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Autor: Takagi, Yosio / Koshiishi, Itsuki / Tabata, Harumi
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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

Yosio TAKAGI
Deputy Manager
East Japan Railway Co.
Tokyo, Japan

Itsuki KOSHIISHI
Deputy Manager
East Japan Railway Co.
Tokyo, Japan

Harumi TABATA
Civil Engineer
East Japan Railway Co.
Tokyo, Japan

Atsushi ICHIKAWA
Chief Engineer
Railway Techn. Res. Institute
Tokyo, Japan

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 terms of strength concerning basic safety of the structure like the proof stress durability, etc. Corresponds to "Physical strength" and the its decrease 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.

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

σ_m is allowable maintenance limit stress used for evaluation of steel girders 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 influenced besides static strength. σ_m (tensile stress degree) is shown in Table-1.

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

tonnage	span (m) influence line length	wrought iron Bessemer steel	S S 4 0 0		
			before 1928	1928~1950	1951~1969
over 20*10 ⁶ ton	<10	115	140	150	150
	10 ≤ L < 20				
	≥ 20				
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 generate in the materials when they at the maximum speed. The σ is determined 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 diminished through corrosion. This index is shown in Table-2.

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

S_R (%)	Class
$S_R \leq 100$	AA
$100 < S_R \leq 120$	A ₁ or A ₂

AA : Repair immediately
A₁ : Repair at an early date
A₂ : 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 durability of the whole structure is taken up in terms of service life or residual life expectancy.

Therefore, it is decided to express 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 are ① economical life, ② functional life or ③ physical life.

In the text, it refers to physical life, which is supposed to depend on "Fatigue". It is thought that physical life is predominantly dependent on "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 expectancy 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 based 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 $(D) = \sum (n_i / N_i)$

N_i : Number of repetitions where crack occurs under a certain stress range is repe ated.

n_i : Number of repetitions of the stress range.

That is, it is thought that the fatigue failme comes when the sum of $D_{p,T}$ and $D_{a,T}$ shown in Figure-1 becomes equal to unity in the girder in service.

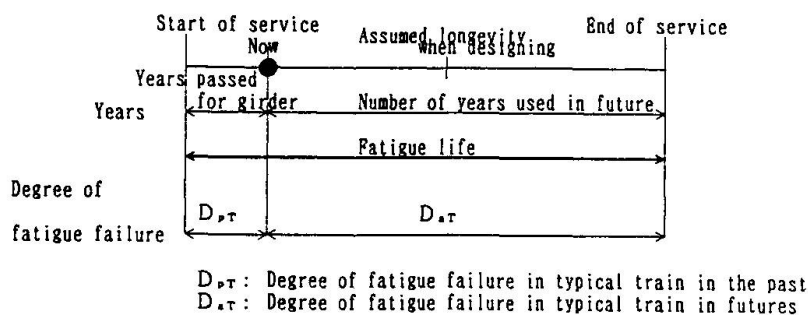


Fig-1 Fatigue life of steel girder

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

A₁ : Repair at an early date
A₂ : 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 longitudinal 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

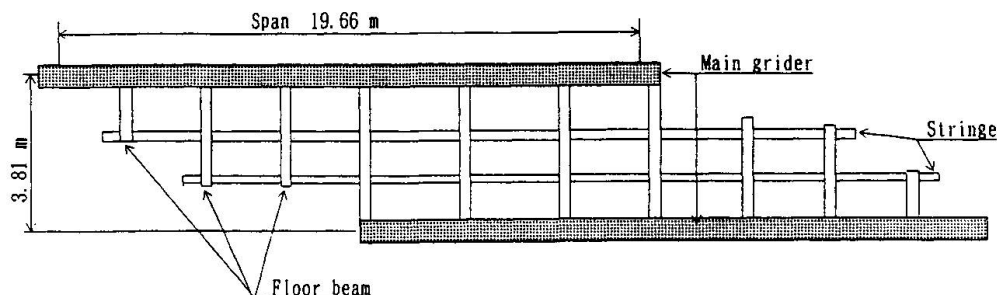


Fig-2 Plain view of Through Plate Girder

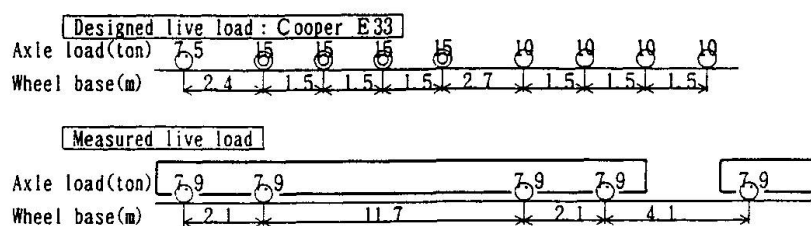


Fig-3 Live load

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.

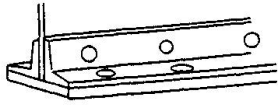
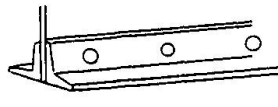

As a result, it was confirmed that the soundness for the proof stress was satisfactory enough.

2-3 Durability

① Range of permissible joint stress to be used in evaluation of fatigue(σ_{fo})
 Table-4 shows range (σ_{fo}) of the joint stress at to evaluate 2,000,000 times of repetitum used for fatigue evaluation.

The inclination of S-N diagram was assumed three and it was adopted because 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_{10})

kinds of connection	detail	σ_{10} (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 gu- sset 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.

- 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.
- 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.

$$D_{PT} = \frac{n_{eq(1)} \times N_{PT}}{2 \times 10^6}$$

$n_{eq(1)}$ 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.

$$T_F = \frac{(1 - D_{PT}) \times 2 \times 10^6}{n_{eq(1)} \times N_{AT}}$$

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.

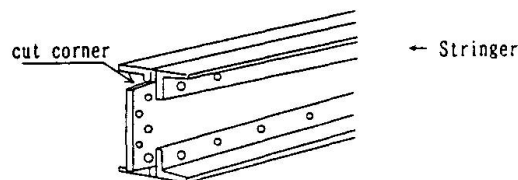
A measured result and an analytical result are shown in Table-5.

Table-5 Standard for judging the soundness against stress ratio

member · place	measured stress(MPa)			σ_{r0} (MPa)	D (%)	class	T_r (years)
	σ_{max}	σ_{min}	σ^{*1}				
center to span of main girders, lower flange	35.1	-1.8	36.9	$\frac{A}{125}$	25	—	19
center to track of floor beams, lower flange	22.6	-15.6	38.2	$\frac{A}{125}$	28	—	13
center to span of stringers, lower flange	29.8	-0.4	30.2	$\frac{B}{155}$	31	—	22
reentrant corner of intermediate stringer*2	29.9	-9.7	39.6	$\frac{C}{155}$	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.

- The soundness of a main girder is secured.
- 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 reported because this bridge is a structure of the multi point support.

3. In conclusion

In the evaluation of soundness 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.

- When serious deformation overlooked in routine maintenance is anticipated.
- When a deformation which cannot be tolerated for operation planning happens.
- When it costs dear to make repairs.

In our company, the above-mentioned items are judged overall and the best timing for repair and replacement is decided.

The idea is that by doing this, we as a railway operator can ensure safe transport.