Kyoto Univ. and UTC Joint Summer Training Course of Road Infrastructure Asset Management

Bridge Management (3)
Deterministic Deterioration Prediction

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Research Experience

**Vibration Engineering** (1995-Present)
- Bridge Vibration Monitoring
- Structure Performance Evaluation
- Damage Identification

**Asset Management** (2001-Present)
- Statistical Deterioration Prediction
- Life Cycle Cost Analysis
- Policy Evaluation

Infrastructure Management
Professional Affiliation

Osaka University
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Current Status in Japan

Changes in No. of Bridges over 50 Years (National Road & Highway)

No. of Bridges over 50 Years increases to 17 times in 2020 due to concentrative construction in the high economic growth period in 1960’s to 70’s

Age Distribution of Civil Engineers in a Major Railway Company

Experts in 40’s and 50’s account for 75%.

Caused by management’s rationalization after privatization of JNR

Expected declining birthrate and a growing properties of elderly people
Asset Management

Institution, Constraint

Request

Stakeholder (Tax Payer, User)

Infrastructure Accounting System

Technical Information DB

Repair/ Rehabilitation DB

Revised

Planning

Data Acquisition

Modeling

Evaluation

Decision Making

- Long Term
- Short Term
- Visual Inspection
- Monitoring
- Deterioration Path
- Structural Performance
- LCC Analysis
- Priority
- Repair/ Rehabilitation

Bridges

Revised
Contents of Today’s Lecture

1. Importance of Visual Inspection
   - Through a Case Study of Bridge Management in New York City

2. Deterministic Deterioration Prediction
   - Methodology: Deterioration Rates
   - Empirical Study: Painting Period

3. Probabilistic Deterioration Prediction
   - Methodology: Markov Chain Model
   - Empirical Study: Reinforced Concrete Deck

   : Information Infrastructures
Importance of Visual Inspection
- Case Study of New York City -
Strong Awareness for Bridge Management

NYC is responsible for 764 bridges (2000)

- Average Age: about 75 years  Aging
- Severe Condition in Winters  Corrosion
- Capital City of the World  Fatigue Crack
- Bitter Experience in the Past
  Collapse of West Side Highway,
  Closure of Williamsburg Br.

Systemization of Bridge Management
based on Visual Inspection
General Outline of Visual Inspection

Complies not with *Bridge Inspection Manual by FHWA* but with *State of New York, Department of Transportation*

- Carried out for all bridges at least every 2 years
- Applied for 25 members of superstructure and 22 of substructure
- Evaluate the performance by rating from 1 to 7
  (7: new construction → 1: limit in service)

Subjective Empirical  <  Simplicity Fastness
### Rating System

<table>
<thead>
<tr>
<th>Rating</th>
<th>Physical Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>New Construction</td>
</tr>
<tr>
<td>6</td>
<td>Between 7 &amp; 5</td>
</tr>
<tr>
<td>5</td>
<td>Graze Damage Satisfying with the required performance</td>
</tr>
<tr>
<td>4</td>
<td>Between 5 &amp; 3</td>
</tr>
<tr>
<td>3</td>
<td>Serious damage or not Satisfying with the required performance</td>
</tr>
<tr>
<td>2</td>
<td>Between 3 &amp; 1</td>
</tr>
<tr>
<td>1</td>
<td>Collapse or Potential Hazard</td>
</tr>
</tbody>
</table>

### Original State Evaluation of NYC

<table>
<thead>
<tr>
<th>Rating</th>
<th>Verbal Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-6</td>
<td>Very Good</td>
</tr>
<tr>
<td>6-5</td>
<td>Good</td>
</tr>
<tr>
<td>5-3</td>
<td>Fair</td>
</tr>
<tr>
<td>3-1</td>
<td>Poor</td>
</tr>
</tbody>
</table>
### Inspection Sheet for Substructure

#### B.I.N
- Team Leader
- P.E. No.
- Ratings 1~7
- Flags Urgent need of repair/rehabilitation
- Signature

#### Table: Vertical Clearance and Load Postings

<table>
<thead>
<tr>
<th>Joint with deck</th>
<th>Bridge seat and pedestals</th>
<th>Bridge side</th>
<th>Backwall</th>
<th>Stem (abutment)</th>
<th>Bridge stack</th>
<th>Erosion or scour</th>
<th>Footing</th>
<th>Piles</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>begin end</td>
<td>begin end</td>
<td></td>
<td></td>
<td>begin end</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Flags
- Yellow structural
- Red structural
- Red non-structural
- Yellow non-structural
- Green (recommended)

#### Reviewed by
- P.E. Number
- Date
Database
Bridge Rating

Evaluation of Whole Bridge Rating

Weighted Average focusing on the major 13 members

\[ R = \frac{\sum_{i=1}^{13} w_i r_i}{\sum_{i=1}^{13} w_i} \]

- \( R \): Whole bridge rating
- \( i \): Member No.
- \( r_i \): Rating of Member \( i \)
- \( w_i \): Weight of Member \( i \)

Subjectively Selected 13 members, and decided the values of weights through the experience

<table>
<thead>
<tr>
<th>No.</th>
<th>Member</th>
<th>Weight ( w_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bearing</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Back Walls</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Abutments</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Wingwalls</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Bridge Seat</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Primary Member</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Secondary Member</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>Curbs</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Sidewalks</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>Deck</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>Wearing Surface</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Piers</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>Joints</td>
<td>4</td>
</tr>
</tbody>
</table>

Whole bridge rating = 72
Example of Utilization

Averaged Rating of Bridges in NYC (1992 to 2000)

- Tends to be increased year by year
- reaches to rating 5 (Good) in 2010

Utilizes for budget acquisition in the city assembly

Positive, effective use of visual inspection data
Discloser of Information

New York City Bridges and Tunnels Annual Condition Report (1982～)

- Outline of repair/rehabilitation works, its costs and schedules
- Concept of Rating system
- Ratings of all bridges
- Description of Technical terms

Disclosure of information
Deterministic Prediction
- Focusing on Deterioration Rates -
**Motivation**

**The basic purposes of Asset Management**

- To lay the base for effective maintenance strategy under budgetary restrictions
- To enhance the accountability to the stakeholders(taxpayers)
- To obtain the necessary budget autonomously

**Minimization of Life Cycle Costs (LCC)**

A cost minimization problem by treating the repair/rehabilitation costs and timing as variables

- Costs: Database of repair/rehabilitation
- Timing: Deterioration prediction method
Deterioration Prediction

How can we estimate a deterioration curve based on actual data?
- What kind of data are available in the filed side?
- Which methodology is appropriate?
Classification of Deterioration Prediction Methods

- **Aggregative methods**
- **Disaggregative methods**
- **Probabilistic methods** (Taking uncertainty into consideration)
- **Deterministic methods** (Not taking uncertainty into consideration)

**Physical method**

**Statistical method**

**Deterministic methods**

**Probabilistic methods** (Taking uncertainty into consideration)

**Aggregative methods**

**Disaggregative methods**

Based on the mechanical deterioration mechanisms. Decision making about micro-level issues such as the life time estimation of individual infrastructures and its repair/rehabilitation tactics.

Based on inspection data carried out in the past. Decision making about macro-level issues such as the budgetary management of the whole infrastructure system and their maintenance strategy in the future.
Objectives

Toward asset management system for infrastructures (bridges)

I. Construction of Methodology
   Deterioration prediction of bridge members based upon inspection data, focusing on deterioration rates

II. Verification Study
   Making a decision of painting period using the prediction results
The Simplest Method and Disadvantage

1. Plot all ratings (inspection data) for their ages.
2. Classify them into several segments.
3. Calculate average ratings per each segment and connect them.

Difficulties

Deterioration curve by this method tends to be slower declines than real.

The method does not take into account the effects of any repair/rehabilitation done to the bridge members in the past.
Example: NY City

- Using about 750 ratings in 1994
- Original bridge rating system (’82)
  7 to 1 (7: new, 1: failure)

Investigated repair and rehabilitation history for all bridges and excluded them.

Total Bridge No. used in his analysis
750 → 40

Reliable?
Proposed Method: Step 1

1. Calculate deterioration rates between $r_{n+1}$ and $r_n$.

$$v = \frac{r_{n+1} - r_n}{t_{n+1} - t_n}$$

2. Make several segments for ratings and classify all ratings into the appropriate segments and put rate $v$ in the same segment with the corresponded $r_n$.

3. Calculate average deterioration rates $v_i$ per each segment, then give deterioration time $T_i$ as the follows.

$$T_i = \frac{L}{v_i}$$
4. Accumulate averaged deterioration time for each segment to obtain total deterioration time.

\[ T = \sum_{i} T_i \]

**Advantage:**

Only deterioration rates (a series of ratings and inspection dates) are required to calculate deterioration curve.
Comparison with the Existing Method

Database of Visual Inspection Data for Bridges in NY City (1992-2000)

No. of Bridges: 828
No. of Samples: 8241
excluding \( v > 0 \)
Width of Class: 0.1, No. of Class: 71

Results of Analysis

Expected Life Time: about 80 years
The Worst Case: 25 years

Almost Similar to the results of the existing method
Actual Inspection Results

Visual Inspection results for painting deterioration of about 3,500 steel girders since 1987

<table>
<thead>
<tr>
<th>Rating</th>
<th>Rating Description</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Fine</td>
<td>23.2%</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
<td>43.5%</td>
</tr>
<tr>
<td>3</td>
<td>Permissible Damage</td>
<td>10.2%</td>
</tr>
<tr>
<td>2</td>
<td>Potential hazardous condition</td>
<td>20.9%</td>
</tr>
<tr>
<td>1</td>
<td>Failure or imminent failure</td>
<td>2.23%</td>
</tr>
</tbody>
</table>

4,313 samples

Corrosion
Results by the Existing Method

- Deterioration rating of painting goes down in more than 40 years on average.
- The painting period would be 25 years on 95% confidence interval.
Result by the Proposed Method

Painting is durable for 20 years on average.

The current painting period 8-15 years is reasonable from 95% confidence interval.

The lower classes do not have enough samples, reliability of quantity still remains.
Investigation of Cause of Corrosion

The leakage of water at the edge of the steel girder, peeling, rainwater, and others make up 30% of the causes. The histogram shows a second peak at a deterioration rate of around -0.6.

Histogram of deterioration rates
Corrosion gives crucial damage to steel member in 10 years.

Doing actively preventive maintenance for corroded member, painting period can be extended up to 20 years with 95% confidence interval.

LCC can be saved in some cases, and the accountability for necessity of painting is possible to be carried with this quantitative results.