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ScienceDirect

Procedia Engineering 189 (2017) 598 – 604

Procedia Engineering

www.elsevier.com/locate/procedia

Transportation Geotechnics and Geoecology, TGG 2017, 17-19 May 2017, Saint Petersburg, Russia

Forecast for Terms of Culvert Inspection and Repair

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Abstract

Culverts which were built in different years, by different organizations and of different types of materials are one of the most important elements of railways and highways. The culverts work jointly with the foundation and roadbed grounds, thus degeneration processes in pipes and culverts has a direct influence on the safety and reliability of the transport object they belong to.

Consequently, importance of the technical condition estimation and forecast increases. The repair of the underground objects requires significant financial expenses that can be avoided by proper forecast for terms of culver repair.

The method of the forecast for terms of railway and highway culverts inspection and repair based on fuzzy logic is presented in this paper. The degradation rate that depends on the culvert age and technical condition is obtained as a result.

The considered approach allows planning the terms of culverts inspection and repairing reasonably, that significantly increases the safety of the transportation objects and decreases the maintenance expenses.

Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology

Keywords: forecast for condition; fuzzy logic; degradation rate; roadbed; foundation grounds

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Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology
doi:10.1016/j.proeng.2017.05.095

1. Introduction

The pipes and culverts are very important components of the railway and highway system. They let the water through the roadbed and preserve it from the erosion. The failure of such construction may lead to the interruption of the functioning of the significant part of the road. This will cause serious financial expenses because the disorder in the water offtake leads to the traffic suspension or speed limit may be required till the end of the repair.

The federal highways of a common use total length in Russian Federation is estimated by the Federal road Agency “Rosavtodor” as 1,396 million km. The total length of the railway lines is 87 thousand km. Normally, there are one or two culverts per kilometer of the road. The culverts inspection is an expensive and resource-intensive process. At the same time, any defects or deformations which appear in culverts have strong influence on the safety and reliability of the transportation object the culverts belong to.

The forecast for the culvert condition allows defining the terms of the inspection and repairing correctly. That will help to increase the intervals between the inspections, and rationally distribute the resources and thus to decrease the maintenance expenses.

2. The method of the culvert condition scoring.

The culvert condition estimation usually consists of two steps. On the first step the culvert is inspected by methods of the direct observation (visual, video) and methods of nondestructive monitoring (radar, sonar, ultrasound, acoustic emission), telediagnostics. On the second step the observation result data is converted to the culvert condition scores.

The culvert condition estimation is based on the “Instruction for the railway structures condition and maintenance estimation in Russian Federation” [1]. According to this document the culvert condition and maintenance estimation is performed by the system of the scores.

The main point of the culvert condition scores method is to assign a score to every observed defect with respect to the defect gradation system. After that all the scores are summed and culvert condition can be estimated.

Defect categories, basic scores (BS) and risk coefficients depend on the defect characteristics [1, 2]. The reduced culvert condition score is computed by formula [1]:

$$K_{BS}^{*} = K_{BS}^{*1} - (N_I \alpha_I + N_{II} \alpha_{II}) \quad (1)$$

where K_{BS}^{*1} - culvert base score [1];
α_I , α_{II} - risk coefficients of the I and II category;
N_I , N_{II} - the number of the observed defects of the I and II category ;
There are following quality indication for the reduced condition scores of every culvert:

- «excellent» for 4.5 - 5.0;
- «good» for 3.5 - 4.5;
- «fair» for 2.5 - 3.5;
- «poor» for 2.5.

However, if there are no defects on the culvert “poor” score is not a reason to impose special limits on the road.

3. Determination of the culvert degradation speed using a fuzzy logic.

In actual practice using of the condition score methods is rather imprecise and subjective because it significantly depends on the opinion of the monitoring specialist. Moreover, condition score methods does not allow to estimate the correlation between the culvert condition and its age which is necessary for making a reasonable decision about the terms of the repair or next monitoring.

According to the studies in this area [4…11] the most objective results for the current engineering structures condition estimation which was done by the results of the different observations and also for the terms forecast can be obtained by using the fuzzy logic, based on the conception of fuzzy sets. Fuzzy set is an object with the membership function that changes on the whole interval from 0 to 1, not only 0 or 1.

In comparison to classic logic in the fuzzy one instead of "true" and "false" values the grade that can get any value from 0 to 1 is used. Thus the quality estimation of the process in grade form can be obtained based on the set of parameters that are measured with low precision. In the regulations [1] the scores are presented as ranges that are convenient to work with in terms of fuzzy logic. It is possible to perform using MATLAB.

Data which is obtained by visual or nondestructive monitoring and the age of the culvert are used as an input data. All data is presented as fuzzy ranges. The ages of culvert ranges are presented in Table1 [3].

Table 1. Culvert age ranges.

Age	q1	q2	q3
New	0	0	20
Young	0	20	40
Medium	20	40	70
Old	40	70	100
Very old	70	100	100

In MATLAB these ranges will look as follows (fig. 1):

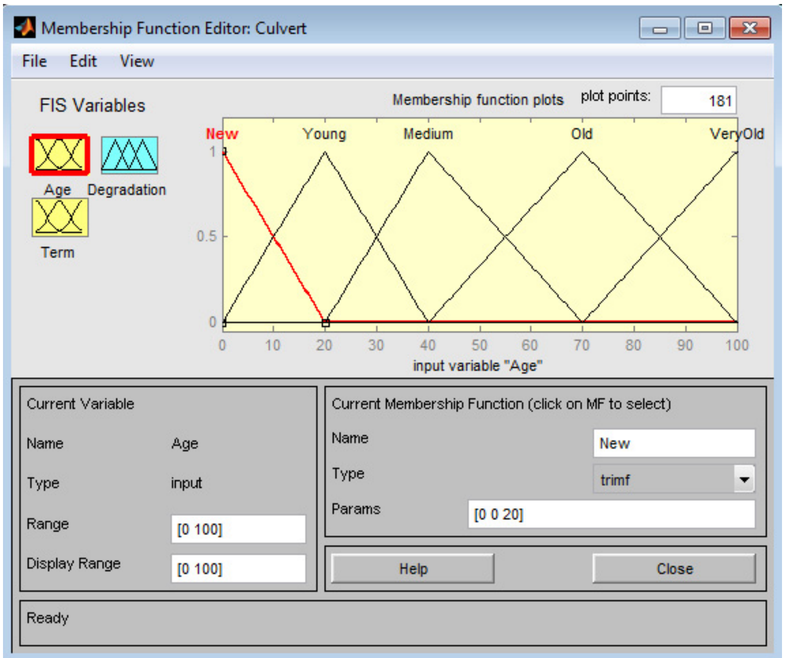

Fig. 1. Culvert age ranges.

Culvert condition converted to scores can be presented in the same way (fig.2):

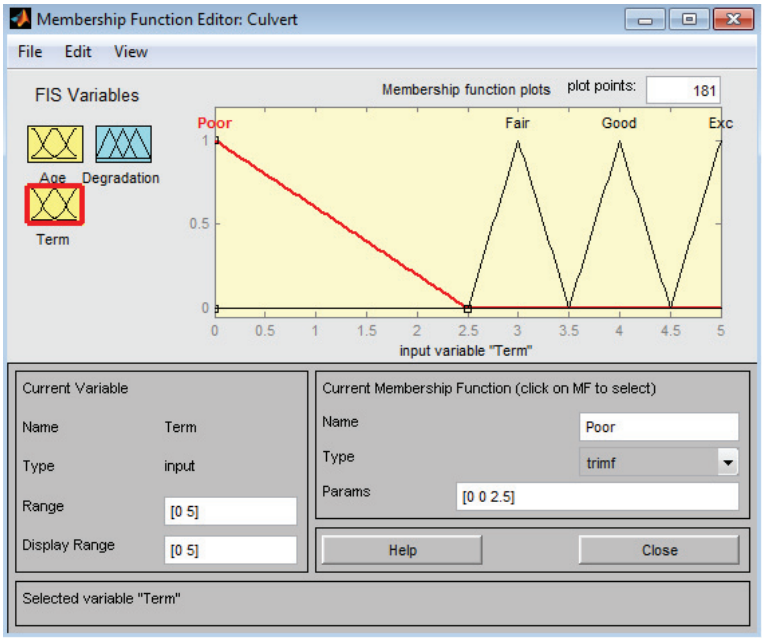

Fig. 2. Culvert condition scores range.

The culvert degradation speed which depends on the age and technical condition is obtained as a result.

The culvert condition scores are presented as a range from 0 to 5 with 4 quality indications. For the calculation the critical values are taken. Then the degradation speed can be presented as follows (fig.3):

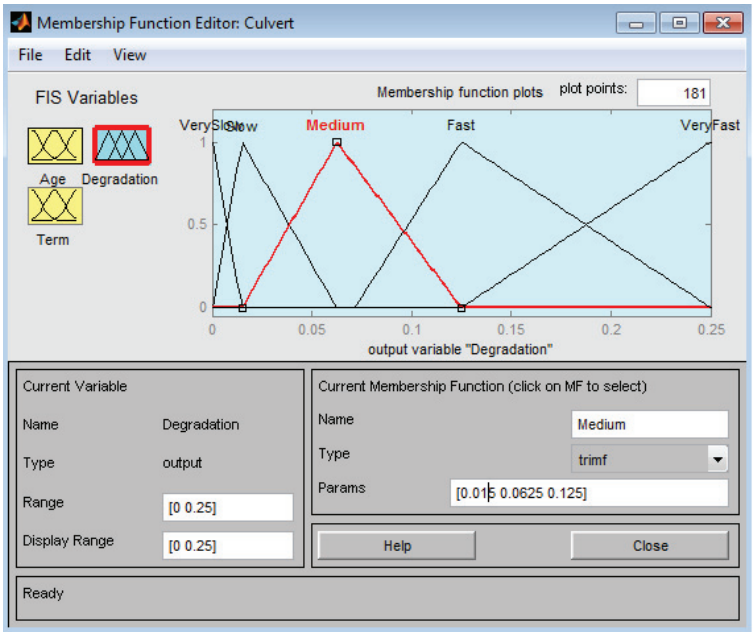

Fig. 3. Culvert degradation speed ranges.

The final relation between the culvert degradation speed, its age and technical condition is presented as a surface (fig.4) and formed by the rules based on the culvert monitoring data.

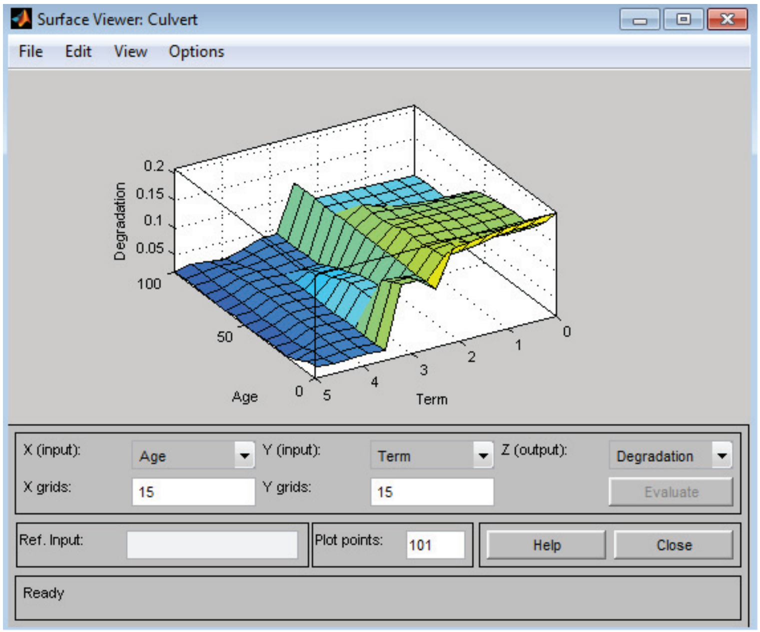

Fig. 4. Final relation between the culvert degradation speed, its age and technical condition.

The mathematical model is verified by the former monitoring results. After the verification the model can be used for the forecast for the culvert condition and assigning the terms of the next inspection and repair.

4. Numerical example

The inspection data of the culverts on the Federal Highways M7 “Volga” (Moscow-Ufa 1350 км) was used in the research. The degradation speeds of 11 culverts of different ages and different conditions were calculated using developed mathematical model. In this paper the calculations for one of the culverts is presented as a numerical example. The inspection of the culvert was performed 35 years after it was built. It`s necessary to determine the time of the next inspection.

The list of culvert defects is presented in Table 2.

Table 2. List of the culvert defects

Category	#	Description of defect	Note
I	2	Waterbed siltation. The culvert openings are closed by mud, waste, ice for 20% without backwater.	-
II	1	Destructed chute on 5-10 m.	-
	3	The culvert openings are closed by mud, waste, ice from 20% to 50 %	-
	9	Masonry weakening with the fall of separate stones.	-
	10	Seams between the culvert elements are opend for 2-5 cm without getting the ground inside.	-

The maximum observed category for this culvert is II, therefore $K_{BS}^{*1} = 3.5$ [1].

Number of the I category defects is 1, number of the II category defects is 4. Reduced culvert condition score is:

$$K_{BS}^{*} = K_{BS}^{*1} - (N_I \alpha_I + N_{II} \alpha_{II}) = 3.5 - (1 \cdot 0{,}05 + 4 \cdot 0{,}20) = 2{,}65 \quad (2)$$

Determine the degradation speed using the developed mathematical model.

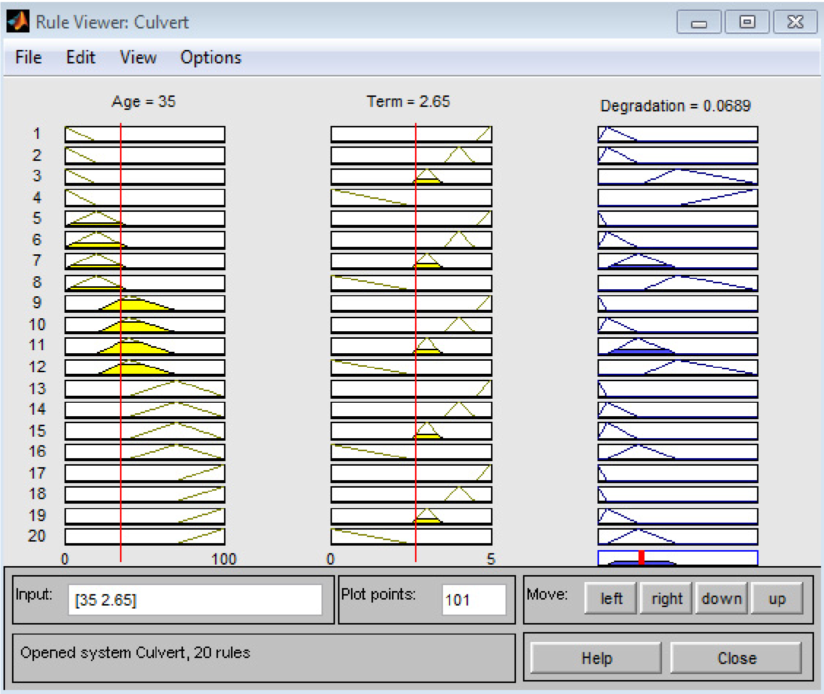

Fig. 5. Determining of the degradation speed.

As a result the degradation speed (fig. 5):

$$V_{деgр.} = 0{,}0689 .$$

Determine the age when the culvert condition becomes poor:

$$T = \frac{K_{BS}^{0} - K_{BS}^{poor}}{V_{\deg}} , \quad (3)$$

where

$K_{BS}^{0} = 5$ - basic score when the culvert was set up;

$K_{BS}^{poor} = 2.5$ - score at the moment when the culvert condition becomes poor.

Then:

$$T = \frac{5 - 2{,}5}{0{,}0689} = 36.3$$

$$T^{*} = T - T_{age} = 36.3 - 35 = 1.3 years ,$$

where T_{age} - the age of culvert

Thus the culvert has to be repaired in 1 year and 4 month.

5. Conclusions

The developed mathematical model allows solving the following engineering problems:

- to obtain the relation between the culvert degradation speed, its age and technical condition;
- to forecast the possibility culvert failure;
- using the obtained relation to assign a reasonable date for the next inspection;
- using the obtained relation to decide about the necessity of the culvert repair or renovation;
- to forecast the culvert condition after the repair and the probability of decreasing of its technical characteristics depending on the age and environment;
- data that is collected from significant number of culverts, obtained and analyzed by fuzzy logic methods can be used for codes development.

Acknowledgements

The authors gratefully acknowledge the support of Emperor Nicolas II Moscow State of Railway Engineering and Emperor Alexander I St. Petersburg State Transport University.

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