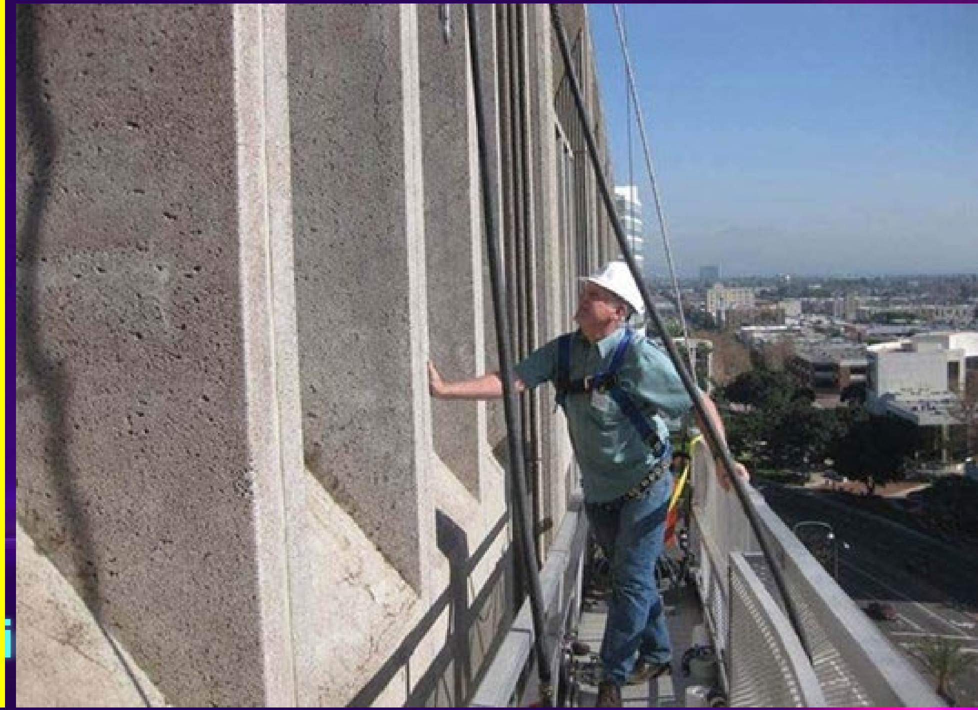
QUALIFICATION OF THE INSPECTORS
مؤهلات المشرف

He should utilize his technical skills to preserve and maintain all existing structures so that they may continue to serve us until they can no longer endure the burdens of modern-day loadings.

- Awareness of potential hazards الوعي بالمخاطر المحتملة
- Implement safety precautions احتياطات السلامة
- Plan and prepare the inspection requirements التفتيش وإعداد متطلبات
- Using non-destructive methods of tests استخدام كافة طرق الاختبارات
- Detecting serious defects. تحليل كل مهمة خطرة بتمعن



VISUAL INSPECTION

الفحص البصري

Developing a systematic method to evaluate structural elements throughout the building

تطوير منهجية لتقييم العناصر الهيكلية في جميع أنحاء المباني

AND evaluating the structural integrity of each element for proposed new uses.

و تقييم السلامة الهيكلية لكل عنصر من أجل الاستخدامات الجديدة المقترحة.

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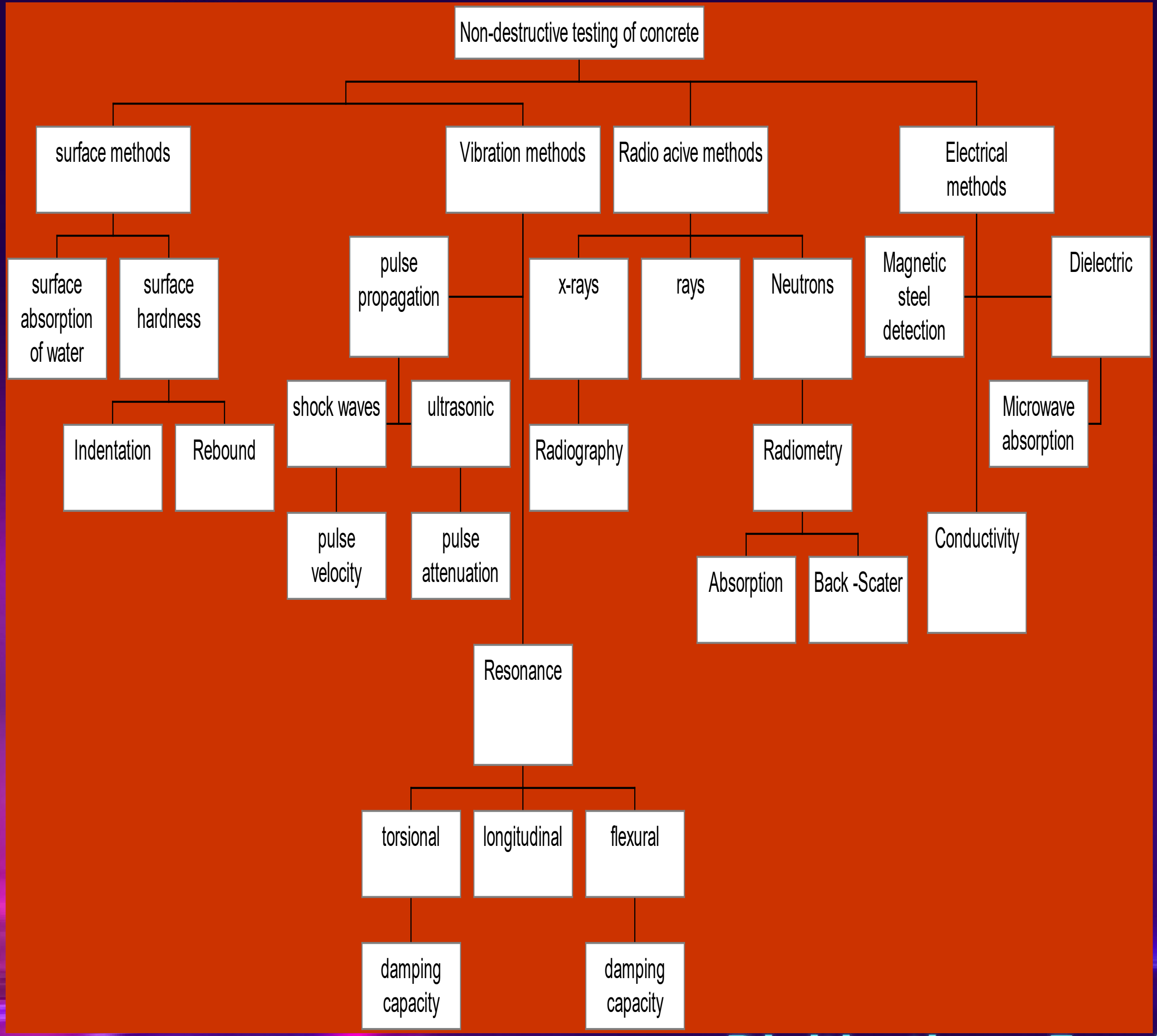
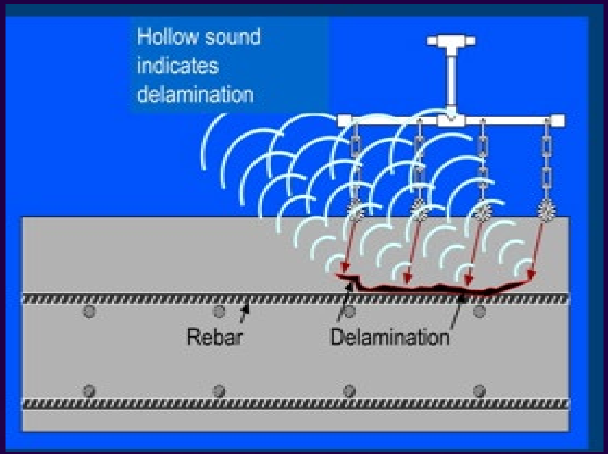
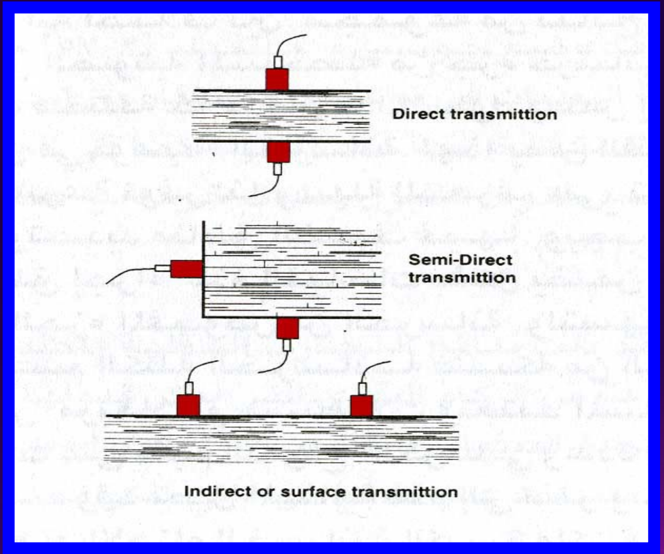


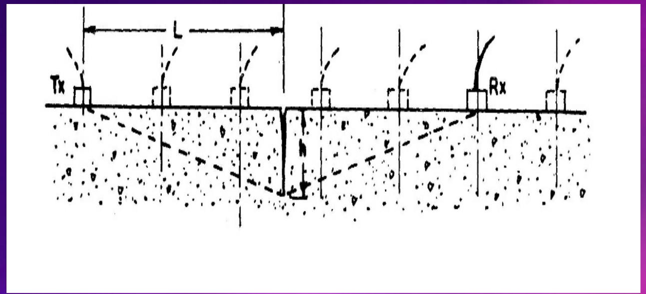


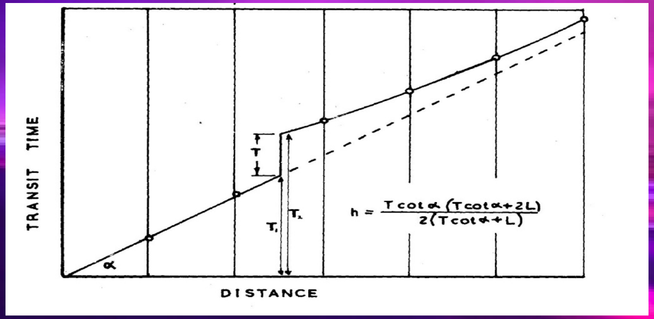
FUNDAMENTAL PRINCIPLE :

- **The pulse velocity V (in km/s or m/s) is given by:**

V= L / T
Where:
V=Pulse velocity
L= Path length, mm
T= effective time, microseconds







Pulse Velocity (km/sec)	Concrete Quality (Grading)
4.85Above	Excellent
3.66 - 4.57	Good
3.05 - 3.66	Medium or Doubtful
2.14 - 3.00	Weak
2.14Below	Very weak

REBOUND HAMMER (ASTM C803/C803M-17)

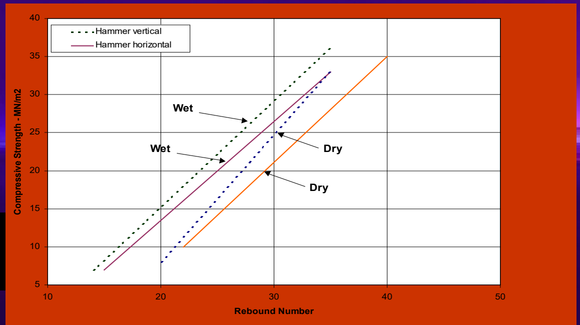
فحص الارتداد

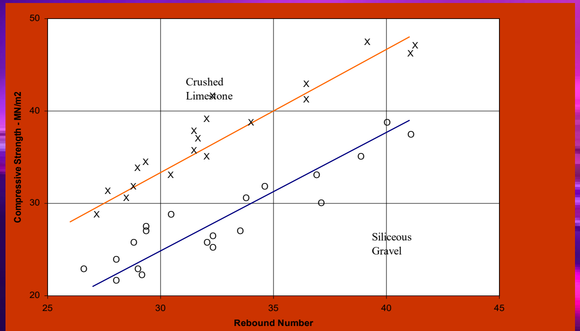
ADVANTAGES

- Speed
- Low Cost
- Relatively low expertise required

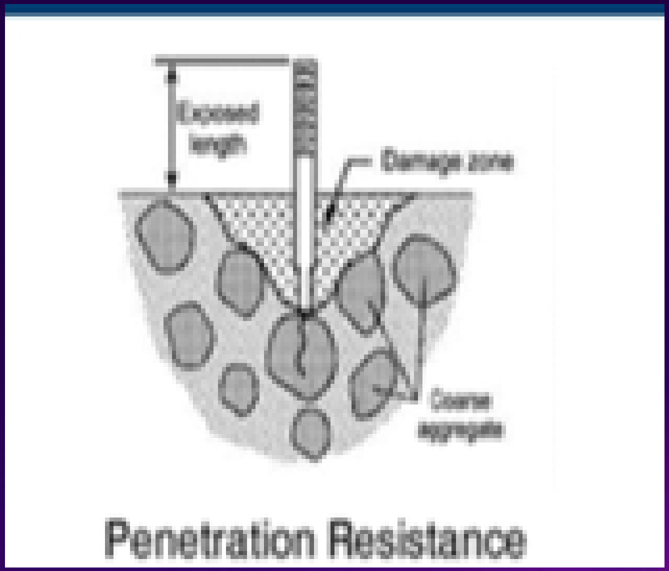
LIMITATIONS

- Relates to only surface zone
- Results influences by
  - Surface texture
  - Moisture condition
  - Type of aggregate
  - Carbonation
  - Type of cement
  - Movement of concrete under test





Probe Penetration (Windsor Probe)



ADVANTAGES

- Simple to operate, durable, and with minimum maintenance.
- Fewer number of variables for correlation.

LIMITATIONS

- Minimum member thickness: 100 mm.
- Not recommended for lightweight concrete.
- Lower power level for fc′<28 MPa.
- Edges and corners.
- Typical coefficient of variation of test is >10%.

CORING TEST

- ASTM C42-04: “Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete”
- The Concrete Society and BS 1881: Part 120 suggest that cores should be kept as short as possible (l/d = 1.0→ 1.2).
- Correction factors are minimized if the core length/diameter ratio is close to 2.0 and this view is supported by ASTM C42
- FACTORS THAT INFLUENCE MEASURED CORE COMPRESSIVE STRENGTH
  - Concrete characteristics
  - Testing variables

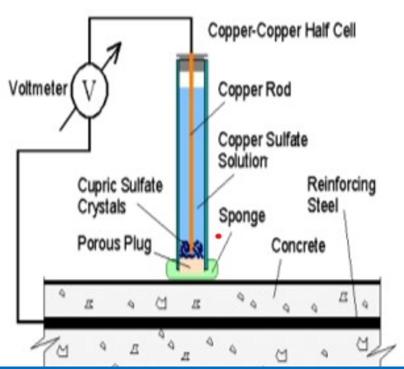
    Length/diameter ratio of core, Diameter of core,
    The direction of drilling, Method of capping
    Reinforcement)



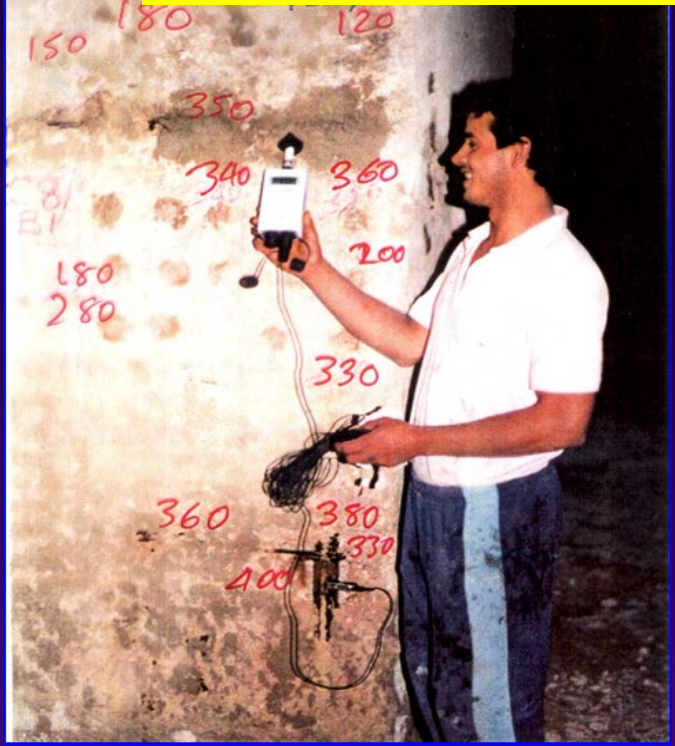
CORROSION

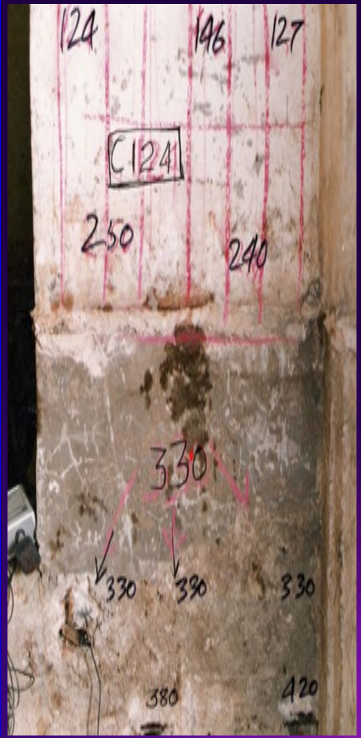
CORROSION POTENTIAL (ASTM C876)

- Estimates electrical corrosion potential and determines corrosion activity (probability of corrosion).
- Any time during the life of concrete.
- Does no



HALFCELL POTENTIAL





CORROSION RATE (ASTM G59)

Provide instantaneous Corrosion rate

Potential P (mV)	Risk of corrosion
P > -200 mV	5 %
-350< P< -200	50 %
P< -350	95 %

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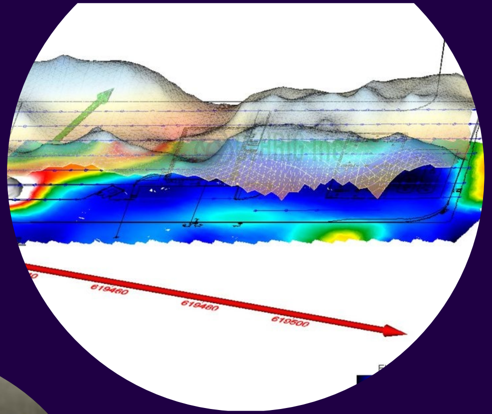
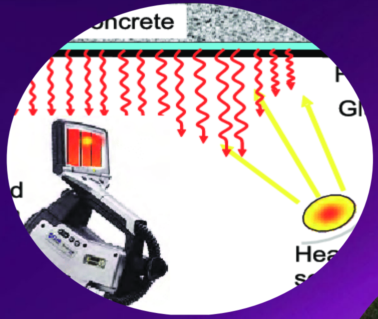
INFRARED THERMOGRAPHY



- Many applications can be obtained from this method, like:
  - detection of dampness,
  - detection of subsurface defects,
  - thermal characterization of materials

GEOPHYSICS



- Geophysical prospection involves non-invasive methods to study the Earth's interior by measuring physical properties at the surface.
- it is commonly used to assess civil engineering structures and infrastructure through surveys that detect gravimetric, magnetic fields, or seismic accelerations.

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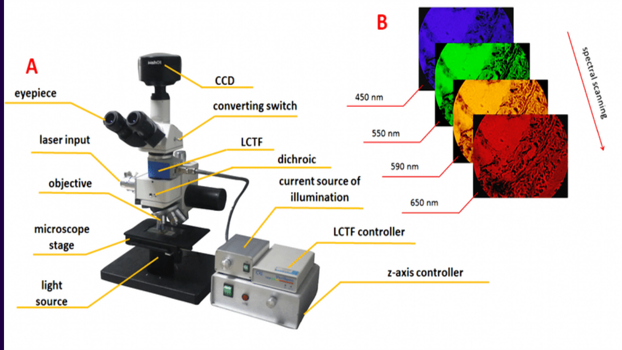
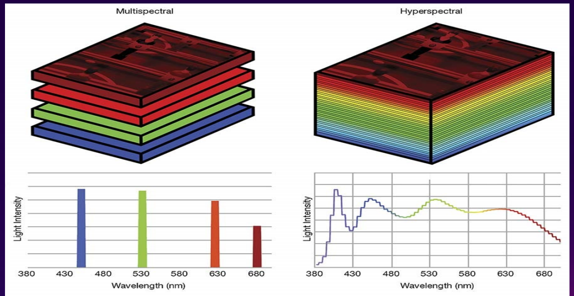
MULTISPECTRAL IMAGING

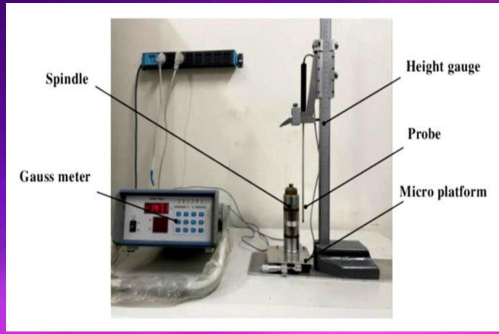


- In this technique, different regions of the electromagnetic spectrum are extracted from one or more sensors and assessed in the form of a 2D image.



MAGNETIC INDUCTION (MI)

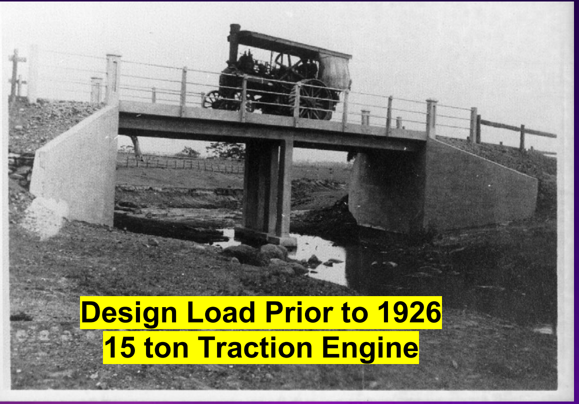
- a non-destructive testing method used to check ferromagnetic materials for defects or irregularities, including cracks, corrosion, pitting and material loss.



LOAD TEST Code 437-2-13

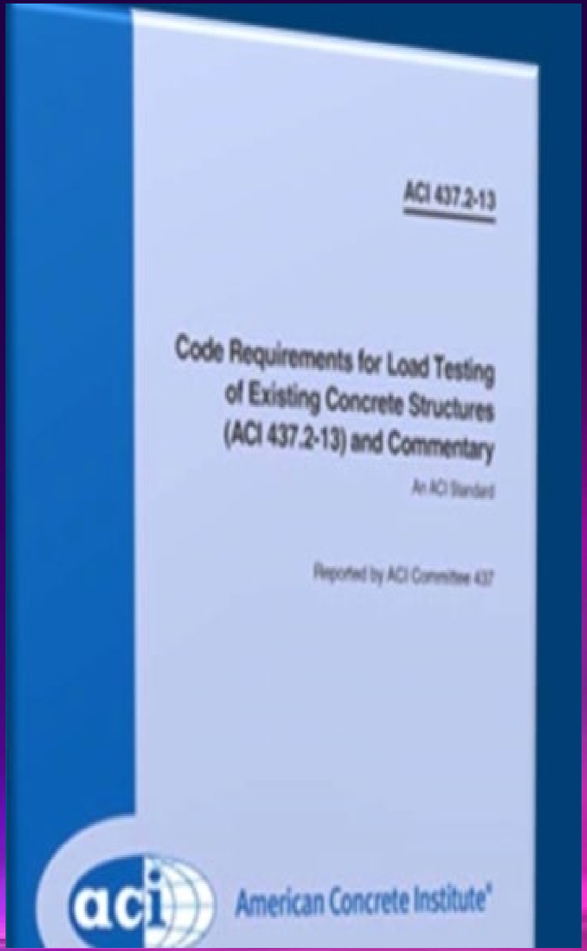
LOAD TESTING CAN BE USED:

- When it is challenging to verify as-built construction or assess current conditions, such as incomplete design records or potential structural degradation.
- hen evaluation tests are not conclusive
- To validate the success of repairs by ensuring the structure can handle intended loads.



Design Load Prior to 1926
15 ton Traction Engine

90 t B-Triple



45.5 t Semi-trailer

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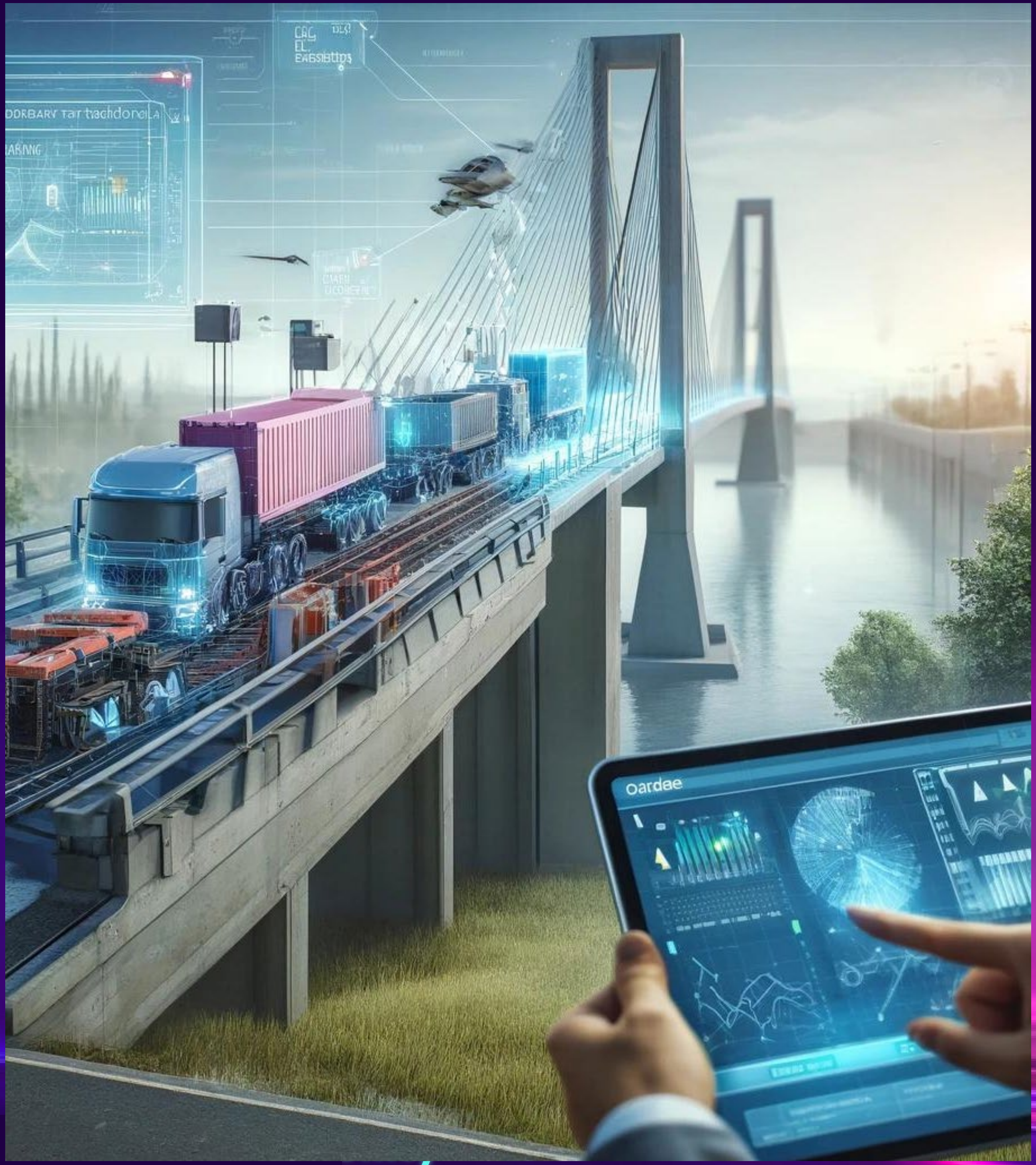


MONITORING المراقبة

Monitoring is “the act of measuring change in the state, number or presence of characteristics of something.” It involves the repeated collection of a specific set of information over time and analyzing the results to detect the changes that are occurring.

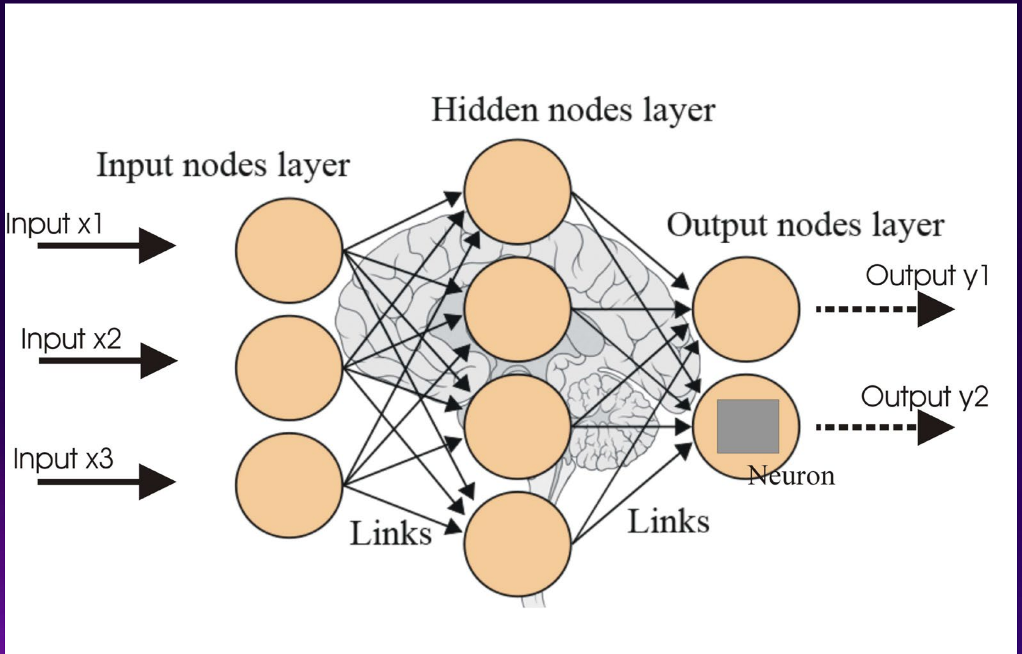
الرصد هو "عمل قياس التغير في وضع أو خصائص لعنصر ما". وهو ينطوي على جمع متكرر لمجموعة محددة من المعلومات مع مرور الوقت وتحليل النتائج للكشف عن التغييرات التي تحدث

CONCRETE SENSORS (مستشعرات)

- Strain Gauges
- Temperature Sensors
- Humidity/Moisture Sensors
- Acoustic Emission Sensors
- Load Cells
- pH Sensors
- Corrosion Sensors
- Fiber Optic Sensors

For monitoring the absolute cap motion, the transducers were supported directly from the ground.
لرصد حركة الجسور بدقة دعمت المحولات مباشرة من الأرض.

ARTIFICIAL INTELLIGENCE APPLICATIONS IN BUILDING EVALUATION



Correlation in Non-Destructive Testing Data

- NDT Data can be complex and difficult to interrupt especially when concrete properties are included
- Machine learning is an advanced analysis technique way more than standard statistical techniques

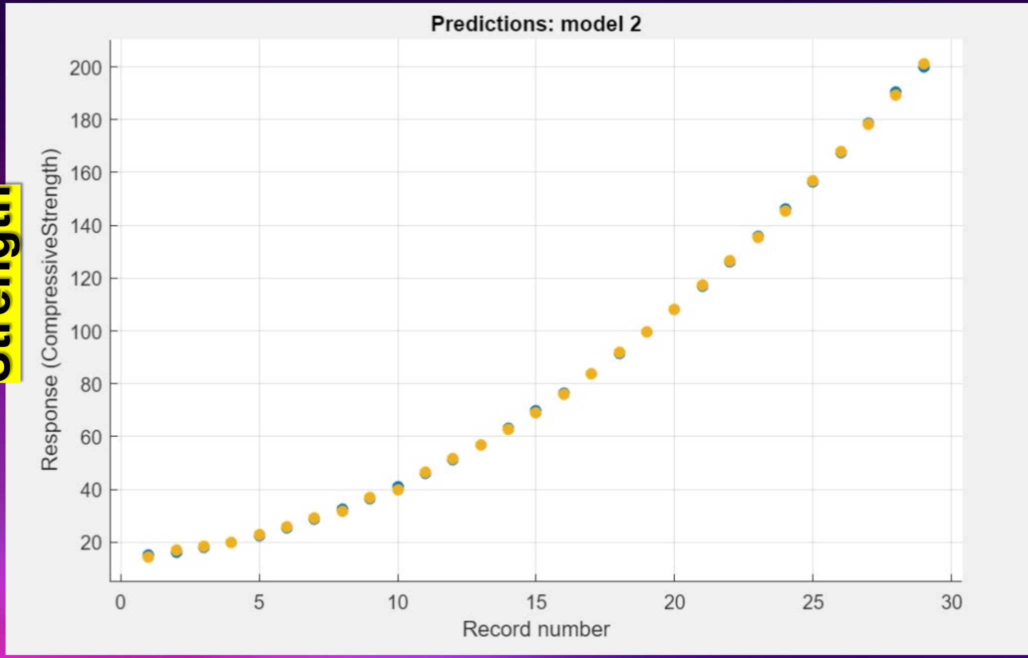
- Machine learning analysis can find patterns and trends in any data set with great R-squared
- Machine learning techniques simply find correlation between certain INPUTS and a desired OUTPUT

[redacted]

COMBINING MACHINE LEARNING WITH ADVANCED NON-DESTRUCTIVE TESTING TECHNIQUES

- The analysis results shows a great accuracy of prediction

Predicted Compressive Strength



Actual Compressive Strength

Training Results

RMSE (Validation)	0.54876
R-Squared (Validation)	1.00
MSE (Validation)	0.30113
MAE (Validation)	0.4408
Prediction speed	~210 obs/sec
Training time	8.2712 sec
Model size (Compact)	~4 kB

R-squared value indication high ML accuracy

```
>> yfit = NeuralNetwork.predictFcn(35)

yfit =

   18.8261

fx >>
```

When the Pulse Velocity Reading is 18 m/s then Compressive Strength I 18.8 MPa

Example: Remote Drone Bridge Inspection

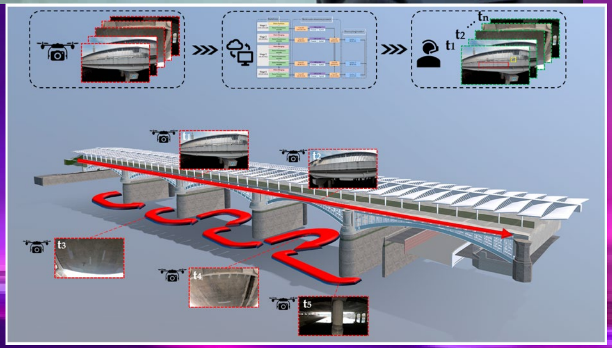
- **Ensure all the equipment is available and all devices are properly charged.**
- **The equipment list goes as follows:**

  - Drone
  - Drone's remote control
  - Smartphone
  - Drone spare batteries
  - Spare propeller blades
  - Drone battery charger and cable
  - Phone charger and cable
  - Electrical power station
  - Anemometer
  - Take-off/landing platform
  - First aid kit
  - Fire blanket
  - Visibility vest
  - Gloves
  - Laptop
  - A paper copy of the flight plan
  - Satellite link antenna and router

Example: Remote Drone Bridge Inspection

- **This Example Utilize Artificial Intelligence (AI) and Augmented Reality (AR) for bridge inspection using remote-controlled drones.**

Traditional Approach	AI Approach
Engineers manually walk across bridge decks to inspect for cracks.	Drones equipped with high-resolution cameras, controlled by engineers, fly over the bridge to capture detailed images
Crack mapping and measurements are done by hand or with limited equipment.	AI software analyzes images to identify, classify, and measure cracks
Subject to inconsistencies between inspectors.	Machine learning models use historical data to predict crack propagation and structural integrity.




PART- THREE
MAINTENANCE AND REPAIR OF STRUCTURES
THE ROLE OF ARTIFICIAL INTELIGENCE
الذكاء الاصطناعي وربوتات الدردشة: مستقبل إدارة الأصول وصيانتها

SIGNIFICANCE OF THE PROBLEM FOR BRIDGES

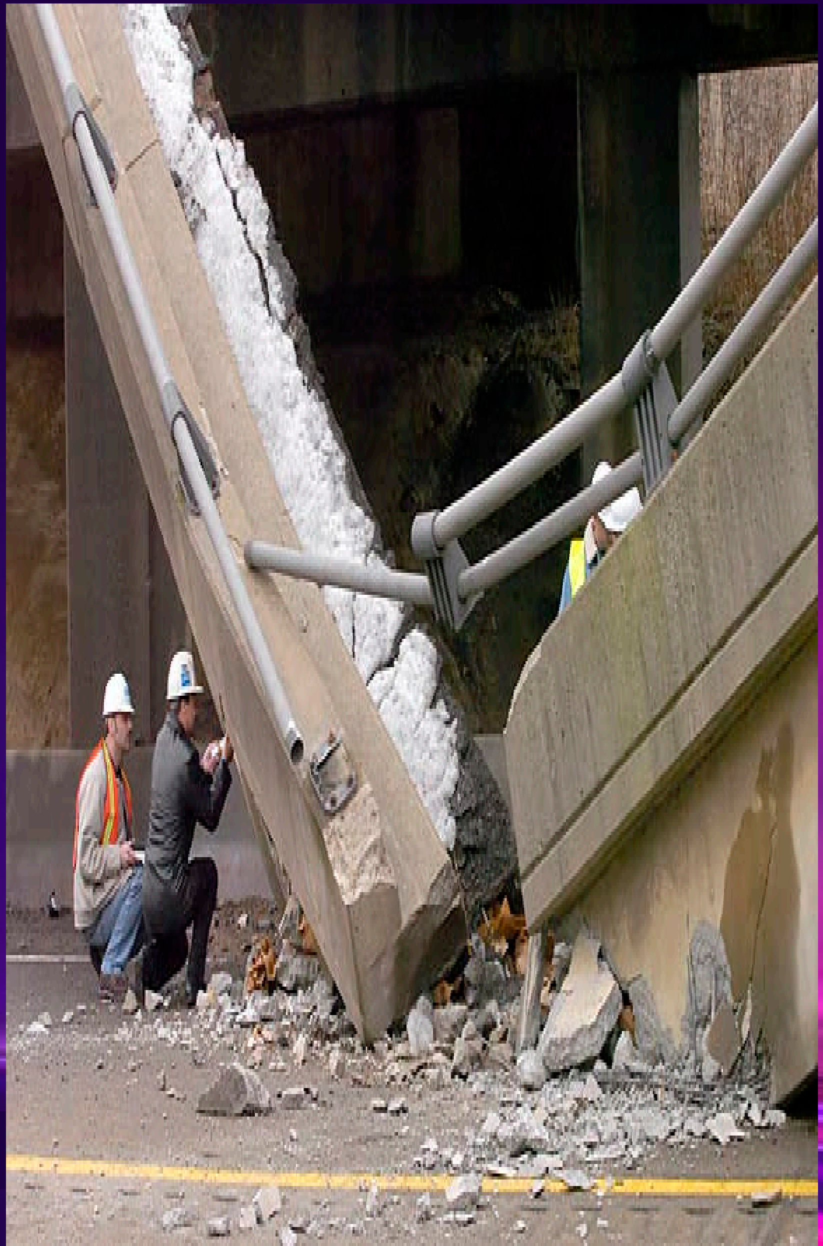
- Deterioration of concrete bridges is a major problem that attacks our transportation infrastructure

Lower performance
Reduce service life
Increase cost

As of 2024, the United States has over 600,000 bridges.

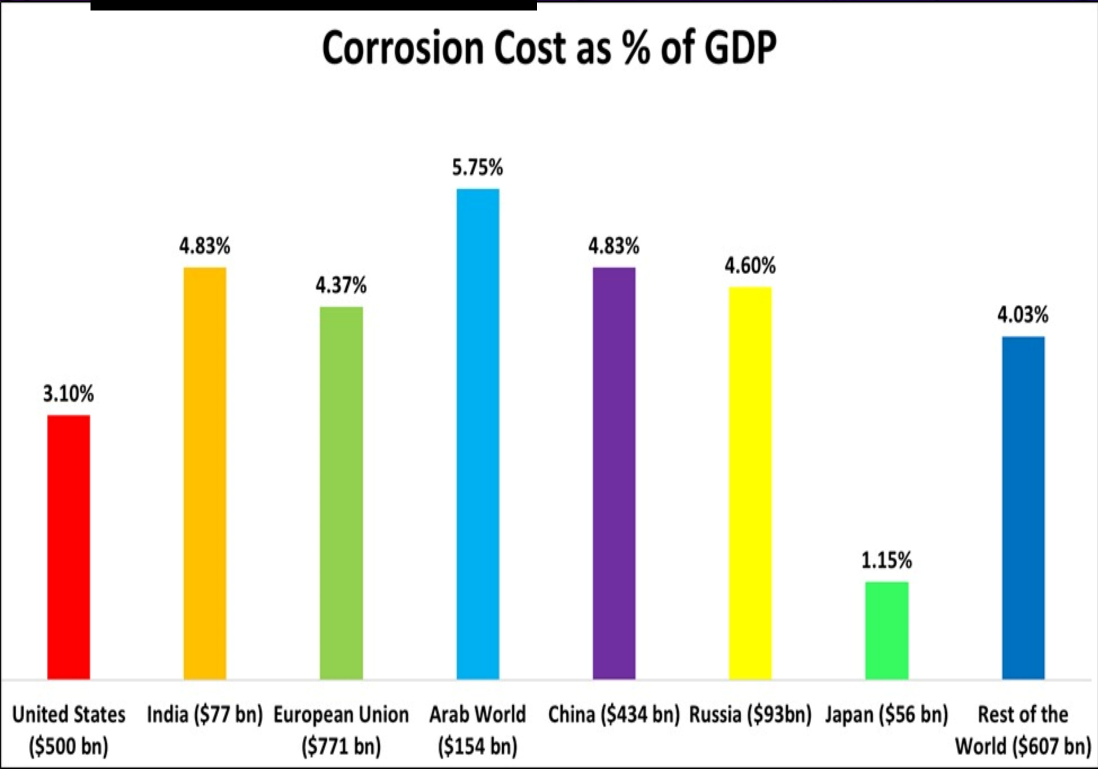
According to the Federal Highway Administration's National Bridge Inventory, approximately 36% of these bridges—over 222,000—require major repair work or replacement.

THE ESTIMATED COST OF REPAIRING THESE BRIDGES WAS **$260 BILLION DOLLARS IN 2021, $319 IN 2023 AND $400 BILLION IN 2024.**



OVERVIEW OF CORROSION

[redacted]



The total direct cost of corrosion in the United States is approximately $500 billion per year.

The corrosion costs more than 771 billion EUR for the European region alone.

Saudi Arabia's yearly corrosion cost was projected to be $25 billion, UAE projected to be 15 billion and Qatar projected to be 8 billion

The global cost of corrosion is estimated to be US$2.5 trillion which is equivalent to 3.4% of the global GDP

SEVERAL METHODS TO STRENGTHEN A STRUCTURE:

Conventional:

- Concrete enlargement
- Supplemental structural steel

Post-Tensioning

FRP

Structural strengthening is required to address:

Existing strength deficiency

Higher new design loads

Effects of wind and earthquake loads

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EVALUATION AND REPAIR DOCUMENTS

201.1R—Guide for Conducting a Visual Inspection of Concrete in Service
214.4R — Guide for Obtaining Cores and Interpreting Compressive Strength Results

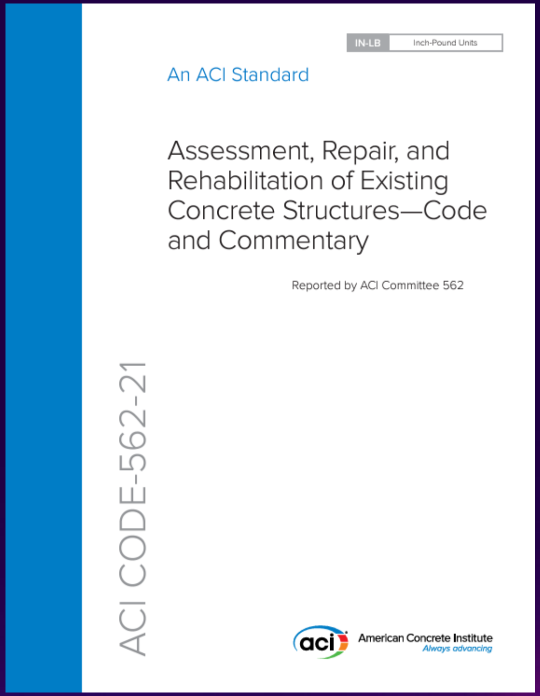
224.1R—Causes, Evaluation, and Repair of Cracks in Concrete Structures

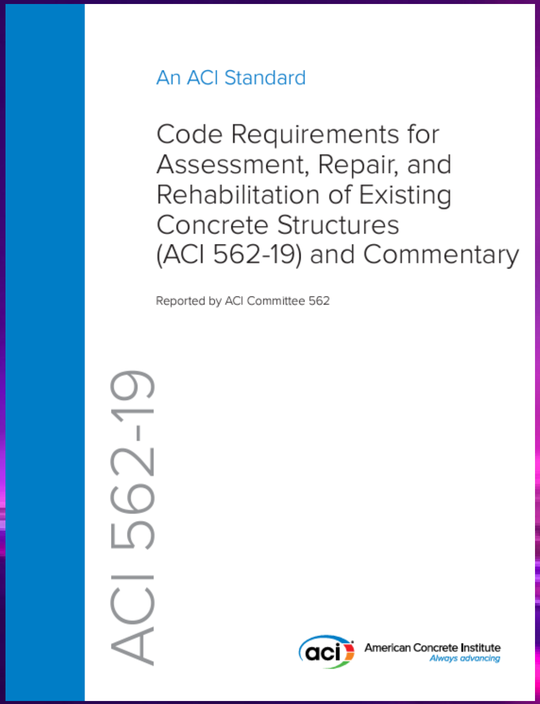
228.2R—Nondestructive Test Methods for Evaluation of Concrete in Structures

325.13R_ Concrete Overlays for pavement Rehabilitation
341.3R Seismic Evaluation and Retrofit Techniques for Concrete Bridges

364.1-13T Repair Tech Notes

364.1R—Guide for Evaluation of Concrete Structures before Rehabilitation
364.3R__Guide for Cementitious Repair Material Data Sheet
437R—Strength Evaluation of Existing Concrete Buildings
437.1R__Load Tests of Concrete Structures: Methods, Magnitude, Protocols, and Acceptance Criteria
503.5R__Guide for the Selection of Polymer Adhesives with Concrete
503.7__Specification for Crack Repair by Epoxy Injection
506.2__Specification for Shotcrete
546R—Concrete Repair Guide
546.3R__Guide for the Selection of materials of the Repair of Concrete
E706__Repair Application Procedures (RAP) 1-14





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APPLICATION OF FRP COMPOSITES

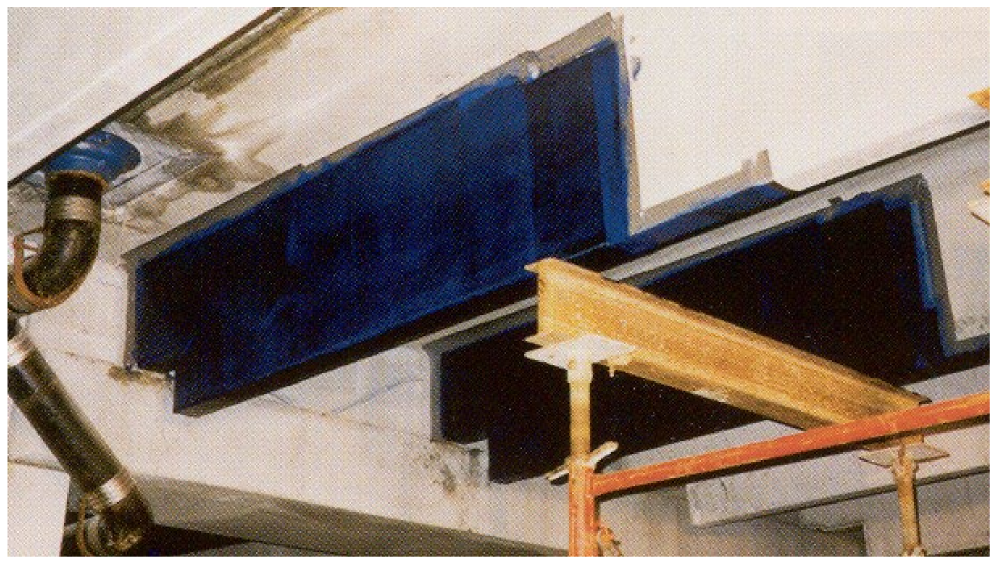
The lightweight, high strength, and corrosion resistance of fiber-reinforced polymers (FRP) make them ideally suited for quick and effective structural repairs.

As a result, they have been favored for conducting emergency bridge repairs where speed is of the essence.

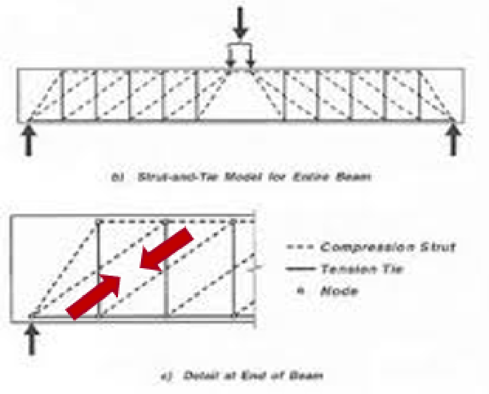
FRP should only be installed in or on sound concrete

FRP applications can be categorized as: Bond-critical, Contact-critical

SHEAR



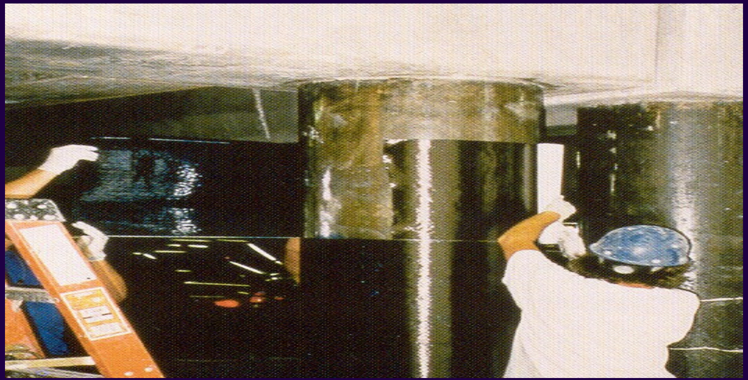
$$V_n = V_c + V_s + \psi_f V_f$$

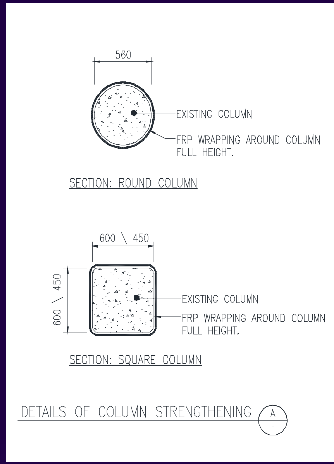


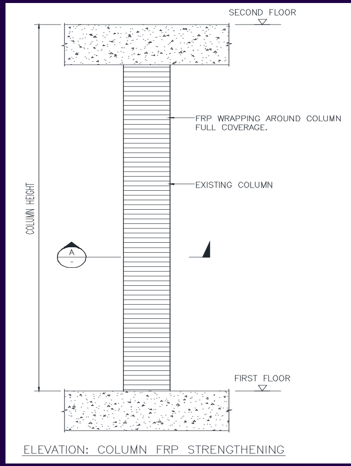
$$V_s + V_f \le 0.66\sqrt{f'_c}\, b_w d$$

$\psi_f = 0.95$	Completely wrapped members
$\psi_f = 0.85$	Three-sided U-wraps or bonded face plies

FRP Strengthening of Columns



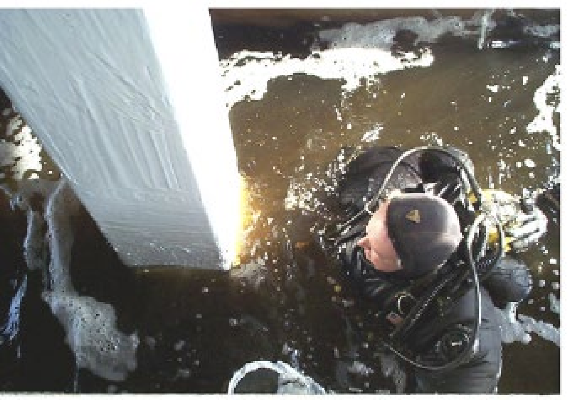




CASE STUDY ACI 562-21

- The study evaluates the repair of shear-damaged reinforced concrete (RC) beams using externally bonded carbon fiber reinforced polymer (EB CFRP).
- Objectives include assessing shear strength recovery, the impact of internal stirrups.
- Damaged beams were repaired with epoxy injections and CFRP U-shaped wraps. Virgin beams were tested for comparison.

UNDERWATER CONCRETE CASTING



software (e.g., Photoshop) to highlight the cracks.
•Measure and annotate the crack dimensions (length, width, depth).
•Sync the data with the robot to localize the cracks.

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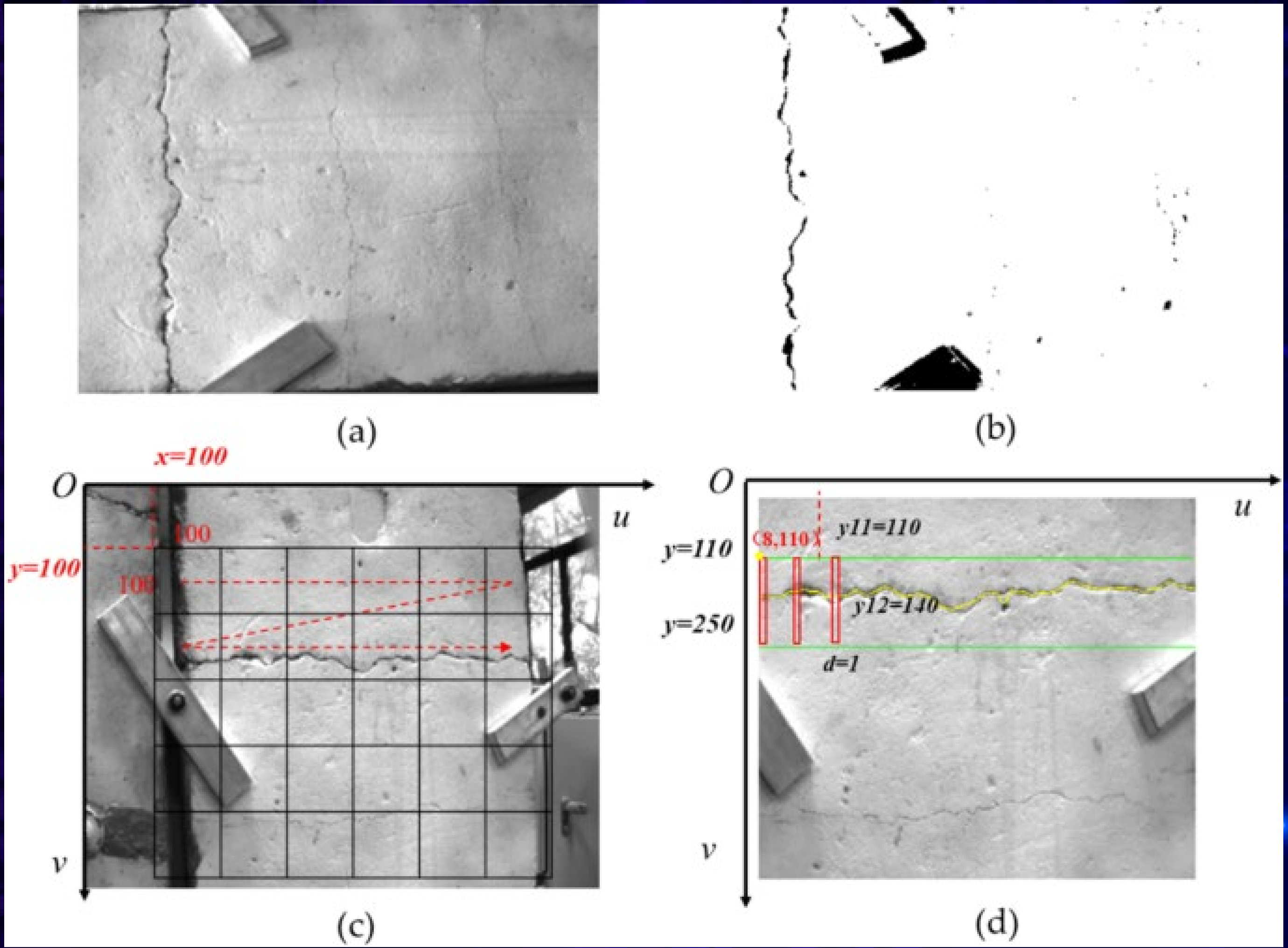
Case Study 1: Crack Sealing through AI

1. Photograph the cracked concrete.
2. Use software (e.g., Photoshop) to highlight the cracks.
3. Measure and annotate the crack dimensions (length, width, depth).
4. Sync the data with the robot to localize the cracks.

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THANK YOU