

# General Rules for Design of Railway Bogie Frame Strength and Approach based on Finite Element Analysis and Strength Evaluation

Satoshi KIKKO\*

## Abstract

*Bogies for railway rolling stocks are equipped with motors, wheels, axles, driving gears, and other equipment and support the car body load on which passengers ride. The bogie frame such as the main frame for equipment placement and load transfer has general rules for strength design and static load test as standards for the strength design method. In accordance with these standards, at the design stage, the outer surface stress by calculating the safety factor of the entire field of view by FE analysis and the weld roots by the composite stress intensity factors method are evaluated. FE analysis improves the accuracy of evaluation of stress on the outer surface, and is expected to be used not only at the design stage, but also at the time of inspection of important parts during operation, to improve the depth and efficiency of non-destructive testing, and to prevent inspection omissions. We aim to further improve the accuracy of the weld roots through fatigue tests and evaluation of the actual rolling stock.*

## 1. Introduction

Bogies for railway rolling stocks are equipped with main motors, wheels, axles, driving gears, and other equipment, and support via air springs the car body load on which passengers ride (Fig. 1). The bogie frame is the main frame which supports the equipment placement and transfers the load, and it is important to secure the

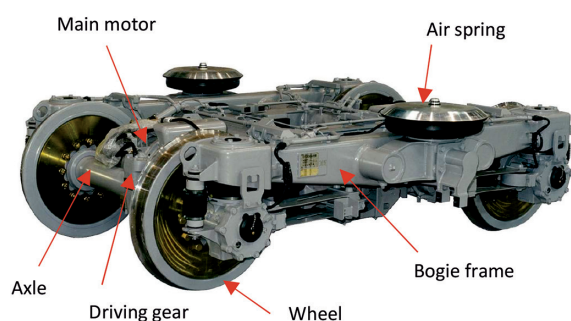


Fig. 1 Example of railway bogie

strength of the bogie frame.

The overview, design flow, and the standards for strength design methods are introduced in the Fatigue Design Method for Beginners edited by The Society of Materials Science, Japan.<sup>1)</sup> This report quotes Reference 1), and reports additionally, the contents of the revisions of strength design methods conducted in 2019 and of the test methods conducted in 2021 in the JIS standard. The finite element analysis (FEA: hereinafter referred to as FE analysis) conducted pursuant to such standards, and the strength evaluation method utilizing the analysis are described.

## 2. Overview of Bogie Frame and Design Flow

### 2.1 Overview of bogie frame

An example of a railway bogie frame is shown in Fig. 2. A bogie frame consists of side beams installed in the longitudinal direction, cross beams installed in the lateral direction, and the additional structure (brackets) to mount components such as motors and driving gears. These constituent elements are made of cast steel (material and shape simultaneously processed); however, of late, many of

\* Senior Manager, Railway Products Design Review Section, Railway Wheel, Axle & Bogie Quality Control Dept., Quality Management Div., Kansai Works 1-109, Shimaya 5-chome, Konohana-ku, Osaka City, Osaka Pref. 554-0024

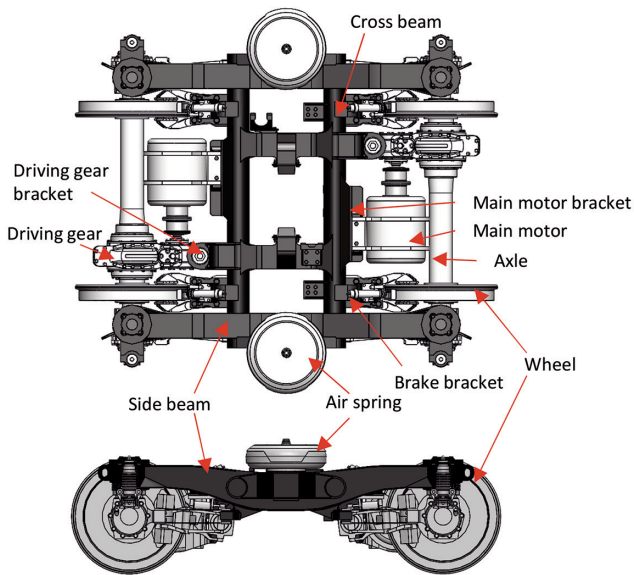


Fig. 2 Example of railway bogie frame (gray in the figure)

them are fabricated by welding the structural use steel plates. Furthermore, all of these constituent elements are integrated by welding to a single body of the bogie frame. Accordingly, the bogie frame is one of the typical welded structures in the field of mechanical engineering. In addition, there are two parts in the welds. In one part, the weld bead shape is ground to a smooth finish with a grinder (hereinafter abbreviated as the Gr-finished part), and in the other part, the weld bead is left as welded without finishing (hereinafter abbreviated as the As-weld part).

## 2.2 Strength design of bogie frame

Figure 3 shows the general flow from strength design to mass production of bogie frames. The strength design is conducted in the order of: 1) decision of load condition, 2) preparation of structure plan, 3) calculation of stress, and 4) strength evaluation, pursuant to JIS E 4207.<sup>2)</sup> The details of each item are described later. The concept is to separate the entire load into static load and dynamic load, and for each of them, stress is calculated, then synthesized, and then the stress limit diagram conforming to the Modified Goodman Diagram is referenced.

After the completion of the design, a prototype bogie frame is fabricated, and a static load test is conducted for bench evaluation. The static load test is conducted on all newly designed bogie frames pursuant to JIS E 4208-1.<sup>3)</sup> Their main purpose is to confirm the results of the stress calculations in the design, and to re-evaluate the strength based thereon. Therefore, the static load test serves as an experimental complement to the strength design described above.

The actual rolling stock on-track test, which is the test of an actual rolling stock, was standardized in 2021 as JIS E 4208-2.<sup>4)</sup> The actual rolling stock on-track test is conducted to verify the overall strength reliability, including the validity of the load values considered in the design. Specifically, the vibration acceleration of the bogie frame and the bogie frame components during traveling and the actual stress of the high-stress in the aforementioned static load test are measured, and the validity of the dynamic load is confirmed using the measurement data obtained. Methods to display the measurement result include evaluation with the stress limit diagram which employs peak stress, and fatigue life evaluation by calculat-

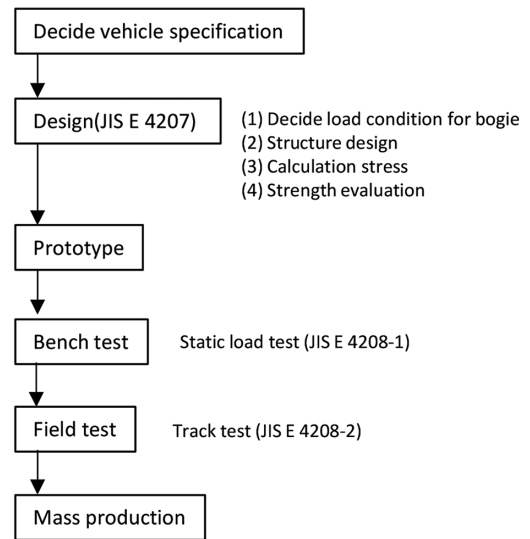


Fig. 3 Design and production process for railway bogie frames<sup>1)</sup>

ing the cumulative damage from the linear cumulative damage rule (modified Miner's law).

Hereunder, the details of the strength design and the static load test of a bogie frame are described, focusing on JIS E 4207 and JIS E 4208-1. Fatigue tests may be conducted to verify the strength of the prototype bogie frame. However, a fatigue test is conducted only when there are significant changes in the units due to a design that differs from conventional design, unlike the static load test being conducted on all newly designed bogie frames. The fatigue test method is standardized in the European standard EN13749; however, in JIS, it remains as a subject for future study.

## 3. Bogie Frame Design and Strength Evaluation based on JIS

### 3.1 Design of bogie frame (JIS E 4207)

#### 3.1.1 Applied load condition

As railway rolling stocks travel, an extremely wide range of loads is exerted on a bogie frame in a combined manner. In JIS, firstly, these loads are classified into, and handled, as static load and dynamic load.

#### (1) Static load

Static load is the load applied to the bogie frame when the rolling stock is stopped. Static load is given by the following formula because, in many cases, the dead weight and the loading weight are independently designated as the rolling stock specification, and further it clarifies the rolling stock characteristics conveniently for designers.

$$W = W_1 + W_2 + W_3 \quad (1)$$

Where,

$W$ : static load applied to a bogie frame

$W_1$ : load by mass of car body that one bogie bears

$W_2$ : load of burden mass borne by a bogie

$W_3$ : load by mass of a bogie frame and bogie frame components (components mounted on a bogie frame like main motor, driving gear, and so forth)

#### (2) Dynamic load

The dynamic load is the load applied to the bogie frame while the rolling stock is travelling, and is provided in Table 1. In other words, there are many types of loads because the direction of loads

Table 1 Dynamic load conditions<sup>Excerpt from 2)</sup>

Classification	Type	Load	
Vertical direction	Load by bouncing of burden mass	$(0.2 \text{ to } 0.5) \times W^a)$	
	Load by bouncing of mass of mounting component	Side beam mounting component	$(1 \text{ to } 2) \times L_p^b)$
		Cross beam mounting component	$(3 \text{ to } 10) \times L_p^b)$
		End beam mounting component	$(5 \text{ to } 10) \times L_p^b)$
	Load acting on driving unit bracket by driving force	$(0.2 \text{ to } 0.4) \times L_a^c)$	
	Load acting on brake equipment bracket by brake force	$p^d) \times f^e)$	
Lateral direction	Load by oscillation of burden mass and load by centrifugal force	$(0.2 \text{ to } 0.4) \times W^a)$	
	Load by oscillation of mass of mounting component	$(2 \text{ to } 4) \times L_p^b)$	
Longitudinal direction	Load by tractive force	$(0.2 \text{ to } 0.4) \times L_a^c)$	
	Load by oscillation of mass of mounting component	$(1 \text{ to } 3) \times L_p^b)$	
	Load by brake	$p^d)$	
Torsion	Torsional displacement due to e.g. a gradual decrease in the superelevation of an outer rail mm	Lateral displacement is given at a diagonal wheel position of one bogie.: 10 to 15	

Notes

- a) Static load applied to a bogie frame as given in Formula (1).
- b) Static load by mass of mounting components (mass  $\times$  gravitational acceleration)
- c) Axle load
- d) Brake block force
- e) The coefficient of friction between a brake shoe and a wheel tread, and/or a brake lining and a brake disc

due to rolling stock vibration during traveling is three-dimensional, and many bogie frame parts are also affected in addition to the rolling stock body. Furthermore, the respective load value is provided as the additional portion (ratio) with respect to the static load, and since the loads vary depending on the track condition, speed condition, and load generating mechanism, the normally conceivable range is shown. In the actual design, the additional load coefficient is determined, taking these conditions into account, and for instance, the coefficient of vertical load of 0.3 is taken for the bogie of an electric rolling stock travelling at 100 km/h. Furthermore, among the dynamic loads, there are many alternative dynamic loads like the load acting in the upward and downward directions due to bouncing; however, there are also some pulsating loads like the load acting on a lateral movement stopper.

3.1.2 Stress calculation

By exerting a static load and a dynamic load on a bogie frame, the stress generated in the respective part of the bogie frame is calculated per type of the load. In JIS, the calculation method is not described; however, in recent years, the numerical calculation by means of Finite Element analysis is generally practiced. The specific technology of Nippon Steel Corporation pertaining to this calculation is shown in Chapter 4. The stress generated at each load is synthesized using the following formula to calculate the average stress  $\sigma_m$  and the varying stress (stress amplitude)  $\sigma_a$ .

$$\sigma_m = \sigma_{Sta} + \sum_{j=1}^k \frac{1}{2} \sigma_{Dyn2,j} \tag{2}$$

$$\sigma_a = \sqrt{\sum_{i=1}^{n-k} (\sigma_{Dyn1,i})^2 + \sum_{j=1}^k \left(\frac{1}{2} \sigma_{Dyn2,j}\right)^2} \tag{3}$$

Where,

- $\sigma_{Sta}$  : stress due to static load
- $\sigma_{Dyn1,i}$  : stress due to alternative dynamic load  $i$
- $\sigma_{Dyn2,j}$  : stress due to pulsating dynamic load  $j$
- $n$  : total number of dynamic load
- $k$  : total number of pulsating dynamic load

In other words, the mean stress  $\sigma_m$  is calculated as the algebraic sum of the static load and 1/2 of the stress due to pulsating dynamic

load. On the other hand, the varying stress  $\sigma_a$  is calculated as the square root of the sum of the square of the alternate dynamic load and the sum of the square of 1/2 of the pulsating dynamic load. Here, since the stress pertaining to driving and the stress pertaining to braking do not occur simultaneously, the synthesization of the varying stress is separately calculated for the driving period and the braking period, and in general, the higher value is employed for the strength evaluation described hereunder.

As the background to employing this type of calculation method, it is suggested that: 1) it is difficult to evaluate strength by applying the alternative stress fatigue limit and the pulsating stress fatigue limit independently, 2) as a matter of actual phenomena, it is unlikely that all of the various types of dynamic load are exerted on a bogie frame simultaneously, and even if such a case is assumed, the probability of occurrence is very low, and the fatigue is least influenced, and 3) the varying stress calculated by the synthesizing formula nearly agrees with the stress measured in the past actual rolling stock travelling tests.

3.1.3 Strength evaluation

The mean stress and the varying stress calculated by Formulas (2) and (3) are evaluated by the stress limit diagram shown in Fig. 4. The stress limit diagram is provided by the fatigue allowable stress line pursuant to the Modified Goodman's diagram and the allowable yield stress line considered in terms of maximum stress. A bogie frame is designed in such a way that the stress of each of the parts of the bogie frame stay within the range formed by the two allowable stress lines (marked in the Figure).

The allowable stress values to be used for the above are provided for 12 types of steel materials as shown in Table 2. Per steel material, fatigue allowable stress is provided respectively for each of the base metal, grinder-finished weld part (Gr-finished part), and the non-grinder-finished weld part (As-weld part). In JIS E 4207: 2004, only four types of steel materials were listed (SM steel material); however, in the 2021 edition, SMA steel material, STKM steel material, and SC steel material were added.

The fatigue allowable stress is provided based on a number of

fatigue test results of the test specimen, samples taken from structure components, and the actual body. Its value is higher than the value shown in the Guideline for Fatigue Design of the Japanese Society of Steel Construction (JSSC), the General Incorporated Association, provided for general steel structures like bridges.<sup>5,6)</sup>

**3.2 Static load test of bogie frame (JIS E 4208-1)**

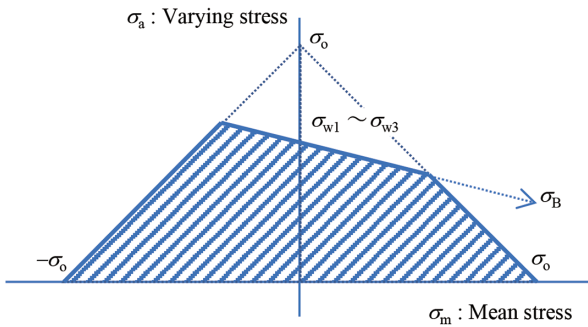
For the newly designed bogie frame, a prototype bogie frame is fabricated, and a static load test is conducted for the purpose of complementing the design experimentally. The procedure is provided in JIS E 4208-1 as the stress measurement by using the strain gauge, and as the strength confirmation based on the measurement. Herein, the following are explained in detail: method of selecting the measuring position, method of using the gauge, loading method, and strength evaluation.

**3.2.1 Method of selecting stress measuring position**

As a stress measuring position, the following parts are provided, where 1) stress concentration is anticipated such as where configuration changes sharply, cross section changes sharply, and the toe position of the weld bead, 2) generation of high stress is anticipated depending on the result of strength calculation in design, and 3) attention is required in welding and fabricating a bogie frame.

**3.2.2 Method of using strain gauge**

Generally, in the stress measurement using the strain gauge, the measured stress often becomes significantly varied depending on the



$\sigma_B$  : Tensile strength of material  
 $\sigma_0$  : Allowable stress to yield of material  
 $\sigma_{w1}$  to  $\sigma_{w3}$  : Fatigue allowable stress

Fig. 4 Stress limit diagram<sup>2)</sup>

type of gauge used and bonding method. Therefore, in JIS, in order to avoid this defect, the following guideline is provided.

Firstly, a 5 mm uniaxial strain gauge is basically used for measurement. However, when it is difficult for a 5 mm gauge to bond to a curved surface with a small radius, a shorter gauge may be used, in which case the values are desired to be calibrated for use in the evaluation of results. Furthermore, in the case of measuring the changes in stress continuously, a stress concentration gauge is used. A gauge is bonded in the direction of the main stress. However, in the case where the main stress direction is unknown, a triaxial gauge is used.

On the other hand, in the case of bonding a gauge to the starting position of a curved surface and/or the weld toe, special attention is required for the gauge bonding method. The bonding position is provided as shown in Fig. 5. Here, in the part where the radius of curvature is small like the toe part of a weld bead, the bonding surface is finished to a curved surface with a radius of about 3 mm. With this bonding method, the measured result tends to vary through recent evaluations, and as countermeasures therefor, the evaluation method using the gauge edge type which lessens the measurement variations<sup>7)</sup> was developed.

**3.2.3 Test load**

Magnitude and the type of the test load are based on those shown in JIS E 4207 (General rules for design). It is desired that the bogie frame supporting method and the loading method of the test load in the static load test be close to those in the actual operational state to the extent possible. Accordingly, it is decided that the loading position must fundamentally match the structure of the bogie frame, and furthermore, for example, use the actual axle springs to support the bogie, and that the main motor receiving load must be located at the position of the center of gravity of the main motor via a load bearing jig. Further, in order to secure stability in the test, a vertical load may be exerted simultaneously when a longitudinal direction load is exerted.

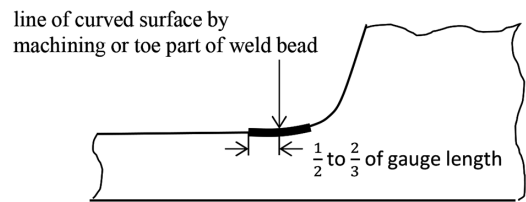


Fig. 5 Example of gauge bonding position<sup>3)</sup>

Table 2 Tensile strength, yield point, and fatigue allowable stress of main materials<sup>2)</sup>

(Unit: MPa)

Item	Type of materials					
	STKM13A	STKM13B	SM400A SM400B SMA400AW SMA400BW	SM490YA SM490YB SMA490AW SMA490BW	STKM18B	SC450
Tensile strength of material ( $\sigma_B$ )	370	440	400	490	490	450
Yield point of material ( $\sigma_s$ )	215	305	235	355	315	225
Allowable stress to yield of material ( $\sigma_0$ )	185	260	205	305	270	190
Fatigue allowable stress	Base material ( $\sigma_{w1}$ )	125	140	135	155	90
	Weld toe	When finishing ( $\sigma_{w2}$ )	110			90
		When not finishing ( $\sigma_{w3}$ )	70			

**3.2.4 Method of evaluating the result**

The method of confirming the bogie frame strength based on the measurement result is the same as the method shown in JIS E 4207 (General rules for design). In other words, mean stress and varying stress are synthesized by Formulas (2) and (3) based on the stress due to static load and the stress due to dynamic load, and the stress limit diagram is referred to in Fig. 4.

The fatigue allowable stress used in the calculation is higher than the value shown in the Guideline for Fatigue Design of the Japanese Society of Steel Construction<sup>5)</sup> as stated in Item 3.1.3. One of the reasons is the difference in how the type of stress is adopted. For the bogie frame, local stress is adopted, and nominal stress is adopted by the Japanese Society of Steel Construction. In the bogie frame, local stress is sought by providing the type of strain gauge to be used and the method of bonding as aforementioned. Further, the allowable stress is based on the accumulation of the past data obtained under this provision. Accordingly, the allowable stress higher than that of the nominal stress provided in the Guideline for Fatigue Design of the Japanese Society of Steel Construction is provided.

As a result of rearranging the past fatigue test results by using the aforementioned gauge edge type, the fatigue strength of 61.6 MPa with a breakage probability of 0.1% after two million cycles was obtained for an As-weld part.<sup>6)</sup> This means that the fatigue allowable stress of 70 MPa at the As-weld part provided in JIS E 4207 shown in Table 2 stays in the dangerous zone. However, it is considered that the fatigue allowable stress provided in JIS E 4207 is applicable, seeing that, based on year-long results, cracks do not appear even when designed pursuant to the General rules for design, and taking into account the extra design load together with the stress generation frequency.

**4. FE Analysis**

As for the FE analysis of a railway bogie frame, in addition to Reference 8), the content is described in the investigation reports<sup>9, 10)</sup> issued by the Japan Transport Safety Board. Herein, the FE analysis technology used in Nippon Steel is presented.

**4.1 Bogie frame strength evaluation method by calculating safety factor of entire field of view<sup>7, 11, 12)</sup>**

Subject to the outer surface where fatigue cracks tend to be triggered, the safety factor evaluation toward the stress limit diagram provided in JIS E 4207 is reproduced by using the result of FE analysis.

**4.1.1 Gauge stress**

In the static load test, a strain is measured by using a 5 mm uni-axial gauge, which is multiplied by Young’s modulus, and then termed as “stress”. The stress obtained by the product of a strain and Young’s modulus is termed “gauge stress” in this report to distinguish it from other types of stress, however, which physically means strain.

$$\text{Gauge stress [MPa]} = \text{strain} \times \text{Young's modulus [MPa]} \quad (4)$$

**4.1.2 Stress prediction accuracy of FE analysis**

The stress obtained from the static load test and the stress obtained from the FE analysis, both conducted on the partial model of a quarter of the side beam of a bogie frame as shown in Fig. 6, are compared and analyzed. For the joint part of the side beam and the spring cap (Gr-finished part), stress is evaluated at the same position where a strain gauge is bonded. As the loading condition, only the

vertical load was provided. For the FE analysis, a general-purpose software NX-Nastran was used, and the quadratic tetrahedral element (global mesh size 12 mm, subdivided to 2.5 mm at the joint part) was adopted. As shown in Fig. 7, the static load test result represented by the gauge stress and the result of the FE analysis agree with each other very well within the difference range of ±20 MPa.

**4.1.3 Preparation of safety factor contour map based on FE analysis result**

In the FE analysis, stress and strain in all directions at a node position are obtainable. Gauge stress in all directions is calculated by FE analysis per type of classified test load provided in JIS E 4207. Mean stress and varying stress are synthesized by Formulas (2) and (3) based on the gauge stress of the respective load, and plotted on the stress limit diagram of Fig. 4, and the loop-shape figure as shown in Fig. 8 is obtained. The loop denotes the combination of the mean stress and the varying stress in all directions at a node position.

In this report, the ratio of the distance from the point of origin to the limit value vs. the distance from the point of origin to a point of the loop is defined as the safety factor, and the value at which the

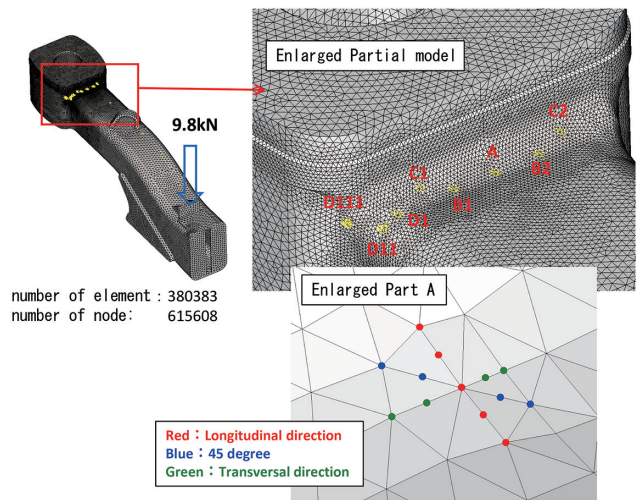


Fig. 6 Partial model and stress evaluation part<sup>12)</sup>

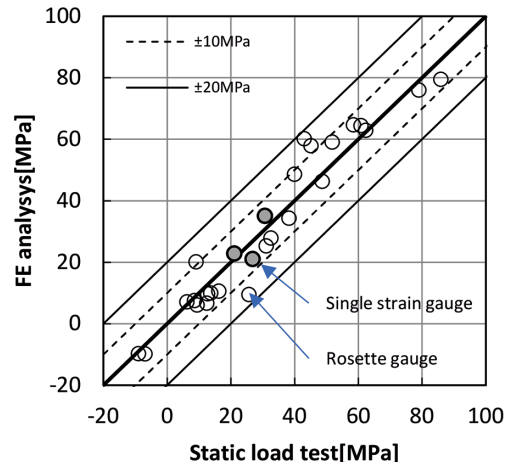


Fig. 7 Comparison of static load test and FE analysis results for the partial model<sup>12)</sup>

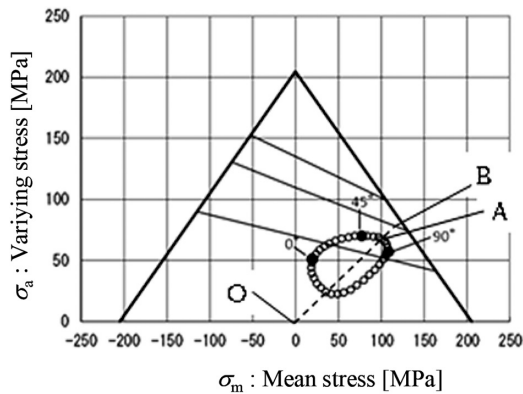


Fig. 8 Evaluation result example on stress limit diagram<sup>2,11)</sup>

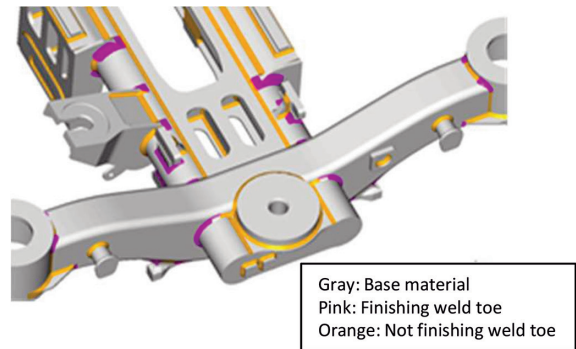


Fig. 9 Example of material classification definition<sup>11)</sup>

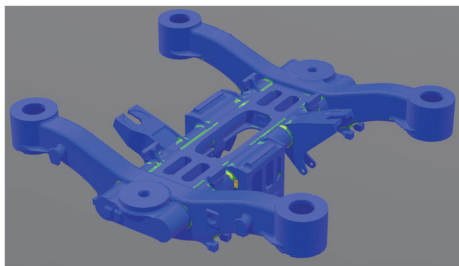
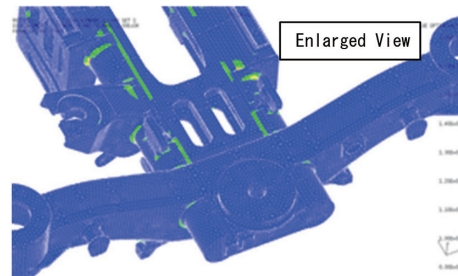


Fig. 10 Safety factor calculation result with contour map<sup>11)</sup>



safety factor is the smallest is defined as the safety factor at the measurement point.

$$\text{Safety factor} = |\text{OB}| / |\text{OA}| \quad (5)$$

A: mean varying stress in the direction where safety factor is smallest  
 B: allowable stress in the direction where safety factor is smallest

As shown in Table 2, allowable stress is defined per type of materials and per whether weld toe is finished or not-finished, and allowable stress at each of all nodes of the FE model is defined. In Fig. 9, an example of material classification definition is shown. Based on the classification definition, for all nodes, the mean stress and the varying stress, obtained per gauge stress of each load, are combined, and the smallest value of the safety factor on the stress limit diagram is calculated. Safety factors so obtained at all nodes are displayed as a contour map. Figure 10 shows an example of a contour map. With this technology, display of the safety factors of the entire field of view is possible. Further, by combining the safety contour map with image processing, output to a 3D printer, project mapping to an actual bogie, and so forth, utilization for sophistication, optimization, and prevention of oversight of non-destructive inspection in the inspection of a crucial part is expected.

## 4.2 Evaluation of weld root part (composite K value)<sup>13)</sup>

### 4.2.1 Overview of composite K value method

One of the locations which possibly triggers fatigue fracture in a weld joint is the weld root part (so-called internal). As a strength evaluation standard for weld-jointed structures, the unwelded part of the weld root is considered as a crack, and evaluated in terms of stress intensity factor.<sup>14)</sup> In the past, a report<sup>15)</sup> was issued on the calculation method of the stress intensity factor of an actual bogie frame by using FE analysis, providing a fatigue design standard employing as an index the stress intensity factor of a weld-jointed structure having an unwelded part. For application to bogie frame design, there was an issue of how to compound the stress intensity

factors generated by various loads. Herein, the compounded stress intensity factor used for evaluation is termed as the composite K value.

In the current evaluation standard based on the stress intensity factor<sup>14)</sup>, the calculation method of the composite K value at the design stage is not provided, and since the K value is evaluated by measuring the stress in the actual rolling stock on-track test after manufacturing of the bogie, the K value cannot be reflected in the design of the subject bogie. In the case of evaluating the composite K value at the design stage, application of the method similar to the composite stress calculation method for the evaluation of the outer surface stress provided in JIS E 4207, in other words, the application of Formulas (2) and (3) in which the stress is replaced with the stress intensity factor is considered. Herein, for the stress intensity factor, employment of the maximum tangential stress intensity factor  $K_{\theta_{\max}}$  which is generally used under a mixed mode condition is considered.<sup>16)</sup> Herein, this method is termed as the JIS reference method.

However, in the case of the calculation with the JIS reference method, since the K value becomes a value obtained by synthesizing the stress intensity factors  $K_{\theta_{\max}}$  having a different maximum tangential direction, there is a concern over the possibility of insufficient proper evaluation of the compressive stress which is considered to have less contribution to the progress of cracks. Accordingly, we proposed a new method: the composite K value is calculated per angle, and the value at the direction providing the smallest value of the safety factor is taken as  $K_{\theta_{\max}}$ . The following method was applied. The stress intensity factor under the respective load condition was synthesized per crack mode, and the mean values and the varying values of K values in all directions around the crack as the center were calculated, and the point of the smallest safety factor on the endurance limit diagram was sought.

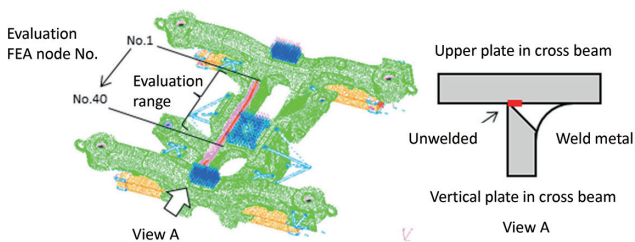


Fig. 11 Bogie frame analysis model<sup>13)</sup>

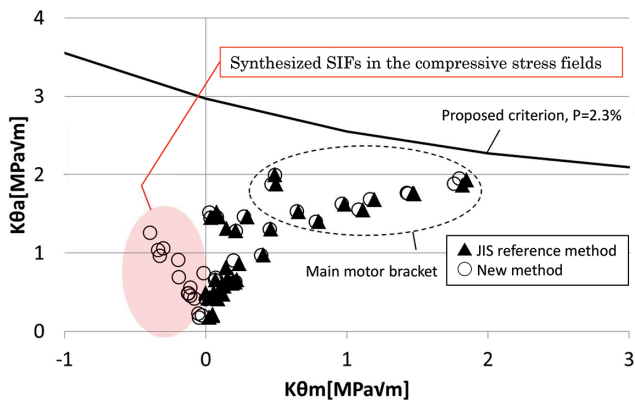


Fig. 12 Comparison with the endurance limit evaluated by the stress intensity factors<sup>13)</sup>

#### 4.2.2 Calculation example

By applying the general commuter train load condition to the bogie frame model shown in Fig. 11, and by applying the new method proposed in this report, comparison and the evaluation regarding the JIS reference method were conducted. The weld root of the upper plate to vertical plate of the cross beam of the bogie frame was evaluated.

In Fig. 12, the comparison of  $K_{\theta max}$  at all evaluation points with the endurance limit line evaluated by the stress intensity factor is shown. In the new method, the mean value in the compression direction is also evaluated.

As a result of the evaluation of the composite K value of the bogie frame model by using the new method, evaluation in the field of compressive stress, evaluation more appropriate than that of the JIS reference method has become possible. Hereafter, we will study the application to other parts in the bogie frame design stage, and we will verify the validity of the method based on the evaluation on an actual rolling stock.

### 5. Conclusion

This paper introduces the strength design methods for railway bogie frames, focusing on the JIS standard. The bogie frame design method is the typical fatigue limit design which is based on keeping the maximum stress repeated in every part of the subject part material below the allowable stress, and is established based on not only the results of many various fatigue tests and the results of the stress measurement in actual rolling stock operation, but also on the results of the analysis of past problem cases.

At the design stage, Nippon Steel conducts evaluation of the outer surface stress by calculating the safety factor of the entire field of view and the evaluation of the internal of the weld root with the composite K value method by utilizing FE analysis. The evaluation accuracy of the outer surface stress has been enhanced by the FE

analysis, and not only at the design stage, but also utilization for sophistication, optimization, and prevention of oversight of non-destructive inspection in the inspection of a crucial part are expected. For the internal of the weld root, we aim at further enhancing accuracy through evaluation of the fatigue test, actual rolling stock operation, and so forth.

### References

- 1) Edited by The Society of Materials Science, Japan: Fatigue Design Method for Beginners. Volume 5. Kyoto, 2013, p.67, 72-77
- 2) JIS E 4207: 2019: Rolling stock - Bogie - General rules for design of bogie frame strength
- 3) JIS E 4208-1: 2021: Rolling stock - Bogie - Strength test - Part 1: Method for static load test
- 4) JIS E 4208-2: 2021: Rolling stock - Bogie - Strength test - Part 2: Method for on-track test
- 5) Edited by the Japanese Society of Steel Construction: Guide Line and Explanation for Fatigue Design of Steel Structures. Revised issue of 2012. Tokyo, Gihodo Shuppan. 2012, p.65-72
- 6) Yokozeki, K. et al.: Proceedings of The Japan Society of Mechanical Engineers. 89 (927), 23-00184 (2023)
- 7) Kato, T. et al.: Proceedings of The Japan Society of Mechanical Engineers. 86 (889), 20-00089 (2020)
- 8) Japan Railway Rolling Stock & Machinery Association: Railway Electric Rolling stock Bogie - Structure, Function and Design -. Japan Railway Rolling Stock & Machinery Association. 2017, p.183-185
- 9) Japan Transport Safety Board: Investigative report on the railway grave incident of rolling stock disorder in the Nagoya Station yard of New To-kaido Line, West Japan Railway Company, R1209-1, p.68-69, 89, 92 (2019)
- 10) Japan Transport Safety Board : Investigative report on the railway incident of rolling stock derailment in the main track Aoto Station yard, Keisei Electric Way, RA2022-2, p.29-31, 36-37, 39 (2022)
- 11) Kikko, S. et al.: Bogie frame strength evaluation method by calculating safety factor of entire field of view by using FEM. Proceedings of 27th Railway Technology and Policy United Symposium (J-RAIL2020). S1-2-4 (2020)
- 12) Kikko, S. et al.: Integrated FE Analysis of Railroad Rolling Stock Bogie Frame Inclusive of Weld Joints. Proceedings of 29th Railway Technology and Policy United Symposium (J-RAIL2022). S2-6-4 (2022)
- 13) Tanimine, T. et al.: Proposal of Strength Evaluation of Weld Root in Bogie Frame Design. Proceedings of 27th Railway Technology and Policy United Symposium (J-RAIL2022). S1-2-5 (2020)
- 14) Makino, T. et al.: Base of fatigue and the latest trend in fatigue design of actual rolling stock 5. Latest Trend of Fatigue Design in Railways. Material. 59 (5). 398-405 (2010)
- 15) Kondo, O. et al.: Evaluation of strength of weld structure having no-welded portions and application to rolling stock frame design standard. Preprint of The Society of Materials Science, Japan 10th Machine and Structure Strength Design and Safety Evaluation Symposium. 9-12 (2006)
- 16) Erdogan, F., Sih, G.C.: On the Crack Extension in Plates Under Plane Loading and Transverse Shear. J. Basic Eng., Trans. of the ASME. 85 (4), 519-525 (1963)



Satoshi KIKKO  
Senior Manager  
Railway Products Design Review Section  
Railway Wheel, Axle & Bogie Quality Control Dept.  
Quality Management Div., Kansai Works  
1-109, Shimaya 5-chome, Konohana-ku, Osaka City,  
Osaka Pref. 554-0024