Bridge
Evaluation and Rehabilitation
(AASHTO)

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Session 47 – Bridges 05

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Training Program

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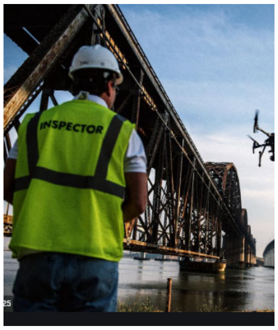
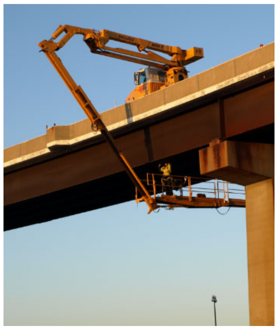
Bridge Inspection
(different than Evaluation)





✓ Ensure public safety; preserve remaining life through the early detection of deficiencies.

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Bridge Inspection

Eight Types of Bridge Inspections

- ✓Initial (Inventory)
- ✓Routine (Periodic)
- ✓Damage
- ✓In-Depth
- ✓Fracture Critical
- ✓Underwater
- ✓Special (Interim)
- ✓Complex

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Routine Inspection

- Regularly scheduled, performed, and recorded
- Every 24 months for most bridges, and every 48 months for some concrete culverts
- Some bridges may need more frequent inspections when conditions warrant
- For inaccessible bridge undersides, use a vehicle with under-bridge platforms.

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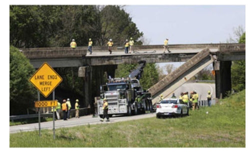
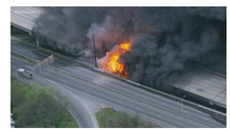
Damage Inspection

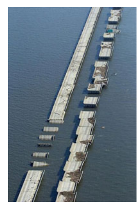
✓After collision, fire, flood, earthquake, significant environmental changes, or loss of structural support.

✓ Report includes:

- photos and measurements
- load rating verifying capacity after event
- channel profiles (when applicable)
- repair recommendations
- load restriction recommendations







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Underwater Inspection

✓Performed every 60 months or more frequently if conditions warrant

✓Inspection methods:

Wading: The most basic, requires only a probing rod and wading boots.

Scuba diving: A more detailed examination of substructure conditions.

Surface Supplied Air Diving: Involves sophisticated diving equipment and a surface supplied air system.

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Special Inspection

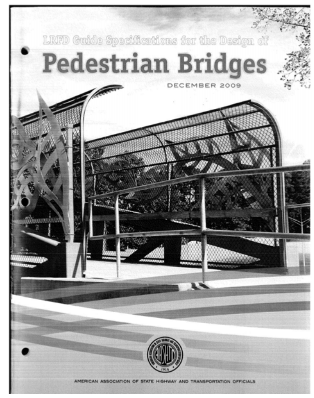
- ✓To monitor a known or suspected deficiency
- ✓Can be recurring or performed on an as-needed basis
- ✓Special Inspection examples:
  - Monitoring the settlement of a substructure every six months
  - Monitoring a specific bearing condition every three months until the bridge is replaced.

Complex Bridge Inspection

- Cable-stayed, suspension, tied-arch, movable, and pontoon bridges as complex.
- Require specialized access equipment and inspection procedures, as well as inspector qualifications.

Pedestrian Bridge Inspection

- A routine safety inspection every 48 months.
- Inspection frequency may be increased to 24 or 12 months.
- Generally considered the same as routine inspection.



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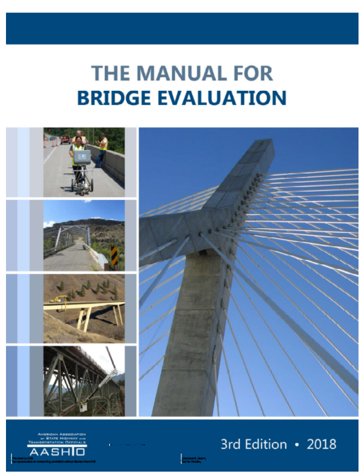
Evaluation of Bridges



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Non-Destructive Load Testing

- ✓Evaluating bridge response under predetermined loadings in the elastic range.
- ✓ Verify both components and system performance under known live loads.
- ✓An alternative to analytical computing.
- ✓Used to verify the performance of bridges compared to design predictions.

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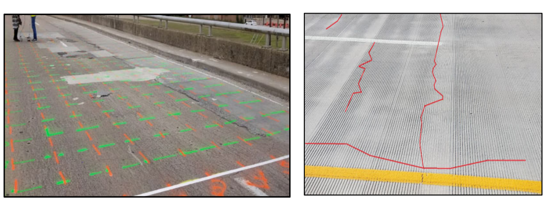
Typical Bridge Problems



Deterioration of the deck

Load Restriction

Cracking of member (steel or concrete)

Section loss

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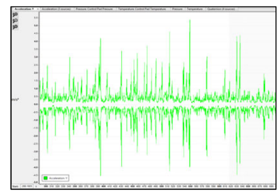
Typical Bridge Problems

Precast deck panel failure


Excessive vibration

Impact Damage

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Load Test Classification

Nondestructive Load Test

Static Load Test

Diagnostic Load Test

Proof Load Test

Dynamic Load Test

Weight-In-Motion Test

Dynamic Response Test

Vibration Test

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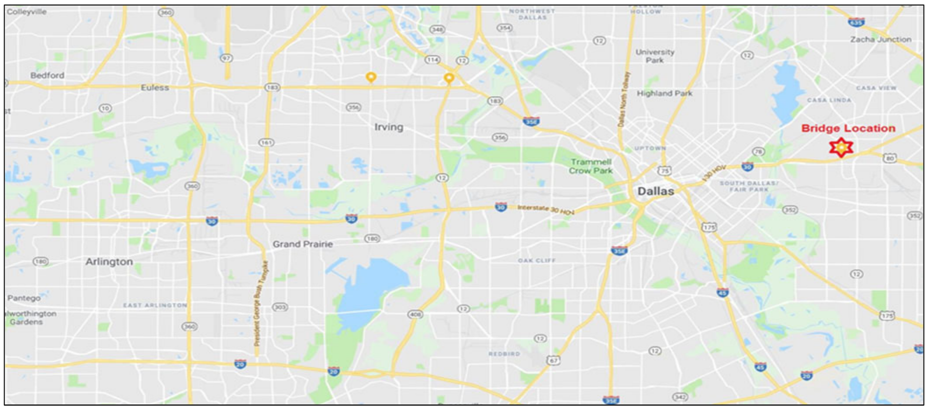
Interesting Factors

- Unintended Composite Action
- Unintended Continuity/Fixity
- Participation of Secondary Members
- Participation of Nonstructural Members
- Portion of Load Carried by Deck

Diagnostic Load Test Example

- ***Bridge:*** St. Francis Bridge, Dallas, Texas (North Bound lanes).
- ***Year of Construction:*** Around 1960s
- ***Span Number:*** Six spans (symmetric about the centerline of the bridge)
- ***Span Length:*** 30 ft., 60 ft., 70 ft.
- ***Steel girders supporting non-composite RC deck.***
- ***Support Condition:*** 30 ft. span simply supported, 60 ft. and 70 ft. spans continuous girder across the bent.
- ***Chosen for Instrumentation:*** Spans 2 and 3

Location of the Bridge



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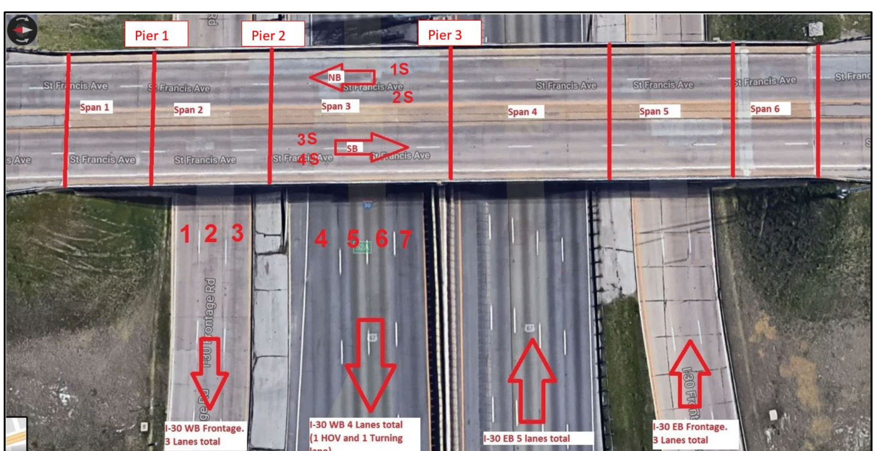
Plan View



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Bridge Profile

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Bridge Impact Video

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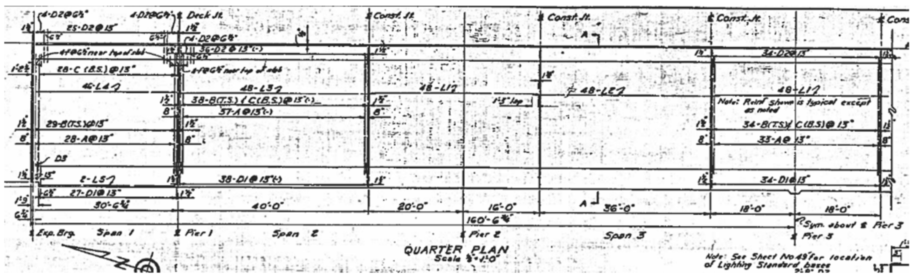
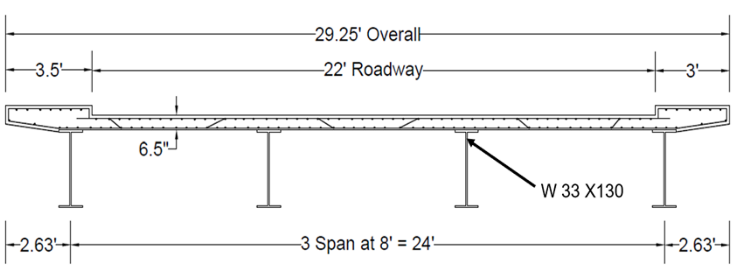
As-Built Plan



Deck rebar layout plan (Quarter plan)

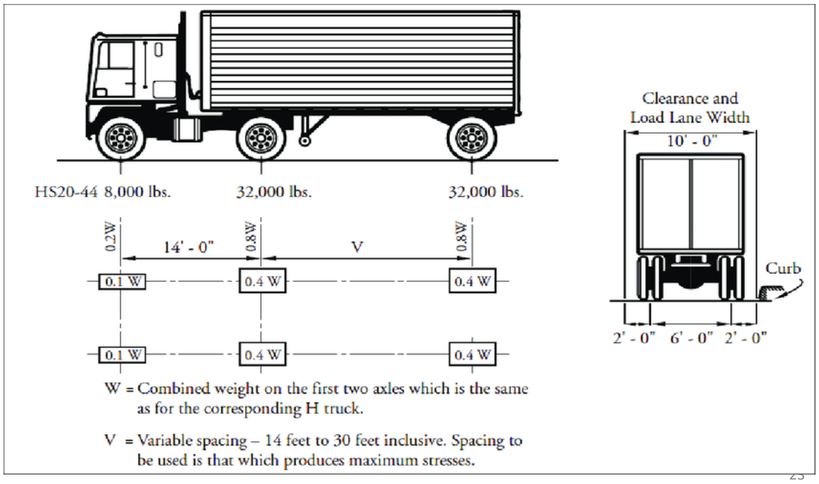
Description of the Bridge



Concrete compressive strength (f'_c)	3 ksi
Yield strength of deck steel	33 ksi
Yield strength of girder steel	40 ksi

Girder Spacing = 8 ft.
Deck thickness = 6.5 in.

HS 20-44 live load



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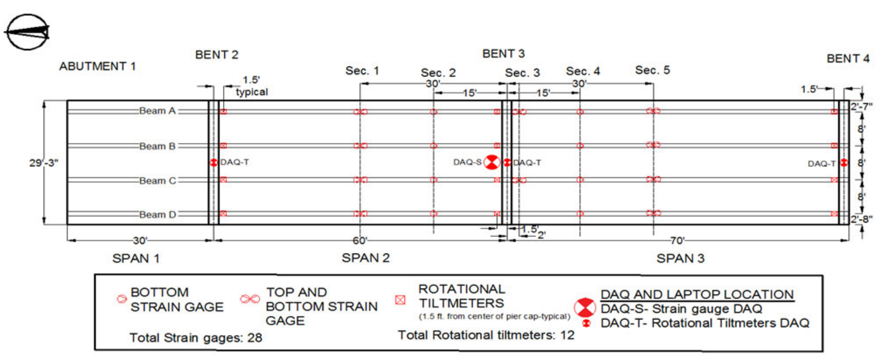
Diagnostic Load Testing Procedure

Instrumentation plan



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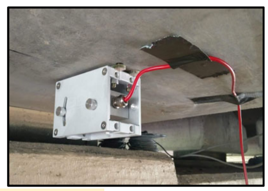
Diagnostic Load Testing Procedure

Instrumentation

Foil Stain Gages

Stain Transducer



Rotational Tiltmeters

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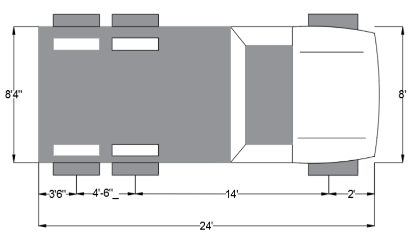
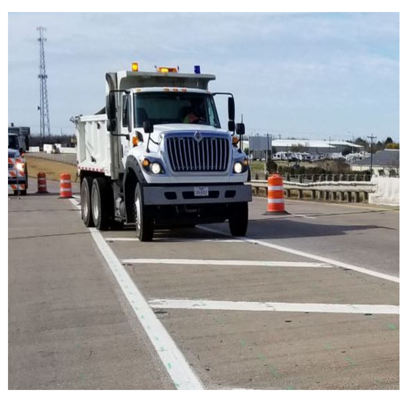
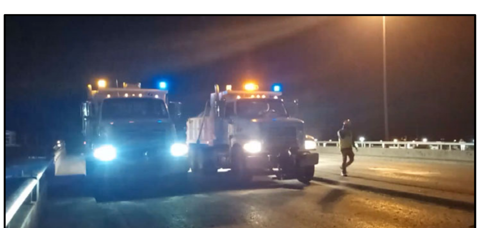
Diagnostic Load Testing Procedure







Live Load (Test Truck)

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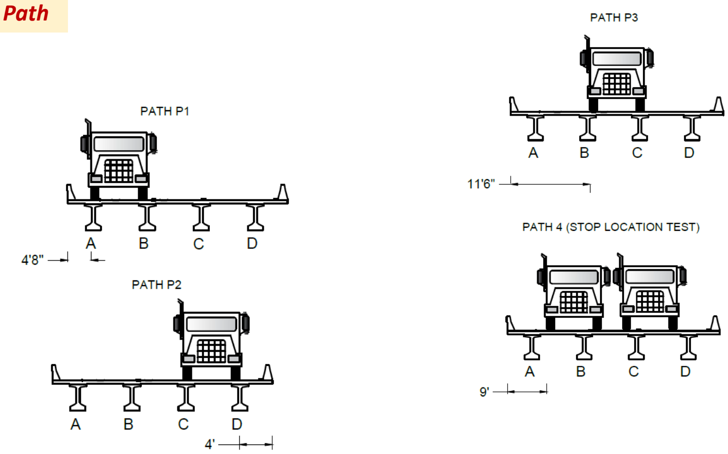
Diagnostic Load Testing Procedure

Test Path



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Diagnostic Load Testing Procedure

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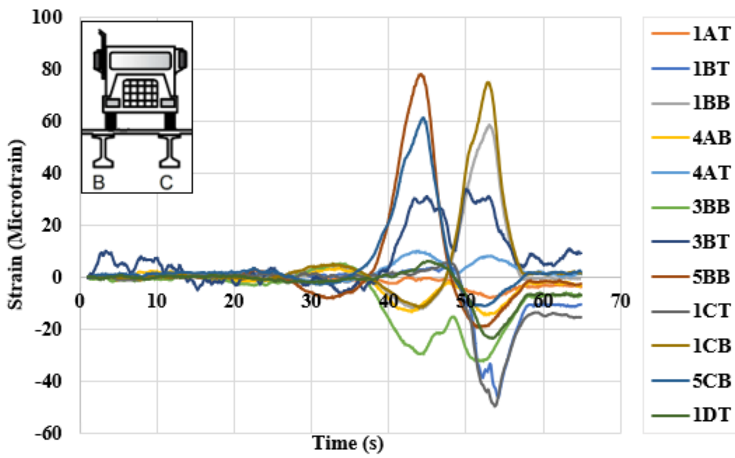
Data Analysis

Modified Strain Data (Noise Free)



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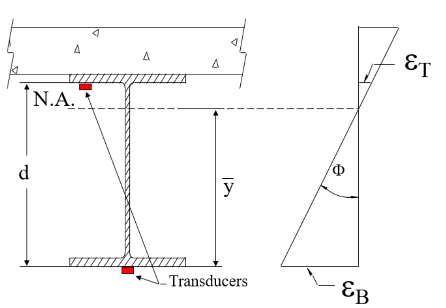
Data Analysis

Experimentally-determined Neutral Axis Location & Curvature



Neutral Axis

$$\bar{y} = \frac{\varepsilon_B \ d}{\varepsilon_B - \varepsilon_T}$$

Curvature

$$\Phi = \frac{\varepsilon_B - \varepsilon_T}{d}$$

Neutral Axis Calculation

$\bar{y}$ = Neutral axis location from the bottom

d = distance between the top and bottom gauges

ε_B = Strain in bottom gauge ($\mu\varepsilon$)

ε_T = Strain in top gauge ($\mu\varepsilon$)

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Load Distribution Factors

$g_i = \frac{\varepsilon_i}{\sum_{j=1}^{n} \varepsilon_j}$ (One lane loaded)

$g_i = \frac{\varepsilon_i * m}{\sum_{j=1}^{n} \varepsilon_j}$ (more than one lane)

g_i = distribution factor of the i^{th} girder

ε_i= maximum strain response recorded in the i^{th} girder

n = total number of girders

ε_i = strain response of each of the other girders at the same time when the maximum strain was recorded in the i^{th} girder

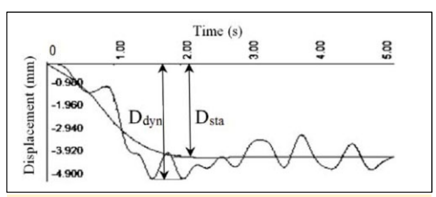
m = number of lanes loaded

Dynamic Impact Factor

Dynamic Impact Factor or Dynamic Load Allowance, DLA = $\frac{D_{dyn}}{D_{sta}}$

D_{dyn} = the absolute maximum dynamic deflection response at any point

D_{sta} = the maximum static response obtained from the dynamic response



Dynamic and static displacement under a vehicle moving

Load Rating

Bridge load rating provides a basis for determining the safe load capacity of a bridge.

It is usually expressed as a Rating Factor (RF) or in terms of tonnage for a particular vehicle).

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Why Do We Load Rate

- Different design vehicles used in the past for the design of bridges (e.g., H-15, HS20-44, HS25, HL93..)
- Some bridges have aged, deteriorated or became structurally deficient over time
- For the safety of general public and traffic, load rating may be needed
- Bridges having insufficient load carrying capacity are posted for restricted loads
- May be used to identify the need for bridge rehabilitation or replacement.

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Load Rating Methods

✓Load Rating first introduced in the 1970 AASHTO Manual

✓Allowable Stress Rating (ASR) - 1970

✓ Load Factor Rating (LFR) – 1978

✓ Load and Resistance Factor Rating (LRFR) - 2003

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Load and Resistance Factor Rating (LRFR)

RF = Rating Factor

C = Capacity = $\varphi_c * \varphi_s * \varphi * Rn$ (for the strength limit state)

γ_{dc}= factor for components

γ_{dw} = factor for wearing surface

$$\boldsymbol{RF = \frac{C - \gamma_{dc}(DC) - \gamma_{dw}(DW)}{\gamma_{ll}(LL + IM)}}$$

γ_{ll} = Evaluation live load factor

φ_c = Condition factor

φ_s = System factor

φ = LRFD resistance factor

DC = Dead load effect for components

DW = Dead load effect due to wearing surface

LL + IM = Live load + Dynamic load allowance

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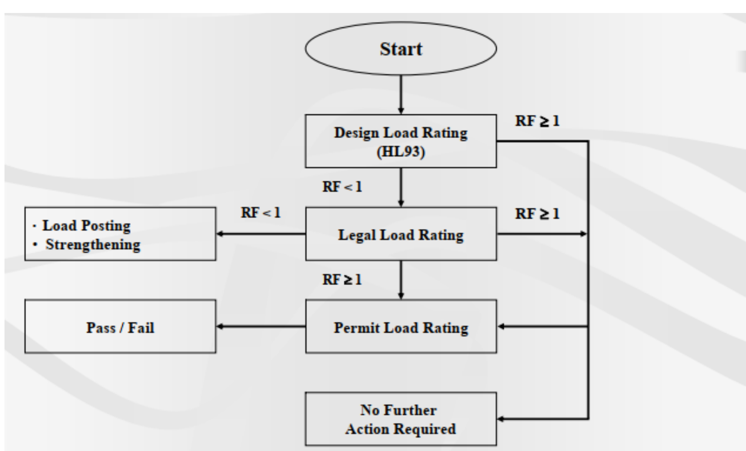
Load and Resistance Factor Rating (LRFR)

Limit States and Load Factors for Load Rating (Table 6A.4.2.2.1)

Bridge Type	Limit State*	Dead Load γ_{DC}	Dead Load γ_{DW}	Design Load Inventory γ_{LL}	Design Load Operating γ_{LL}	Legal Load γ_{LL}	Permit Load γ_{LL}
Steel	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service II	1.00	1.00	1.30	1.00	1.30	1.00
	Fatigue	0.00	0.00	0.75	—	—	—
Reinforced Concrete	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service I	1.00	1.00	—	—	—	1.00
Prestressed Concrete	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
	Service III	1.00	1.00	0.80	—	1.00	—
	Service I	1.00	1.00	—	—	—	1.00
Wood	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1 and 6A.4.4.2.3b-1	—
	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1

AASHTO Manual for Bridge Evaluation

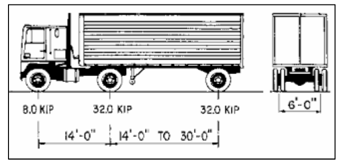
Load and Resistance Factor Rating (LRFR)

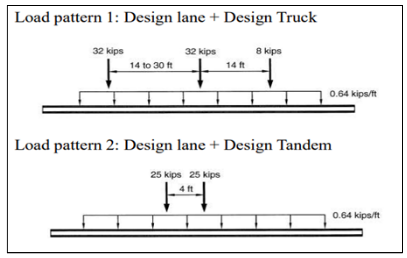


Load and Resistance Factor Rating (LRFR)

Design Load Rating

✓Assesses the performance of existing bridges using the LRFD loading (HL-93) and design standards.





AASHTO Manual for Bridge Evaluation

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Load and Resistance Factor Rating (LRFR)

Legal Load Rating

✓Bridges without sufficient capacity under the design-load rating shall be load rated for legal loads to established the need for load posting or strengthening.

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Load and Resistance Factor Rating (LRFR)

Posting Analysis

- ✓When rating factor, RF, calculated for each legal truck (AASHTO vehicle) is greater than 1, the bridge need not be load posted.
- ✓When for any legal truck the RF is between 0.3 and 1.0, the following equation should be used for the safe load posting for that vehicle type.

$$\text{Safe load posting} = \frac{W}{0.7}\left[(RF) - 0.3\right]$$

W= Weight of rating vehicle.

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Load Factor Rating (LFR)

✓The Following equation may be used regardless of the method (ASR and LFR)

$$\mathrm{RF} = \frac{C - A_1 * D}{A_2 * (L + I)}$$

Member rating = $W * RF$

W = Weight of nominal truck used in determining the live load effects.

A_1 = Factor for dead loads
A_2 = Factor for live load
C = Capacity of the member
D = Dead loads
I = Impact loads
L = Live loads

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Girder Load Rating (LFR)

Total Dead Load = 1.1 $\frac{k}{ft.}$

Dead load moment = $\frac{1}{14}(1.1) \times 70^2 = 385$ k-ft.; from SAP analysis = 411 k-ft

Capacity C = F_y * Z =33 ksi * 467= 1285 k-ft

I = $\frac{50}{L+125}$ <=0.3, AASHTO Manual for Bridge Evaluation $= \frac{50}{70+125}$
= 0.26

LL DF, g = $\frac{\varepsilon_i}{\sum_1^n \varepsilon_i}$

Live load moment calculations for girders:

- Girder A = 788 *1.26*0.12= 120 k-ft
- Girder B= 788 *1.26*0.61= 606 k-ft
- Girder C = 788 *1.26*0.4= 397 k-ft
- Girder D = 788 *1.26*0.43= 427 k-ft

Exterior Girder Rating

Exterior girder-A (example)

- $RF = \frac{C-A1*DL}{A2*(LL+IM)} = \frac{1285-1.3*411.29}{2.17*120} = 2.88$ (Inventory level)
- Bridge Member rating = 36*2.88 = 103.6 tons = 207,360 lb.
- $RF = \frac{C-A1*DL}{A2*(LL+IM)} = \frac{1285-1.3*411.29}{1.3*120} = 4.8$ (Operating level)
- Bridge Member rating = 36*4.8 = 28.8 tons = 345,600lb.

Summary of Girder Rating

Girder	Rating Level	Rating Factor (RF). assuming non-composite	Bridge Member Rating (lb.), assuming non-composite
A	Inventory level	2.88	207,360
	Operating level	4.8	345,600
B	Inventory level	0.57	41,040
	Operating level	0.95	68,400
C	Inventory level	0.87	62,640
	Operating level	1.45	104,400
D	Inventory level	0.81	58,320
	Operating level	1.35	97,200

Bridge Retrofitting

Retrofitting Options	Reduction in Strain (%)	Reduction in Deflection (%)
Chipping old deck concrete	17 (4 ksi) and 33 (6 ksi)	5 (4 ksi) and 7 (6 Ksi)
CFRP strips underneath the deck	57	40
GFRP joist underneath the deck	58	30
Steel joist underneath the deck	51	17
CFRP application on girder	22	10
Local post-tensioning of steel girder	20	8
Welded shear Stud	21	27
Welded shear stud on steel plate	18	25

Cost Analysis

Retrofitting Options	Cost ($)
Chipping old deck concrete	$ 433,860
CFRP strips underneath the deck	$ 166,880
GFRP joists underneath the deck	$ 211,584
Steel joists underneath the deck	$ 396,000
CFRP application on girder	$ 105,000
Local post-tensioning of steel girder	$ 309,875
Welded shear Stud	$ 187,900
Welded shear stud on steel plate	$ 280,062

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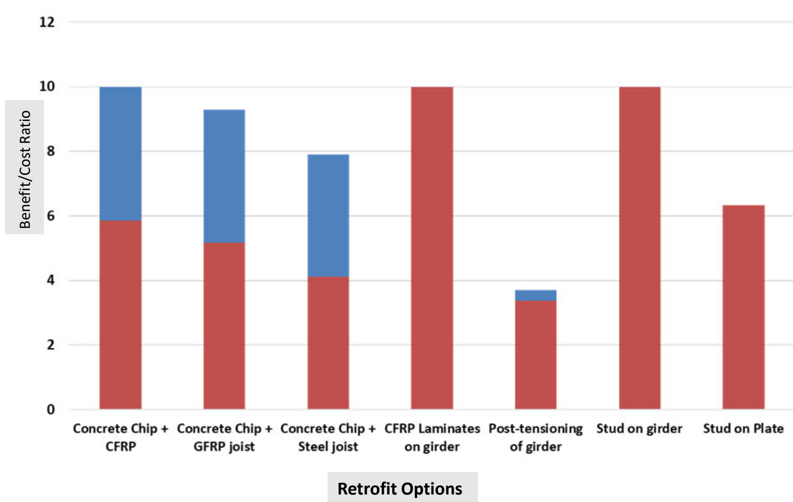
Benefit-Cost Analysis



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Video Clip

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Evaluation of Bridges with Limited or Missing Plans

- Where necessary details, such as reinforcement in a concrete bridge are not available from as-built plans or field measurement, a physical inspection of the bridge by a qualified inspector and evaluation by a qualified engineer may be sufficient to establish an approximate load rating based on rational criteria. Load tests may be helpful in establishing safe load capacity for such structures.
- A concrete bridge or concrete culvert with unknown details need not be posted for restricted loading if it has been carrying normal traffic for an appreciable period and shows no distress. The bridge shall be inspected regularly to verify satisfactory performance.

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Evaluation of Bridges with Limited or Missing Plans

✓Finite element model (via load testing, vibration testing, or combination), and simplified vibration-based assessments are two effective strategies for establishing a starting point for load rating for bridges that has missing parameters.

✓Sometimes Non-Destructive Evaluation (NDE) can help identify some missing properties.

Why NDE for Concrete Bridges?

- Details of the structure with respect to its design, features and past performance.
- Initial visual inspection of the structure can reveal useful information about areas that need a closer look.
- Many causes for the deterioration, so it may be difficult to pinpoint the type of damage.
- However, all types of damage, whether they be load related, environment related, or hazard related, lead to similar signs of deterioration, such as cracking, scaling, delamination and discoloration.

NDE vs. Destructive Evaluation

- Non-destructive: without causing any damage while testing
- Semi-destructive: such as removal of a piece of the material for evaluation.
- Destructive: where the material/structure is tested to failure.
- NDE techniques range in sophistication from simple ones to highly complex ones.
- A good NDE method should be:
  - Sensitive to small flaws
  - Reliable
  - Simple
  - Cheap
  - Portable

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Visual Inspection

- Simplest and cheapest.
- Narrow down the critical areas in a structure that need further investigation.
- Direct or Indirect: Telescopes, Borescopes, Magnifying lenses, Real-time video, Camera, Ruler, measuring tape, crack width gage, Light hammer, chipping / scraping tools.
- Limitations of visual observation:
  - Can only detect surface defects; a clean surface is usually necessary
  - Low reliability
  - Good lighting is necessary
  - Quality will vary with inspector vision
  - Most susceptible among all NDT methods to human factors.

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Semi-Simple NDE

- Chain drag

- Sounding: tapping with hammer.

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Semi-Simple NDE

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NDE Laboratory at The Univ. of Texas at Arlington

Very active with state-of-the-art equipment and know how.

Several bridge evaluation projects.

https://blog.uta.edu/yazdani/

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Ground Penetrating Radar (GPR)

A high-end geophysical device that uses radar pulses to image the subsurface.

Antennae with higher frequency (eg. 2.6 GHz) are used for low depth analysis (0-12 in), while lower frequency (eg. 270, 400 MHz) are used for higher depth evaluation (0-18 ft.).

- Truck Mounted Scanner
- Tri wheel Cart Scanner
- Hand Scanner

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Ground Penetrating Radar (GPR)

Concrete Bridge Inspection:

GPR imaging of concrete provides information about rebar location, rebar clear cover, rebar spacing, utility conduits inside the concrete, post-tensioning duct location, voids, water penetration, concrete deterioration, material properties and a variety of other objects inside the concrete.

Ground Penetrating Radar (GPR)

Drawbacks:

- Variable dialectic constant of different materials for which cores are required for calibration
- Difficult to detect rebars, steel plate or any other object underneath one layer of reinforcements or wire mesh

GPR Data Collection Video

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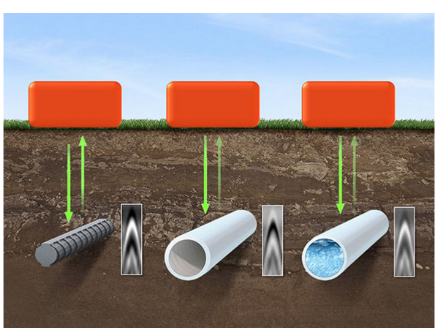
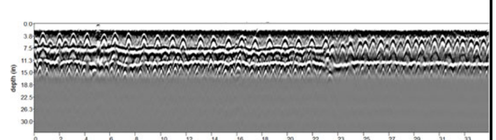
Results from GPR





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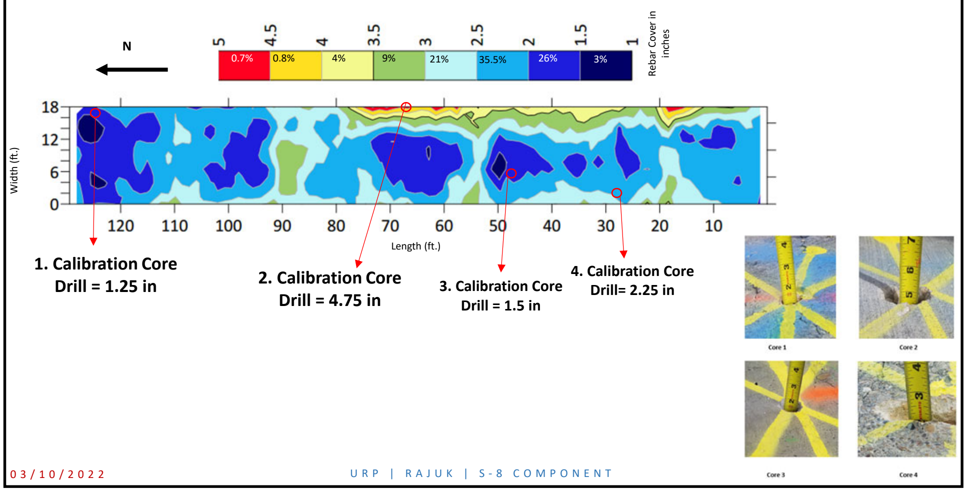
Result from GPR



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Impact Echo (IE)

- Used to determine the delamination condition and thickness of concrete structural members when voids, honeycombs, and cracks are suspected. Creates an impact at a spot on the surface and then records and analyzes the echo. It is a spot scanning device.

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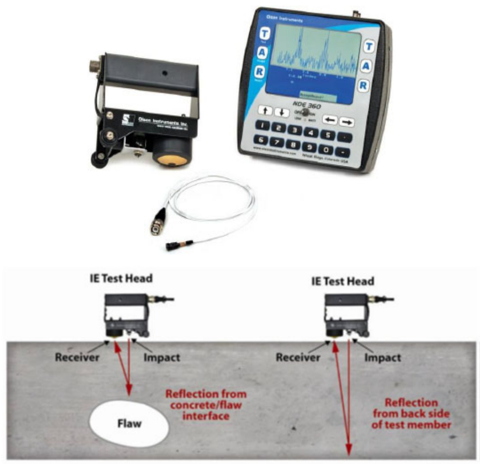
Impact Echo (IE) Device



Current Limitations

- Cannot determine the exact depth of the delamination
- Cannot locate the delamination within 2 inches from the surface

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IE Data Collection Video

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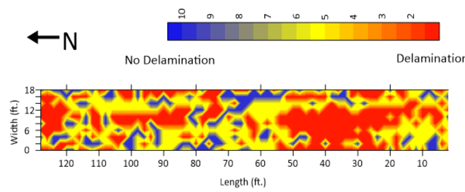
Sample Results from IE



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Ultrasonic Tomograph

Used to determine the delamination condition. Can determine the presence of delamination and the exact depth of the delamination.

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Ultrasonic Tomography Data Collection Video

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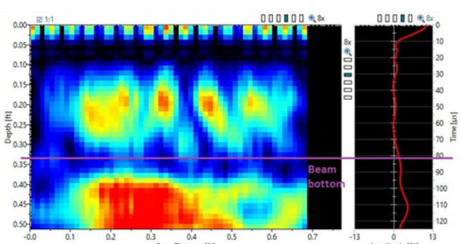
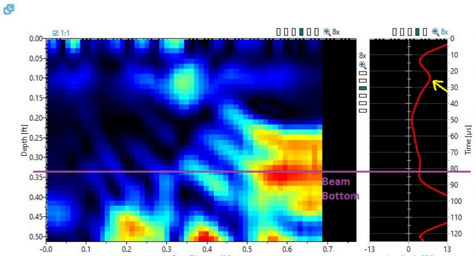
Results from Ultrasonic Tomograph





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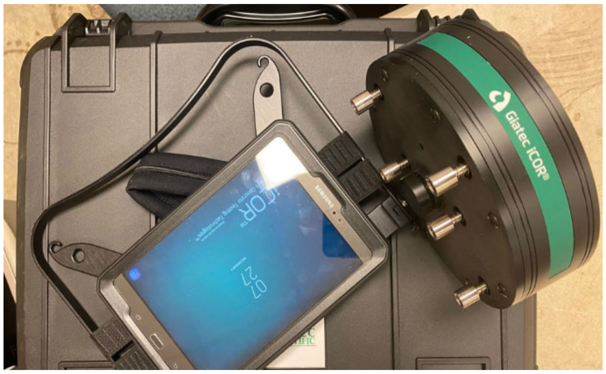
iCOR



For corrosion evaluation and condition assessment of reinforced concrete structures.

Without an electrical connection to the rebar, iCOR can provide corrosion rate mapping and corrosion potential mapping of rebar, in-situ real electrical resistivity of concrete.

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iCOR Data Collection Video

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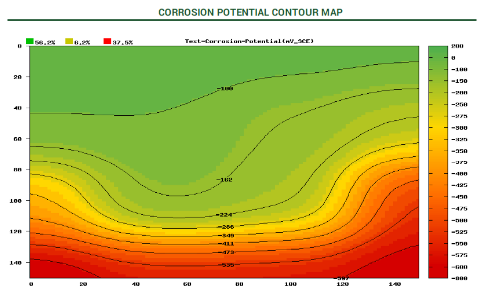
Results from iCOR



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Robotic Scanner (Lidar)

- Combines surveying and 3D scanning to capture high-accuracy measurements. Used in general and topographic surveys, roadway surveys, volumetric surveys, infrastructure surveys, power line inspection, tank calibration, and dimension control. Generates the 3D model which can then be imported into a variety of CAD software.

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Robotic Scanner

Concrete Bridge Evaluation

- For bridge inspection, can be used to monitor the movement of various components with time.

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Trimble Scanner Data Collection Video

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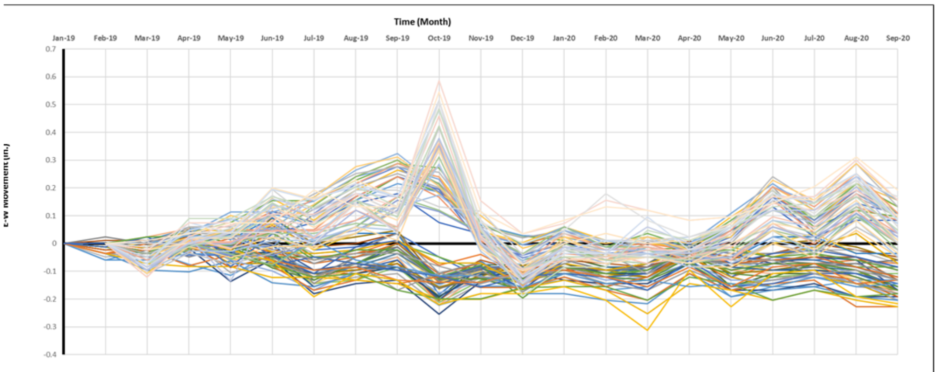
Results from Trimble Scanner (Bridge MSE Wall)



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Infrared Camera

- Can produce a thermograph or temperature profile as high as 1200°F of any surface. For condition monitoring, bridge deck diagnostics, moisture inspection, and energy losses in bridges. Can determine the delamination and bubbles close to the surface of concrete structures or FRP retrofitted concrete structures.

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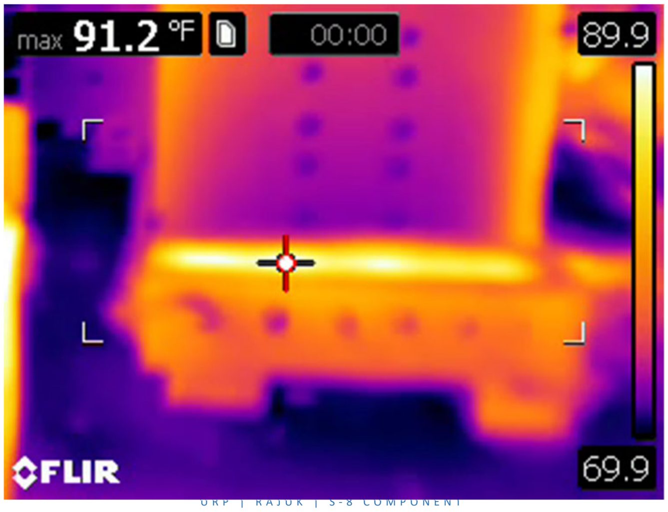
Infrared Camera Data Collection Video



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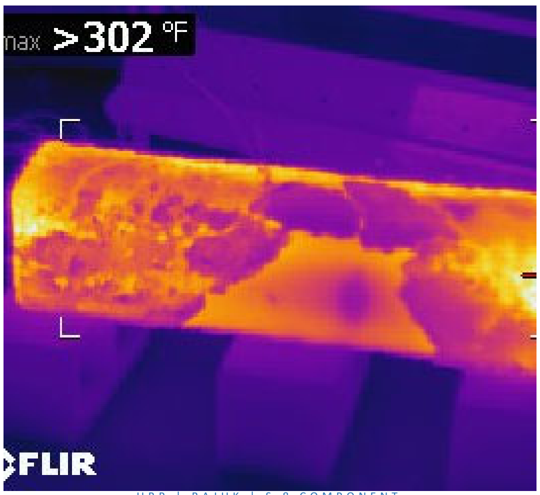
Results from Infrared Camera



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Schmidt/Rebound Hammer

- Used to measure the in-situ compressive strength of concrete.
- Measures the ratio between the rebound velocity and the impact velocity (Q).
- Can convert the rebound number automatically to compressive strengths. The range of measurement is 1450 to 14500 psi.

Schmidt Hammer Data Collection and Results Video

Pull-off Adhesion Testers (partially destructive)

- Quality of concrete repair is determined by the adhesive strength between the repair material and the substrate. Most widely used test method to assess bond strength.

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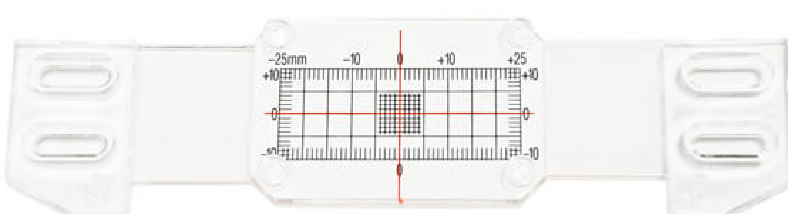
Crack Monitors

- Cracks in concrete structures, roads, buildings, or bridges can signal underlying problems and should be monitored to avoid serious functionality or stability issues.



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Concrete Moisture Testing Equipment

- Can detect moisture present in or migrating through concrete slabs.

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Unmanned Aerial Vehicle (UAV) Bridge Inspection

- UAV or Drones: emerging technology for bridges.
- Promising for bridge inspection due to the logistical challenges to efficiently and effectively visually inspect in challenging locations.
- More suitable as a tool for larger bridges.
- Defects can be identified and viewed with a level of detail equivalent to a close-up photo.
- Right of way and privacy issues are some current limitations.

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UAV Video

- https://www.youtube.com/watch?v=a4QcwQZPwcU

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THANK YOU

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