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Extending the Life of Steel Railway Bridges Using Measure Management

Prolongement de la vie de service des ponts métalliques ferroviaires par gestion des mesures

Verlängerung der Tragfähigkeit für Eisenbahnbrücken mit Vermessung

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SUMMARY

In order to ensure safety, the East Japan Railway Company evaluates the soundness of its bridge stock and plans necessary repairs by making use of measure management of steel girders. The paper discusses the basis and methodology of this approach, and presents an evaluation case study of the steel girders of in railway bridge built in 1918.

RÉSUMÉ

Il est une règle à la compagnie East Japan Railway d'évaluer l'intégrité d'une structure et de prolonger son utilisation grâce à la gestion des mesures effectuées sur les poutres métalliques. Le rapport décrit les principes de l'évaluation de l'intégrité des poutres en acier, des mesures et contrôles effectués sur des ponts métalliques construits il y a plus de 70 ans en zone urbaine.

ZUSAMMENFASSUNG

Die East Japan Railway Company pflegt mit Vermessung die Mangellosigkeit der Stahlträger zu prüfen und die Tragfähigkeit der Brücke zu verlängern. Der Aufsatz diskutiert die Methodik dieses Ansatzes und zeigt ein Fallbeispiel einer Eisenbahnbrücke aus dem Jahr 1918.

1. Concept of soundness degree evaluation

The soundness degree is defined in the text as the performance in teams of strengthsc oncerning basic safety of the structure like the proof stress durability, etc. Corresponds to "Physical strength" and the itsdecrease an advance of age.

1-1 Proof stress

The proof stress of an existence structure is evaluated as "Existing stress ratio" and its the evaluation formula as follows.

$$\text{Existing stress ratio } (S_R) = \frac{\sigma m}{\sigma} \times 100\%$$

σm is allowable maintenance limit stress used for evaluation of steelgirders in service. The tensile load is decided by the length of the line of influence of the stress generated in the girder and number of train passed.
That is, it is the result of some tiredness having inflenced besides static strength.
σm (tensile stress degree) is shown in Table-1.

Table-1 The maintenance limit stress(tensile stress) unit:(MPa)

tonage	span (m) infulence line length	wrought iron Bessemer steel	SS400		
			before1928	1928～1950	1951～1969
over $20*10^6$ ton	<10	115	140	150	150
	10≦L <20				
	≧20		159	170	170
$10*10^6$ ton $20*10^6$ ton	<10	115	165	176	180
	10≦L <20				
	≧20				
under $10*10^6$ ton	<10	115	165	176	184
	10≦L <20				
	≧20				

The σ is a maximum stress degree the vehicles generarte in the materials when they at the maximum speed. The σ is determinated on an actual section where corrosion was considered.
The measures for the utilization limitation will have to be taken when S_R is larger than 100, because smaller S_R means wider area diminighed through corrosion.
This index is shown in Table-2.

Table-2 Standard for judging the soundness against stress ratio(SR)

S_R (%)	Class
$S_R \leqq 100$	AA
$100 < S_R \leqq 120$	A_1 or A_2

AA : Repair immediately
A_1 : Repair at an early date
A_2 : Repair when necessary

1-2 Durability

The durability of the structure ranges from the one related to one related to the whole structure. In the text, the dimability of the whole structure is taken up in terms of service life or residual life expectancy.
Therefore, it is decided to expressed the durability of the entire structure as the life of the structure.
However, there are various interpretations about the life of steel bridge.
In general, expresses in the life etc. which are① economical life, ② functional life or③ physical life .
In the text, it refers to physical life, which is supporsed to depend on "Fatigue".
It is thought that physical life is predominantly dependenton "Fatigue" and "Corrosion".
However, corrosion is not caused so long as the painting film

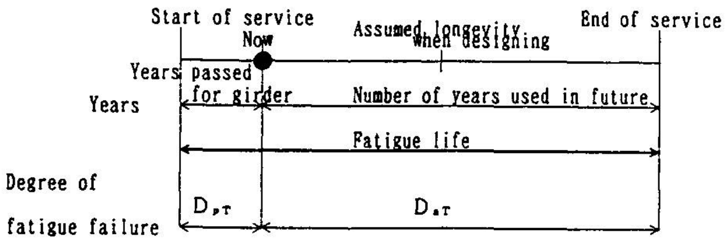
is kept in sound state by proper maintenance.
Therefore, corrosion is decided to be excluded as dimability here.
Figure 1 shows the relation between the residual life expectency and the life from of use to stop of use.
The reason why "Assumed longevity when designing" and "Service life" do not agree is that the condition used for the evaluation is different.
The reasons are that the "Service life" is caluculated baced on thevehicle practically used the distance it run, where "Assumed longevity when designing" is calculated based on the vehicle assumed in design and that the distance it is expected to run.
In general, turns out lower than the weight of the vehicle assumed when the weight of the vehicle which ran actually designs.
Therefore, "Service life" turns out longer than "Assumed longevity when designing".
The fatigue damage degree is obtained in the railway based on the following assumption.

a. The progress of the fatigue damage at a certain stress level is decided solely by the stress and it lineatly accumulates.
b. When the sum total of the fatigue damage at each stress level reaches a constant value, the fatigue failme comese.

Fatigue damage degree $(D) = \Sigma (n_i / N_i)$

N_i : Number of repetitions where crack occurs under a certain stress range is repeated.
n_i : Number of repetitions of the stress range.

That is, it is thought that the fatigue failme comes when the sum of DpT and DaT shown in Figure-1 becomes equal to unity in the girder in service.



D_{pT} : Degree of fatigue failure in typical train in the past
D_{aT} : Degree of fatigue failure in typical train in futures

Fig-1 Fatigue life of steel girder

The stress is measured in a real bridge and the degree of damage by a train is obtained from the measured more from of the stress.
In addition, time of the crack occurrence is forecast from the result is used is presumed.
The soundness ratings by fatigue are shown in Table-3.

Table-3 Standard for Judging the Soundness against Degree of fatigue failure(D)

D (%)	Class
$1.0 \leq D$	A_1
$0.8 \leq D < 1.0$	A_2

A_1 : Repair at an early date
A_2 : Repair when necessary

2. Soundness evaluation of real bridge.

2-1 Bridge parameters

Motohashi's crossed angle is narrow as shown in Figure-2.
Therefore, the longitudial gider is directly supported on the abutment, too and it is

a so-called multi point support.

Kind of bridge girder	:Through plate girder of two main beam
Span	:19.66m*2
Crossed angle	:Right 16° 06
Assembly of beams	:Rivet
Design train load	:Cupar E33 (Figure-3)
Year manufactured	:1918

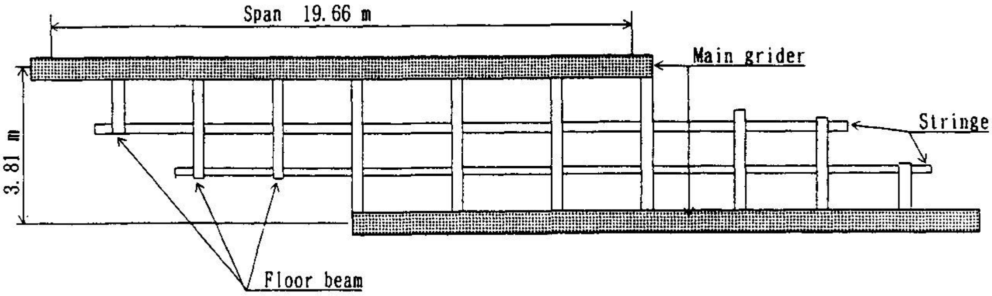


Fig-2 Plain view of Through Plate Girder

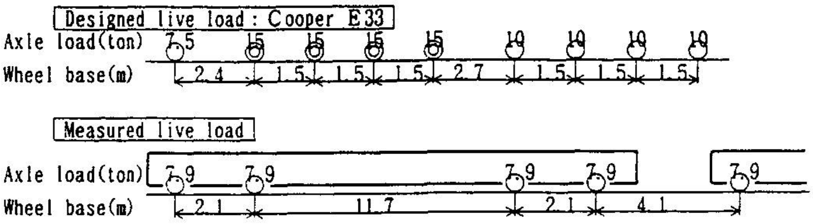


Fig-3 Live load

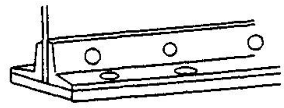
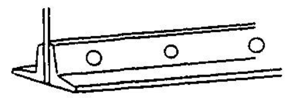
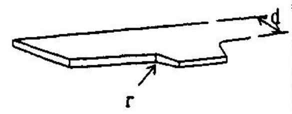
2-2 Proof stress

Prior calculation each girder section area was measured.
As a result, the section area decrease in upper was lower flange and about 0.5mm even in the girder with remarkable corrosion.
The measured train load is for axle arrangement shown in Figure-3 and the maximum axle load is 7.9 tons.
Minimum existing stress ratio(S_R)of each material calculated for this axle load was 227% in main girders, and 220% in cross girders and 220% in longitudinal girders.
As a result, it was confirmed that the soundness for the proof stress was sutisfactory enough.

2-3 Durability

① Range of permissible joint stress to be used in evaluatoin of fatigue(σ_{fo})
Table-4 shows range (σfo) of the joint stress at to evaluate 2,000,000 times of repetitim used for fatigue evaluation.
The inclination of S-N diagram was assumed three and it was adoptedbecause it is on the safety side even in long life range.

Table-4 Allowable fatigue stress range to be used for fatigue life
Cumulative repeated cycle : 2×10^6 (σ_{f0})

kinds of connection		detail	σ_{f0} (MPa)	sketch
A	connection rivets of flanges	円孔を有する板 slight corrosion	125	
B	flang angle		155	
C	base metal wich has clipping gusset plate with fillet	$1/5\leq r/d$	155	

② Fatigue damage degree (D).
It is necessary to investigate the career of the load to calculate D.
It is very difficult to obtain an actual load career.
Motohashi set the following assumption to obtain D.

a. The train, the axle load, the wheel base of the axis, and the travel speed measured this time are the same as those of trains which passed this bridge up this time.
b. In the future, the train, the axle load, the wheel base, the travel speed, and the number of trains measured this time will be same as those of trains which have passed this bridge.

If this is expressed as a formura, becomes as follows.

$$D_{PT}=\frac{n_{eq(1)}\times N_{PT}}{2\times10^{6}}$$

$n_{eq(1)}$ indicates an equivalent repetition of loading per train measured this time.
N_{PT} indicates the number of accumulated passage of vehicles which passed this bridge up to this time.

$$T_F=\frac{(1-D_{PT})\times2\times10^{6}}{n_{eq(1)}\times N_{aT}}$$

T_F is residual life expectancy and N_{aT} is the number of vehicles which passed this bridge in one year.
Dating back to the opening of the main lines in the Tokyo metropolitan district where residual life became a problem, the number of the passed trains was investigated from various documents, and the accumulation of passage vehicles was calculated in each line section.
The accumulation passage of vehicles over this bridge is 45,650,000 as of 1990.

Moreover, the number of passed vehicles in one year is 923,000 vehicles.

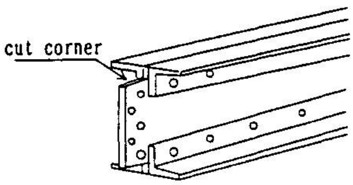
③ Analytical result.
A measured result and an analytical result are shown in Table-5.

Table-5 Standard for judging the sundness against stress ratio

member ・place	measured stress(MPa)			σ_{f0} (MPa)	D (%)	class	T_F (years)
	σ_{max}	σ_{min}	σ^{*1}				
center to span of main girders, lower flange	35.1	-1.8	36.9	A / 125	25	–	19
center to track of floor beams, lower flange	22.6	-15.6	38.2	A / 125	28	–	13
center to span of stringers, lower flange	29.8	-0.4	30.2	B / 155	31	–	22
reentrant corner of intermediate stringer*2	29.9	-9.7	39.6	C / 155	82	A_2	1

$\sigma^{*1} = \sigma_{max} - \sigma_{min}$

*2 intersection of stringers and floor beams



It is judged from this result as follows.
a. The soundness of a main girder is secured.
b. The rating is the notched part of longitudinal girder is A2 and measures will be needed several years later.

Especially, in the notch of the edge longitudinal girder, already, there is the one crack generation already, too.
This is caused is as a result of the damage to the bearing part being reparted because this bridge is a structure of the multi point support.

3. In conclusion

In the evaluation of sondness of this bridge, the physical life referring corrosion and fatigue was determined.
However, it will be necessary to take the following in to consideration besides this before deciding on the replacement of the bridge.
a. When serious deformation overlooked in routine maintenance is anticipated.
b. When a deformation which cannot be tolesated for operation plannig happens.
c. When it costs dear to make repairs.

In our company, the above-mentioned items are judged overall and the best timing for repair and replasement is decided.
The idea is that by doring this, we as a railway operator can ensure safe transport.