

The Role of Technology in Managing Aging Highway Bridges



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The Role of Technology

- Objective
 - To make the case that quantitative data is essential for adequate management of the multi-trillion dollars worth of assets we refer to as the highway infrastructure.

The Role of Technology

Overview

- Present background on infrastructure management in the United States
- Present a few examples of how technology has been used in infrastructure management
- Discuss future directions and research needs for infrastructure management and the role of technology

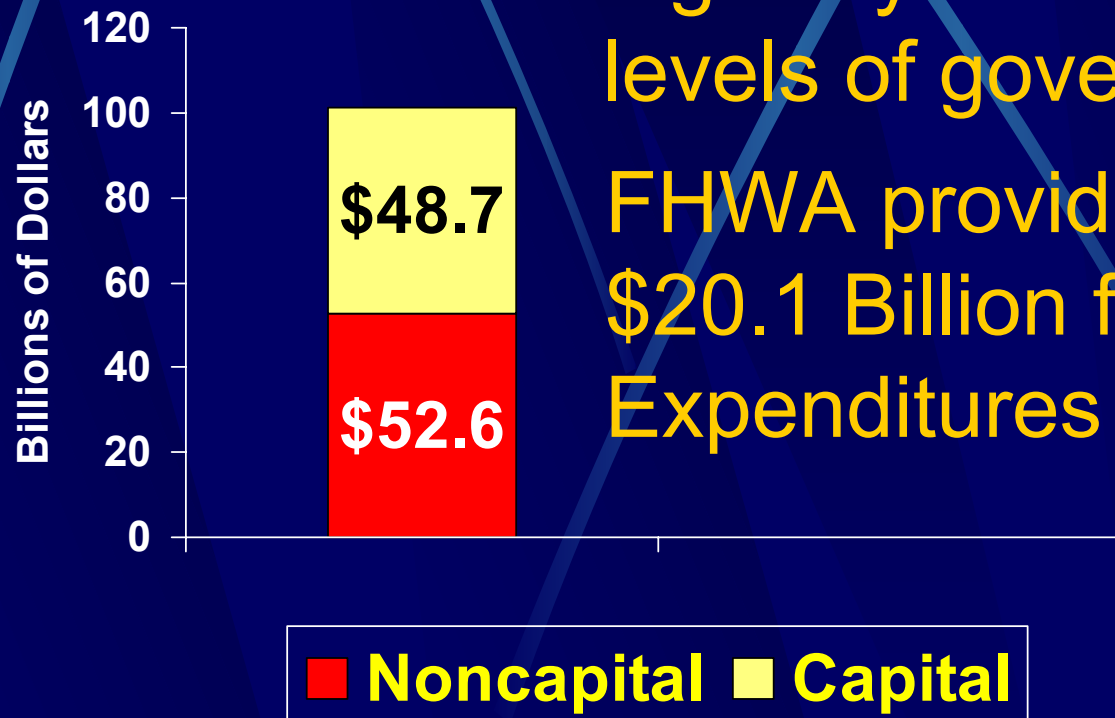
Some National Highway Statistics

- 3.95 million miles of public roads
- 8.3 million lane miles
- 2.5 trillion vehicles miles in 1997
- 593,000 highway bridges
- 3.2 billion square feet of bridge deck
- 3 billion bridge crossing per day

Total Highway Expenditures

\$101.3 Billion expended on highways in 1997 by all levels of government

FHWA provided \$20.1 Billion for Capital Expenditures



The Role of Technology

- Bridge management as example
 - History of national bridge program
 - Current bridge management practice
 - Limitations of BMS
 - Summary of recent R&D to address limitations
 - The technology in the management of bridges

Silver Bridge Collapse

December, 1967 46 Fatalities



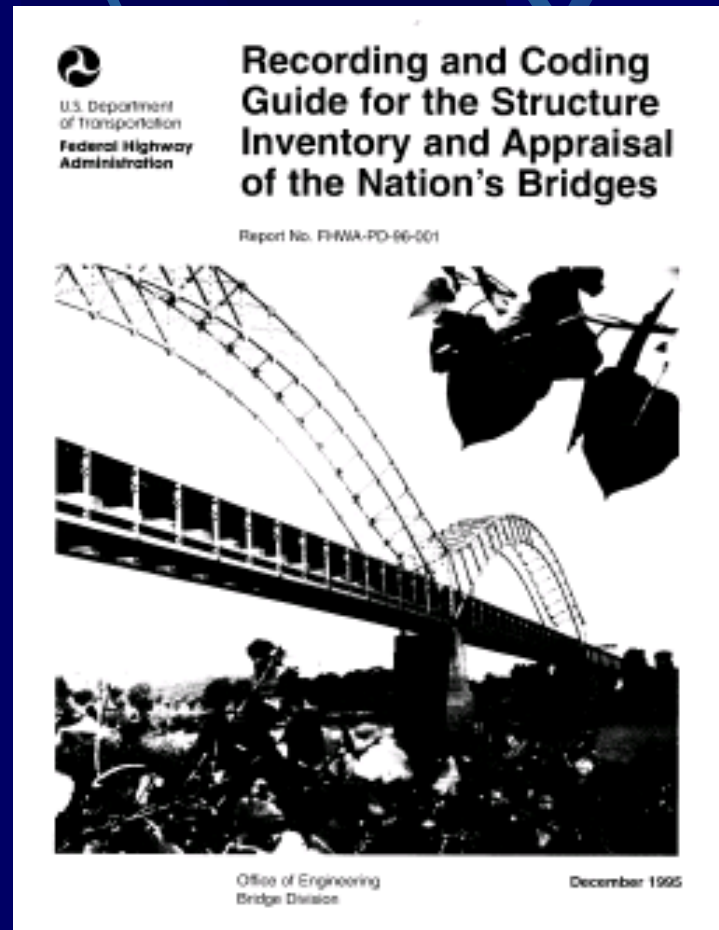
FHWA Bridge Program

- NBI Program began in 1971
- Establishment of National Bridge Inspection Program and National Bridge Inventory
- Focused on Elimination of Deficient Bridges

National Bridge Inspection Program

- National Bridge Inspection Program
 - Bi-annual Inspections
 - 593,000 bridges
 - 116 fields of data collected
 - Inspectors provide condition and appraisal ratings
- Eligibility for HBRRP determined by deficiency

NBI Coding Guide



NBI Ratings

(Numeric Code 0 to 9)

- Condition Ratings
 - Superstructure
 - Substructure
 - Deck
 - Culverts
- Appraisal Ratings
 - Waterway Adequacy (Frequency of overtopping)
 - Structural Evaluation (Load rating)
 - Approach Alignment
 - Deck Geometry (Roadway Width)
 - Underclearances (Vertical and Lateral)

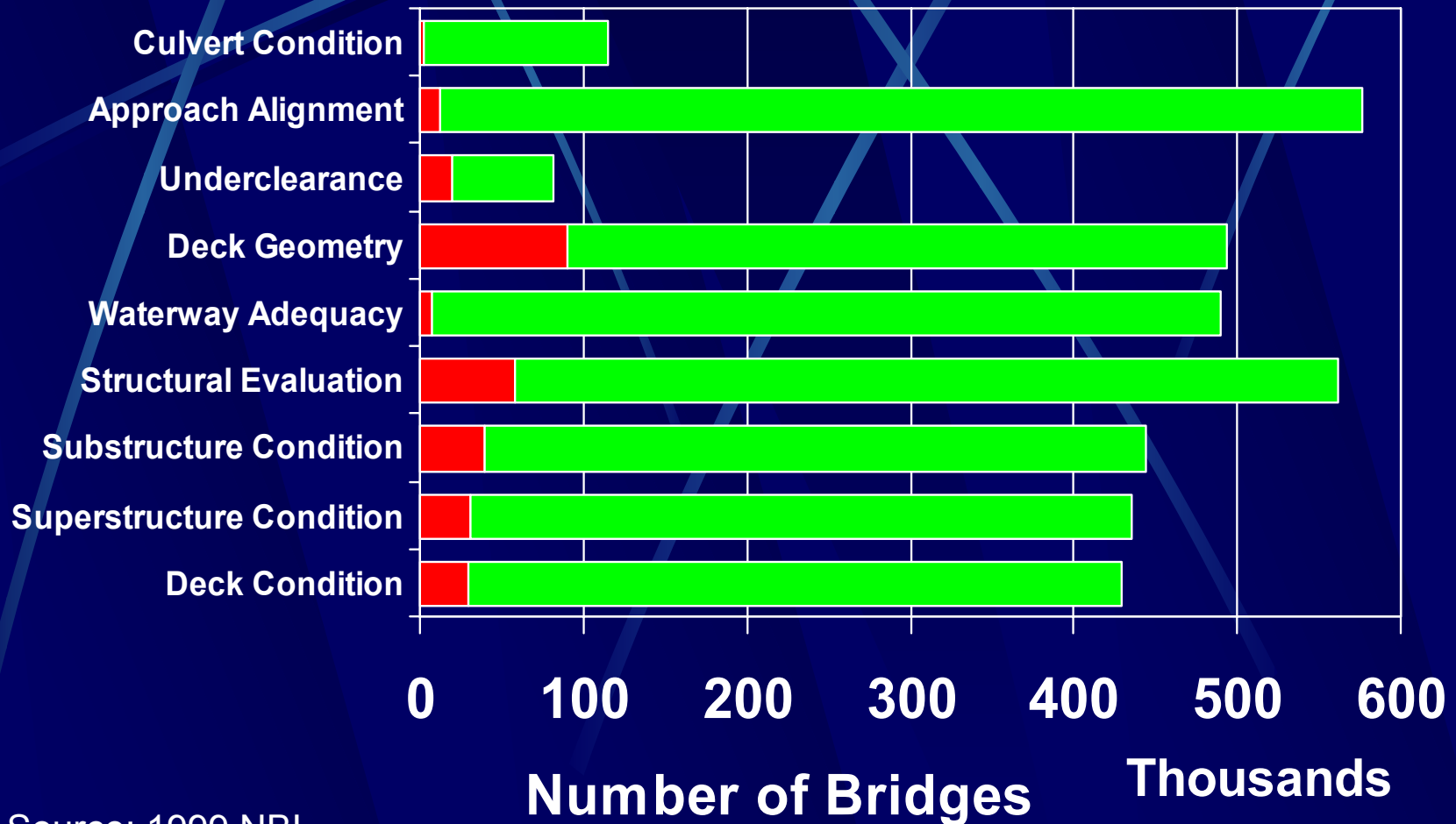
NBI Condition Ratings

- 9 - EXCELLENT CONDITION
- 8 - VERY GOOD CONDITION
- 7 - GOOD CONDITION
- 6 - SATISFACTORY CONDITION
- 5 - FAIR CONDITION
- 4 - POOR CONDITION
- 3 - SERIOUS CONDITION
- 2 - CRITICAL CONDITION
- 1 - "IMMINENT" FAILURE CONDITION
- 0 - FAILED CONDITION.

NBI Appraisal Ratings

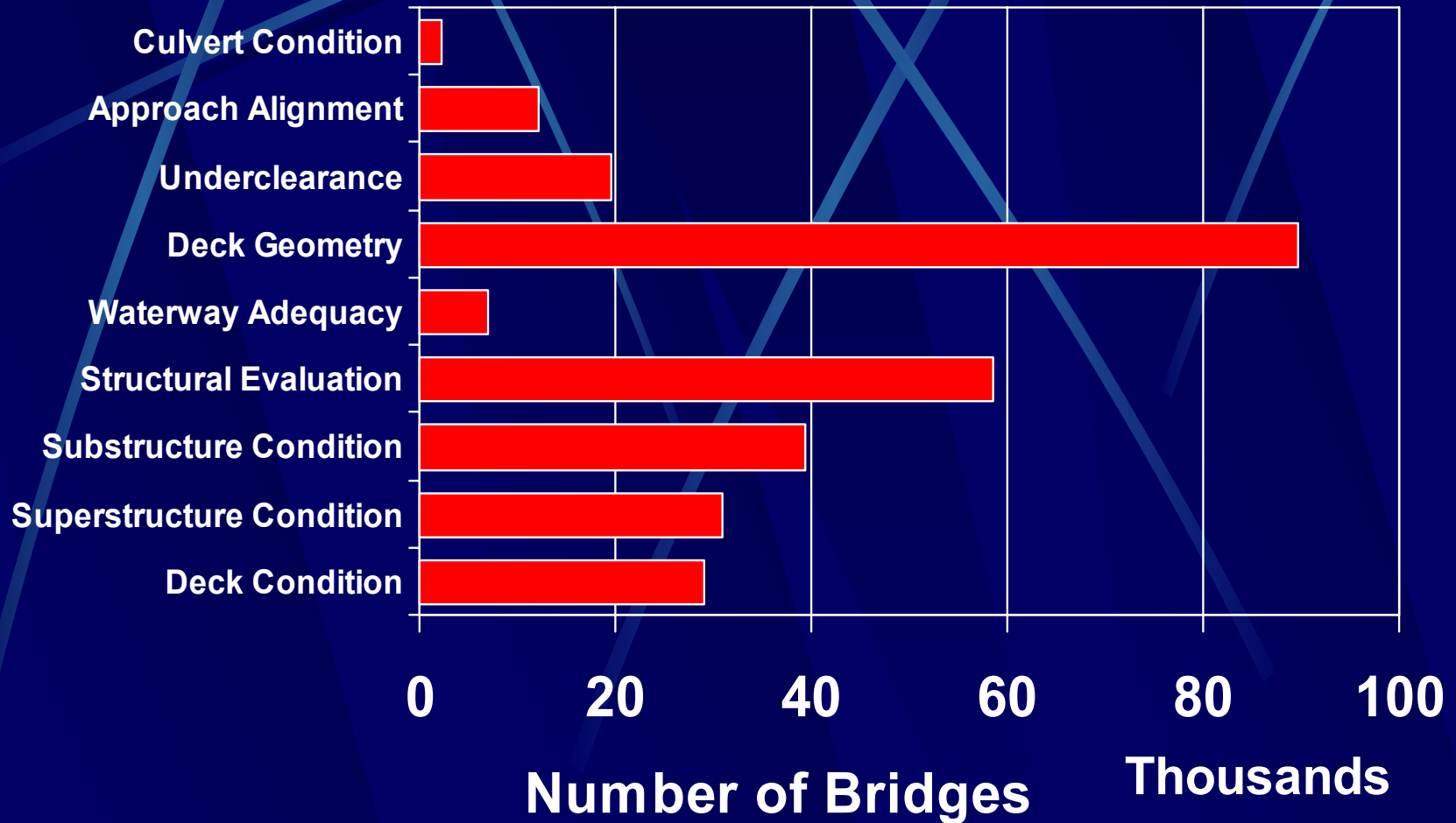
- 9 - Superior to present desirable criteria
- 8 - Equal to present desirable criteria
- 7 - Better than present minimum criteria
- 6 - Equal to present minimum criteria
- 5 - Somewhat better than minimum adequacy to tolerate being left in place as is
- 4 - Meets minimum tolerable limits to be left in place as is
- 3 - Basically intolerable requiring high priority of corrective action
- 2 - Basically intolerable requiring high priority of replacement
- 1 - not used
- 0 - Bridge closed

NBI Bridge Deficiencies



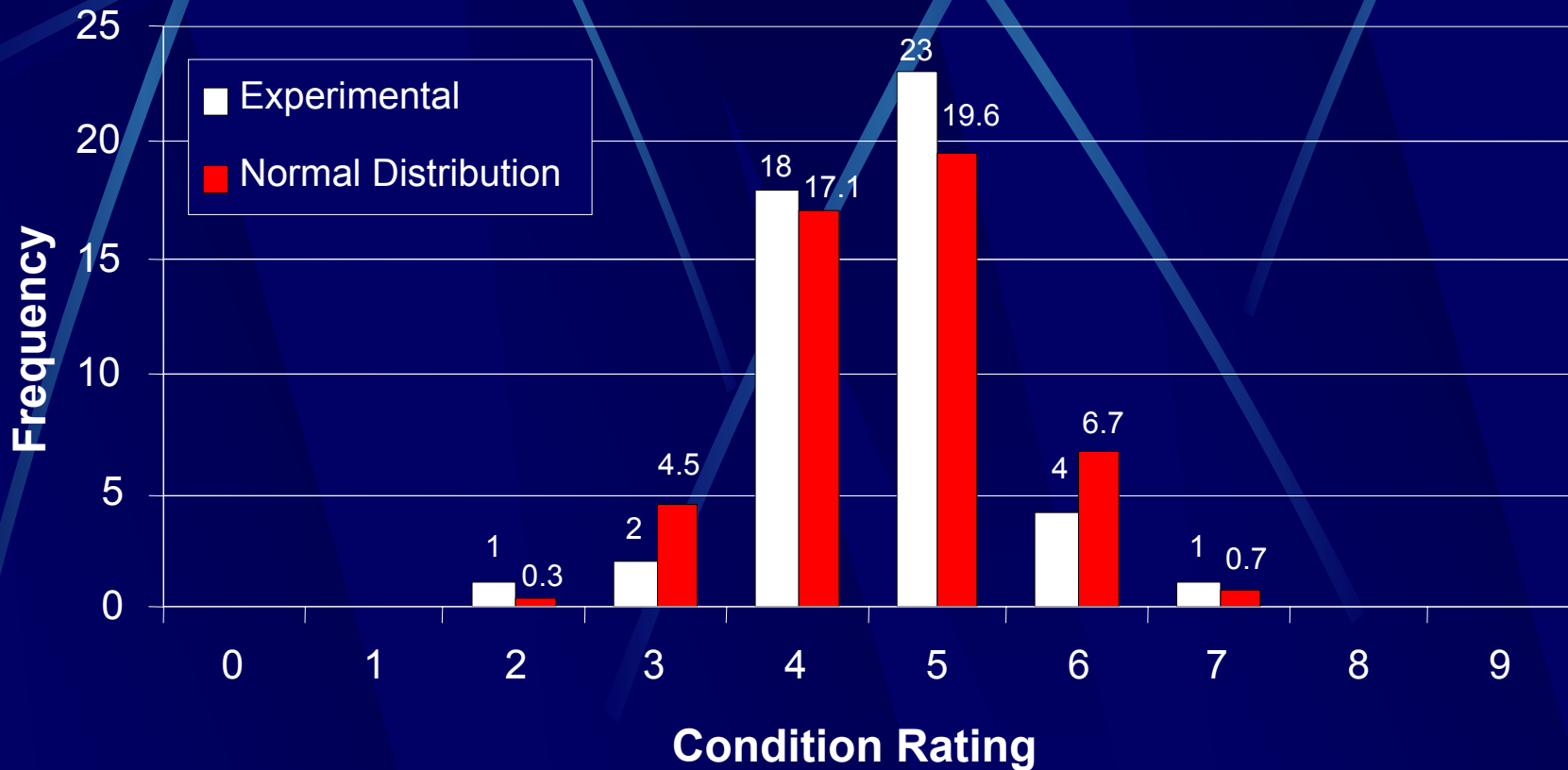
Source: 1999 NBI

NBI Deficiencies



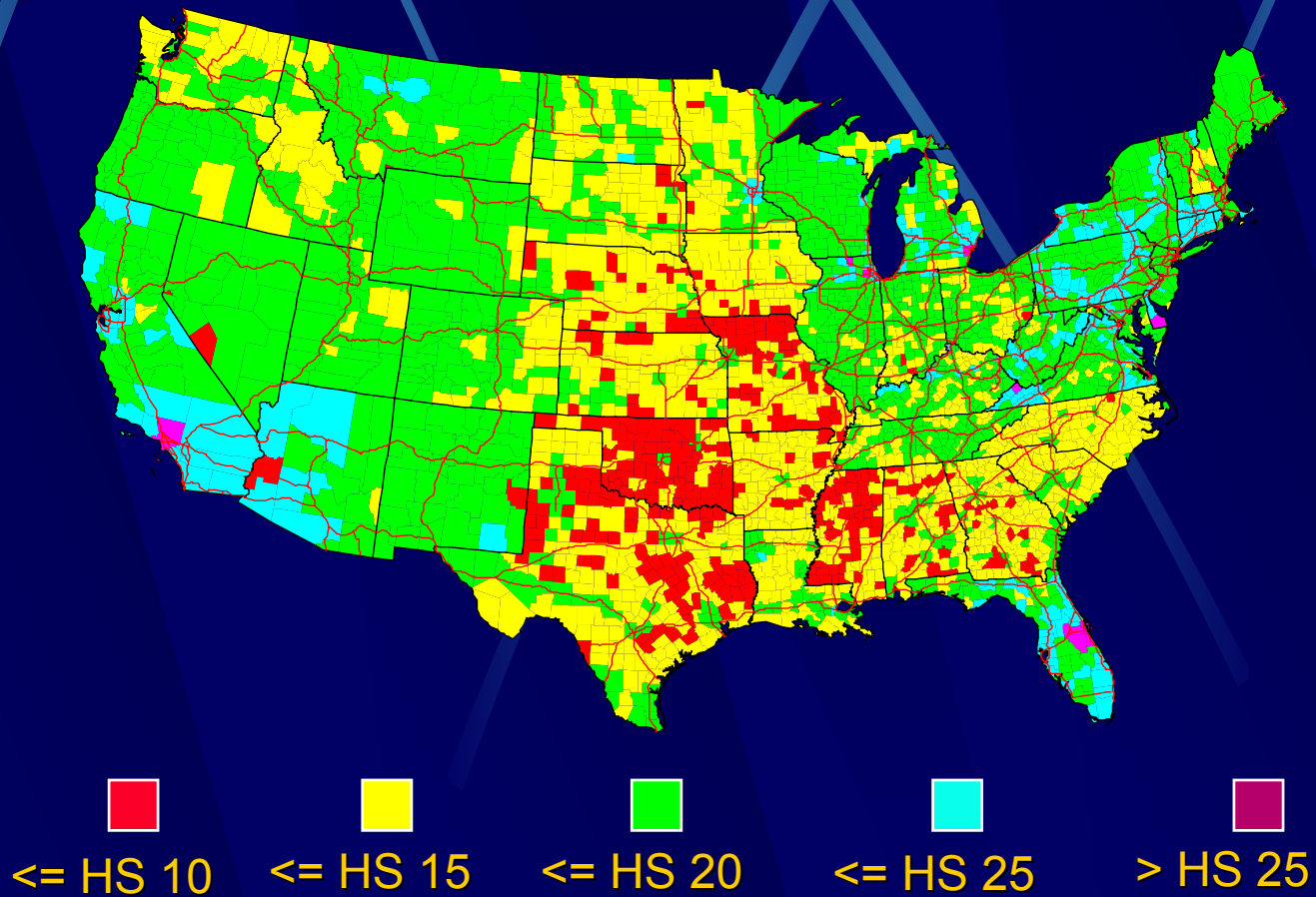
Source: 1999 NBI

Reliability of Condition Rating?



NBI Data

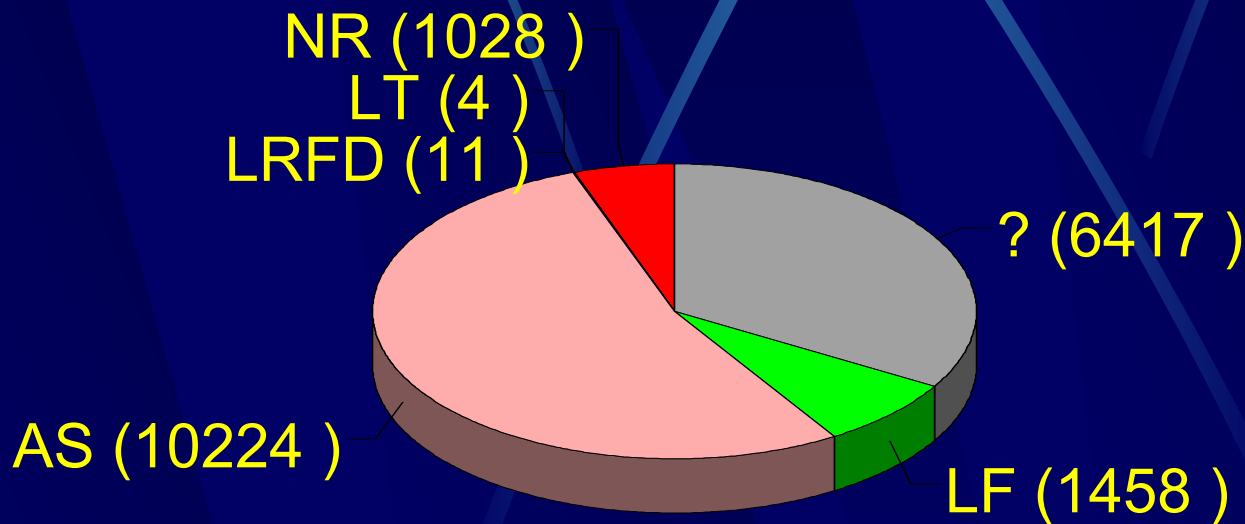
Average HS Inventory Rating



Reliability of Load Ratings?

1999 SD Bridges (SA Only)

Method used to Determine IR



Shortcomings of NBIP

- NBIP adequate for administration of national HBRRP program
- Inadequate for bridge performance measurement
- Most states augment NBI data
- Condition Ratings based on subjective visual inspection
- Not adequate for owner level bridge management

Element Level Inspection

- PONTIS
 - Element level inspections
 - More discretized condition state data
 - More quantitative condition state data
 - Provides network (population) level decision support
- Significant advance

Typical Condition State Definition

Open Steel Stringer (Painted)

- Condition State 1
 - Sound paint, no corrosion, no section loss
- Condition State 2
 - Early distress of paint, little or no corrosion, no section loss
- Condition State 3
 - Paint not effective, surface rust, no section loss
- Condition State 4
 - Paint failed, surface pitting, section loss incidental
- Condition State 5
 - Paint failed, advanced corrosion, section loss sufficient to warrant analysis
- Quantity in each state recorded

Limitations of Element Inspections

- Condition states still based solely upon visual inspection
- Invisible deterioration, damage or distress not detected or measured
- Operational performance not measured
- Vulnerability and reliability not adequately considered

Detection and measurement needs

- Damage
 - Impact
 - Overload
 - Scour
 - Seismic
 - Fracture
 - Settlement
 - Loss of section
 - Inoperative bearings
- Movement
 - Lack of movement
 - Cracking
- Deterioration
 - Corrosion
 - Fatigue
 - Water absorption
 - Loss of prestress
 - Unintended structural behavior

Detection and measurement needs

- Operation
 - ADT
 - WIM
 - Stress
 - Strain
 - Deflection
 - Displacement
- Service
 - Congestion
 - Accidents
 - Side friction
 - Performance measures

Additional Data Needs

- Data to support life cycle cost analysis
- Data to support performance based specifications
- Data to support performance measures

R&D to meet these needs

- Global health monitoring
- Rapid measurement of load capacity
- Vulnerability
 - Fatigue and fracture
 - Flood and seismic
 - Overloads
 - Impacts
- Critical component monitoring
- Integration with BMS

Commodore John Barry Bridge Real Time Health Monitoring System

Truck Weight & Weather
Monitoring Station

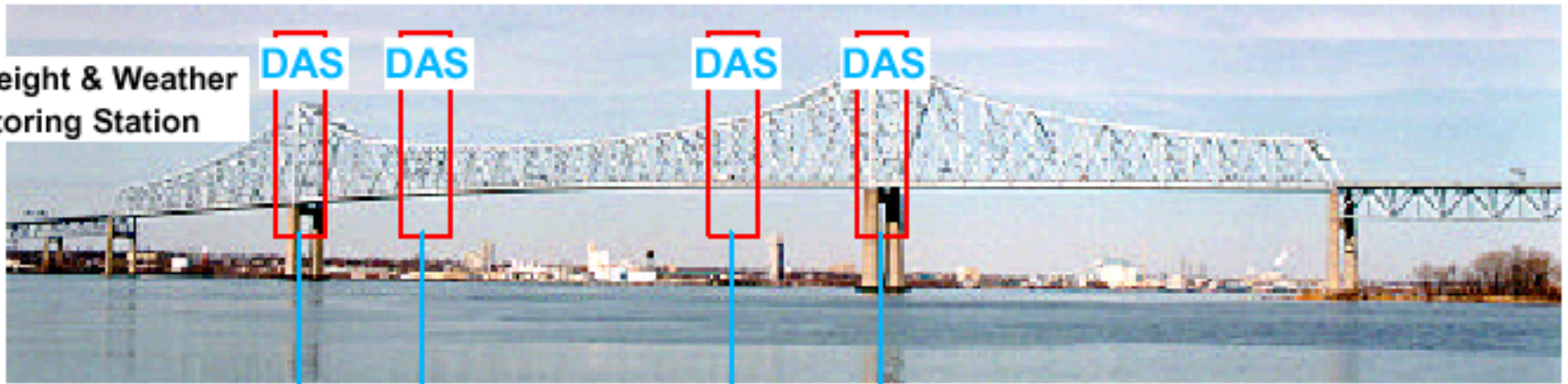
DAS

DAS

DAS

DAS

DAS



Fiber Optic Local Area Network (LAN)

Remote Wireless Component of LAN



WIM



Video Cameras



Weather Station



Bridge Sensing
Systems



Typical DAS



Sensor
Installation

Internet

Real Time
Access via Web
Browser

LAN Server



Integrated Legacy &
Data Archive Databases

Laser Radar Measurement System

**Rapid non-contact
measurement
of structural deflections**

Range 2 to 30 meters

Resolution ~0.1 mm

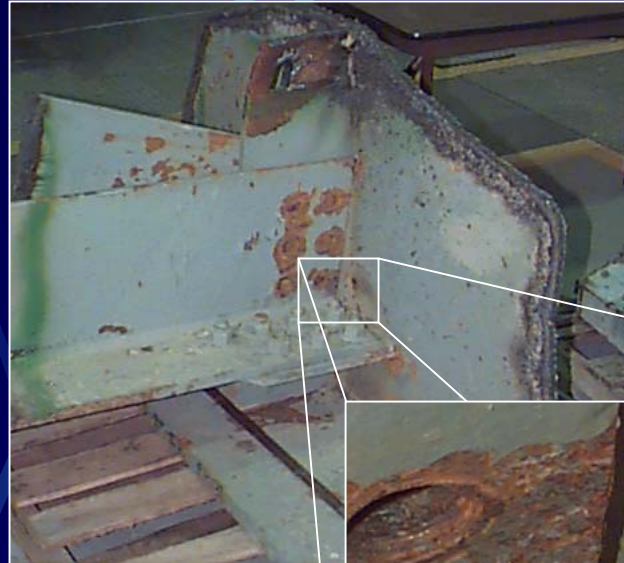
**Rapid measurement capabilities
(100's of points per minute)**

Totally portable

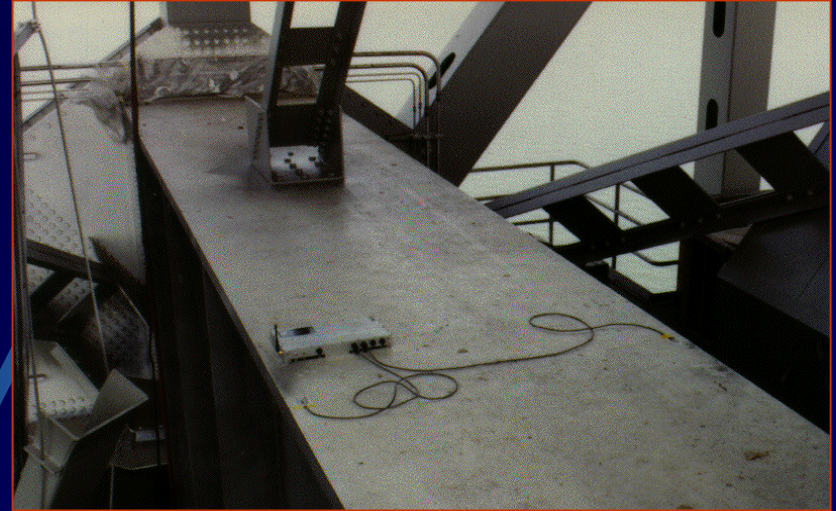


Recent Brittle Fracture

Milwaukee, WI December 2000



Wireless Strain Measurement

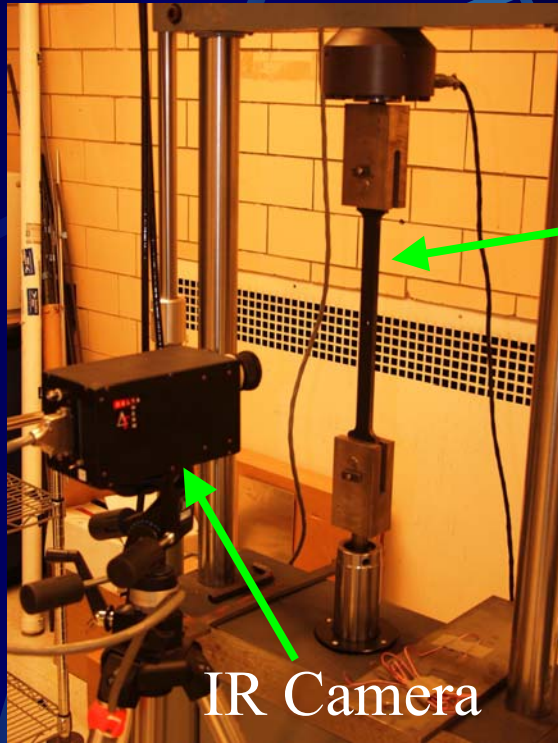


- Characterization of fatigue
- Measures random cyclic stress at several locations
- Battery powered

- Digital Spread Spectrum
- Adaptive wireless network
- Telemetry Range (~1.5 Km)
- Low Noise
- High Dynamic Range

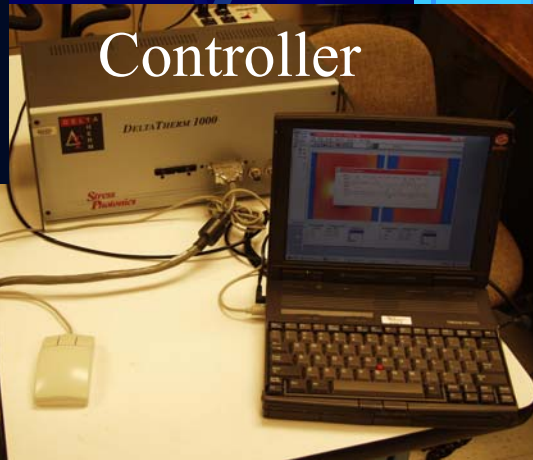
Thermoelastic Measurement of Stress Concentrations

- Determine the stress concentrations at welded details in fatigue categories
- Correlate the apparent concentration with the fatigue category
- Might define fatigue categories more accurately – or differently - for uncatalogued details



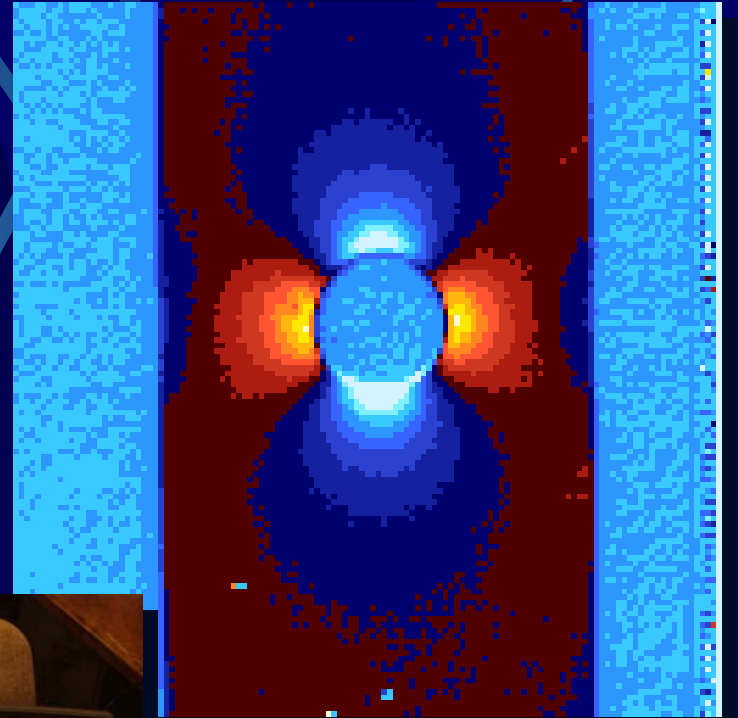
Specimen w/
hole

IR Camera

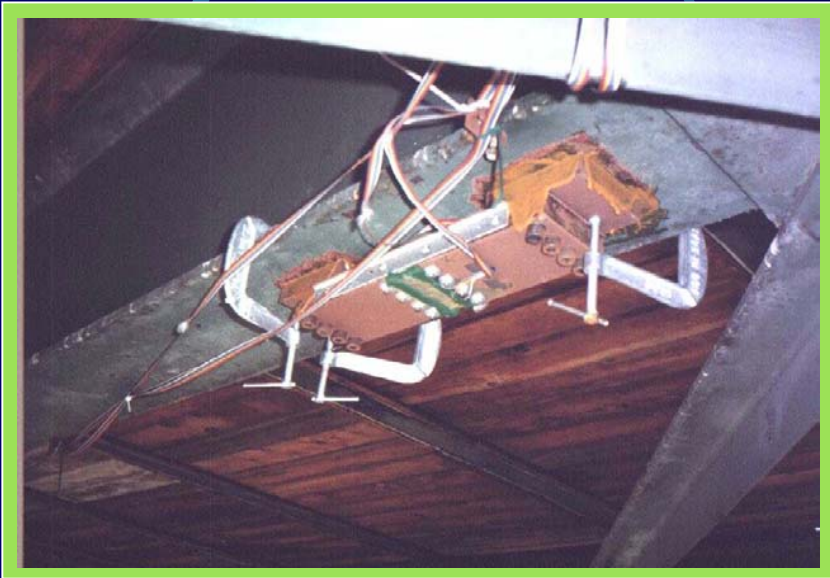


Controller

Laptop computer



Passive Fatigue Load Measurement



**Two aluminum coupons with
manufactured fatigue cracks**

**Fully characterized fatigue
crack growth behavior**

**Integrated continuous resistive
crack length gage**

**Placed on in-service bridged
for extended time**

New AE System for Bridges

Battery powered
8 AE channels
11 Parametric channels
Totally Digital
Remote access and data download

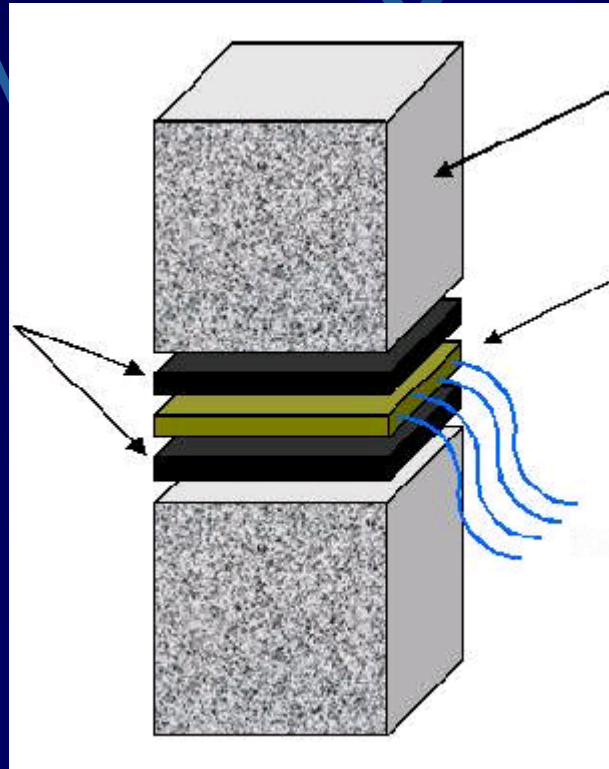


Smart Bearings

Neoprene Pads



Prototype



Bridge

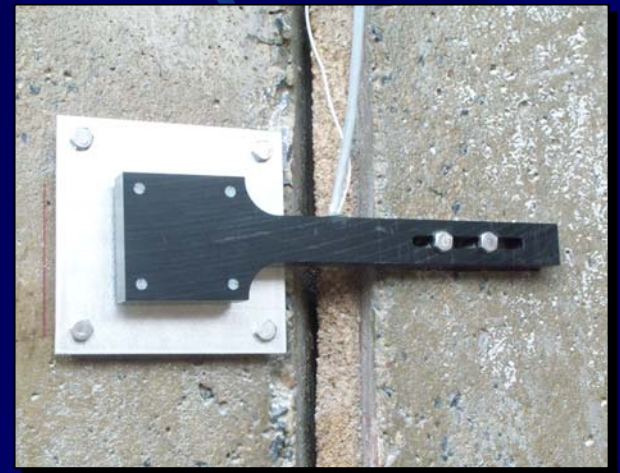
Composite
load cell using
multi axis fiber
optic strain
sensors

***Images obtained from
Blue Road Research**

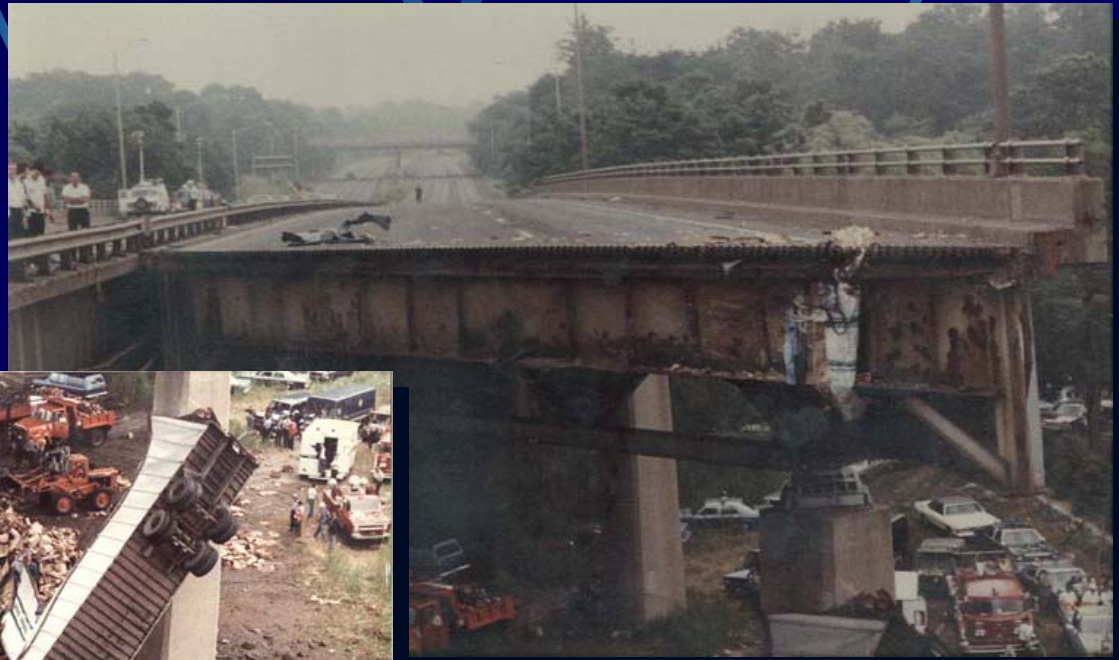
Wingwall Monitor



Eddy Current
Displacement Sensor



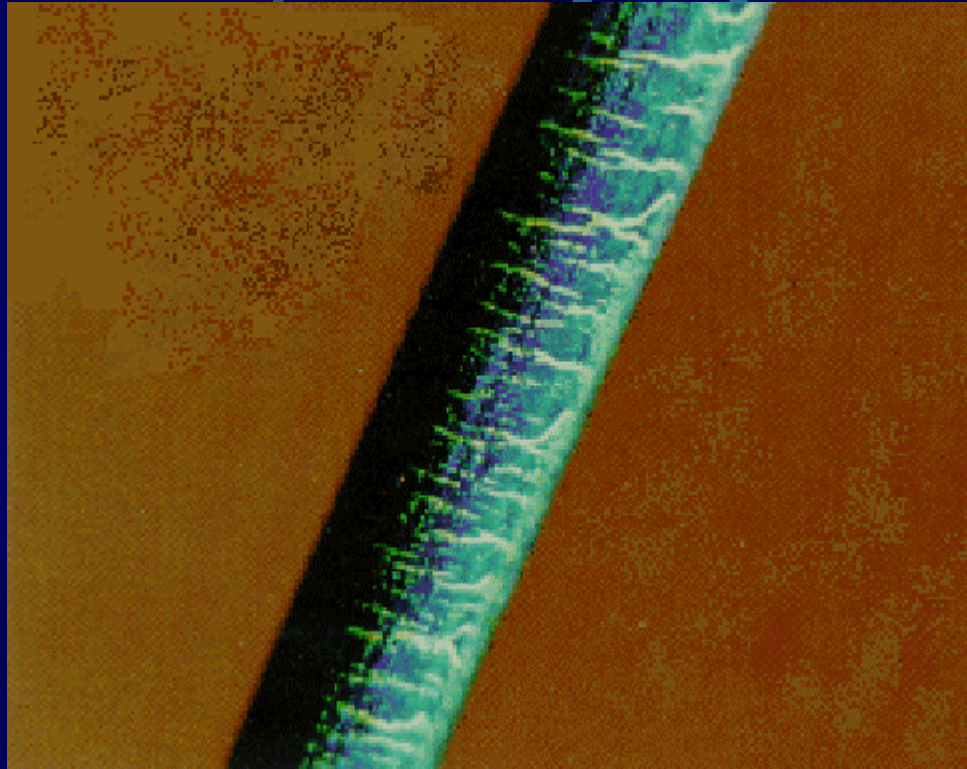
Mianus River Bridge 1983 Pin & Hanger Failure



Monitoring Critical Bridge Components



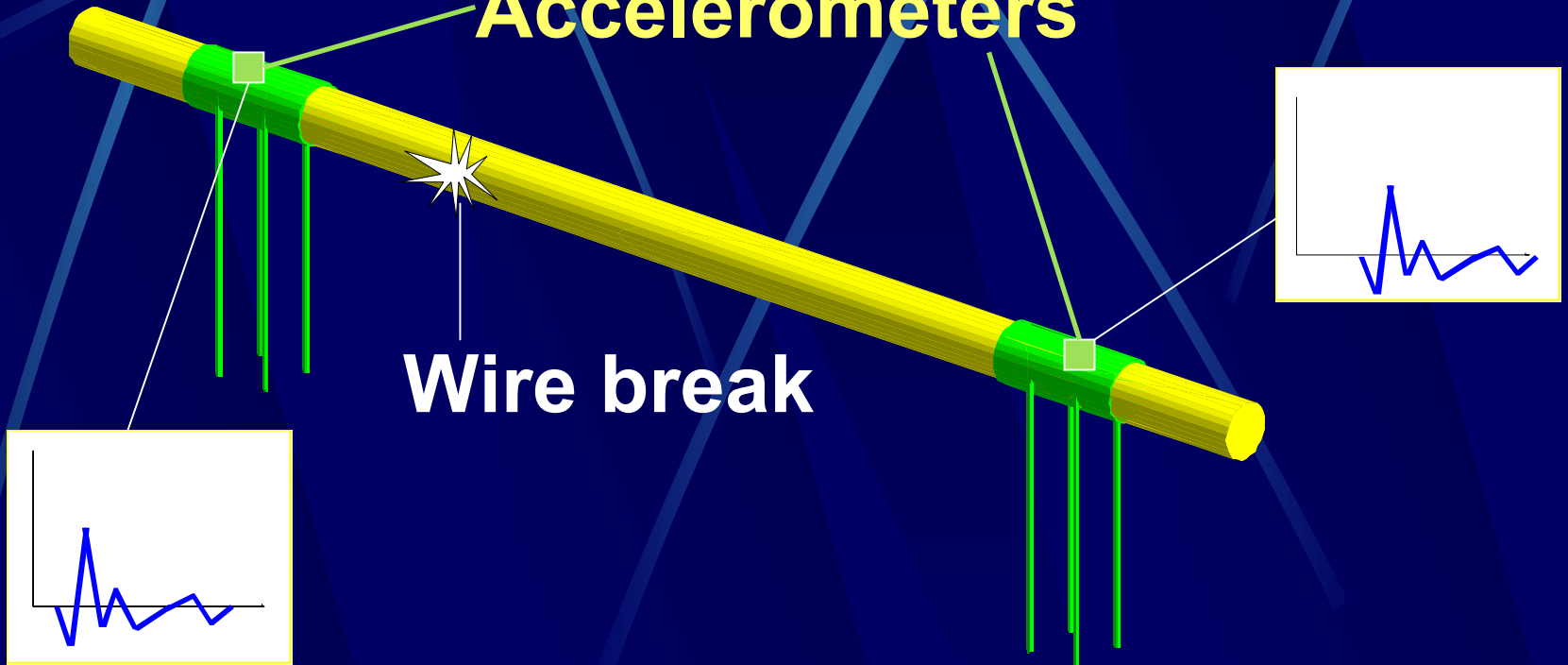
High strength steel wires are susceptible to stress corrosion cracking



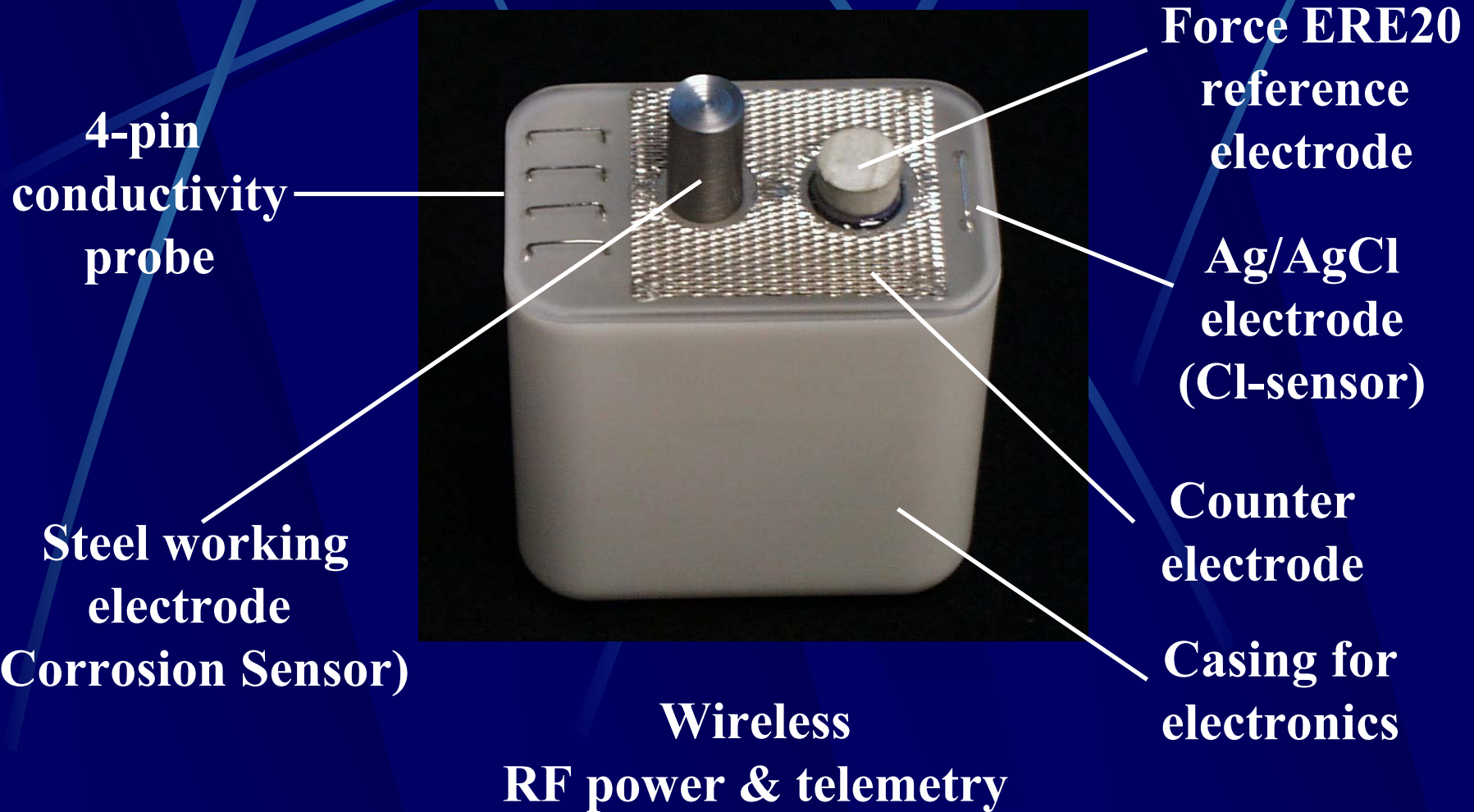
Acoustic monitoring of wire breaks

Accelerometers

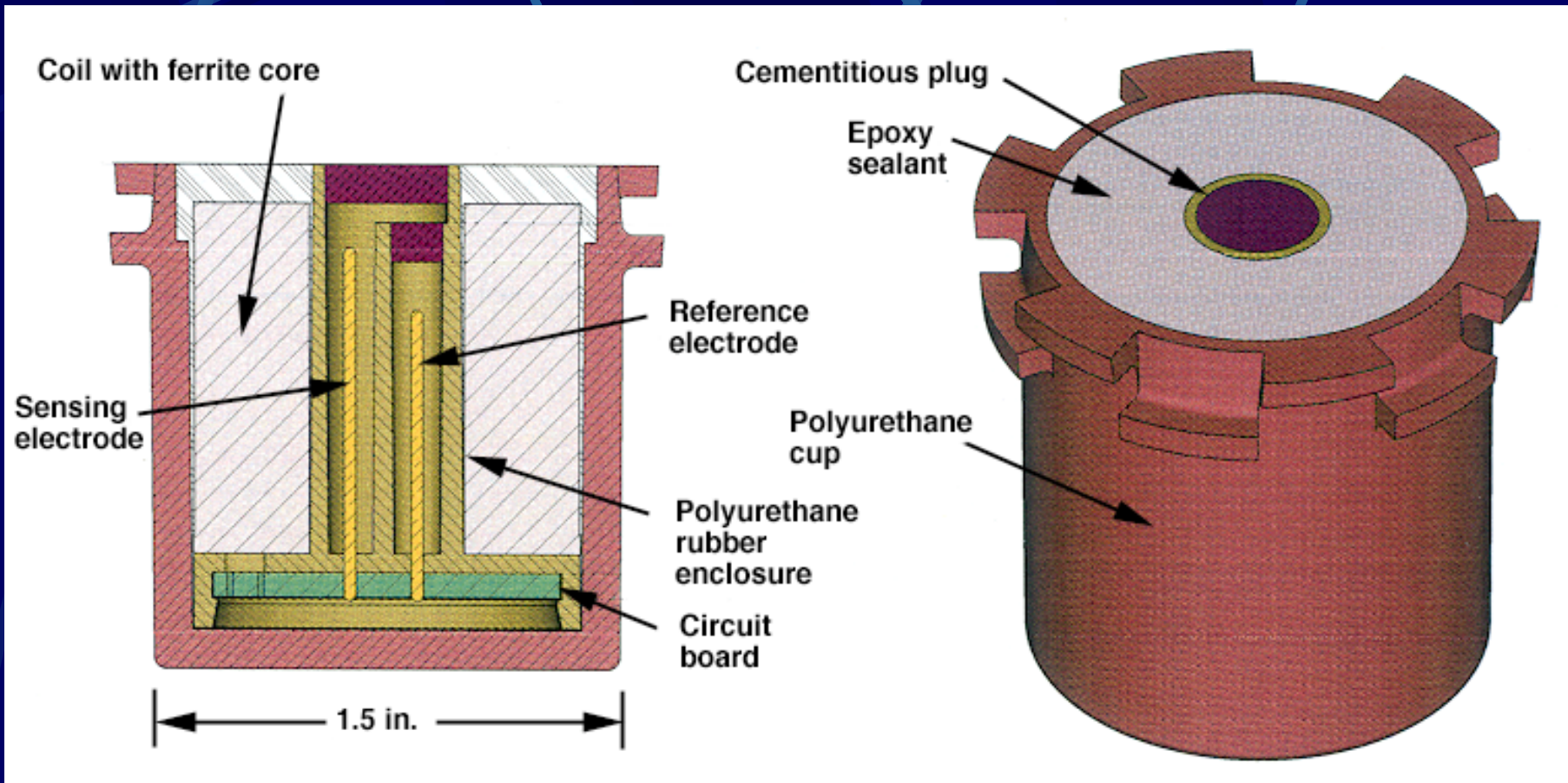
Wire break



Embeddable Corrosion Sensor



Smart Pebble Construction



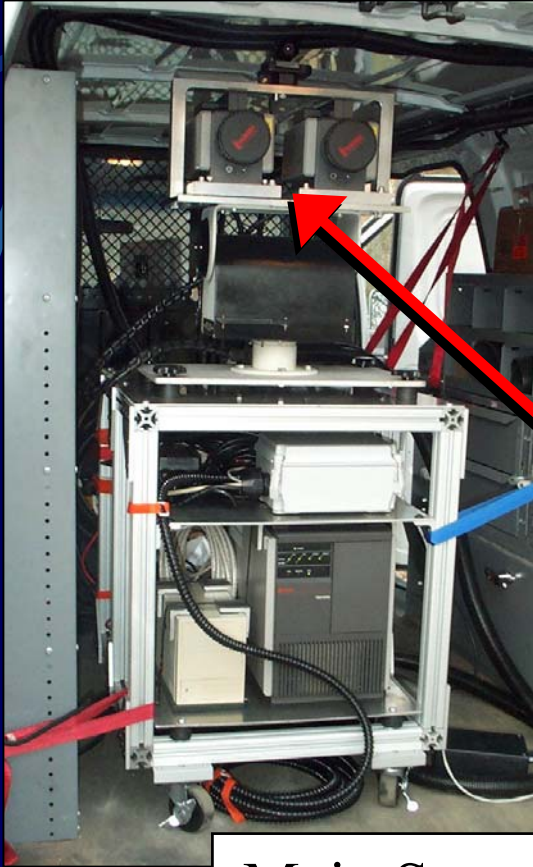
Smart Pebble™



Infrared Defect Detection

- Inspection of concrete and concrete/composite structures
- Passive methods use heat contained within the intact concrete vs. heat in thin layers (delaminations)

System Description



Infrared
Cameras

Main System

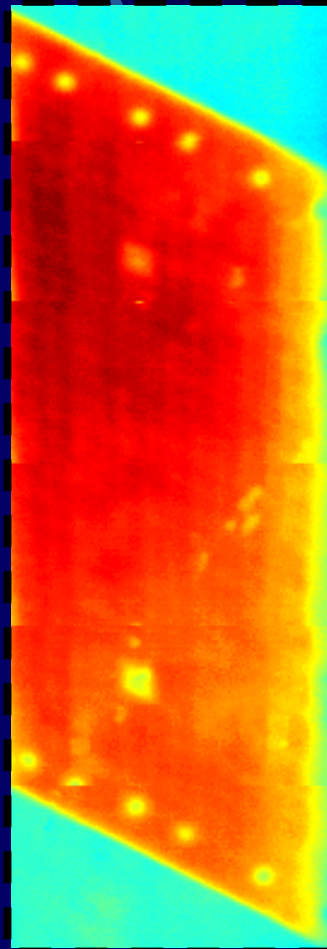


Infrared Data

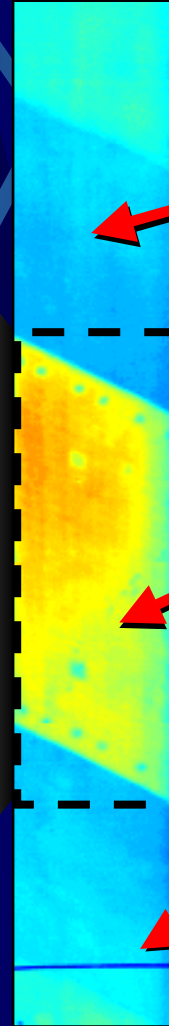
North

Rt. 248 South of
Rexville, NY

Northbound Lane



South



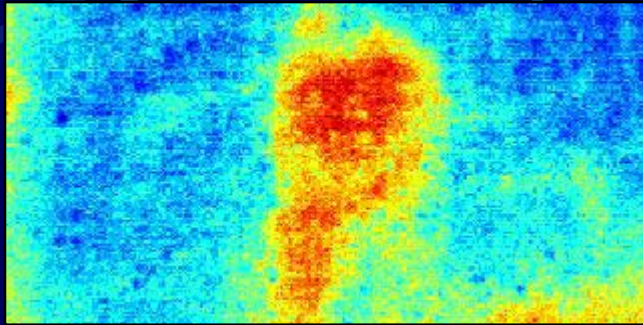
Approach Slab

Deck

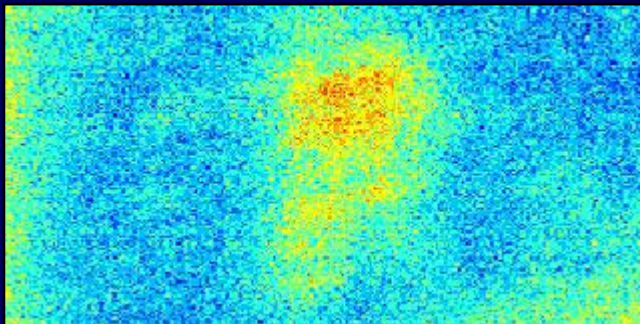
Aluminum Tape

Infrared Data

NDEVC Test Bridge, Van Buren St



Long Wave



Short Wave



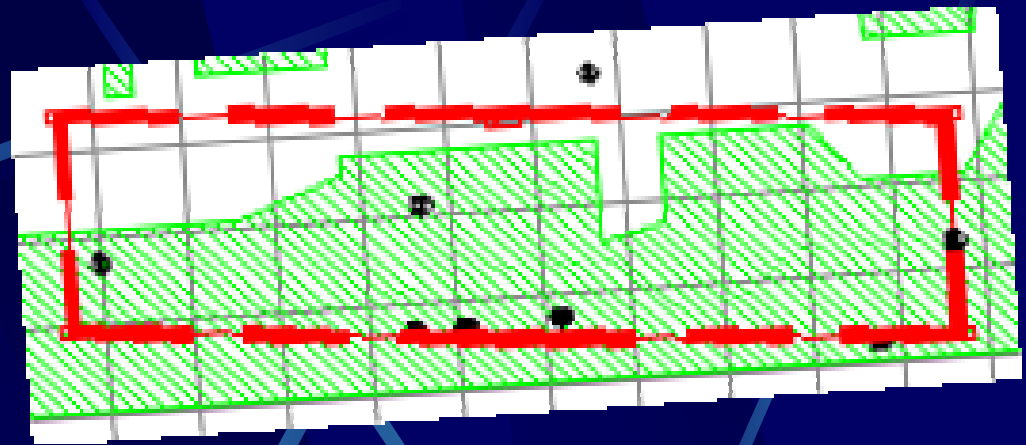
Video Image

PERES II

Ground Penetrating Radar

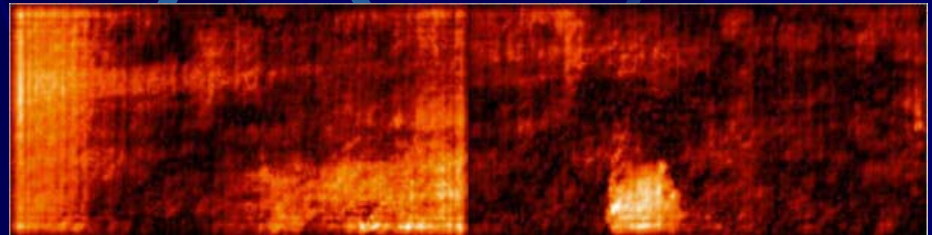


Chain drag data:
Lake Anna Bridge deck
Green hatch=delaminated

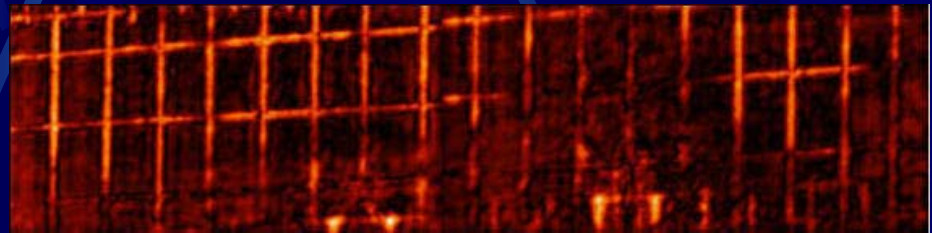


PERES II data:

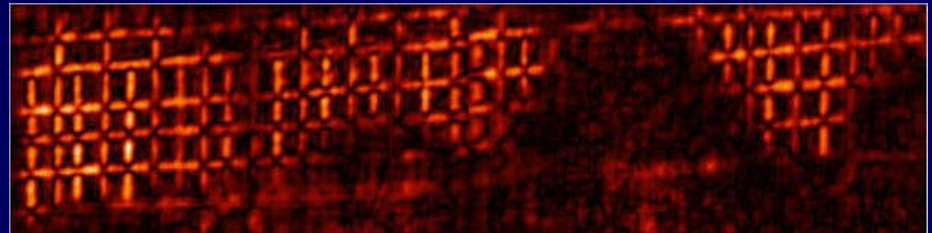
Surface reflection



Top layer of
reinforcing steel



Bottom layer of
reinforcing steel



Lowe's Motor Speedway North Carolina



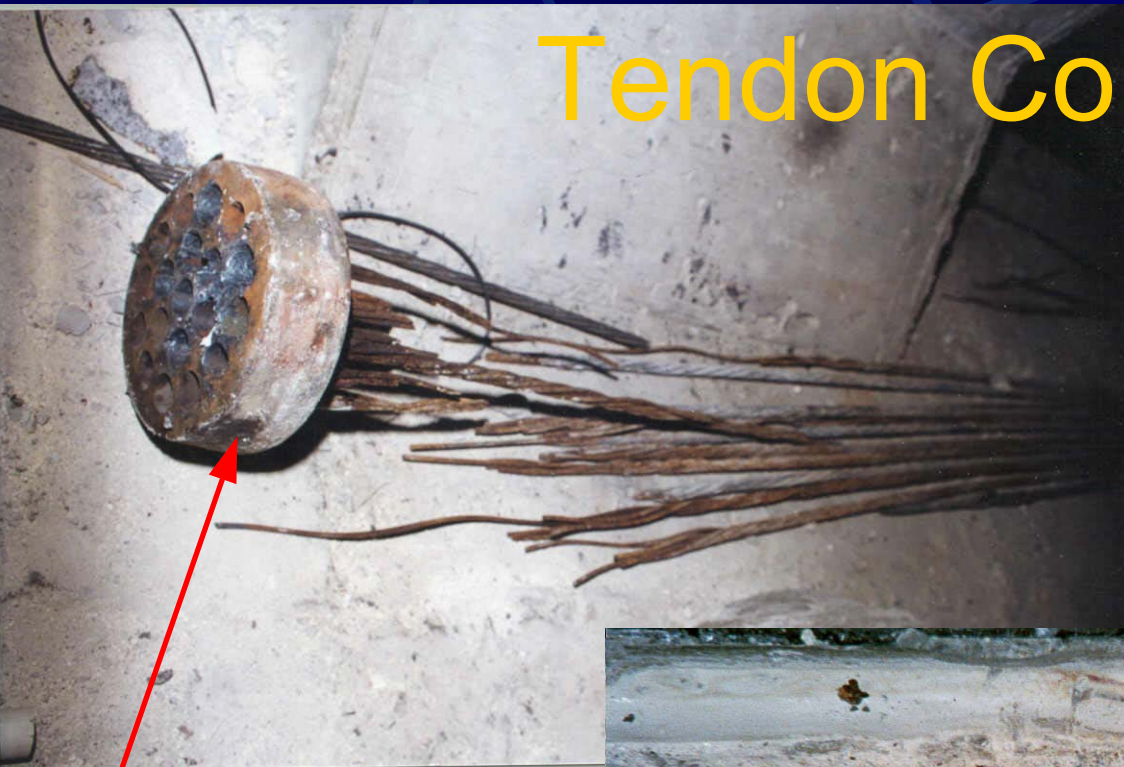
Segmental Construction

Anchorage

Ducts



Tendon Corrosion



Anchor
Block



Strand

Grout

HDPE
Duct

RADIOGRAPHY OF BRIDGES

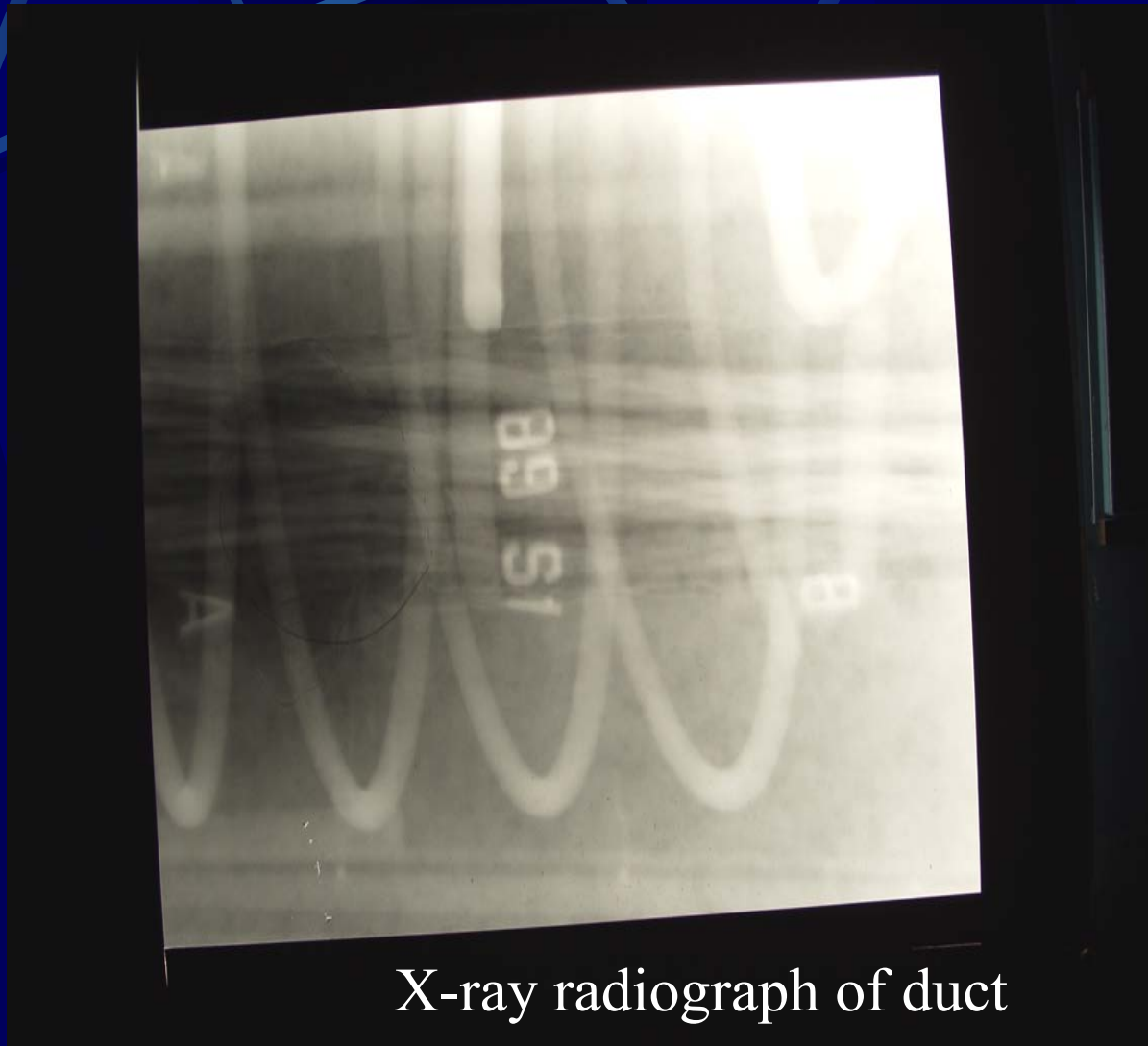


X-ray source



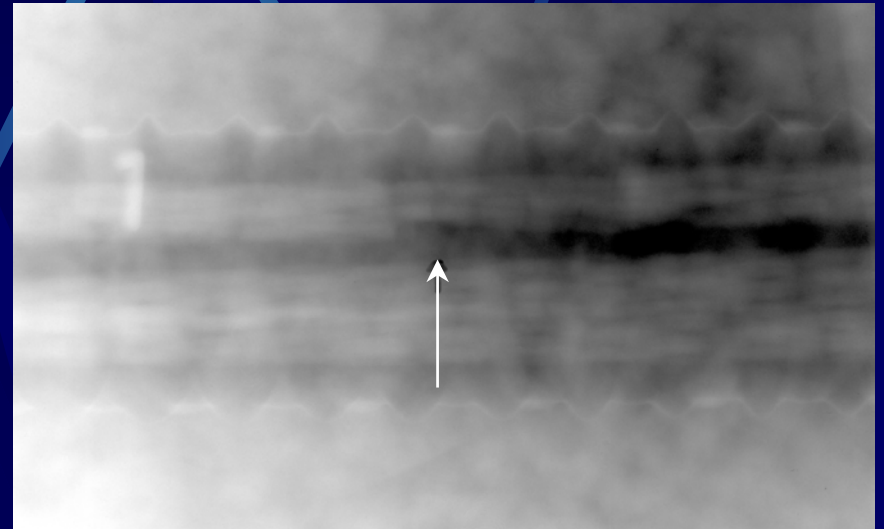
Film loading

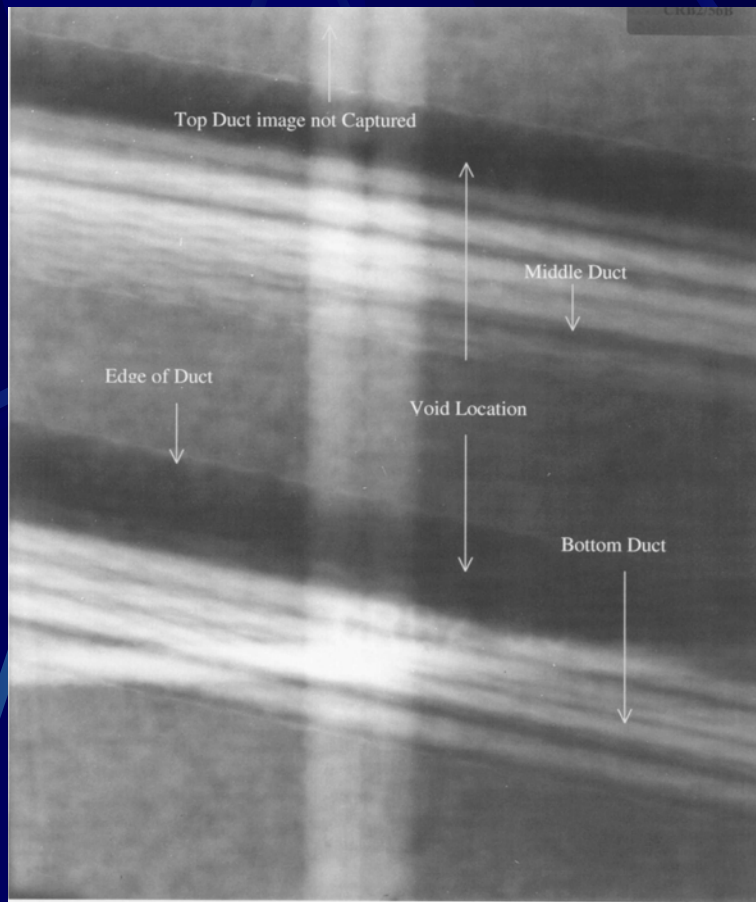
RESULTS



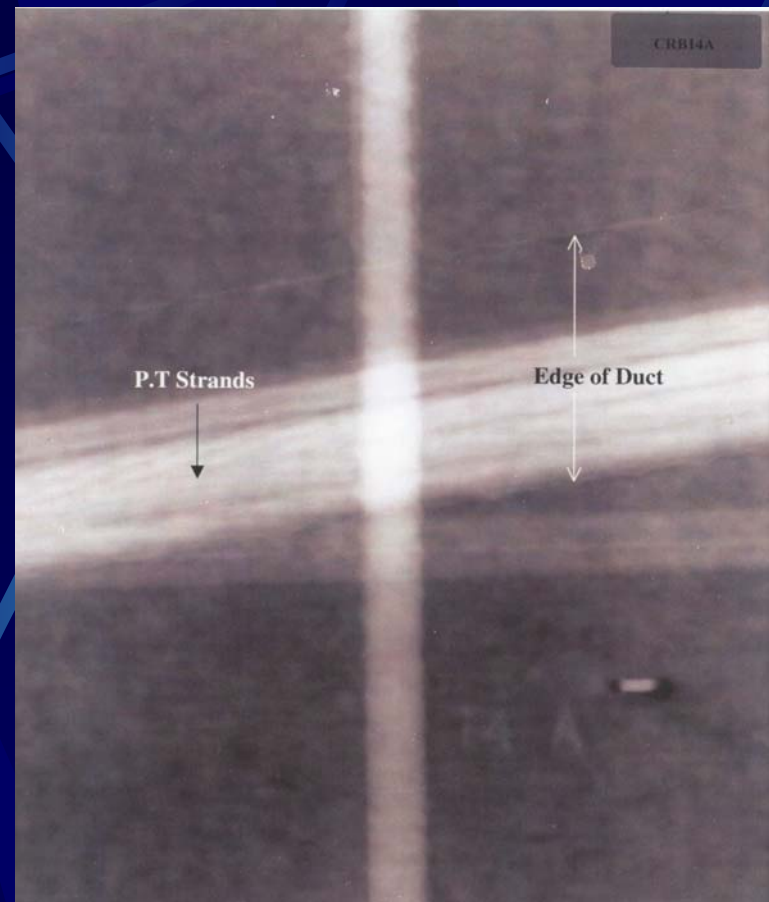
X-ray radiograph of duct

Detection of Broken Strands



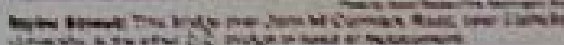


Void



No Void

REF: Central Artery/Tunnel Project
Radiography: Jack Moore Associates, Inc.



© 2000 Blackwell Science Ltd

Each day, an average of more than 10 million cars, trucks and buses drive through and on I-95. Bridges that incorporate sustainable technology including, reducing light pollution of roadway.

for earnings of more than \$100,000. The Taxpayer, who owns 100% of the corporation, received an additional \$100,000 from the corporation.

100

Handmade of these remarkable fibers are the hats at the University of Maryland and Virginia. Now come — if not sweat — at the shells are spun are not "pressed." They give you an astringent and an "anti-itch" cream. Unusually and highly to radiate about spinning around a heat lamp and the other side there is a strong, a shiny, perfectly finished in elegant simplicity, the entire work.

1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 2679, 26

inspired by those with which I must have
the most close contact — the dog — as
the superior, disappointed intelligence
will become aware in connection. There
exists a line that every creature that the
adorable being, as one of mental and
physical existence can be said to be
A. Brown

Ballet's difficulty being a different one. There was that, as ballet involves discipline, there were

Always include references that are relevant, in the form of a bibliography and provide them in the appendix.

The members of The Washington Council of the Marine Veterinary Association will be in charge. A National Marine Veterinary Association meeting was held in 1973 in Washington, D.C. and many of the members are active in the field of marine veterinary medicine.

...and the evidence by the Crown shows that such is a case of large budget deficits, important arguments of the Crown's policy-makers, and the fact that the

National Institutes of Health is the largest federal research agency, with the largest budget in the world. It is the largest agency in the Department of Health and Human Services.

¹¹ See, e.g., *United States v. Gurnea*, 199 F.3d 1005, 1010 (9th Cir. 2000) (quoting *United States v. Gurnea*, 199 F.3d 1005, 1010 (9th Cir. 2000)).

These two substructures are 3-4
more degenerate. M. Kohnen
1994

The government wants to speed up the rate of the infrastructure with the same intention it wants to speed up the rate of the Department of Education with the same intention of the Department of Education.

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