Damage of steel bridges in the earthquake

Outline of damage in the Kobe Earthquake

- Classification of damage of steel piers of Hanshin Expressway

Table 2 Damage Degree of Steel Piers (number)

Damage Degree					Total
As	A	B	C	D	
4 (1%)	11 (3%)	36 (10%)	138 (39%)	166 (47%)	355 (100%)

Table 1 Definition of Damage Degree of Steel Piers

Damage Degree	Definition
As	Collapsed. Extremely serious damage or deformation.
A	Cracking, buckling or serious deformation.
B	Partial buckling or deformation of members.
C	Localized light buckling or deformation.
D	No damage, or if there is, extremely minor damage that will not effect the load bearing capacity.

Ref [Nishikawa et al. : AN EXPERIMENTAL STUDY ON SEISMIC RETROFIT OF STEEL BRIDGE PIERS, US-JAPAN BRIDGE WORKSHOP]

Outline of damage in the Kobe Earthquake

- Classification of damage of superstructures of Hanshin Expressway

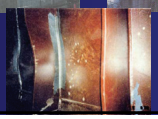
Part of Superstructure	Damage Degree				
	A	B	C	D	Total
Surroundings of Bearings	112 (7%)	142 (8%)	62 (4%)	1,364 (81%)	1,680 (100%)
Portions where Falling-down Prevention Devices are Connected	4 (0%)	24 (2%)	38 (3%)	1,317 (95%)	1,382 (100%)
Deck Itself	1 (0%)	5 (0%)	2 (0%)	1,672 (100%)	1,680 (100%)
Others	26 (14%)	29 (16%)	12 (6%)	120 (64%)	187 (100%)
Total	143 (3%)	200 (4%)	114 (2%)	4,473 (91%)	4,930 (100%)

(c) Superstructure

Damage Degree	Definition
As	Falling-down of superstructure
A	Major damage of main members to cause loss of bearing capacity such as rupture of lower flange in steel girders and extensive drop-off of concrete in concrete girders
B	Moderate damage of main members to cause loss of bearing capacity such as deformation of lower flange of steel bridges and large cracks of concrete in concrete girders
C	Damage of secondary members
D	No damage or minor damage

Ref [K. KAWASHIMA and S. UNJOU :INPACT OF HANSHIN/AWAJI EARTHQUAKE ON SEISMIC DESIGN AND SEISMIC STERNGHENING OF HIGHWAY BRIDGES, J. Struct. Mech. / Earthquake Engrg., JSCE, No.556/I-38, pp.1-30]

Damage of steel bridges piers (Rectangular section)

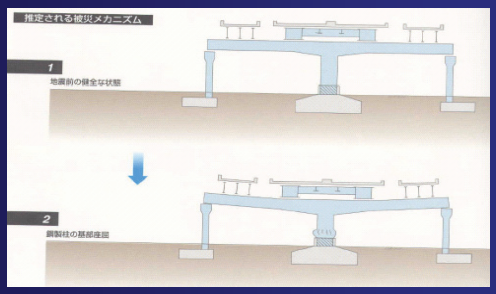


Collapse of steel bridge piers

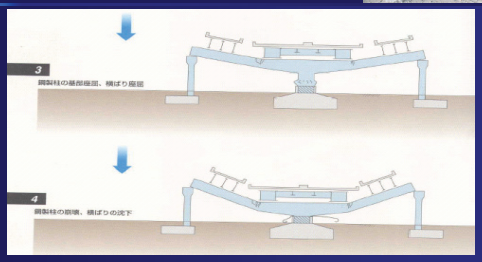
- Iwaya crossing

- Tateishi

Failure mechanism of highway bridges at Tateishi

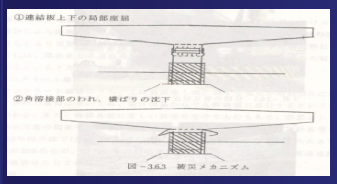


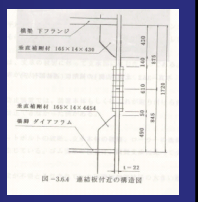
Failure mechanism of highway bridges at Tateishi



Ref [. Ministry of Construction:: Report on the damage of Highway Bridges by the Hyogo ken Nanbu Earthquake, Committee for Investigation on the Damage of Highway Bridges caused by the Hyogo-ken Nanbu Earthquake]

Failure mechanism of highway bridges at Iwaya





Ref [. Ministry of Construction:: Report on the damage of Highway Bridges by the Hyogo ken Nanbu Earthquake, Committee for Investigation on the Damage of Highway Bridges caused by the Hyogo-ken Nanbu Earthquake]

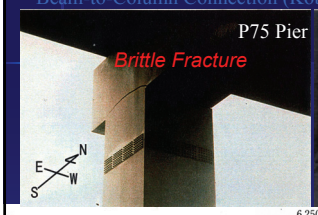
Damage of steel bridges piers (Circular section)

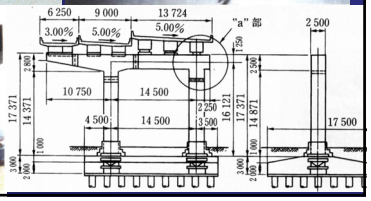
Damage of steel beiges piers (Circular section)

- Elephant foot buckling

Damage Cases in Hyogo-ken Nanbu Earthquake

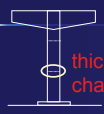
Beam-to-Column Connection (Kobe Harbor Highway)



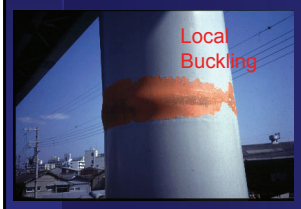


Damage Cases in Hyogo-ken Nanbu Earthquake

3. Circular Pier

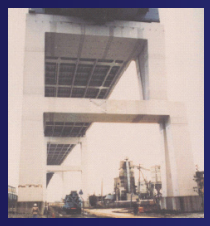


thickness changing point



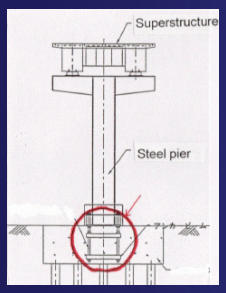
Material Tests

Shear Buckling of beam members

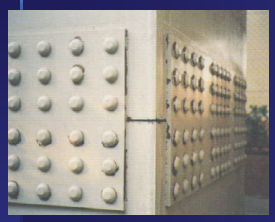


- Steel rigid frame pier

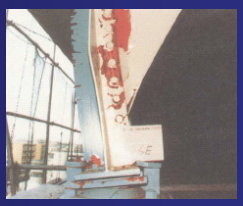
Damage of anchor bolts



Damage of joints

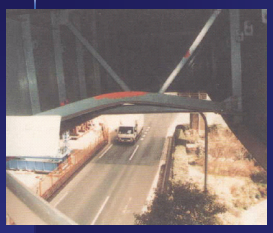


Damage of superstructures



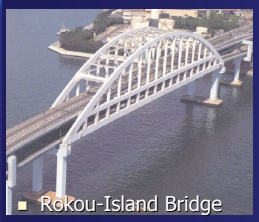
Damage of superstructures

Damage of superstructures

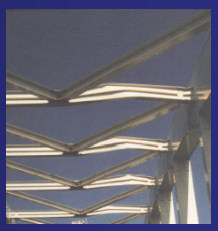


- Buckling of lateral bracing

Damage of superstructures

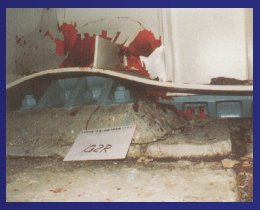


- Rokou-Island Bridge



- Buckling of upper lateral bracing

Damage of superstructures



- Damage of surroundings of bearings

Damage of bearing supports

- Damage of bearings

Damage of superstructures

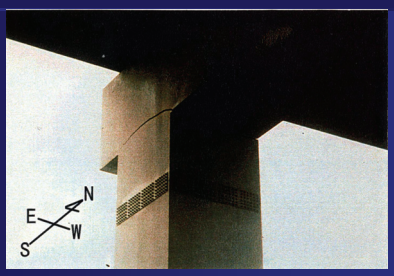
- Plastic deformation of steel cable

Damage of bearing supports

- Steel rigid frame pier of railway bridges

Damage of bearing supports

Brittle failure of beam-to-column connection



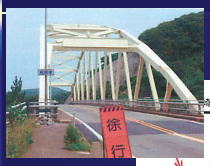
- Steel rigid frame pier of harbor highway bridges

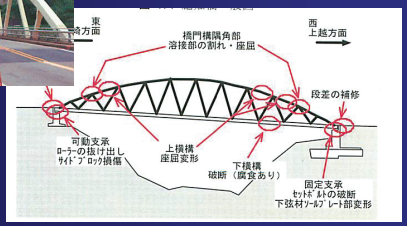
Niigata-ken Chuetsu-oki Earthquake

Ref [National Institute for Land and Infrastructure Management: Report on Damage to Infrastructure and Buildings by the 2007 Niigata-ken Chuetsu-oki Earthquake, Technical Note of National Institute for Land and Infrastructure Management, No.439, 2008.]

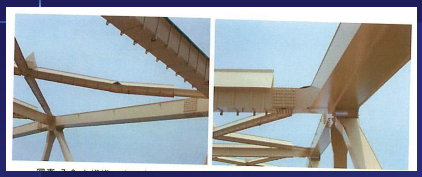
http://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0439.htm

Damage at Yonahime bridge

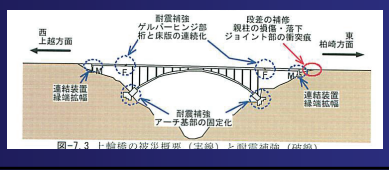




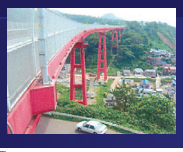
Damage at Yonahime bridge

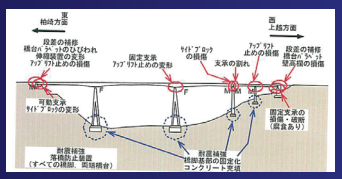


Damage at Agewa bridge

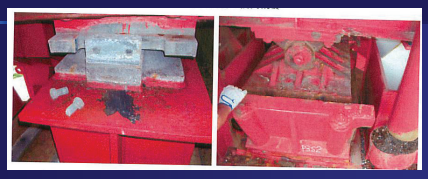


Damage at Yoneyama bridge

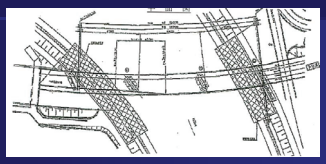


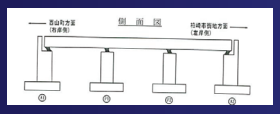


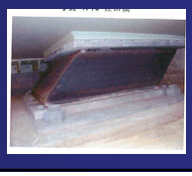
Damage at Yoneyama bridge



Damage at Toyoda bridge





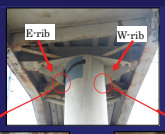


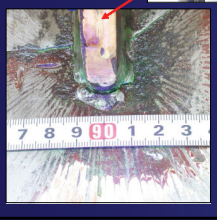
Cause Identification of Fracture in Steel Pipe Column of Pedestrian Bridge

Fractured Pedestrian Bridge

Location of Fracture

Cracks and Damage in 'P1' Column





Damage in Superstructure

Examinations for Cause Identification of Fracture

Luder's Bands

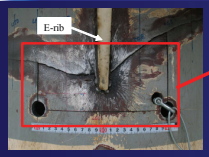
Damage in Superstructure

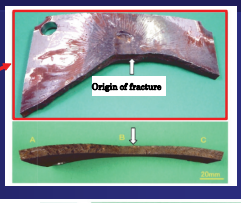
The possibility that the fracture may have been caused by Car Crash

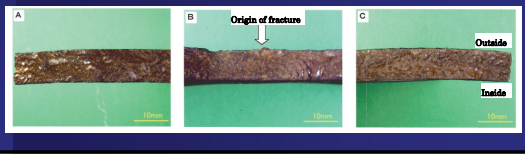
Following examinations were conducted

- Observation of crack surfaces
- Chemical analysis, Charpy V-notch impact tests, Vickers hardness tests
- Stress (Strain) measurements

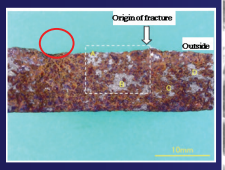
Visual Observation (E-rib)

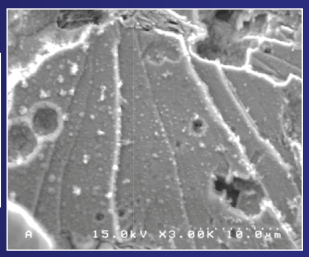






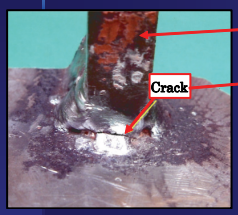
SEM Observation (E-rib)



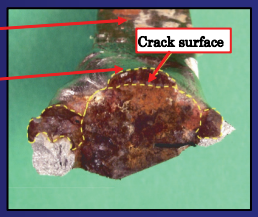


(×3,000)

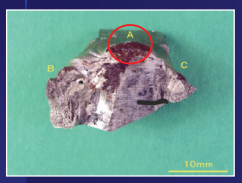
Visual Observation (W-rib)

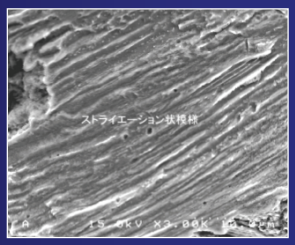


W-rib



SEM Observation (W-rib)





(×3,000)

Chemical Analysis

	C	Si	Mn	P	S
Base Metal	0.20	0.009	0.49	0.010	0.015
SS400 (JIS)	-	-	-	<0.050	<0.050
STK400 (JIS)	<0.25	-	-	<0.040	<0.040

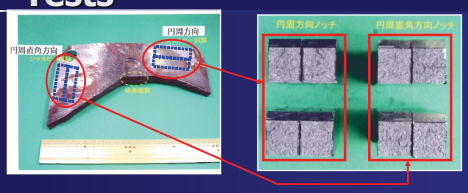
・Chemical components of the fractured pipe column satisfied those specified in JIS at that time

Vickers Hardness Tests

Measured Value (HV)					Average Value
146	151	160	173	162	158

・The tensile strength estimated form 158 HV was 510MPa that satisfied the tensile strength of SS400 at that time.

Charpy V-notch Impact Tests

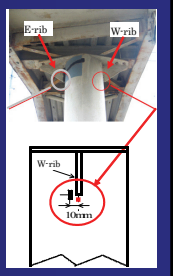


Direction that test specimens were removed from	Temperature (°C)	Absorbed energy (J)	Percentage brittle failure (%)
Circumference	0	10	95
	0	6	95
Perpendicular to circumference	0	4	100
	0	6	100

Stress (Strain) Measurements

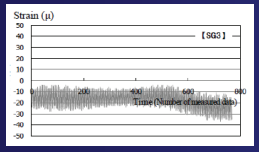
Cases of strain measurements

- ・Case 1: Traffic of vehicles
- ・Case 2: 1 pedestrian's walking or running
- ・Case 3: 3 pedestrians' walking or running

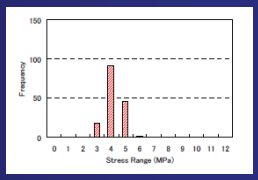


Measuring point of strain

Strain Response and Stress Range Histogram by Bus

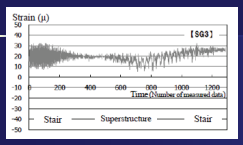


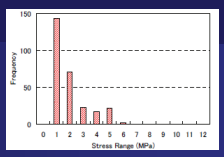
Strain Response



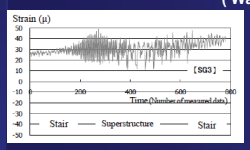
Stress Range Histogram

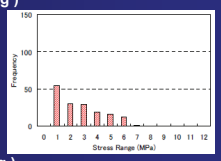
Strain Response and Stress Range Histogram by 1 Pedestrian





(Walking)



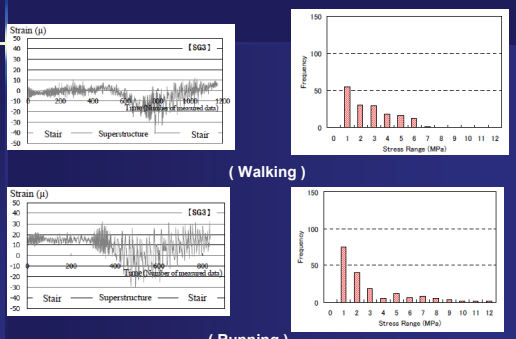


(Running)

Strain Response

Stress Range Histogram

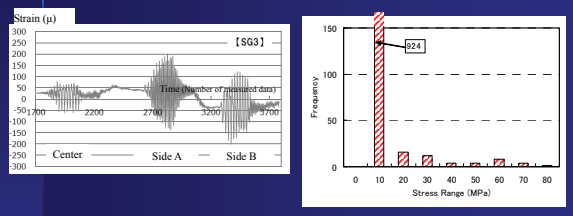
Strain Response and Stress Range Histogram by 3 Pedestrians



Strain Response

Stress Range Histogram

Strain Response and Stress Range Histogram by 5 Pedestrians' Jumping



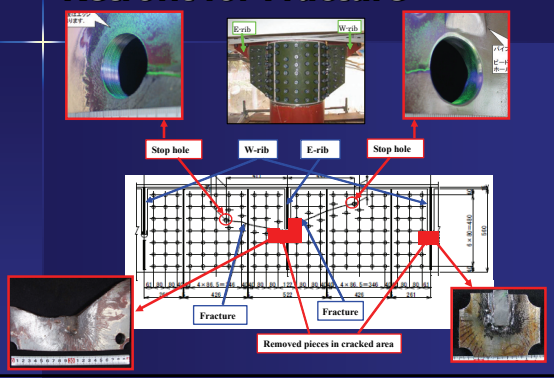
Strain Response

Stress Range Histogram

Estimated Mechanism of Fracture

- Fatigue cracks originated form welding cracks at poor welding.
- Fatigue cracks propagated by the stress under the service condition and crack length reached a certain length.
- The serious fracture was caused by car crash.

Retrofit for Fracture



Pedestrian Bridge after Retrofitting and Repainting