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Problems in Concrete Culvert Durability Studies

Problèmes liés à l'étude de la durabilité des ponceaux en béton

Probleme mit Untersuchungen zu Dauerhaftigkeit von Betondurchlässen

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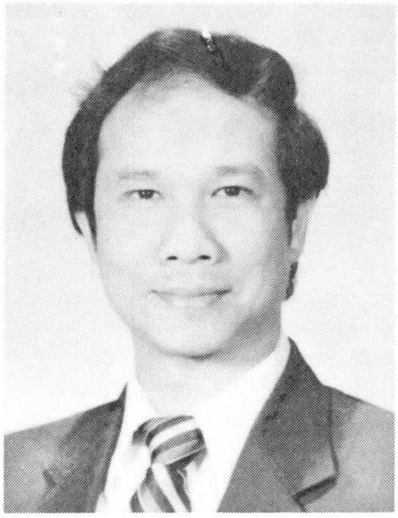

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SUMMARY

Several studies made concerning the durability of concrete culverts have led to inconclusive results. Inadequate consideration of enabling and triggering events contributed to the general problems in assessing the life expectancy of culverts. The more recent techniques using regression analyses for determining the culvert's service life encountered problems related to the inadequacy of sample data representative of the culverts and the inferior concepts employed to treat the data.

RÉSUMÉ

Quelques études, menées sur la durabilité des ponceaux en béton, ont débouché sur des résultats peu concluants. Des considérations insuffisantes, en ce qui concerne les multiples paramètres à considérer, contribuèrent à rendre difficile le problème général de la prévision de la durabilité des ponceaux. Des techniques d'analyse récentes, basées sur les régressions, furent appliquées à la détermination de l'aptitude au service des ponceaux. Toutefois, ces analyses se sont heurtées à l'inadéquation aussi bien des données simplifiées représentatives des ponceaux que de l'infériorité des concepts employés pour traiter les informations.

ZUSAMMENFASSUNG

Verschiedene Untersuchungen zur Dauerhaftigkeit von Betondurchlässen führten nicht zu schlüssigen Resultaten. Ungenügende Berücksichtigung der massgebenden Einflüsse führten zu Problemen bei Lebensdauerprognosen. Neuere Versuche unter Verwendung von Regressionstechniken scheitern an mangelhafter, nicht representativer Datenbasis und an ungenügenden Konzepten bei der Verarbeitung der Daten.

1. INTRODUCTION

Emphases of earlier studies of culvert durability are primarily placed on field surveys and experience of the analysts. Simple manipulations and statistics were performed manually to estimate culvert service life. Certain studies show the effects of enabling events resulting from pipe manufacturing and installation procedures. Examples of these events are the inadequacy of material, design, or construction processes. However, during the culvert durability studies, information concerning these events was not considered. The most frequently investigated events that caused the deterioration of culverts are the environmental conditions. These conditions are called the triggering events or external events that triggered the deterioration of the culverts, such as, the acid attack and flow velocity in the culverts. Current studies emphasize more on these events.

With the utilization of computers, more sophisticated statistical models can be performed using a large number of data. Unfortunately, this does not necessarily guarantee the reliability of the techniques developed. In some cases, casual observations were performed, and inadequate number of data was used to force the production of prediction models. In the following section, significant studies on durability of concrete culverts from several sources, including the author's own investigations, are presented. Emphasis of the studies are placed on the problems that may occur in relation to the reliability of the results.

2. STUDIES OF CONCRETE CULVERT DURABILITY

Annual deterioration, qualitative, and regression studies had been performed for the durability of concrete culverts. The following are examples of such studies performed in various states and summarized in Tables 1 and 2. Experimental studies are not discussed here.

2.1 Annual Deterioration and Qualitative Studies [1]

The earliest culvert durability study known to the author was performed in the State of Georgia in 1928, where 252 monolithic concrete culverts and 326 concrete concrete culverts were examined. The culverts were installed between 1915 and 1924. The average life expectancy is 31.2 and 27.6 years for monolithic culverts and concrete culverts, respectively. Another survey of 1,837 reinforced concrete pipe culverts was conducted in West Virginia between 1932 and 1933. The age of the culverts inspected ranges from 3 to 11 years. Variables contributing to concrete durability were discussed. The study results in 50 years average expected service life with an average annual deterioration of 2%. In 1947, Pennsylvania Department of Highways performed culvert study based on a survey of 10,439 concrete culverts installed from year 1918 to 1927. The study concludes a life expectancy of 40 years assuming that yearly deterioration remained constant.

A total of 442 concrete pipes were investigated in the State of Mississippi in 1964. The age of pipes ranges between 5 to 41 years, averaging 22.9 years. The study that was conducted qualitatively based only on field performance prescribed no life expectancy. However, it concluded an excellent condition of the pipes.

2.2 Regression Studies [1]

The research performed in 1974 for the State of Utah may be the first study of concrete culvert durability using regression analysis. Fifty eight pipe culverts were studied; however, only 14 of them were of concrete. A rating scale from 0 (failure) to 10 (excellent) was used in the study. Several dependent variables were used such as pH, soluble salt content, and electric resistivity. Pipe rating was used as the dependent variable. The study recommended service lives of 40 years for the design of interstate highways and 30 years for other installations.

Two surveys of concrete culverts were conducted by the Ohio Department of Transportation: the first was in 1972 for 545 culverts and the second was the reinspection of 64 concrete pipes in 1984. In the first study the rating scale used ranges from 1 (excellent) to 5 (poor). Pipe rating was used as the dependent variable, while age, slope, pH, sediment depth, and rise were used as independent variables. Two sample groups, pH below 7 and above 7, were analyzed for separate prediction models. Emphasis was placed on the latter group which resulted in prediction models. For pH value over 7, the models yield culvert service life of thousands of years. The second study is a refinement of the earlier one performed for sample group of pH below 7. Pipe ratings from 0 (as manufactured) to 100 (reinforcing gone) were used here. Rating was used as the dependent variable, while flow, pH, pipe size, slope, and sediment depth were used as the independent variables.

The author of this paper performed two regression studies. The first is based on information of 521 sections of concrete culverts made available by the Ohio Department of Transportation (ODOT) [1]. Rating scale with ranges similar to that of ODOT (1=excellent to 5=poor) was used in the study. Pipe rating was used as the dependent variable, while age, rise, pH, slope, and sediment depth become the independent variables. No grouping of pH values was performed here. Six multiplicative and six additive models were generated as the results of the study. However, these models can not be used for predicting the service life of a particular culvert. The expected "service life" of the culverts yield 86 years. The second study was performed by the author as a discussion of of ODOT's culvert study [3].

3. PROBLEMS ENCOUNTERED IN STUDIES

3.1 General Problems

Studies for determining the life expectancy of culverts have not been completely satisfactory. The variability in the design, material, manufacturing, installation, and maintenance of concrete culverts were seldom included in the analyses since usually such information is not available. Table 2 shows that only the earlier study in Georgia investigated the enabling events. Other studies had implicitly included the existence of these events through the rating scales. Furthermore, observations of culverts are usually performed at a certain "point in time" during the survey, where the variables related to the culvert geometry and triggering events are measured. During the observations, these triggering events are assumed constant. However, events such as, flow velocity, flow depth, sediment depth, and acidity may not be the same throughout the life span of culverts. These factors may contribute to the inaccuracy and unreliable results of analyses based on the average annual deterioration or regression analyses.

3.2 Inadequacy of Culvert Data

Many of the sample data, including those used by the author, are not representative of culverts in a particular state. For example, Figure 1 shows a bi-nodal sample distribution of pH values of observations in the State of Ohio. A representative sample data is expected to have a uninodal distribution. A plot of the variable Age and pH of these data shows a "boxing" of culvert ages above pH=7 as shown in Figure 2. These data indicate the lack of observations in other pH regions.

3.3 Conceptual Problems

In the regresssion analyses, the rating of culverts is usually treated as the response variable dependent upon other variables, such as, age, rise, flow depth, flow velocity, sediment depth, slope, and pH values. Only independent variables that contribute any information to the prediction of the culvert rating are included in the regresssion equation. An example of such an equation is as follows [2]:

$$RATE = -05469+0.0316AGE+0.0099RISE+11.2484/PH+0.2377SLOPE^{1/2}$$

In several studies, the variable AGE is algebraically exchanged with variable RATE, such that AGE becomes the response variable. Then, as RATE is set to a scale that represents the expiration of the culvert's service life, AGE becomes the "service life" of the culvert and the prediction equation is used for predicting a particular culvert for given variables. This technique is erroneous since throughout the regresssion, AGE is assumed, as it should be, an independent variable, but at the same time becomes a dependent variable when algebraically altered with RATE. Also, an attempt to treat AGE as a response variable for use in the regression analysis is inapropriate, since AGE is the time from installation to inspection of the culverts and is logically independent from other variables [3].

Incomplete or inadequate data adds to the problem of predicting the culvert's service life. For example, in a sample data set, the majority of the data were related to culverts still in service, and only a small fraction of the inspected samples represent expired culverts [3]. Despite the fact that none of the culverts in the data set are over 60 years old, yet through the algebraically altered prediction equation, one could predict that many of these culverts are already several hundred years old. Figure 3 shows an example result showing the relation between the

TABLE 1. Method of analysis and life expectancy of culverts

STATE	METHOD	SAMPLES	AGE (YRS)	LIFE EXP. (YRS)
Georgia	Avg. Annual Loss	252 monol. 326 pipes	2-13	31.2. 27.6.
W. Virginia	Avg. Annual Deterioration	1,837 RC pipe	3-11	50.0
Pennsylvania	Avg. Annual Deterioration	10,439 culv.	20-29	40
Mississippi	Qualitative Field Perf.	442 pipes	5-41	NA
Utah	Regression	14 pipes	NA	30-40
Ohio (ODOT)	Regression	545 pipes	1-45	Varies
Ohio (ODOT)	Regression	64 pipes	14-56	Varies
Ohio (ODOT)	Regression	198 pipes	5-57	Varies
Ohio (OSU)	Regression	521 pipes	1-45	86 (avg)
Ohio (OSU)	Regression	198 pipes	5-57	NA

TABLE 2. Enabling and triggering events considered for analysis of culvert

STATE	TIME OF SURVEY	VARIABLES RELATED TO ENABLING EVENT	VARIABLES RELATED TO TRIGGERING EVENT
Georgia	1928	*Fill height *Poor quality control of concrete mat'l *Joint failure of rigid sectional culverts *Poor alignment *Poor maintenance	*Wet/dry cond. *Scour cond.
W. Virginia	1932	*Type of fill *Trenching method	*Acidity *Flow of water
Pennsylvania	1947	NA	*Flow of water *Wooded area
Mississippi	1964	*Alignment offset *Faulty joints	*Clay flow upward and outward *Acidity
Utah	1974	NA	*Acidity *Soluble salt *Electric Resistivity
Ohio (ODOT)	1972, 1984, 1988	NA	*Acidity *Sediment depth *Presence of sediment *Flow depth *Flow velocity
Ohio (OSU)	1986, 1988	NA	*Flow depth *Flow velocity *Acidity *Sediment depth *Presence of sediment

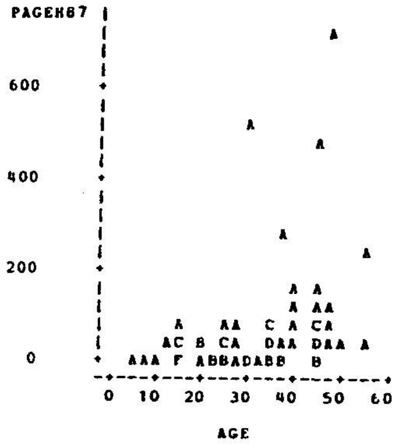

Fig. 3. Actual Age vs. Predicted age

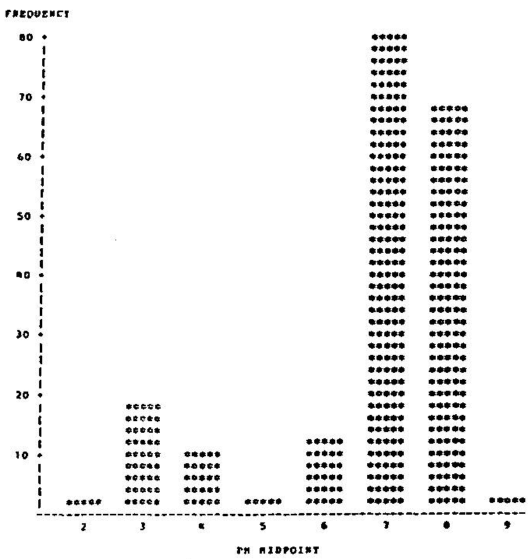

Figure 1. Binodal sample distr.

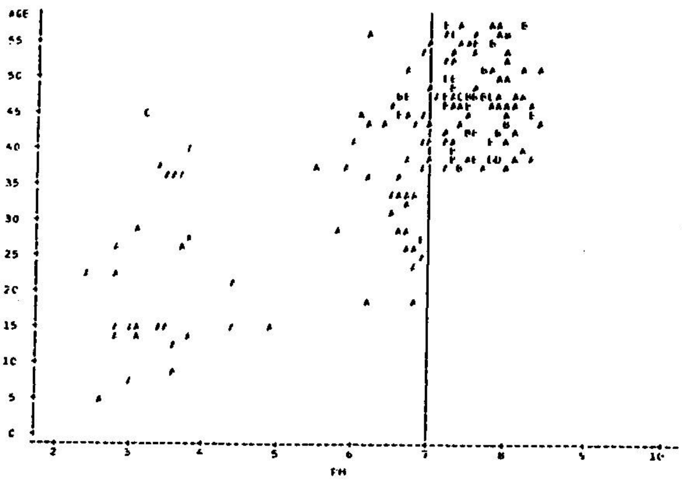

Fig. 2 . Boxing effect of sample data

predicted age (obtained using the prediction equation) and the actual age of the culverts [3]. Note that about 30% of the predicted ages are more than the oldest culverts in the sample. In the figure, the correct term of "predicted age" is used instead of the "predicted service life" of the culverts. Such an equation could erroneously predict up to nearly 3,500 years of concrete culvert service life.

4. CONCLUSIONS

The inadequacies of data and information concerning the culverts, in addition to the often conceptual problems involving the methods of treating the data, have resulted in the large variability of the predicted "service life" of the culverts. With the emergence of computers, culvert experts began to capitalize the use of regression techniques. However, the author feels that the results of recently applied regression techniques are not conclusive, if not unreliable. Problems had occurred in relation to the culvert data and the concept employed for analyzing the data. Several culvert data sample sets used for regresssion analyses are inadequate and not representative of culverts of a particular environment. Furthermore, these sample sets often represent culverts still in service while regression analyses were employed to generate prediction equations for determining the expiration of culverts' life.

The author of this paper feels that much has to be done if one expects reliable yet accurate results using regression techniques. Specifically, adequate amount of expired culvert samples from the same environmental conditions are required. Also, samples manufactured and installed in a relatively similar period of time (small range of age) are preferred. In addition, experimental accelerated testing of culverts installed in certain environmental conditions should also be considered.

5. REFERENCES

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