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Reliability of a Concrete Railway Bridge

Fiabilité d'un pont-rail en béton

Zuverlässigkeit einer Betoneisenbahnbrücke

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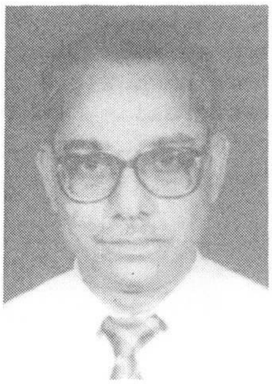

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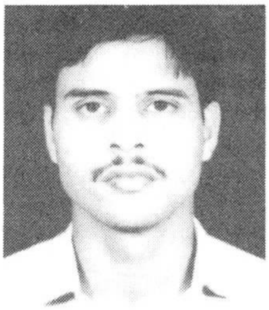

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SUMMARY

The paper deals with the reliability analysis of short span concrete bridge commonly used in Indian railways. Available load spectrum based on actual field data is used for the analysis. Based on the experimental work, values of constants in Paris crack growth equation are fixed. Using Monte Carlo technique, fatigue crack growth reliability is calculated for different desired remaining cycles and initial depth of crack. Even after a crack is detected, it is observed that there is sufficient remaining life for the bridge to serve. Calculated reliability may be useful in development of inspection strategy.

RÉSUMÉ

L'étude traite de la fiabilité des ponts en béton à faible portée, tels que ceux couramment utilisés par les chemins de fer en Inde. Il se base sur des spectres de charges provenant de données d'exploitation réelles. A partir de données expérimentales, les paramètres sont déterminés sur la base de la formule de propagation des fissures d'après Paris. Le calcul de fiabilité prenant en compte la progression des fissures superficielles à la fatigue se fait au moyen de la méthode de simulation de Monte Carlo, cela pour différentes fréquences des cycles de charges désirées ainsi que des longueurs initiales de fissures. De tels calculs de fiabilité peuvent servir à la mise au point de stratégies de contrôles.

ZUSAMMENFASSUNG

Der Beitrag behandelt die Zuverlässigkeitsuntersuchung kurzer Betonbrücken, wie sie bei den Indischen Eisenbahnen häufig anzutreffen sind. Für die Untersuchung stehen Lastspektren aus echten Betriebsdaten zur Verfügung. Anhand experimenteller Daten werden die Parameter in der Risswachstumsformel nach Paris bestimmt. Die Zuverlässigkeit gegenüber Fortschreiten von Ermüdungsrissen wird für verschiedene gewünschte Lastwechsel und Anfangsrisslängen mittels Monte-Carlo-Simulationen berechnet. Selbst nach Sichtbarkeit eines Risses besteht demnach eine ausreichende Restlebensdauer für die Brücke. Solche Zuverlässigkeitsberechnungen können für die Entwicklung von Inspektionsstrategien nützlich sein.

1. INTRODUCTION

Short span reinforced cement concrete (RCC) bridges are common in Indian Railways. Safety of a bridge is to be evaluated against different failure criteria. Significant work has been done in the evaluation of a concrete bridge at the strength limit states viz. limit states of collapse in flexure and shear. Evaluation of reliabilty of a bridge under fatigue is one of the important factor. Though much work has been done on fatigue reliabilty of steel offshore structures and bridges, no significant work is reported in the case of concrete structures especially evaluating fatigue crack growth reliability. Under the action of fluctuating loads, crack initiates, propogates and may cause the final failure. To avoid such failures, it is necessary to know the behaviour of crack propogation in a bridge during lifetime of the structure. Knowledge of crack propogation also, may be useful for preparing maintenance and inspection schedule. In this paper, a method to determine behaviour of a crack in RCC bridge is presented by making use of fracture mechanics. Use of Paris equation is made to determine the depth of a crack at a given time. The empirical constants involved in the Paris equation are established by subjecting RCC test specimens to constant amplitude fatigue load. A typical RCC railway bridge under Indian Railway conditions is taken for present study. Fatigue reliability of the bridge is evaluated.

2. DETAILS OF THE BRIDGE AND LOAD SPECTRUM

Details of a typical short span RCC railway bridge commonly used in Indian Railways are shown in Fig.1. It consists of precast RCC units placed side by side and simply supported at its ends. The span of the bridge is 6.1 m. There are two broad gauge railway tracks. Concrete mix M 20(cube strength 20 N/mm^2) and high yield strength deformed bars(yield strength 415 N/mm^2) are used for tension steel and vertical stirrups.

Detailed traffic survey has been carried out and based on this a load spectrum has been developed [1]. This consists of eleven load categories, first ten for freight traffic and the last one for passenger train loading. The same is used in the present study.

3. DETERMINATION OF CONSTANTS c AND m IN PARIS EQUATION

To establish the empirical constants involved in the Paris crack growth equation[2], six RCC test specimens have been tested under constant amplitude fatigue loading. Size of the specimen used is 150 x 300 x 2300mm. Ordinary portland cement and aggregate with maximum size 12mm, have been used. Beams have been cured for minimum 28 days before testing. Fe 415 grade steel(yield strength 415 N/mm^2) has been used for tension steel and stirrups. Details of tested six specimens are given in Table 1. The beams have been tested after 28 days of curing. Beam is simply supported with 2000mm effective span and loads are applied at 1/3 rd spans. In the beginning of the test each beam has been subjected to monotonically increasing load, till the visible crack develops. Then the beam has been subjected to dynamic loading. In all the cases, the minimum load has been maintained as 18 KN and maximum load has been maintained equal to or less than the load corresponding to the first crack. Constant amplitude fatigue load at frequency 8 hertz has been applied. Beams have been observed physicaly frequently throughout the test. Crack growth has been continuously monitored. Each beam has been subjected to 2 million load cycles.

At the end of the test, a plot of depth of crack and number of cycles is obtained (Fig.2). Exponential best fit is drawn. From the graph a plot of crack growth rate, da/dN, and stress intensity factor range, Δk, is obtained by adopting the procedure given in ASTM standard[2]. Plot of log(da/dN) and

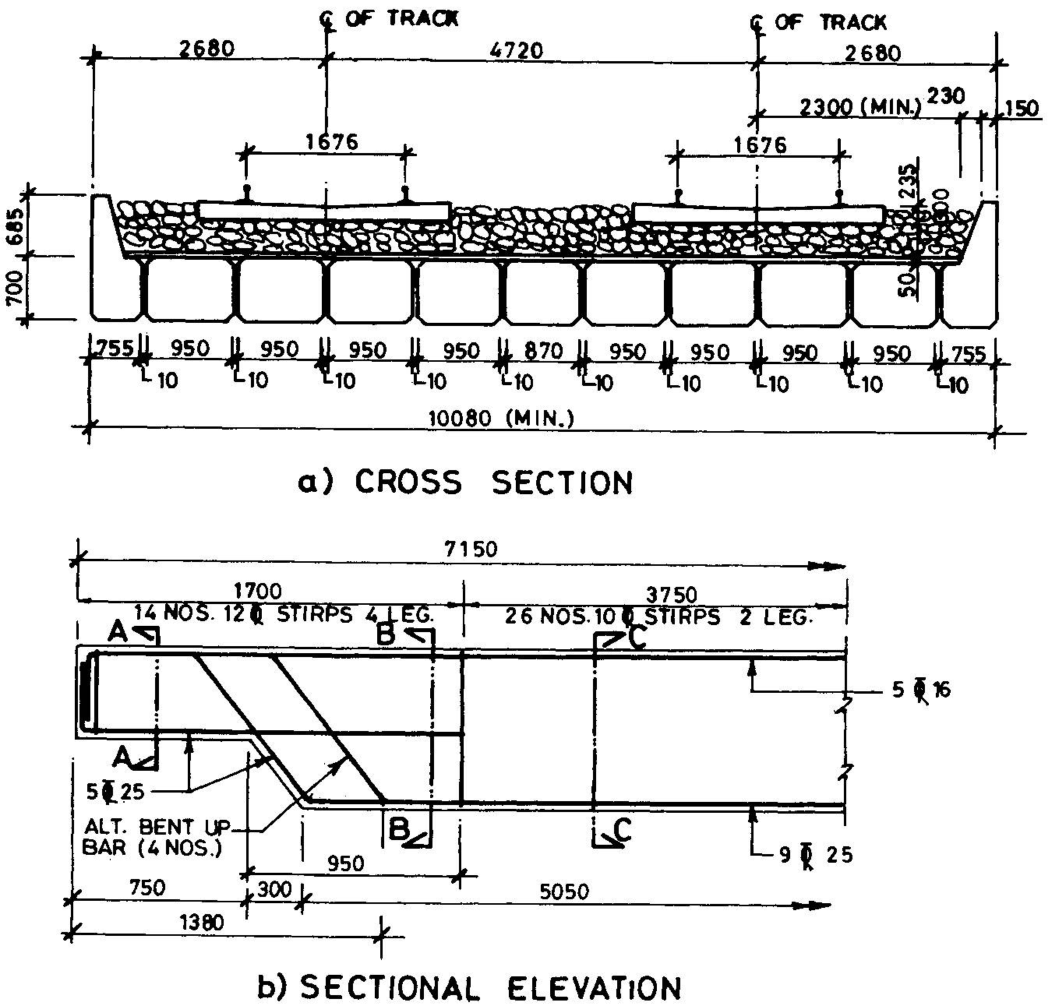

Fig.1 Details of a typical short span RCC railway bridge

$\log(\Delta K)$, shown in Fig.2 is a straight line. Slope and intercept on vertical axis of this line gives values of m and c in Paris equation. For each beam, two curves are studied one on eitheer side of the beam. From the test results, it is observed that the variation in the value of m is negligible and is found to be equal to 2.

Beam No.	28 days Cube Strength (MPa)	Tension Steel (per cent)	Maximum Applied Load (KN)
1	23.200	0.38	33.0
2	23.200	0.38	35.0
3	35.704	0.38	35.0
4	35.704	0.38	35.0
5	36.593	0.74	55.0
6	36.593	0.74	70.0

Table 1 Details of Test Specimens

4. FATIGUE RELIABILITY

If the flaws which exist in the structure are nearly planer, then the crack growth starts from the first load application. From the experimental studies, crack growth rate da/dN is given by the following equation, knwon as Paris crack growth equation [3].

$$\frac{da}{dN} = c(\Delta k)^{m} \qquad \ldots(1)$$

Where, $$\Delta k = k_{max} - k_{min} \qquad \ldots(2)$$

Stress intensity factor K, is expressed as

$$k = F(a)\ S\ \sqrt{\pi/a} \qquad \ldots(3)$$

Where, F(a) is finite geometry correction factor, S is stress range and a is crack depth. For concrete structures, it can be expressed as [4]

$$F(a) = \frac{1}{\sqrt{\pi}}\ \frac{1.99-A(1-A)(2.15-3.93A+2.7A^{2})}{(1+2A)(1-A)^{1.5}} \qquad \ldots(4)$$

where, A = a/d and d is depth of beam. To calculate the number of cycles to failure when crack propogates from initial depth a_i to final depth a_f, Eq.1 is integrated from limit a_i to a_f.

$$N = \int_{a_i}^{a_f} \frac{da}{c(\Delta k)^{m}} \qquad \ldots(5)$$

For available load spectrum the equivalent stress range, S_{re}, is computed by the following equation [5].

$$S_{re} = [\sum_i P_i\ S^{m}_{ri}]^{\frac{1}{m}} \qquad \ldots(6)$$

Where, P_i is the frequency of occurance of the ith stress range, S_{ri}, and n is slope of cyclic crack growth rate curve.

To calculate reliability in fatigue crack growth, Monte Carlo simulation technique is used. From the Paris equation, the number of cycles required to propogate the crack from initial depth a_i to final depth a_f is calculated by making use of Eqs. 3, 4 and 5. Equation 3 is modified as,

$$\Delta k = B_m\ F(a)\ s_{re}\ I_f\ \sqrt{\pi\ /\ a} \qquad \ldots(7)$$

Where, B_m is model uncertainty parameter, S_{re} is equivalent stress range, and I_f is impact factor. Bridge is analysed for the load spectrum consisting eleven load categories as mentioned in Sec.2 and equivalent stress range is obtained as 162.514 MPa, by taking n = 2 in Eq.6. Failure function is written as,

$$Z = N - n \qquad \ldots(8)$$

Where, n is desired number of cycles (say 2 million cycles) and N is number of cycles required to reach the crack from a_i to a_f. While generating number of samples of Z by using Monte Carlo technique, a counter is made when Z < o. Then the reliability is given by,

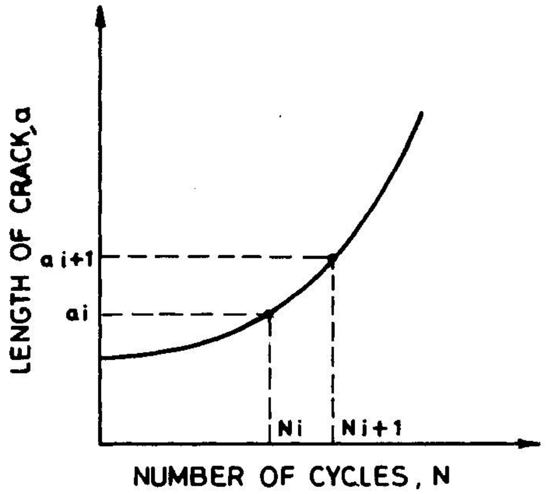

Fig.2 Typical crack growth curve

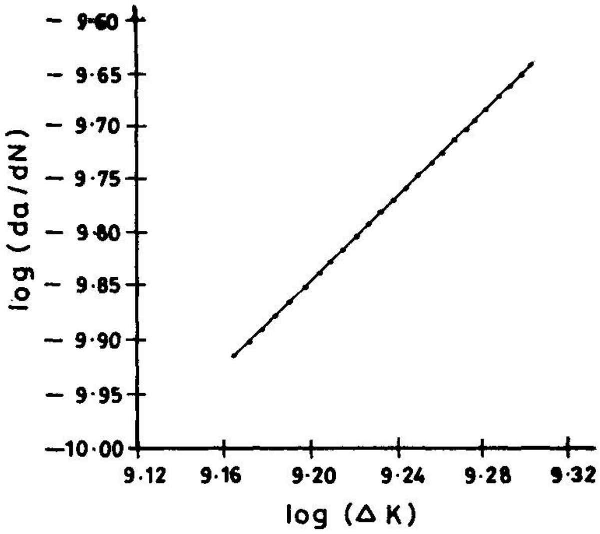

Fig. 3 Typical crack growth rate curve

$$R_e = 1 - p_f = 1 - \frac{n_f}{n_s} \qquad \ldots(9)$$

where, n_f is number of times value $Z < 0$ and n_s is total number of samples generated. Reliability index, β_e is given by

$$\beta = -\Phi^{-1}(p_f) \qquad \ldots(10)$$

Where Φ is cumulative probability of standard normal variable.

From the test results it is observed that the variation in the value of m is negligible and hence it is assumed to be deterministic. From the analysis of the bridge for eleven load categories it is found that equivalent stress range is approximately equal to 70.0 per cent of the permissible stress in steel. Corresponding to this stress range the mean value of c, from test results, is obtained as 0.442×10^{-12} with coefficient of variation 75 per cent for present case. Statistics of variables used in fatigue reliability analysis are given in Table 2. Using the same and the method explained earlier, fatigue crack growth reliability is calculated for various values of a_i and N. The results are shown in Table 3.

5. CONCLUSION

An attempt has been made to evaluate fatigue crack growth reliability of a concrete bridge used in Indian railways. Within the limitations of the experimental programme, it is observed that (i) value of m in Paris equation is 2 and statistical variation in m is negligible and (ii) lower values of c in Paris equation are obtained for higher values of initial depth of crack, percentage of steel and magnitude of loads. Parameter c is subjected to considerable statistical variation and is observed to be 75 per cent for applied stress range equal to 60 per cent of permissible stress in steel. It is observed also that experimental and theoretical results by making use of Paris crack growth equation are in good agreement. From Table 3 it is noted that fatigue relibility is sensitive to initial depth of crack and it is observed that fatigue crack growth reliability index β is equal to 2.32 corresponding to

Variable	Mean	Coefficient of Variation in Percentage	Distribution
Initial depth	25.0,50.0,100.0, 150.0 mm	15.0	Truncared lognormal
Final depth	525.0 mm	15.0	Truncated lognormal
c	0.442×10^{-12}	75.0	Lognormal
Equivalent stress range	162.514 MPa	15.0	Type 1 extremal (largest)
Model parameter	1.01	20.0	Lognormal
Impact factor	1.70	20.0	Lognormal

Table 2 Statistics of variables for fatigue reliability analysis

the desired remaining life of 2 million cycles with initial depth of crack equal to 25 mm. This means that there is sufficient capacity(remaining life) for the bridge to serve even after a crack is detected and there is sufficient time available to carry out repair work. Calculated fatigue crack growth relibility may be useful for developement of inspection strategy.

Initial depth of crack (mm)	Values of β (corresponding p_f) for			
	$N = 2.0\times10^6$	$N = 1.5\times10^6$	$N = 1.0\times10^6$	$N = 0.5\times10^6$
25.0	2.32(0.0102)	2.50(0.0062)	2.82(0.0024)	3.37(0.0004)
50.0	2.16(0.0156)	2.35(0.0094)	2.64(0.0041)	3.19(0.0007)
100.0	1.67(0.0048)	1.89(0.0029)	2.22(0.0013)	2.75(0.0029)
150.0	0.53(0.2960)	0.53(0.2223)	1.27(0.1025)	1.88(0.0299)

Table 3 Results of fatigue reliability analysis

REFERENCES

1. Ravi,G,Fatigue Reliability Analysis and Design Approach to Railway Rivetted Steel Bridges, Ph.d Thesis Report, Civil Engineering Department, I.I.T., Bombay, July, 1993.
2. ASTM Committee E-24, Standard Test Methods for Measurement of Fatigue Crack Growth Rate, ASTM Standard, E-647, V03.01, pp.646-666.
3. The Committee on Fatigue and Fracture reliability, Fatigue Reliability: Introduction, Journal of Struct. Engg. ASCE, 108 (1), Jan.1982, pp. 3-24.
4. Jenq., Y., and Shah, S.P., Two parameter Fracture Model for Concrete, Journal of Engineering Mechanics, III (10), October 1985, pp. 1227-1241.
5. Schilling, C.G., Stress Cycle for fatigue Design of Steel Bridges, Journal of Struct. Engg. Div., ASCE, 110 (6), June, 1984, pp.1222-1234.