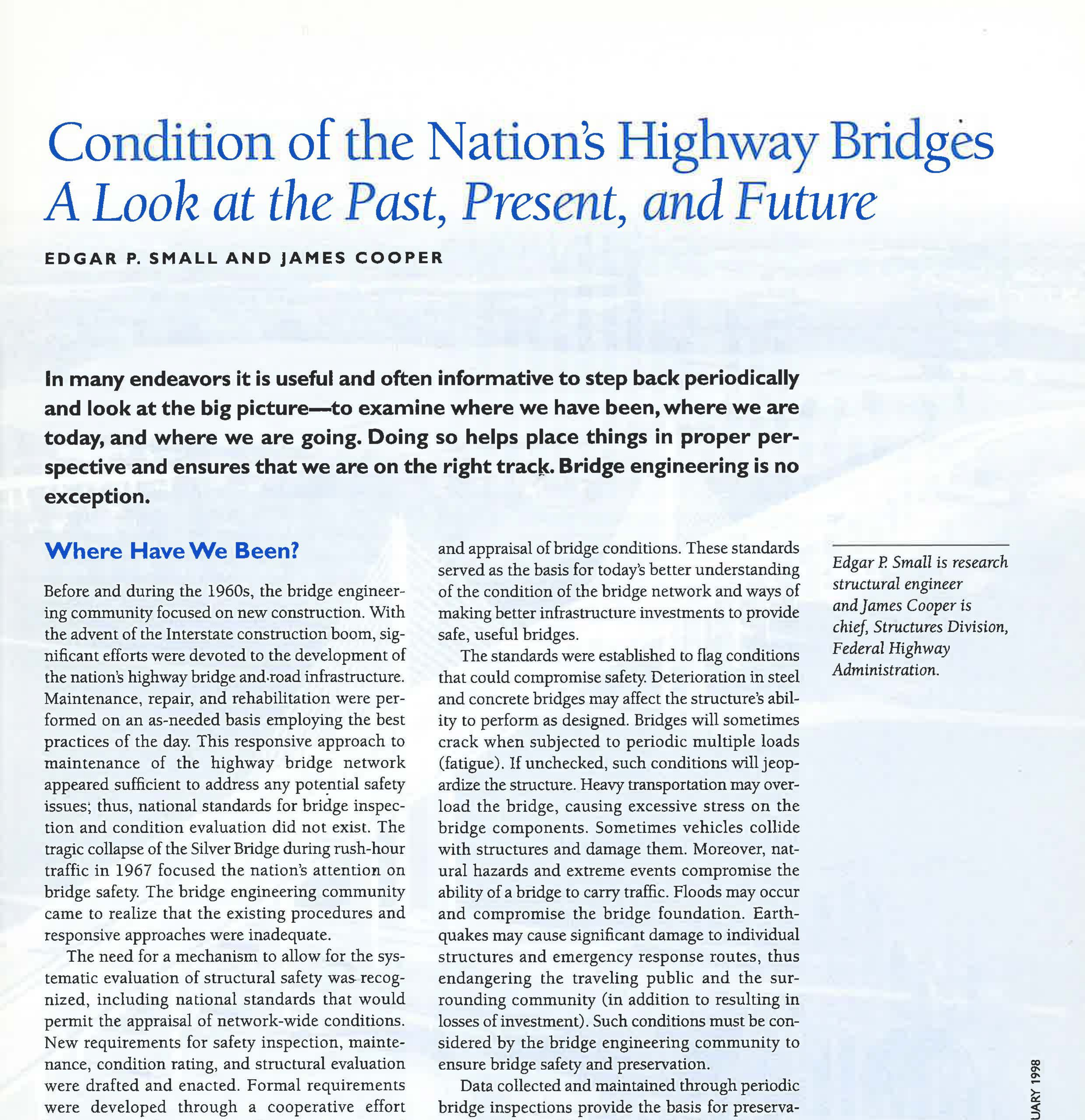

Condition of the Nation's Highway Bridges
A Look at the Past, Present, and Future

EDGAR P. SMALL AND JAMES COOPER

In many endeavors it is useful and often informative to step back periodically and look at the big picture—to examine where we have been, where we are today, and where we are going. Doing so helps place things in proper perspective and ensures that we are on the right track. Bridge engineering is no exception.

Edgar P. Small is research structural engineer and James Cooper is chief, Structures Division, Federal Highway Administration.

Where Have We Been?

Before and during the 1960s, the bridge engineering community focused on new construction. With the advent of the Interstate construction boom, significant efforts were devoted to the development of the nation's highway bridge and road infrastructure. Maintenance, repair, and rehabilitation were performed on an as-needed basis employing the best practices of the day. This responsive approach to maintenance of the highway bridge network appeared sufficient to address any potential safety issues; thus, national standards for bridge inspection and condition evaluation did not exist. The tragic collapse of the Silver Bridge during rush-hour traffic in 1967 focused the nation's attention on bridge safety. The bridge engineering community came to realize that the existing procedures and responsive approaches were inadequate.

The need for a mechanism to allow for the systematic evaluation of structural safety was recognized, including national standards that would permit the appraisal of network-wide conditions. New requirements for safety inspection, maintenance, condition rating, and structural evaluation were drafted and enacted. Formal requirements were developed through a cooperative effort between state departments of transportation and the Federal Highway Administration. The resulting provisions were implemented through the National Bridge Inspection Standards (NBIS), issued in April 1971. These provisions mandated the establishment of accepted, uniform procedures for the collection and maintenance of inventory and inspection data, minimum qualifications for bridge inspection personnel, and standardized methods for evaluation and appraisal of bridge conditions. These standards served as the basis for today's better understanding of the condition of the bridge network and ways of making better infrastructure investments to provide safe, useful bridges.

The standards were established to flag conditions that could compromise safety. Deterioration in steel and concrete bridges may affect the structure's ability to perform as designed. Bridges will sometimes crack when subjected to periodic multiple loads (fatigue). If unchecked, such conditions will jeopardize the structure. Heavy transportation may overload the bridge, causing excessive stress on the bridge components. Sometimes vehicles collide with structures and damage them. Moreover, natural hazards and extreme events compromise the ability of a bridge to carry traffic. Floods may occur and compromise the bridge foundation. Earthquakes may cause significant damage to individual structures and emergency response routes, thus endangering the traveling public and the surrounding community (in addition to resulting in losses of investment). Such conditions must be considered by the bridge engineering community to ensure bridge safety and preservation.

Data collected and maintained through periodic bridge inspections provide the basis for preservation and safety efforts. Each state collects and maintains, as a minimum, the data required by the new standards. This information is submitted annually by the states to FHWA, where it is maintained in the National Bridge Inventory (NBI) database. The NBI data support federal funding programs, such as the Highway Bridge Repair and Rehabilitation Program and the Special Bridge Program, which provide discretionary funding. Such programs facil-

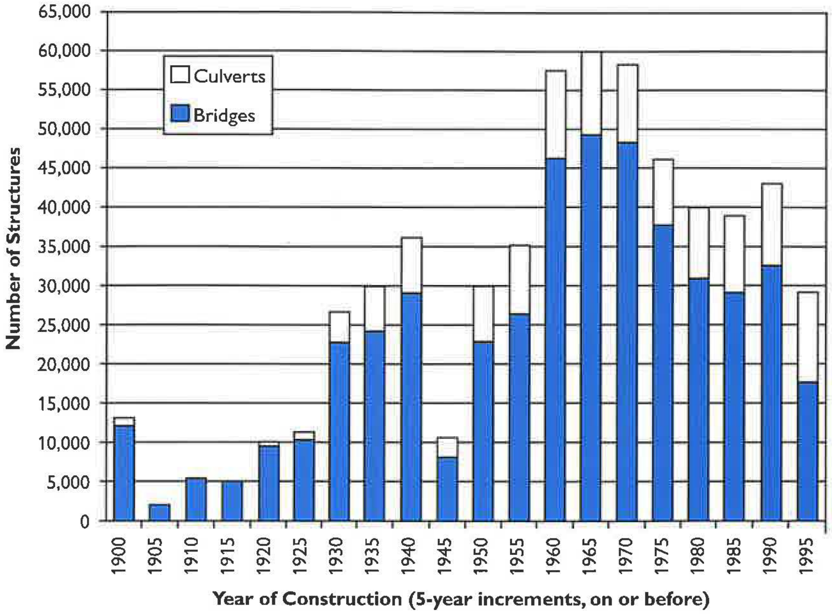

FIGURE 1 **Year of construction distribution for bridges and culverts.**

itate the initiation and performance of required work on the bridge network.

The NBI information, collected and maintained for more than 25 years, represents the most comprehensive source of information on the status of the U.S. highway bridge network. Significant insight into the composition and condition of bridges can be obtained through examination of the NBI data. Stepping back and performing such an examination yields valuable insight into where we are today.

Where Are We Today?

In the 1995 archival NBI database, records are maintained for approximately 590,000 structures that are more than 20 feet in length. (Structures of less than 20 feet are not maintained and recorded in the NBI, although individual states may elect to record and maintain information on these smaller structures.) Roughly 80 percent (475,850) of the NBI records describe bridges, while 20 percent (114,435) describe culverts (which are smaller structures typically used for drainage openings, pedestrian underpasses, and livestock crossings beneath roadway embankments). From a funding standpoint, bridges and culverts may be considered together; however, when addressing the composition of the network, a distinction should be made between the two types of structures. In this discussion, culverts and bridges are therefore treated separately.

Examination of the character, composition, and condition of the structures maintained within the inventory provides useful insights. Considering the year of construction distribution for bridges in service, as depicted in Figure 1, the Interstate construction boom that occurred from the late 1950s through the 1970s is evident. The average age of structures is highly influenced by this peak period of construction. Roughly half of all structures in service today were constructed during this 20-year period. Many structures are now 30 to 50 years old, and are beginning to require increasing maintenance, repair, and rehabilitation and functional improvements. Many are approaching the end of their design service life and will require replacement in the near future. It is anticipated that network-wide needs will dramatically increase as these structures continue to age.

Additional observations and insights can be derived by examining other variables. For example, the percentages for each of the major superstructure material types for the 475,850 highway bridges are shown in the upper portion of Figure 2. This figure also shows the percentages by the total number of structures and by the cumulative traffic carried (average daily traffic, or ADT). By either measure, steel structures predominate; however, there are also significant percentages of concrete, prestressed concrete, and timber bridges. Figure 3 shows the influence of new materials and technology. Prestressed concrete, first used in the early 1950s, has become the material of choice for new bridges. Today almost half of the bridges constructed nationwide have prestressed concrete superstructures. Bridges with timber superstructures represent roughly 9 percent of the number of bridges in the inventory, and yet account for less than 1 percent of the total daily traffic volume. It would thus appear that bridges with timber superstructures are located primarily on low-volume roadways, such as rural collectors and local roads. This observation is confirmed in Table 1, which presents percentages for superstructure material types and functional classification for both number of bridges and traffic volume.

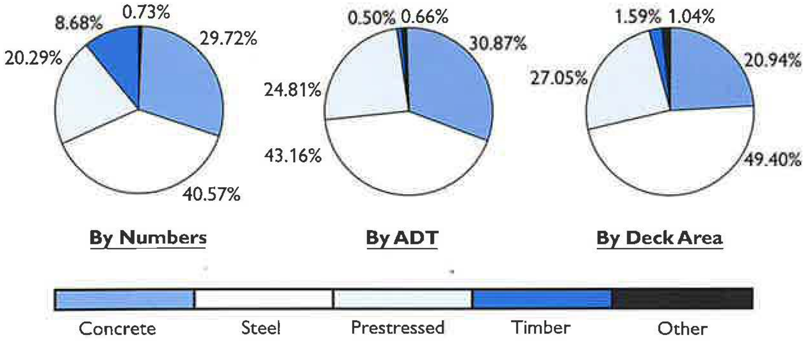

FIGURE 2 **Superstructure material types used and traffic carried for bridges and culverts.**

TABLE 1 Percentage of Bridges and Traffic Carried by Material[a]

Functional Classification	Concrete	Steel	Prestressed	Timber	Other	Total
Percentage of Bridges by Material						
Interstates/Expressways	11.33	13.77	17.45	0.04	15.28	12.61
Other Principal Arterials	11.15	8.36	11.66	0.98	7.90	9.22
Minor Arterials	12.09	8.16	9.60	2.52	12.21	9.16
Collectors	32.54	22.82	25.62	19.86	25.33	26.04
Local	32.89	46.89	35.67	76.60	39.29	42.97
Percentage of Traffic by Material						
Interstates/Expressways	56.32	63.71	62.41	2.85	42.89	60.67
Other Principal Arterials	20.16	17.15	17.63	10.40	20.97	18.19
Minor Arterials	10.98	8.61	8.44	15.54	19.44	9.41
Collectors	8.60	6.46	6.91	34.26	11.55	7.41
Local	3.94	4.06	4.60	36.95	5.15	4.33

[a] Based on the 1995 NBI. Information is presented for bridges exclusive of culverts.

Further examination of the information contained in Table 1 reveals the importance of Interstate and principal arterial structures. Fewer than one-quarter of all bridges are classified within these two functional categories, yet these structures service 80 percent of the total daily traffic volume. Such structures (Interstates, other expressways, and other principal arterials) are thus of singular importance to the nation's economy, defense, and mobility. Bridges required for intermodal connectivity, as for ports and railways, may carry smaller volumes of traffic, but are equally important to the nation's economic well-being and defense.

In 1995 the National Highway System Designation Act was signed into law. This legislation officially designated over 260 000 kilometers (161,000 miles) of roadways as essential for the nation's economic vitality, defense, and mobility. The National Highway System will serve as "the backbone of our national transportation network in the 21st century. It is going to affect every American either directly or indirectly" (*1*,p.29). More than 20 percent of the nation's highway bridges are on the National Highway System. These structures comprise better than 50 percent of the total bridge deck area in the United States and bear 80 percent of the total traffic volume carried by the bridge network. The significance of highway bridges as critical links in the nation's surface transportation system quickly becomes evident.

Performance and Health of the Nation's Highway Bridges

Standard indexes have been developed over the years to gauge the health and performance of highway bridges. These indexes are based on information maintained in the NBI: the health of a structure is expressed in terms of structural deficiency, while the performance is expressed in terms of functional obsolescence. A bridge is classified as structurally deficient if the condition of the deck, superstructure, or substructure is poor or worse. The bridge can also be structurally deficient if its load-carrying capacity is very low or if there are frequent delays due to flooding. In this case, the classification does not imply that the structure is unsafe, but indicates that deterioration or other processes are beginning to affect its serviceability and functionality. Thus a low rating serves to flag the structure's need for attention, enabling proactive mitigation of potential safety problems before they occur.

Functional obsolescence is the result of narrow bridge deck widths, inadequate clearances (horizontal or vertical), or unsafe geometrical alignments. A bridge may also be classified as functionally

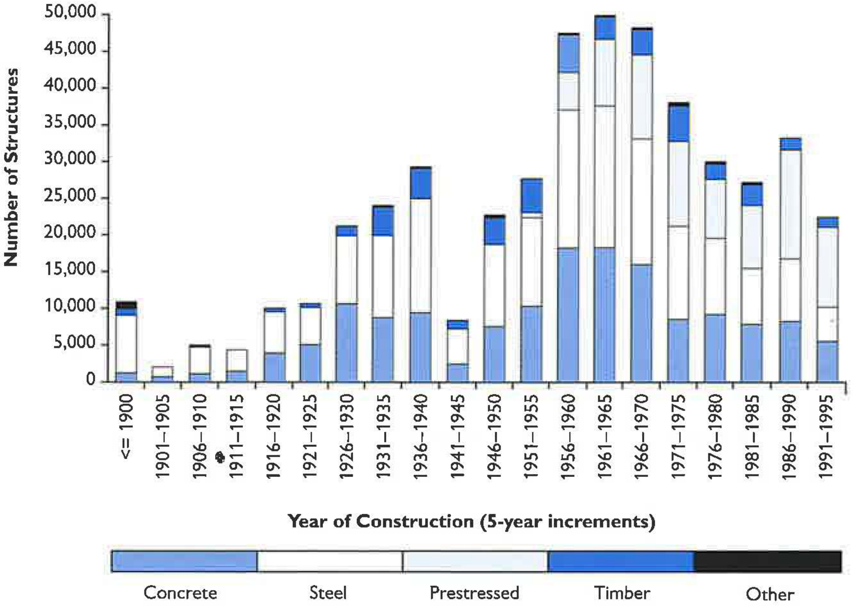

FIGURE 3 Year of construction for bridges by superstructure material.

TABLE 2 Bridge Deficiencies[a]

Deficiency Type	Number of Bridges	Percent of Bridges	Percent of Total ADT Carried
Only Structurally Deficient	50,438	10.60	4.56
Only Functionally Obsolete	88,716	18.64	28.96
Structurally Deficient and Functionally Obsolete	54,028	11.35	7.30
Total	193,182	40.59	40.82

[a] Based on the 1995 NBI. Information is presented for bridges exclusive of culverts.

obsolete if the design load-carrying capacity does not adequately service load demands or if frequent flooding occurs. Thus functional obsolescence implies that the structure is not adequately servicing the traffic demands placed upon it by the traveling public.

Percentages of structural deficiency and functional obsolescence are shown in Table 2 by number of bridges and total volume of traffic carried. Of the approximately 104,500 bridges in the category of structurally deficient or structurally deficient and functionally obsolete (roughly 20 percent of the total bridge population), about 78,000 have inadequate (poor or worse) condition ratings, 53,300 have inadequate structural appraisal ratings, and 3,100 have inadequate waterway ratings. Further categorization reveals that of the 78,000 structures with poor or worse condition ratings, 36,000 have poor deck conditions, 40,000 have poor superstructure conditions, and 50,000 have poor substructure conditions.

As noted, functional obsolescence results from inadequate deck geometry, underclearances, geometric alignment, structural appraisal ratings, and/or waterways. Physical characteristics (deck geometry, underclearances, and alignments) are the primary cause of functional obsolescence. Of the approximately 142,000 functionally obsolete bridges, which represent roughly 30 percent of the total population, 100,000 have deck geometry appraisal inadequacies, 27,000 have inadequate underclearances, and 15,000 have inadequate approach alignments. There are also almost 19,000 bridges considered functionally obsolete because of inadequate structural appraisal ratings (low load-carrying capacity), and 5,000 bridges considered functionally obsolete because of waterway inadequacy.

Culvert Conditions

Unlike bridges, culverts are often embedded within the roadway embankment and show no clear distinction among the deck, superstructure, and substructure elements. The only distinguishing element for a culvert is the culvert itself. Culverts and bridges thus have different design properties and are subject to different loading patterns.

If one examines the composition of the culvert network, one finds little variation in material composition, in contrast with the bridge network as previously discussed. Close to 90 percent of culverts are constructed using reinforced concrete, with the remaining 10 percent constructed using steel. Further examination reveals that the use of culverts has been increasing. From the year-of-construction distributions presented in Figure 1, it can be seen that through the 1920s, culverts were used relatively infrequently, whereas today they comprise roughly 20 percent of all bridge and culvert structures built. This growth is primarily the result of the economical construction costs of culverts and their efficiency for small crossings. The use of culverts is expected to dominate the small crossing and underpass segment of the bridge market in the future.

With regard to culvert conditions, approximately 3.5 percent of the 114,000 culverts in the NBI are characterized as structurally deficient. The causes for structural deficiences in the culvert network, along with associated numbers of culverts, are as follows: 3,000 are structurally deficient as a result of inadequate culvert condition ratings, 1,300 as a result of inadequate structural appraisal ratings, and 300 as a result of waterway inadequacy.

As with bridges, functional obsolescence of culverts results from inadequate geometry, underclearances, and/or alignments; inadequate structural appraisal ratings; and low waterway adequacy ratings. Many culverts do not have traditional bridge decks. Bridge deck geometry ratings are not applicable for more than 65 percent of culverts, indicating that there is no roadway constriction over the culvert. Of the remaining culverts, 3,000 are functionally obsolete because of inadequate deck geometry, 820 because of inadequate approach roadway alignment ratings, 900 because of inadequate structural appraisal ratings, and 1,000 because of waterway inadequacy. In total, there are approximately 5,500 functionally obsolete culverts (roughly 5 percent of all culverts).

The lower percentage of culvert deficiencies relative to bridges can be attributed to two factors. First, these structures are much less complex than bridges, act integrally with the ground, and thus do not respond (move) as much under traffic loads. Second, the culvert population has a younger average age than the corresponding bridge population.

Status of Structures in NBI

In considering overall conditions, culvert and bridge records are combined. The combined data reveal that approximately 104,500 bridges and 4,000 culverts are classified as structurally deficient. These structures represent about 18 percent of the total inventory. Likewise, approximately 25 percent of the structures (140,000 bridges and 3,000 culverts) are functionally obsolete. It should be noted, however, that many of the functionally obsolete structures are also structurally deficient, as shown for bridges in Table 2. For funding purposes, structural deficiencies take precedence; therefore, structures with both types of deficiency are considered to be within the structurally deficient population instead of the functionally obsolete population. With this consideration in mind, approximately 10 percent of the structures are functionally obsolete (without structural deficiencies). Thus, approximately 30 percent of the structures within the national bridge and culvert network are considered deficient.

Where Do We Go from Here?

As documented in the Highway Bridge Repair and Rehabilitation Program Reports to Congress and summarized in Figure 4, the total number of deficient structures and associated percentages have been decreasing in recent years. The data shown in Figure 4 clearly reveal that deficiencies in the nation's bridges and culverts have been reduced. Although there are no definitive answers explaining these reductions, one can identify certain trends that indicate contributing factors. These trends include technology advances and a better understanding of how bridges respond to loads and the environment. Decreased deficiencies may also have resulted from increased funding for preservation (with associated decreased expenditures for new construction). This increased funding, however, is not considered a predominant factor since needs have increased in parallel.

The focus of new materials and designs has been on increased durability with fewer maintenance requirements. Precast concrete is the most frequently used material today, with concrete members being formed, placed, and cured under controlled environmental conditions. This approach greatly facilitates quality control and quality assurance, thus minimizing conditions that could adversely affect the properties of the concrete. New compliant coatings, epoxy-covered reinforcement, and high-strength, durable, low-weight materials have all advanced the state of the practice. Trends indicate better performance and, in most cases, lower life-cycle costs with increased safety. New designs have addressed details that have contributed to structural degradation in the past. Jointless bridges are now frequently employed, thus eliminating potential problems and maintenance of the structure at the expansion joints while decreasing the vulnerability of the structure to potential damage from natural hazards. Fatigue-resistant design details increase the capacity of a structure to service multiple cycles of heavy loads.

Better information has also been a direct factor in reducing the deficiencies in the bridge network. With periodic inspection and associated recording, bridge managers and engineers can now focus attention on structures with more critical problems. Trends show that the bridge engineering community is meeting the challenge of preserving the highway bridge network. However, as the inventory continues to age, additional demands will be placed on bridge engineers and managers. In particular, the large volume of structures built during the Interstate construction era will require increasing maintenance, major rehabilitation, and in some cases replacement. Given these projected needs and anticipated static budgets, further progress in the removal of deficiencies is in question.

Bridge management systems, including those using software such as Pontis and BRIDGIT, have been developed to optimize actions and associated funds expended within the bridge network. These systems are introducing new approaches to management of the nation's highway bridges. Component-level inspection (i.e., deck, superstructure, and substructure) is being replaced by detailed element-level inspection (e.g., girders, bearings, joints, piers), thus enabling more detailed modeling of the structure and associated deterioration. These new bridge management systems allow decision makers to consider future conditions and future demands on individual structures and the network of struc-

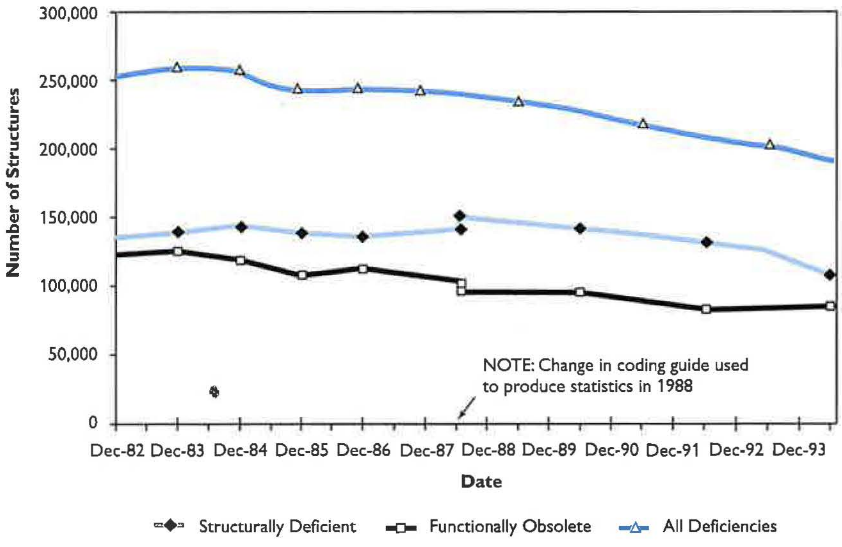

FIGURE 4 Deficiency trends.

A bridge is to a road what a diamond is to a ring.

Joseph Gies in *Bridges and Men*

tures when allocating available budgets. Optimization is performed for maintenance, repair, and rehabilitative preservation efforts in conjunction with functional improvements. Long-term strategies are developed over a 10- to 20-year planning horizon. Bridge management systems have been well received by state highway departments, the vast majority of which are either implementing or planning for such systems.

New technologies and structural materials are continually being developed through research and are frequently implemented. A noteworthy example is the application of composite materials for bridge column and pier repair, rehabilitation, and seismic retrofit. Seismic retrofitting techniques routinely employ composite material column-wrapping techniques to strengthen vulnerable columns, thus reducing the risk of damage and enhancing the safety of the traveling public.

High-performance concrete, high-performance steel, aluminum, and composite fiber reinforced polymer materials have been developed and are being utilized within the bridge design and construction community through pilot projects in many states. These materials promise increased longevity with decreased maintenance requirements and therefore lower life-cycle costs. In many instances, lower construction costs also result from the use of these new materials and designs.

New inspection techniques incorporating automated data collection and maintenance in conjunction with nondestructive testing and evaluation have been developed as well. For example, visual inspection methods do not permit the examination of deck conditions in lieu of removing an asphalt overlay system. Radar and infrared systems have been developed to isolate bridge deck conditions for structures with overlays, thereby enabling the use of quantified bridge condition information for the evaluation of structural performance and assignment of maintenance actions. Research is also being performed to integrate these nondestructive testing and evaluation technologies within the bridge management system decision-making process. With the integration of nondestructive evaluation into bridge management systems, the subjectivity associated with current visual inspection techniques will be eliminated, and decisions will be made on the basis of quantified condition information.

Summary and Conclusions

Bridge safety has significantly improved as a result of biennial bridge inspections by bridge owners. Since 1971 important data have been collected through these inspections, data that are now used to identify bridge vulnerabilities, such as where fatigue problems and material deterioration and degradation occur, and which bridge details cause ancillary problems (e.g., with expansion joints and bearings). Design countermeasures have been developed to improve bridge durability. For example, structural detailing has been modified; the use of expansion joints has been reduced; stable, more maintenance-free bearings have been developed; and flood and scour protection systems have been devised. New protective systems, including coatings (paints), concrete grouts, and barriers to reduce salt infiltration, have been developed and are now in use. Alternative deicing chemicals have been developed, thus reducing bridge deck deterioration caused by salting.

Stronger, more durable materials—concrete, steel, and laminated composite timber—are now being employed in bridge construction and rehabilitation. New methods of foundation design and construction, coupled with the use of more effective ground-modification technologies, reduce adverse bridge movement. On the horizon, a new breed of space-age structural materials that are lighter, stronger, and much more durable, coupled with the advent of nontraditional designs, gives hope for nearly maintenance-free bridges in the next millennium.

The bottom line is that the U.S. highway bridge network is one of the safest in the world. Failures in the 1960s, and occasional failures since then, have reminded the bridge engineering community of the need to be vigilant with respect to constantly evaluating the condition of the nation's bridges and improving the way these valuable assets are managed. The use of comprehensive condition data, the application of new technologies, and the ability to project future conditions and needs are all part of an inventory asset management approach that is now under development. When fully implemented, this approach will incorporate the use of higher technology while optimizing the application of financial resources to provide a safe, durable, and efficient highway system.

Reference

1. Slater, R. E. *Public Roads Magazine*. Winter 1996.