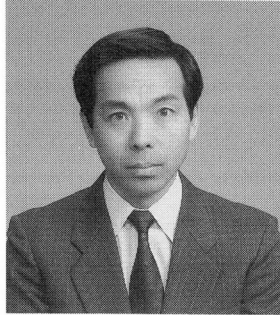


**FLEXURAL FATIGUE CURVE FOR CONCRETE PAVEMENT SLAB DESIGN
IN CONSIDERATION OF PROBABILISTIC PROPERTIES**

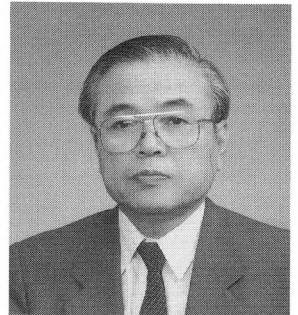
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SYNOPSIS

The purposes of this study are to clarify the effect of the static flexural strength of pavement concrete on the flexural fatigue curve and to determine the flexural fatigue design curve to take the reliability of concrete pavement into account. As a result of the statistical analysis of the fatigue tests, it was found that there is almost no effect of the static strength on the flexural fatigue curve for concrete pavement design. By means of the present simulation which took account of the scatter of the fatigue strength, the relationship between the failure probability of the flexural fatigue curve and the reliability of concrete pavement was obtained.

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1. INTRODUCTION

The authors have previously reported on experiments conducted on the stress ratio (minimum stress/maximum stress) for flexural fatigue strength of pavement concrete and the influence of the maximum size of coarse aggregate[1]. This paper further reports on the results of experiments conducted on the influence of the difference in static flexural strength of pavement concrete and on the results of examinations concerning the design flexural fatigue curve of pavement concrete considering the probabilistic properties of flexural fatigue failure as a summarization of this study.

In Japan, 45kgf/cm^2 is considered as the standard for the design flexural strength of pavement concrete, while the use of 40 kgf/cm^2 is permitted in part[2]. However, ready-mixed concrete actually produced as pavement concrete, according to Reference[3], is in the range of compressive strength distribution of 150 to 300kgf/cm^2 , and when this is converted to flexural strength, the range is around 30 to 60kgf/cm^2 . The experiments previously reported were conducted taking into account that the design flexural strength of 45kgf/cm^2 (target strength 52kgf/cm^2). Hence, it is necessary to examine the fatigue characteristics of the concrete having static flexural strength in an even wider range. Therefore, in the experiments reported here, fatigue tests were performed on concrete with target strength of 40 and 60kgf/cm^2 .

In the mechanical design method for concrete pavement, the flexural fatigue curve has a great influence when analyzing the fatigue life of the pavement. Therefore, in order to design rationally concrete pavements, it is necessary to determine the design flexural fatigue curve considering the probabilistic properties of the fatigue phenomenon of concrete. In this study, in view of such a situation, the probabilistic properties of flexural fatigue failure are obtained from test results. And, applying a Monte Carlo simulation technique to them, an analysis is made of the influence of scatter in the fatigue phenomenon of concrete on the service life of concrete pavements, and an investigation is made on the flexural fatigue curve used when designing concrete pavements.

2. FLEXURAL FATIGUE TEST

2.1 Materials and mix proportions

The cement used in the tests was ordinary Portland cement. As aggregates, pit sand from Yuri-gun, and crushed stone from Senboku-gun, Akita Prefecture, were used. The Maximum size of coarse aggregate was 20mm.

The concrete used in the tests, similarly to the previous experiments[1], were mixed to have slump of 8.0cm and air content of 4.0%, and aimed for flexural strength as 28-day age of 40 and 60 kgf/cm^2 . The mix proportions are given in Table 1. An air-entraining and water-reducing agent was used as an admixture.

Table 1 Mix Proportion of Concrete

Target Strength kgf/cm ²	Slump cm	Air Content %	Water Cement Ratio %	Sand Per- cent %	Unit Weight (kgf/m ³)				
					Water	Cement	Fine Aggregate	Coarse Aggregate	Admix- ture
40	8.0 ± 1.5	4 ± 0.5	60	35	150	250	652	1273	0.63
60	8.0 ± 1.5	4 ± 0.5	35	32	140	400	566	1264	1.00

Mixing was performed using a 50-liter forced action mixer and 3 specimens for static strength tests and 6 specimens for fatigue strength tests were made from each batch. The specimens, with dimensions of 15x15x53cm, were cured in a constant-temperature water tank of water temperature 20°C until loading tests. Fatigue tests were begun after 2-month age in consideration of stability of specimen strength.

2.2 Test method

The test method was third point loading of span 45cm for both static strength tests and fatigue strength tests.

The static flexural strength for the individual batches are given in Table 2. In case of target strength of 40kgf/cm², the average flexural strength and standard deviation for all specimens were 43.9kgf/cm² and 2.88kgf/cm², respectively, while in case of target strength of 60kgf/cm², they were 63.1kgf/cm² and 4.25kgf/cm².

According to other experiments conducted by the authors[4], the flexural strength of concrete is sensitively influenced by changes of moisture condition in the specimen. Therefore, in order to stabilize the moisture conditions of the specimens, grease was coated on the specimens, and further, the specimens were covered with thin membranes of vinyl plastic, similarly to the previous experiments.

The stress waveform of fatigue tests were taken to be sinusoidal curve variations of frequency 5Hz. The ratio of the maximum stress(σ_{max}) of this cyclic stress to static strength(σ_b) is defined as stress level ($S = \sigma_{max}/\sigma_b$). The stress levels in the fatigue tests of this study were of the four stages of 0.90, 0.85, 0.80, and 0.70. The numbers of specimens for each stress levels were as given in Table 3.

The minimum stress of the cyclic stress waveform was taken to be 2.5kgf/cm². In view of the results of the previous study[1], in case of failure of a specimen not occurring as 2,000,000 cycles in these tests, the tests were run out.

2.3 Test results

Table 4 gives the fatigue test results for the cases of target strength of 40kgf/cm² and 60kgf/cm². The arrows in the table indicate run out specimens as 2,000,000 cycles.

Table 2 Results of Flexural Strength Test

Target Strength kgf/cm ²	Batch No.	Flexural Strength			Mean kgf/cm ²
		kgf/cm ²			
40	1	44.8	46.9	45.0	46
	2	42.9	45.5	49.0	46
	3	45.8	37.4	45.4	43
	4	44.1	43.5	39.8	42
	5	45.5	45.1	43.9	45
	6	40.5	41.7	41.0	41
	7	46.1	44.9	44.1	45
	8	39.6	47.5	43.6	44
60	1	70.0	63.6	69.0	68
	2	59.4	65.3	58.8	61
	3	66.6	64.0	63.1	65
	4	71.2	69.2	65.1	69
	5	65.8	61.2	62.3	63
	6	59.4	58.7	55.3	58
	7	64.7	63.1	65.2	64
	8	57.5	58.4	57.8	58

Table 3 Number of Specimens

Target Strength kgf/cm ²	Stress Level	Number of Specimens
40	0.90	1 2
	0.85	1 2
	0.80	1 2
	0.70	1 2
60	0.90	1 2
	0.85	1 2
	0.80	1 2
	0.70	1 2

3. INFLUENCE OF STATIC STRENGTH ON FLEXURAL FATIGUE STRENGTH

The fatigue failure characteristics of concrete of different static strength were examined for each stress level supplementing the results in case of target strength of 52kgf/cm² in the previous tests to the results of fatigue tests for the two kinds of target strength.

As can be seen in Table 4, the results of fatigue tests show a fair amount of scatter. Therefore, this scatter must be considered when examining the influence of difference of target strength.

In this study, the fatigue test results for each stress level with specimens of the respective target strength were considered as one sample, and testing of the statistical hypothesis was done regarding the mean values and dispersions of the populations which the respective samples belonging to. In testing of mean value, the hypothesis set up was that "the mean values of two distributions are equal," and in testing of dispersion, the hypothesis set up was that "the dispersions of two distributions are equal." And, the t-test was used for mean value and the F-test for dispersion in testing of the hypothesis.

The stress levels at which testing was done were the two stages of $S = 0.90$ and $S = 0.80$, and investigation were made individually regarding the fatigue test results of the cases of target strength 40 and 60kgf/cm², 60 and 52kgf/cm², and 40 and 52kgf/cm² for the respective stress levels. As a result, the hypothesis were affirmed with their levels of significance 5% for both mean value and dispersion in either case, and it was ascertained that in a zone where the stress level is high, the relationship of stress level and number of cycles to flexural fatigue failure is the same even though static strength differ.

On the other hand, at stress level $S = 0.70$, on comparing the ratios of specimens which had been run out, whereas in case of target strength of 40kgf/cm² they were 3 out of 12 specimens(25%), there were 11 out of 18(61%) in case of 52kgf/cm², and 8 out of 12(67%) in case of 60kgf/cm². The ratio of specimens run out increased as target strength increased. In effect, it may be seen that there is a trend for fatigue strength to be increased with increase in static strength.

Table 4 Results of Fatigue Test

Target Strength kgf/cm ²	Stress Level			
	0.90	0.85	0.80	0.70
40	1947	979	722515	773439
	663	1665	6671	1423374
	22886	4837	10767	847262
	6359	1372	740	1714121
	17219	1759	4204	2000000→
	1805	4193	10224	109410
	4297	3257	23439	2000000→
	471	1647	38699	1100128
	4801	6666	44809	897491
	1307	45970	32077	67943
60	49020	989	50999	1245830
	10423	5455	25838	2000000→
	670	3997	5729	2000000→
	1957	1093	76584	2000000→
	733	652	49526	937874
	14197	1966	160099	1532671
	3245	2511	66784	2000000→
	952	8897	65603	452906
	14214	1346	3124	2000000→
	22269	13668	75169	622111
	150	4897	10473	2000000→
	319	11345	36637	2000000→
	1081	34699	2000000→	2000000→
	3849	4367	2000000→	2000000→

4. PROBABILISTIC PROPERTIES OF FLEXURAL FATIGUE OF CONCRETE

As described above, the influence of static strength on flexural fatigue life is seen somewhat in the data for stress level $S = 0.70$, but in the zone of $S = 0.80$ and higher, which has an especially great influence on fatigue analysis in the design of concrete pavements, the influence of static strength may be ignored. Therefore, all data for target strength of 40, 52, and 60kgf/cm² were used and the flexural fatigue curve was newly prepared.

Fatigue failures are scattered over broad ranges for the individual stress levels in fatigue tests (Table 4). This scatter can be considered to be a specific property of the fatigue phenomenon, and a statistical study is required in preparation of a fatigue curve. That is, the probability distribution function for each stress level must be determined considering the test results of each stress level as a single population.

The failure probability of specimens belonging to the individual populations, according to the method of ordered statistics, is given by the following equation:

$$P_{fi} = \frac{i}{n + 1} \quad \dots(1)$$

where, P_{fi} : failure probability of i -th specimen in case of fatigue lives at each stress level arrayed in order of cycles to failure
 n : number of specimens at each stress level

When the run out specimens are included, the failure probability is given by the following equation[5]:

$$P_{fi} = \frac{i}{n + 2} \quad \dots(2)$$

The n in Eq.(2) includes the number of run out specimens.

On calculation of failure probability of each stress level using Eqs.(1) and (2), the results will be as given in Table 5. When these results are plotted on a log-normal probability paper, it will be as shown in Fig.1, the data for the individual stress levels being arrayed on roughly a straight line. Consequently, the data for the individual stress levels were shown to respectively belong to a population of log-normal distribution. This was confirmed by the method of Kolmogorov-Smirnov of significance level of 5 %.

Table 6 gives the parameters λ and ζ of log-normal distributions at the individual stress levels indicated by natural logarithm values. From this, it is possible to determine the number of cycles N to fatigue failure for a certain failure probability P_f . Further, as is clear from Table 6, there is a tendency seen for scatter of data to become greater as the stress level becomes lower, and the maximum was at $S = 0.80$.

Since the probability distribution function of flexural fatigue at the individual stress levels have been made clear by the above, it is possible to determine the fatigue curve for a certain failure probability P_f which is the relationship of the stress level S and number of cycles N to fatigue failure. The fatigue curves for failure probabilities $P_f = 10$ to 90% are shown in Fig. 2. In general, a fatigue curve is expressed in the form of Eq.(3), with a and b being coefficients determined from experiments.

$$S = b - a \times \log(N) \quad \dots(3)$$

where, S : stress level

N : number of cycles to failure

Of the fatigue curves shown for each failure probability in Fig. 2, a and b for

Table 5 Probability of Failure of Specimens

i	S=0.90		S=0.85		S=0.80		S=0.70	
	C. F.	P _f	C. F.	P _f	C. F.	P _f	C. F.	P _f
1	150	0.021	315	0.027	740	0.020	2.3E4	0.022
2	264	0.043	451	0.054	1547	0.039	6.8E4	0.046
3	319	0.064	652	0.081	3124	0.059	1.1E5	0.068
4	471	0.085	811	0.108	3685	0.078	1.1E5	0.090
5	498	0.106	979	0.135	4204	0.098	2.1E5	0.114
6	591	0.128	989	0.162	5729	0.118	3.4E5	0.136
7	663	0.149	1093	0.189	5980	0.137	4.5E5	0.159
8	670	0.170	1274	0.216	6671	0.157	5.9E5	0.182
9	733	0.192	1346	0.243	7582	0.177	6.2E5	0.205
10	952	0.213	1372	0.270	9525	0.196	7.7E5	0.227
11	952	0.234	1647	0.297	1.0E4	0.216	8.5E5	0.250
12	1081	0.255	1665	0.324	1.0E4	0.235	9.0E5	0.273
13	1307	0.277	1759	0.351	1.0E4	0.254	9.4E5	0.296
14	1444	0.298	1966	0.378	1.1E4	0.275	1.1E6	0.318
15	1767	0.319	2511	0.405	1.6E4	0.294	1.2E6	0.341
16	1805	0.340	3060	0.432	2.3E4	0.313	1.4E6	0.364
17	1947	0.362	3257	0.460	2.3E4	0.333	1.5E6	0.386
18	1957	0.383	3640	0.487	2.6E4	0.353	1.7E6	0.409
19	2283	0.404	3997	0.514	3.2E4	0.373	2.1E6	0.432
20	2834	0.426	4193	0.541	3.2E4	0.392	2.6E6	0.455
21	2845	0.447	4367	0.568	3.2E4	0.412	2.0E6→	
22	3245	0.468	4837	0.595	3.7E4	0.431	2.0E6→	
23	3849	0.489	4897	0.622	3.9E4	0.451	2.0E6→	
24	3907	0.511	5455	0.649	4.2E4	0.471	2.0E6→	
25	4147	0.532	6232	0.676	4.5E4	0.490	2.0E6→	
26	4297	0.553	6666	0.703	4.6E4	0.510	2.0E6→	
27	4464	0.575	8897	0.730	5.1E4	0.529	2.0E6→	
28	4506	0.596	1.1E4	0.757	5.1E4	0.549	2.0E6→	
29	4801	0.617	1.1E4	0.784	6.6E4	0.569	2.0E6→	
30	5714	0.638	1.4E4	0.811	6.7E4	0.588	2.0E6→	
31	6359	0.660	1.8E4	0.838	7.5E4	0.608	2.0E6→	
32	8900	0.681	3.4E4	0.865	7.7E4	0.628	2.0E6→	
33	1.0E4	0.702	3.5E4	0.895	1.6E5	0.647	2.0E6→	
34	1.4E4	0.723	4.6E4	0.919	2.4E5	0.667	2.0E6→	
35	1.4E4	0.745	6.9E5	0.946	4.2E5	0.686	2.0E6→	
36	1.4E4	0.766	9.6E5	0.973	7.2E5	0.706	2.0E6→	
37	1.7E4	0.787			7.4E5	0.726	2.0E6→	
38	2.1E4	0.809			1.2E6	0.745	5.0E6→	
39	2.2E4	0.830			1.4E6	0.765	5.0E6→	
40	2.3E4	0.851			1.5E6	0.784	5.0E6→	
41	2.3E4	0.872			2.1E6	0.804	5.0E6→	
42	2.5E4	0.894			3.1E6	0.824	5.0E6→	
43	2.7E4	0.915			2.0E6→			
44	3.0E4	0.936			2.0E6→			
45	4.9E4	0.957			2.0E6→			
46	3.0E5	0.979			3.0E6→			
47					3.0E6→			
48					5.0E6→			
49					5.0E6→			

S:Stress Level C.F.:Cycles to Failure
P_f:Probability of Failure

Table 6 Parameters of Log-Normal Distribution for Fatigue Strength

S	λ	ζ
0.90	8.231	1.6972
0.85	8.431	1.9955
0.80	11.401	2.7894
0.70	15.137	2.3832

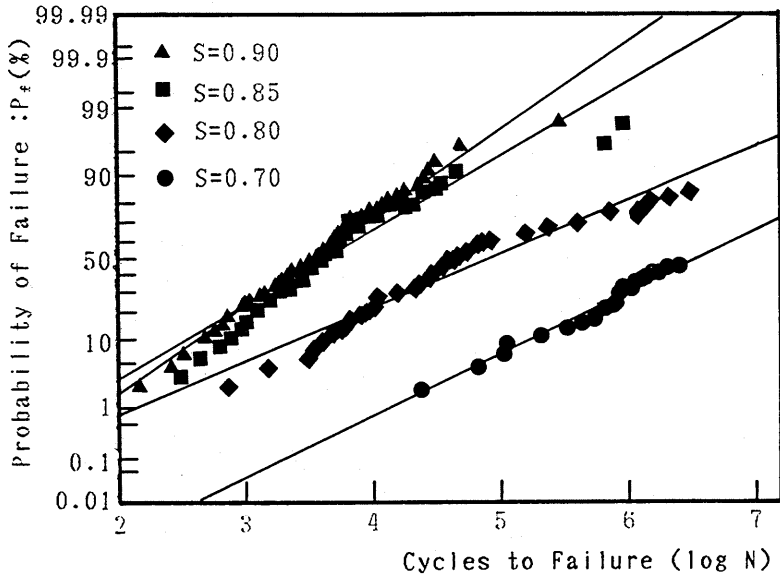


Fig.1 P_f -N Diagram for Stress Level

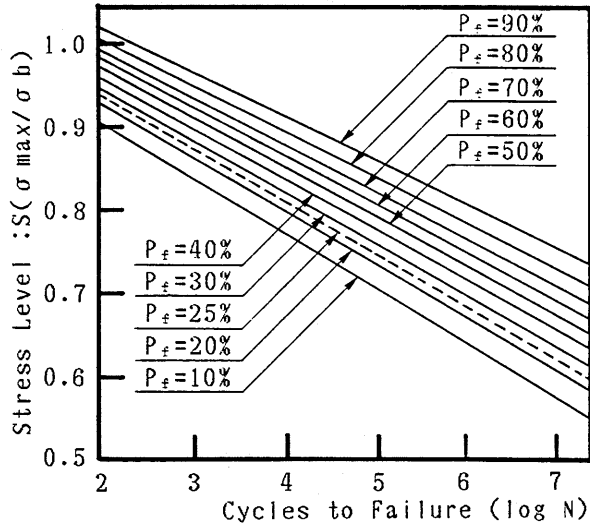


Fig.2 S-N Diagram for P_f

each curve concerning failure probability $P_f = 10$ to 50% are as given in Table 7, where $N \geq 100$.

Further, the authors showed fatigue curves in the previous report[1], and when making a comparison with fatigue curves obtained this time taking the case of $P_f = 50\%$ as an example, the differences in stress levels S for the same number of cycles N are approximately 0.01 to 0.02, and essentially there is no difference between the two.

Table 7 Coefficients of Fatigue Strength Equation

P_f (%)	a	b
10	1.037	0.065
20	1.058	0.063
25	1.066	0.063
30	1.072	0.062
40	1.082	0.061
50	1.091	0.059

5. RELATIONSHIP BETWEEN FAILURE PROBABILITY OF FLEXURAL FATIGUE CURVE AND FATIGUE DAMAGE OF CONCRETE SLAB

In the mechanical design method of concrete pavements, the design flexural fatigue curve is selected in order to give the design results on the conservative side. In case of the design method of the Appendix in the Manual for Design and Construction of Concrete Pavements, the envelope of the experimental values of fatigue failure, namely, the curve for failure probability 0% is selected for the design flexural fatigue curve[2],[6]. But in such a method, the relationship between this failure probability of the flexural fatigue curve and the fatigue damage of a concrete slab is not made distinct, and hence, the reliability of a design result is handled while indistinct quantitatively. Therefore, in this study, the relationship of the failure probability of flexural fatigue curve and the fatigue damage of concrete slabs was examined by Monte Carlo simulation.

The flow chart of the simulation made in this study is given in Fig. 3. For fatigue analysis of the concrete slab to be the basis for this simulation, the design method of the Manual was partially modified and used. With regard to this modified design method, the compatibility with performance of actual pavements has been ascertained in past studies by the authors[7]. The principal modification

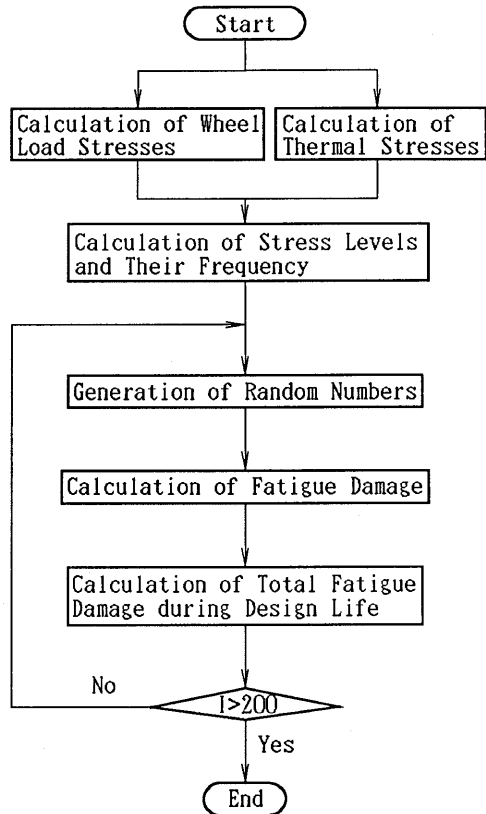


Fig. 3 Flow Chart of Simulation

points are as follows:

- (a) The fatigue characteristics of concrete given as the result of this study are used.
- (b) The transverse joint edge of the concrete slab is made the basis of stress analysis.
- (c) For passing position of wheel loads and its frequency, Table 8 giving the results of survey by the authors[8] is used.
- (d) For distribution of wheel loads, Table 9[9] giving the results of measurements by the Ministry of Construction is used.

Table 8 Transverse Distribution of Wheel Load Placement and Its Relative Frequency[8]

Placement of Wheel Load* (cm)	1 5	4 5	7 5	Over 7 5
Relative Frequency (%)	5 1	4 3	5	1

*Distance from the Center of the Most Frequent Passing Position of Wheel Loads

Table 9 Distribution of Wheel Loads[9]

Traffic Volume Level	M. N. T. V.	M. N. C. V.	Number of Wheel Loads											
			0-1 t	1-2 t	2-3 t	3-4 t	4-5 t	5-6 t	6-7 t	7-8 t	8-9 t	9-10 t	10-12 t	12-14 t
B-traffic	4986	749	8371	810	420	229	119	79	45	27	15	6.7	4.3	0.70
C-traffic	8930	1889	13934	1855	1210	620	335	208	118	59	30	13.0	8.5	1.81
D-traffic	12727	4696	16610	3611	3091	1978	1005	623	378	176	86	36.0	19.0	2.04

M. N. T. V. : Mean Number of Total Vehicles(V/day/direction)

M. N. C. V. : Mean Number of Commercial Vehicles(V/day/direction)

In the simulation, the combined stresses of wheel load stresses and thermal stresses are first obtained, and the stress levels and their frequency are calculated from this combined stresses. Next, random numbers corresponding to the frequency are made to occur. These random numbers were obtained applying the central limiting theory to uniformly random numbers according to the multiplicative congruential method, and were produced according to log-normal distribution having the parameters λ and ζ given in Table 6. The allowable number of cycles to fatigue failure are obtained by the respective random numbers, and by applying Miner's rule to them, the fatigue damage of the concrete slab is calculated. This simulation was made multiplying the number of wheel load passages in Table 9 by 365 for the traffic during one year. And the fatigue damage in design life of 20 years was determined by multiplying the fatigue damage obtained in this simulation by 20. Furthermore, the service life was calculated from the fatigue damage obtained. The number of simulations that were tried was set at 200 times referring to the study on this type of simulation made by the authors[10].

The concrete pavement and the traffic conditions considered in the simulations were as follows:

Flexural strength of concrete	$\sigma_b = 45\text{kgf/cm}^2$
Elastic modulus of concrete	$E = 350,000\text{kgf/cm}^2$
Poisson's ratio of concrete	$\mu = 0.25$
Coefficient of thermal expansion of concrete	$\alpha = 0.00001/^\circ\text{C}$

Modulus of subbase reaction
 Concrete slab thickness
 Traffic volume level

$K_{75} = 8\text{kgf/cm}^3$
 $H = 25\text{cm}$
 D-traffic

Figure 4 is a histogram indicating the scatter in service life obtained as a result of the simulation. Next, this histogram was approximated by the beta-distribution function as indicated in the figure. Here, the area obtained by integrating the zone of service life ≥ 20 yr of this curve is the reliability of the concrete pavement against failure caused by scatter in fatigue strength of concrete. If this reliability concerning fatigue is represented by P_R , then $P_R = 29.4\%$ in this example.

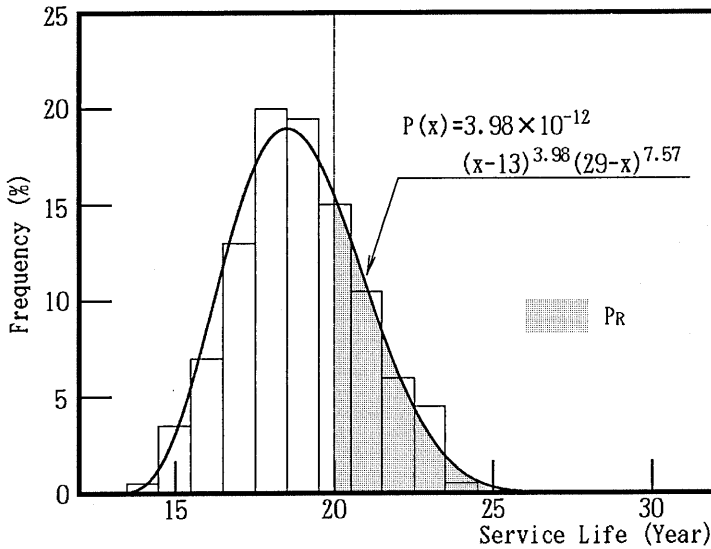


Fig.4 Service Life Distribution

On the other hand, when analysis is performed deterministically using the flexural fatigue curve of a certain probability of failure P_f the fatigue damage FD in that case can be obtained. For example, using the flexural fatigue curve for $P_f = 50\%$, the relationship of P_R - FD in case of varying modulus of subbase reaction, elastic modulus and Poisson's ratio of concrete will be as shown in Fig. 5.

According to Fig. 5, that the fatigue damage FD obtained by the deterministic fatigue analysis, and the reliability P_R obtained by simulation have a roughly linear relationship can be seen. Further, this relationship changes to the form shown in Fig. 6 by changing the failure probability P_f of the fatigue curve used in the deterministic analysis. Therefore, on obtaining from this P_R - P_f - FD relationship the relationship of P_R and P_f at fatigue damage $FD = 1.0$ to be the basis in designing, the result will be the solid line(D-traffic) in Fig. 7. That is, in case of designing using the flexural fatigue curve of failure probability $P_f = 25\%$, the reliability P_R in the design life of 20 years will be approximately 85%.

In the present study, the foregoing analysis was performed for slab thickness of $H = 23$ and 25cm , and traffic volume level of B, C, and D, and the P_R - P_f - FD relationship for design conditions of even broader scope was determined. The

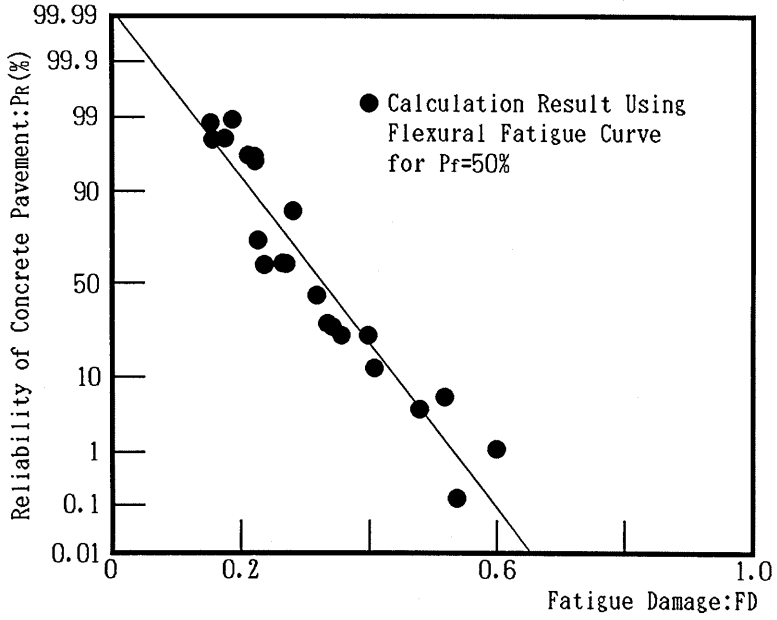


Fig.5 Relationship between Fatigue Damage and Reliability in Case of $H=25\text{cm}$, $D\text{-traffic}$

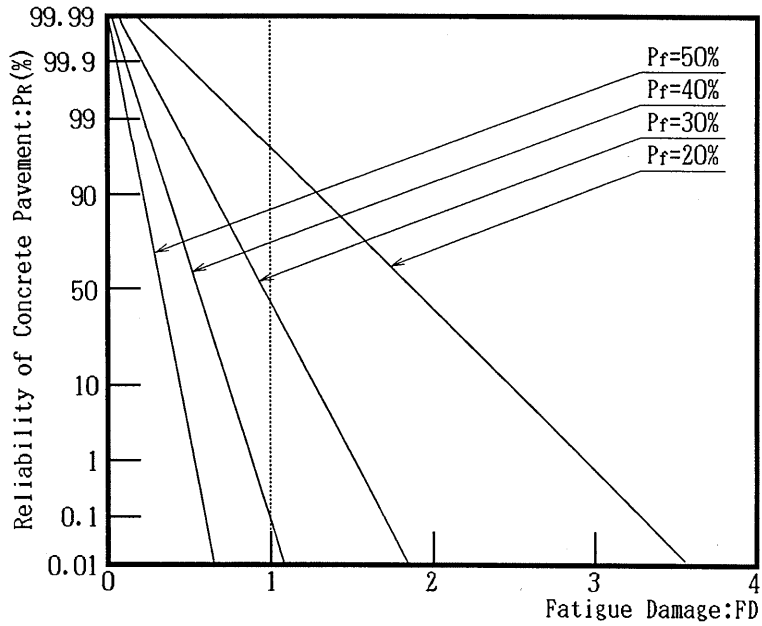


Fig.6 PR-Pr-FD Relationship in Case of $H=25\text{cm}$, $D\text{-traffic}$

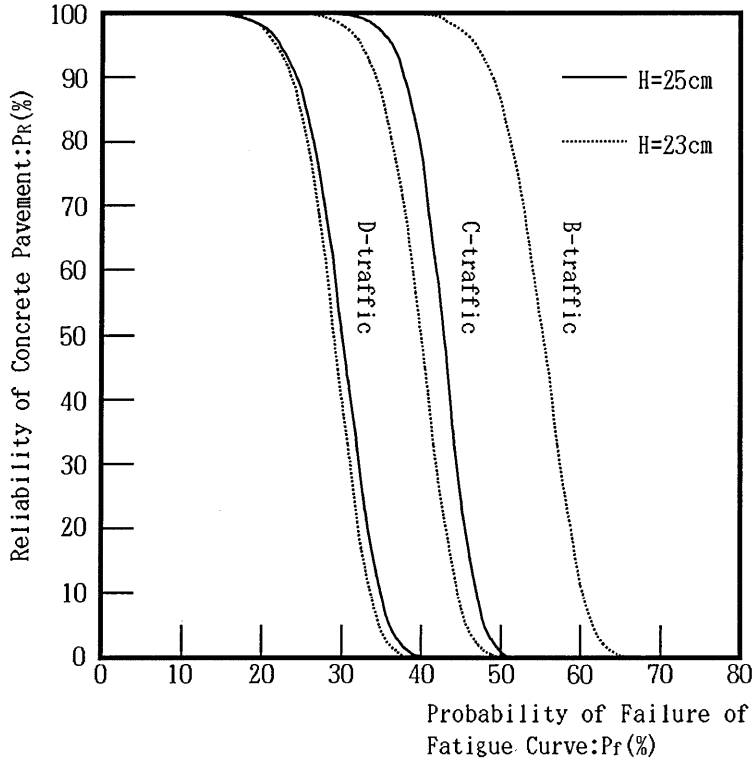


Fig.7 Relationship between P_R and P_F

pavement structure conditions made the objects of calculations were selected covering a wide range, but since in the fatigue analysis, the results are the same in case the numbers of cycles for each stress levels are the same, when the pavement structure conditions for which calculations were made are arranged in order, they will be as shown in Tables 10 and 11. Further, in case of slab thickness 28cm and over, according to the modified design method used in the present analysis, failure due to fatigue of the concrete slab will not occur during the design life of 20 years, so that this was excluded as an object of the study.

On comparison of the cases of C-traffic and D-traffic in Fig. 7, when the traffic conditions are the same, the relationship of P_F and P_R may be said to indicate a roughly similar trend irrespective of slab thickness. In effect, it may be comprehended that the reliability P_R does not depend on the structure of the concrete pavement, but is determined by the failure probability P_F of the flexural fatigue curve selected and traffic conditions. Furthermore, it may be seen that, according to the same figure, in order to obtain the same level of reliability P_R , the failure probability P_F of the flexural fatigue design curve must be made smaller the heavier the traffic.

Table 10 Calculation Condition for Slab Thickness of H=23cm

B-traffic					C-traffic					D-traffic				
K _{TS}	μ	E	P _R	FD	K _{TS}	μ	E	P _R	FD	K _{TS}	μ	E	P _R	FD
5	0.20	300000	95.518	0.741	8	0.20	300000	99.726	0.250	9	0.18	300000	99.039	0.164
8	0.25	330000	99.134	0.761	9	0.18	320000	99.608	0.267	10	0.18	310000	97.046	0.163
6	0.20	320000	98.408	0.800	10	0.20	330000	99.109	0.346	10	0.20	310000	94.848	0.213
8	0.20	350000	97.661	0.841	9	0.20	320000	99.619	0.354	10	0.18	320000	92.703	0.246
7	0.25	320000	98.981	0.885	8	0.20	310000	99.264	0.381	9	0.20	300000	92.405	0.215
7	0.20	340000	97.666	0.969	10	0.18	340000	98.922	0.399	9	0.18	310000	78.002	0.248
9	0.25	350000	92.955	1.066	9	0.18	330000	99.476	0.406	8	0.18	300000	73.222	0.263
5	0.20	310000	33.621	1.130	8	0.18	320000	68.775	0.436	10	0.20	320000	67.951	0.322
8	0.25	340000	26.955	1.160	7	0.20	300000	29.268	0.438	9	0.20	310000	64.570	0.326
6	0.20	330000	15.843	1.217	7	0.18	310000	29.310	0.500	10	0.18	330000	46.189	0.373
7	0.25	330000	13.877	1.351	10	0.20	340000	69.147	0.527	8	0.18	310000	10.820	0.400
7	0.20	350000	32.141	1.472	9	0.20	330000	67.113	0.539	8	0.20	300000	3.608	0.347
5	0.25	300000	3.548	1.614	8	0.20	320000	24.098	0.581	7	0.18	300000	2.765	0.452
5	0.20	320000	1.778	1.723	9	0.18	340000	51.795	0.617	9	0.18	320000	1.867	0.377
8	0.25	350000	5.203	1.767	6	0.18	300000	18.363	0.624	10	0.18	340000	1.367	0.564
6	0.20	340000	2.877	1.852	8	0.18	330000	20.323	0.663	9	0.18	330000	1.317	0.570
					7	0.20	310000	20.343	0.669	9	0.20	320000	1.027	0.496
					7	0.18	320000	7.779	0.761	10	0.20	330000	0.751	0.489
					9	0.20	340000	14.049	0.819	8	0.20	310000	0.329	0.528
					6	0.20	300000	1.046	0.840					
					8	0.20	330000	5.463	0.884					

Table 11 Calculation Condition for Slab Thickness of H=25cm

C-traffic					D-traffic				
K _{TS}	μ	E	P _R	FD	K _{TS}	μ	E	P _R	FD
5	0.25	320000	99.487	0.375	10	0.25	350000	98.637	0.154
7	0.25	350000	99.403	0.380	7	0.25	320000	97.709	0.158
5	0.20	340000	99.834	0.430	5	0.20	310000	97.776	0.176
5	0.25	330000	88.549	0.567	7	0.20	340000	98.799	0.188
5	0.20	350000	34.479	0.647	6	0.20	330000	96.191	0.213
5	0.25	340000	21.915	0.857	9	0.25	350000	96.104	0.222
					8	0.25	340000	95.487	0.223
					5	0.25	300000	72.786	0.228
					7	0.25	330000	60.519	0.237
					5	0.20	320000	61.485	0.265
					6	0.25	320000	61.135	0.271
					7	0.20	350000	84.309	0.282
					6	0.20	340000	43.873	0.319
					8	0.25	350000	29.422	0.336
					5	0.25	310000	27.777	0.344
					7	0.25	340000	24.103	0.357
					5	0.20	330000	24.119	0.399
					6	0.25	330000	12.323	0.409
					6	0.20	350000	0.479	0.479
					5	0.25	320000	5.870	0.518
					7	0.25	350000	0.157	0.537
					5	0.20	340000	1.151	0.599

6. Conclusions

This paper reports the results of examinations concerning fatigue curves considering failure probabilities as a summarization of the results of experiments conducted on the influences of target flexural strength of pavement concrete on fatigue failure of concrete, and of a series of studies on flexural fatigue of pavement concrete carried out by the authors. The main conclusions drawn are as follows:

In results of experiments on flexural fatigue of concrete, in the region of

stress level $S \geq 0.80$, it was shown by statistical testing that even though the static flexural strength of concrete differ, the relationship of stress level and the number of cycles to flexural fatigue failure remain the same. On the other hand, in the region of stress level $S < 0.80$, there is a trend for fatigue strength to increase with increase in static flexural strength. However, in the design of concrete pavements, since design results are significantly affected by the stress condition of stress level $S \geq 0.80$, it may be said that the influence of difference in static flexural strength of concrete may be ignored for practical purposes.

The effect of scatter in the flexural fatigue phenomenon of concrete on fatigue failure of concrete slabs was examined by Monte Carlo simulation. As the results, the relationship between failure probability of flexural fatigue curve of concrete and reliability of concrete pavement against fatigue failure of concrete was obtained. By using the design flexural fatigue curve selected based on this relationship, it will be possible to assure the reliability of the concrete pavement concerning flexural fatigue phenomenon of concrete. Furthermore, it was learned that this relationship, within the scope of pavement structure conditions considered in this study, is not related to the structural characteristics of the pavement, but is affected only by traffic conditions.

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