Study on bogie strength design considering seismic motion

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Contents

- ✓ Research Background
- ✓ Evaluation of the force acting on the bogie frame due to seismic motion
- ✓ Strength evaluation and fatigue damage evaluation for bogie frame

Research Background

When strong forces are applied to bogies due to huge earthquakes, they may suffer damage such as cracks or permanent deformation.

⇒ From the perspective of running safety, it is important to evaluate the strength and damage of bogie frames exposed to seismic motion.

Example of Shinkansen derailment during an earthquake

(2004.10.23) Joetsu Shinkansen	Niigata Chuetsu Earthquake
(2011. 3.11) Tohoku Shinkansen	Great East Japan Earthquake
(2016. 4.14) Kyushu Shinkansen	Kumamoto Earthquake
(2022. 3.16) Tohoku Shinkansen (Stopped)	Fukushima Earthquake

Joetsu Shinkansen derailment accident

Tohoku Shinkansen derailment accident

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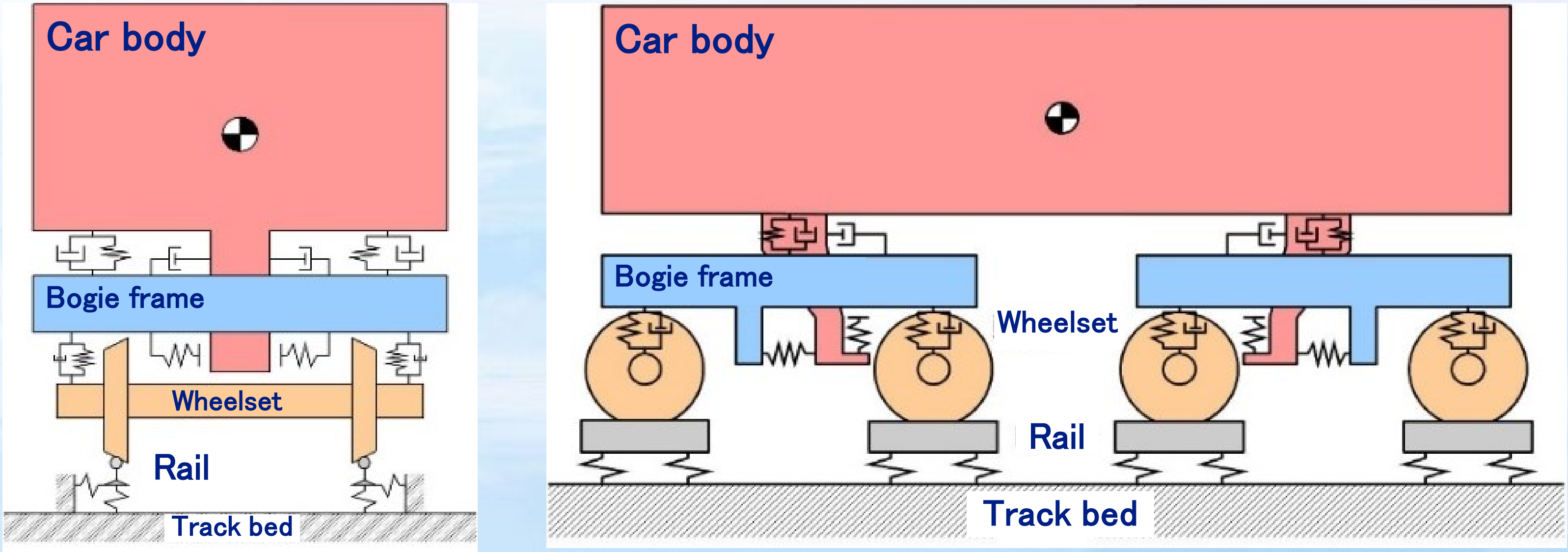
Evaluate of forces acting on each part of a bogie by analysis of vehicle behavior during an earthquake

Evaluating the forces acting on the bogie frame using multibody dynamics simulation



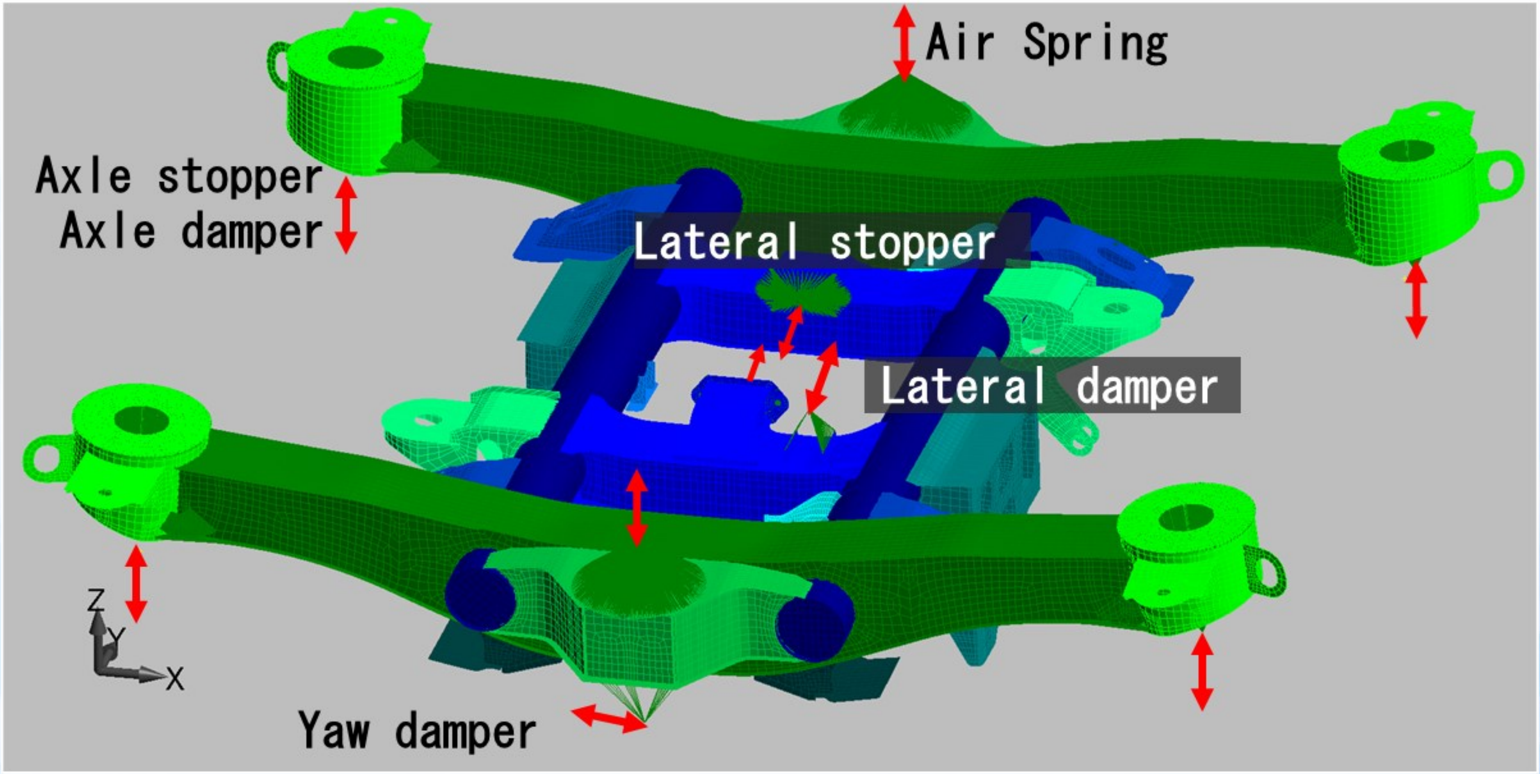
(a)Front view (b)Side view

Analytical model for vehicle behavior analysis during earthquake

Analysis Condition

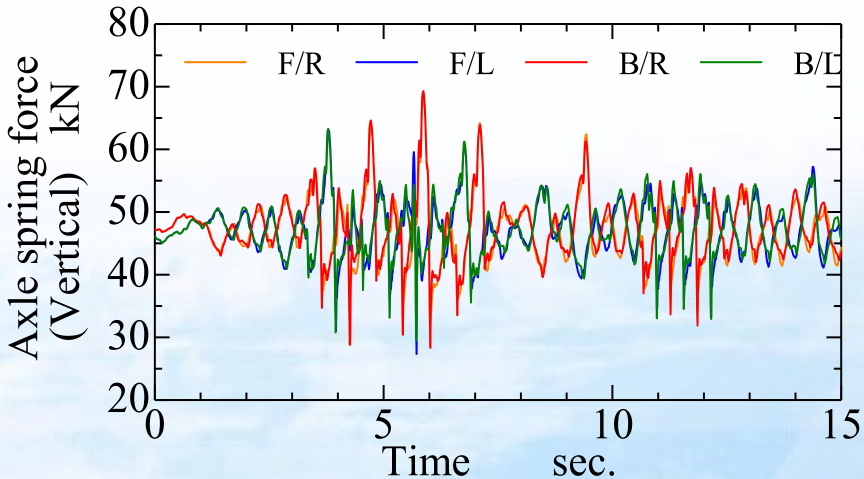
- Vehicle speed: 320km/h

Analysis of forces acting on each part of a bogie by analysis of vehicle behavior during an earthquake

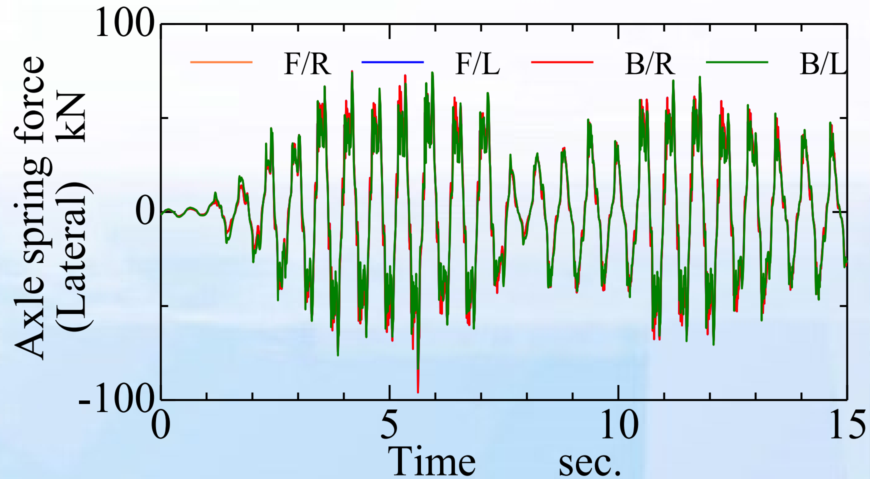


Load applied to bogie frame

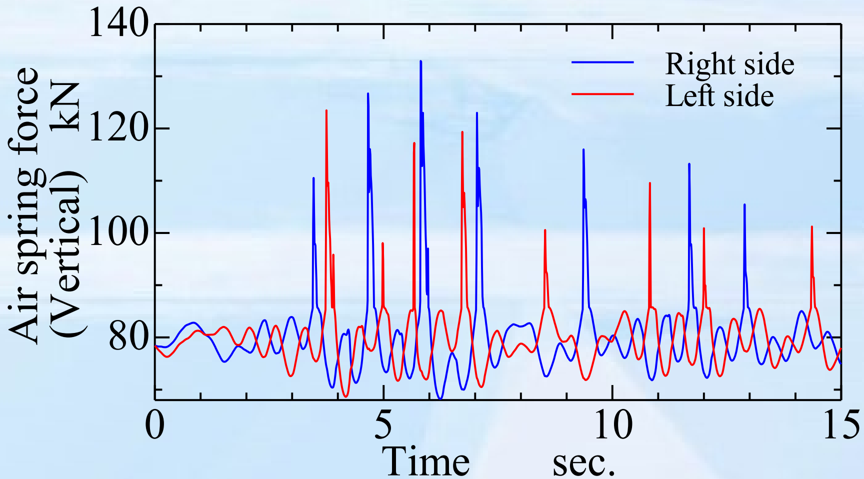
Results of vehicle motion simulation



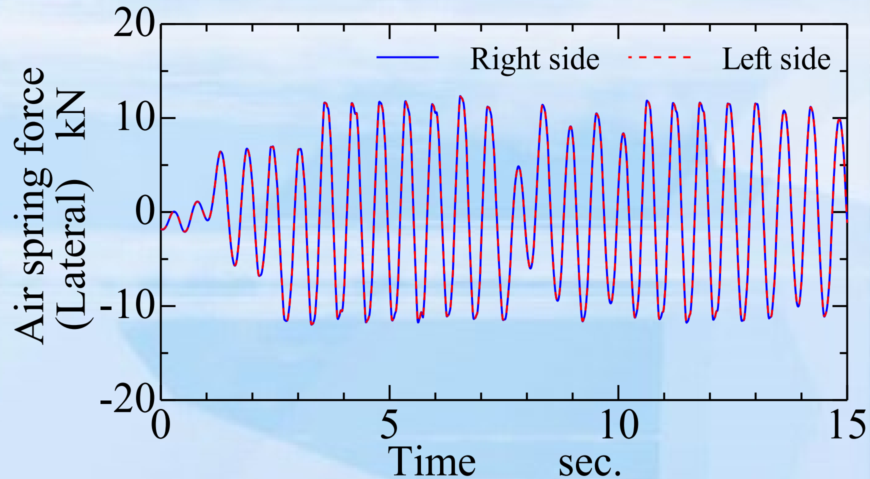
Time history of axle spring force (Vertical)



Time history of axle spring force (Lateral)

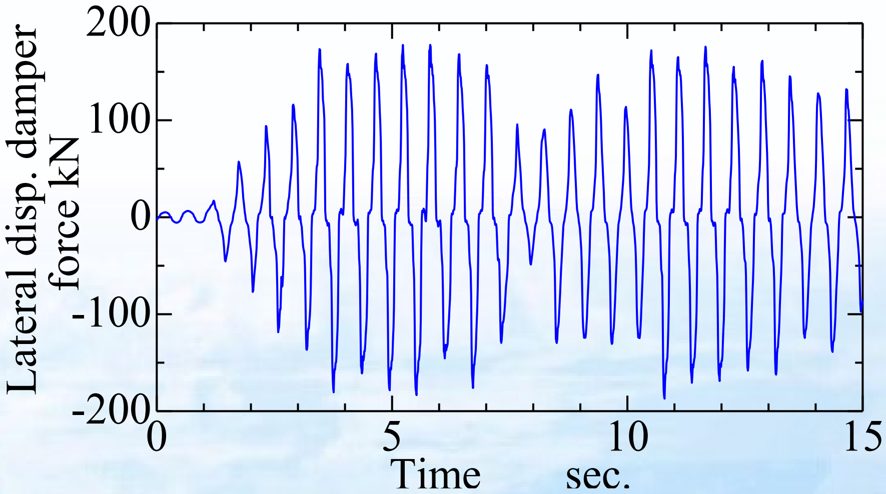


Time history of air spring force (Vertical)

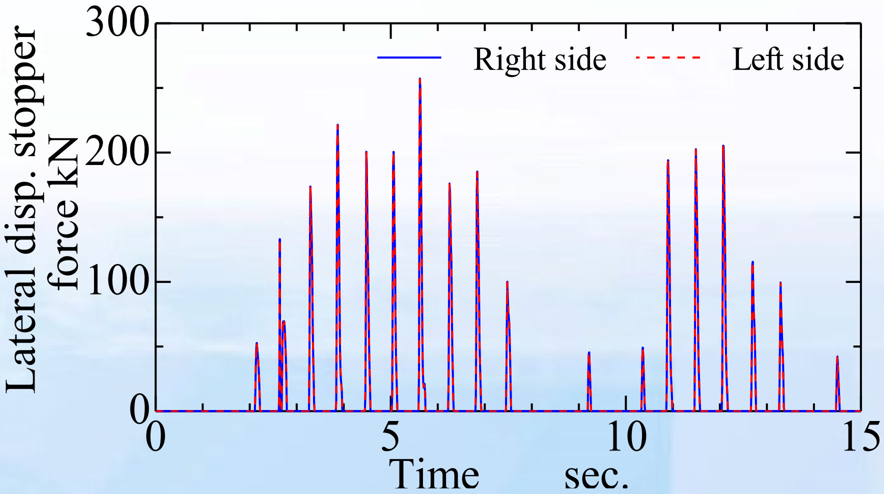


Time history of air spring force (Lateral)

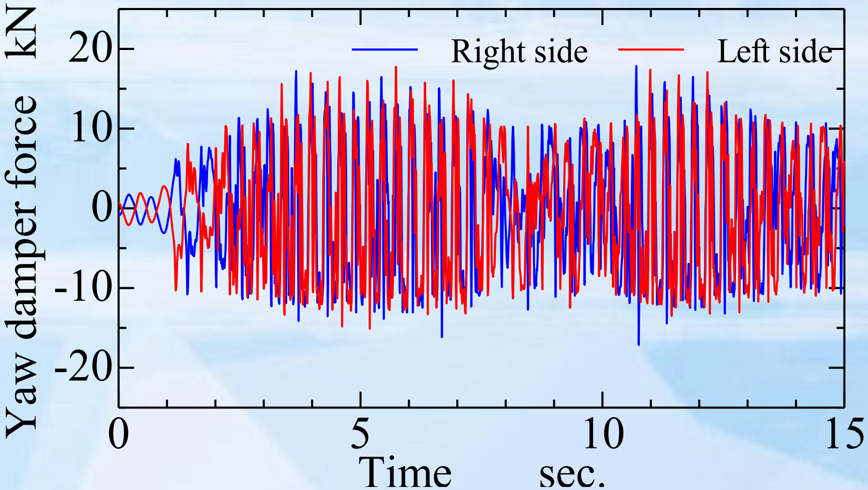
Results of vehicle motion simulation



Time history of lateral disp. damper force



Time history of lateral disp. stopper force



Time history of yaw damper force

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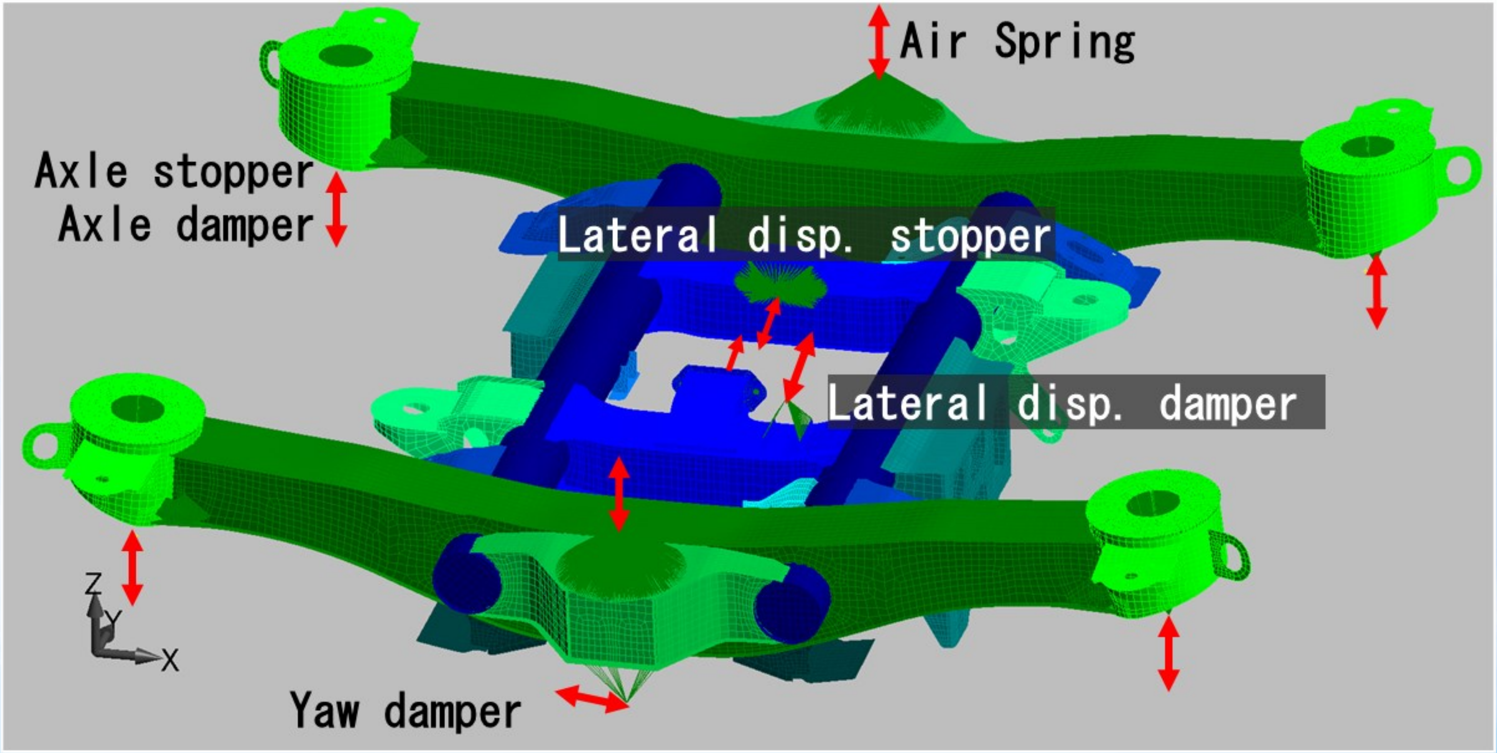
Strength evaluation of bogie frame by FEM analysis

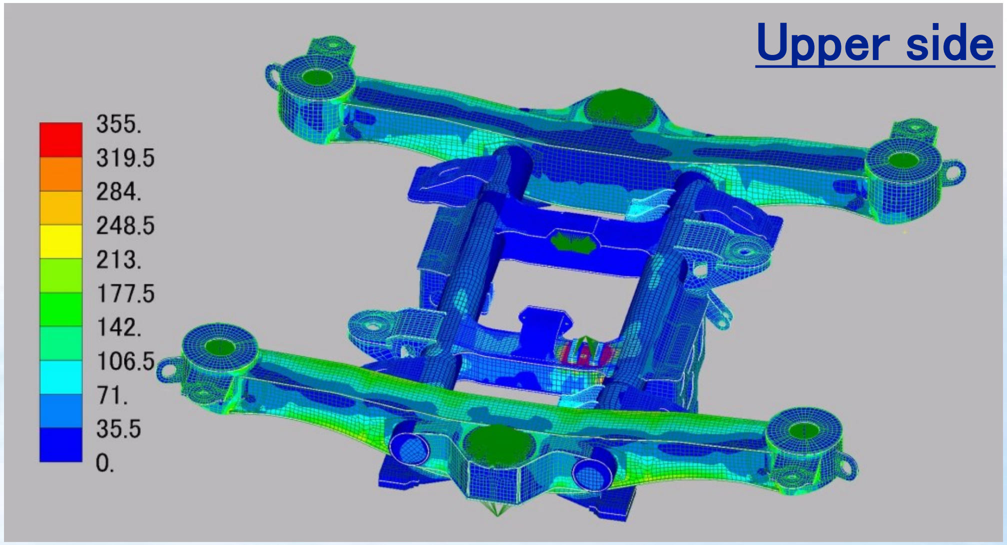


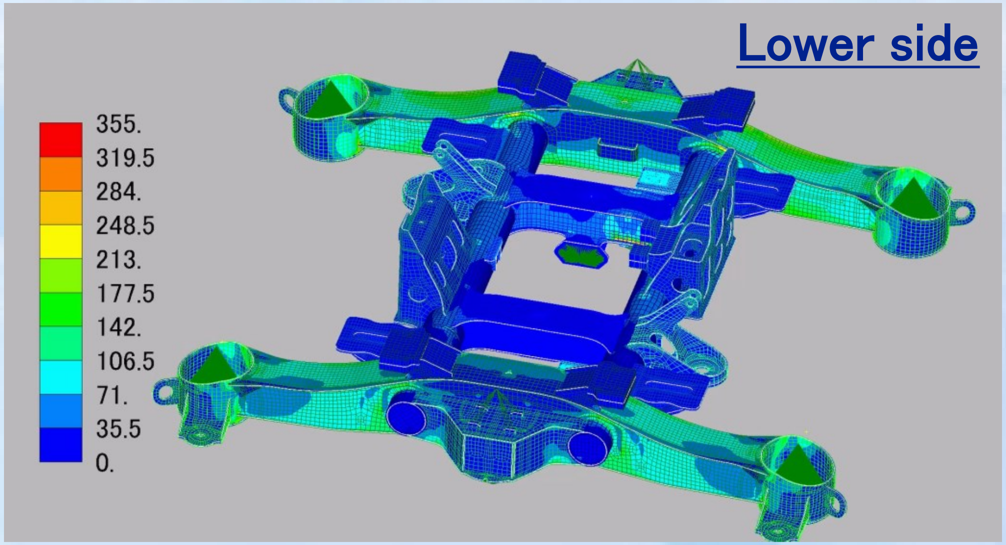
FEM analysis model of bogie frame

Material constants

SM490YB steel:	Young's modulus	205 GPa
	Poisson's ratio	0.3
	Yield stress	355 MPa
	Density	7.85 t/mm^3

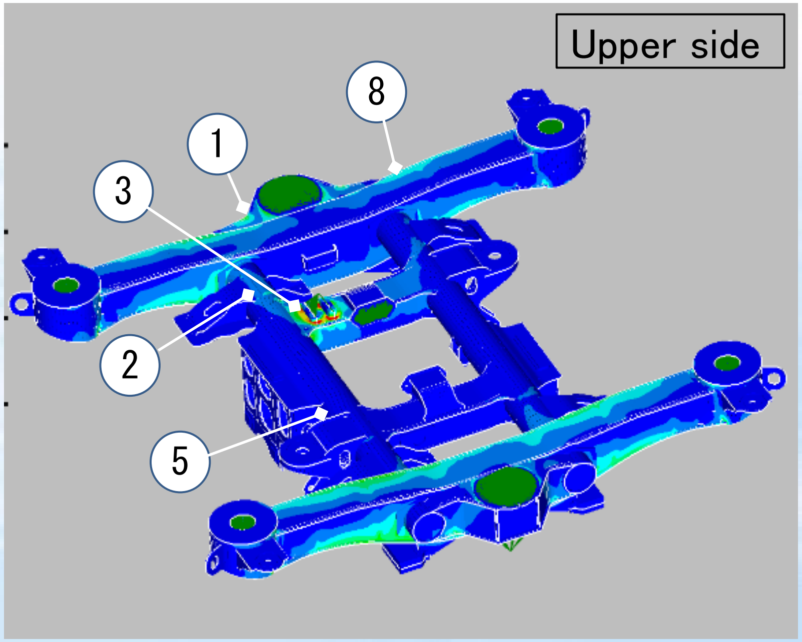
Equivalent stress contour diagram

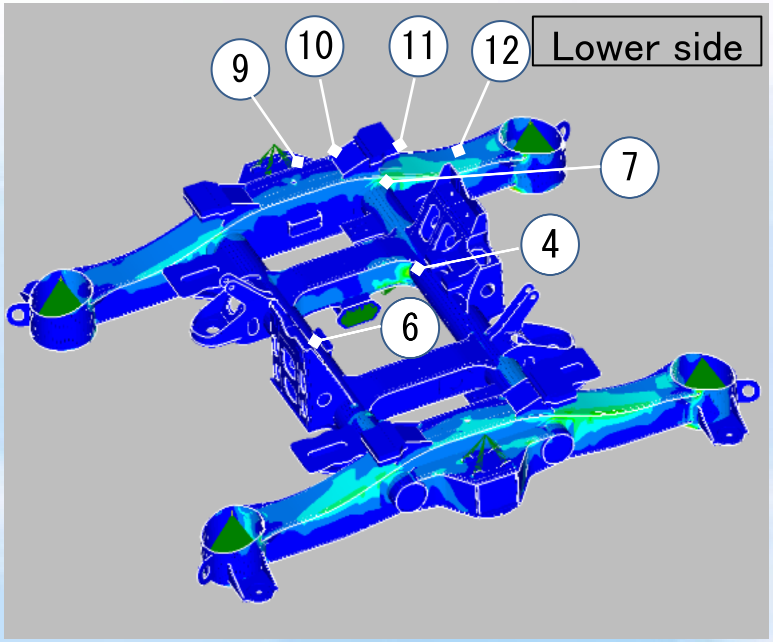




Extraction of evaluation targets related to the effects of seismic motion

A stress analysis of the bogie frame was conducted assuming a load equivalent to the Northern Pacific Coast Earthquake.

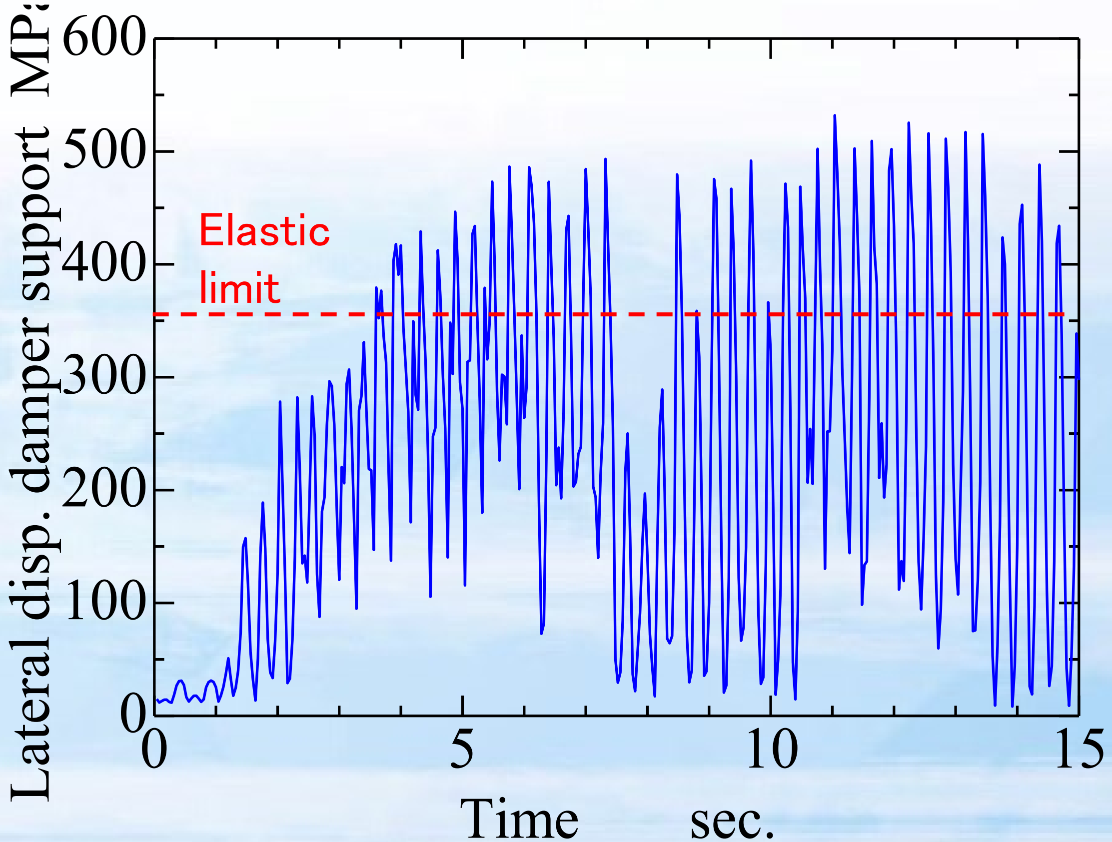




High load areas when seismic motion acts

	High load area		
1	Air spring seat	7	Joint of side beam/cross beam (Lower)
2	Upper surface of cross beam	8	Upper surface of side beam
3	Edge of Lateral damper seat	9	Lower surface of cross beam（Center）
4	Joint of connection beam/cross beam(Side）	10	Joint of axle beam/side beam
5	Joint of connection beam/cross beam(Upper）	11	Axle beam seat
6	Joint of traction motor seat/cross beam	12	Lower surface of side beam

Stress time history of the part where the elastic limit was exceeded



Time history of equivalent stress
at Edge of Lateral displacement damper support

Fatigue damage evaluation of bogie frame

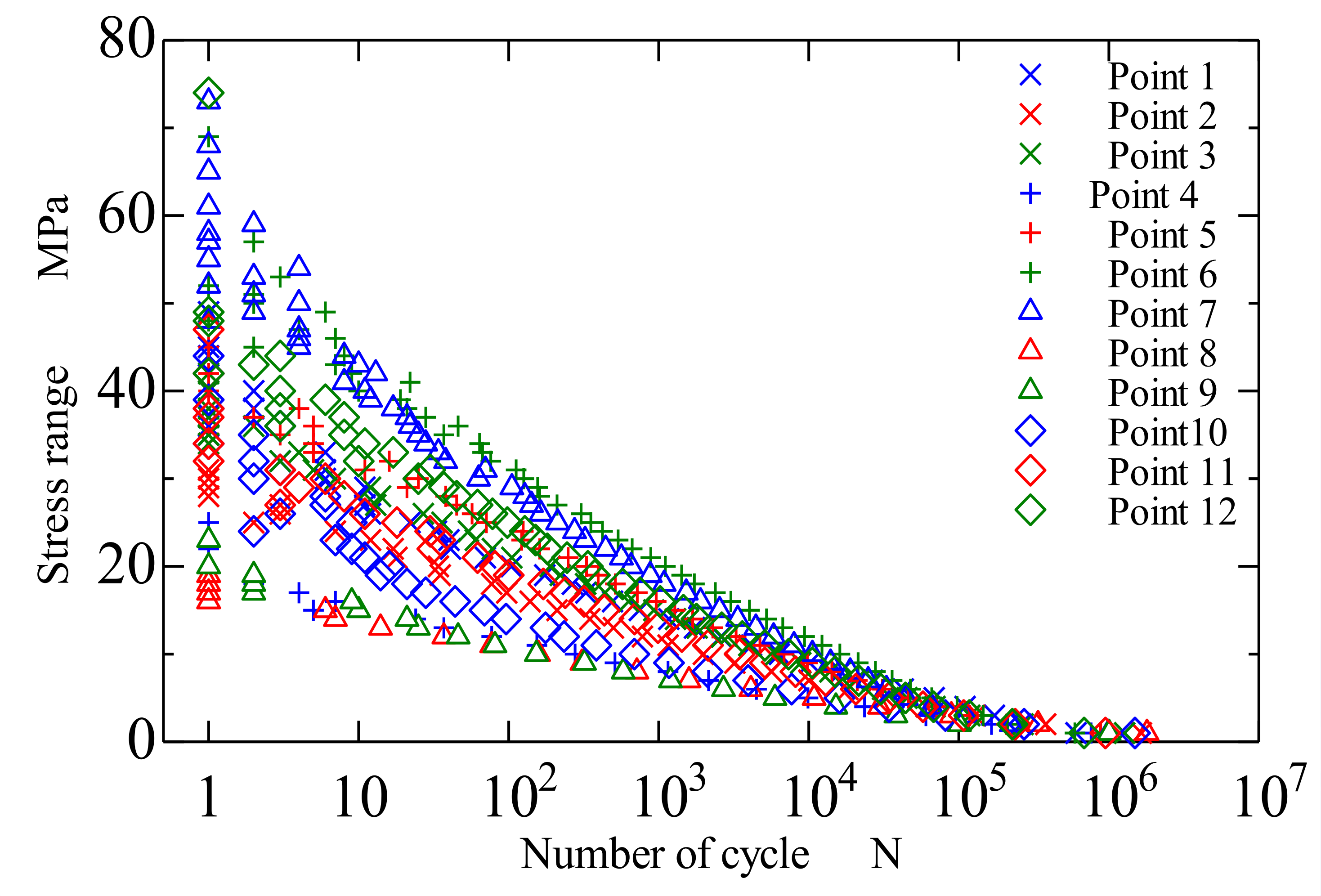
Running test overview

- Measurement object: Bogie frame of Shinkansen trains
- Measurement section: Commercial line
- Measurement item: Fluctuating stress

fluctuating stress measured in running tests

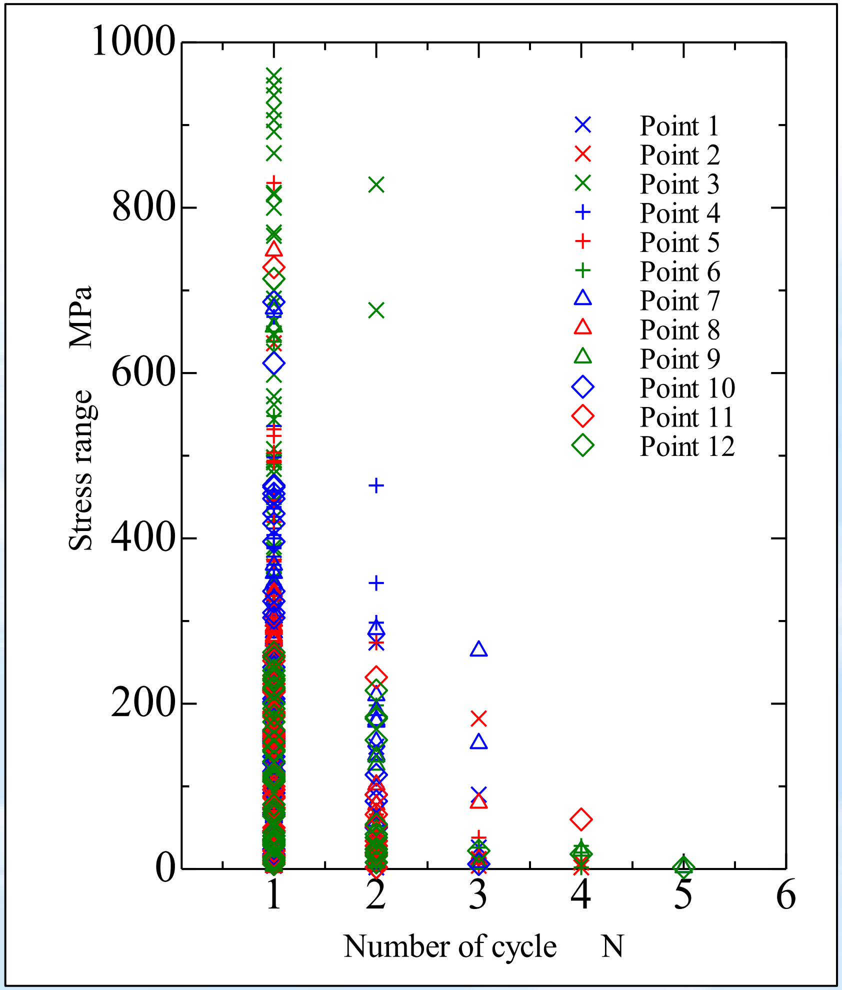
No.	Measurement pint	Max Stress MPa	Min stress MPa	Stress range MPa
1	Air spring seat	29	-20	49
2	Upper surface of cross beam	19	-16	35
3	Edge of Lateral damper seat	19	-23	42
4	Joint of connection beam/cross beam(Side)	16	-7	23
5	Joint of connection beam/cross beam(Upper)	24	-22	46
6	Joint of support of traction motor/cross beam	34	-35	69
7	Joint of side beam/cross beam (Lower)	40	-33	73
8	Upper surface of side beam	11	-9	20
9	Lower surface of cross beam (Center)	13	-10	23
10	Joint of axle beam/side beam	23	-21	44
11	Axle beam seat	29	-18	47
12	Lower surface of side beam	27	-33	60

Fatigue damage evaluation of bogie frame



Stress frequency distribution in running test

Fatigue damage evaluation for bogie frame receiving the seismic load



Frequency distribution of stress generated in the bogie frame due to earthquake motion

Cumulative damage degree by modified Minor rule

$$D = \sum \frac{n_i}{N_i}$$

Frequency n_i for stress range $\Delta \sigma_i$

Limit fatigue repetition number Ni

D =1 ⇒Fatigue failure

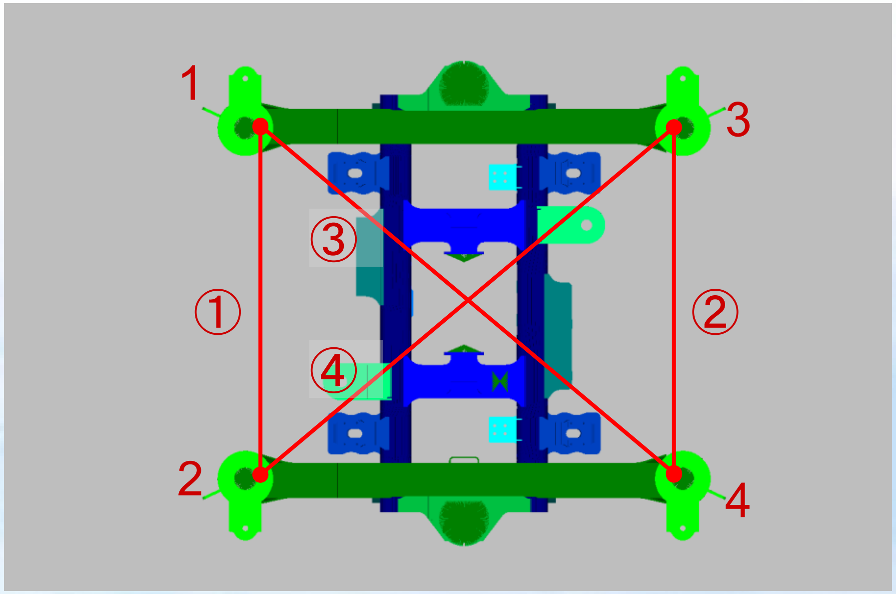
Evaluation of the Effect of Earthquake Motion on Bogie Frames

Cumulative fatigue damage assuming seismic loading

No.	Evaluation point	Degree of damage due to normal running D_n	Degree of damage due to seismic motion D_{eq}	Total Damage $D = D_n + D_{eq}$
1	Air spring seat	0.1340	0.0288	0.163
2	Upper surface of cross beam	0.0727	0.0192	0.092
3	Edge of Lateral damper seat	0.0367	0.061	0.098
4	Joint of connection beam/cross beam(Side)	0.0123	0.0093	0.022
5	Joint of connection beam/cross beam(Upper)	0.1377	0.0337	0.171
6	Joint of support of traction motor/cross beam	0.1953	0.0274	0.223
7	Joint of side beam/cross beam (Lower)	0.2163	0.0331	0.249
8	Upper surface of side beam	0.0840	0.0088	0.093
9	Lower surface of cross beam (Center)	0.0680	0.0006	0.069
10	Joint of axle beam/side beam	0.0913	0.0256	0.117
11	Axle beam seat	0.1650	0.0165	0.182
12	Lower surface of side beam	0.2060	0.0192	0.225

＊ The degree of damage during normal driving is assumed to be 20 million km from the time the car is new to the time it is scrapped.

Evaluation of the Effect of seismic Motion on Bogie Frames



Affect of plastic deformation due to seismic force

Center of Axle spring seat	Distance between centers of spring mm	Permanent deformation mm	Manufacture tolerance mm
①1-2	2000	0.42	0.5
②3-4	2000	0.39	
③1-4	3202	0.15	1.0
④2-3	3202	0.38	

Concept of bogie frame design against seismic motion

Strength design
Stress evaluation under static load/dynamic load

Structural design
Shape, material, welded structure

Design based on JIS standards (conventional design)

↓

Seismic motion assumption

↓

Evaluation of the force acting on the bogie frame during an earthquake
Vehicle Dynamics analysis

→

Evaluation of stress and permanent deformation of bogie frame due to Seismic motion
Elastoplastic stress analysis

↓

Verifying that the mechanical performance of the bogie frame structure conform to the standard

Concept of bogie frame design against seicsmic motion

...Thank you
for your kind attention