Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 39 (1982)

Artikel: Rating and evaluation of first-built composite girder bridge in Japan

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DOI: https://doi.org/10.5169/seals-30170

Rating and Evaluation of First-Built Composite Girder Bridge in Japan

Estimation et évaluation du premier pont à poutre mixte au Japon

Beurteilung und Wertung der ersten Verbundträger-Brücke in Japan

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SUMMARY
The paper presents a continued study on the first-built composite girder bridge in Japan, which was removed in 1978 after 25 years' service. A probability of failure at the time of the removal and the remaining life of the bridge are evaluated on the basis of probabilistic analysis from the test results of full-size specimens of structural members cut off from the bridge and the results of traffic measurements.

RESUME
Le rapport présente une étude continue du premier pont à poutre mixte au Japon, qui a été démoli en 1978, après 25 ans de service. La probabilité de ruine au moment de la démolition et la vie restante du pont sont évaluées sur la base d'analyses probabilistes de résultats d'essais d'éléments originaux du pont, découpés, ainsi que sur la base des résultats de mesures de trafic.

ZUSAMMENFASSUNG
Dieser Bericht stellt eine über längere Zeit unternommene Studie über die erste Verbundträger-Brücke in Japan, welche 1978 nach 25 Betriebsjahren abgebrochen wurde, dar. Die Versagenswahrscheinlichkeit zur Zeit des Abbruchs und die Restlebensdauer der Brücke wurden mit Hilfe einer Wahrscheinlichkeitsanalyse und aufgrund von Versuchsresultaten die an herausgetrennten Brückenbauteilen erhalten wurden sowie anhand von Verkehrsmessungsergebnissen berechnet.

1. INTRODUCTION

The paper presents a comprehensive study on the rating of deterioration and the evaluation of existing static strength and remaining life of an actual highway bridge. The bridge was Kanzaki Bridge, Osaka, Japan, consisted of 18 spans of 12 m length of composite I-beams, 7 spans of 12 m length of composite welded girders and 2 spans of 10 m length of non-composite I-beams. It was the first composite girder bridge in Japan built in 1953 and was removed in 1978 after 25 years' service to meet a further increase in traffic and to provide against the control of flood tide in the river. In 1969, the width of roadway was enlarged from 6.0 m to 8.0 m plus a footway of 2.0 m. The original design live load was 127.4 kN trucks as one of the 1st-class bridges.

On the occasion of removal, full-size specimens, such as full-span composite welded girders, reinforced concrete slabs supported at the spacing of 1.5 m and push-out specimens of block-type shear connectors, and coupons of steel and concrete cylinders for material tests, were cut off from the bridge. Simultaneously, measurements of traffic loads and volume at the site were carried out, too.

The authors tried to investigate about deterioration, existing static strengths and remaining lives of various structural members of the bridge from the test results and probability analysis. Lessons from the composite girders after 25 years' service seem to have a great significance for future plans of maintenance and rehabilitation of bridges.

2. STATIC STRENGTHS

Mechanical properties of materials and ultimate strengths of structural members are summarized in Tables 1 and 2, respectively. In Table 2, the theoretical values and the previous test results[2] obtained at the time of the original construction are shown. The test results of the members are summarized as follows:

(1) All test composite girders showed bending failure forming a full-plastic hinge at a cross section under a loading point. So, the theoretical values of the girders at the ultimate bending failure were obtained by assuming the full-plastic stress distribution at the section.

(2) One of the slab-specimens and the slab of a two-web composite test girder showed punching shear failure under a rectangular pad. Generally, the ultimate load-carrying capacity of a slab may be defined by such punching failure. But, there is no rational theory for estimating the ultimate punching load under the rectangular pad. The authors proposed a new formula of Eq.(1) by assuming the failure pattern as shown in Fig.1. The effectiveness of the equation was evaluated by the existing data of about 100 specimens. The mean value and standard deviation of the ratios of test values to theoretical ones were 0.984 and 0.078, respectively.

$$P=\tau_{s_{max}}\{2(a+2x_m)x_d+2(b+2x_d)x_m\}+\sigma_{t_{max}}\{(b+2d_d+4c_d)2c_m+(a+2d_m)2c_d\} \quad (1)$$

(3) Seven push-out specimens were tested to examine the ultimate shear strengths of block-type shear connectors. All the specimens showed concrete crushing at the ultimate state.

Table 1 Material properties

(μ : Mean value, σ : Standard deviation)

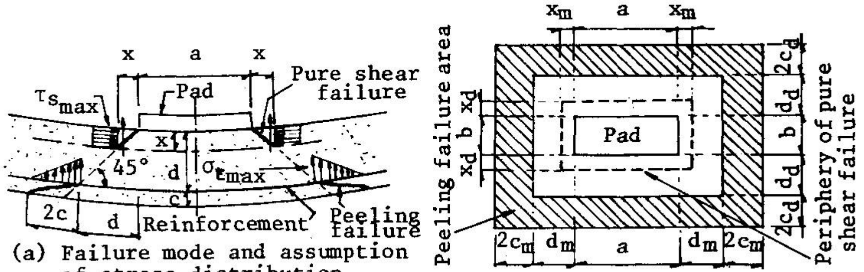
Material	E (GPa)		σ_y (MPa)		σ_b (MPa)		σ_c (MPa)	
	μ	σ	μ	σ	μ	σ	μ	σ
Steel plate	193	6.9	257	12.5	426 (402~490)	34.1	-	-
Reinforcement ϕ=12mm	208	10.4	265	23.9	380	20.5	-	-
Concrete	28.0	3.58	-	-	-	-	35.4 (24.8)	3.33 (2.13)

( ) : Previous tests

Table 2 Ultimate strengths of structural members

Structural member		Ultimate strength Exp. v.	Ultimate strength Theo. v.	Failure mode	Loading pattern
Girger	Single web	1940 kN·m (1955 ″)	1940 kN·m (1700 ″)	Flexural failure	
		2097 kN·m	1970 kN·m	Flexural failure	
	Two webs	760 kN	742 kN	Punching shear f.	
		2528 kN·m	2764 kN·m	Flexural failure	
Shear connector		1651 kN (1658 ″)	- -	Bearing failure	
Concrete slab		608 kN	575 kN	Punching shear f.	

At first, steel plate materials of the girders were judged to correspond to SS34 steel which was a mild steel designated by the Japan Industrial Standards. Strengths of the concrete had increased about 43 % more than the initial 28-days strength.



(a) Failure mode and assumption of stress distribution

(b) Modeling of failure zone

Fig.1 Modeling of punching shear failure.

Then, regarding the ultimate strengths of the structural members, comparisons between the present test results and the theoretical values, and between the present and previous test results gave the following conclusion. Namely, the reduction of load-carrying capacities of the structural members can be scarecely seen even after the 25 years' service. The soundness seems to have been retained by inexperience of severe cracking in the slabs, of serious corrosion and large traffic loads and volume. The main reasons for the constraint of severe slab cracking seem to be due to a small spacing of the girders of 1.5 m and a comparatively thick slab of 18 cm. In the slab tests, the average bending crack depth was estimated to be only 5 cm from the bottom surface.

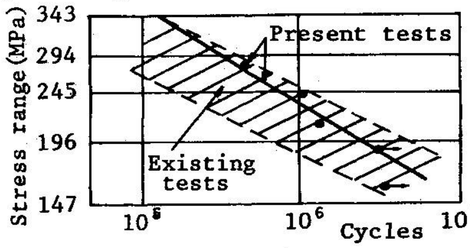


Fig.2 S-N relations of parent material.

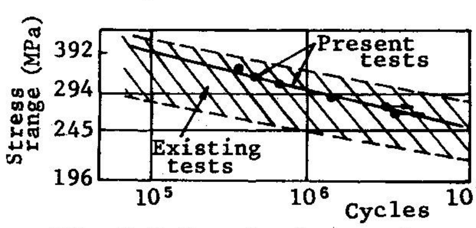


Fig.3 S-N relations of fillet weld of flange.

3. FATIGUE STRENGTHS

To investigate influences of traffic loads during 25 years on the fatigue strengths and to get S-N relations, fatigue tests of steel coupons and structural members were conducted. The coupon specimens were of parent materials, of fillet welds connecting a flange to a web plate, and groove welds of two flange plates different in thickness. The specimens of the structural members were a full-span single-web composite welded girder, three RC slabs and four push-out specimens of shear connectors. The test results were obtained in terms of S-N relations as follows:

(1) Steel plates

Three kinds of the results were plotted on S-N diagrams with existing similar data as shown in Figs.2 to 4. From the fairly good agreement between the present results and the existing data as seen in Figs.2 and 3, accumulation of fatigue damages in the parent materials and fillet welds could be neglected. For only groove welds, a clear reduction of the fatigue strengths can be seen. It seems to be not due to cumulative damages, but due to the influence of bending caused by a difference of thickness and a stress concentration on the surface of the as-welded metal. In conclusion, Kanzaki Bridge can be rated as it had not suffered from

Table 3 Loading for fatigue test of full-span girder

σ_{range} (Mpa)	Cycles ($x10^6$)	Loading pattern
98.0	1.5	2m
107.8	2.65	1m
112.7	0.50	

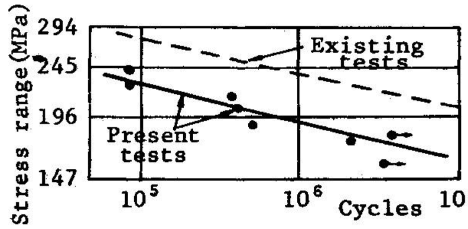


Fig.4 S-N relations of transverse groove weld of flange.

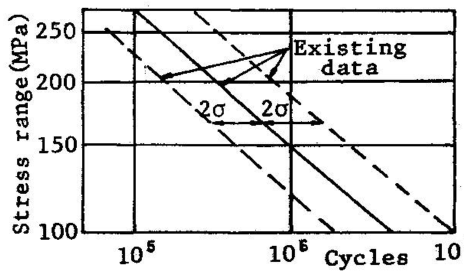


Fig.5 S-N relation of transverse non-load carrying fillet weld.

fatigue damages until the removal.

(2) Full-span composite girder

Loadings, stress ranges and loading cycles, for the test girder are shown in Table 3. At the total cycles of 4.65×10^6, a fatigue crack occurred from the toe at the lower end of fillet welds for a vertical stiffener. This fatigue failure can be evaluated with the existing data as shown in Fig. 5,[3] for transverse non-load carrying fillet welding joints.

(3) RC slabs

One of the three specimens, which was subjected to a fatigue load of 235.2~19.6 kN, showed a fatigue failure at about 2.65×10^6 cycles. This result was plotted on a S-N diagram with existing data as shown in Fig.6, which were defined by fracture of reinforcements. The other two specimens subjected to loads of 156.8~19.6 kN or 196.0~19.6 kN did not show any clear indication of fatigue even after 5×10^6 or 2.5×10^6 cycles' loading, respectively.

(4) Shear connectors

Four test values in terms of S-N relation were obtained as shown in Fig.7. Existing fatigue data for such block-type shear connectors were hardly found. So, a S-N curve was decided from these four values.

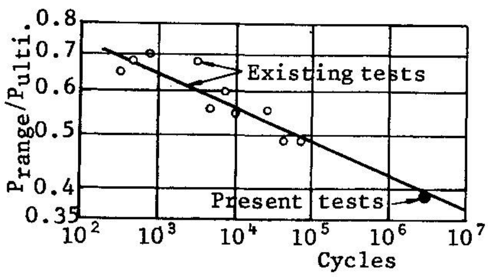


Fig.6 S-N relation of RC slab.

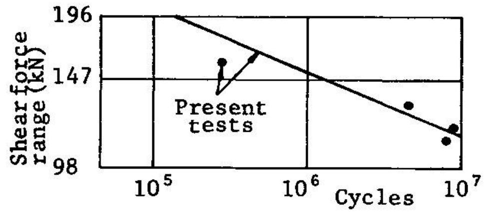


Fig.7 S-N relation of shear connector.

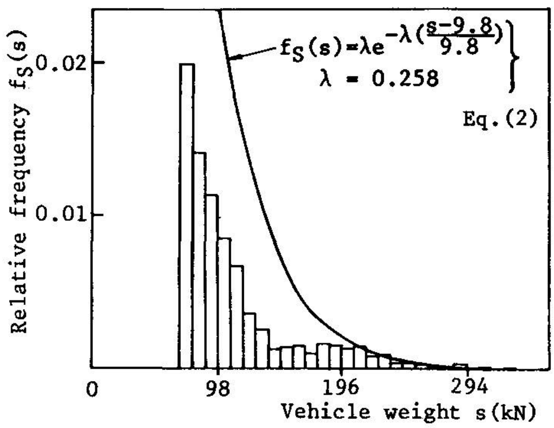


Fig.8 Observed load spectra(1980).

4. TRAFFIC MEASUREMENTS AND LOAD SPECTRA

For evaluation of probabilities of failure and remaining lives of members of a bridge, its own load spectra, loading history and traffic volume are important variables in conjuction with the resistances and S-N relations. Therefore, in 1980, traffic measurements were conducted on a temporary rampway approaching to the new Kanzaki Bridge, which has almost the same width of roadway and could be presumed to have the same traffic pattern, as the old Kanzaki Bridge. The load spectra and daily traffic volume history were obtained as shown in Figs.8 and 9. For the obtained spectra, Eq.(2) shown in Fig.8 was found to give the most fitting probability density function.

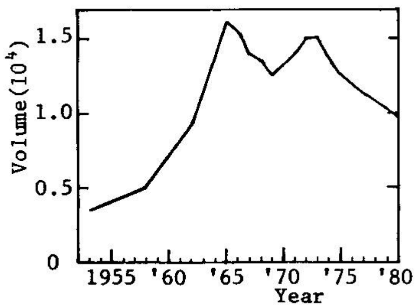


Fig.9 History of daily traffic volume per one way.

5. PROBABILITY OF FAILURE AND REMAINING LIFE

5.1 Probabilities of static failure of structural members

Characteristics of the static resistance R of the main structural members were already defined by the tests. Generally, in the field of probability of failure, serviceability states besides ultimate states have to be considered. Here, they were evaluated in terms of an allowable deflection of a composite girder and a critical slip between slab and girder. The allowable deflection is L/(20000/L) m specified at the Bridge Specification in Japan, where L is the span length of a girder. 55% of the ultimate push-out load as proposed by Johnson[4] could be used for the critical slip load. The mean value μ_r and standard deviation σ_r regarding the resistance of each member are summarized in Table 4. A normal distribution may be adopted for a probability density function to express each of the resistances. Subsequently, the load effect S for each member in the bridge has to be determined by conversion of the vehicle load spectra with distributions of path of wheels and proper influence lines for aimed points of the members. For the former, the data obtained by the Ministry of Construction in Japan as shown in Fig.10 are available. For the latter, reasonable influence lines are obtained from the three-dimensional analysis. The mean value μ_s and standard deviation σ_s regarding the load effect for each member are obtained as shown in Table 4. The probability density functions for the load effects become exponential distributions. Finally, the probabilities of failure p_f of all the members are determined together with their safety indexes β as shown in Table 4. The probabilities of failure for all the members are very small compared with conventional probabilities of failure of $10^{-4}\sim10^{-6}$. These results seem to show that Kanzaki Bridge were almost sound at the time of removal.

Table 4 Resistance, load and probability of failure of structural members of Kanzaki Bridge

Member		Resistance μ_r	Resistance σ_r	Load μ_s	Load σ_s	p_f	$\beta=\frac{\mu_r-\mu_s}{\sqrt{\sigma_r^2+\sigma_s^2}}$
Girder (Moment)	Ultimate strength	1799 kN·m	254 kN·m	21.3 kN·m	16.7 kN·m	1.2×10^{-12}	6.98
	Deflection	519 kN·m	51.8 kN·m	21.3 kN·m	16.7 kN·m	5.8×10^{-10}	9.14
Shear connector (Load)	Ultimate strength	1812 kN	272 kN	12.4 kN	9.7 kN	6.1×10^{-12}	6.62
	Critical slip	979 kN	82.1 kN	12.4 kN	9.7 kN	1.8×10^{-11}	6.57
RC slab (Load)	Ultimate strength	738 kN	142 kN	15.2 kN	11.2 kN	4.9×10^{-8}	5.13

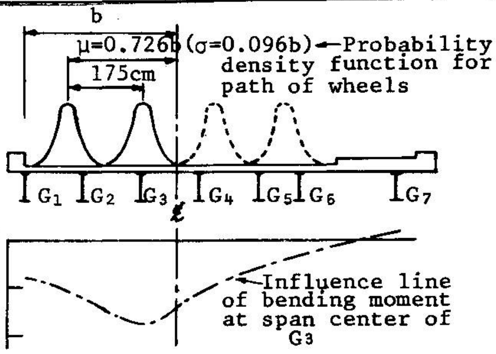


Fig.10 Distributions of path of wheels and influence line.

5.2 Probabilities of fatigue failure of structural members

A reliability function L(n) for fatigue proposed by Ang[5] is

$$L(n)=\exp\left[-\left\{\frac{n}{\bar{n}}\cdot\Gamma(1+\Omega_n^{1.08})\right\}^{\Omega_n^{-1.08}}\right]. \qquad (3)$$

Using the S-N curves in Chapter 3 and Eq.(3), each reliability for fatigue of the main members could be calculated as in Fig.11. From the figure, the reliability for fatigue, L(n), probability for fatigue, (1-L(n)), at any time, or the remaining life under a certain reliability can be calculated. Table 5 is the results of probabilities of fatigue failure of the members at the time of removal. It can be seen from the results that the Bridge had had also a sufficient safaty for fatigue at the time of removal.

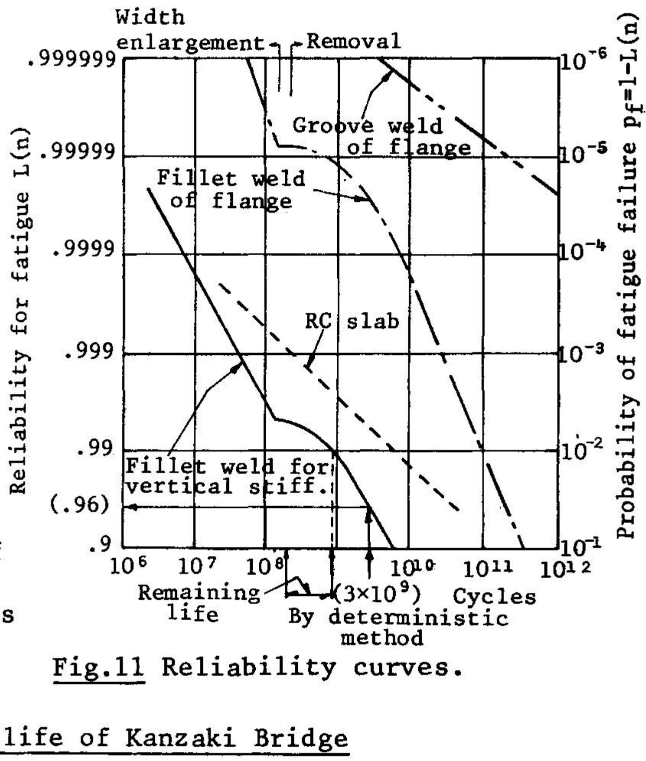


Fig.11 Reliability curves.

5.3 Probability of fatigue and remaining life of Kanzaki Bridge

To tell the truth, probability of failure and remaining life of a bridge has to be evaluated against its system failure. However, mechanism of the system failure is unsolved yet and existing data are hardly found out. Therefore, the authors have to consider at this time that probability of failure and remaining life of a bridge may be defined by the maximum probability of failure and the smallest remaining life among those obtained indpendently of each member.

So, the probability of failure of Kanzaki Bridge is evaluated to be 4.87×10^{-8} in terms of the ultimate strength of RC slab. The probability seems to be less by 2-order than the conventional values of $10^{-4}\sim10^{-6}$.

Table 5 Reliabilities L(n) and probabilities p_f for fatigue of members

Member	L(n)	p_f=1-L(n)
Flange (Parent)	.999999999	3.0×10^{-9}
Fillet weld of flange	.9999925	7.5×10^{-6}
Groove weld of flange	.99999970	3.0×10^{-7}
Fillet weld of v. stiff.	.9955	4.5×10^{-3}
Concrete slab	.99952	4.8×10^{-4}
Shear connector	.99999995	5.0×10^{-8}

The remaining life can be considered with the occurrence of a fatigue crack at the toe of the lower end of fillet weld for the vertical stiffener at the span center of G_3-girder. Because the probability of fatigue failure at the toe is the maximum and the occurrence of the fatigue crack was recognized at the full-span girder test. However, here, a simple question comes out that how high reliability level has to be taken for evaluation of the remaining life. To answer the question, the authors calculated the fatigue life under the actual load spectra at the reliability for fatigue of 95 % about the fatigue crack at the toe in the girder test by a deterministic method using Miner's rule. The obtained fatigue life was about 3×10^9cycles as seen in Fig.11. Then, the reliability level by the reliability function corresponding to the life was found to be about 0.96. It showed that the both reliabilities obtained by the deterministic method and by the reliability function were almost coincident with. From this experience, the authors think that the reliability level for evaluation of the remaining life from the reliability function is enough with 0.99 from a viewpoint of safety side. As the result, the remaining life of Kanzaki Bridge could be estimated to be about 100 years.

Table 6 Remaining life for fatigue at toe of fillet weld of v. stiff.

	L(n)=0.999	L(n)=0.99
Remaining life	-20 years	100 years

6. CONCLUSIONS

Through the tests of full-size girders or specimens and the probability analysis, the followings are concluded for Kanzaki Bridge:

(1) Deterioration, reduction of the static strength and cumulative fatigue damage of Kanzaki Bridge were scarecely observed after 25 years' service.

(2) The probability of failure of Kanzaki Bridge is less by 2-order than the conventional values of $10^{-4}\sim10^{-6}$.

(3) The remaining life of Kanzaki Bridge seems to be 100 years more under the same traffic load spectra and traffic volume as observed in 1980.

(4) The soundness of Kanzaki Bridge was dependent on the careful design to choose a small spacing of girders and a thick slab, the use of quality assured materials and rather smaller traffic loads and less volume.

REFERENCES

1. MAEDA, Y. *et. al.*, Behavior of First-Built Composite Girder Bridge in Japan, Proc. IABSE 11th Congress, Vienna, 1980.
2. KONDO, K. and A. MATSUNAGA, Design and Fabrication of Composite Girders of Kanzaki Bridge, Osaka, J. Civil Engineering, Vol.8, No.9, 1957. (in Japanese)
3. MEADA, Y., Fatigue Cracks of Thin-Walled Plate Girders, TRR 664 Bridge Eng., Vol.1, TRB, 1978.
4. JOHNSON, R.P. and R.J. BUCKBY, Composite Structures of Steel and Concrete, Vol.2, Constrado Monographs, GRANADA, 1979.
5. ANG, A. H-S., Structural Reliability and Probability-Based Design, Lecture Note at Osaka University, May 1976.