Life-Cycle Performance of New York City Bridges

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The 1991 annual report of the New York City Department of Transportation (NYC DOT) Bridge Bureau lists 872 bridge structures under its purview. Included are the 4 East River crossings, 25 movable bridges, 5 tunnels, and a large variety of structures over land, with a total number of spans approaching 6,000. The average age of the bridges in this network is approximately 68 years. This is in sharp contrast with the average age of 28 years of the nearly 600 bridges in the metropolitan area, which are managed by New York State Department of Transportation (NYS DOT). As a result of the federally mandated bridge inspection program, which was originated in the late 1970s, it is currently possible to consider the bridge structural condition as a variable with respect to time. The length of the period since inspections began and the large variety of bridge conditions reveal for the first time certain patterns in the life-cycle performance of the bridges in New York City. This deterioration model analysis is regarded as a fundamental tool of the bridge management program stipulated by the Intermodal Surface Transportation Efficiency Act of 1991. Of particular interest are certain bridge components, such as deck, primary member, joints, and the like. The inspection records established by NYS DOT allow review of the performance of such components over time. The results may yield not only an insight into the behavior of various structural members, but also certain indications of their relationship. From the deterioration patterns obtained from inspection records and the knowledge of maintenance, repair, and reconstruction costs, it is possible to select optimal strategies of bridge management and superior design. The conclusions are specific to the geographic area under consideration and the period of the data on which they are based. The term "optimal" implies a certain set of constraints. It is recognized that the optimal state of a bridge network may not be the highest priority in optimizing a local budget. The overall optimization process is beyond the scope of this paper. It is pertinent, however, to investigate the degree to which bridge life-cycle behavior may be assessed in an unconstrained environment and the potential effects of budget constraints during design, construction, and maintenance. Results of deterioration modeling for bridges and bridge components performed at the Bridge Bureau of NYC DOT during the past 2 years are summarized.

Life-cycle cost considerations in the design selection for new bridges and the optimal operation of existing ones are among the most frequently discussed issues related to bridge management. Noteworthy articles on the subject include those by T. R. Kuesel (*1*) and R. L. Nickerson and D. Veshosky (*2*). These authors favor incorporating life-cycle cost considerations in bridge design and management. In another article, D. Veshosky and C. R. Beidleman (*3*) argue that life-cycle cost analysis does not work for bridges, at least for the present. The authors point out that the number of significant variables associated with life-cycle decisions is considerable and the knowledge of these variables is both limited and restricted to the past. As a result, life-cycle analysis might introduce more uncertainty than useful forecasting. In a move that appears to support this view, FHWA has discontinued the use of the bridge inventory bracket for estimating remaining structural life.

Foremost among the variables necessary for a life-cycle cost estimate is the bridge deterioration rate. This rate is clearly (although not exclusively) a function of (a) structural type and design, (b) construction quality, (c) local climate, (d) traffic, and (e) maintenance.

Because items c–e may vary during the life of the structure, it is questionable whether a deterioration rate can be reliably established over a time comparable to the expected period of bridge use. Within certain limitations, however, information exists that may be translated into patterns of bridge deterioration. This is primarily because of the federally mandated biennial and interim bridge inspections, which have provided a consistent rating of bridge conditions for approximately 15 years.

The resulting bridge inspection reports provide for the first time insight into the behavior of bridges over a significant time period. No such data are available for bridge structures in other developed countries. Consequently the inspection program is the subject of considerable international interest (*4,5*). Two main points should be considered during a review of the information available from bridge inventory and inspection reports. First, all meaningful information should be extracted from the inspection reports and used to its maximum value. Second, the limitations of the available data should be fully recognized. This would serve to prevent the formulation of erroneous conclusions and provide guidance for future bridge data acquisition.

Certain deterioration curves for bridges and bridge components with respect to time are discussed here. The reported results were obtained at the New York City Department of Transportation (NYC DOT) Bureau of Bridges using data from inspection reports primarily from New York State bridge inspection files. Although confined to bridges located in the New York metropolitan area and to a period of only 15 years, the results are intended to show the possibilities open to life-cycle performance considerations with the refinement and expansion of bridge condition data.

BASIC ASSUMPTIONS AND LIMITATIONS

The bridges examined in this study are located in the New York City metropolitan area. They include 872 bridges owned

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by New York City with approximately 5,200 spans and an average age of 68 years and 550 state-owned ones with approximately 3,000 spans and an average age of 28 years. Approximately 600 bridges managed by other organizations in the area are also included.

All bridges support street and highway vehicular traffic. The magnitude of traffic varies according to the bridge location. The East River crossings carry an average daily traffic of up to 250,000 passengers, whereas certain street bridges carry well below 25,000 passengers. The difference in traffic volume has not been used to distinguish between different structures.

The source of bridge condition data consists of biennial and interim inspections performed by consultants for the New York State Department of Transportation (NYS DOT) or NYC DOT according to state standards. The inspections date from 1978 to the present.

The bridge condition is a real number from 1 to 7 computed on the basis of weighted averages of certain bridge component conditions, as shown in Figure 1. Bridge components receive integer condition ratings from 1 to 7:

- Rating 1: Potentially hazardous;
- Rating 2: Used to shade between a rating of 1 and 3;
- Rating 3: Serious deterioration or not functioning as originally designed;
- Rating 4: Used to shade between a rating of 3 and 5;
- Rating 5: Minor deterioration, but functioning as originally designed;
- Rating 6: Used to shade between a rating of 5 and 7;
- Rating 7: New condition;
- Rating 8: Not applicable;
- Rating 9: Unknown [due to inaccessibility (e.g., footings or piles)].

BIN: FEATURE CARRIED:

DATE: FEATURE CROSSED:

INSPECTED BY: TITLE:

ELEMENT #	(1) WEIGHT	(2) CONDITION*	(1) X (2) WEIGHTED CONDITION	REMARKS
1. BEARING TP 349-24, 25, 350-35	6			
2. BACK WALLS TP 349-28, 29	5			
3. ABUTMENTS TP 349-30, 31	8			
4. WINGWALLS TP 349-46, 47	5			
5. BRIDGE SEATS TP 349-26, 27 TP 350-36, 37	6			
6. PRIMARY MEMBERS TP 350-30	10			
7. SECONDARY MEMBERS TP 350-31	5			
8. CURBS TP 350-21	1			
9. SIDEWALKS TP 350-22	2			
10. DECK TP 350-29	8			
11. WEARING SURFACE TP 350-19	4			
12. PIERS TP 350-38, 39, 40, 41	8			
13. JOINTS TP 349-22, 23 TP 350-33	4			
TOTAL WEIGHTS		TOTAL WEIGHTED CONDITION		

* DON'T USE AN 8 OR 9

OVERALL RATED VALUE OF STRUCTURE = TOTAL WEIGHTED CONDITION / TOTAL WEIGHTS = ______

FIGURE 1 Average bridge condition rating, New York state bridge inspections.

These ratings (both individual elements and weighted average) are recorded on NYSDOT Inspection Report Forms. Together with photos and explanatory descriptions, the ratings provide the bureau with information on the existing condition of each bridge. In addition, bridge inspectors assign a general recommendation integer rating from 1 to 7 to the bridges.

The bridge condition rating incorporates two significant assumptions. One is the set of structural components and corresponding weights assigned to them, as shown in Figure 1. The selection is based on engineering experience and reliability estimates which, even if fundamentally sound, are not always formally defined. Second is the decision to use only the lowest condition rating of all spans for each of the structural components in Figure 1. This is motivated by the objective to identify the weakest link on any bridge. Consequently a single poor span affects the rating of an entire multispan structure.

The general recommendation rating reflects the assessment of the inspecting engineer. This rating should be assigned at the conclusion of the bridge inspection, subsequent to rating all individual components in all spans, but before and independently of computing the condition rating.

The correlation between the general recommendation and the bridge condition ratings is shown in Figure 2. Despite the inevitable scatter, which varies over the years, the two ratings appear to compare well, suggesting that the two rating procedures are in general compatible.

It must be noted that the bridge rating system serving as the basis for the deterioration models obtained herein has the significant limitation of being subjective. The judgment of one inspector is not identical to that of another who inspects the same bridge. The state requires that the same inspector not inspect the same bridge two consecutive times.

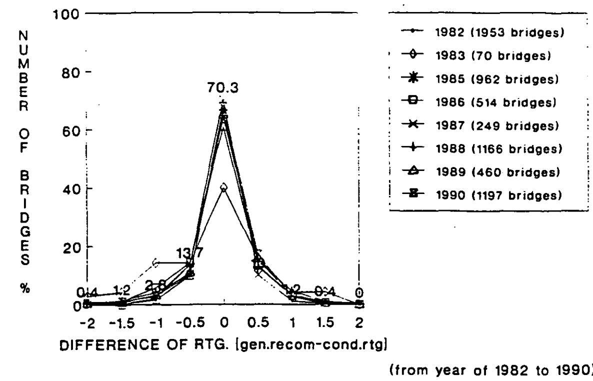


FIGURE 2 Comparison of general recommendation with condition rating for all inspection years.

There is no quantifiable basis for the ratings. The rating system is essentially a relative one, despite efforts to introduce quantities of deterioration as much as possible in the inspection reports. The load-bearing capacity of a bridge does not change significantly over a rating change from 7 to 4, but is presumably reduced by the time the bridge is rated 3. This, however, is not always the case. Load-rating procedures are established independently of the condition ratings.

Subjectivity affects the deterioration models to a varying degree at the different ratings from 1 to 7. It is noted that inspectors show a propensity for rating toward the middle of the scale (e.g., 4) and not toward the extreme values. This tendency coincides with the objectively normal distribution of bridge conditions observed for the general bridge population, as shown in Figure 3. The degree to which the objective

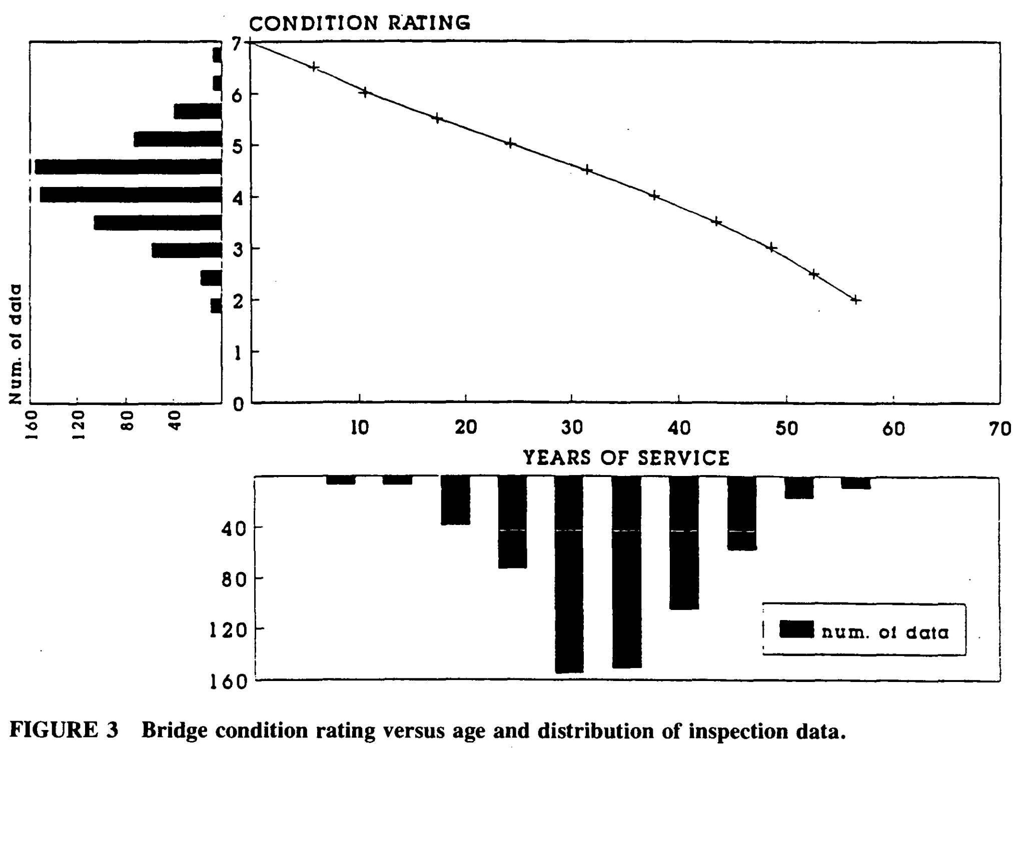


FIGURE 3 Bridge condition rating versus age and distribution of inspection data.

and subjective influences contribute to the normal distribution of ratings is not known.

The bridge rating system is a combination of serviceability and physical deterioration criteria. Needs for repairs are not immediately apparent from any rating level. Bridge ratings are increasingly considered as fuzzy sets. Probabilistic techniques such as Markov chain models are applied to the problem, as for instance in work by M. Cesare et al. (*6*)

Bridge condition ratings were used in this study on the assumption that they have the same bias throughout the data acquisition period (1978–1990).

Maintenance is expected to significantly affect the deterioration rate. The exact effect, however, can only be estimated. It is assumed herein that maintenance was constant during the study period. Further, it is assumed that the maintenance was negligible. Maintenance consists primarily of painting, spot painting, and cleaning of wearing surfaces and drainage systems.

Most major rehabilitations of bridges are recorded in the bridge files. Repairs of various components such as joints, decks, steel primary members, and the like, however, are not possible to identify from the records. As a result, the effects of certain such repairs are implicit in the deterioration models. These repairs do not include temporary measures, such as timber shoring, steel deck plates, and so forth, which eliminate hazardous conditions but do not improve the rating of a bridge component.

DETERIORATION MODELS

Within the prescribed assumptions and limitations, the rating of overall bridge conditions, bridge decks, and primary members are considered as a function of their age. Two methods are used for generating the bridge rating versus age models.

Model 1

The rate of change is calculated for each rating (e.g., from 7 to 6.5, from 6.5 to 6, and so on). The average rate of change is plotted over time. The results for the bridges of the metropolitan area with no record of major rehabilitation are shown in Figure 3.

Also plotted is the data distribution as a function of the bridge age and as a function of the bridge ratings. Both distributions are normal, indicating that the most voluminous data are in the central portion of the structural lifespan.

The resulting deterioration model is near linear, with an average loss of one rating point per 10 years. Thus, the condition of 3 (not functioning as designed) is reached in 40 to 45 years and 1 (defunct) is reached in an average of 60 years.

Figure 4 shows the same curve, along with the deterioration model for bridges that have undergone capital rehabilitation. The slope of deterioration for rehabilitated bridges is steeper. This suggests that, in all cases, the rehabilitated bridges do not revert back to rating of 7 but instead improve to a rating of 6 and proceed to decline at a rate faster than that of a new bridge.

The conclusion that rehabilitated bridge components are improved only to a level of 6 instead of 7 has been incorporated in the New York State bridge management system. It is shown here that the same holds true for the rehabilitation of entire bridges.

Model 2

In this model the bridge ratings for bridges of all ages are simply averaged. This method has been applied for obtaining several deterioration curves.

The ratings of all bridges in the metropolitan area and their respective ages are shown in Figure 5. It indicates that bridges are maintained at a level of approximately 4.3. In contrast with the preceding figures, this one shows the effect of all repairs and rehabilitations performed on the bridges. The ratings and respective ages for steel and concrete primary members with and without joints in the deck are shown in Figure 6. Ostensibly the joints accelerate the deterioration process. The respective performance of bridge decks with and without overlays are shown in Figure 7. Once again, the presence of joints demonstrates the same detrimental effect.

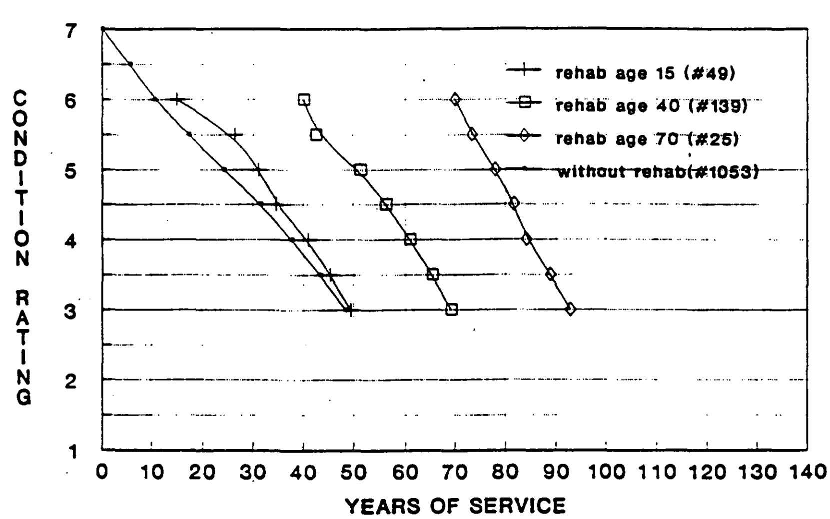


FIGURE 4 Bridge condition rating versus years of service.

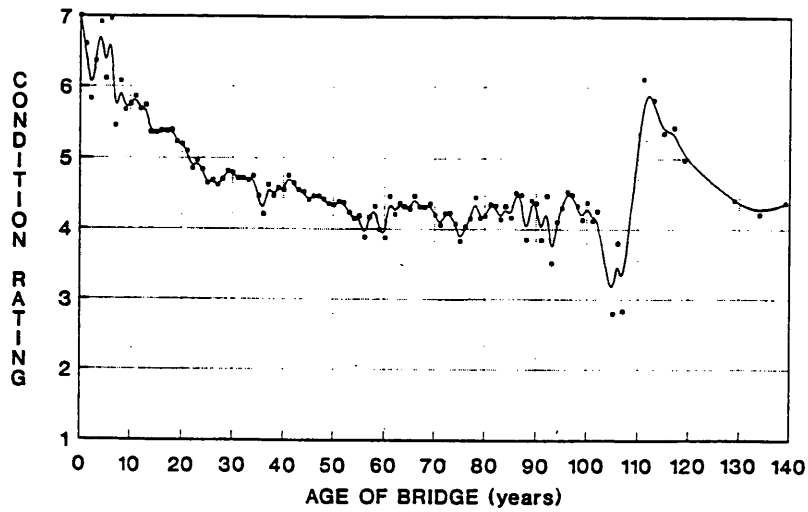
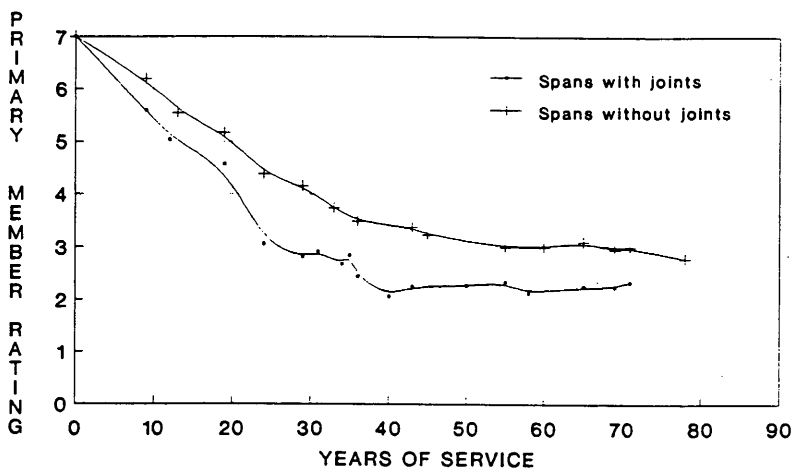


FIGURE 5 Bridge condition rating versus age.



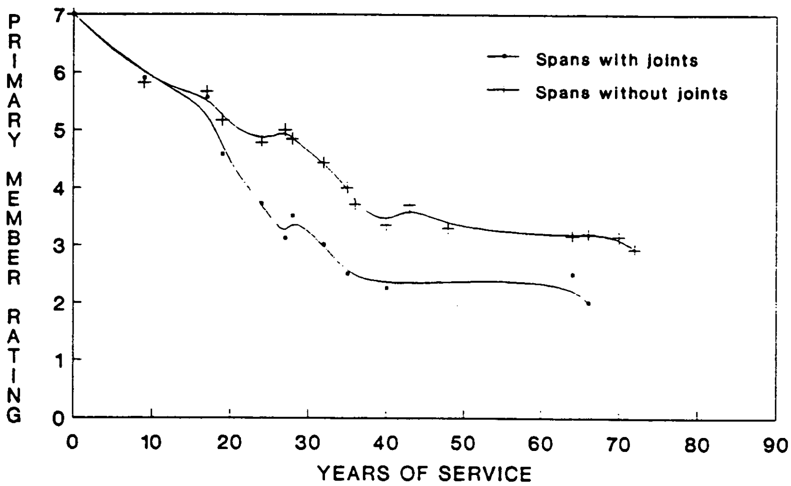
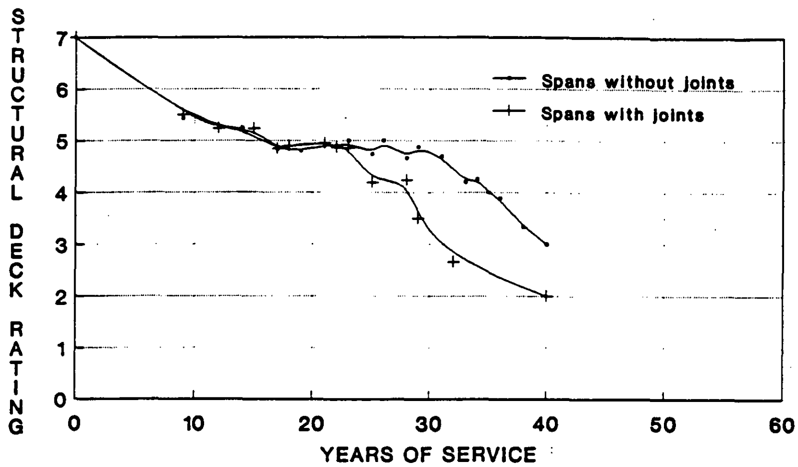


FIGURE 6 Steel (*top*) and concrete (*bottom*) primary member rating versus age.



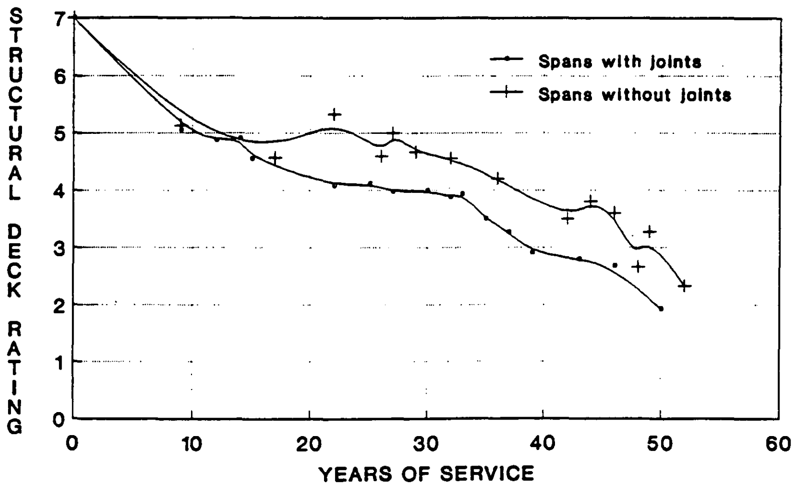


FIGURE 7 Structural deck rating versus age, spans with overlays (*top*) and without overlays (*bottom*).

Deck deterioration rates in the cases with and without overlays have been investigated by J. Llanos and B. Yanev (*7*). The resulting deterioration models are shown in Figure 8. These models are based on a limited number of decks without replacement or major repair. Rehabilitated decks are included in Figure 7. A comparison of the results suggests that deck repairs have been performed on most bridges without overlays, bringing their deterioration rate up to that of the decks with overlays. In all cases the data pertain to decks with uncoated reinforcement. Asphalt resurfacing of decks with overlays has regularly occurred for most New York City bridges at 5- to 10-year intervals.

The deck deterioration patterns appear to agree with similar results obtained for the bridges managed by the New York Thruway Authority, as reported by K. E. Giles (*8*).

CONCLUSIONS AND RECOMMENDATIONS

The ultimate goal of obtaining bridge deterioration models is to gain knowledge of the expected bridge useful life and level of service. The following conclusions may be drawn from the models discussed in this paper.

At the past level of maintenance, and in the absence of rehabilitation, New York City bridges may be expected to reach the rating of 3 (not functioning as designed) in 40 years and to reach the end their useful lives in 60 years. Bridge decks would have to be replaced at least once if they have no overlay (or resurfaced regularly if they do) during this period.

The bridges of New York City are maintained at an average condition level of approximately 4.3 during most of their service lives. This average is below the level of 5, which is considered serviceable. Consequently the bridges do not provide optimal service to the community. Further, the maintenance of the bridge population at this average level implies a considerable number of bridges below, as well as above, the mean. Such a state involves certain hazardous conditions and substantial repairs, frequently under emergency conditions. It is therefore highly probable that this strategy, besides yielding less than optimal service, is a more expensive one than keeping the bridge condition at 5.5 by intensified maintenance. Further investigation, which should include maintenance versus repair costs and could serve as a guide toward an optimal maintenance strategy, is required.

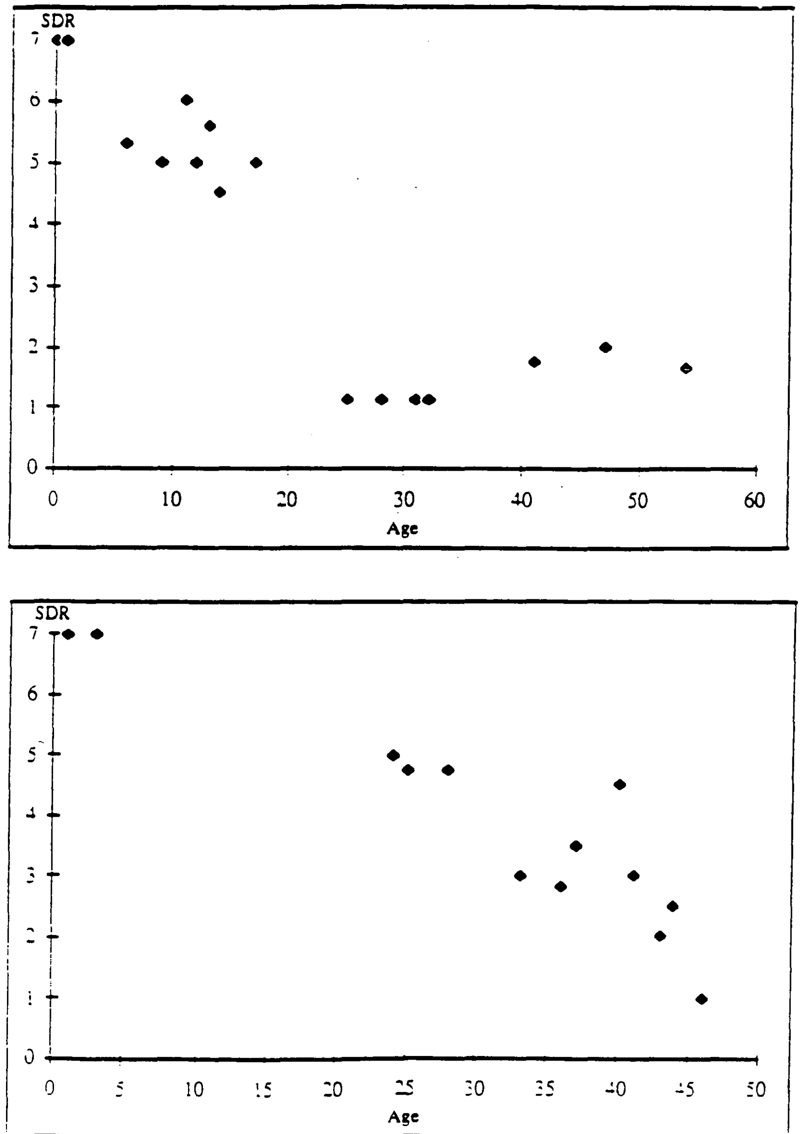


FIGURE 8 Condition rating as a function of time for bridge decks without overlays (*top*) and with overlays (*bottom*) (data from NYC DOT bridge inspection and management data base).

Concrete and steel primary members appear to decline at a similar rate. It should be noted that steel primary members have not received adequate painting and therefore did not perform optimally. Further, steel primary members outnumber concrete ones by approximately 4 to 1, and their average age is roughly twice that of the concrete members. The similarity between the two models is therefore inconclusive.

Joints have a pronounced detrimental effect on both steel and concrete primary members and on concrete decks with and without overlays.

Bridge rehabilitation restores bridge condition ratings to approximately 6 instead of 7, and the ensuing deterioration rate is faster than that of a new bridge.

All of these conclusions should be viewed as specific to the New York City environment and the negligible maintenance of the 1970s and 1980s. Further sensitivity studies could improve the insight into the performance of bridge types and components during the period under consideration.

The current policy of improving bridge maintenance with added cleaning, spot painting, and regular full repainting ought to have a retarding effect on bridge deterioration. The modeling methods used here, however, would not reflect such an effect from the first few years of implementation. Future modeling would require an accurate statement of the maintenance level in order to remain distinct from the one in which maintenance was assumed to be negligible.

In order to derive accurate conclusions from the obtained models, it is necessary to identify the significant factors determining the deterioration rate. For instance, the presence of alkali-silica gel in concrete decks may have been typical for bridges of a certain age. The elimination of alkali-silica reactions would affect the deterioration rate in a significant way, which has yet to be demonstrated.

The recent introduction of condition rating for each bridge span in New York State adds another refinement to the modeling procedure. Past inspection reports can be reviewed in the light of this enhancement and the effect on the models of deterioration can be evaluated.

With further refinement and added data, bridge deterioration models can become an accurate indicator of bridge management efficiency and a reliable guide to improved bridge design and maintenance.

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