Research Report
UKTRP-86-9

USE OF NONDESTRUCTIVE TESTING TO PREVENT FAILURES OF IN-SERVICE METAL BRIDGES

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ABSTRAIT

L'éffondrement des ponts métalliques en usage, sujets aux problèmes de fracture dûs principalement à la fatigue du métal, peut être prévenu ou rendu minimal par l'exécution d'épreuves périodiques non-détruisantes (ne causant pas de dommages). Facteurs qui servent à justifier la consolidation de fonds pour tels épreuves incluent danger latent d'éffondrement des ponts, analyses des risques, les conséquences d'éffondrement, stratégies d'inspections. Facteurs qui influencent la solidité de la structure sont le dessin structural, la qualité de la construction, le régime des charges de ces structures.

Un systeme ordinateur/jauge de tensions est décrit ici en détail, conçu pour acquisition de données sur la tension dans les éléments structuraux d'importance critique. Les données sont analysées pour déterminer la repartition de l'emplitude des contraintes, le nombre de périodes de contrainte, le calcul de l'emplitude de la contrainte moyenne, la nécéssité de l'inspection de structure, la valeur critique de la fissure, la meilleure méthode d'inspection, et les intervales pour les contrôles nécessairs.

Les facteurs reliant la méthodologie de ces épreuves non-détruisantes à la fréquence d'inspections périodiques sont présentés. L'application d'un système d'émissions acoustiques pour inspection non-détruisante des ponts est décrite. Les méthodes optimales pour ponts suspendus et ponts à poutres sont présentées.

ABSTRAKT

Dem Versagen von Metallbrücken, welche hauptsächlich durch Zermürbeerscheinungen des Metalls verursachten Bruchproblemen während der Benützung unterworfen sind, kann vorgebeugt werden, oder das Versagen kann auf minimal gesenkt werden indem man periodisch nicht-schädigende Untersuchungsprüfungen durchführt. Einlschlägige Faktoren welche das Finanzieren von solchen Inspektionen rechtfertigen sind die Möglichkeit eines Brückeneinsturzes, Konsequenzen des Brückeneinsturzes, Analyse der Risken, und Ausführungstechniken der Inspektion. Faktoren welche die baumässige Verläßlichkeit der Brücken beeinflussen sind die Baupläne, die Qualität der Konstruktion, und die Benützungsbelastungen.

Einzelheiten eines Komputer/Spannungsmeßsystems, das fähig ist Spannungsmeßergebnisse über kritische Strukturelemente zu geben, werden hier beschrieben. Die Ergebnisse werden verarbeitet um die Verteilung der Spannungsbereiche, die Nummer der Belastungszyklen, den berechneten Mittelwert der Belastungsgrenzen, die Notwendigkeit einer strukturellen Überprüfung, die kritische Größe des Bruches, die geeignete Inspektionsmethode, und die Häufigkeit der zu ausführenden Überprüfung festzustellen.

Es werden jene Faktoren aufgezeigt die zur Anwendung der nicht-schädigenden Überprüfungsmethoden bei den periodischen Inspektionen führen. Die Anwendungen eines, durch akustische Emissionen funktionierenden Systems, welches sich zum nicht-schädigenden Prüfen von Brücken eignet, werden beschrieben. Es werden optimale Testmethoden für konventionelle und Seilbrücken vorgetragen.

ABSTRACT

The failure of metal bridges, subject to in-service fracture problems mainly caused by fatigue, may be prevented or minimized by performance of periodic nondestructive testing. Attendant factors that justify funding for such inspections include the potential for bridge failure, the consequences of bridge collapse, risk analyses, and inspection strategies. Factors that affect structural integrity include structural design, construction quality, and service loadings.

Details of a computer/strain-gage system capable of obtaining strain-gage data from critical structural elements are described. Data are processed to determine the stress-range distribution, number of stress cycles, resolved mean stress range, need for structural inspection, critical crack size, suitability of the inspection method, and required inspection interval.

Factors relating nondestructive test methods to periodic inspections are presented. The application of a functional acoustic-emission system suitable for bridge nondestructive inspection of bridges are described. Optimum test methods for conventional and cable bridges are presented.

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L'éffondrement des ponts métalliques en usage, sujets aux problèmes de fracture dûs principalement à la fatigue du métal, peut être prévenu ou rendu minimal par l'exécution de'épreuves périodiques non-détruisantes (ne causant pas de dommages). Facteurs qui servent à justifier la consolidation de fonds pour tels épreuves incluent danger latent d'éffondrement des ponts, analyses des risques, les conséquences d'éffondrement, stratégies d'inspections. Facteurs qui influencent la solidité de la structure sont le dessin structural, la qualité de la construction, le régime des charges de ces structures.

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INTRODUCTION

Cracking in metal bridges poses a serious danger in terms of structural failure. Many metal bridges have major members that are structurally non-redundant (termed fracture-critical). Should one of those members sustain a single fracture, the entire bridge could collapse.

During the past 35 years, a number of metal bridges have suffered major cracking problems. Worldwide, those bridges include the Duplessis Bridge, Quebec, Canada (1950) and the Kings Bridge, Melbourne, Australia (1962). Problem bridges in the United States include the Silver Bridge, Point Pleasant, West Virginia (1967); the Bryte Bend Bridge, Sacramento, California (1970); the Fremont Bridge, Portland, Oregon (1971); the Quinnipac Bridge, New Haven, Connecticut (1973); the I-24 Bridge, Paducah, Kentucky (1975); the I-79 Bridge, Neville Island, Pennsylvania (1978); the US Grant Bridge, Portsmouth, Ohio (1978); and the US-18 Bridge, Prairie DuChien, Wisconsin (1981).

Some cracking problems may be related to environmentally assisted corrosion processes. However, most cracking problems in metal bridges are related to the welding process in fabrication and to the cyclic loading (fatigue) in service. Welding significantly increases the chances of introducing subcritical or critical-size defects in a structure during fabrication. Cyclic loads induce subcritical fatigue-crack growth at service-level stresses. When a fatigue crack reaches a critical size in tensile or flexural loading, the afflicted structural member will usually fail catastrophically. If the crack can be detected prior to reaching critical size, it may be repaired. Close inspections are required to detect such cracks.

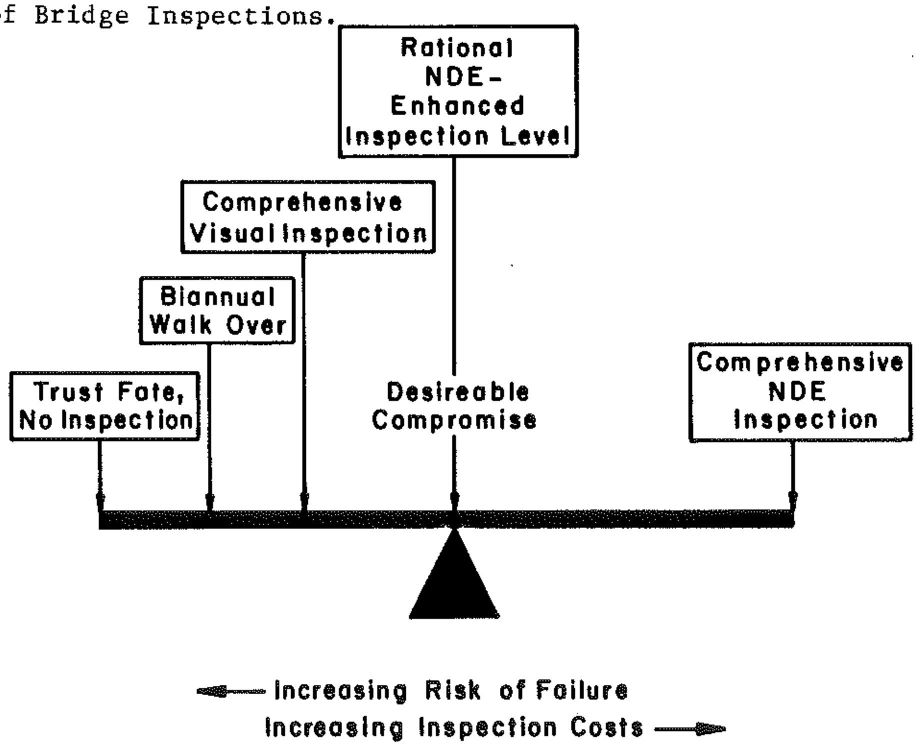
Nondestructive evaluation (NDE) of welded bridge members for crack detection is now commonplace in the shop. Those nondestructive test methods are widely accepted and technology is firmly in place. The opposite is true for routine nondestructive testing of existing bridges. Field testing is desirable, but it is rarely accomplished. No form of nondestructive testing is widely recognized as being effective for field inspections. Such work, when performed in the United States, is done primarily by private testing companies. The work is very expensive and results are sometimes questionable. Transportation agencies need to use existing techniques and develop methodologies to perform periodic nondestructive field inspections of metal bridges in an economical and effective manner.

TYPES OF BRIDGE INSPECTIONS

Presently, bridge inspections in the United States fall near the two extremes of the NDE scale (Figure 1). Recent experience has shown obvious dangers inherent in the complete lack of inspection or "Trust Fate" attitude that results in the lowest short-term cost for the bridge owner but entails the highest risk.

All bridges on federal routes in the United States must be inspected at least once every two years by a professional engineer or by personnel who have completed specialized training in maintenance inspection of bridges. Sometimes, those inspections are too superficial to detect cracks that could affect structural integrity. Those inspections are "walk-overs" by those who also must be equally concerned with unrelated

Figure 1. Scale of Bridge Inspections.



matters such as the function of lights, the condition of paint, and the quality of the bridge deck. On many bridges, there may be limited access to critical structural areas, thereby preventing or restricting close visual crack detection.

An intermediate form of inspection, superior to federally mandated biannual inspections, is the comprehensive visual inspection. However, there are several unfavorable aspects to this type of inspection, especially when compared to NDE-enhanced inspection techniques. Visual inspection is limited to surface flaws. The same equipment (snoopers and lift buckets) must be used to access structural members as would be used for NDE. Inspectors must have physical and technical qualifications. An NDE method must be employed to verify any indication detected by visual inspection. Also, total visual inspection costs may exceed some testing costs involving NDE methods.

On the costlier end of the inspection scale envisioned in Figure 1 is the comprehensive nondestructive inspection. Historically, that type work has been performed for three reasons: a crack was observed previously on the bridge, the extent or accuracy of the fabrication shop inspection was questionable, or similar bridges had experienced cracking problems. Poor fabrication shop inspection record keeping could be a contributing factor in each case.

Usually, comprehensive nondestructive inspection entails the use of one or more NDE consultants who perform inspections using a number of conventional NDE methods such as ultrasound, radiography, magnetic particle, or dye penetrant. Subsurface defects detected by ultrasound or radiography often are removed by coring and taken to a laboratory for examination by sectioning or tomography (Pittsburg Testing Laboratory, 1983; Frank and Colwell, 1982).

Unfortunately, while this approach may detect cracks, it also has some drawbacks. NDE testing is very expensive and may approach $500,000 for a large bridge. Such testing may lead to traffic disruptions lasting for several months. When test results indicate no defects, even if only a small percentage of the bridge's fracture-critical members are inspected, bridge authorities may conclude that the structure contains no potential or undetected defects. The structure may never again be closely inspected.

In some instances, comprehensive nondestructive inspections of bridges may be warranted. Usually, however, the limited inspection funds available are better utilized protecting the public by employing other approaches to bridge nondestructive inspection:

(1) using allocated funds on less extensive inspections of more bridges and

(2) conducting less extensive inspections, but repeating the inspections at more frequent intervals.

Considering that only limited NDE inspection funds may ever be available to bridge authorities, it is desirable that some compromise be achieved between nominal inspection of all bridges within the jurisdiction and large financial expenditures on the inspection of a single bridge.

The type and size of defect to be detected does not have to be closely related to the codes or specifications to which the structure was constructed. Consideration of rejectable flaws may be limited to cracks of given minimum size and disposition. As larger sizes of maximum permissible flaws are sought, they become easier to detect by NDE. Also, the inspection time may be reduced significantly, thereby reducing inspection costs.

When defects (cracks) are detected by such inspections, more comprehensive nondestructive inspection of a bridge may be justified. However, under most circumstances, inspections of bridges should not be considered final or "one-shot" affairs. There are two main reasons for this. First, flaws may be overlooked even by conscientious, competent inspectors. Second, subcritical fatigue crack growth may occur with time; and in several years, the structural integrity of a bridge may be threatened by growing cracks that did not exist at the time of the comprehensive inspection (or were too small to be detected). Proper NDE scanning, conducted at reasonable intervals, will detect growing cracks before they damage or destroy a bridge.

INSPECTION STRATEGIES

Inspection or reliability strategies are written plans set forth by bridge authorities as rationale for impending inspections. The formulation of those plans is necessary to ensure that efforts expended will produce desired results (e.g., assurance of structural integrity of the bridges inspected).

Inspection strategies should be prepared prior to the performance of actual field inspections. They may be employed to 1) define the purpose and scope of NDE tests, 2) aid in requesting funds, 3) select candidate bridges, 4) determine inspection locations and frequency, and 5) choose appropriate test method(s).

Due to differing circumstances, strategies employed by bridge authorities may vary. The rationale and focus of strategies also may differ. Therefore, inspection strategies may be based on a wide variety of information including historical data, estimated costs associated with failure, estimated risks, bridge inventories, estimated inspection costs, traffic data, bridge design loadings and criteria, weather data, fracture mechanics data, reliability assessments, previous inspection reports, inspector requirements, and equipment requirements. Many reliability and risk assessment techniques have been formulated by structural, energy, aircraft, and naval researchers (Bowman and Yao, 1983; Johnson, 1979; Walker and Covello, 1984; Stancampiano, 1977; Allen and Cannon, 1982; Marshall, 1979; Bush, 1981). Those may be adapted for use as bridge inspection strategies.

In preparing inspection strategies for bridges, both structural risks and human risks should be considered. These usually are interdependent and may be combined to provide an accurate indication of not only the total risk but also the anticipated consequences of bridge failure.

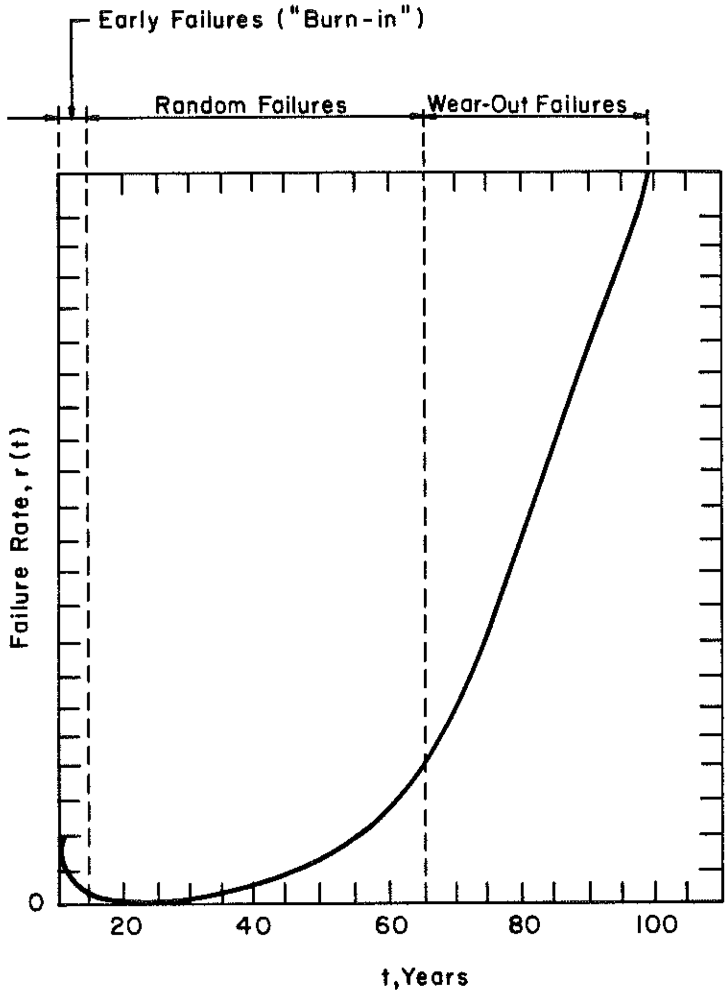
Structural risk depends on 1) structural redundancy, 2) loading history, 3) present loading, 4) anticipated future loading, 5) structural details, and 6) bridge environs (e.g., atmosphere, approaches, highway geometrics, and bridge deck profile).

Historical data suggest that, since the turn of the century, a major bridge in the United States has collapsed or failed structurally about once every 15-20 years. Based on simple probability, the odds against bridge failure in a given year are about 1,000 to 1. While those odds at first glance appear to preclude failure, combined with other data, they may be used as a crude justification for funding.

Figure 2 shows a failure rate versus time (bathtub) curve that is typical for a multitude of manufactured items ranging from electronic components to bridges (Henley and Kumamoto, 1981). The initial or "burn-in" portion of the curve shows a higher failure rate than the middle portion of the curve. Bridge failures that occur in this portion of the curve are usually caused by poor construction materials, improper weld techniques and repairs, and defects overlooked during fabrication shop inspections. Many recent bridge problems due to weld cracking may be considered "burn-in" failures. In the middle or "prime-of-life" portion of the curve, failures occur randomly in an unexpected manner (termed catastrophes). An example was the Silver Bridge failure at Point Pleasant, West Virginia, in 1967.

The "wear-out" or "burn-out" final portion of the curve reflects the cumulative effects of corrosion and subcritical crack growth. Such

Figure 2. Failure Rates versus Time (Bathtub Curve) (Bush, 1981, p 167).



failures also are termed "on-line" failures and should be anticipated. Bridges that exceed their original design or anticipated service lives may be subject to "on-line" failure.

Human risk due to structural collapse will differ between bridges due to many factors: 1) average number of motorists on the bridge at any time, 2) maximum number of motorists on the bridge at specific times, 3) physical consequences of collapse (fall distance, covering debris, and underlying water), and 4) highway geometrics. As shown in Table 1, existing generalized human risk data may not, at a glance, support the need for periodic NDE surveillance for many types of bridges. However, one must assume that bridge failure constitutes an involuntary risk, whereas driving usually entails a voluntary risk. Involuntary risks should be three or four times less than voluntary risks to be considered equivalent based on present social values. When the risk of bridge collapse exceeds the normal risk exposure for motorists, inspections are warranted.

Even more justification for periodic nondestructive inspections may be based upon consideration of the total consequences of bridge collapse or structural dilapidation. Major direct costs of bridge failure may include 1) cost of litigation due to loss of life or injury, 2) structure replacement or repair, 3) provision for alternate traffic routing, 4) accident investigation, and 5) clearing of underlying waterways. It is difficult to determine the total cost of these factors.

The estimated total cost of the Silver Bridge collapse at Point Pleasant, West Virginia, in 1967 was $175 million (Gerhard and Haynie, 1974). Considering the recent growth in litigation and general inflation,

TABLE 1. RISK OF FATALITY BY VARIOUS CAUSES
(Optimizing the Inspection Process, 1976)

TYPE OF EVENT	INDIVIDUAL RISK (FATALITIES X 10^{10}/EXPOSURE (HOUR))
Flying, General Aviation	300,000
Brittle Failure of PP-Type Highly Stressed Bridge (40th to 70th Year, Given Survival after 40 Years)	35,000
Driving (All Accidents)	10,000
Brittle Failure of PP-Type, Highly Stressed Bridge (First 40 Years of Life)	8,000
Driving (Accidents Caused by Defective Motor Vehicle)	530
Brittle Failure of Moderately Stressed Bridge (Worst-Case Estimate)	50*
Nuclear Power Plants	10*
Brittle Failure of Moderately Stressed Bridge (Best Estimate)	2.2*
Natural Disasters	1

*These values are calculated from risk analyses and are not based on actual fatalities.

it would not be presumptuous to assume that today a similar failure would cost considerably more.

The level of funding for statewide routine periodic NDE surveillance may be approximated by

$$\text{Level of Funding} = \text{Risk (probability of failure)} \times \text{Consequences (cost of failure)}. \quad (1)$$

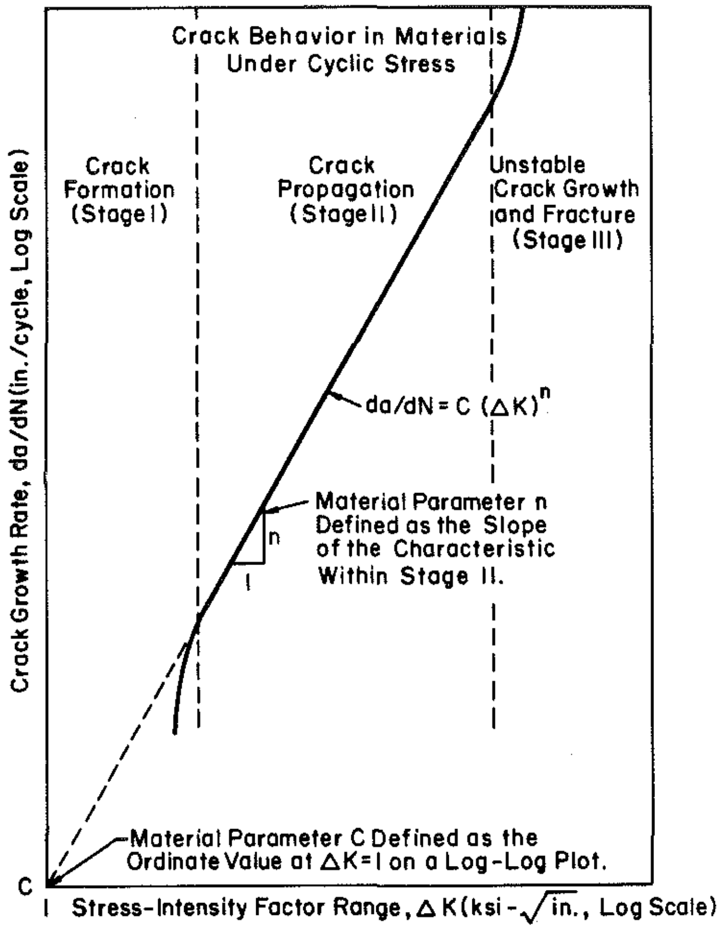
For example, if the failure risk is 1 in a 1,000 per year and the anticipated maximum cost of failure is $500 million, a justifiable funding level would be $500,000. This is a gross simplication, but it demonstrates that appropriate funding levels may be deduced.

In most static-loading cases, linear elastic fracture mechanics (LEFM) is not a viable tool for predicting the maximum crack size that a bridge member will tolerate. This is due to the relatively low yield strengths of steels employed in bridges. However, during a significant portion of the growth of a NDE-detectable subcritical fatigue crack, the Paris LEFM fatigue-crack growth law is valid (Figure 3)(Steel and Lam, 1983). This relationship has the form

$$da/dN = C(\Delta K)^n, \quad (2)$$

in which da/dN = fatigue crack growth rate per cycle,
ΔK = stress-intensity range = $K_{max} - K_{min}$, and
C and n = material and test-related constants.

Figure 3. Paris Fatigue-Crack Growth Law (Steele and Lam, 1983, p 101).



Knowing the cyclic loading rate and the initial crack size, the time required to achieve the critical crack size for failure may be determined. By selecting an appropriately sensitive NDE test method and by using the LEFM fatigue-crack growth law, the frequency of NDE surveillance for a bridge may be determined. The interaction between the sensitivity of the NDE surveillance method and test frequency should be such that follow-up inspections will detect any growing fatigue cracks previously too small to be discovered before those cracks could cause structural failure (Figure 4).

A computer-based strain-gage system intended for use on bridges has been developed. The system incorporates a strain-gage conditioner and a portable computer. The computer contains a digital-to-analog converter to digitize the analog signal from the strain-gage conditioner. The computer stores the digitized signals and, after the monitoring period, it post-processes the load cycles using the "rainfall" counting method. The stress spectrum determined from the rainfall counting may be summed and a resolved root mean stress may be determined from

$$S_{rms} = (\Sigma \gamma_i S_{ri})^{1/2} \qquad (3)$$

in which γ_i = frequency of occurrence of stress range S_{ri}.

Using allowable stress range versus load cycle curves, a prediction may be made of whether a strain-gaged bridge member of Category E, level of severity (American Association of State Highway and Transportation Officials) for example, has a potential fatigue problem (Figure 5)(Fisher, 1977). Crack growth rates, critical crack sizes, NDE inspection intervals, and inspection confidence may be determined using existing

Figure 4. Life Extension Curves. At higher inspection sensitivity level (Flaw Length I), the inspection interval can be increased compared to a less sensitive inspection level (Flaw Length II) (Boisvert, Lewis, and Sproat, 1981, p 19).

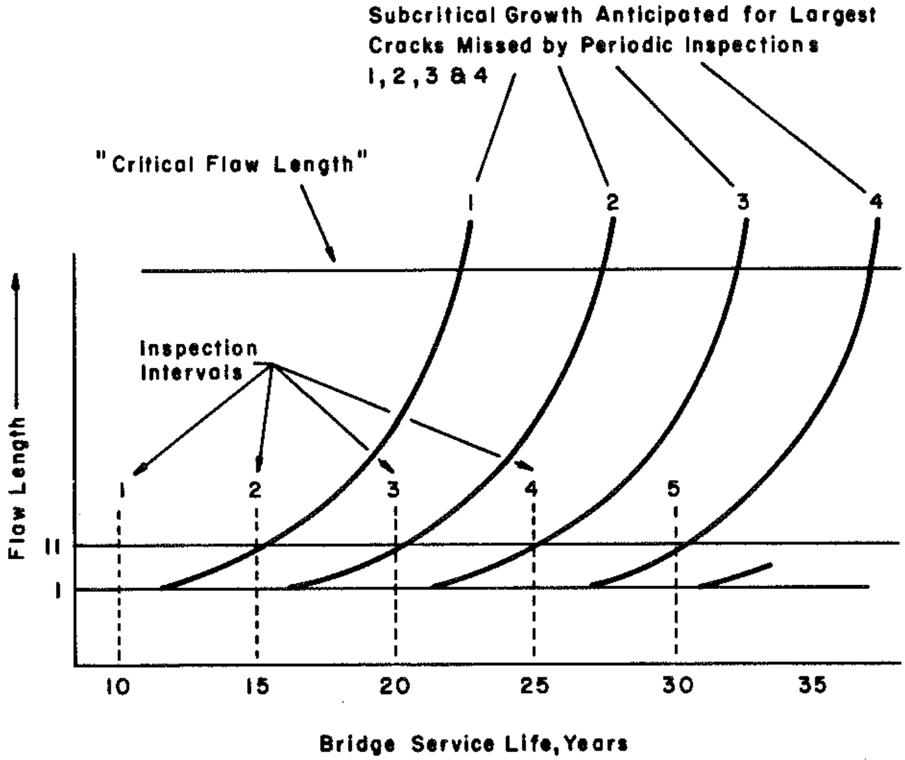
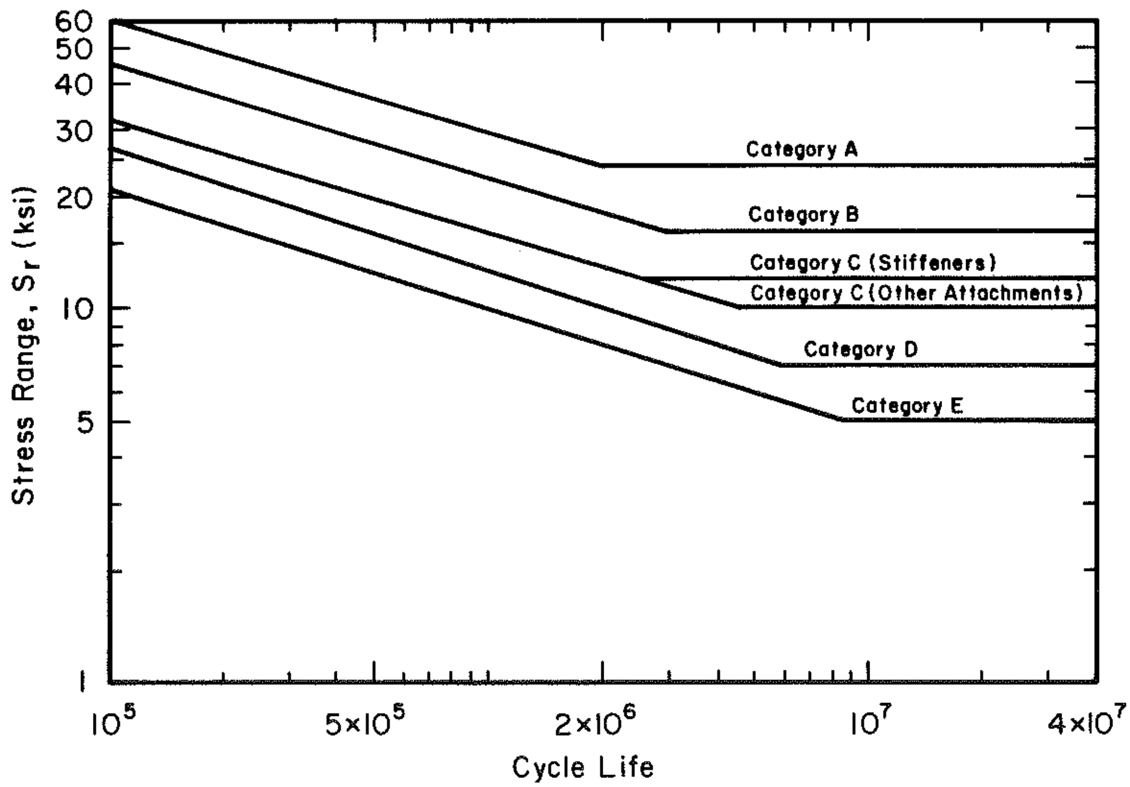


Figure 5. Allowable Stress Ranges for Various Fatigue Details (American Association of State Highway and Transportation Officials -- Fatigue Detail Levels of Service, Categories A-E) (Fisher, 1977, p 19).



commercial fracture mechanics software (Broeck, 1985). That information will allow the bridge engineer to quickly evaluate the need for inspection from a fracture potential standpoint. He also will be able to quickly select the best NDE method for the particular bridge detail being inspected.

Inspection strategies may be used effectively to reduce the inspection inventory. In fact, one major objective in performing this task is to eliminate bridges or structural members on bridges where either the risk is minimal or the results of structural failure are not catastrophic. A routine NDE surveillance program would require the combined efforts of design and maintenance units to achieve this goal.

In most states, either the design or maintenance unit maintains the bridge inventory. This may be an imposing task. Kentucky, for example, has 7,000 bridges inventoried. Of those, approximately 1,000 are classified as steel bridges. One hundred and sixty of those bridges have non-redundant or fracture-critical load-carrying members.

NDE METHODS

The most important components of routine NDE surveillance of bridges are the test methods employed and the operators who use them. Much of the success or failure of NDE techniques presently employed rests on the knowledge and skill of the equipment operator (Table 2). Therefore, when discussing most test methods, the NDE test method-operator couple should be considered (Boisvert, Lewis, and Sproat, 1981).

Most NDE methods involve deliberate, tedious effort on the part of the equipment operator. Much time consumed in those inspections is spent evaluating flaws in accordance with some formal inspection procedure such as the American Welding Society code. This has several disadvantages: 1) test results may not be more significant than when simpler techniques were employed, 2) harmless flaws may be classified as rejectable defects, 3) the test method may induce operator errors (false-calls), 4) the code may require extensive test-site surface conditioning, and 5) the ability of the NDE test method to find the smallest reliably detectable defect size may be minimized. The net result is that field NDE work incorporating fabrication codes may be expensive and time consuming. Also, initial expectations about the correctness and usefulness of data derived from such nondestructive inspections may prove to be so discouraging as to curtail plans for other nondestructive inspections.

When routine, periodic NDE surveillance of bridges is attempted, much of the inspection effort must be devoted to scanning or searching for defects. Productivity becomes a more important consideration, and some tradeoff must be made between inspection rate and test sensitivity. While this may result in shorter inspection intervals compared to code-based flaw-evaluation inspections, it is more than offset by the greatly reduced cost of each inspection. Another advantage is that the scanning operation

TABLE 2. FACTORS AFFECTING NDE PROFICIENCY
(Boisvert, Lewis, and Sproat, 1981)

HUMAN	PHYSICAL
Dexterity	Environment
Formal Training	Inspection Rate
Cognition	Type of Structure
Psychomotor Skill	NDE Method
Rational Ability	Flaw Size & Density
Motivation	Part Geometry

may be tailored to a known minimum defect size and that indications from smaller nonrelevant flaws can be neglected. Test rationale is established from previously discussed LEFM fatigue-crack growth calculations and from qualification testing of flawed specimens using the NDE procedure, equipment, and operators to be employed in the actual field tests. In testing of large bridges where thousands of linear feet of welds need to be inspected, this approach will yield the maximum benefit. The NDE scanning method may provide more useful information concerning the physical dimensions of existing defects than a code-based flaw-evaluation technique. Also, the scanning method may allow inspection of the bridge with minimum surface conditioning of test areas.

In either scanning or flaw-evaluation NDE tests of in-service bridges, several test-method attributes are desirable. Test results should be easy to document, with direct hard-copy output being most beneficial. Test results should be confirmable by another NDE method. Time-consuming surface conditioning of test areas should not be required. Paint removal, cleaning, and grinding may be almost as time consuming and expensive as the NDE work. NDE test equipment should be portable and should allow the operator sufficient time to inspect large remote areas before having to return to his base of operations for resupply or recalibration.

There are three general types of nondestructive inspections applicable to bridges: 1) surface indication methods, 2) subsurface indication methods, and 3) acoustic emission methods. The first two entail geometric defect sizing. The latter detects subcritical flaw activity.

Relevant surface methods include dye penetrants (visible and fluorescent), magnetic particle (visible and fluorescent), and eddy current. In many cases, these methods may be used effectively in locations where surface-breaking cracks are sought. The first two methods require nominal capital equipment outlay and may not necessitate extensive formal operator training. Unfortunately, those methods require paint removal and cleaning to be effective, which in turn increase inspection costs. Also, consumption of expendable supplies, penetrants and ferrous powders, may prove expensive if many bridges are inspected.

Visible surface NDE tests are effective in direct sunlight. However, in heavily shaded areas (under a bridge deck) or closed areas (inside a box beam), supplemental lighting is necessary. At those locations, fluorescent inspection may prove more beneficial. Fluorescent testing cannot be performed effectively under direct sunlight. On at least one occasion, a highway authority has performed fluorescent magnetic-particle testing on tie chords of a large arch bridge by inspecting the structure at night.

Eddy-current testing may prove more effective for surface-crack inspection than either the dye-penetrant or the magnetic-particle methods. Eddy-current testing requires minimal surface conditioning of test areas. Portable eddy-current devices are expensive. However, they do not require significant expenditures for consumable supplies. Also, the units allow operators to work on remote portions of bridges for extended periods. Some operator training is required, but this training does not need to be as extensive as that for ultrasonic operators using code-based flaw-evaluation techniques.

Several eddy-current or magnetic-field disturbance units have potential for inspecting welds. A typical portable commercial unit uses a cathode ray tube screen to differentiate between the presence of cracks and the lift-off effects of irregular weld surfaces. The US Federal Highway Administration has sponsored development of the Magnetic Crack Definer, used to locate and measure surface cracks. The unit is designed to be used by relatively inexperienced inspection personnel and, therefore, has simplified controls and readouts.

The two main subsurface methods, radiography and ultrasound, also use geometric defect sizing. Transmission radiography has not been considered for routine NDE surveillance due its high cost, low productivity, and safety requirements.

Ultrasonic inspection is useful for both scanning and flaw-evaluation inspections. Generally, ultrasonic testing requires significant expenditures in equipment and personnel training. Due to its versatility, however, it should be considered an essential ingredient in any routine NDE surveillance program, if only to be used for flaw evaluation.

In more recently constructed bridges fabricated with lamination-free steel, ultrasonic techniques may prove useful in inspecting for relatively small subsurface defects. In older bridges, the presence of laminations in the steel may curtail its effectiveness by creating false calls and slowing the inspection rate.

The Federal Highway Administration also has sponsored development of the Acoustic Crack Detector, used for subsurface crack detection on bridges. This device uses gated ultrasound to detect cracks. As with the Magnetic Crack Definer, the device is designed to minimize operator requirements.

Acoustic emission testing shows much promise as a tool for scanning bridges. Among its advantages are 1) only active growing defects will produce acoustic emissions; 2) the bulk of the physical work may be performed by relatively unskilled labor; 3) large areas of a bridge may be scanned simultaneously; 4) a very small defect may be detected, maximizing inspection intervals; 5) minimal surface conditioning on the structure is required; 6) while acoustic emission testing is in progress, inspection personnel may attend to other tasks (a "set and forget" feature); 7) active defects may be accurately located along the test surface; 8) the equipment can produce hard-copy records at the test site; and 9) the method lends itself well to the performance of low-cost, high-productivity nondestructive inspection, necessary traits for routine NDE surveillance.

Over the past four years, a unique acoustic-emission monitor developed by GARD Inc. of Niles, Illinois, has been tested successfully on bridges (Hopwood and Prine, 1985; Prine and Hopwood, 1983; Prine and Hopwood, 1985). A total of twelve tests on eight bridges in three states have been evaluated. A technique called pattern recognition is used to distinguish between the large amounts of mechanical noise typical of most bridge members and acoustic emissions emitted by cracks. To date, four active cracks have been monitored successfully in those bridges.

Acoustic emission testing cannot be used to geometrically define defects. Any acoustic emission source must be located and sized using a more conventional NDE method. Also, the structure must be loaded sufficiently to assure crack growth or fretting. When normal traffic is used to drive cracks, extended monitoring periods may be required to detect crack-related acoustic emission activity.

CLOSURE

Ten years ago, the high cost of conducting periodic routine NDE inspections of in-service bridges rendered such work almost unthinkable. However, NDE techniques and inspection procedures that will significantly reduce those costs and make such testing a reality are rapidly evolving. When those techniques and procedures are technically mature and proven, it would be feasible for all bridge authorities to perform such inspections.

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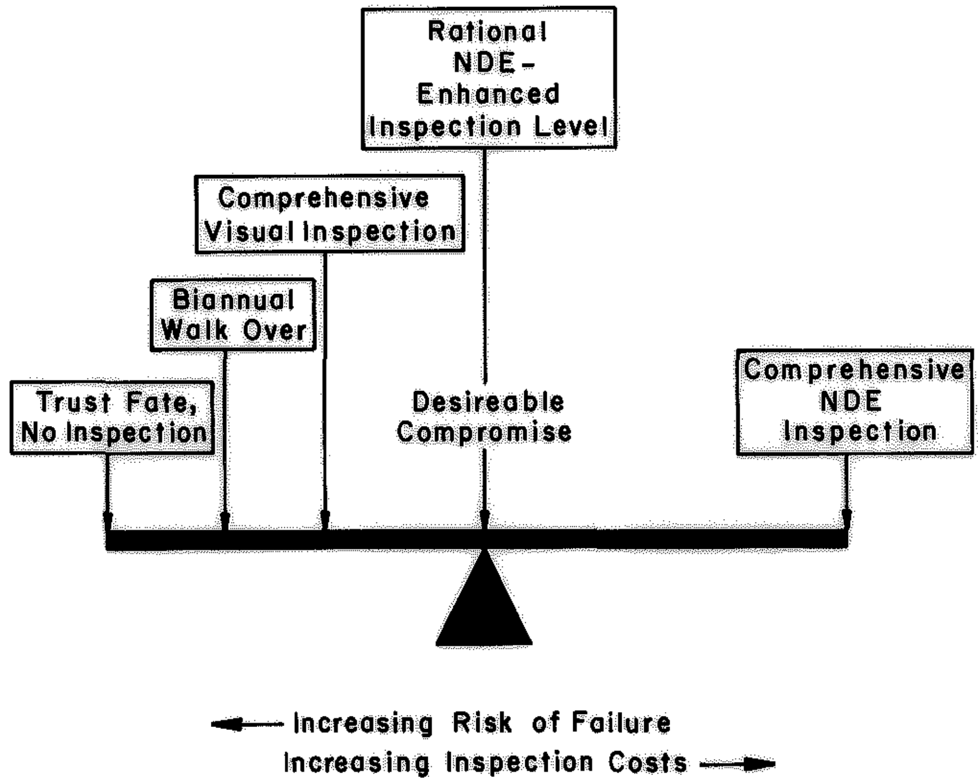
Rational NDE-Enhanced Inspection Level
Comprehensive Visual Inspection
Biannual Walk Over
Trust Fate, No Inspection
Desireable Compromise
Comprehensive NDE Inspection
Increasing Risk of Failure
Increasing Inspection Costs

Fig 1

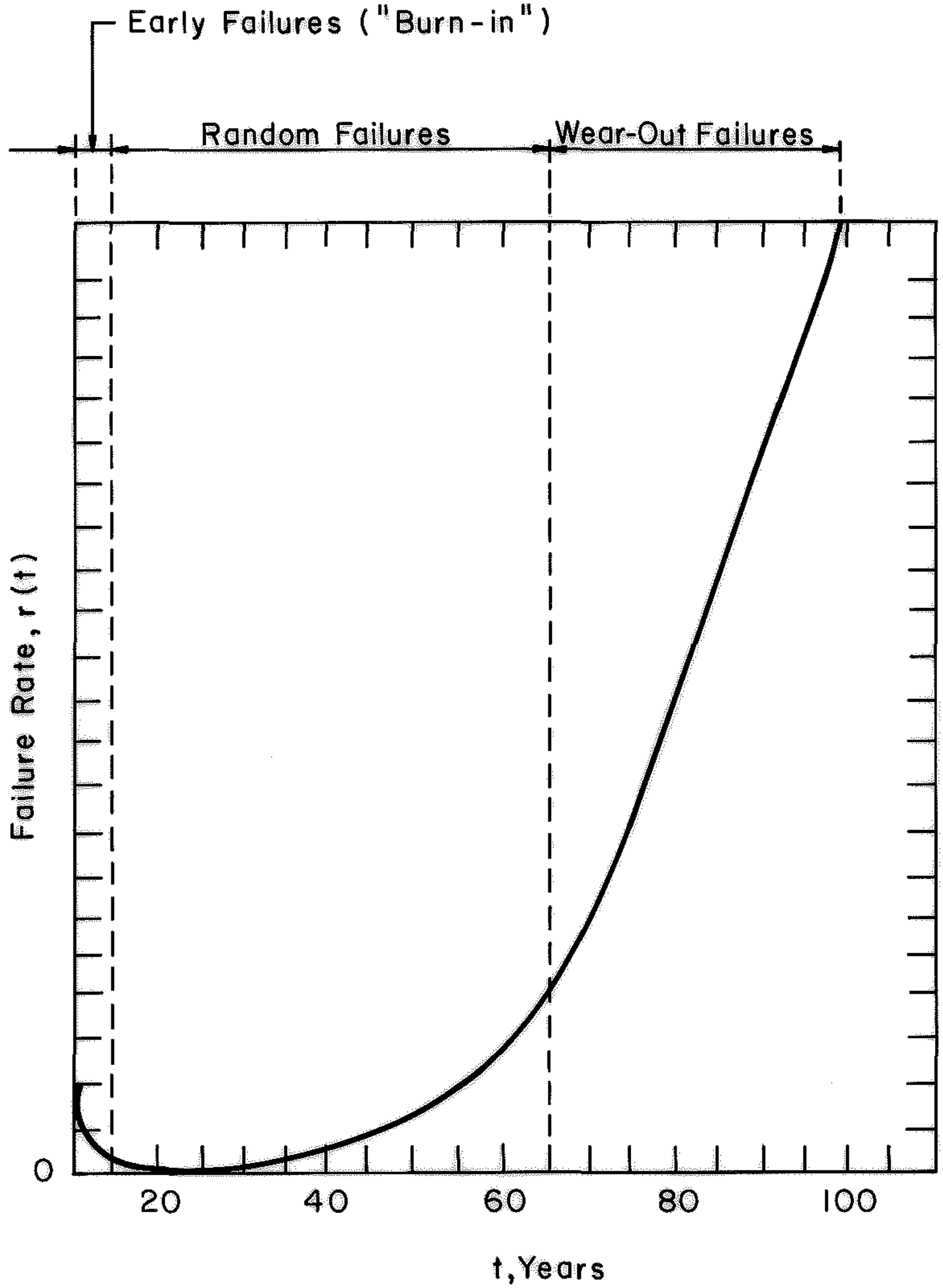
Early Failures ("Burn-in")
Random Failures
Wear-Out Failures
Failure Rate, r(t)
0
20
40
60
80
100
t, Years

FIG 2

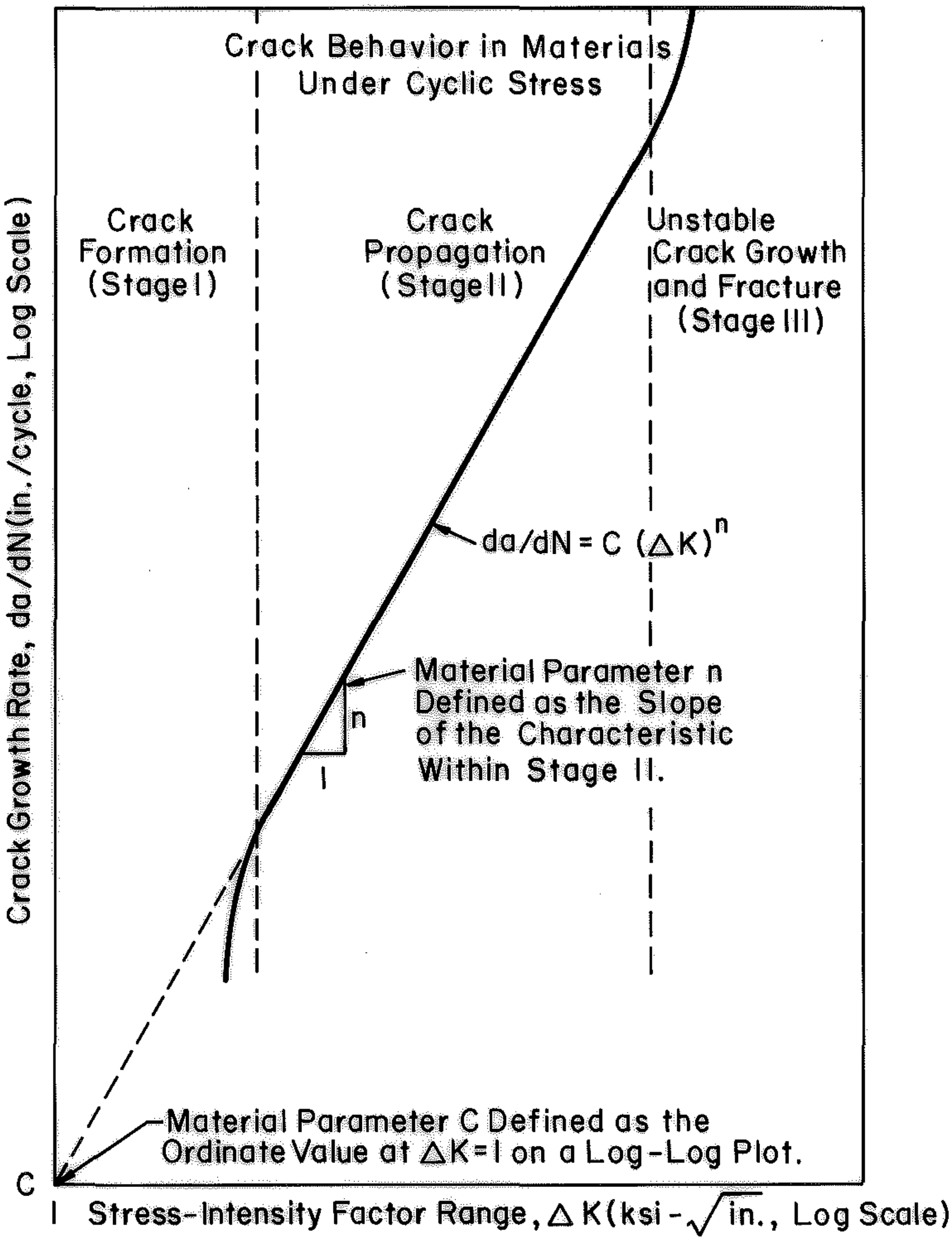
Crack Behavior in Materials
Under Cyclic Stress
Crack
Formation
(Stage I)
Crack
Propagation
(Stage II)
Unstable
Crack Growth
and Fracture
(Stage III)
da/dN = C (ΔK)^n
Material Parameter n
Defined as the Slope
of the Characteristic
Within Stage II.
n
1
Material Parameter C Defined as the
Ordinate Value at ΔK=1 on a Log-Log Plot.
C
1
Crack Growth Rate, da/dN(in./cycle, Log Scale)
Stress-Intensity Factor Range, ΔK(ksi-√in., Log Scale)

Fig 3.

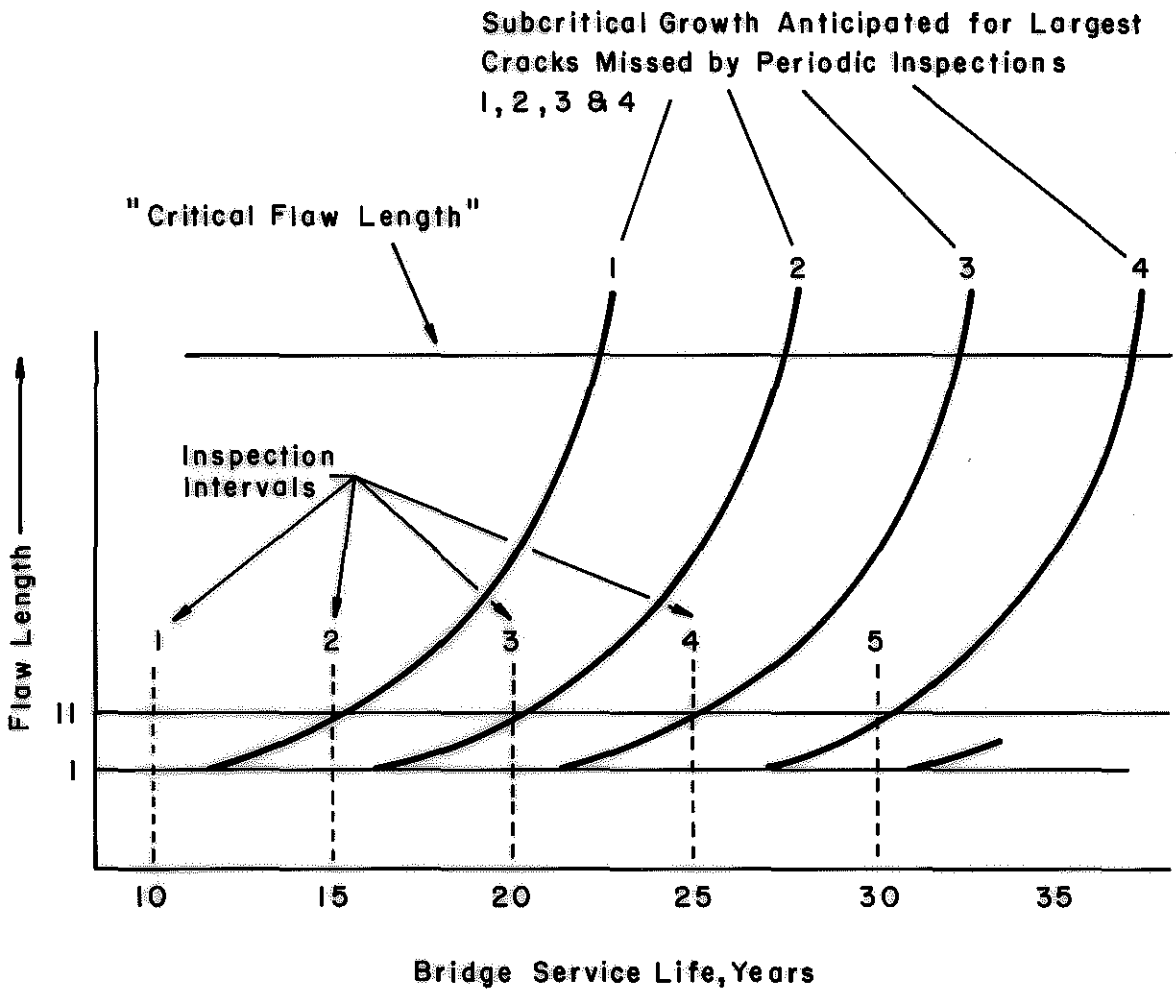
Subcritical Growth Anticipated for Largest Cracks Missed by Periodic Inspections 1, 2, 3 & 4
"Critical Flaw Length"
1
2
3
4
Inspection Intervals
1
2
3
4
5
Flaw Length
II
I
10
15
20
25
30
35
Bridge Service Life, Years

FIG 4

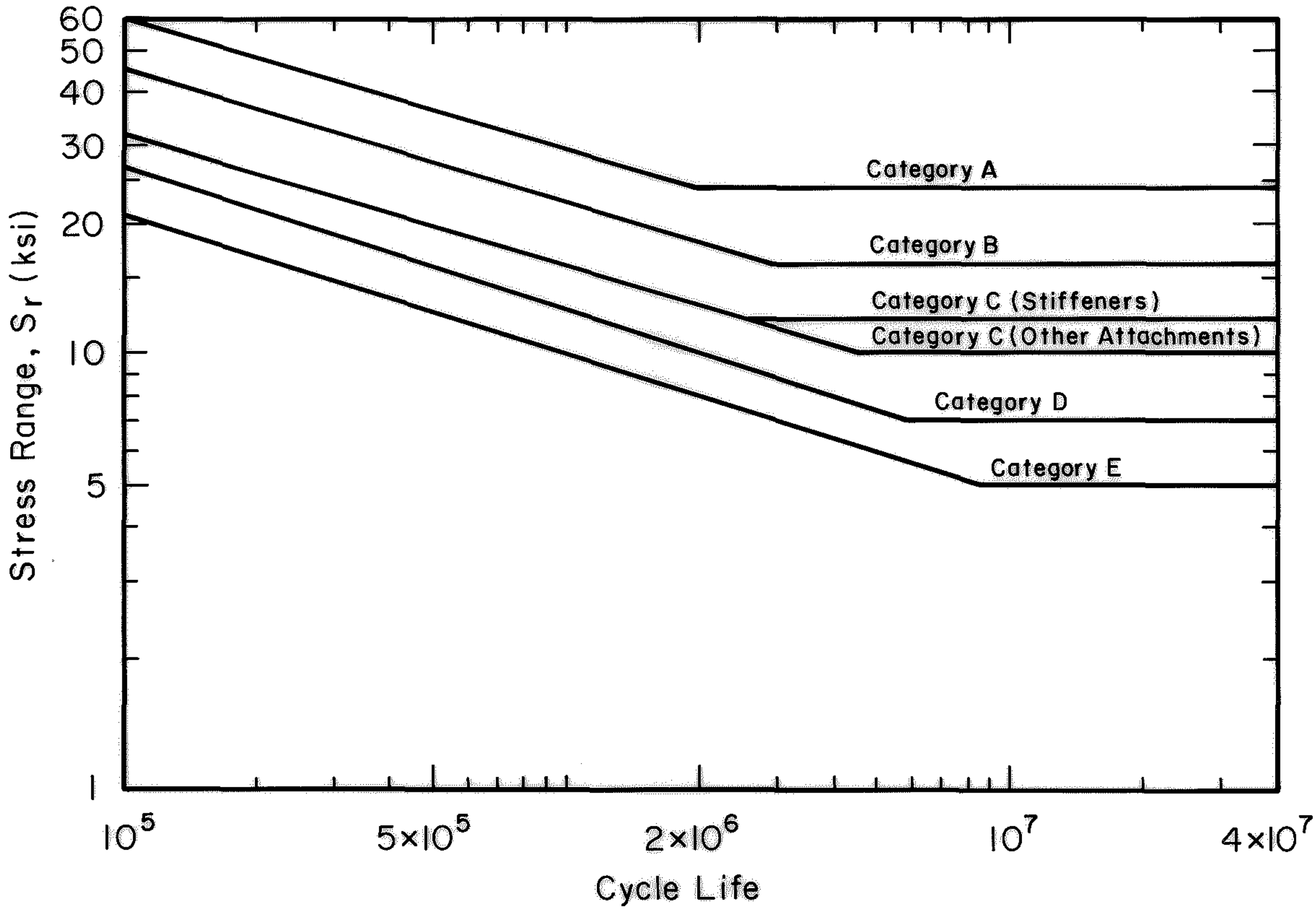
60
50
40
30
20
10
5
1
Stress Range, S_r (ksi)
Category A
Category B
Category C (Stiffeners)
Category C (Other Attachments)
Category D
Category E
10^5
5×10^5
2×10^6
10^7
4×10^7
Cycle Life

FIG 5

Rapport sur Projet de Recherche
UKTRP-86-9

Emploi d'Épreuves Non-Détruisantes pour la Prévention d'Éffondrement de Ponts Métalliques en Usage

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Avril 1986

Forschungsreport
UKTRP-86-9

ANWENDUNG VON NICHT-SCHÄDIGENDEN EIGNUNGSTESTEN ZUR VERHINDERUNG DES VERSAGENS VON UNTER BENÜTZUNG STEHENDEN METALLBRÜCKEN

bei

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Forschungsprogram für Transport
Universität von Kentucky

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am 2ten Internationalen Konferenz über
Strukturelles Versagen, Haftpflicht für
Produkte und Technische Versicherung
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