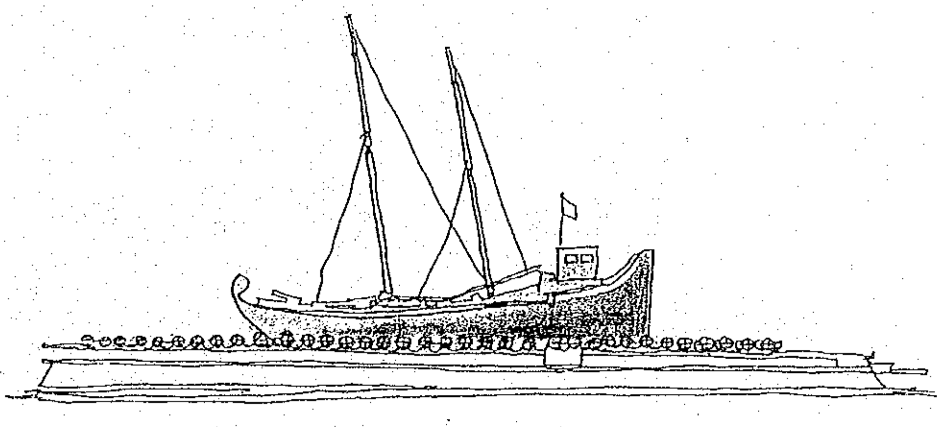
CHAPTER 5 LOAD TEST OF THE EXISTING BRIDGES



CHAPTER 5

LOAD TEST OF THE EXISTING BRIDGES

5.1 Method of Load Test

1) Purpose of the Load Test

The planning and scheduling of the load testing has been described in the Flow Chart in the previous Chapter 3 and 4. The nondestructive testing of bridges using the static load vehicle defines the load testing in this chapter.

The load tests of the 9 bridges (6 RC bridges and 3 PC bridges) were performed in 2 stages of Stage 1 and Stage 2 as follows:

Stage 1 Test .... 4 RC Bridges
Stage 2 Test .... 2 RC Bridges, 3 PC Bridges

The load test was performed on all bridges by selecting the span in the worst condition and conducting the static load test with the load test vehicle. The bridge deflection together with the strain in the reinforcing bar, strain in the concrete, and thermal strain caused by the deflection are measured, and the results compared with the theoretical values (grid framework analysis). Changes in the bridge are thus obtained to determine the safe load capacity of the bridge and filed with the load characteristics of the bridges.

2) Method of Test

a) The Load Testing Vehicle

The load testing vehicle is a dump truck with a water tank strapped on the truck bed. The front wheel load and rear wheel load are measured at a weigh station in Muscat so that the truck with the water tank will meet the T-20 ton rating. The following values were obtained.

	Front Wheel (1 axle x 2)	Rear Wheel (1 axle x 2)
T-20 ton (water load)	3.0 x 2 ton	7.0 x 2 ton
T-14.6 ton (no water load)	2.7 x 2 ton	4.6 x 2 ton

The bridge inspections were performed using a test load vehicle with the above characteristics.

b) The Position of the Load Testing Vehicle

The positioning of the load test vehicle on the bridges is single and the rear wheel load is located at the center of the section of the bridge span. The spacing of the front and rear wheel axles is 4.90 m, and the spacing of the rear wheel axles is 1.85 m. The method of truck loads applied to the bridge is as described in Fig. 5.1.

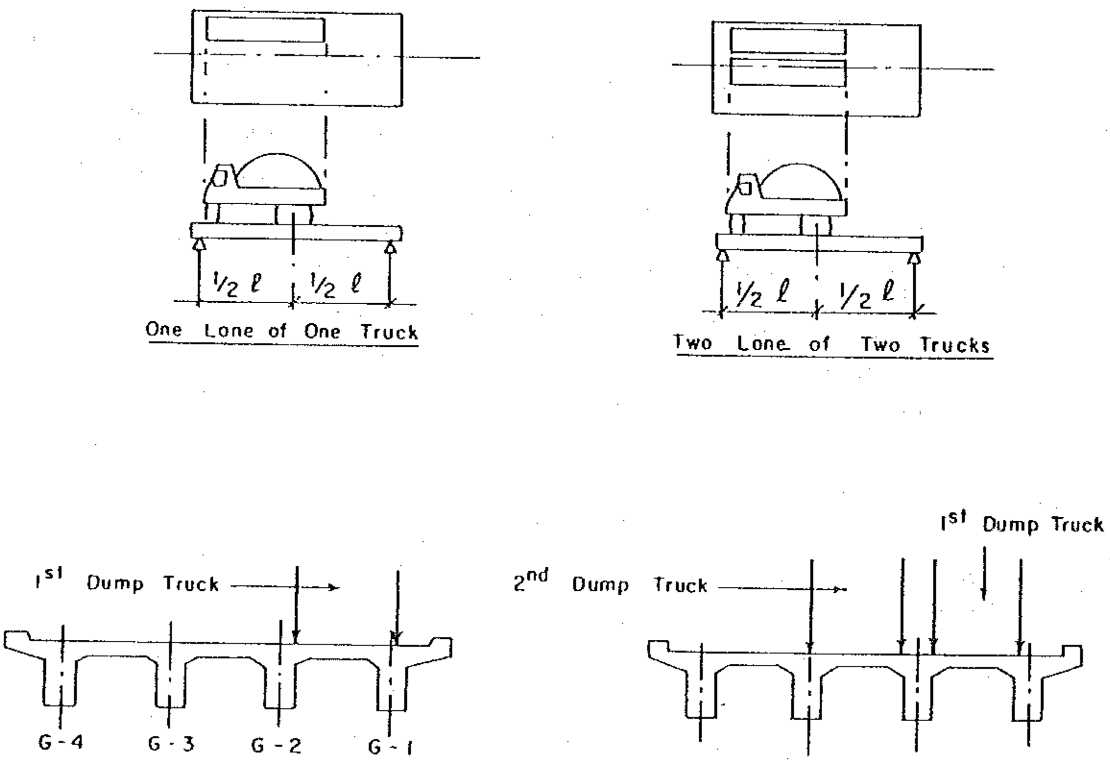


Fig. 5.1 Loading Position of Bridges

The load testing of the bridges consists of the T-20 ton (water load) and T-14.6 ton (no water load), applied on a single lane, and to the double lane (1 truck, 2 trucks), for a total of 4 cases. Due to the amount of traffic and the detour routes, there were some bridges where the T-20 ton truck was applied to the single lane, double lane, and finally 2 trucks in 2 lanes.

Loading Case on Bridges

(Unit: ton)

Case No.	A-Load					B-Load					Total Load
	A.F.W.	A.F.W.	A.R.W.	A.R.W.	A-Total	B.F.W.	B.F.W.	B.R.W.	B.R.W.	B-Total	
1	3.0	3.0	7.0	7.0	20.0						20.0
2	3.0	3.0	7.0	7.0	20.0	3.0	3.0	7.0	7.0	20.0	40.0
3	2.7	2.7	4.6	4.6	14.6						14.6
4	2.7	2.7	4.6	4.6	14.6	2.7	2.7	4.6	4.6	14.6	29.2

Legend

A.F.W. : A-Truck Load Front Wheel
A.R.W. : A-Truck Load Rear Wheel
B.F.W. : B-Truck Load Front Wheel
B.R.W. : B-Truck Load Rear Wheel

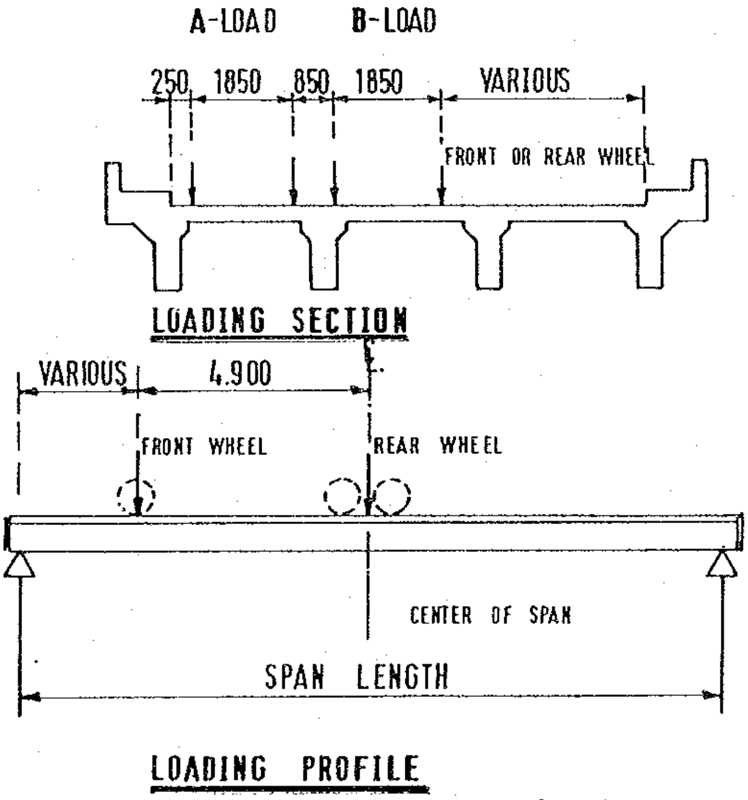


Fig. 5.2 Load Condition of Each Case

3) Measuring Method and Measuring Positions

Monitoring the behaviour of the structures is made using the various instruments, and the measuring was made in accordance with the following flow chart in Fig. 5.3.

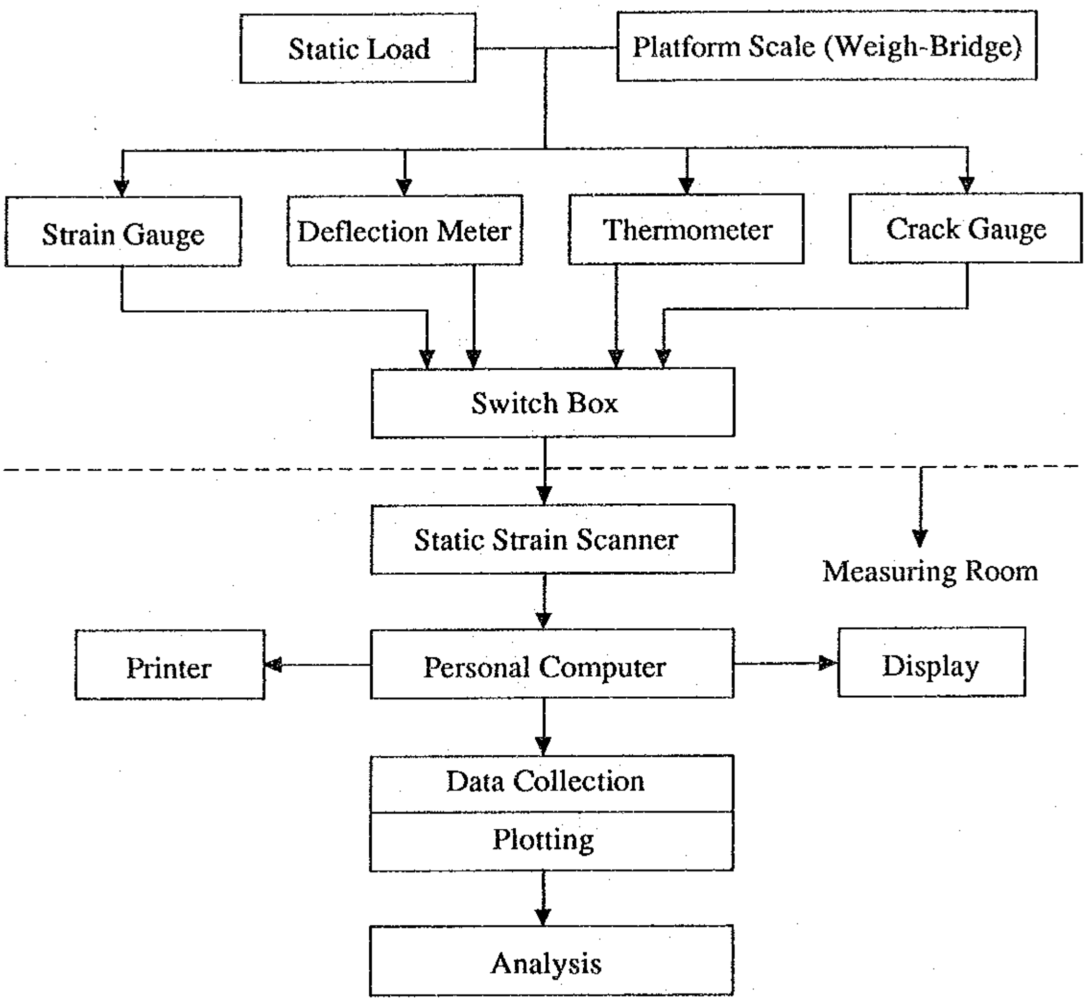


Fig. 5.3 Flow of Static Strain Load Test

The various tests by strain gauge, deflection, and crack were taken at each bridge and are as indicated in Table 5.1.

Table 5.1 Number of Measurement Equipment (1 bridge, 1 span)

		For RC Beam
1	Strain Gauge for Rebar (FLK-2)	36 Nos.
2	Strain Gauge for Concrete (BT-102B)	32 Nos.
3	Deflection Meter (CDP-50-100)	28 Points
4	Crack Gauge (KV-5C, KV-25B)	11 Points
5	Crack Meter (BCD-5B)	12 Points
6	Thermometer (BT-102B)	8 Points
7	Thermo Gauge (KTR-KTC)	8 Points
8	Plate Mirror	5 Points

The actual location of the measurement points on the RC bridges and PC bridges were at the center of the span or at the halfway points, and were performed in accordance with the following diagrams.

Location of Strain Gauges on RC bridges (Fig. 5.4)
Location of Strain Gauges on PC bridges (Fig. 5.5)
Location of Strain Gauges on RC, PC bridges (Fig. 5.6)

The total number of test points on all the 9 bridges are in accordance with Table 5.2.

Description of Equipment

- Strain Gauge (Steel Plate and Steel Bar)

  Apply thin foil to surfaces of reinforcing bar and steel pipe with epoxy glues, read and evaluate strain on the foil by photoetching techniques. Foil gauges can be applied easily to curved surfaces, they have lower transverse sensitivity, exhibit negligible hysteresis under cycling loads, creep little under sustained loads, and can be stacked on top of each other.

- Strain Gauge (Concrete)

  Electrical-resistance wire gauges are bonded onto a polyester for protection with a felt pad. Surface strains (stress by Hooke's law) can be measured on concrete surfaces.

- Crack Gauge

  A strain gauge is applied onto a spring plate, and is used to measure cracks in concrete.

- Deflection Meter

  The deflection meter is used to measure subsiding and horizontal movements of structures. CDP-50 is used to measure movements of 50 mm and 1/100 mm.

- Explanation of Strain

  When a force is applied to a material tension (or compression) is developed an amount of deformation as strain is caused. Strain denotes the ratio of a material's deformed dimension to a material's original dimensions. For example, strain in a longitudinal direction is computed by dividing the change in length by the original length.

$$\text{Strain } (\varepsilon) = \frac{\text{Change in Length } (\Delta L)}{\text{Original Length } (L)}$$

where, ε : strain

L : original length

ΔL : deformation caused by external force

Multiplying the strain (ε) by the Modulus of Elasticity of the material, the stress can be obtained.

$$\sigma = \varepsilon \cdot E$$

where, σ : stress corresponding to strain

ε : strain

E : Modulus of Elasticity of the material

- Static Strain Scanner

  An instrument which converts strain or deformation by the change in the material causing changes in the electrical resistance of the gauge.

- Switch Box

  An electrical device used for connecting multiple static strain instruments and the gauges can be used to monitor the gauges from a central location on or near the bridge.

- Personal Computer

  A device used to compute data measured by static strain gauges and records and stores this information, and can print out the data being received and or recorded, while monitoring the information.

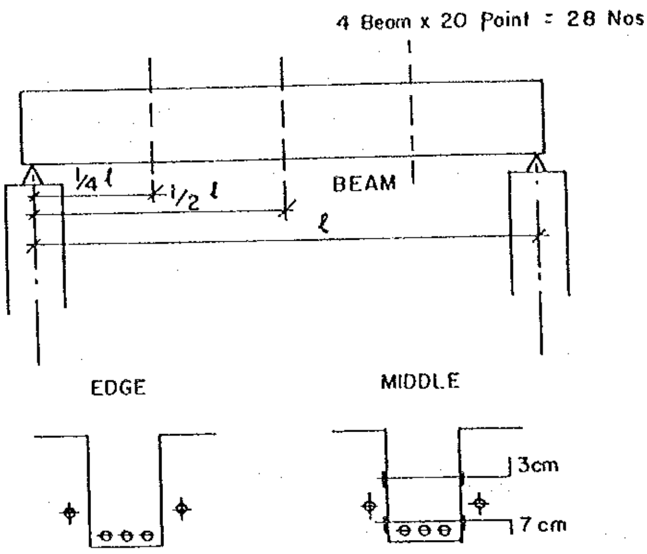


Fig. 5.4 Setting Point of Strain Gauge (RC Bridge)

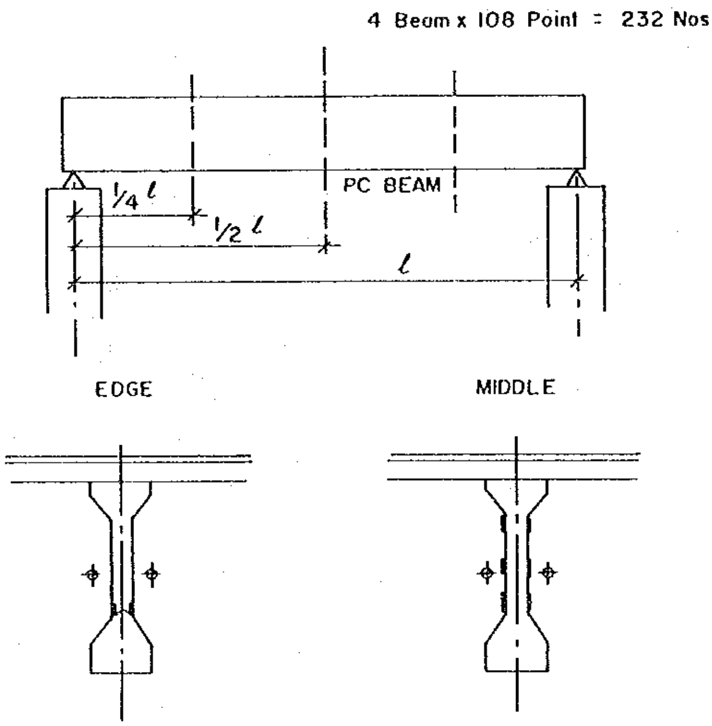
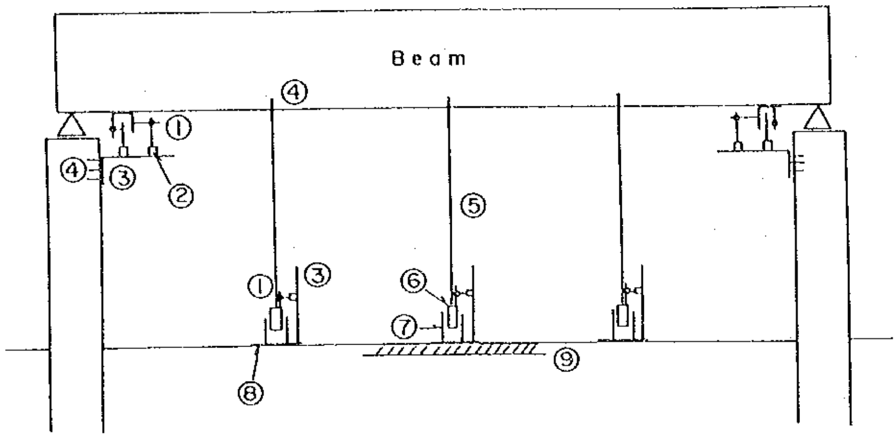


Fig. 5.5 Setting Point of Strain Gauge (PC Bridge)

4 beams x 7 nos = 28nos

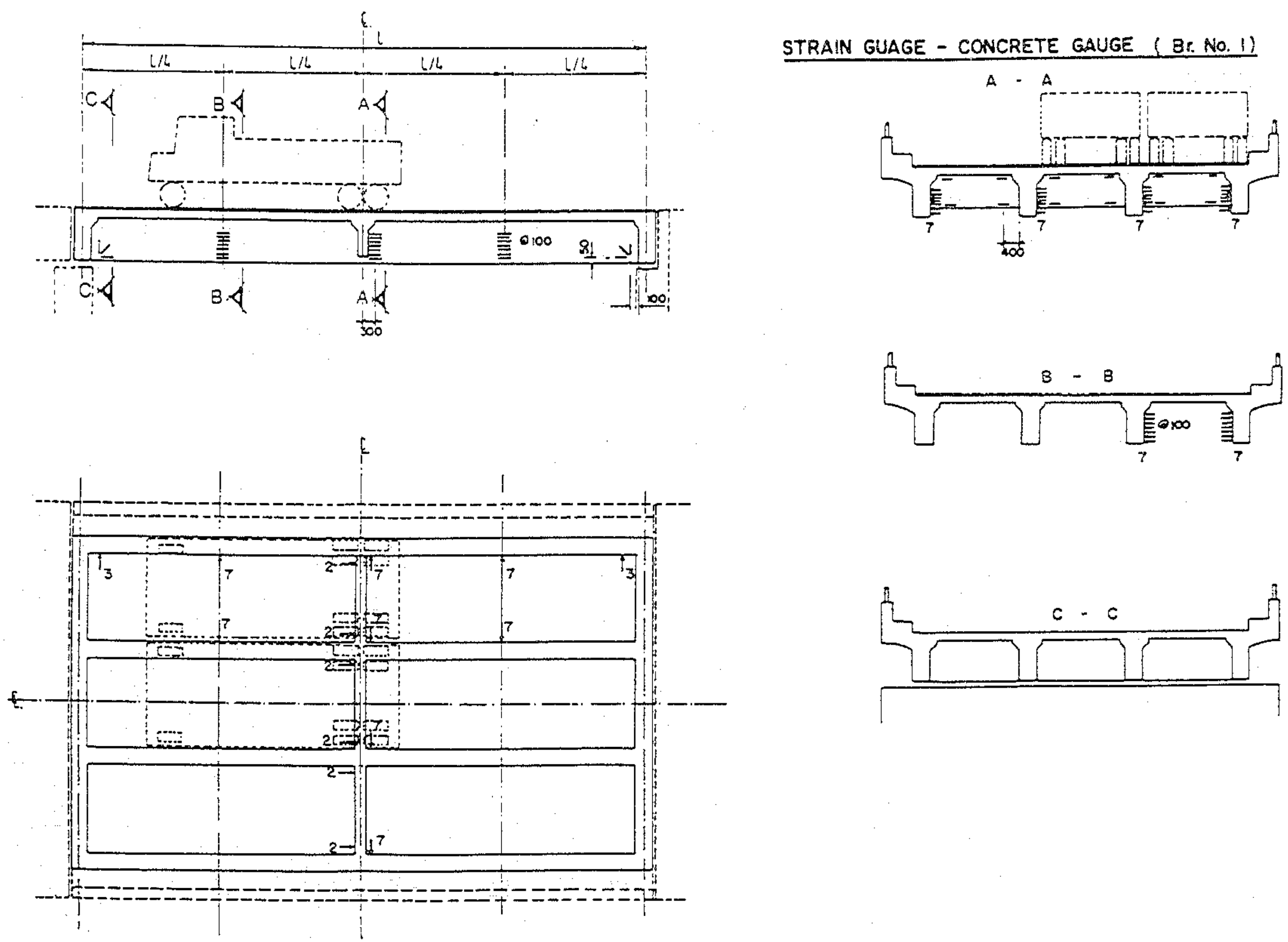


① Deflection Meter CDP – 50 ~ 100mm
② Magnet Stand
③ Fixing Arm
④ Anchor Bolt
⑤ Pc Wire
⑥ Weight 80 x 170
⑦ Sway Stopper
⑧ Fixing Plate
⑨ Scaffolding Pipe or River Bed

Fig. 5.6 Setting Point of Deflection Meter (RC, PC)

Table 5.2 Actual Set Numbers of Measurement Equipment

Bridge No.	Number of Measurement Equipment				
	Strain Gauge for Rebar	Strain Gauge for Concrete	Deflection Meter	Crack Gauge	Thermo Gauge
1	24	74	35	4	10
2	36	46	31	4	10
3	16	58	35	4	10
4	28	50	35	5	10
5	16	62	35	4	10
6	–	96	36	–	7
7	–	52	34	–	7
8	20	70	35	4	10
9	–	84	35	–	8
Total	140	592	311	25	82



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.7 Setting Position of Measurement Equipment (Br.No.1)

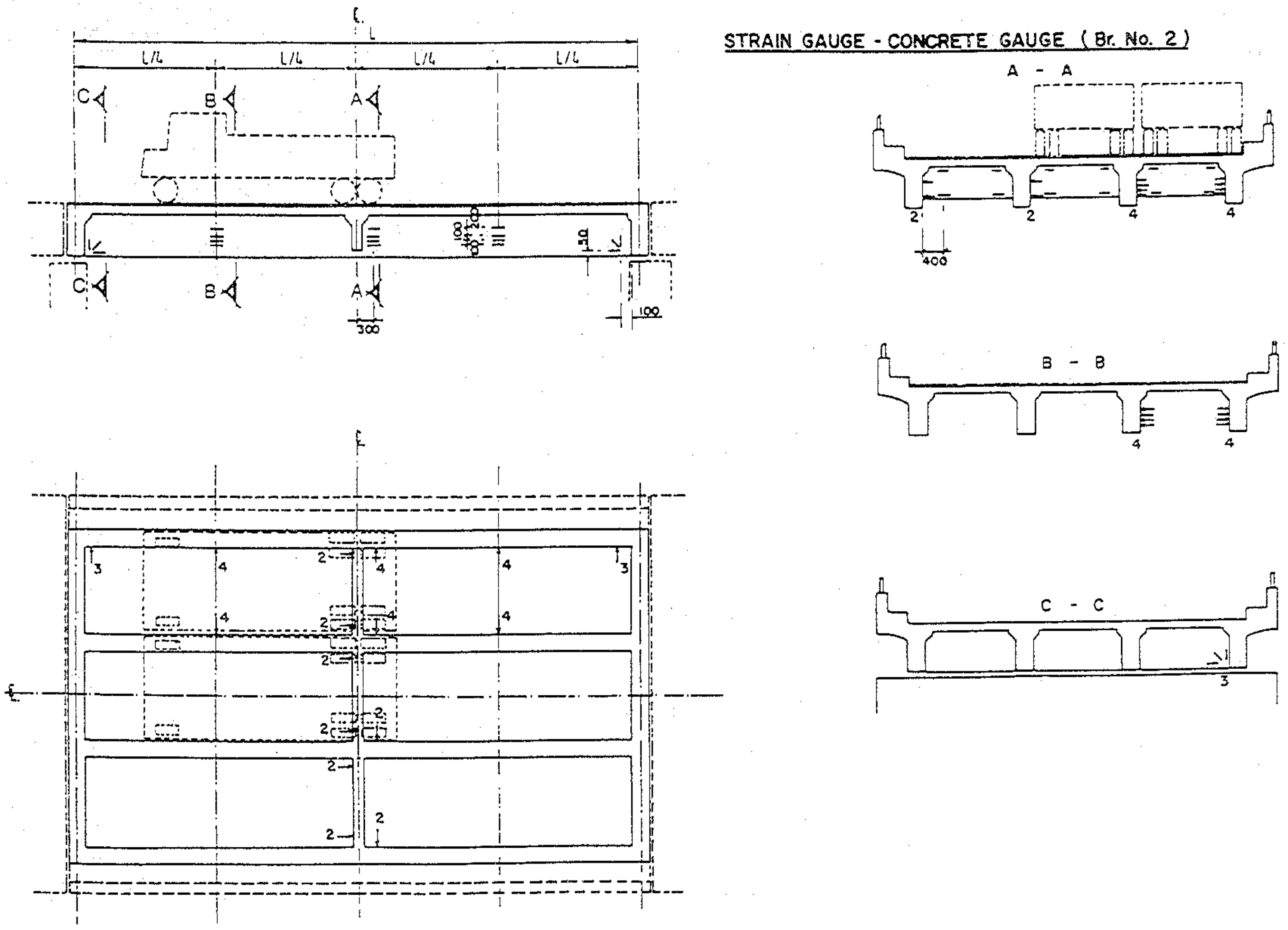


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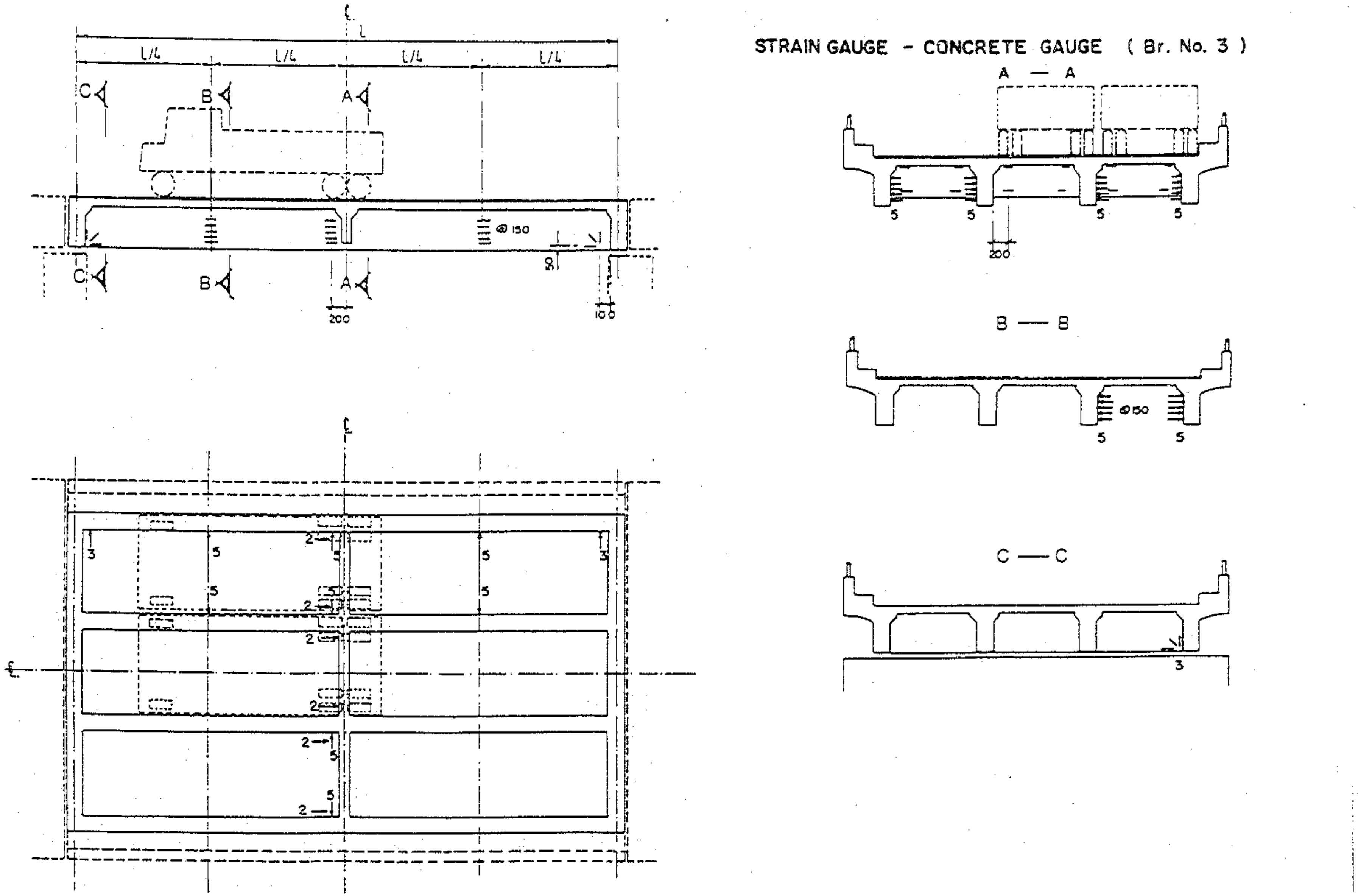
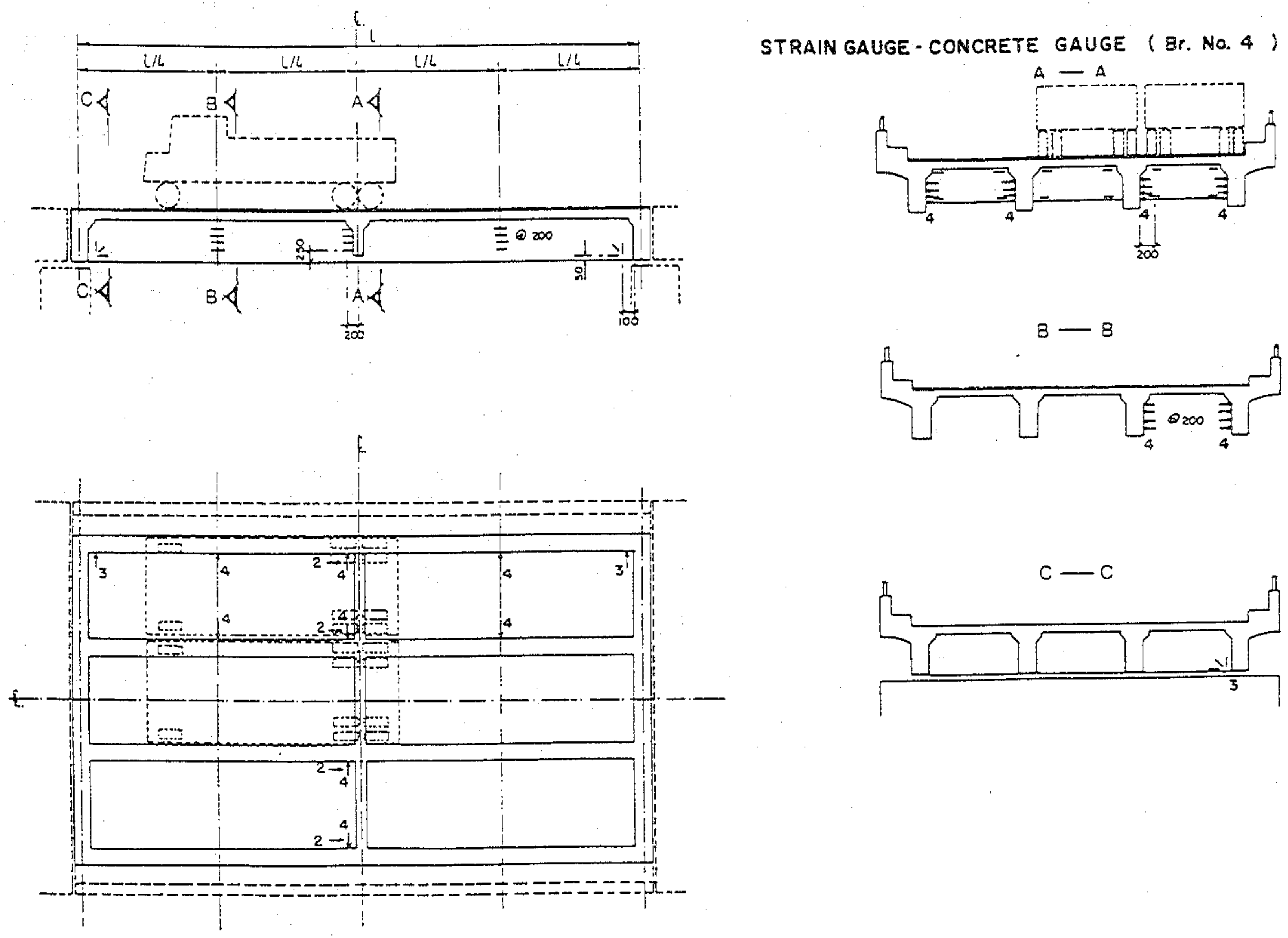
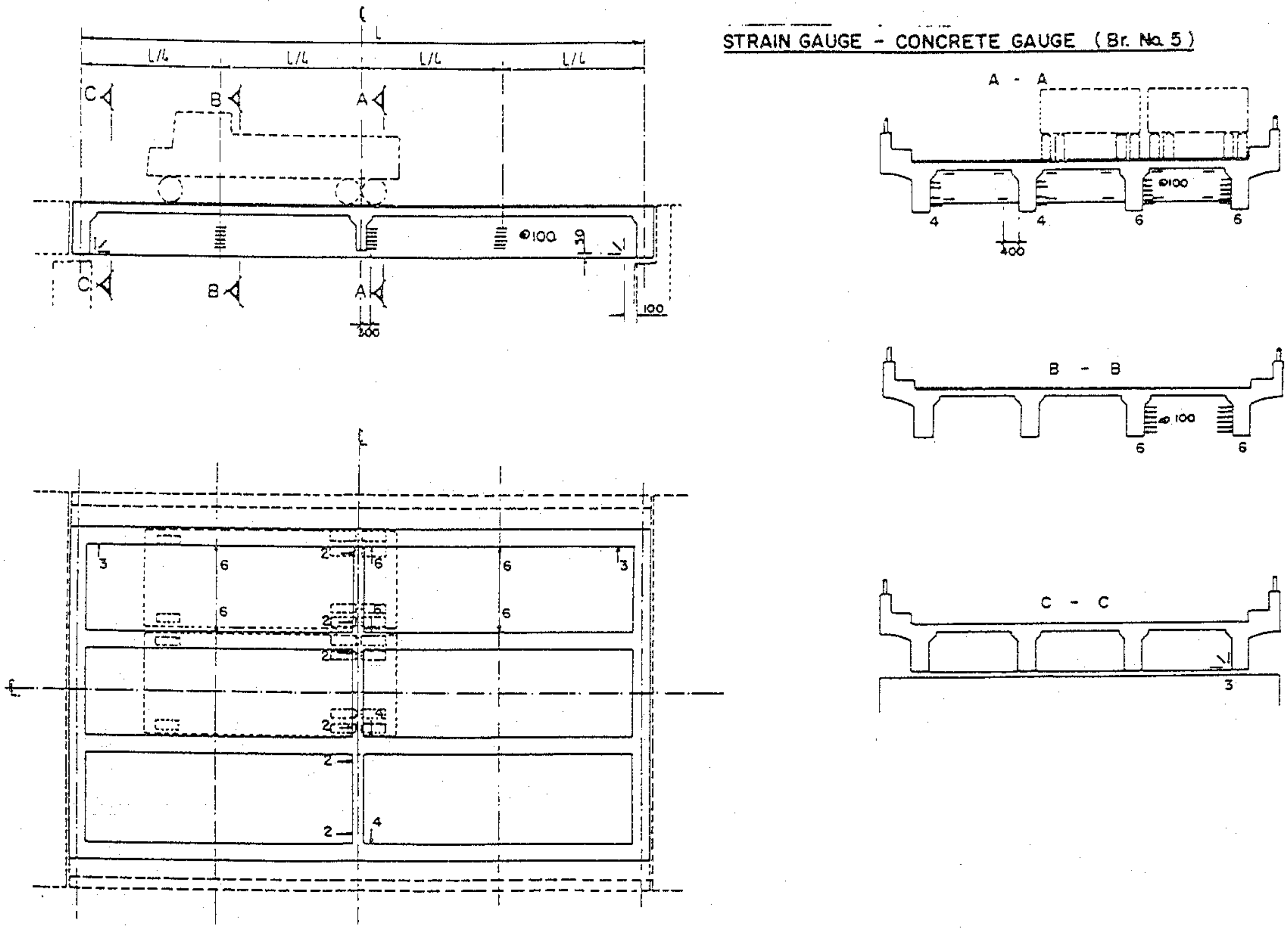
Fig 5.8 Setting Position of Measurement Equipment (Br.No.2)



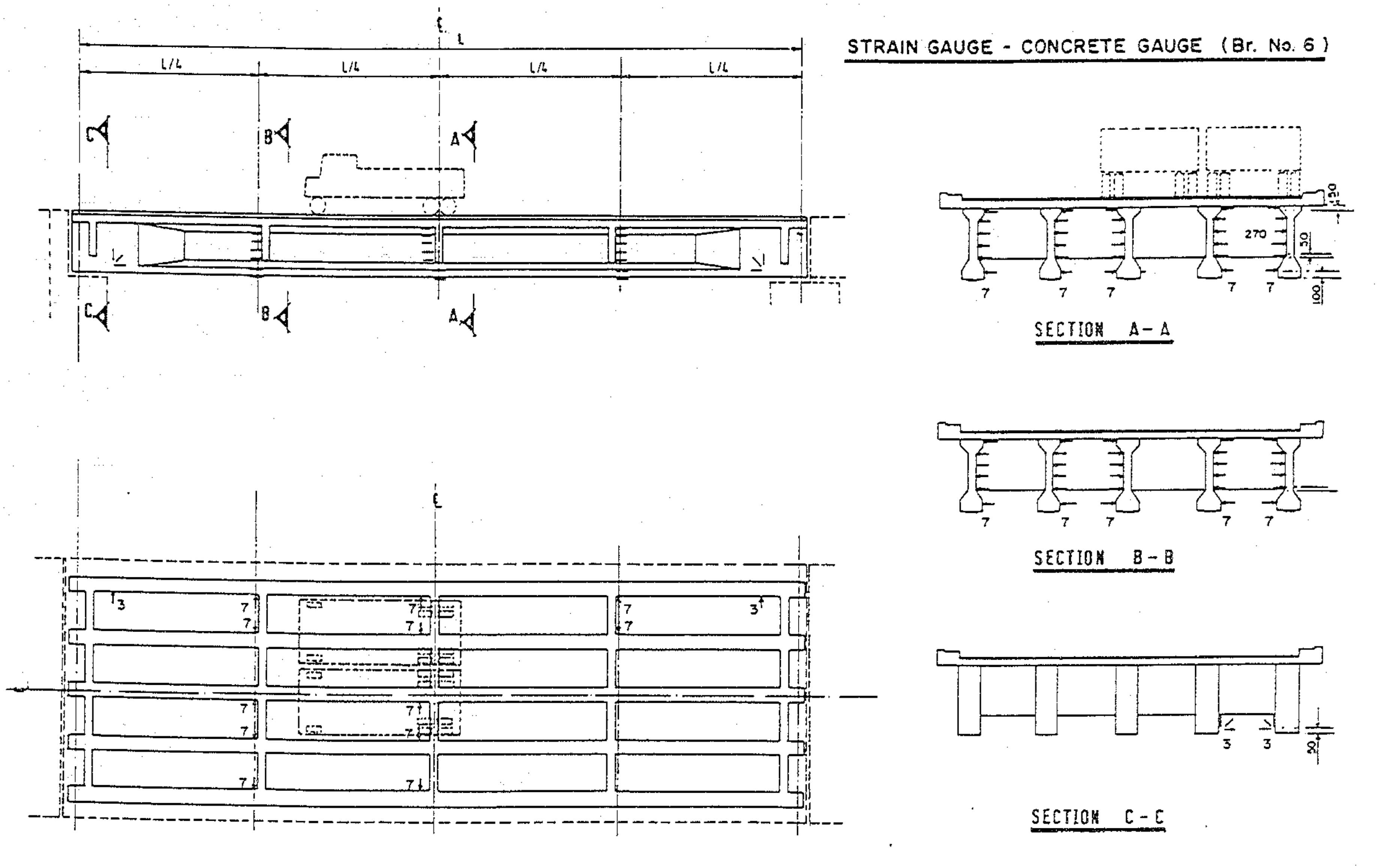
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.9 Setting Position of Measurement Equipment (Br.No.3)



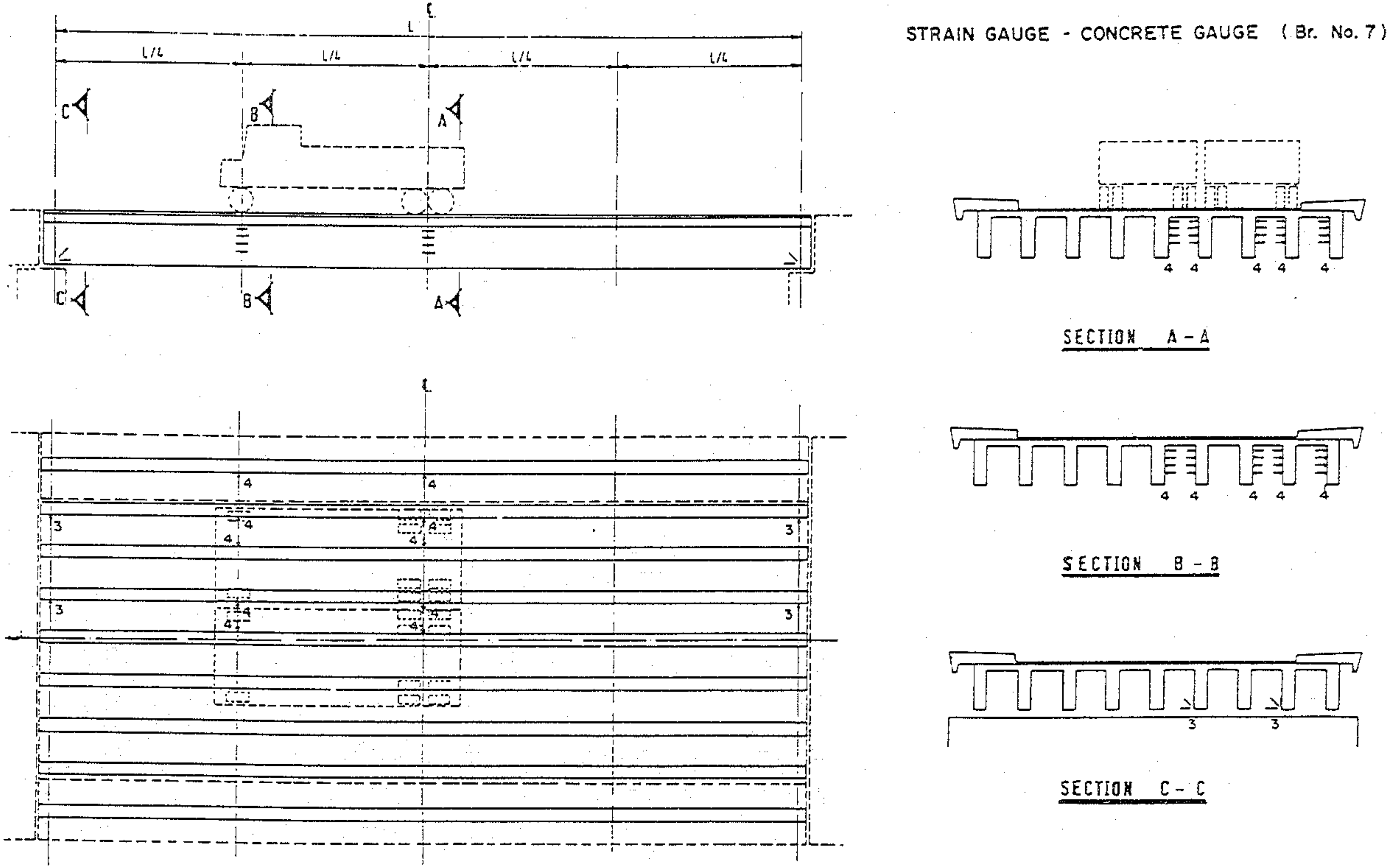
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.10 Setting Position of Measurement Equipment (Br.No.4)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.11 Setting Position of Measurement Equipment (Br.No.5)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.12 Setting Position of Measurement Equipment (Br.No.6)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.13 Setting Position of Measurement Equipment (Br.No.7)

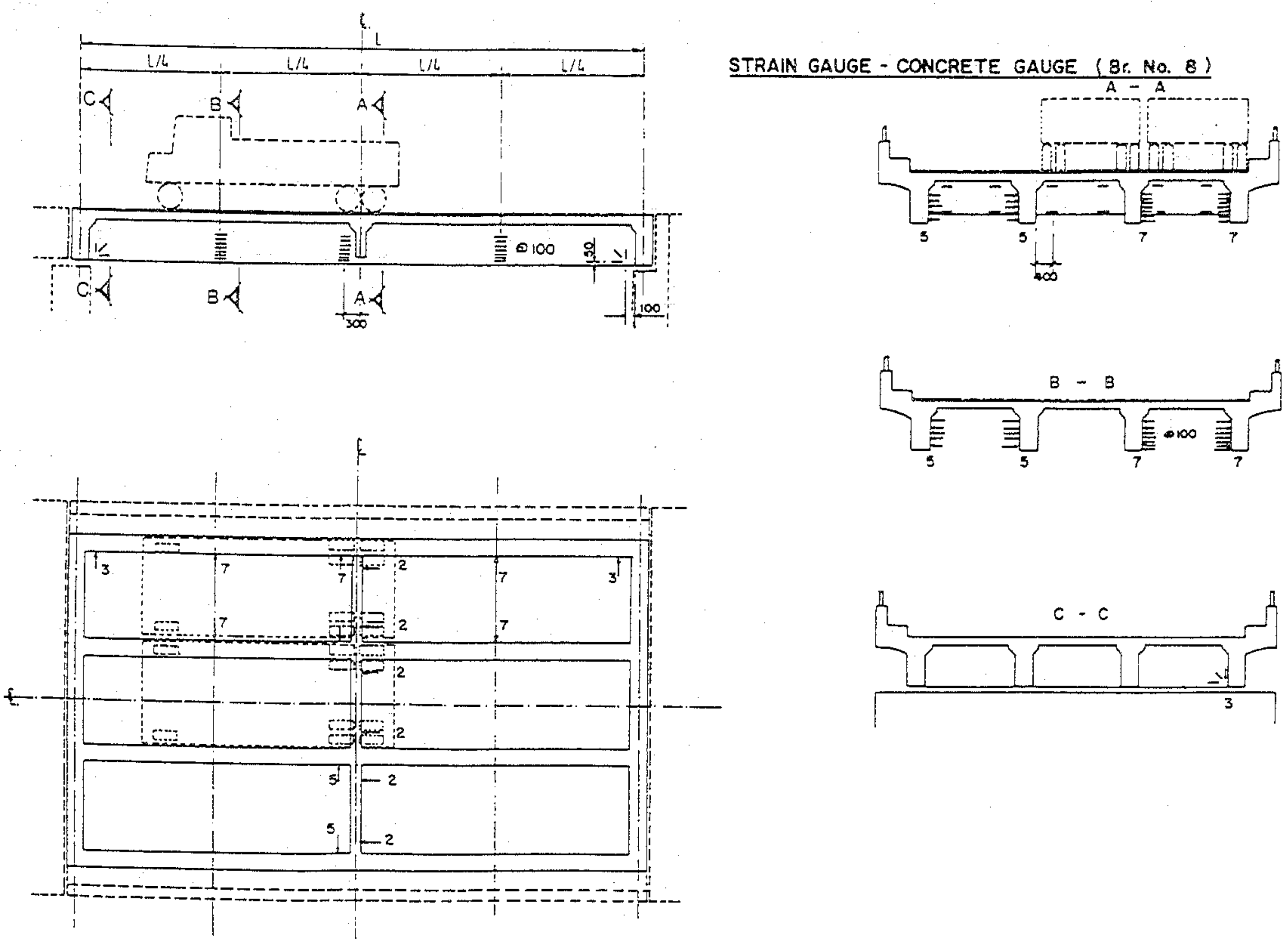


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Fig 5.14 Setting Position of Measurement Equipment (Br.No.8)

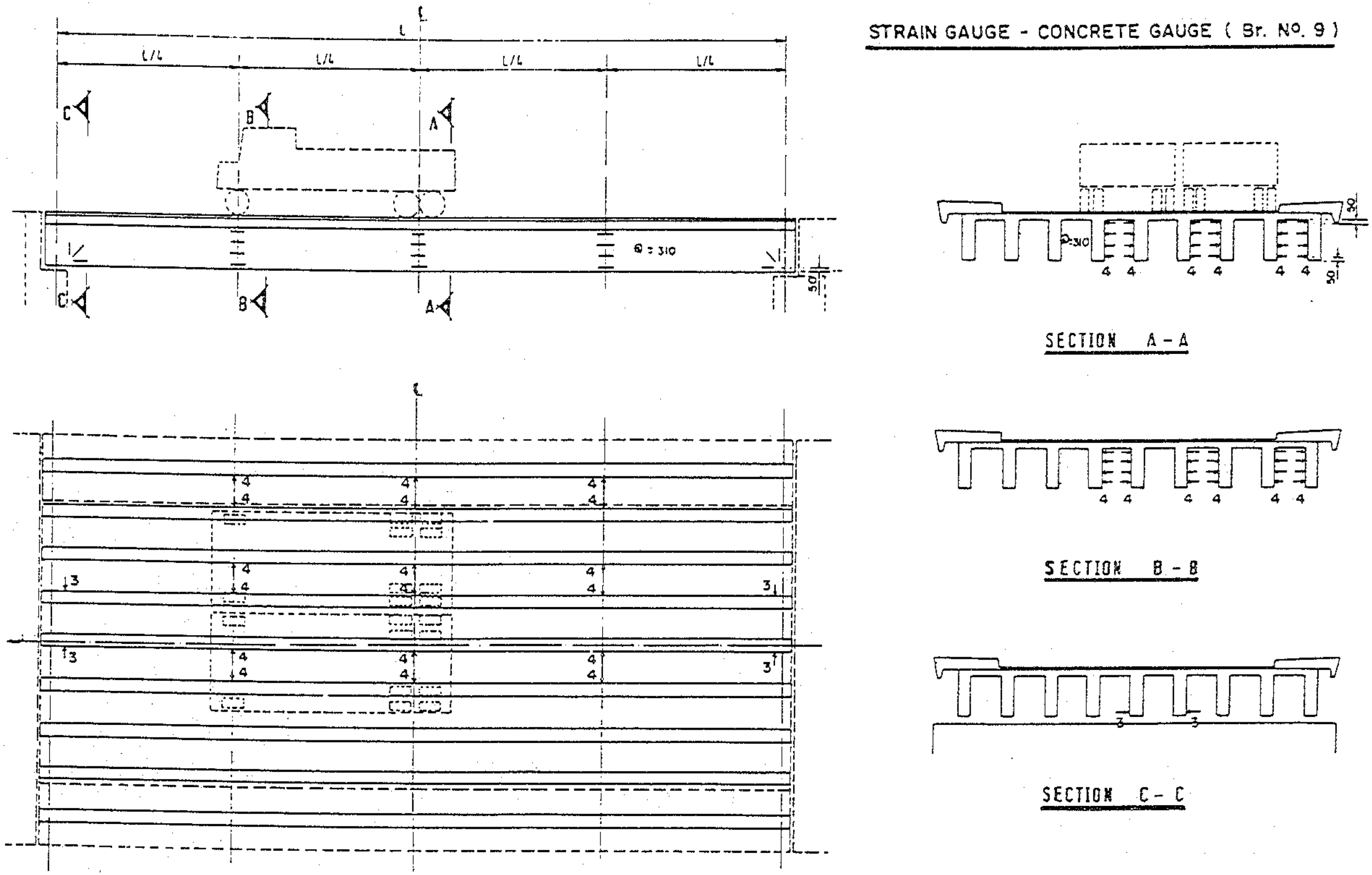

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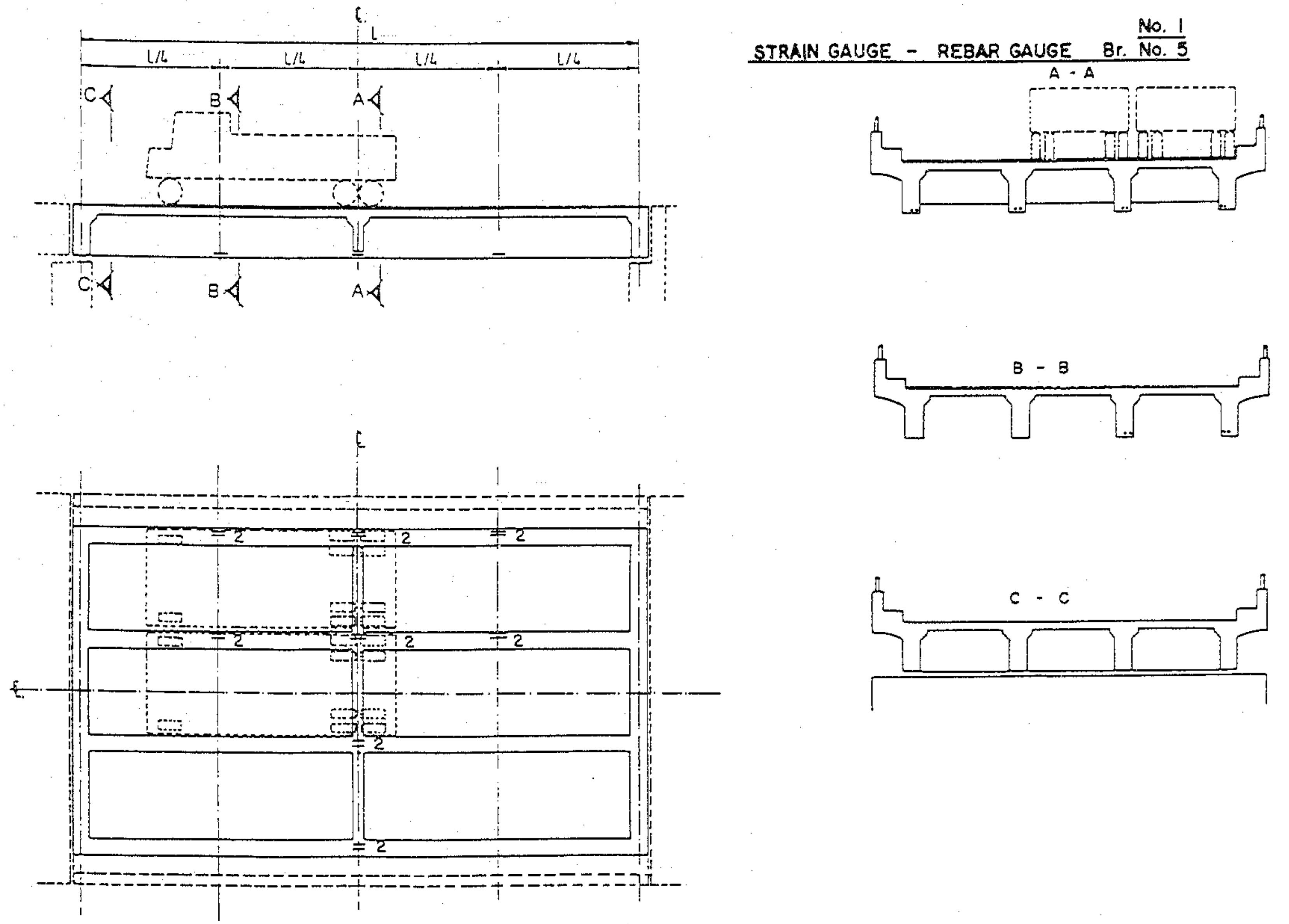
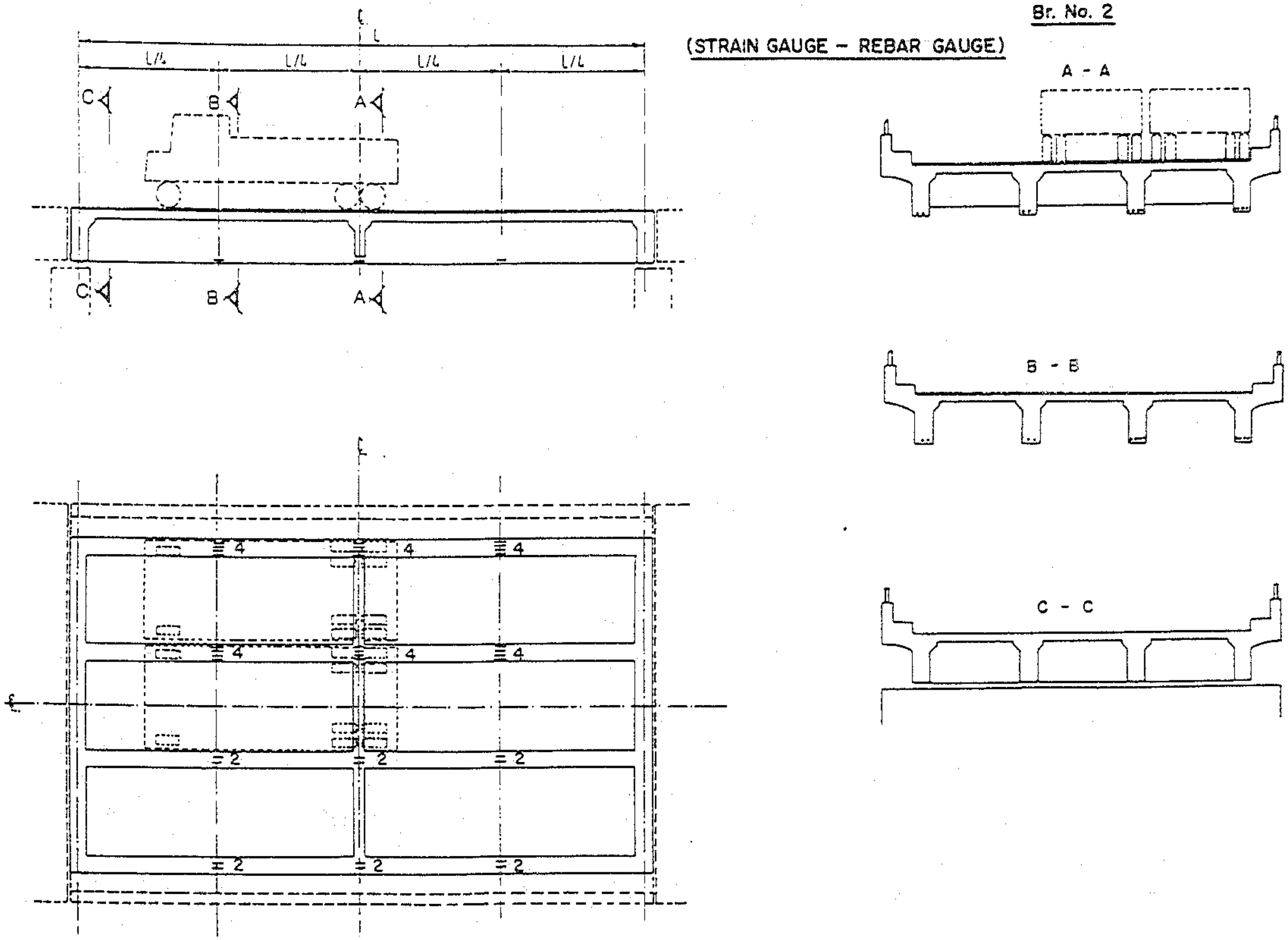
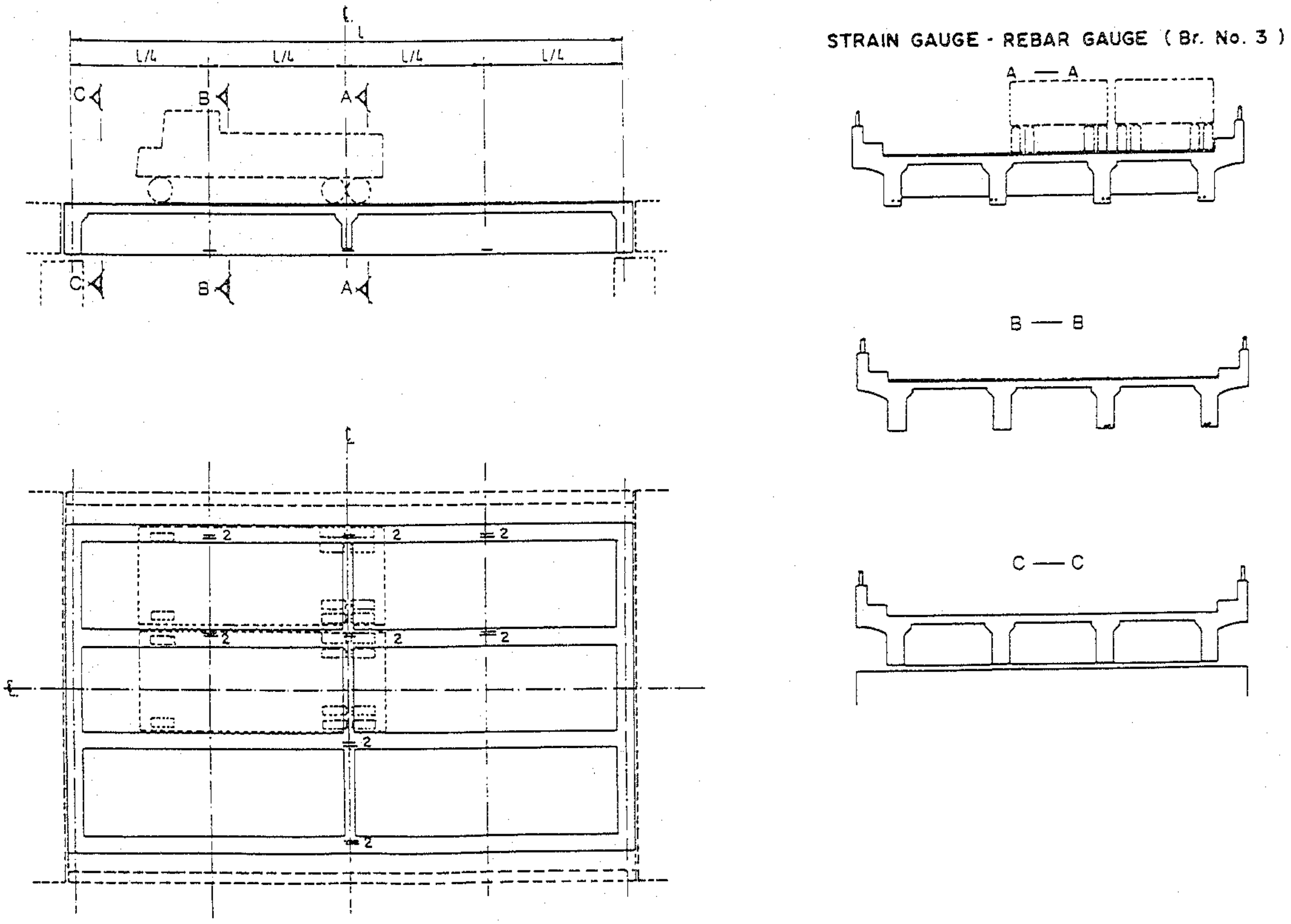
Fig 5.15 Setting Position of Measurement Equipment (Br.No.9)



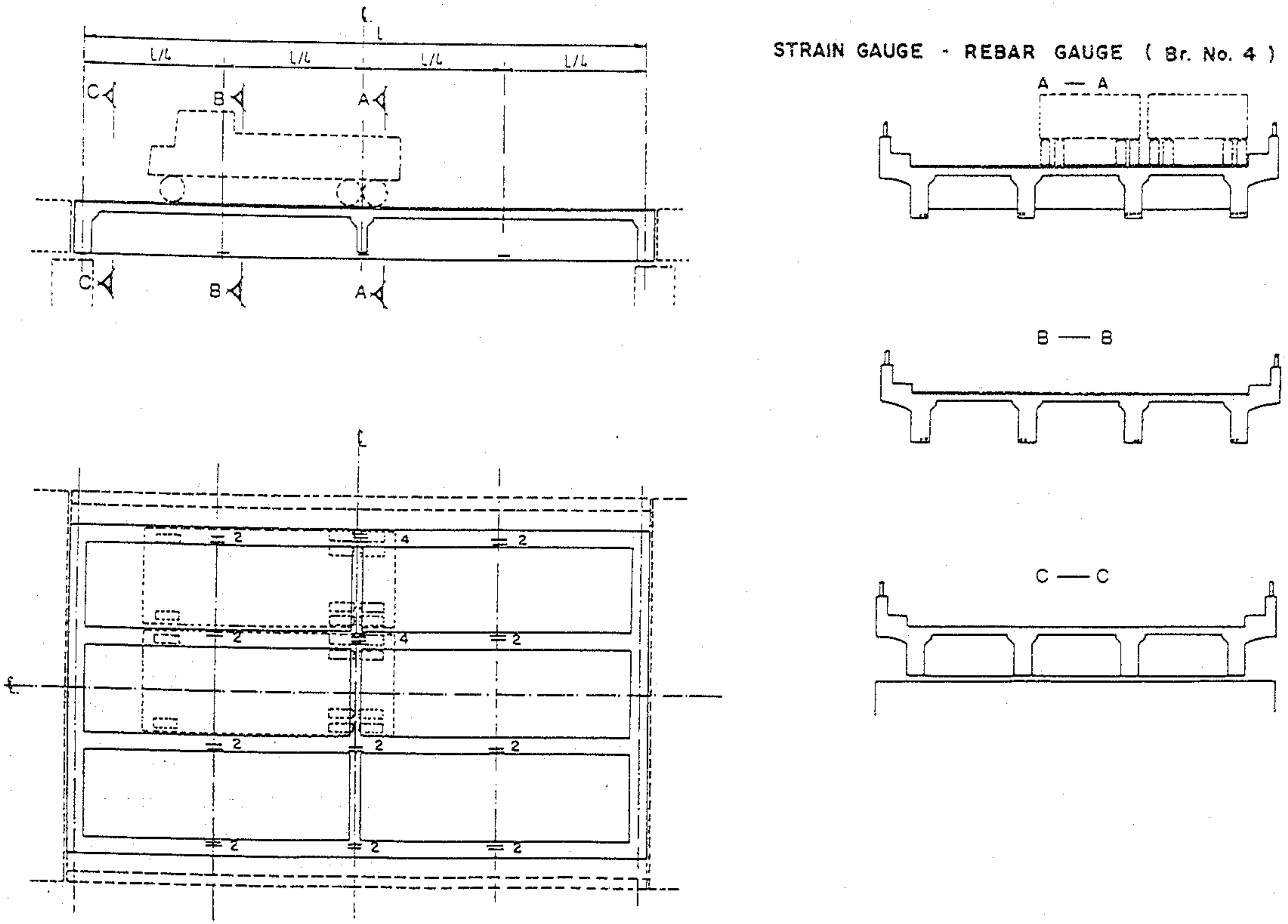
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.16 Setting Position of Measurement Equipment (Br.No.1,5)



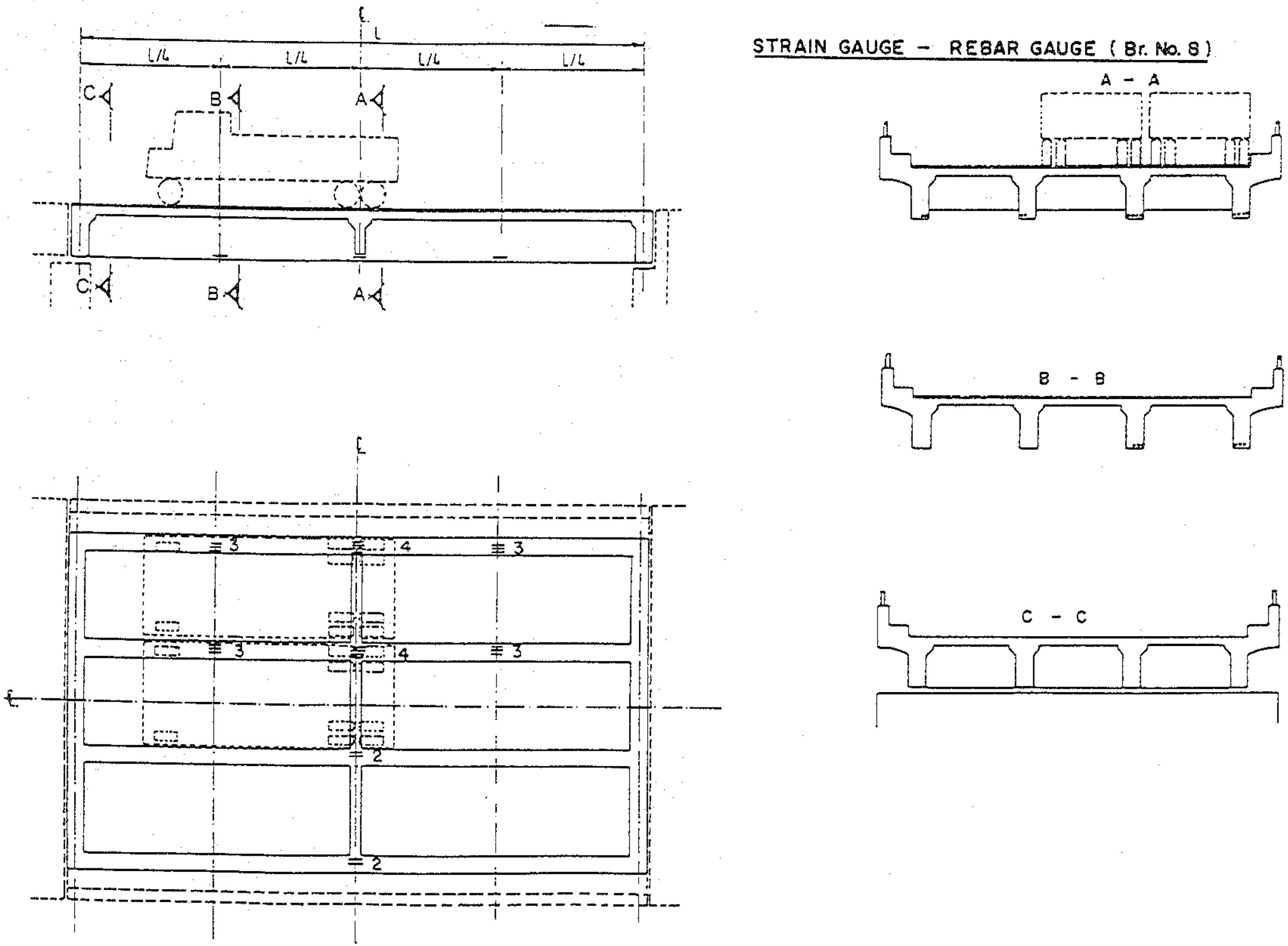
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.17 Setting Position of Measurement Equipment (Br.No.2)



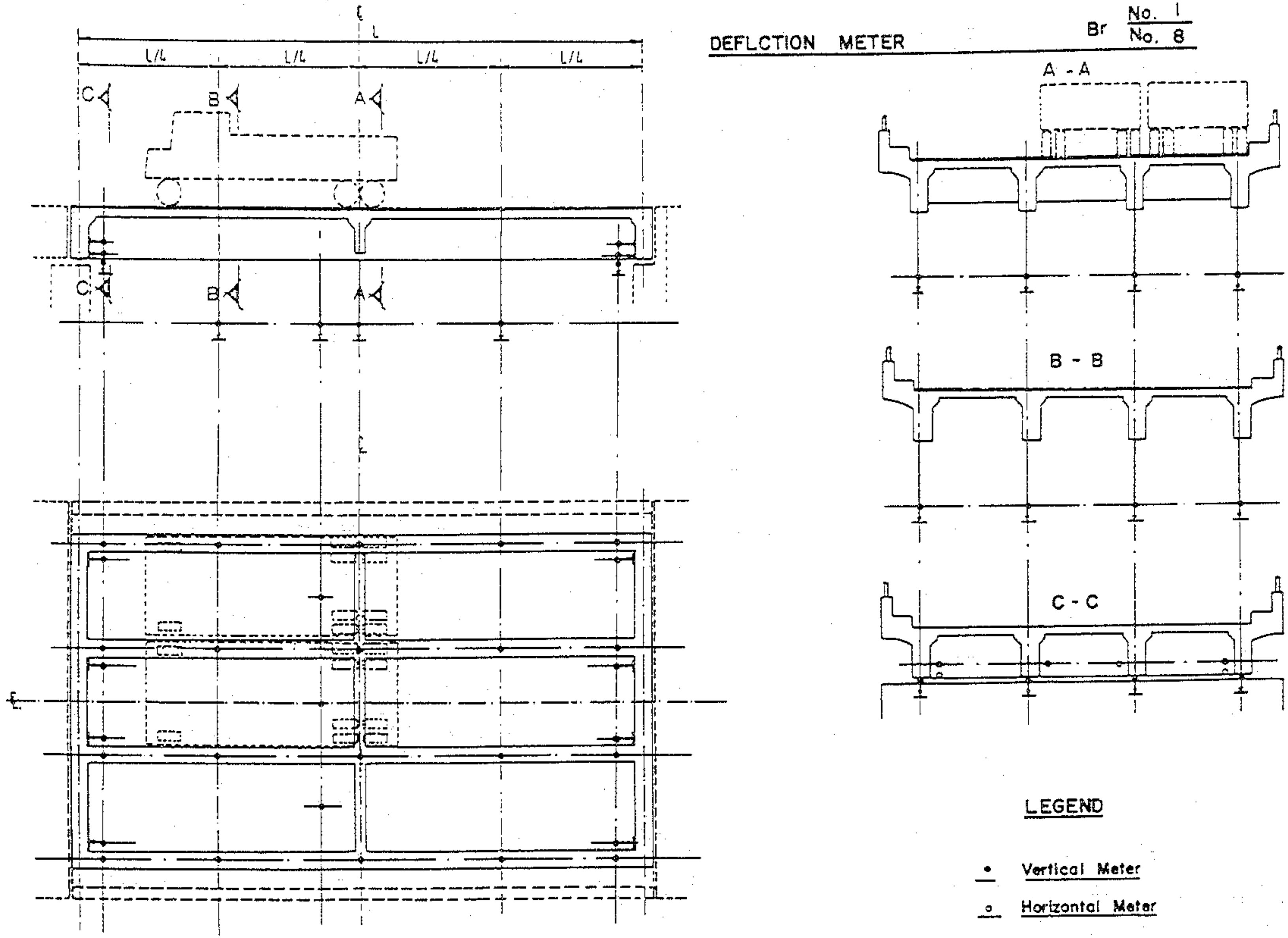
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.18 Setting Position of Measurement Equipment (Br.No.3)



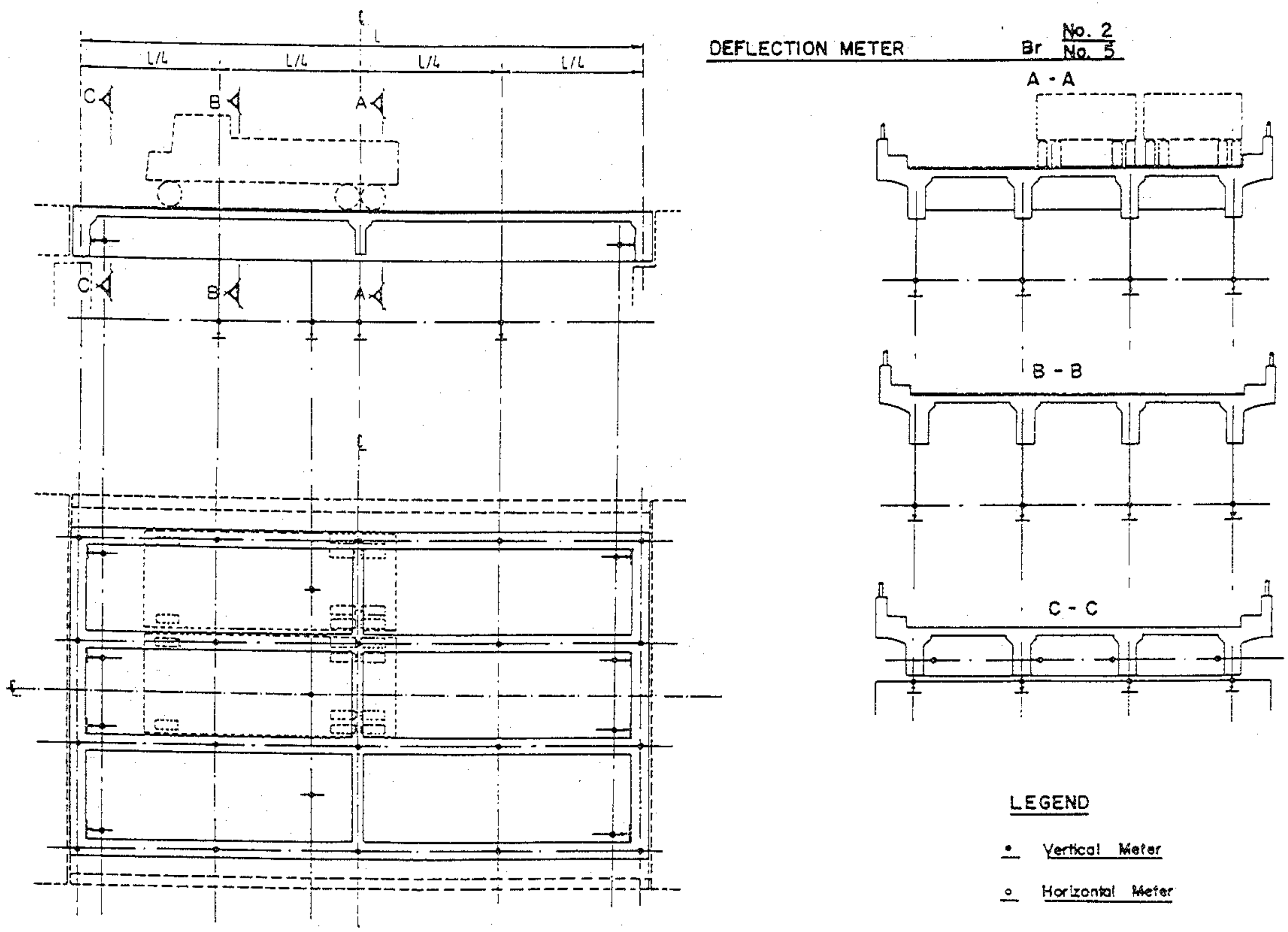
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.19 Setting Position of Measurement Equipment (Br.No.4)



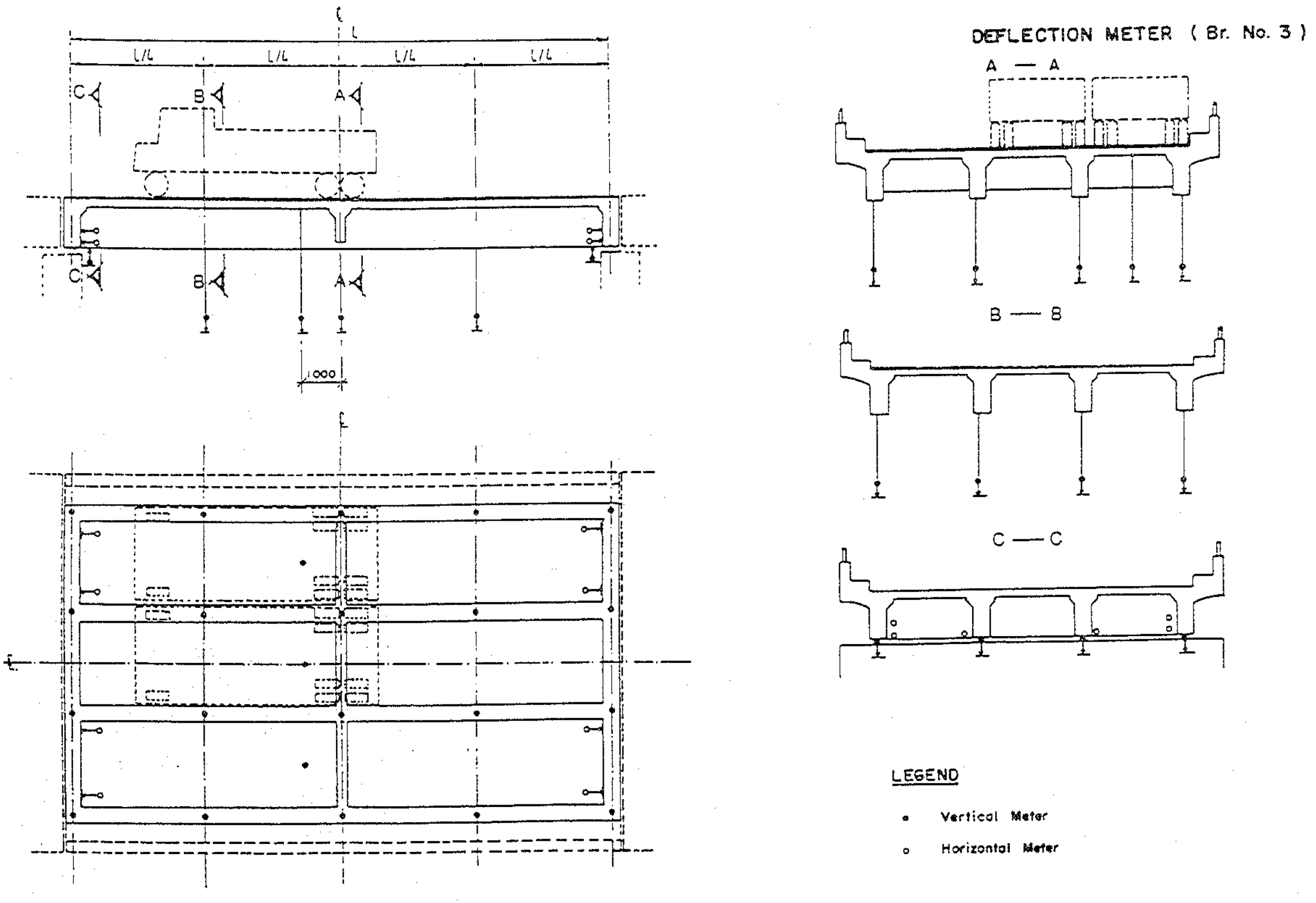
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.20 Setting Position of Measurement Equipment (Br.No.8)



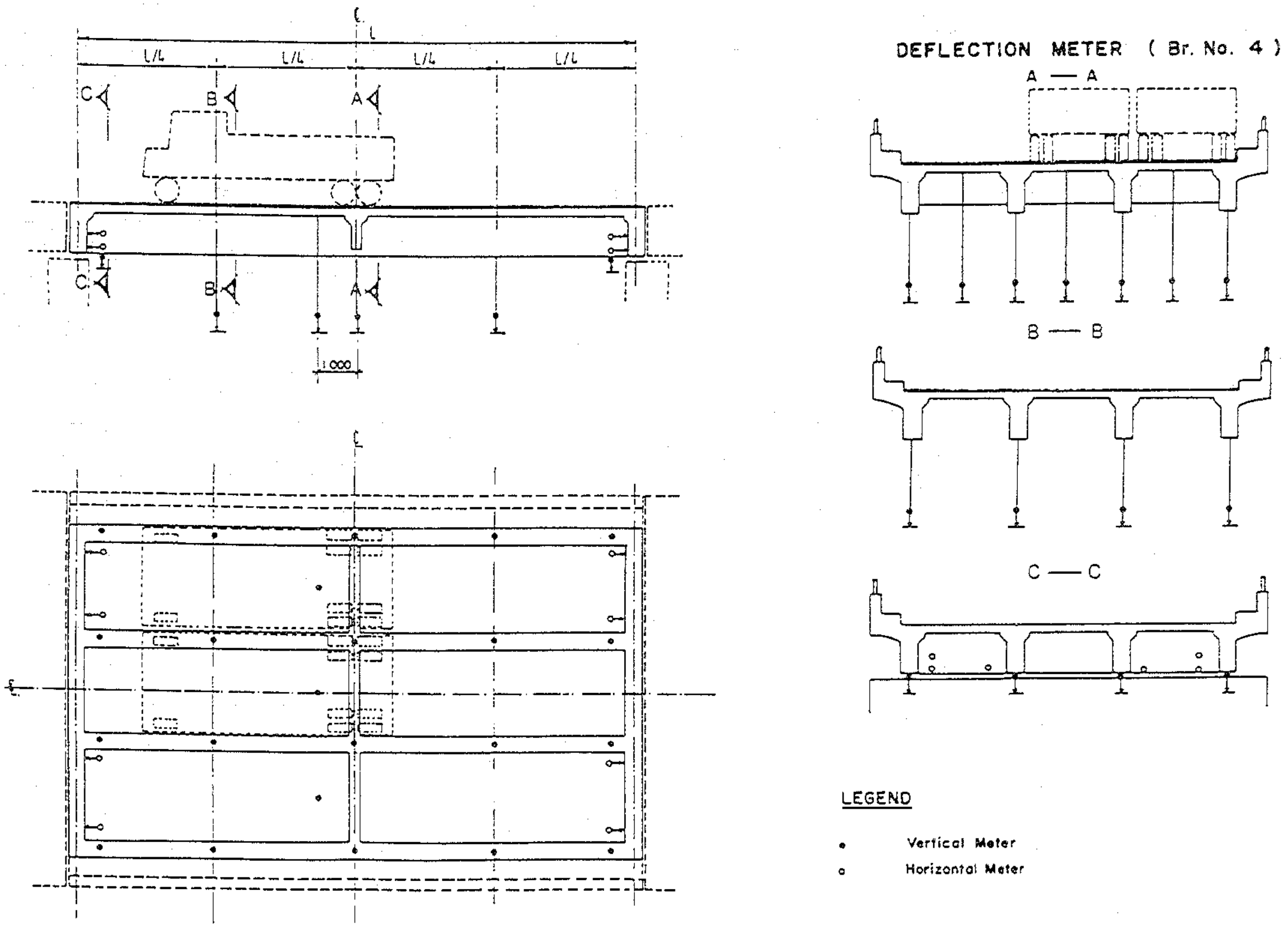
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.21 Setting Position of Measurement Equipment (Br.No.1,8)



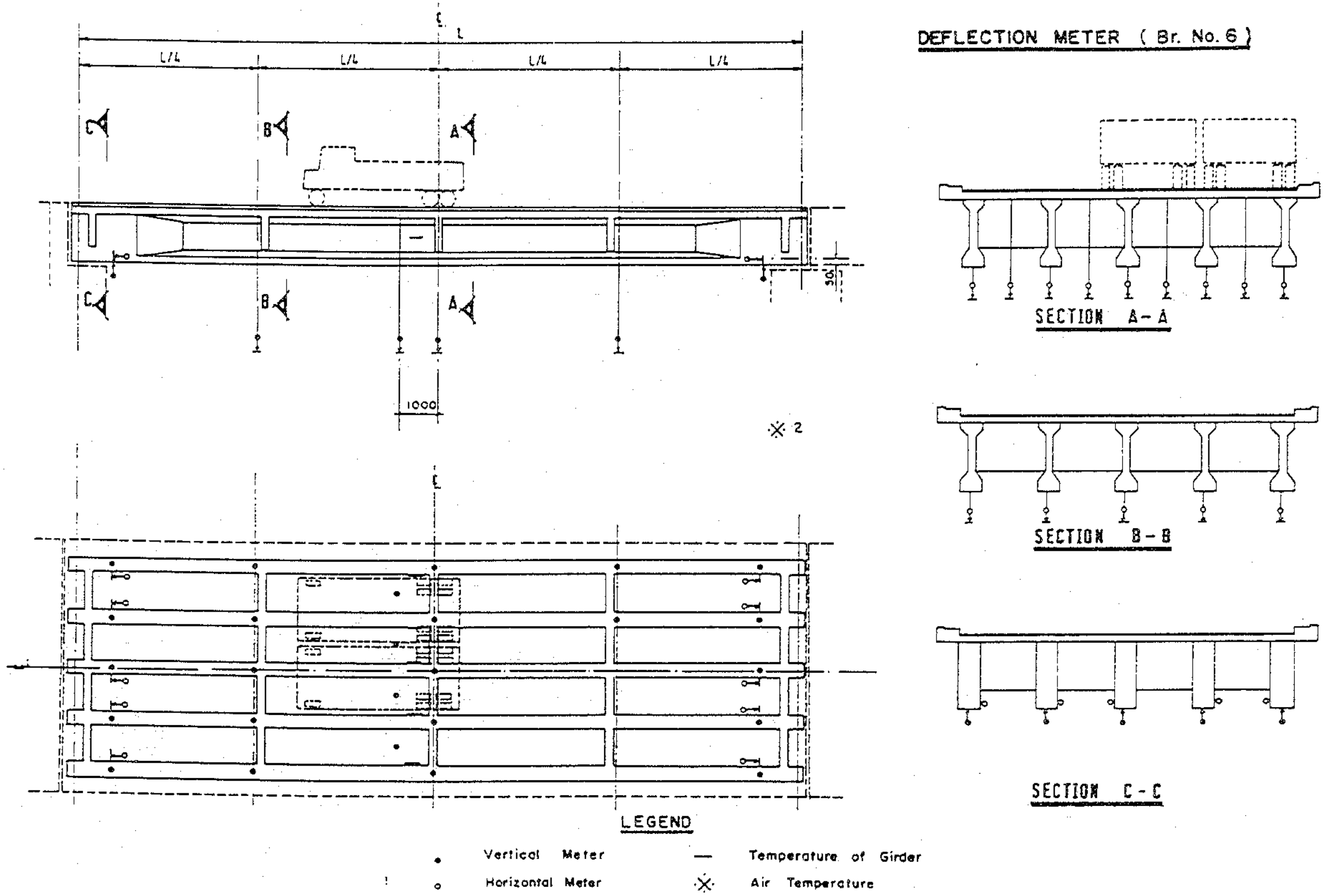
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.22 Setting Position of Measurement Equipment (Br.No.2,5)



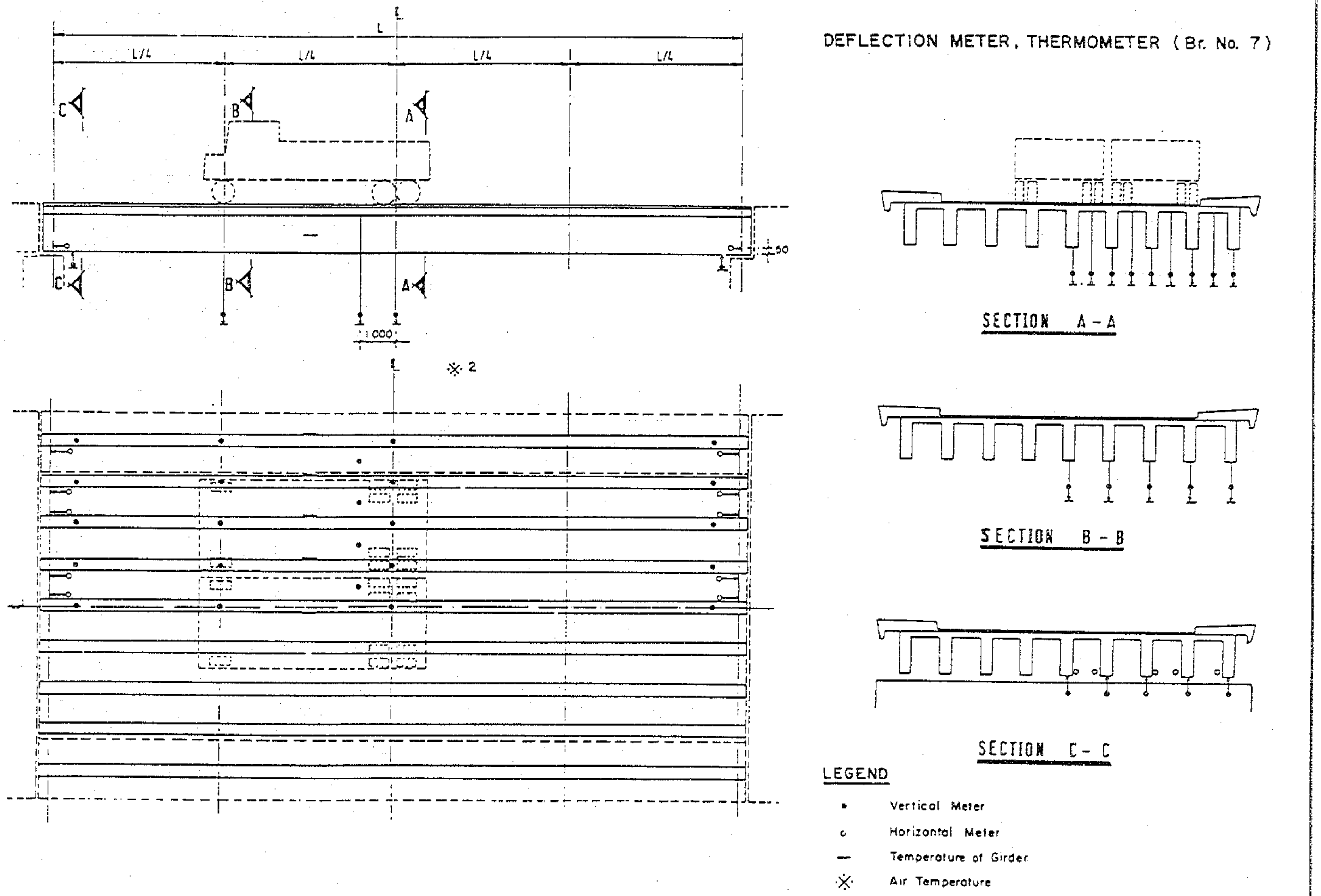
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.23 Setting Position of Measurement Equipment (Br.No.3)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.24 Setting Position of Measurement Equipment (Br.No.4)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.25 Setting Position of Measurement Equipment (Br.No.6)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.26 Setting Position of Measurement Equipment (Br.No.7)

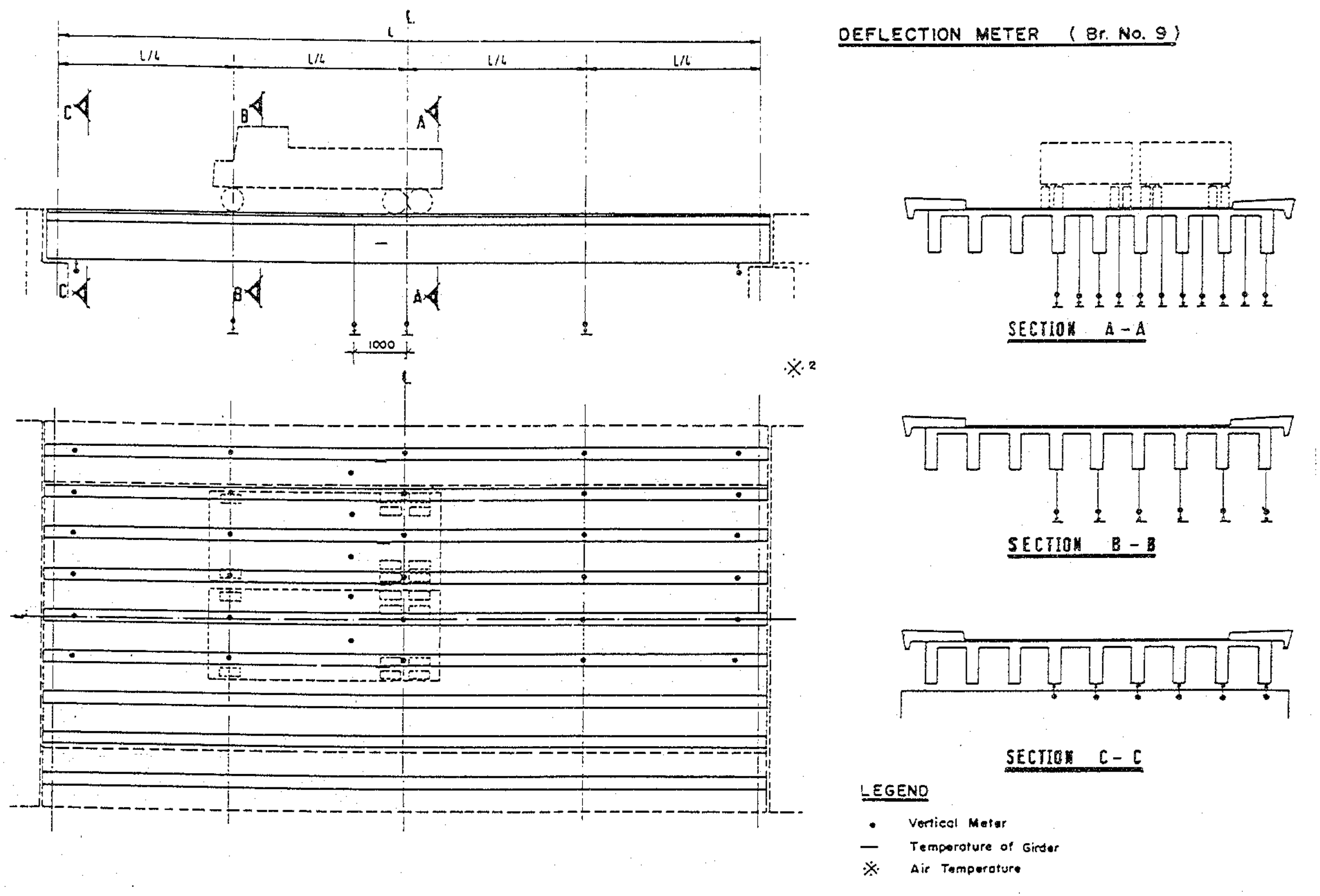


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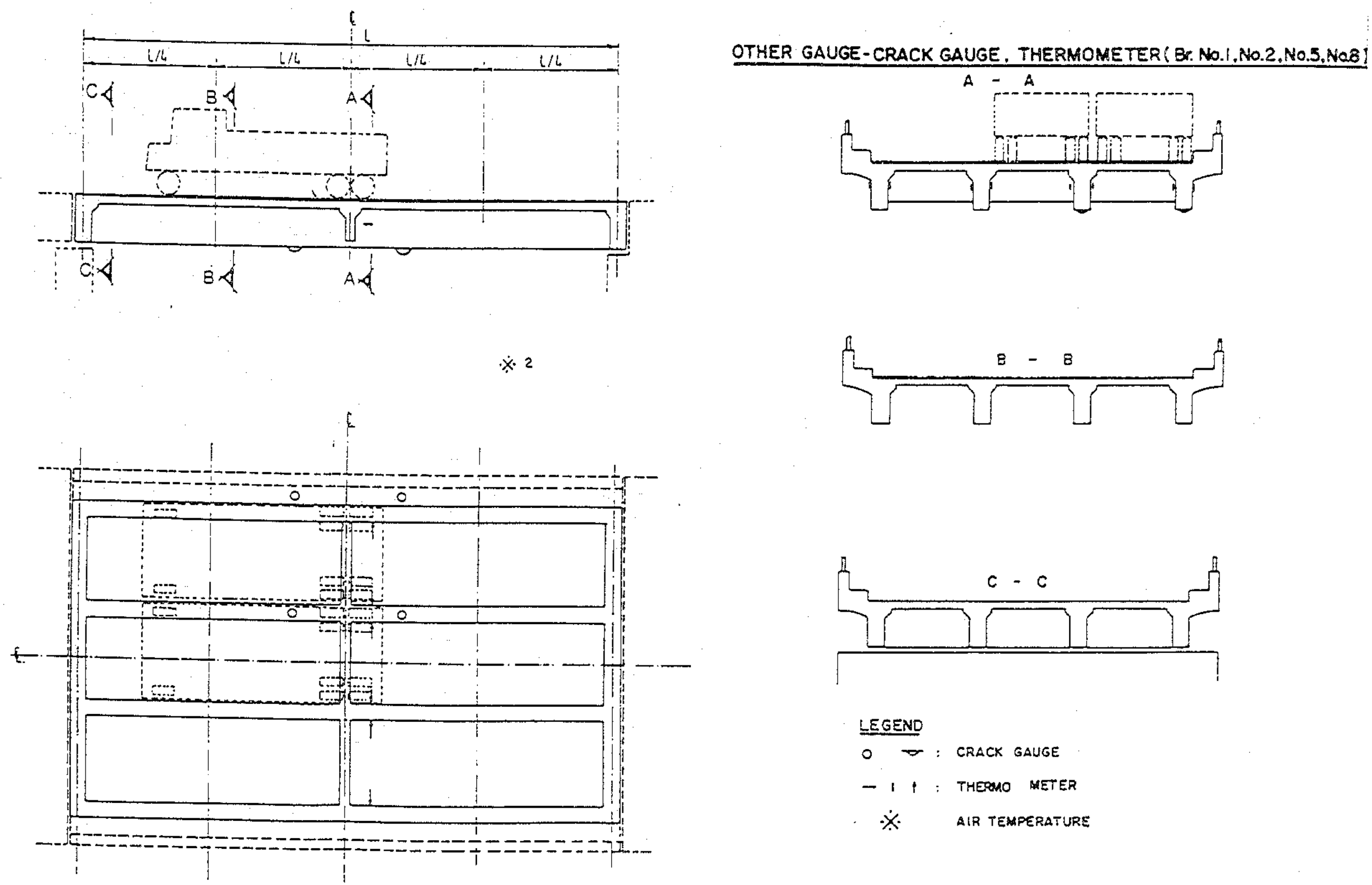
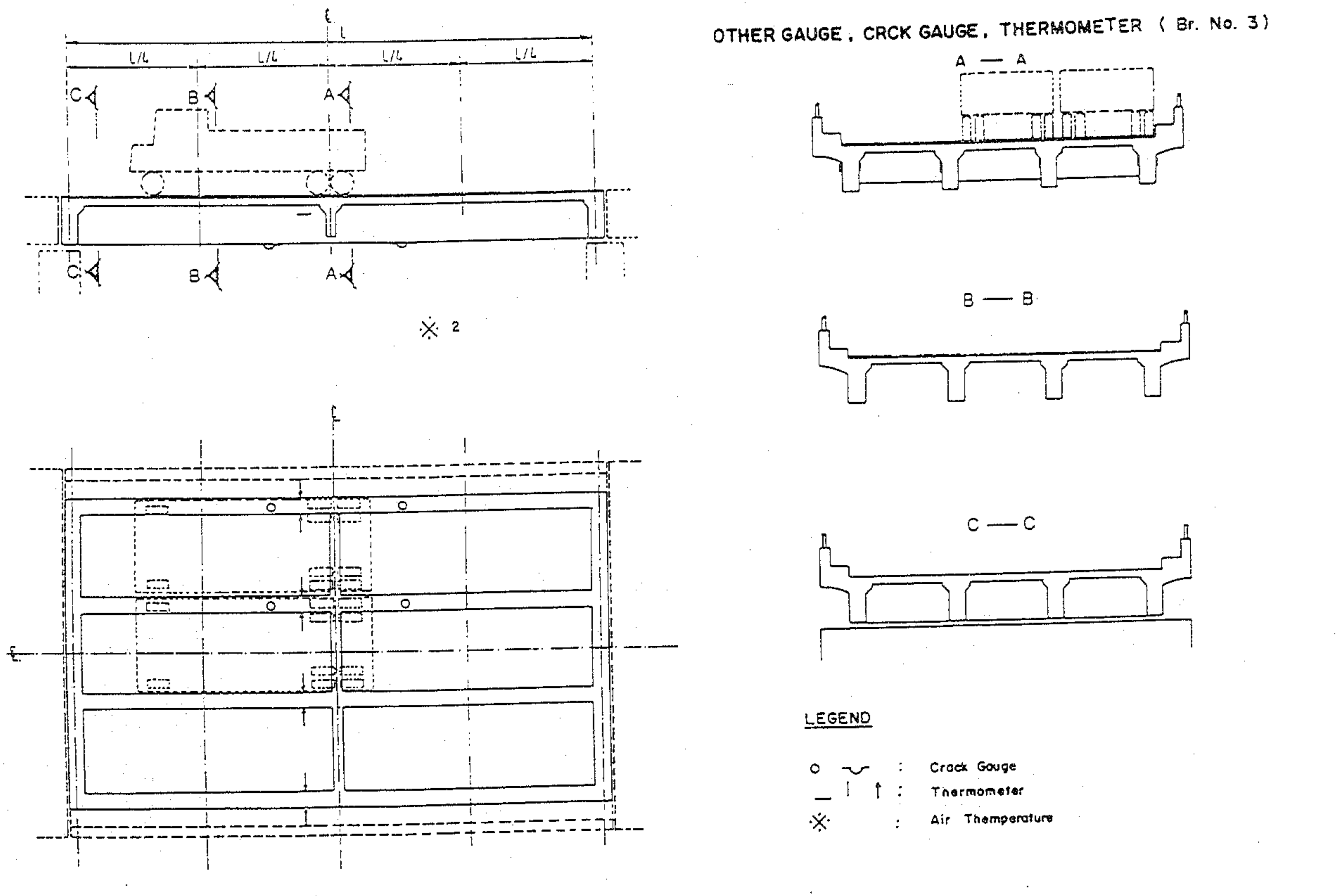
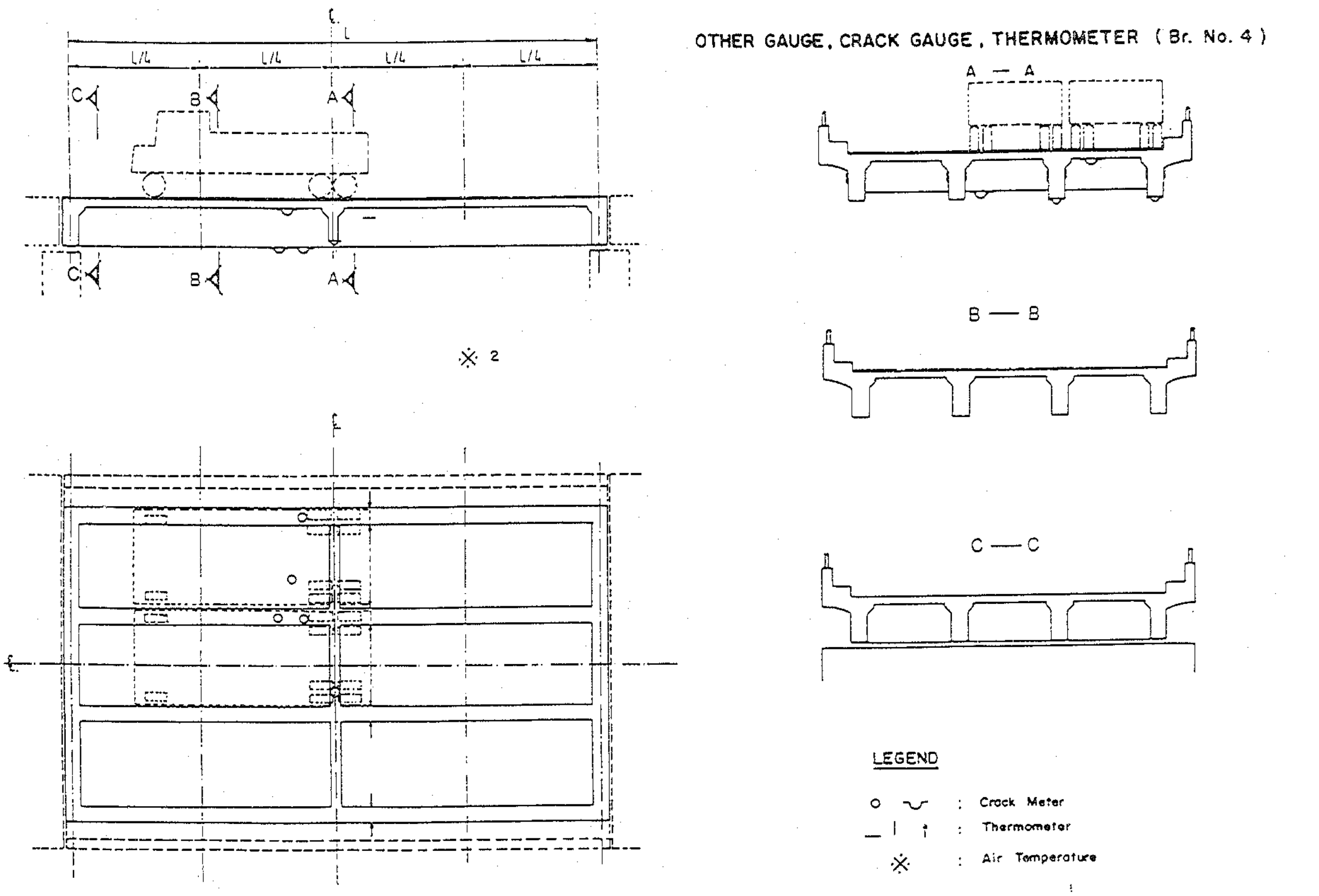
Fig 5.27 Setting Position of Measurement Equipment (Br.No.9)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.28 Setting Position of Measurement Equipment (Br.No.1,2,5,8)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.29 Setting Position of Measurement Equipment (Br.No.3)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.30 Setting Position of Measurement Equipment (Br.No.4)

5.2 Results of the Load Test

The results of the monitoring of the 9 bridges (6 RC bridges, 3 PC bridges) were recorded using the testing instruments, and the strain in the reinforcing bar and the concrete were calculated.

Based on the load testing, the stress in the bridge components was calculated for the various cases in accordance with the following formula, and the summarized values and detail values described in Table 5.3 through Table 5.43.

$$\sigma_c\ (\sigma_s) = \varepsilon \bullet E_c\ (E_s)$$

where, σ_c : concrete stress (σ_s : reinforcing bar stress) kg/cm^2

ε : value of strain 10^{-6}

E_c : elasticity modulus of concrete
(E_s : elasticity modulus of reinforcing bar) kg/cm^2

Also it has been noticed that there are numerous cracks in the RC bridges, and the crack gauges have been set at these cracks, and the increase in the cracks with the application of live loads were measured. These results have been shown in Table 5.44 through Table 5.46.

Based on the above load tests, the relation of the results of the live loads for each case and the maximum strain at the middle of the span in the rebars and bridge deflection have been plotted in the graphs in Fig. 5.31 thru Fig. 5.39. The results will have an important bearing on the evaluation of the load capacity described in the following chapters.

Table 5.3 Summary of Loading Test Results for Br. No. 1

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain x 10^{-6}	Stress kg/cm^2	Strain x 10^{-6}	Stress kg/cm^2	
Exterior Beam	Case 1 (20 ton)	44	92.4	10	–	0.67
	Case 2 (40 ton)	68	142.8	14	–	0.95
	Case 3 (14.6 ton)	–	–	–	–	–
	Case 4 (29.2 ton)	–	–	–	–	–
Interior Beam	Case 1 (20 ton)	40	84.0	8	–	0.56
	Case 2 (40 ton)	86	180.6	16	–	1.23
	Case 3 (14.6 ton)	–	–	–	–	–
	Case 4 (29.2 ton)	–	–	–	–	–

Stress = ε • Ec (Es)

ε : Value of Strain (x 10^{-6})
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.4 Detail of Loading Test Results for Br. No. 1

Case 1 (20 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	16	44	26	
		Stress kg/cm^2	33.6	92.4	54.6	
	Concrete	Strain x10^{-6}	12 (73)	10 (73)	46 (7)	
		Stress kg/cm^2	–	–	–	
	Deflection mm		0.53	0.67	0.46	
	Width by crack gauge mm		–	0.01	–	
	Thermometer °C		–	29.2	–	
	Remaining Strain & Deflection (Center of Span) R: 1 (x10^{-6}), C: 2 (x10^{-6}), 0.03 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	14	40	20	
		Stress kg/cm^2	29.4	84.0	42.0	
	Concrete	Strain x10^{-6}	21 (28)	8 (88)	5 (88)	
		Stress kg/cm^2	–	–	–	
	Deflection mm		0.37	0.56	0.41	
	Width by crack gauge mm		–	0	–	
	Thermometer °C		–	28.9	–	
	Remaining Strain & Deflection (Center of Span) R: 5 (x10^{-6}), C: 2 (x10^{-6}), 0.11 (mm)					No Loading

Table 5.5 Detail of Loading Test Results for Br. No. 1

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	26	68	39	
		Stress kg/cm^2	54.6	142.8	81.9	
	Concrete	Strain x10^{-6}	16 (73)	14 (88)	67 (7)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.81	0.95	0.68	
	Width by crack gauge	mm	–	0.02	–	
	Thermometer	°C	–	29.6	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	27	86	42	
		Stress kg/cm^2	56.7	180.6	88.2	
	Concrete	Strain x10^{-6}	42 (28)	16 (89)	9 (88)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.74	1.23	0.92	
	Width by crack gauge	mm	–	0.01	–	
	Thermometer	°C	–	29.3	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.6 Summary of Loading Test Results for Br. No. 2

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain x 10^{-6}	Stress kg/cm^2	Strain x 10^{-6}	Stress kg/cm^2	
Exterior Beam	Case 1 (20 ton)	86	180.6	16	–	1.77
	Case 2 (40 ton)	110	231.0	19	–	2.29
	Case 3 (14.6 ton)	72	151.2	17	–	1.29
	Case 4 (29.2 ton)	92	193.2	19	–	1.70
Interior Beam	Case 1 (20 ton)	63	132.3	9	–	1.61
	Case 2 (40 ton)	132	277.2	20	–	3.32
	Case 3 (14.6 ton)	47	98.7	15	–	1.38
	Case 4 (29.2 ton)	94	197.4	17	–	2.50

Stress = ε • Ec (Es)

ε : Value of Strain (x 10^{-6})
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.7 Detail of Loading Test Results for Br. No. 2

Case 1 (20 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	52	86	50	
		Stress kg/cm^2	109.2	180.6	105.0	
	Concrete	Strain x10^{-6}	5 (49)	16 (39)	105 (39)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.10	1.77	1.13	
	Width by crack gauge	mm	–	0.03	–	
	Thermometer	°C	–	27.7	–	
	Remaining Strain & Deflection (Center of Span) R: 1 (x10^{-6}), C: 6 (x10^{-6}), 0.05 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	43	63	32	
		Stress kg/cm^2	90.3	132.3	67.2	
	Concrete	Strain x10^{-6}	14 (49)	9 (59)	22 (59)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.95	1.61	0.91	
	Width by crack gauge	mm	–	0.07	–	
	Thermometer	°C	–	27.6	–	
	Remaining Strain & Deflection (Center of Span) R: 2 (x10^{-6}), C: 8 (x10^{-6}), 0.15 (mm)					No Loading

Table 5.8 Detail of Loading Test Results for Br. No. 2

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $x 10^{-6}$	66	110	68	
		Stress kg/cm^2	138.6	231.0	142.8	
	Concrete	Strain $x10^{-6}$	7 (79)	19 (13)	132 (39)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.49	2.29	1.54	
	Width by crack gauge	mm	–	0.05	–	
	Thermometer	°C	–	27.8	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain $x 10^{-6}$	91	132	68	
		Stress kg/cm^2	191.1	277.2	142.8	
	Concrete	Strain $x10^{-6}$	17 (49)	20 (59)	76 (59)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	2.11	3.32	1.94	
	Width by crack gauge	mm	–	0.03	–	
	Thermometer	°C	–	27.7	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.9 Detail of Loading Test Results for Br. No. 2

Case 3 (14.6 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $x 10^{-6}$	40	72	35	
		Stress kg/cm^2	84.0	151.2	73.5	
	Concrete	Strain $x10^{-6}$	15 (49)	17 (39)	73 (39)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.90	1.29	0.79	
	Width by crack gauge	mm	–	0.05	–	
	Thermometer	°C	–	27.8	–	
	Remaining Strain & Deflection (Center of Span) R: -5 ($x10^{-6}$), C: 9 ($x10^{-6}$), 0.12 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain $x 10^{-6}$	32	47	21	
		Stress kg/cm^2	67.2	98.7	44.1	
	Concrete	Strain $x10^{-6}$	17 (49)	15 (59)	19 (59)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.72	1.38	0.65	
	Width by crack gauge	mm	–	0	–	
	Thermometer	°C	–	27.8	–	
	Remaining Strain & Deflection (Center of Span) R: 9 ($x10^{-6}$), C: 11 ($x10^{-6}$), 0.49 (mm)					No Loading

Table 5.10 Detail of Loading Test Results for Br. No. 2

Case 4 (29.2 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	52	92	49	
		Stress kg/cm^2	109.2	193.2	102.9	
	Concrete	Strain $\times 10^{-6}$	12 (49)	19 (39)	92 (39)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.19	1.70	1.07	
	Width by crack gauge	mm	–	0.03	–	
	Thermometer	°C	–	27.5	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	69	94	44	
		Stress kg/cm^2	144.9	197.4	92.4	
	Concrete	Strain $\times 10^{-6}$	19 (49)	17 (59)	46 (59)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.54	2.50	1.36	
	Width by crack gauge	mm	–	0.01	–	
	Thermometer	°C	–	27.6	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.11 Summary of Loading Test Results for Br. No. 3

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain x 10^{-6}	Stress kg/cm²	Strain x 10^{-6}	Stress kg/cm²	
Exterior Beam	Case 1 (20 ton)	76	159.6	8	–	1.77
	Case 2 (40 ton)	100	210.0	12	–	2.33
	Case 3 (14.6 ton)	–	–	–	–	–
	Case 4 (29.2 ton)	–	–	–	–	–
Interior Beam	Case 1 (20 ton)	57	119.7	5	–	1.35
	Case 2 (40 ton)	117	245.7	10	–	2.81
	Case 3 (14.6 ton)	–	–	–	–	–
	Case 4 (29.2 ton)	–	–	–	–	–

Stress = ε • Ec (Es)

ε : Value of Strain (x 10^{-6})
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.12 Detail of Loading Test Results for Br. No. 3

Case 1 (20 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	66	76	57	
		Stress kg/cm²	138.6	159.6	119.7	
	Concrete	Strain x10^{-6}	1 (30)	8 (30)	8 (45)	
		Stress kg/cm²	–	–	–	
	Deflection	mm	1.37	1.77	1.27	
	Width by crack gauge	mm	–	0.03	–	
	Thermometer	°C	–	36.8	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	39	57	32	
		Stress kg/cm²	81.9	119.7	67.2	
	Concrete	Strain x10^{-6}	106 (15)	5 (30)	5 (45)	
		Stress kg/cm²	–	–	–	
	Deflection	mm	0.93	1.35	0.98	
	Width by crack gauge	mm	–	0.03	–	
	Thermometer	°C	–	34.4	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.13 Detail of Loading Test Results for Br. No. 3

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	87	100	80	
		Stress kg/cm^2	182.7	210.0	168.0	
	Concrete	Strain x10^{-6}	0 (15)	12 (60)	9 (45)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.81	2.33	1.65	
	Width by crack gauge	mm	–	0.04	–	
	Thermometer	°C	–	37.1	–	
	Remaining Strain & Deflection (Center of Span) R: -1 (x10^{-6}), C: 0 (x10^{-6}), 0.05 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	85	117	70	
		Stress kg/cm^2	178.5	245.7	147.0	
	Concrete	Strain x10^{-6}	211 (15)	10 (30)	9 (30)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	2.09	2.81	1.87	
	Width by crack gauge	mm	–	0.03	–	
	Thermometer	°C	–	34.6	–	
	Remaining Strain & Deflection (Center of Span) R: -1 (x10^{-6}), C: 1 (x10^{-6}), 0.05 (mm)					No Loading

Table 5.14 Summary of Loading Test Results for Br. No. 4

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain x 10^{-6}	Stress kg/cm^2	Strain x 10^{-6}	Stress kg/cm^2	
Exterior Beam	Case 1 (20 ton)	64	134.4	212	–	1.47
	Case 2 (40 ton)	83	174.3	241	–	1.93
	Case 3 (14.6 ton)	44	92.4	146	–	1.03
	Case 4 (29.2 ton)	58	121.8	166	–	1.32
Interior Beam	Case 1 (20 ton)	49	102.9	35	–	1.18
	Case 2 (40 ton)	104	218.4	78	–	2.62
	Case 3 (14.6 ton)	32	67.2	25	–	0.80
	Case 4 (29.2 ton)	73	153.3	57	–	1.89

Stress = ε • Ec (Es)

ε : Value of Strain (x 10^{-6})
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.15 Detail of Loading Test Results for Br. No. 4

Case 1 (20 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	41	64	41	
		Stress kg/cm^2	86.1	134.4	86.1	
	Concrete	Strain x10^{-6}	7 (65)	212 (65)	9 (85)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.96	1.47	0.95	
	Width by crack gauge	mm	–	0.02	–	
	Thermometer	°C	–	38.1	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	24	49	24	
		Stress kg/cm^2	50.4	102.9	50.4	
	Concrete	Strain x10^{-6}	0 (85)	35 (25)	34 (25)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.71	1.18	0.73	
	Width by crack gauge	mm	–	0.01	–	
	Thermometer	°C	–	38.1	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.16 Detail of Loading Test Results for Br. No. 4

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $x\ 10^{-6}$	54	83	52	
		Stress kg/cm^2	113.4	174.3	109.2	
	Concrete	Strain $x10^{-6}$	10 (65)	241 (65)	12 (85)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.24	1.93	1.23	
	Width by crack gauge	mm	–	0.03	–	
	Thermometer	°C	–	37.9	–	
	Remaining Strain & Deflection (Center of Span) R: 0 ($x10^{-6}$), C: 5 ($x10^{-6}$), 0.02 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain $x\ 10^{-6}$	50	104	53	
		Stress kg/cm^2	105.0	218.4	111.3	
	Concrete	Strain $x10^{-6}$	1 (65)	78 (25)	87 (25)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.67	2.62	1.70	
	Width by crack gauge	mm	–	0.03	–	
	Thermometer	°C	–	38.0	–	
	Remaining Strain & Deflection (Center of Span) R: 0 ($x10^{-6}$), C: 1 ($x10^{-6}$), 0.03 (mm)					No Loading

Table 5.17 Detail of Loading Test Results for Br. No. 4

Case 3 (14.6 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $x\ 10^{-6}$	30	44	28	
		Stress kg/cm^2	63.0	92.4	58.8	
	Concrete	Strain $x10^{-6}$	6 (65)	146 (65)	4 (25)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.70	1.03	0.67	
	Width by crack gauge	mm	–	0.01	–	
	Thermometer	°C	–	36.9	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain $x\ 10^{-6}$	17	32	16	
		Stress kg/cm^2	35.7	67.2	33.6	
	Concrete	Strain $x10^{-6}$	0 (45)	25 (25)	21 (25)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	0.52	0.80	0.52	
	Width by crack gauge	mm	–	0.01	–	
	Thermometer	°C	–	36.9	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.18 Detail of Loading Test Results for Br. No. 4

Case 4 (29.2 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	54	58	36	
		Stress kg/cm^2	81.9	121.8	75.6	
	Concrete	Strain x10^{-6}	6 (65)	166 (65)	7 (85)	
		Stress kg/cm^2	-	-	-	
	Deflection mm		0.89	1.32	0.86	
	Width by crack gauge mm		-	0.02	-	
	Thermometer °C		-	36.9	-	
	Remaining Strain & Deflection (Center of Span) R: 1 (x10^{-6}), C: 3 (x10^{-6}), 0.01 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	37	73	36	
		Stress kg/cm^2	77.7	153.3	75.6	
	Concrete	Strain x10^{-6}	1 (65)	57 (25)	61 (25	
		Stress kg/cm^2	-	-	-	
	Deflection mm		1.24	1.89	1.23	
	Width by crack gauge mm		-	0.02	-	
	Thermometer °C		-	37.0	-	
	Remaining Strain & Deflection (Center of Span) R: 1 (x10^{-6}), C: 1 (x10^{-6}), 0.01 (mm)					No Loading

Table 5.19 Summary of Loading Test Results for Br. No. 5

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain x 10^{-6}	Stress kg/cm^2	Strain x 10^{-6}	Stress kg/cm^2	
Exterior Beam	Case 1 (20 ton)	114	239.4	7	-	1.73
	Case 2 (40 ton)	142	298.2	9	-	2.32
	Case 3 (14.6 ton)	76	159.6	4	-	1.20
	Case 4 (29.2 ton)	98	205.8	5	-	1.62
Interior Beam	Case 1 (20 ton)	84	176.4	9	-	1.62
	Case 2 (40 ton)	159	333.9	15	-	3.22
	Case 3 (14.6 ton)	57	119.7	5	-	1.11
	Case 4 (29.2 ton)	107	224.7	9	-	2.23

Stress = ε • Ec (Es)

ε : Value of Strain (x 10^{-6})
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.20 Detail of Loading Test Results for Br. No. 5

Case 1 (20 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	63	114	58	
		Stress kg/cm^2	132.3	239.4	121.8	
	Concrete	Strain x10^{-6}	11 (59)	7 (69)	7 (89)	
		Stress kg/cm^2	-	-	-	
	Deflection mm		1.30	1.73	1.18	
	Width by crack gauge mm		-	0.01	-	
	Thermometer °C		-	26.1	-	
	Remaining Strain & Deflection (Center of Span) R: 3 (x10^{-6}), C: 2 (x10^{-6}), 0.06 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	53	84	40	
		Stress kg/cm^2	111.3	176.4	84.0	
	Concrete	Strain x10^{-6}	30	9	5	
		Stress kg/cm^2	-	-	-	
	Deflection mm		1.18	1.62	1.08	
	Width by crack gauge mm		-	0.01	-	
	Thermometer °C		-	25.8	-	
	Remaining Strain & Deflection (Center of Span) R: 4 (x10^{-6}), C: 2 (x10^{-6}), 0.14 (mm)					No Loading

Table 5.21 Detail of Loading Test Results for Br. No. 5

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	82	142	79	
		Stress kg/cm^2	172.2	298.2	165.9	
	Concrete	Strain x10^{-6}	14	9	8	
		Stress kg/cm^2	–	–	–	
	Deflection mm		1.72	2.32	1.58	
	Width by crack gauge mm		–	0.01	–	
	Thermometer °C		–	27.3	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	104	159	80	
		Stress kg/cm^2	218.4	333.9	168.0	
	Concrete	Strain x10^{-6}	61	15	5	
		Stress kg/cm^2	–	–	–	
	Deflection mm		2.38	3.22	2.17	
	Width by crack gauge mm		–	0.02	–	
	Thermometer °C		–	26.9	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.22 Detail of Loading Test Results for Br. No. 5

Case 3 (14.6 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	45	76	39	
		Stress kg/cm^2	94.5	159.6	81.9	
	Concrete	Strain x10^{-6}	7 (59)	4 (69)	3 (87)	
		Stress kg/cm^2	–	–	–	
	Deflection mm		0.91	1.20	0.82	
	Width by crack gauge mm		–	0	–	
	Thermometer °C		–	28.7	–	
	Remaining Strain & Deflection (Center of Span) R: 3 (x10^{-6}), C: 0 (x10^{-6}), 0.03 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	38	57	25	
		Stress kg/cm^2	79.8	119.7	52.5	
	Concrete	Strain x10^{-6}	20 (39)	5 (39)	1 (39)	
		Stress kg/cm^2	–	–	–	
	Deflection mm		0.83	1.11	0.73	
	Width by crack gauge mm		–	0.01	–	
	Thermometer °C		–	28.4	–	
	Remaining Strain & Deflection (Center of Span) R: 1 (x10^{-6}), C: 01 (x10^{-6}), 0.07 (mm)					No Loading

Table 5.23 Detail of Loading Test Results for Br. No. 5

Case 4 (29.2 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	59	98	53	
		Stress kg/cm^2	123.9	205.8	111.3	
	Concrete	Strain $x10^{-6}$	8 (59)	5 (69)	4 (87)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.22	1.62	1.11	
	Width by crack gauge	mm	–	0.01	–	
	Thermometer	°C	–	29.0	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	75	107	52	
		Stress kg/cm^2	157.5	224.7	109.2	
	Concrete	Strain $x10^{-6}$	43 (39)	9 (39)	2 (39)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.68	2.23	1.48	
	Width by crack gauge	mm	–	0.02	–	
	Thermometer	°C	–	28.7	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.24 Summary of Loading Test Results for Br. No. 6

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain $\times 10^{-6}$	Stress kg/cm^2	Strain $\times 10^{-6}$	Stress kg/cm^2	
Exterior Beam	Case 1 (20 ton)	–	–	43	12.9	1.65
	Case 2 (40 ton)	–	–	61	18.3	2.43
	Case 3 (14.6 ton)	–	–	27	8.1	1.22
	Case 4 (29.2 ton)	–	–	42	12.6	1.83
Interior Beam	Case 1 (20 ton)	–	–	30	9.0	1.36
	Case 2 (40 ton)	–	–	49	14.7	2.31
	Case 3 (14.6 ton)	–	–	18	5.4	0.99
	Case 4 (29.2 ton)	–	–	33	9.9	1.76

Stress = $\varepsilon \bullet$ Ec (Es)

ε : Value of Strain ($\times 10^{-6}$)
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.25 Detail of Loading Test Results for Br. No. 6

Case 1 (20 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	–	–	–	
		Stress kg/cm^2	–	–	–	
	Concrete	Strain $\times 10^{-6}$	23 (0)	43 (0)	15 (0)	
		Stress kg/cm^2	6.9	12.9	4.5	
	Deflection	mm	1.17	1.65	1.07	
	Width by crack gauge	mm	–	–	–	
	Thermometer	°C	–	40.3	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	–	–	–	
		Stress kg/cm^2	–	–	–	
	Concrete	Strain $\times 10^{-6}$	13	30	13	
		Stress kg/cm^2	3.9	9.0	3.9	
	Deflection	mm	0.93	1.36	0.86	
	Width by crack gauge	mm	–	–	–	
	Thermometer	°C	–	40.2	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.26 Detail of Loading Test Results for Br. No. 6

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $x\ 10^{-6}$	-	-	-	
		Stress kg/cm^2	-	-	-	
	Concrete	Strain $x10^{-6}$	31 (0)	61 (0)	26 (0)	
		Stress kg/cm^2	9.3	18.3	7.8	
	Deflection mm		1.71	2.43	1.43	
	Width by crack gauge mm		-	-	-	
	Thermometer °C		-	40.2	-	
	Remaining Strain & Deflection (Center of Span) ($7 x 10^{-6}$), 0.09 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain $x\ 10^{-6}$	-	-	-	
		Stress kg/cm^2	-	-	-	
	Concrete	Strain $x10^{-6}$	22	49	20	
		Stress kg/cm^2	6.6	14.7	6.0	
	Deflection mm		1.56	2.31	1.48	
	Width by crack gauge mm		-	-	-	
	Thermometer °C		-	40.1	-	
	Remaining Strain & Deflection (Center of Span) ($6 x 10^{-6}$), 0.12 (mm)					No Loading

Table 5.27 Detail of Loading Test Results for Br. No. 6

Case 3 (14.6 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $x\ 10^{-6}$	-	-	-	
		Stress kg/cm^2	-	-	-	
	Concrete	Strain $x10^{-6}$	13 (0)	27 (0)	8 (0)	
		Stress kg/cm^2	3.9	8.1	2.4	
	Deflection mm		0.79	1.22	0.78	
	Width by crack gauge mm		-	-	-	
	Thermometer °C		--	38.7	-	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain $x\ 10^{-6}$	-	-	-	
		Stress kg/cm^2	-	-	-	
	Concrete	Strain $x10^{-6}$	8	18	7	
		Stress kg/cm^2	2.4	5.4	2.1	
	Deflection mm		0.67	0.99	0.66	
	Width by crack gauge mm		-	-	-	
	Thermometer °C		-	38.8	-	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.28 Detail of Loading Test Results for Br. No. 6

Case 4 (29.2 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	–	–	–	
		Stress kg/cm^2	–	–	–	
	Concrete	Strain x10^{-6}	18 (0)	42 (0)	14 (0)	
		Stress kg/cm^2	5.4	12.6	4.2	
	Deflection	mm	1.20	1.83	1.23	
	Width by crack gauge	mm	–	–	–	
	Thermometer	°C	–	38.5	–	
	Remaining Strain & Deflection (Center of Span) 1 (x10^{-6}), 0.15 mm					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	–	–	–	
		Stress kg/cm^2	–	–	–	
	Concrete	Strain x10^{-6}	15	33	14	
		Stress kg/cm^2	4.5	9.9	4.2	
	Deflection	mm	1.19	1.76	1.18	
	Width by crack gauge	mm	–	–	–	
	Thermometer	°C	–	38.5	–	
	Remaining Strain & Deflection (Center of Span) 1 (x10^{-6}), 0.17 mm					No Loading

Table 5.29 Summary of Loading Test Results for Br. No. 7

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain x 10^{-6}	Stress kg/cm^2	Strain x 10^{-6}	Stress kg/cm^2	
Exterior Beam	Case 1 (20 ton)	–	–	23	7.1	2.28
	Case 2 (40 ton)	–	–	25	7.7	2.51
	Case 3 (14.6 ton)	–	–	15	4.6	1.59
	Case 4 (29.2 ton)	–	–	16	4.9	1.76
Interior Beam	Case 1 (20 ton)	–	–	30 (G3)	9.2	3.40
	Case 2 (40 ton)	–	–	59 (G5)	18.2	5.86
	Case 3 (14.6 ton)	–	–	30 (G3)	9.2	2.43
	Case 4 (29.2 ton)	–	–	49 (G4)	15.1	4.23

Stress = $\varepsilon \bullet$ Ec (Es)

ε : Value of Strain (x 10^{-6})
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.30 Detail of Loading Test Results for Br. No. 7

Case 1 (20 ton)				1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain	x 10^{-6}	–	–		
		Stress	kg/cm^2	–	–		
	Concrete	Strain	x10^{-6}	15 (17)	23 (17)		
		Stress	kg/cm^2	4.6	7.1		
	Deflection		mm	1.56	2.28		
	Width by crack gauge		mm	–	–		
	Thermometer		°C	–	37.5		
	Remaining Strain & Deflection (Center of Span)						No Loading
Interior Beam	Reinforcing Bar	Strain	x 10^{-6}	–	–		
		Stress	kg/cm^2	–	–		
	Concrete	Strain	x10^{-6}	30 (17)	42 (17)		
		Stress	kg/cm^2	9.2	12.9		
	Deflection		mm	2.23	3.40		
	Width by crack gauge		mm	–	–		
	Thermometer		°C	–	37.2		
	Remaining Strain & Deflection (Center of Span)						No Loading

Table 5.31 Detail of Loading Test Results for Br. No. 7

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	–	–		
		Stress kg/cm^2	–	–		
	Concrete	Strain $\times 10^{-6}$	15 (17)	25 (17)		
		Stress kg/cm^2	4.6	7.7		
	Deflection	mm	1.72	2.51		
	Width by crack gauge	mm	–	–		
	Thermometer	°C	–	37.2		
	Remaining Strain & Deflection (Center of Span) 0 ($\times 10^{-6}$), 0.04 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	–	–		
		Stress kg/cm^2	–	–		
	Concrete	Strain $\times 10^{-6}$	31 (17)	59 (17)		
		Stress kg/cm^2	9.5	18.2		
	Deflection	mm	3.88	5.86		
	Width by crack gauge	mm	–	–		
	Thermometer	°C	–	37.0		
	Remaining Strain & Deflection (Center of Span) 0 ($\times 10^{-6}$), 0.04 (mm)					No Loading

Table 5.32 Detail of Loading Test Results for Br. No. 7

Case 3 (14.6 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	–	–		
		Stress kg/cm^2	–	–		
	Concrete	Strain $\times 10^{-6}$	11 (17)	15 (17)		
		Stress kg/cm^2	3.4	4.6		
	Deflection	mm	1.07	1.59		
	Width by crack gauge	mm	–	–		
	Thermometer	°C	–	35.7		
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	–	–		
		Stress kg/cm^2	–	–		
	Concrete	Strain $\times 10^{-6}$	22 (17)	30 (17)		
		Stress kg/cm^2	6.8	9.2		
	Deflection	mm	1.61	2.43		
	Width by crack gauge	mm	–	–		
	Thermometer	°C	–	35.5		
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.33 Detail of Loading Test Results for Br. No. 7

Case 4 (29.2 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	-	-		
		Stress kg/cm^2	-	-		
	Concrete	Strain x10^{-6}	11 (17)	16 (17)		
		Stress kg/cm^2	3.4	4.9		
	Deflection mm		1.18	1.76		
	Width by crack gauge mm		-	-		
	Thermometer °C		-	35.7		
	Remaining Strain & Deflection (Center of Span) 0 (x10^{-6}), 0.01 mm					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	-	-		
		Stress kg/cm^2	-	-		
	Concrete	Strain x10^{-6}	32 (17)	49 (17)		
		Stress kg/cm^2	9.9	15.1		
	Deflection mm		2.74	4.23		
	Width by crack gauge mm		-	-		
	Thermometer °C		-	35.5		
	Remaining Strain & Deflection (Center of Span) 0 (x10^{-6}), 0.05 mm					No Loading

Table 5.34 Summary of Loading Test Results for Br. No. 8

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain x 10^{-6}	Stress kg/cm^2	Strain x 10^{-6}	Stress kg/cm^2	
Exterior Beam	Case 1 (20 ton)	88	184.8	30	–	1.64
	Case 2 (40 ton)	117	245.7	19	–	2.11
	Case 3 (14.6 ton)	58	121.8	7	–	1.11
	Case 4 (29.2 ton)	75	157.5	6	–	1.44
Interior Beam	Case 1 (20 ton)	74	155.4	10	–	1.60
	Case 2 (40 ton)	142	298.2	11	–	3.09
	Case 3 (14.6 ton)	44	92.4	3	–	1.04
	Case 4 (29.2 ton)	91	191.1	2	–	2.10

Stress = ε • Ec (Es)

ε : Value of Strain (x 10^{-6})
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.35 Detail of Loading Test Results for Br. No. 8

Case 1 (20 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	63	88	55	
		Stress kg/cm^2	132.3	184.8	115.5	
	Concrete	Strain x10^{-6}	11 (55)	30 (7)	16 (7)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.26	1.64	1.07	
	Width by crack gauge	mm	–	0.02	–	
	Thermometer	°C	–	26.2	–	
	Remaining Strain & Deflection (Center of Span) R: 5 (x10^{-6}), C: 4 (x10^{-6}), 0.04 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	52	74	46	
		Stress kg/cm^2	109.2	155.4	96.6	
	Concrete	Strain x10^{-6}	11 (85)	10 (35)	10 (85)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.06	1.60	1.08	
	Width by crack gauge	mm	–	0.02	–	
	Thermometer	°C	–	26.0	–	
	Remaining Strain & Deflection (Center of Span) R: 5 (x10^{-6}), C: 4 (x10^{-6}), 0.04 (mm)					No Loading

Table 5.36 Detail of Loading Test Results for Br. No. 8

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	63	117	62	
		Stress kg/cm^2	132.3	245.7	130.2	
	Concrete	Strain x10^{-6}	10 (45)	19 (55)	18 (7)	
		Stress kg/cm^2	–	–	–	
	Deflection mm		1.58	2.11	1.39	
	Width by crack gauge mm		–	0.02	–	
	Thermometer °C		–	28.0	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	94	142	81	
		Stress kg/cm^2	197.4	298.2	170.1	
	Concrete	Strain x10^{-6}	4 (45)	11 (45)	13 (35)	
		Stress kg/cm^2	–	–	–	
	Deflection mm		2.06	3.09	2.02	
	Width by crack gauge mm		–	0.03	–	
	Thermometer °C		–	27.9	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.37 Detail of Loading Test Results for Br. No. 8

Case 3 (14.6 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	31	58	28	
		Stress kg/cm^2	65.1	121.8	58.8	
	Concrete	Strain x10^{-6}	3 (45)	7 (55)	4 (7)	
		Stress kg/cm^2	–	–	–	
	Deflection mm		0.85	1.11	0.74	
	Width by crack gauge mm		–	0.01	–	
	Thermometer °C		–	31.5	–	
	Remaining Strain & Deflection (Center of Span) R: -2 (x10^{-6}), C: 12 (x10^{-6}), -0.01 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	32	44	24	
		Stress kg/cm^2	67.2	92.4	50.4	
	Concrete	Strain x10^{-6}	3 (45)	7 (55)	4 (7)	
		Stress kg/cm^2	–	–	–	
	Deflection mm		0.71	1.04	0.64	
	Width by crack gauge mm		–	0.01	–	
	Thermometer °C		–	31.3	–	
	Remaining Strain & Deflection (Center of Span) R: -1 (x10^{-6}), C: 0 (x10^{-6}), -0.06 (mm)					No Loading

Table 5.38 Detail of Loading Test Results for Br. No. 8

Case 4 (29.2 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	38	75	33	
		Stress kg/cm^2	79.8	157.5	69.3	
	Concrete	Strain $\times 10^{-6}$	5 (45)	6 (55)	8 (7)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.06	1.44	0.95	
	Width by crack gauge	mm	–	0.02	–	
	Thermometer	°C	–	31.7	–	
	Remaining Strain & Deflection (Center of Span)					No Loading
Interior Beam	Reinforcing Bar	Strain $\times 10^{-6}$	68	91	50	
		Stress kg/cm^2	142.8	191.1	105.0	
	Concrete	Strain $\times 10^{-6}$	5 (45)	6 (55)	8 (7)	
		Stress kg/cm^2	–	–	–	
	Deflection	mm	1.48	2.10	1.26	
	Width by crack gauge	mm	–	0.02	–	
	Thermometer	°C	–	31.5	–	
	Remaining Strain & Deflection (Center of Span)					No Loading

Table 5.39 Summary of Loading Test Results for Br. No. 9

Center of Span (Point 2/4)		Reinforcing Bar		Concrete		Deflection (mm)
		Strain x 10^{-6}	Stress kg/cm^2	Strain x 10^{-6}	Stress kg/cm^2	
Exterior Beam	Case 1 (20 ton)	–	–	27	8.64	1.79
	Case 2 (40 ton)	–	–	30	9.60	2.02
	Case 3 (14.6 ton)	–	–	21	6.72	1.36
	Case 4 (29.2 ton)	–	–	23	7.36	1.54
Interior Beam	Case 1 (20 ton)	–	–	38 (G3)	12.16	2.11
	Case 2 (40 ton)	–	–	61 (G4)	19.52	3.50
	Case 3 (14.6 ton)	–	–	27 (G3)	8.64	1.49
	Case 4 (29.2 ton)	–	–	42 (G5)	13.44	2.61

Stress = ε • Ec (Es)

ε : Value of Strain (x 10^{-6})
Ec(Es) : Modulus of elasticity of concrete (Reinforcing bar)

Table 5.40 Detail of Loading Test Results for Br. No. 9

Case 1 (20 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	–	–	–	
		Stress kg/cm^2	–	–	–	
	Concrete	Strain x10^{-6}	17 (5)	27 (5)	13 (5)	
		Stress kg/cm^2	5.44	8.64	4.16	
	Deflection	mm	1.22	1.79	1.16	
	Width by crack gauge	mm	–	–	–	
	Thermometer	°C	–	38.6	–	
	Remaining Strain & Deflection (Center of Span) 5 (x10^{-5}), 0.00 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	–	–	–	
		Stress kg/cm^2	–	–	–	
	Concrete	Strain x10^{-6}	22	38	20	
		Stress kg/cm^2	7.04	12.16	6.40	
	Deflection	mm	1.43	2.11	1.33	
	Width by crack gauge	mm	–	–	–	
	Thermometer	°C	–	38.3	–	
	Remaining Strain & Deflection (Center of Span) 3 (x10^{-6}), 0.06 (mm)					No Loading

Table 5.41 Detail of Loading Test Results for Br. No. 9

Case 2 (40 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $x10^{-6}$	-	-	-	
		Stress kg/cm^2	-	-	-	
	Concrete	Strain $x10^{-6}$	18 (5)	30 (5)	14 (5)	
		Stress kg/cm^2	5.76	9.60	4.48	
	Deflection mm		1.31	2.02	1.30	
	Width by crack gauge mm		-	-	-	
	Thermometer °C		-	38.4	-	
	Remaining Strain & Deflection (Center of Span)		5 ($x10^{-6}$), 0.00 (mm)			No Loading
Interior Beam	Reinforcing Bar	Strain $x10^{-6}$	-	-	-	
		Stress kg/cm^2	-	-	-	
	Concrete	Strain $x10^{-6}$	46	61	29	
		Stress kg/cm^2	14.72	19.52	9.28	
	Deflection mm		2.36	3.50	2.25	
	Width by crack gauge mm		-	-	-	
	Thermometer °C		-	38.3	-	
	Remaining Strain & Deflection (Center of Span)		3 ($x10^{-6}$), 0.08 (mm)			No Loading

Table 5.42 Detail of Loading Test Results for Br. No. 9

Case 3 (14.6 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain $x10^{-6}$	-	-	-	
		Stress kg/cm^2	-	-	-	
	Concrete	Strain $x10^{-6}$	13 (5)	21 (5)	10 (5)	
		Stress kg/cm^2	4.16	6.72	3.20	
	Deflection mm		0.93	1.36	0.85	
	Width by crack gauge mm		-	-	-	
	Thermometer °C		-	37.6	-	
	Remaining Strain & Deflection (Center of Span)		1 ($x10^{-6}$), 0.04 (mm)			No Loading
Interior Beam	Reinforcing Bar	Strain $x10^{-6}$	-	-	-	
		Stress kg/cm^2	-	-	-	
	Concrete	Strain $x10^{-6}$	16	2.7	15	
		Stress kg/cm^2	5.12	8.64	4.80	
	Deflection mm		1.00	1.49	0.93	
	Width by crack gauge mm		-	-	-	
	Thermometer °C		-	37.3	-	
	Remaining Strain & Deflection (Center of Span)		1 ($x10^{-6}$), 0.09 (mm)			No Loading

Table 5.43 Detail of Loading Test Results for Br. No. 9

Case 4 (29.2 ton)			1/4 of Span	Center of Span (2/4)	3/4 of Span	Remarks
Exterior Beam	Reinforcing Bar	Strain x 10^{-6}	–	–	–	
		Stress kg/cm²	–	–	–	
	Concrete	Strain x10^{-6}	14 (5)	23 (5)	11 (5)	
		Stress kg/cm²	4.48	7.36	3.52	
	Deflection mm		1.04	1.54	0.95	
	Width by crack gauge mm		–	–	–	
	Thermometer °C		–	37.5	–	
	Remaining Strain & Deflection (Center of Span) 1 (x10^{-6}), 0.04 (mm)					No Loading
Interior Beam	Reinforcing Bar	Strain x 10^{-6}	–	–	–	
		Stress kg/cm²	–	–	–	
	Concrete	Strain x10^{-6}	28	42	15	
		Stress kg/cm²	8.96	13.44	4.80	
	Deflection mm		1.75	2.61	1.55	
	Width by crack gauge mm		–	–	–	
	Thermometer °C		–	37.4	–	
	Remaining Strain & Deflection (Center of Span) 0 (x10^{-6}), 0.08 (mm)					No Loading

Table 5.44 Value of Crack Width due to Truck Loading (No. 1)

Bridge No. (Load Time)	Case No.	Final Value of Gauge Position				Value of Gauge Position after No Loading			
		1-A	1-B	2-A	2-B	1-A	1-B	2-A	2-B
No. 2 (10) minutes	1	0.03	0.03	0.02	0.01	–	–	–	–
	2	0.05	0.04	0.03	0.03	0.00	0.00	0.00	0.00
	3	0.07	0.02	0.00	0.00	–	–	–	–
	4	0.06	0.03	0.01	0.00	0.10	0.00	0.01	0.01
No. 5 (10) minutes	1	0.01	0.01	0.00	0.01	–	–	–	–
	2	0.01	0.01	0.01	0.03	0.00	0.00	0.00	0.00
	3	0.00	0.00	0.00	0.01	–	–	–	–
	4	0.01	0.01	0.01	0.02	0.00	0.00	0.00	0.00
No. 1 (10) minutes	1	0.01	0.01	0.00	0.00	–	–	–	–
	2	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00
	3	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–

Crack Gauge Position

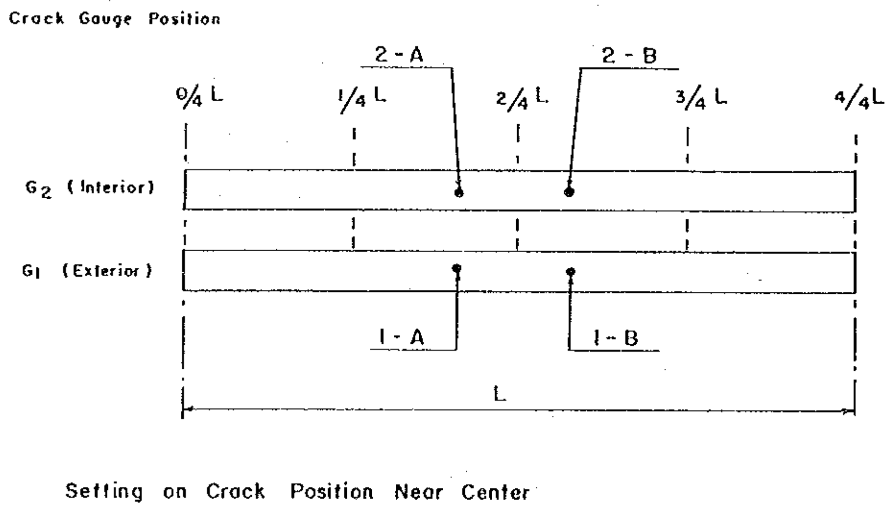
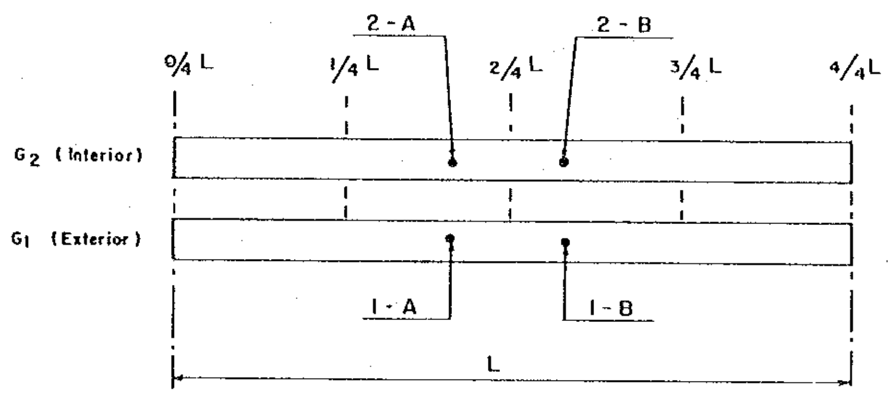


Table 5.45 Value of Crack Width due to Truck Loading (No. 2)

Bridge No. (Load Time)	Case No.	Final Value of Gauge Position				Value of Gauge Position after No Loading			
		1-A	1-B	2-A	2-B	1-A	1-B	2-A	2-B
No. 8 (5) minutes	1	0.01	0.02	0.02		–	–	–	–
	2	0.02	0.02	0.03					
	3	0.01	0.01	0.01		–	–	–	–
	4	0.01	0.02	0.01					
No. 3 (5) minutes	1	0.03	0.03	0.01	0.01	–	–	–	–
	2	0.04	0.03	0.03	0.03	0.00	0.00	0.00	0.00
	3	–	–	–	–	–	–	–	–
	4	–	–	–	–	–	–	–	–

Crack Gauge Position

Crack Gauge Position

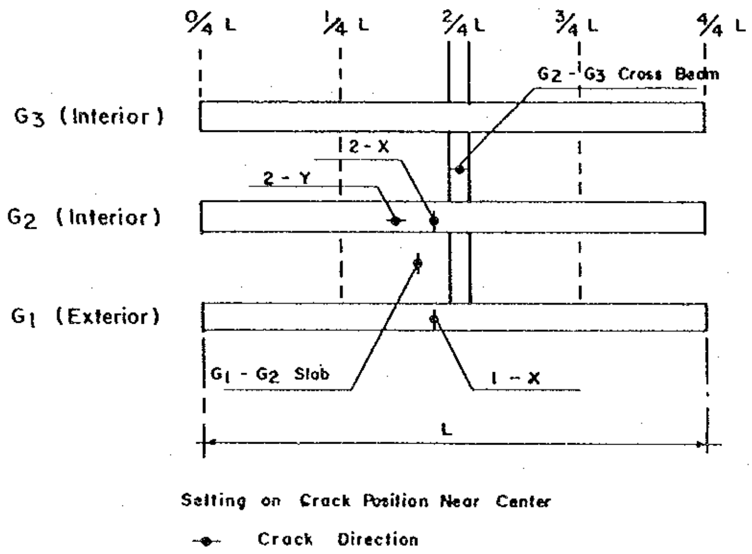


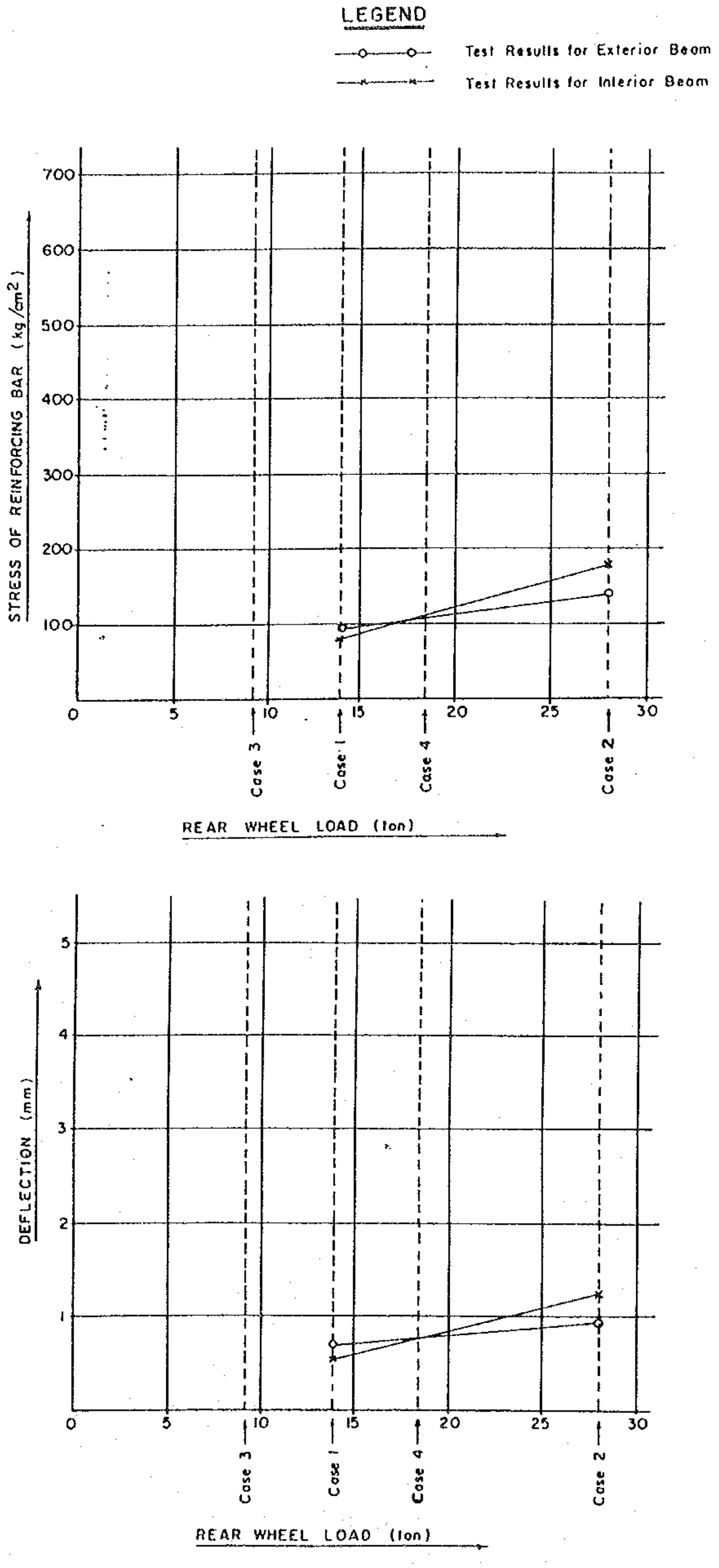
Setting on Crack Position Near Center

Table 5.46 Value of Crack Width due to Truck Loading (No. 3)

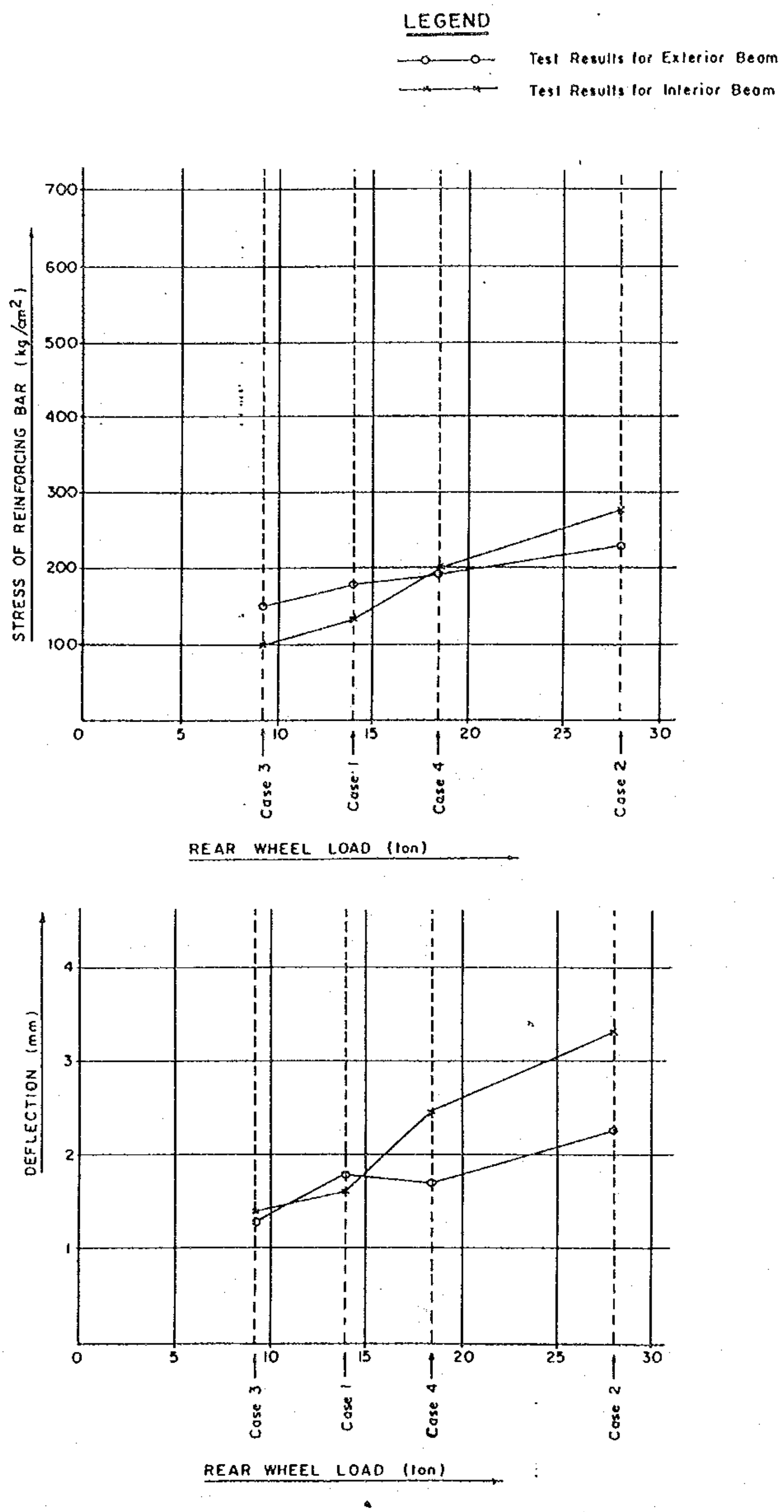
Bridge No. (Load Time)	Case No.	Final Value of Gauge Position					Value of Gauge Position after Removing of Load				
		1-X	2-X	2-Y	Slab	Cross Beam	1-X	2-X	2-Y	Slab	Cross Beam
No. 4 (5) minutes	1	0.02	0.01	0.00	0.00	0.00	-	-	-	-	-
	2	0.03	0.03	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00
	3	0.01	0.01	0.00	0.00	0.00	-	-	-	-	-
	4	0.02	0.02	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00

<u>Crack Gauge Position</u>

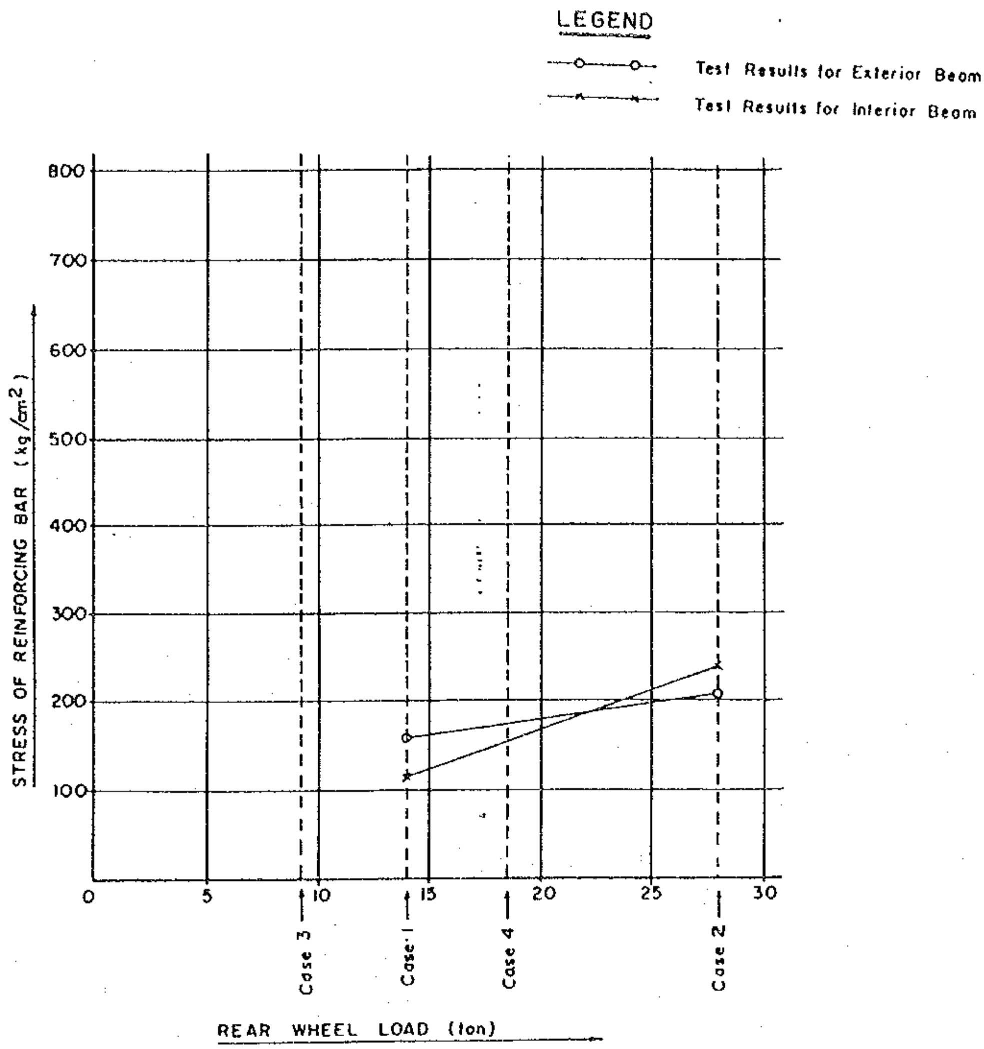


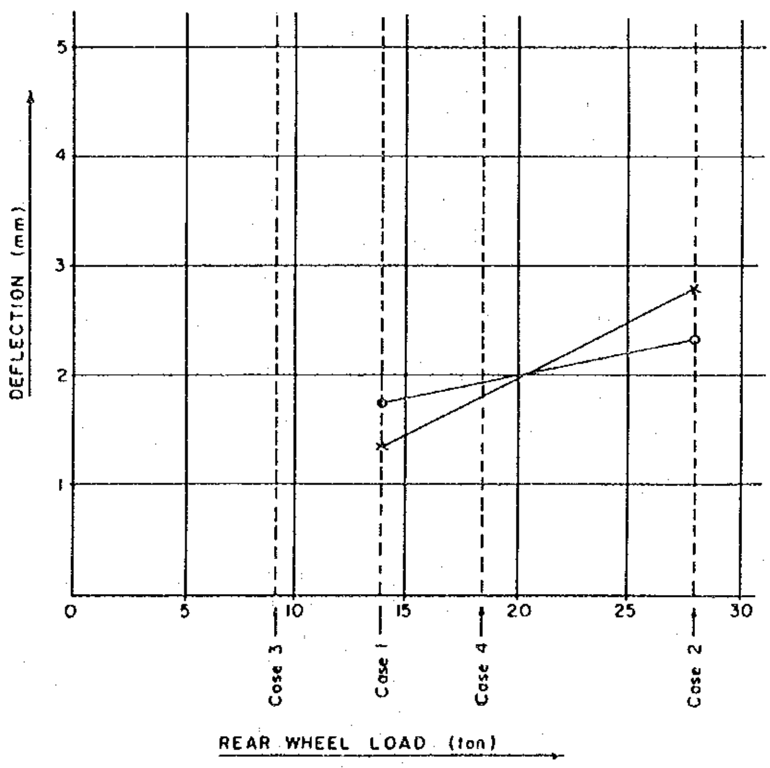


THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.31 Relation between Live Load & Stress, Deflection for Br.No.1(RC)

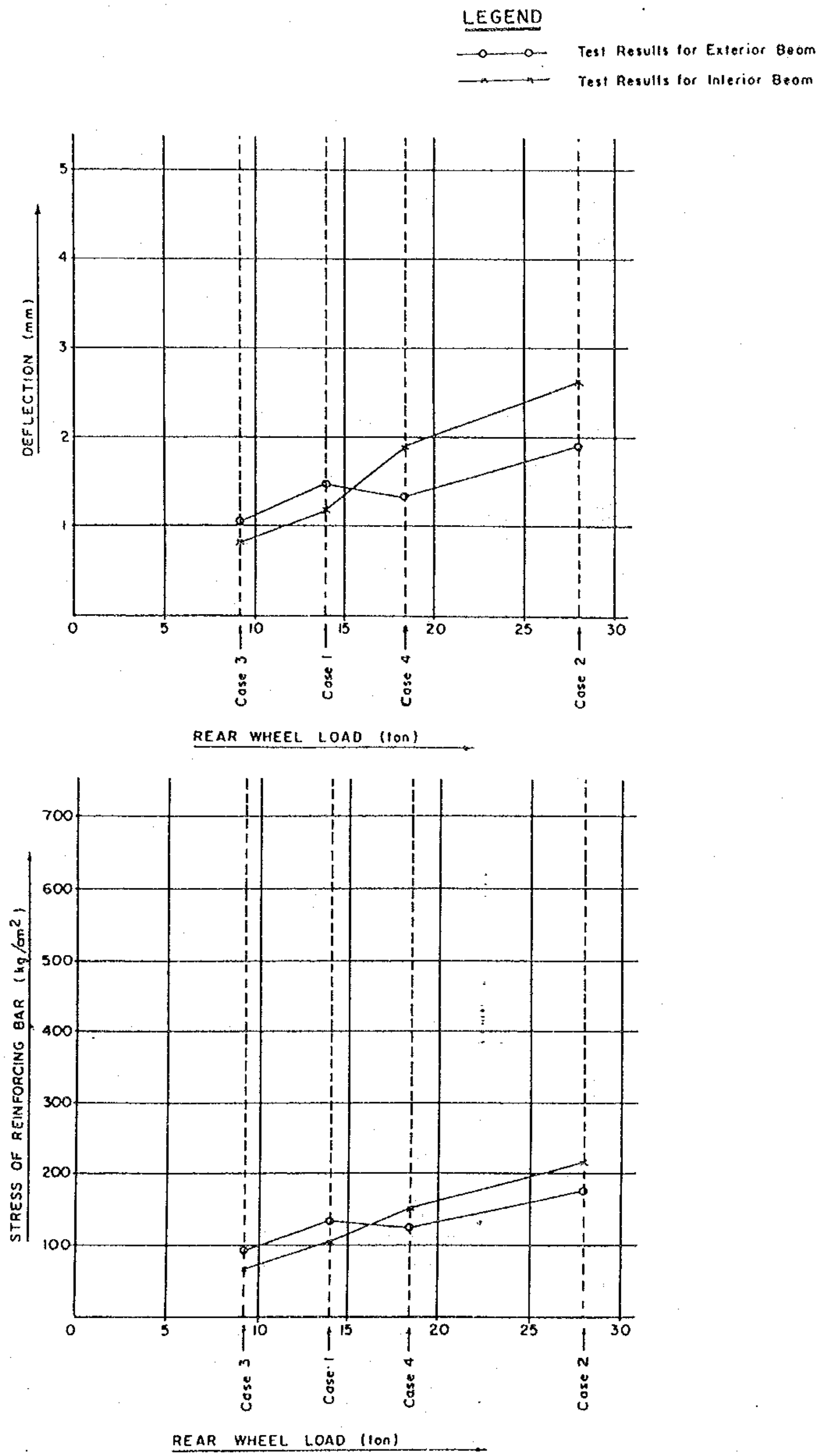


THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.32 Relation between Live Load & Stress,Deflection for Br.No.2(RC)

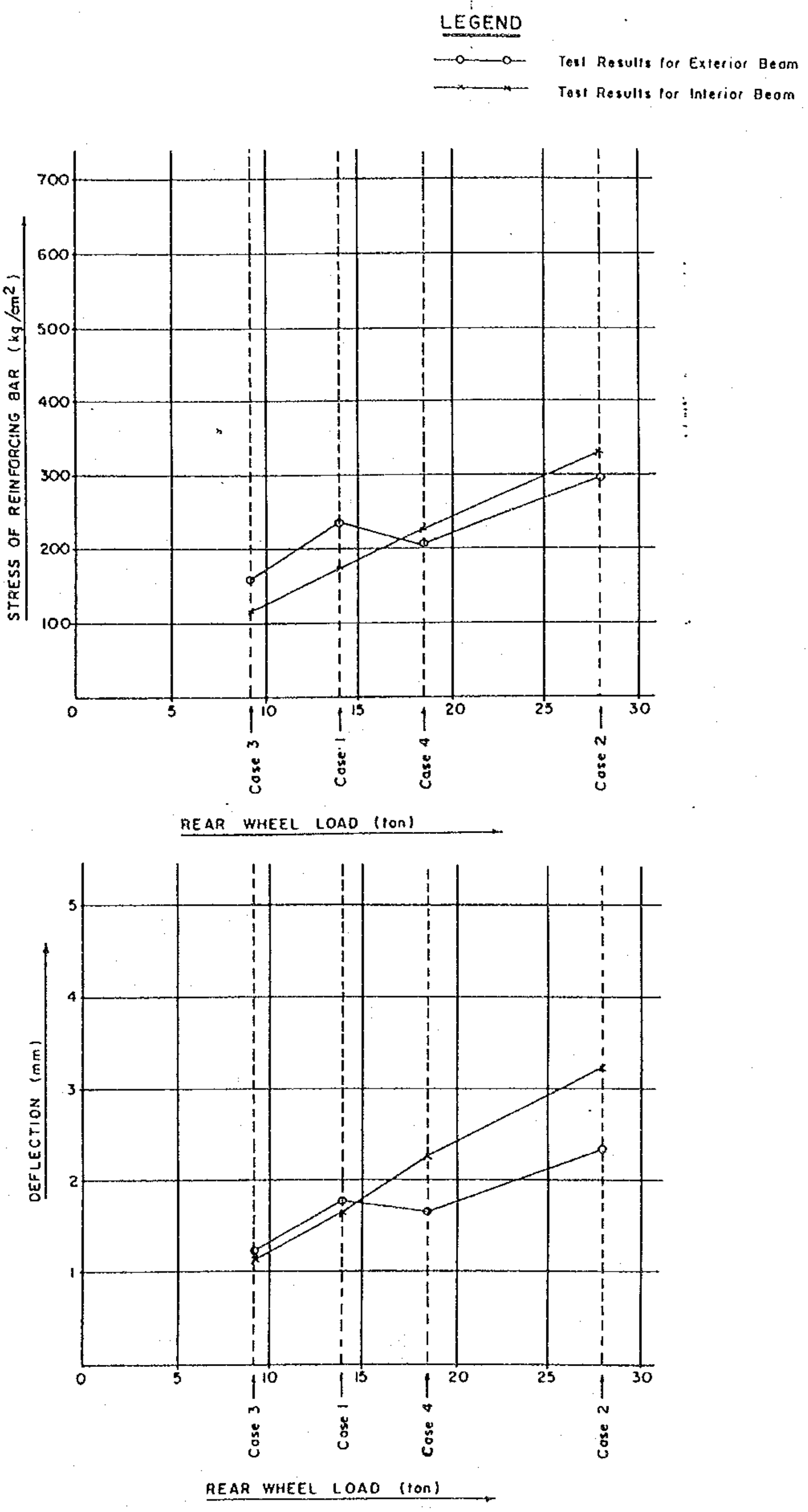




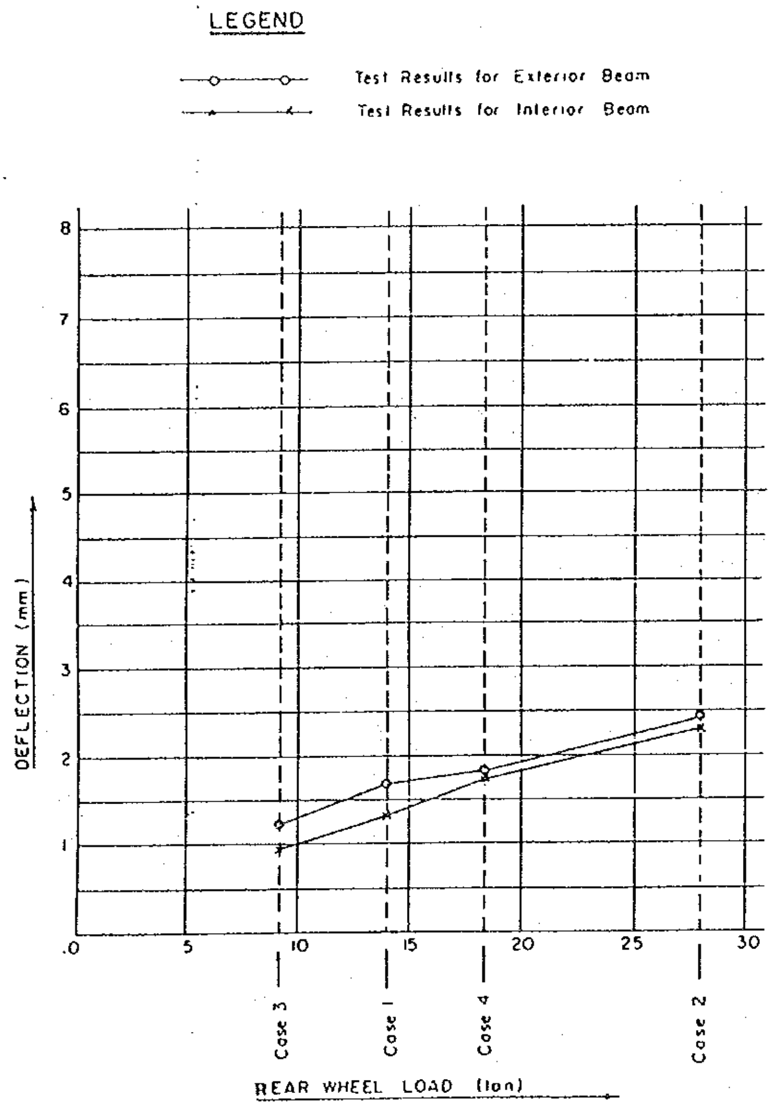
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.33 Relation between Live Load & Stress, Deflection for Br.No.3(RC)



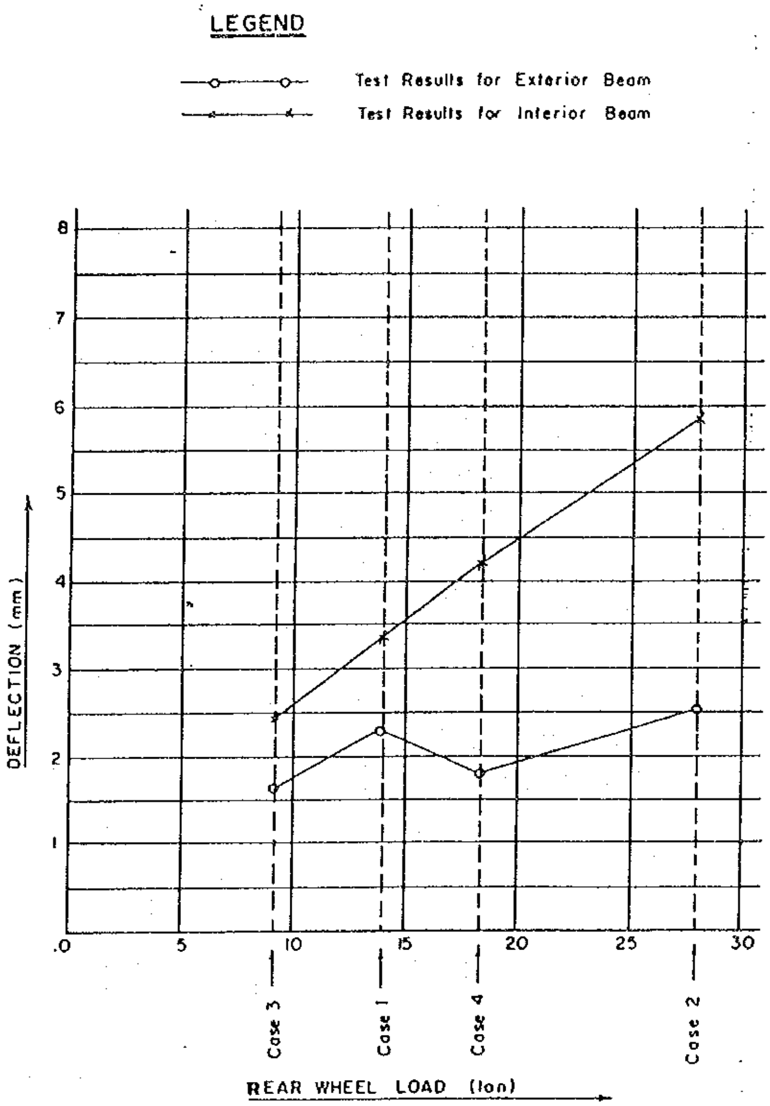
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.34 Relation between Live Load & Stress,Deflection for Br.No.4(RC)



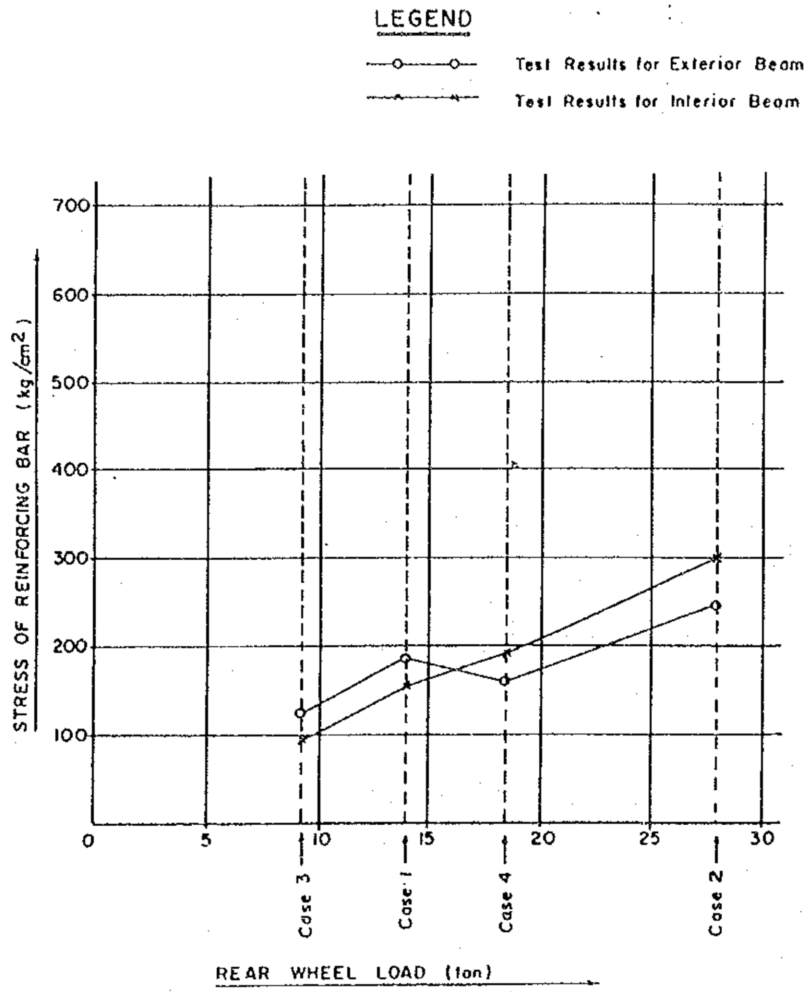
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.35 Relation between Live Load & Stress, Deflection for Br.No.5(RC)

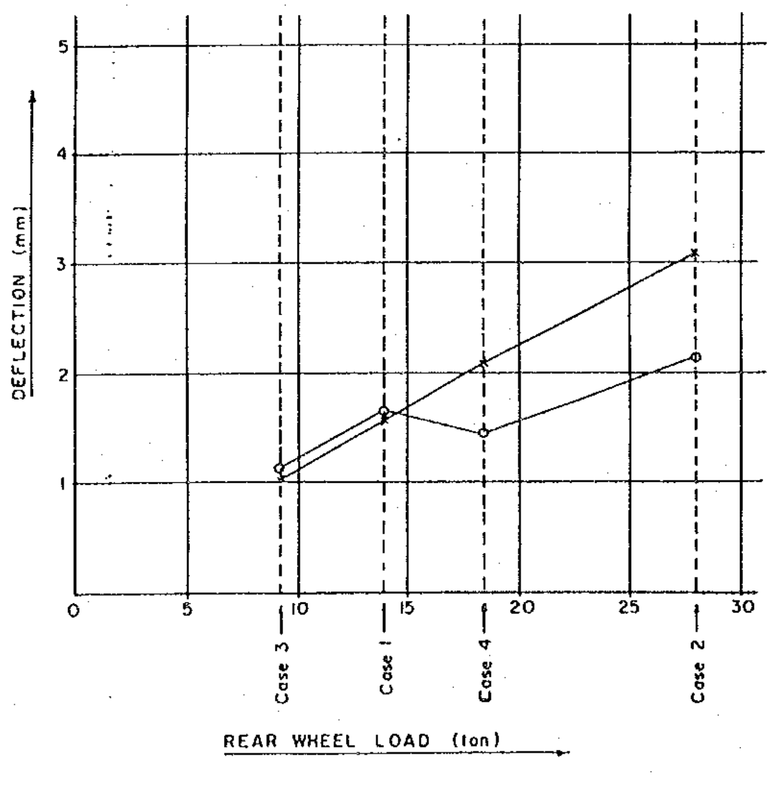


THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.36 Relation between Live Load & Deflection for Br.No.6(PC)

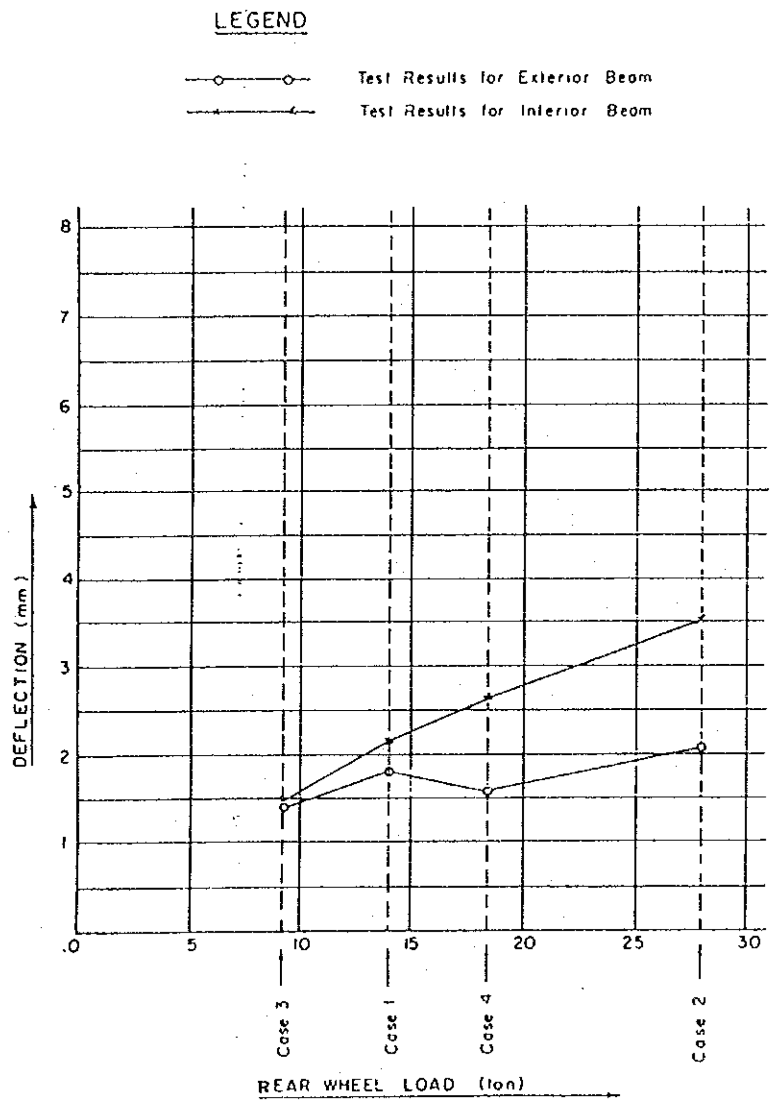


THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.37 Relation between Live Load & Deflection for Br.No.7(PC)





THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.38 Relation between Live Load & Stress, Deflection for Br.No.8(RC)



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 5.39 Relation between Live Load & Deflection for Br.No.9(PC)

CHAPTER 6 THE EVALUATION METHOD FOR EXISTING BRIDGES

CHAPTER 6

THE EVALUATION METHOD FOR EXISTING BRIDGES

The investigation of bridges and their load testing in this project was conducted for 6 reinforced (RC) bridges and 3 prestressed concrete (PC) bridges, a total of 9 bridges. The results of the investigation and load tests are described in the previous chapters, and the overall evaluation of the soundness of the existing bridges will be described as follows:

1. Evaluation of Soundness of Existing Bridges Based on Their Degree of Deterioration:

   Based on the table of determination for each bridge, the soundness of the bridges were evaluated from their durability (α) and load bearing capacity (β).

2. Evaluation Method Based on the Test of Component Materials of Concrete and Reinforcing Bar:

   The component materials of the bridges were tested for their strength and durability by performing compressive and tensile tests and carbonation of concrete, and the tensile strength of reinforcing bar as described in the previous chapter. The strength of the bridge materials were compared for their strength at the time of completion and their present strength or their deterioration with time. The soundness of the bridges were evaluated from this test.

3. Evaluation of the Bridges Using Loading Tests:

   Load bearing tests were performed mainly to check the deflection of the reinforced concrete bridge structures. The results measured in the field were compared with theoretical calculations (grid framework analysis) and the degree of differences were used to determine the soundness of the bridges.

   The degree of deflection of the bridges is important to determine the rigidity of the bridge materials and it is important to analyse the bridges based on this test. It is also important to observe how the cracks in the concrete increase with the passing of live loads to determine the soundness of the existing bridges.

4. Evaluation of the Existing Bridges Based on Their Load Bearing Capacity:

The load bearing capacity and strength of reinforced concrete bridges will vary with the design conditions, year of completion, the amount of traffic, and the degree of maintenance performed. The capacity of the bridge is determined by calculation of the strength for the type of vehicles that can safely pass over it. Reinforced concrete bridges are rated for the ultimate bending strength of the main girder, and prestressed concrete bridges are rated for the ultimate bending moment to determine their safe carrying capacity.

6.1 Evaluation of Soundness of Existing Bridges Based on Their Degree of Deterioration

1) Evaluation Method for Bridge Soundness

The bridge soundness is generally performed by qualitative methods by use of numerical methods.

When the degree of damage is great, repairs and strengthening is required, and in the worst case, bridge replacement is required. Such unsound bridges would be given the highest points, and fairly sound bridges would have lower points in evaluation.

In practice, the evaluated factors are represented by numbers, and a final decision is made by the overall summary of the totals calculated. The evaluated items are assigned a weighted number according to their importance and the final decision are fixed by numbers. Weight factors are applied to each criteria or objective indicating how important each factor is in reaching a decision.

At the present time, the following system is used:

① Specialist technicians judge each component based on their individual professional judgment.

② Several specialist technicians determine a rating as a team based on their past experience and technical judgment, and hold further discussions and pass their judgment for the appraisal and rating.

③ Statistical analysis of past data is conducted, and final appraisal made.

Since a decision can not be made readily from the above three methods, technical judgment is considered in reaching a final decision. This method is commonly used to reach decisions in Japan today.

As a general rule, Method ③ is used for statistical analysis when there are many bridges on the order of 100 to 1,000 bridges are involved. In this project as there are 9 bridges for which a detailed condition report and load tests are being performed, either Method ① or ② will be adopted and weight factors will be used to make calculations.

It will be necessary to find the elements that affect the degree of soundness of bridges, and the elements that affect the determination of safety can be classified as follows:

i. Problems of deterioration of bridges with the passing of time and the surrounding environment;

ii. Problems of structural capability of the bridges to bear up to the volume of traffic and the live loads in terms of their size; and

iii. Problems of functions of the bridges to contain the volume of traffic in terms of their effective width and use of the space under the bridges, together with environmental issues, including aesthetics.

The above three elements will be discussed in further detail for the appraisal of the bridges.

From the point of bridge durability, the various bridge members are evaluated individually, and the overall evaluation of the bridge is appraised.

From the point of bridge load capacity, the bridges are appraised for the changes to their original design specifications (the increase in the bridge loads from the original design and the increase of the traffic volumes and loads and their impact).

From the point of bridge function, the bridges are appraised to see if they are performing their functions, however it is difficult to appraise the functions at this time.

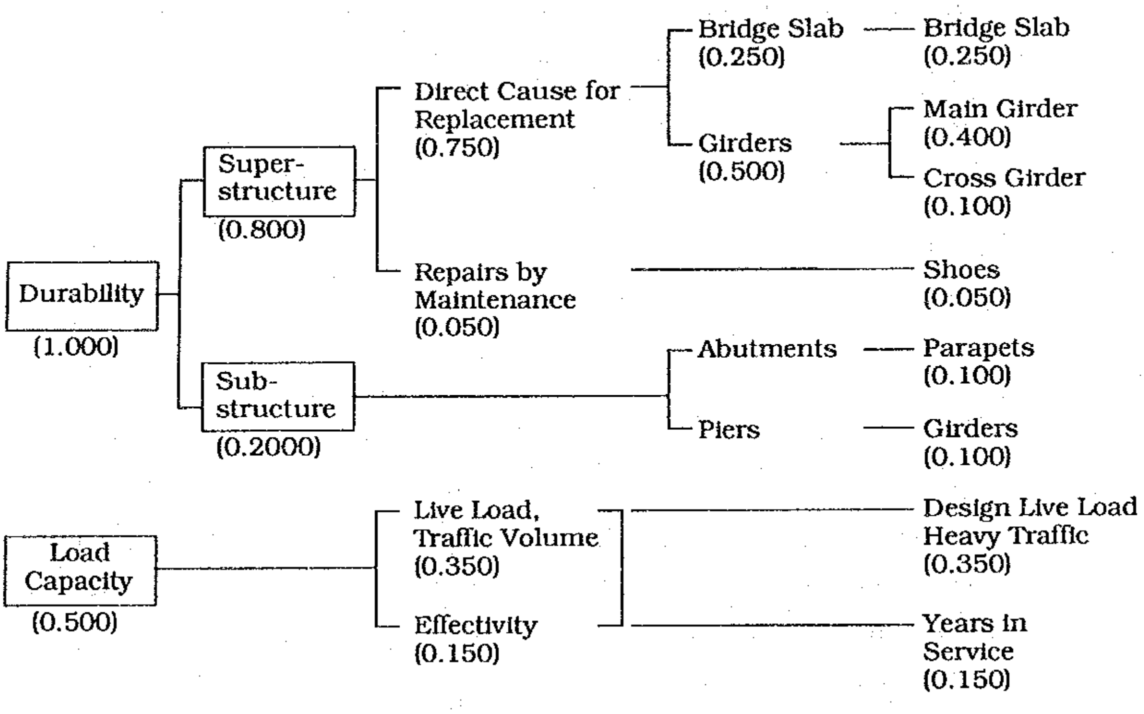
Therefore, it has been decided to appraise the current physical state of the bridges from their "**durability**" and "**load capacity**".

Appraisal of Durability: Based on physical changes in the main bridge structural members

Appraisal of Load Capacity: Based on changes in traffic volumes, heavy vehicle traffic from the original bridge specifications with the passing of time

This project proposes to make studies of the bridges based on the Damage Ranking List and prepare a list of the principal bridge elements to appraise the durability and load capacity of the bridges, and grade them by points. The evaluated weight of the items will have the factors (bt) given in Table 6.1.

Table 6.1 Establishment of Weight Factors (bt) for Evaluation Items



Notes: Figures in ( ) indicate Durability and Load Capacity as 1.000, 0.500, and Weight Factor (bt) (Research Data: Ministry of Construction in Japan)

The Evaluated Points (at) for the durability will be defined as follows:

A: 1 point

B: 2 points

C: 3 points

D: 4 points

E: 5 points

The points (at) appraising bridges for Load Capacity are as follows:

Live Load and Heavy Vehicle Traffic	Load per axle less than 7.0 tonnes, and little heavy vehicle traffic	:	1 point
	Load per axle more than 7 tonnes, and heavy vehicle traffic	:	3 points
Year Bridge Completed (Time in Service)	Completed after 1975 (less than 20 years in service)	:	1 point
	Completed before 1975 (more than 20 years in service)	:	3 points

The overall evaluated points are calculated by multiplying the evaluated points (at) by the weight factor (bt in the previous table), and the bridges will be ranked by the points.

Table 6.2 gives the evaluation elements (at) and the weight factors (bt).

Table 6.2 Evaluation Element (at) and Weight Factor (bt)

		Evaluated Item	Evaluation (at)		Weight Factor (bt)	Points at x bt
Durability	Super-structure	Girder, Main	A-1, B-2, C-3, D-4, E-5		0.400	
		Girder, Cross	A-1, B-2, C-3, D-4, E-5		0.100	
		Slab	A-1, B-2, C-3, D-4, E-5		0.250	
		Shoe	A-1, B-2, C-3, D-4, E-5		0.050	
	Sub-structure	Abutment	A-1, B-2, C-3, D-4, E-5		0.100	
		Pier	A-1, B-2, C-3, D-4, E-5		0.100	
Load Capacity	Live Load & Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic		1	0.350	
		Weight per axle more than 7.0 ton, with heavy traffic		3	0.350	
	Year Bridge Completed	Completed after 1975 (less than 20 years service)		1	0.150	
		Completed before 1975 (more than 20 years service)		3	0.150	
Overall evaluated points						

2) Overall Decision of Bridge Soundness

From Table 6.2 the overall points are calculated by multiplying the Evaluated Points (at) by the Weight Factor (bt), and all 9 bridges are ranked for their degree of soundness.

The overall degree of soundness is listed for their degree of soundness in Fig. 6.1.

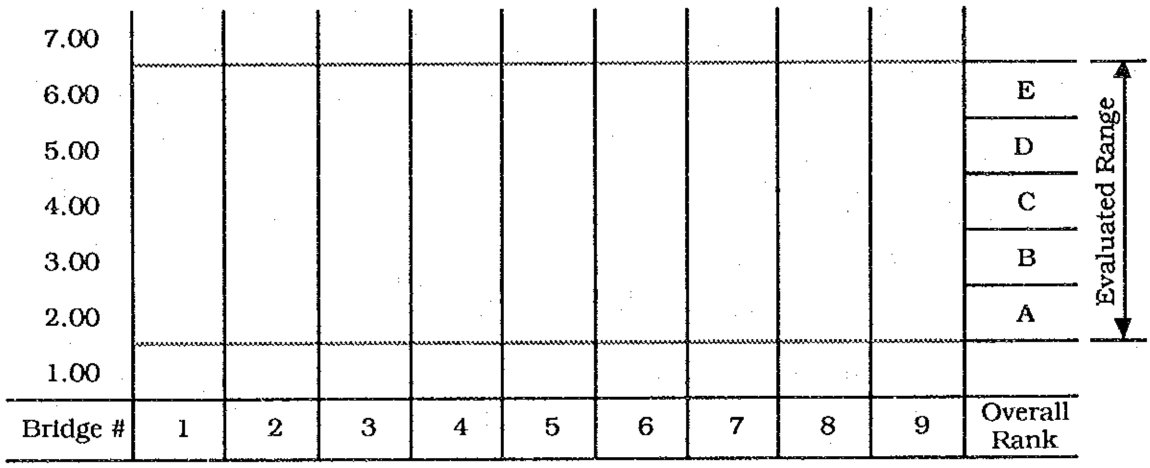


Fig. 6.1 Composite Evaluation Diagram for Soundness

6.2 Evaluation of Bridges Based on the Test Results of Concrete and Reinforcing Bar

The results of the tests of the materials for the RC bridges and PC bridges are evaluated by establishing standards for the appraisal, and it is determined whether or not they comply with them.

As a general rule the design standards prevailing at the time of completion of the bridges will be used and except for the strength requirements, the design standards of Japan and the AASHTO will be used.

The tests were made principally of the main girder materials and the average values of the bridges were used. The evaluation based on the results of tests of the materials are given in Table 6.3.

Table 6.3 Evaluation Based on the Testing of Concrete and Reinforcing Steel

Rank	Description of Evaluation
I	Satisfies standard value
II	Meets requirements of standard value or is somewhat less than the standard value
III	Is much less than the standard value

6.3 Evaluation of the Bridges Using Loading Tests

Loading tests were performed at the center of the bridge and at quarter span points in order to measure the deflection and to determine the strength of the reinforcing bar and concrete by using the following formula:

Stress of Reinforcing Bar (Stress of Concrete) (kg/cm^2)

= Strain ($x10^{-6}$) x Modulus of Elasticity for Reinforcing Bar (Concrete) (kg/cm^2)

The deflection of beams was obtained by a deflection meter.

On the other hand, theoretical calculations were made using a load similar to the loaded truck used in the test, and the stresses in the concrete, reinforcing bar and the deflection. The differences in the test and the calculations were compared.

When there are large cracks in the main girders and slab as in this case, there are large variances in the deflection of the concrete and it is not easy to compare the field test results with those obtained from the calculations. Hence it was decided to evaluate the bridges based on the rigidity of the concrete which is affected by the sag, and strength of the reinforcing bars which affect tensile strength.

At bridges with large cracks, crack gauges were installed to measure the increase of the crack width when they were loaded with live loads.

Since the loading tests were of the non-destructive type and the rear wheel loads of the test load truck are from 7 to 10 tons, the loads for the RC bridges were of the T-20 tons, and the loads for the PC bridges also were of T-20 tons as the rigidity of the girders were larger, as the measurements of the deflection to be taken and the deflection of the concrete were larger considering the span 20 m to 30 m long.

The differences between the field test results and theory are related in a later chapter. The results will be applied in developing the factors for calculating the load bearing factor.

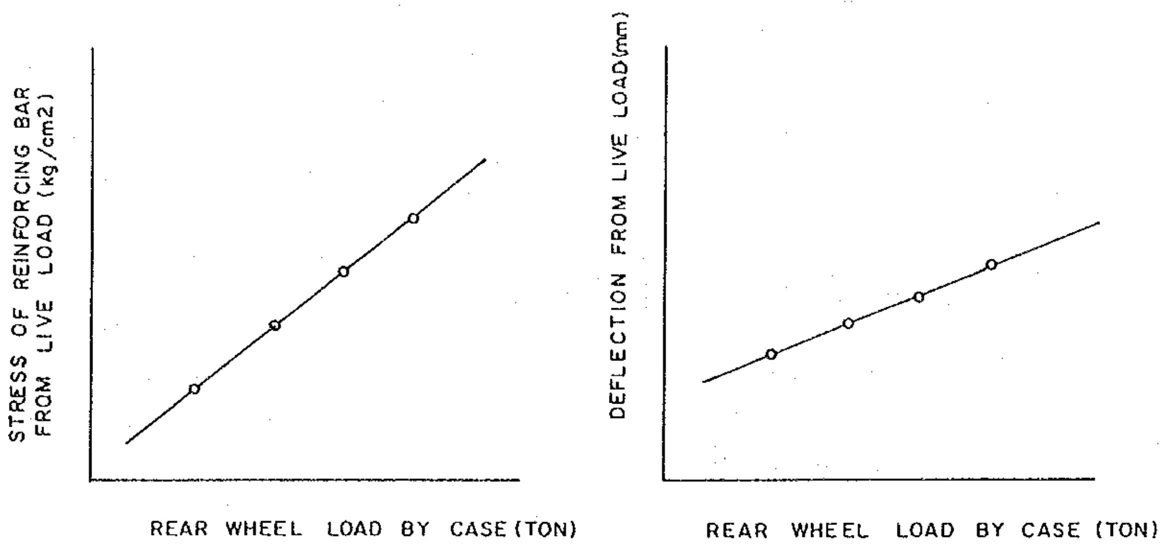


Fig. 6.2 Relation between Rear Wheel Load and Deflection, Stress

1) Judgment Factor for Strength and Deflection

(1) Decision for the Degree of Stress

a) RC Structures

The strength of the concrete and the reinforcing bar are obtained from the results of tests of the quality of the materials.

The value of compression tests by concrete core is divided by a factor of 3 to determine the allowable stress in the concrete.

The stresses in the reinforcing steel are obtained by calculating the tensile strength and yield strength by performing tests on the bridges.

– Determination of the Stress –

Concrete:	When the stress exceeds the allowed stress or does not exceed 75% of the critical limit value σ_{cu}.
Reinforcing bar:	When the stress exceeds the allowed stress or does not exceed the allowed yield point.

In the above cases, there is no failure of the structure due to the deformation, but the structure must be strengthened.

In the case of 75% of the critical value of concrete, the safety factor is about 1.3, and the deflection in the concrete is about half of the deflection at failure, and failure from deflection is not expected.

In the case where the stress exceeds 75% of critical value of σ_{cu} of concrete, or where the stress in the reinforcing bar equals the yield point, or the cracks and deflection in the concrete increases, there could be structure failure, and therefore necessary to strengthen the structure or to replace the structure immediately.

b) PC Structures

When determining the strength of PC structures, it is necessary to obtain the effective prestress amount of the structure. However, the effective prestress amounts on the structure vary with the quality of the concrete, amount of prestressing applied, amount of creep in the concrete, and the shrinkage of the concrete during the drying process. There is a direct method to appraise the condition of prestressed concrete super-structures. Hence, it is necessary to obtain copies of the original construction design documents or specifications. If they are not available, it is necessary to perform load tests and check the structure for cracks and inspect the condition of the structure.

When a general stressed condition can be assumed, the variances in stresses of PC component strands are generally 0 to 8 kg/cm^2 although the effective prestress amounts could differ. If measured results exceed this value due to insufficient stressing of strands, inferior anchorage, loosening of the steel strands, or breakage, repairs to correct the deficiencies are necessary. If cracks are noticed around the tension and shear zones under dead load conditions, this is an indication of loss of effective prestress, and the components should be considered as RC members. When there are no cracks in the PC members under bending conditions, the member should be performing its function over its cross section and the load on the PC member should be less than 5 kg/cm^2. When cracks appear on the surface of the PC member, the load on the PC member is borne by the prestressed steel strands, and the changes in stress on the steel are several times the designed stress. Although it does not cause immediate failure of the member, the cracks propagate and the steel members corrode, causing the member to eventually fail, so corrective measures should be taken immediately.

(2) Judgment of the Deflection (Sag)

When there is a deflection in the PC member at the supporting point, the actual amount of deflection should be computed by discounting the amount of deflection of the support. I the amount is small or if it is within the allowable amount of deflection, the member can be considered safe, however, it is necessary to check the rigidity of the concrete and the reduction of the modulus of elasticity of the concrete from the amount of the deflection.

As a general rule, the measured deflection can be much smaller than the theoretical value. This is due to the pedestrian walkway and bridge railing acting together with the girder which were not considered in the theoretical calculation. In the case of RC girders, when cracks appear, the rigidity is reduced and the deflection could increase, and the reduction of the concrete and the strain factors could also cause this to happen. When the measured deflection is larger than the calculated value, it is necessary to check the rigidity of the member. For PC beams, the amount of deflection of the measured amount should be compared with the calculated value, and the girder should be checked for any changed conditions.

In PC girders, there is a camber in the member caused by the prestressing. This camber increases with the creep of the concrete, and proceeds to 80% in the first week, and is said to cease within 3 to 5 years. Hence if there is any irregularity noticed it could be due to excessive stressing of the prestressed strands, insufficient dead loads, and deteriorating of concrete. Such a component should be kept under close observation.

6.4 Evaluation of the Existing Bridges Based on Their Load Bearing Capacity

The load bearing capacity of the main girders of the existing RC and PC bridges allow the calculation of the live load that can be permitted on the existing bridges. The calculations of the load bearing capacity differs for the RC bridges and the PC bridges and they are explained in this chapter.

A grid framework analysis was made based on the live load case based on the design standards established by the Sultanate of Oman. The results of the calculations were compared with the allowable stresses and check should be made whether the actual stresses meet with the allowable stresses.

1) Calculation Method of the Allowable Loads for RC Bridges

The bending bearing stress for the main girders is expressed by the current design live load (AASHTO load) Bending Safety Factor (γ). The load bearing capacity of the outer girder and inner girder was calculated and the minimum value be used to determine the load bearing capacity of the bridges.

$$\gamma = f \bullet \frac{M_u - 1.1\, M_d}{M\ell}$$

$$M_u = A_s \bullet \sigma_{sy} \bullet (d - 1/2 \bullet \frac{A_s \bullet \sigma_{sy}}{0.85 \bullet \sigma_{28} \bullet b})$$

where,

- γ : safe ultimate bending ratio of the main girder to AASHTO load
- f : measured and calculated stress ratio = calculated/measured
- M_u : ultimate bending moment of girder (t•m)
- M_d : bending moment of girder due to existing dead load (t•m)
- $M\ell$: bending moment of girder due to AASHTO load (t•m)
- σ_{sy} : yield stress of reinforcing bar (test value at time of construction, σ_{sao} = 1800 was 4,200 kg/cm^2)
- b : effective width of compressed flange (cm)
- d : effective height to main reinforcing bar (cm)
- σ_{28} : standard design strength of concrete (kg/cm^2)
- A_s : Area of main steel bar for tension (cm^2)

The method of calculation of the load bearing capacity is made in accordance with the four methods given in Table 6.4. The method for calculating δ_o, σ_o,

$M\ell$ is made by the same methods (simplified method or the load distribution method).

Table 6.4 Calculation Method of Load Bearing Capacity

Load Capacity Calculation	Calculation Standard	Value of f (Ratio of Measured and Calculated Stress)
Method #1	Calculate $M\ell$ by the simplified method, and obtain γ using f = 1.4	1.4
Method #2	Obtain the value of $M\ell$ considering distribution of loads on the girder and calculate γ using f = 1.0	1.0
Method #3	Measure deflection by load test, for f divide the calculated deflection by the measured value and calculate γ	$\frac{\delta_o}{\delta} = \frac{\text{calculated defl.}}{\text{measured defl.}}$
Method #4	Measure the stress in the rebar with loading test, for f divide the calculated stress by the measured stress and calculate γ	$\frac{\sigma_o}{\sigma} = \frac{\text{calculated stress}}{\text{measured stress}}$

The load bearing capacity shall be calculated starting with Method #1 to #4, and when the value for α exceeds 1.0, the bridge shall be considered safe to carry loads, and the largest value of the four methods shall be determined as the load bearing capacity α of the bridge. When all the values for α are less than 1.0, the value for γ calculated from Method #4 is the failure factor under live loads γ for the bridge.

$$\alpha = \frac{\gamma}{\beta}$$

where, α : load bearing ratio

β : failure safety factor for the bridge required under AASHTO live load and is a value determined for the actual traffic on the bridge and fixed from the number of years that the bridge will be in service and $\beta_{met} = 2.5$

The Load Bearing Capacity (P) for the bridge will be as follows:

$$P = \text{AASHTO Live Load} \times \alpha \text{ (ton)}$$

2) Evaluation of Load Bearing Capacity of PC Bridges

The evaluation of load bearing capacity of existing PC bridges is the same as for bridges where the RC components are still active in the axial direction, and the stresses imposed on the bridge are not proportional with the stresses on the cross section. Also the stress in the wires and the type of wire used for tensioning the member becomes important. The load bearing capacity of the component is determined by the ultimate bending moment of the cross section which is compared with the safety factor (load factor design method) at ultimate breaking strength of the member.

The ultimate bending moment is obtained from the original design documents and AASHTO HS 20-44 live load system by the grid framework analysis.

- Design Condition: The amount of PC wire (AP cm^2)
  The breaking factor of the PC wire (tension) (σ_{pu} kg/cm^2)
  The effective prestress load (σ_{pe} kg/cm^2)
  Effective width of compression flange (B cm)
  Standard design strength of concrete (σ_{28} kg/cm^2)
  Effective height (d cm)
  Dead load bending moment of each main girder (M_d t•m)
  Live load bending moment of each main girder ($M\ell$ t•m)
  Properties of the PC cable (E_p kg/cm^2)
  Ultimate deflection of concrete (ε_{cu})
  Combined tension (T kg)
  Combined compression (C kg)
  Distance to combined compression from compression edge (k • x cm)

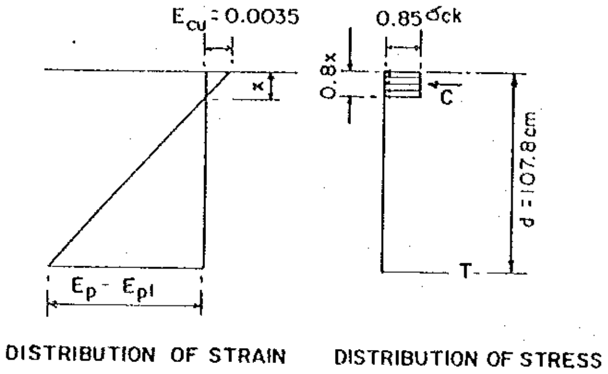


Fig. 6.3 Distribution of Stress and Strain

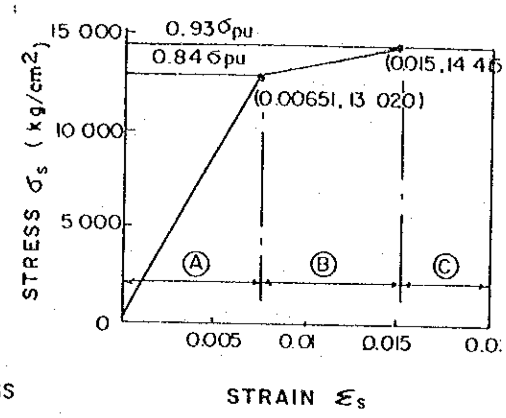


Fig. 6.4 Stress and Strain Diagram of 7mm PC Cable

Ultimate bending moment (M_u t•m)

$$M_u = T(d - k \cdot x)$$

The ultimate load (M_{du}) will be as follows:

a) 1.3 [dead load] + 2.5 [live load]

b) 1.7 [dead load + live load]

Therefore the safe load of PC bridges will be considered safe when

$$\frac{M_u}{M_{du}} > 1.0$$

3) Study of Stress According to the Omani Design Standard

The bending moment for the representative bridges No. 1, 2, 6 and 9 shall be calculated for the dead load and live load using the live load design standards of various countries and prepare Fig. 6.5, and from the results the maximum bending moment, it corresponds to the Omani Design Standard case for loading a 2-lane highway with a 60 ton truck.

So for the bridges in this project, the case of the representative live loads are the two cases in Fig. 6.6 and Fig. 6.7, theoretical calculation will be performed and the actual stresses are calculated and compared with the allowable stresses, and the load capability is studied.

① Bridge No. 1, RC Bridge with T-Girders (L = 15 m)

② Bridge No. 2, RC Bridge with T-Girders (L = 15 m)

③ Bridge No. 5, RC Bridge with T-Girders (L = 15 m)

④ Bridge No. 6, PC Bridge with T-Girders (L = 30 m)

⑤ Bridge No. 9, PC Bridge with T-Girders (L = 21 m)

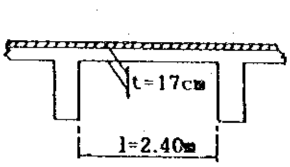
For all 9 bridges, theoretical calculations (grid framework analysis) cases are given in Table 6.6 and summarized as the theoretical calculation list. The list in the Table also gives the load capacity obtained under the AASHTO calculation case.

– Load Bearing Capacity of Reinforcing Concrete Slab –

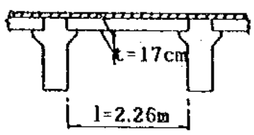
1. Analysis

The heaviest wheel load (P) in the specifications throughout the world is AASHTO Standard (AASHTO-HS-32) comparing BS, Japan and Oman.

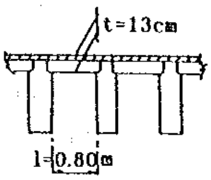
The calculation of each bridge is classified into 4 types as shown below.



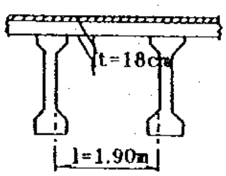
Br. No. 1



Br. No. 2, 3, 4, 5, 8



Br. No. 7, 9



Br. No. 6

2. Formula for Calculation

2-1 Bending Moment by Dead Load

Simple Slab $Md = \frac{1}{8} \cdot Wd \cdot \ell^2$

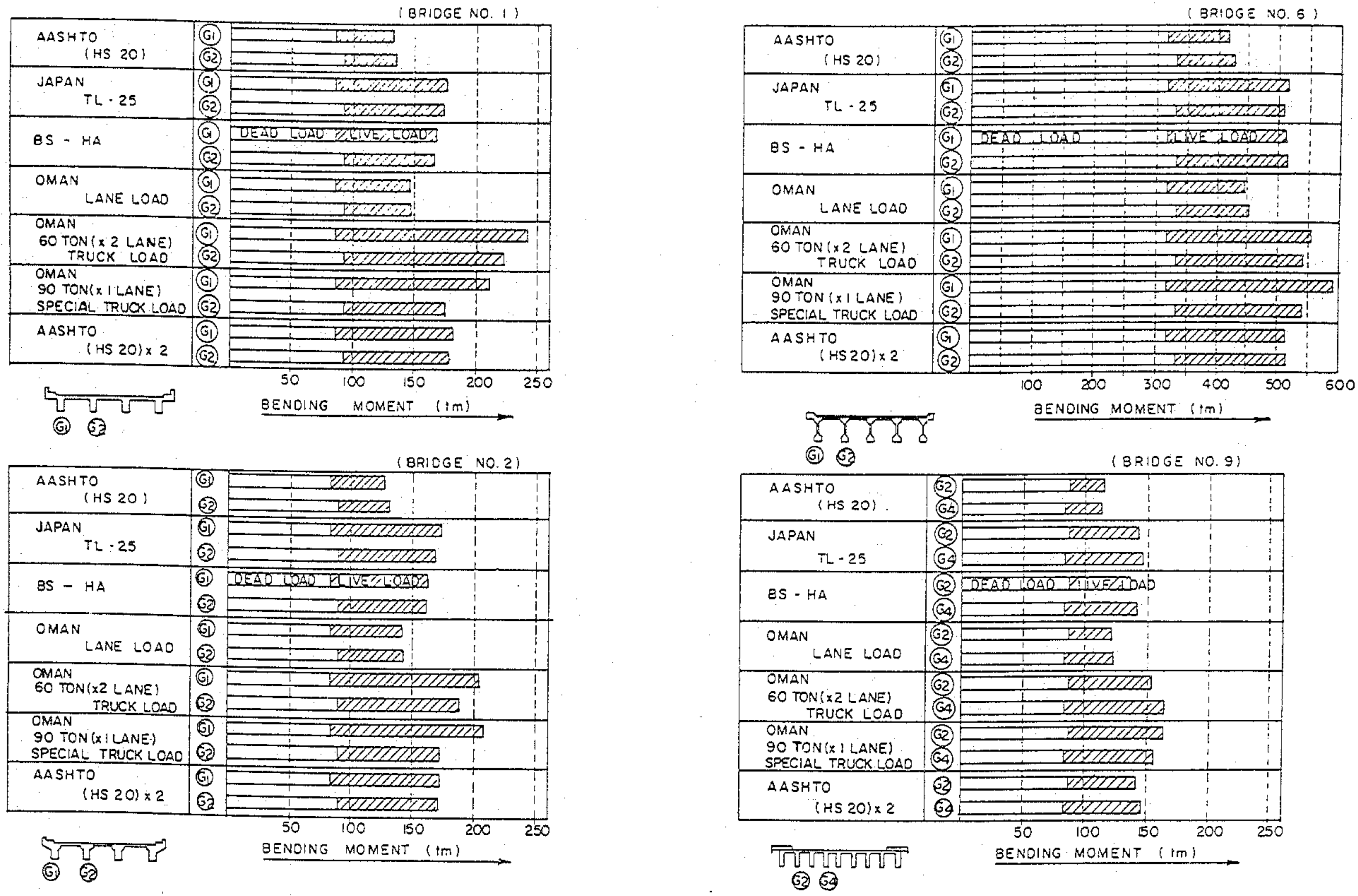
Continuous Slab $Md = \frac{1}{10} \cdot Wd \cdot \ell^2$ $(Wd = 2.5 \cdot t + 2.3 \cdot 0.05)$

2-2 Bending Moment by Live Load Using AASHTO Formula

Simple $M\ell = \left(\frac{\ell + 0.61}{9.74}\right) \cdot P \cdot (1 + i)$

Continuous $M\ell = \left(\frac{\ell + 0.61}{9.74}\right) \cdot P \cdot (1 + i)$

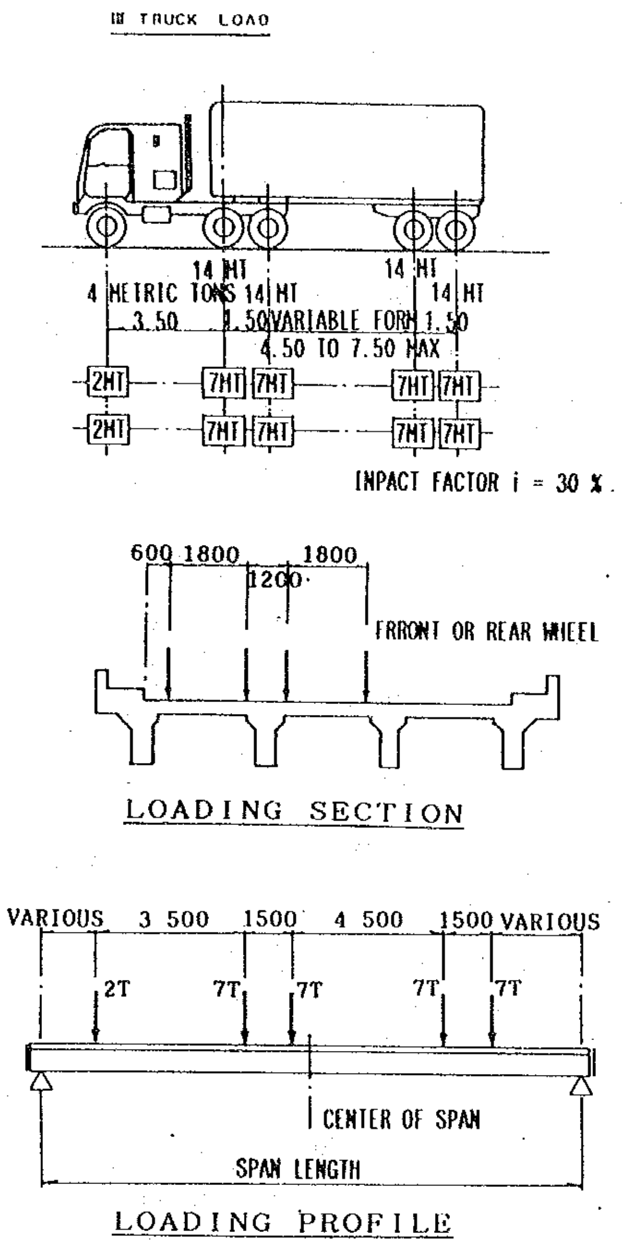
$\left(i = \frac{15.24}{\ell + 38} \leq 0.30 \right)$



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig. 6.5 Comparison of Bending Moment by Each Specification

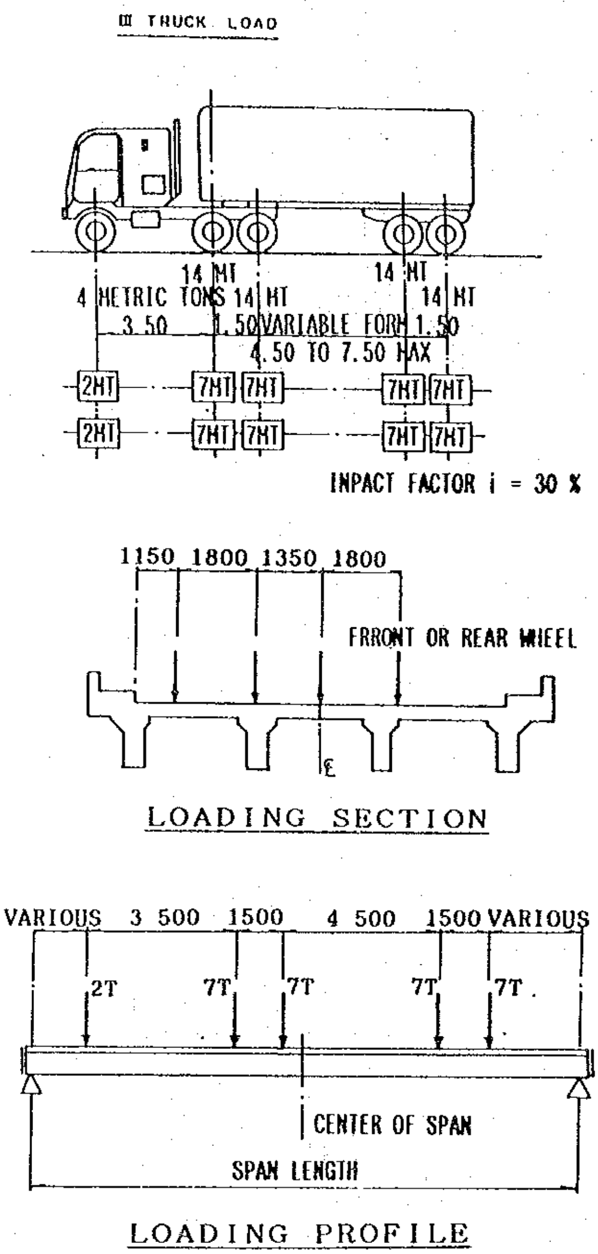
CASE A

LINE LOADING BY OMAN TRUCK 60 TON

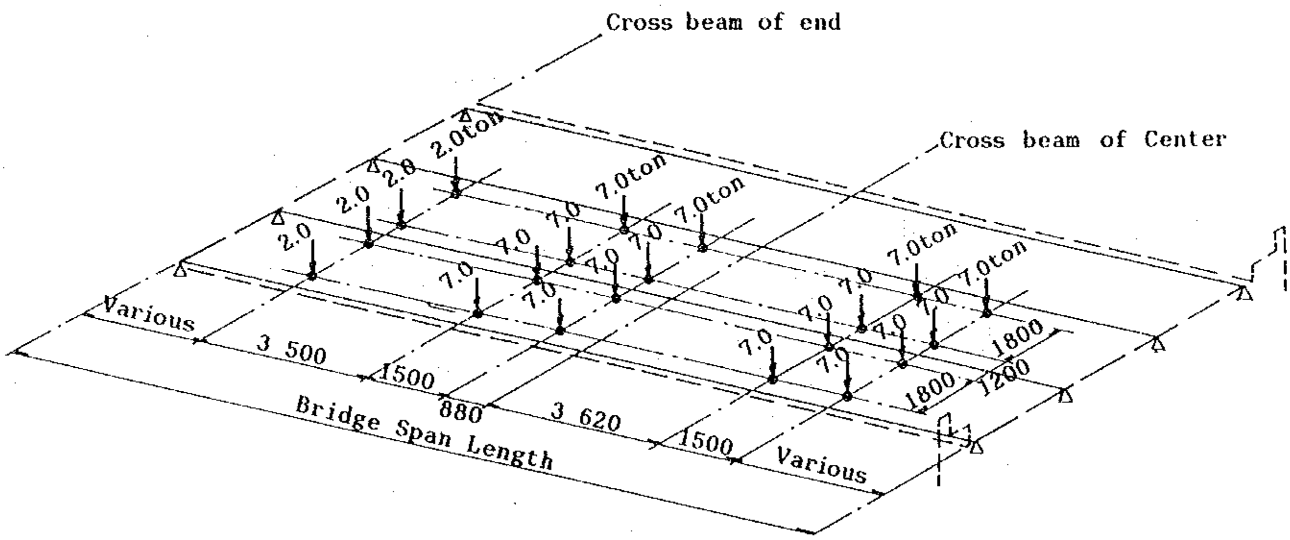


CASE B

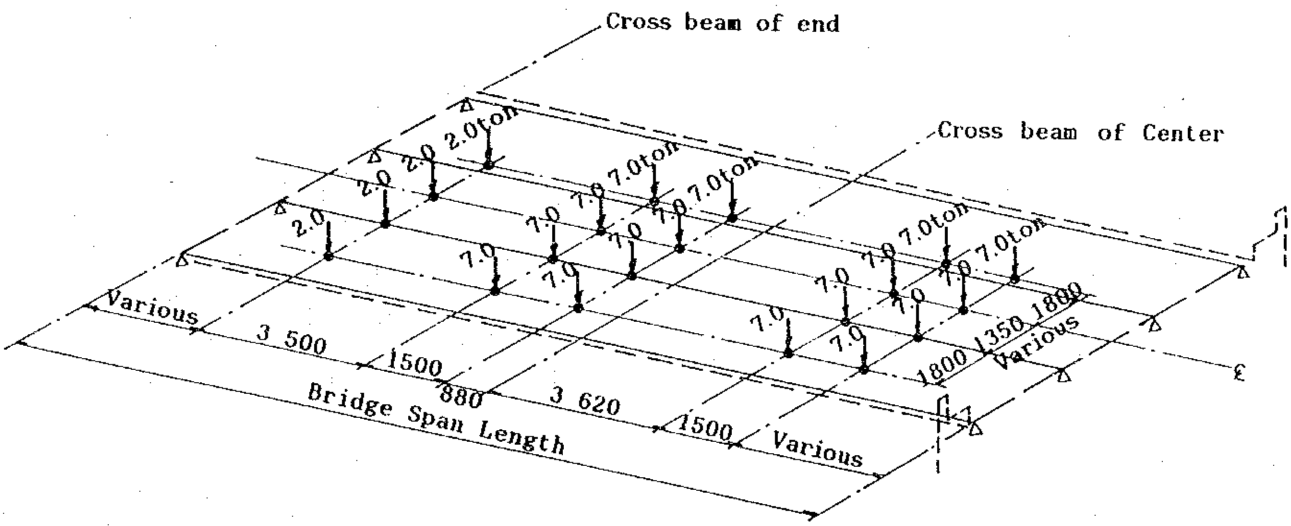
LINE LOADING BY OMAN TRUCK 60 TON



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. 6.6 Loading Condition by OMAN Design Standard**



CASE A: OMAN LINE LOADING (60 TON TRUCK×2)



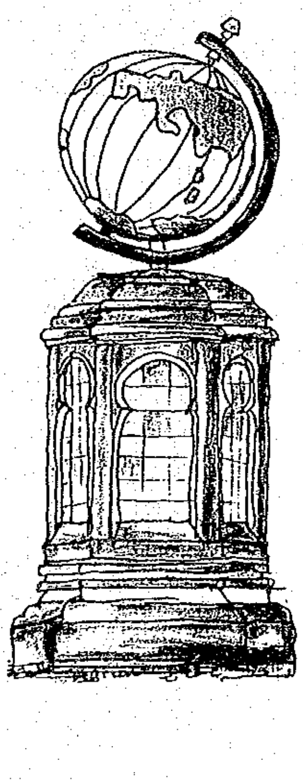
CASE B: OMAN LINE LOADING (60 TON TRUCK×2)

THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. 6.7 Loading Condition by OMAN Design Standard**

Table 6.6 Summary of Calculation Case (Grid Analysis)

Bridge No.	Tested Load				Oman Truck Load (60 ton x 2)		AASHTO HS20 Load	Durability due to AASHTO HS20		Remarks
	Case 1	Case 2	Case 3	Case 4	Case A	Case B		Calculation for Load Proof α, P	Calculation for Safety Factor $\frac{Mu}{Mdu} > 1.0$	
1	○	○	–	–	○	○	○	○	–	
2	○	○	○	○	○	○	○	○	–	
3	Same as No. 2	Same as No. 2	Same as No. 2	Same as No. 2	Same as No. 2	Same as No. 2	–	–	–	
4	Same as No. 2	Same as No. 2	Same as No. 2	Same as No. 2	Same as No. 2	Same as No. 2	–	–	–	
5	○	○	○	○	○	○	○	○	–	
6	○	○	○	○	–	○	○	–	○	
7	Same as No. 9	Same as No. 9	Same as No. 9	Same as No. 9	Same as No. 9	Same as No. 9	–	–	–	
8	Same as No. 5	Same as No. 5	Same as No. 5	Same as No. 5	Same as No. 5	Same as No. 5	–	–	–	
9	○	○	○	○	–	○	○	–	○	
Total										

CHAPTER 7 RESULTS OF EVALUATION OF EXISTING BRIDGES



CHAPTER 7

RESULTS OF EVALUATION OF EXISTING BRIDGES

7.1 Evaluation of Soundness of Existing Bridges Based on Their Degree of Deterioration

The condition of the bridges in Chapter 4 have been listed in Fig. 7.1 giving their soundness in the order of their ranking. The durability of the bridges have been described by their appraised points (at) and weighted factor (bt). (See Table 7.2 through Table 7.10)

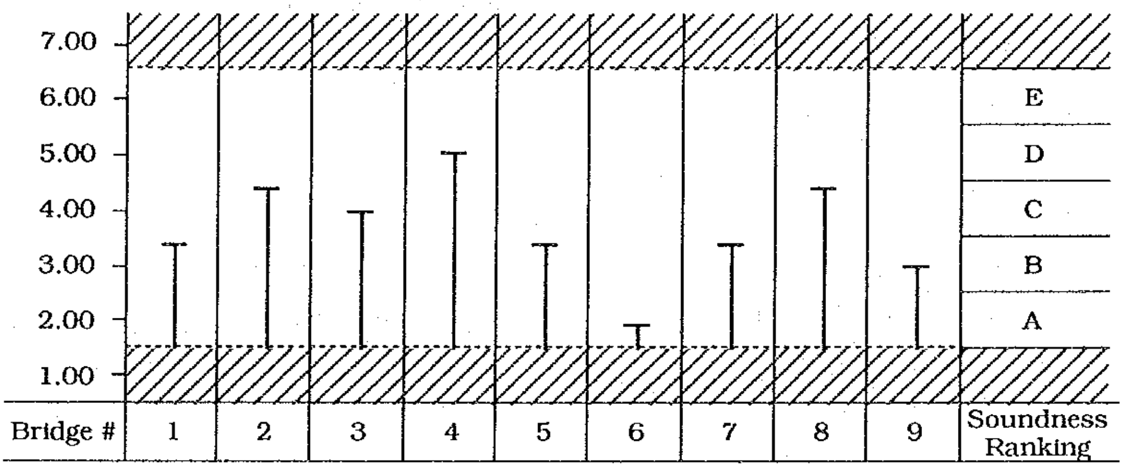


Fig. 7.1 Composite Evaluation Diagram for Soundness

The load capacity evaluation is as follows:

- Live Load and Heavy Vehicle

  The actual volume of traffic and the amount of damage to the bridge slab were investigated in the project area, and the axle weights on the each route was surveyed.

  For reference, the heavy vehicle on each route (present and future) and measured axle weight is given in Table 7.1.

Table 7.1 Summary of Heavy Vehicle Traffic by Survey Data

(March 1994)

Bridge No. (Route)	Heavy Vehicle (Veh/Day/Each Direction)	Target Year (Veh/Day/Each Direction)	Max. Axle Load (Ton)
Bridge No. 1 (Batinah Highway, Rt. 1)	428	1,250	-
Bridge No. 4 (Wadi Bid - Sur, Rt. 7)	62	180	17.6 (58.1)*
Bridge No. 7 (Bid Bid - Sur, Rt. 23)	74	220	12.0 (49.9)
Bridge No. 8 (Rurami/Ibri/Nizwa, Rt. 21)	113	330	12.2 (48.8)
Bridge No. 9 (Bid Bid - Sur, Rt. 23)	48	140	16.0 (58.3)

Notes: 1) (Heavy Vehicle: Medium Truck, Heavy Truck, Bus
2) ( ): Maximum Gross Truck Load in Ton
3) Three Axle

Of the above information, the traffic is classified for each route from the overall consideration as follows:

Less than 7 ton per axle, and Little heavy vehicle traffic	Route 13, Route 15, [Br. No. 5, No. 6]
More than 7 ton per axle, and Much heavy vehicle traffic	Route 1, Route 7, Route 21, Route 23 [Br. No. 1, No. 2, No. 3, No. 4, No. 7, No. 8, No. 9]

- Year Bridges Completed and Number of Years in Service

Concrete bridges are considered to have semi-permanent life, but due to the increase in the traffic and the increase of the width of the roadways, bridges have been damaged by the traffic and other physical collisions and it has become necessary to perform repairs and replacement in some cases.

The bridges in this study can be classified into the following two cases:

Bridges completed after 1975 (in service less than 20 years)	Bridge No. 5 and No. 8
Bridges completed before 1975 (in service more than 20 years)	Bridge No. 1, No. 2, No. 3, No. 4, No. 6, No. 7, No. 9

From the above two classifications detailed studies of the load capacities are appraised.

Table 7.2 Evaluation Element (at) and Weight Factor (bt) for Br. No. 1

		Evaluation Item	Evaluation Points (at)	Weight Factor (bt)	Points at x bt
Durability	Super-structure	Main Girder	A-1, B-2, **C-3**, D-4, E-5	0.400	1.20
		Cross Girder	**A-1**, B-2, C-3, D-4, E-5	0.100	0.10
		Bridge Deck	**A-1**, B-2, C-3, D-4, E-5	0.250	0.25
		Supports	**A-1**, B-2, C-3, D-4, E-5	0.050	0.05
	Sub-structure	Abutment	**A-1**, B-2, C-3, D-4, E-5	0.100	0.10
		Column (Pier)	A-1, **B-2**, C-3, D-4, E-5	0.100	0.20
Load Character-istics	Live Load and Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic	1	0.350	-
		Weight per axle more than 7.0 ton, with heavy traffic	③	0.350	1.05
	Year Bridge Completed	Completed after 1975 (in service less than 20 years)	1	0.150	-
		Completed before 1975 (in service more than 20 years)	③	0.150	0.45
Total Points					3.40

Table 7.3 Evaluation Element (at) and Weight Factor (bt) for Br. No. 2

		Evaluation Item	Evaluation Points (at)	Weight Factor (bt)	Points at x bt
Durability	Super-structure	Main Girder	A-1, B-2, C-3, **D-4**, E-5	0.400	1.60
		Cross Girder	A-1, B-2, C-3, **D-4**, E-5	0.100	0.40
		Bridge Deck	A-1, B-2, **C-3**, D-4, E-5	0.250	0.75
		Supports	**A-1**, B-2, C-3, D-4, E-5	0.050	0.05
	Sub-structure	Abutment	**A-1**, B-2, C-3, D-4, E-5	0.100	0.10
		Column (Pier)	**A-1**, B-2, C-3, D-4, E-5	0.100	0.10
Load Character-istics	Live Load and Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic	1	0.350	-
		Weight per axle more than 7.0 ton, with heavy traffic	③	0.350	1.05
	Year Bridge Completed	Completed after 1975 (in service less than 20 years)	1	0.150	-
		Completed before 1975 (in service more than 20 years)	③	0.150	0.45
Total Points					4.50

Table 7.4 Evaluation Element (at) and Weight Factor (bt) for Br. No. 3

		Evaluation Item	Evaluation Points (at)		Weight Factor (bt)	Points at x bt
Durability	Super-structure	Main Girder	A-1, B-2, C-3, (D-4), E-5		0.400	1.60
		Cross Girder	A-1, B-2, (C-3), D-4, E-5		0.100	0.30
		Bridge Deck	(A-1), B-2, C-3, D-4, E-5		0.250	0.25
		Supports	(A-1), B-2, C-3, D-4, E-5		0.050	0.05
	Sub-structure	Abutment	A-1, (B-2), C-3, D-4, E-5		0.100	0.20
		Column (Pier)	A-1, (B-2), C-3, D-4, E-5		0.100	0.20
Load Character-istics	Live Load and Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic		1	0.350	-
		Weight per axle more than 7.0 ton, with heavy traffic		(3)	0.350	1.05
	Year Bridge Completed	Completed after 1975 (in service less than 20 years)		1	0.150	-
		Completed before 1975 (in service more than 20 years)		(3)	0.150	0.45
Total Points						4.10

Table 7.5 Evaluation Element (at) and Weight Factor (bt) for Br. No. 4

		Evaluation Item	Evaluation Points (at)		Weight Factor (bt)	Points at x bt
Durability	Super-structure	Main Girder	A-1, B-2, C-3, D-4, (E-5)		0.400	2.00
		Cross Girder	A-1, B-2, C-3, (D-4), E-5		0.100	0.40
		Bridge Deck	A-1, B-2, (C-3), D-4, E-5		0.250	0.75
		Supports	(A-1), B-2, C-3, D-4, E-5		0.050	0.05
	Sub-structure	Abutment	A-1, (B-2), C-3, D-4, E-5		0.100	0.20
		Column (Pier)	A-1, (B-2), C-3, D-4, E-5		0.100	0.20
Load Character-istics	Live Load and Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic		1	0.350	-
		Weight per axle more than 7.0 ton, with heavy traffic		(3)	0.350	1.05
	Year Bridge Completed	Completed after 1975 (in service less than 20 years)		1	0.150	-
		Completed before 1975 (in service more than 20 years)		(3)	0.150	0.45
Total Points						5.10

Table 7.6 Evaluation Element (at) and Weight Factor (bt) for Br. No. 5

		Evaluation Item	Evaluation Points (at)		Weight Factor (bt)	Points at x bt
Durability	Super-structure	Main Girder	A-1, B-2, C-3, (D-4), E-5		0.400	1.60
		Cross Girder	A-1, B-2, C-3, (D-4), E-5		0.100	0.40
		Bridge Deck	A-1, (B-2), C-3, D-4, E-5		0.250	0.50
		Supports	A-1, (B-2), C-3, D-4, E-5		0.050	0.10
	Sub-structure	Abutment	A-1, (B-2), C-3, D-4, E-5		0.100	0.20
		Column (Pier)	A-1, (B-2), C-3, D-4, E-5		0.100	0.20
Load Character-istics	Live Load and Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic		①	0.350	0.35
		Weight per axle more than 7.0 ton, with heavy traffic		3	0.350	-
	Year Bridge Completed	Completed after 1975 (in service less than 20 years)		①	0.150	0.15
		Completed before 1975 (in service more than 20 years)		3	0.150	-
Total Points						3.50

Table 7.7 Evaluation Element (at) and Weight Factor (bt) for Br. No. 6

		Evaluation Item	Evaluation Points (at)		Weight Factor (bt)	Points at x bt
Durability	Super-structure	Main Girder	(A-1), B-2, C-3, D-4, E-5		0.400	0.40
		Cross Girder	(A-1), B-2, C-3, D-4, E-5		0.100	0.10
		Bridge Deck	(A-1), B-2, C-3, D-4, E-5		0.250	0.25
		Supports	(A-1), B-2, C-3, D-4, E-5		0.050	0.05
	Sub-structure	Abutment	(A-1), B-2, C-3, D-4, E-5		0.100	0.10
		Column (Pier)	A-1, (B-2), C-3, D-4, E-5		0.100	0.20
Load Character-istics	Live Load and Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic		①	0.350	0.35
		Weight per axle more than 7.0 ton, with heavy traffic		3	0.350	-
	Year Bridge Completed	Completed after 1975 (in service less than 20 years)		1	0.150	-
		Completed before 1975 (in service more than 20 years)		③	0.150	0.45
Total Points						1.90

Table 7.8 Evaluation Element (at) and Weight Factor (bt) for Br. No. 7

		Evaluation Item	Evaluation Points (at)	Weight Factor (bt)	Points at x bt
Durability	Super-structure	Main Girder	(A-1), B-2, C-3, D-4, E-5	0.400	0.40
		Cross Girder	A-1, B-2, C-3, (D-4), E-5	0.100	0.40
		Bridge Deck	A-1, B-2, (C-3), D-4, E-5	0.250	0.75
		Supports	A-1, (B-2), C-3, D-4, E-5	0.050	0.10
	Sub-structure	Abutment	(A-1), B-2, C-3, D-4, E-5	0.100	0.10
		Column (Pier)	(A-1), B-2, C-3, D-4, E-5	0.100	0.10
Load Character-istics	Live Load and Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic	1	0.350	–
		Weight per axle more than 7.0 ton, with heavy traffic	③	0.350	1.05
	Year Bridge Completed	Completed after 1975 (in service less than 20 years)	1	0.150	–
		Completed before 1975 (in service more than 20 years)	③	0.150	0.45
Total Points					3.35

Table 7.9 Evaluation Element (at) and Weight Factor (bt) for Br. No. 8

		Evaluation Item	Evaluation Points (at)	Weight Factor (bt)	Points at x bt
Durability	Super-structure	Main Girder	A-1, B-2, C-3, (D-4), E-5	0.400	1.60
		Cross Girder	A-1, B-2, C-3, (D-4), E-5	0.100	0.40
		Bridge Deck	A-1, B-2, (C-3), D-4, E-5	0.250	0.75
		Supports	A-1, (B-2), C-3, D-4, E-5	0.050	0.10
	Sub-structure	Abutment	A-1, (B-2), C-3, D-4, E-5	0.100	0.20
		Column (Pier)	A-1, (B-2), C-3, D-4, E-5	0.100	0.20
Load Character-istics	Live Load and Heavy Vehicle	Weight per axle less than 7.0 ton, little heavy traffic	1	0.350	–
		Weight per axle more than 7.0 ton, with heavy traffic	③	0.350	1.05
	Year Bridge Completed	Completed after 1975 (in service less than 20 years)	①	0.150	0.15
		Completed before 1975 (in service more than 20 years)	3	0.150	–
Total Points					4.45

Table 7.10 Evaluation Element (at) and Weight Factor (bt) for Br. No. 9

<table>
<tr><th colspan="2"></th><th>Evaluation Item</th><th colspan="2">Evaluation Points (at)</th><th>Weight Factor (bt)</th><th>Points at x bt</th></tr>
<tr><td rowspan="6">Durability</td><td rowspan="4">Super-structure</td><td>Main Girder</td><td colspan="2">(A-1), B-2, C-3, D-4, E-5</td><td>0.400</td><td>0.40</td></tr>
<tr><td>Cross Girder</td><td colspan="2">A-1, B-2, C-3, (D-4), E-5</td><td>0.100</td><td>0.40</td></tr>
<tr><td>Bridge Deck</td><td colspan="2">(A-1), B-2, C-3, D-4, E-5</td><td>0.250</td><td>0.25</td></tr>
<tr><td>Supports</td><td colspan="2">A-1, (B-2), C-3, D-4, E-5</td><td>0.050</td><td>0.10</td></tr>
<tr><td rowspan="2">Sub-structure</td><td>Abutment</td><td colspan="2">A-1, (B-2), C-3, D-4, E-5</td><td>0.100</td><td>0.20</td></tr>
<tr><td>Column (Pier)</td><td colspan="2">A-1, (B-2), C-3, D-4, E-5</td><td>0.100</td><td>0.20</td></tr>
<tr><td rowspan="4">Load Character-istics</td><td rowspan="2">Live Load and Heavy Vehicle</td><td colspan="2">Weight per axle less than 7.0 ton, little heavy traffic</td><td>1</td><td>0.350</td><td>–</td></tr>
<tr><td colspan="2">Weight per axle more than 7.0 ton, with heavy traffic</td><td>(3)</td><td>0.350</td><td>1.05</td></tr>
<tr><td rowspan="2">Year Bridge Completed</td><td colspan="2">Completed after 1975 (in service less than 20 years)</td><td>1</td><td>0.150</td><td>–</td></tr>
<tr><td colspan="2">Completed before 1975 (in service more than 20 years)</td><td>(3)</td><td>0.150</td><td>0.45</td></tr>
<tr><td colspan="6">Total Points</td><td>3.05</td></tr>
</table>

7.2 Evaluation of Bridges Based on the Test Results of Concrete and Reinforcing Bar

According to the ranking explained in 6.2 Evaluation of Bridge Based on the Test Results of Concrete and Reinforcing Bar, the quality of the concrete was evaluated and the results are given in Table 7.11.

In the same manner, the evaluation of the reinforcing bar was made and posted in Table 7.12.

Table 7.11 Judgement due to Results of Concrete Test

Test Item		Bridge No. No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	Standard Evaluation Value (from Const. Dwg. or Design Standard)
Compressive Strength	(kg/cm^2)	383	373 (372)	288 (245)	359 (236)	335 (264)	336 (328)	320 (333)	271	295 (211)	RC Precast $\sigma_{28} = 290$ RC Cast in place $\sigma_{28} = 215$
	Eval.	I	I	II	I	I	II	I	II	II	PC Br. No. 6 $\sigma_{28} = 340$ PC Br. No. 7, No. 9 $\sigma_{28} = 315$
Young's Factor	(kg/cm^2)	3.3 x 10^5	2.2 x 10^5	2.7 x 10^5	2.3 x 10^5	2.1 x 10^5	3.0 x 10^5	2.0 x 10^5	2.4 x 10^5	3.7 x 10^5	RC $\sigma_{28} = 270$ 2.65 x 10^5 RC $\sigma_{28} = 340$ 2.92 x 10^5
	Eval.	I	II	I	II	II	I	(III)	II	I	PC $\sigma_{28} = 315$ 2.85 x 10^5
Tensile Strength	(kg/cm^2)	26	22	27	28	23	28	27	19	30	Tensile Strength
	Eval.	I	I	I	I	I	I	I	I	I	> Compressive Strength x $\frac{1}{10}$
Unit Volume Weight	(t/m^3)	2.5 (2.3)	2.4 (2.5)	2.5 (2.5)	2.4 (2.4)	2.3 (2.4)	2.4 (2.3)	2.4 (2.5)	2.2	2.4 (2.4)	2.35 t/m^3
	Eval.	I	I	I	I	II	I	I	II	I	
Water Absorption	(%)	1.7	3.9 (2.2)	3.7 (2.1)	4.0	4.1	3.9 (4.2)	3.3 (2.1)	4.6	1.6 (2.1)	—
	Eval.	I	II	II	II	II	II	I	(III)	I	
Water Ratio	(%)	2.1	1.4 (2.3)	0.3 (1.9)	1.2	1.7	1.2 (2.5)	0.6 (1.7)	2.6	0.2 (2.4)	—
	Eval.	II	I	I	I	II	I	I	(III)	I	
Neutralization Depth	(mm)	5.6	15.5 (2.2)	18.1	16.8 (22.0)	16.6 (2.7)	19.8 (3.7)	4.7 (1.8)	12.8	13.9 (0)	10 ~ 15mm (More than 20 years after Construction)
	Eval.	I	(III)	(III)	(III)	(III)	(III)	I	II	II	
Schmidt Hammer	(kg/cm^2)	378 (378)	311 (291)	278 (335)	285 (343)	331 (322)	378 (308)	278 (271)	269 (252)	369 (338)	
	Eval.	I	I	II	II	I	I	II	II	I	

Note: ( ) value means slab.

Table 7.12 Judgement due to Results of Reinforcing Bar Test

Test Item			Bridge No.						Standard Evaluation Value (from Const. Dwg. or Design Standard)
			No. 1	No. 2	No. 3	No. 4	No. 5	No. 8	
Nominal Diameter	(mm)		Dø32	Dø36	Dø36	Dø36	Dø32	Dø36	ø32 6.403
Unit Weight	(kg/m)		6.24	7.79	7.78	7.98	6.00	7.87	ø36 7.906
Yield Point Stress	(kg/mm^2)		46	42	42	42	47	42	30 ~ 40
	Eval.		I	I	I	I	I	I	
Tensile Strength	(kg/mm^2)		64	67	63	64	69	66	More than 50
	Eval.		I	I	I	I	I	I	
Elongation	(%)		19	20	22	21	24	24	More than 14
	Eval.		I	I	I	I	I	I	
Chemical Analysis	(%)	C	0.19	0.38	0.25	0.37	0.37	0.37	Maximum 0.40
		Si	0.34	0.27	0.22	0.22	0.24	0.27	Maximum 0.55
		Mn	0.77	1.38	1.28	1.40	1.15	1.39	Maximum 0.80
		P	0.02	0.02	0.02	0.03	0.03	0.02	Maximum 0.05
		S	0.03	0.02	0.02	0.03	0.02	0.02	Maximum 0.05
	Eval.		II	II	II	II	II	II	
Young's Factor	(kg/cm^2)		—	1.84×10^6	—	1.83×10^6	1.99×10^6	1.82×10^6	$2.0 \sim 2.1 \times 10^6$ kg/cm^2
	Eval.			II		II	I	II	

Relationship btween σ 28 and Ec

Specified Compressive Strength of Concrete 28 days : σ 28 kg/cm2		Modulus of Elasticity for Concrete :Ec kg/cm2
RC	270	2.85×10^5
RC	215	2.62×10^5
PC	340	3.20×10^5
PC	315	3.08×10^5

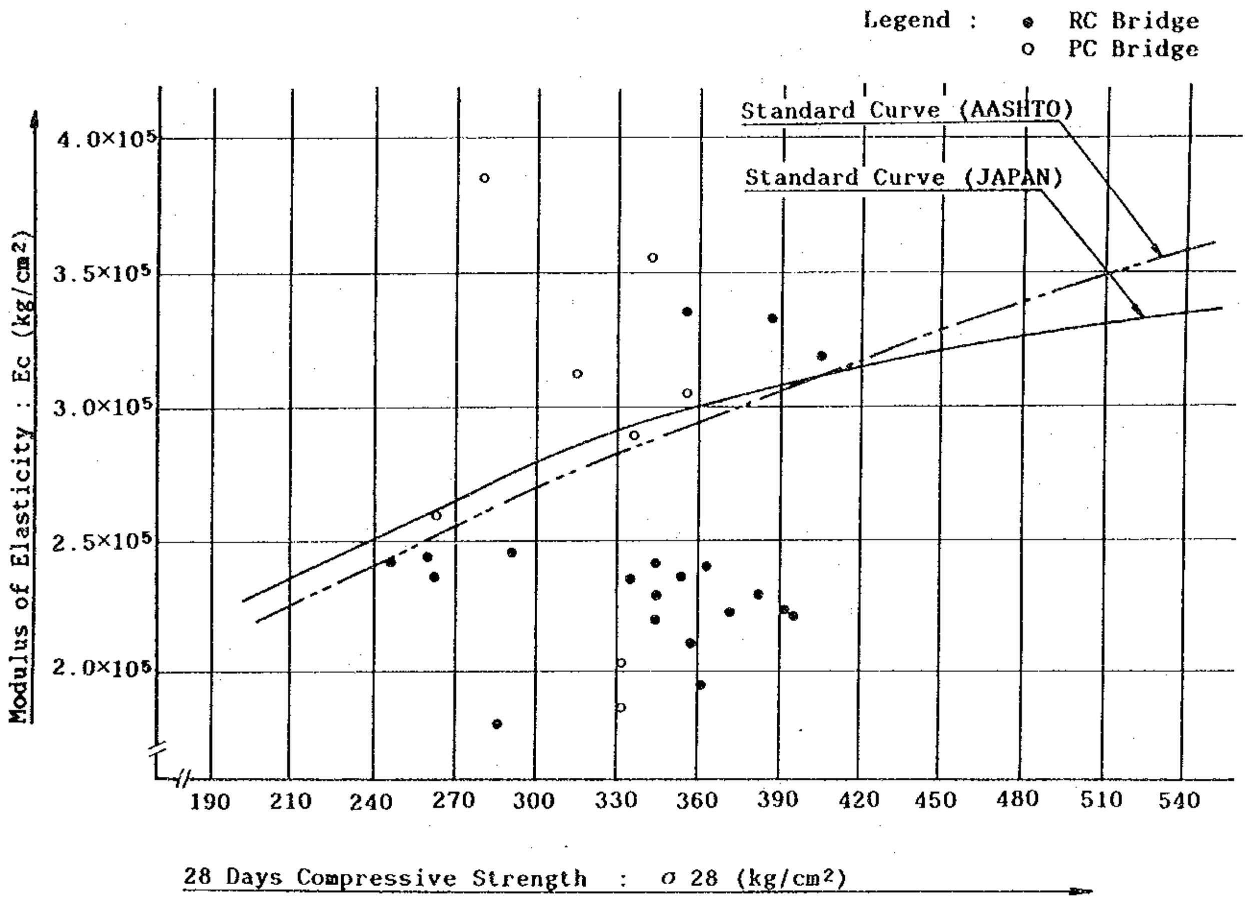


Fig. 7.2 Relationship Between σ_{28} and Ec of Concrete Structure

7.3 Evaluation of Bridges Using Load Tests

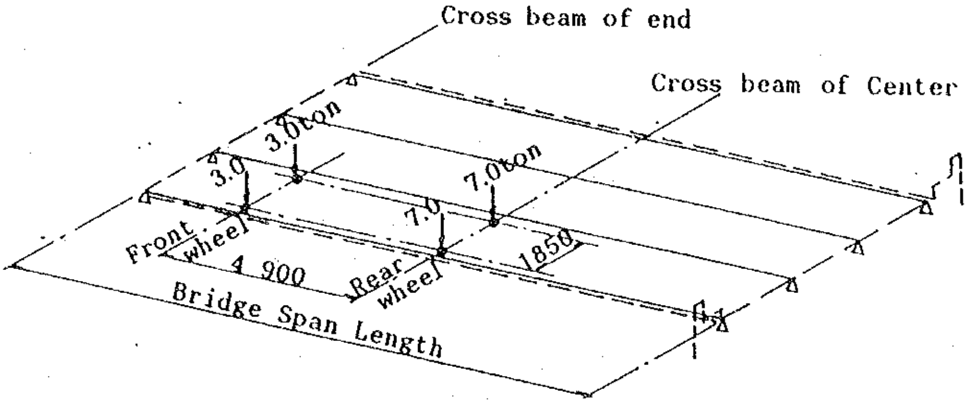
From the investigations conducted in the previous chapter, the strength of reinforcing bar and concrete and the deflections were calculated. From the results, the theoretical value was calculated from a load system similar to the load test, (resulting load test diagram shown in Fig. 7.3-1 and Fig. 7.3-2), and the bending moment, stresses and deflections in the girders of the bridges were calculated.

In the RC bridges, the stresses and deflections of the reinforcing bar were observed, and in the PC bridges deflections were observed (composite graph of the loaded measurement and calculations of the bridges are given in Fig. 7.4 to Fig. 7.12). The relations of these results are given for the RC bridges and they are used to obtain the load capacity of the value of f and larger the value, the bridge have the capability to carry the load.

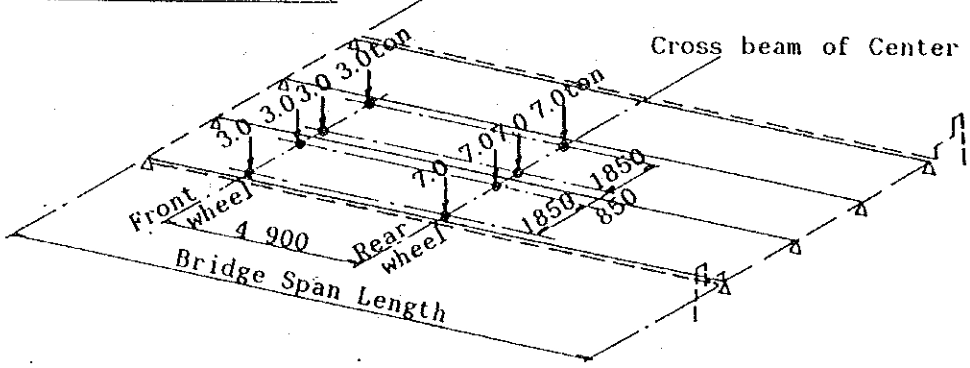
The theoretical calculation of each bridge for the bending moment in the main girder for the dead load and live load have been presented in Table 7.14.

The detailed theoretical calculations for each bridge are given in Tables 7.15 to 7.19.

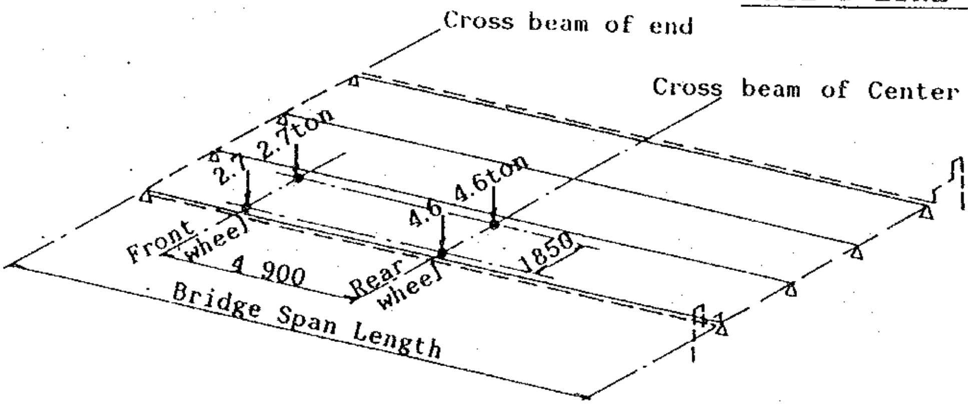
FOR RC BRIDGE



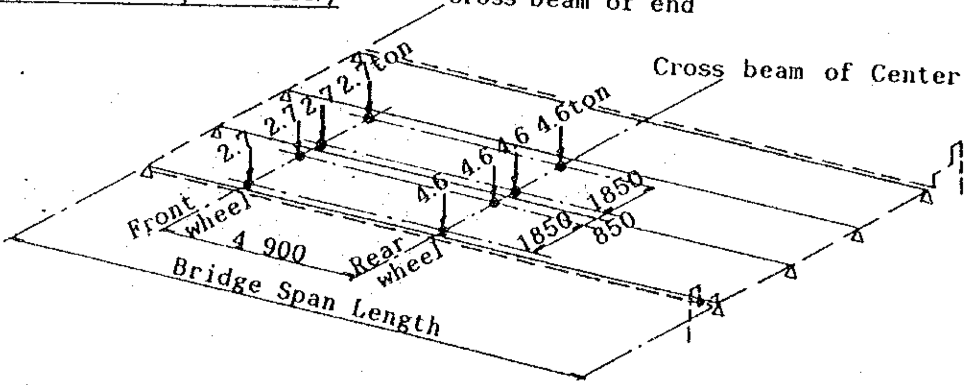
CASE 1 LINE LOADING(20TON)



CASE 2 LINE LOADING(40TON)



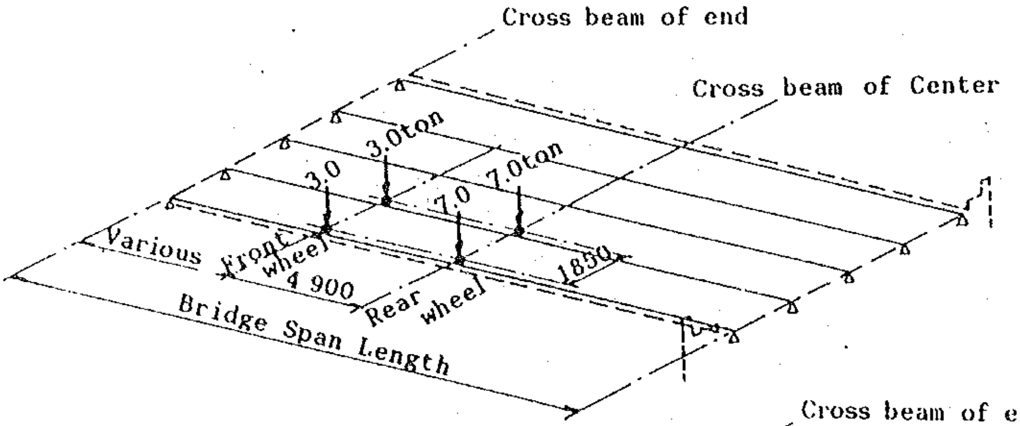
CASE 3 LINE LOADING(14.6TON)



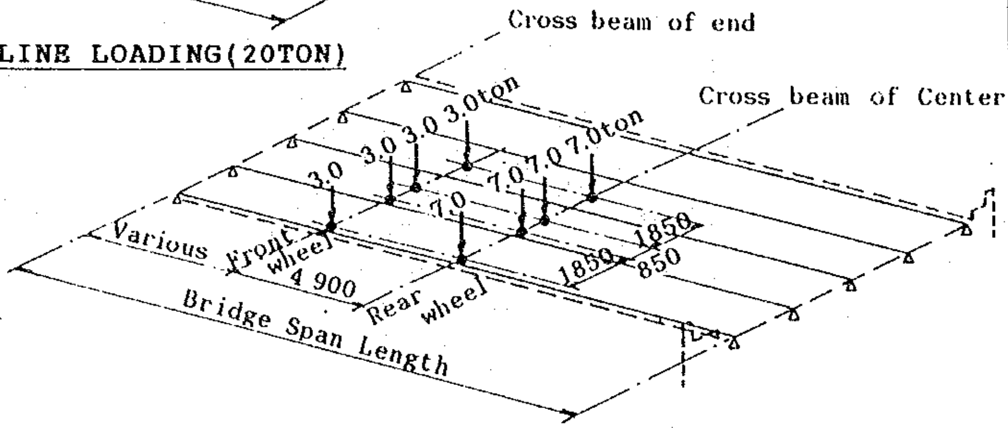
CASE 4 LINE LOADING(29.2TON)

THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	Fig 7.3-1 Loading Case for Calculation (RC Br.)

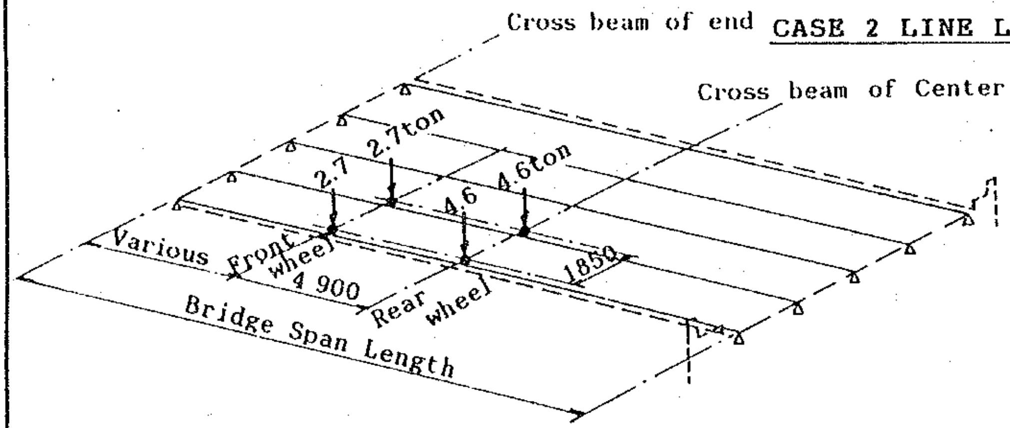
FOR PC BRIDGE



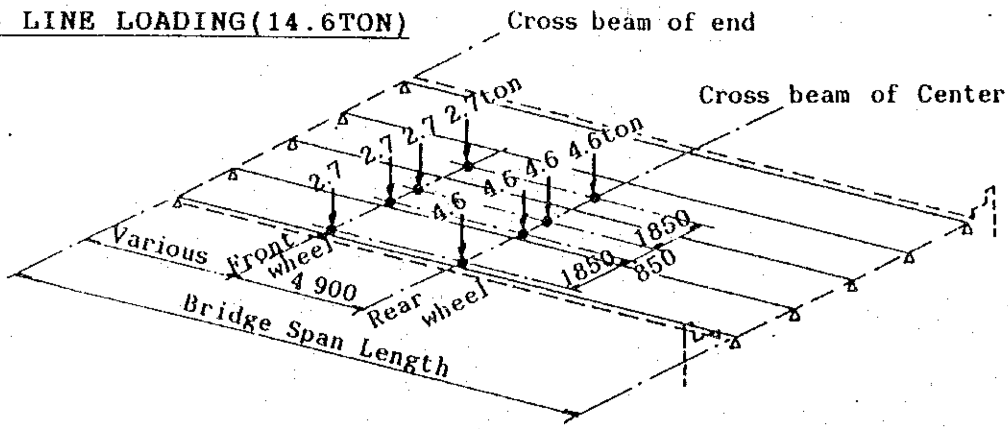
CASE 1 LINE LOADING(20TON)



CASE 2 LINE LOADING(40TON)

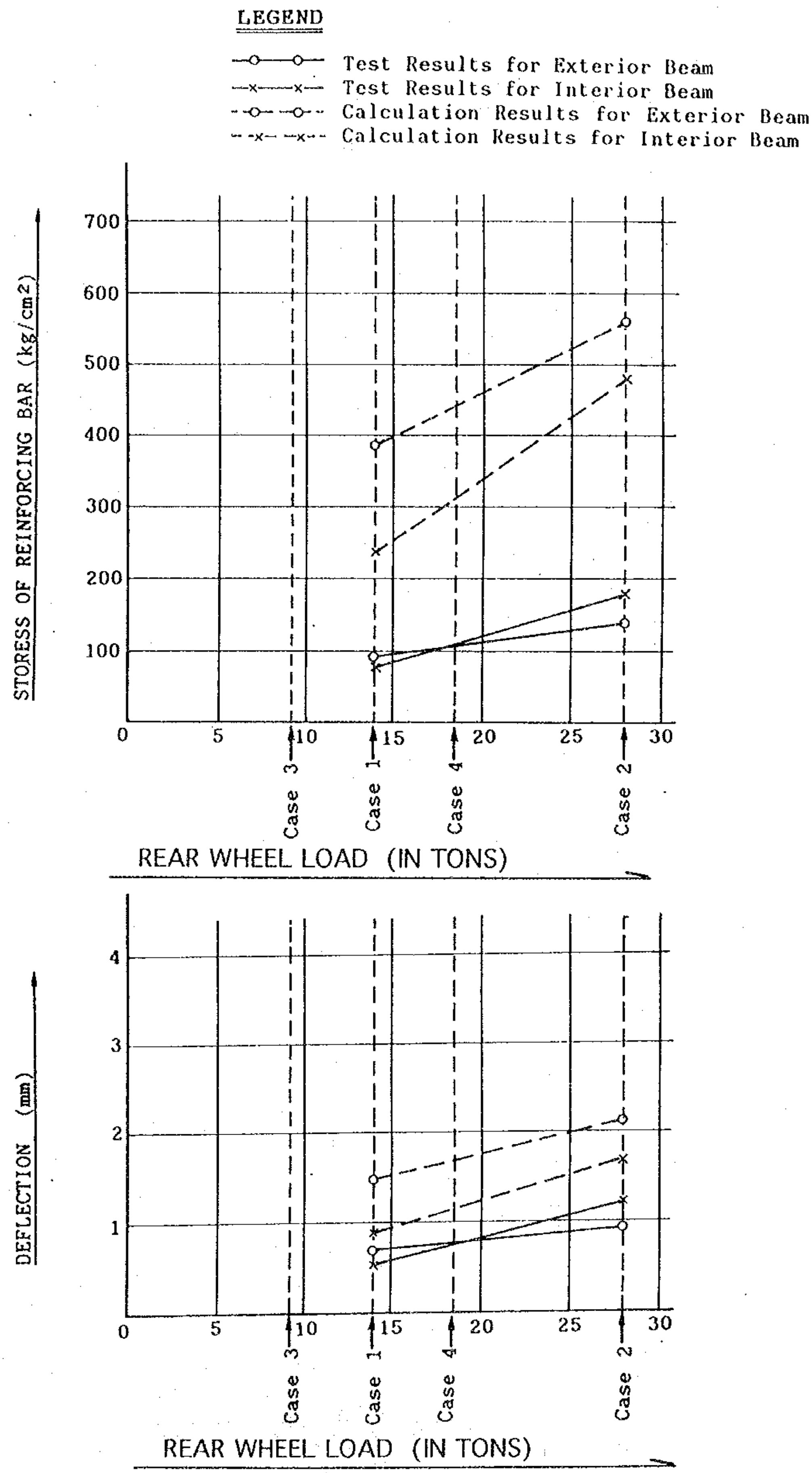


CASE 3 LINE LOADING(14.6TON)

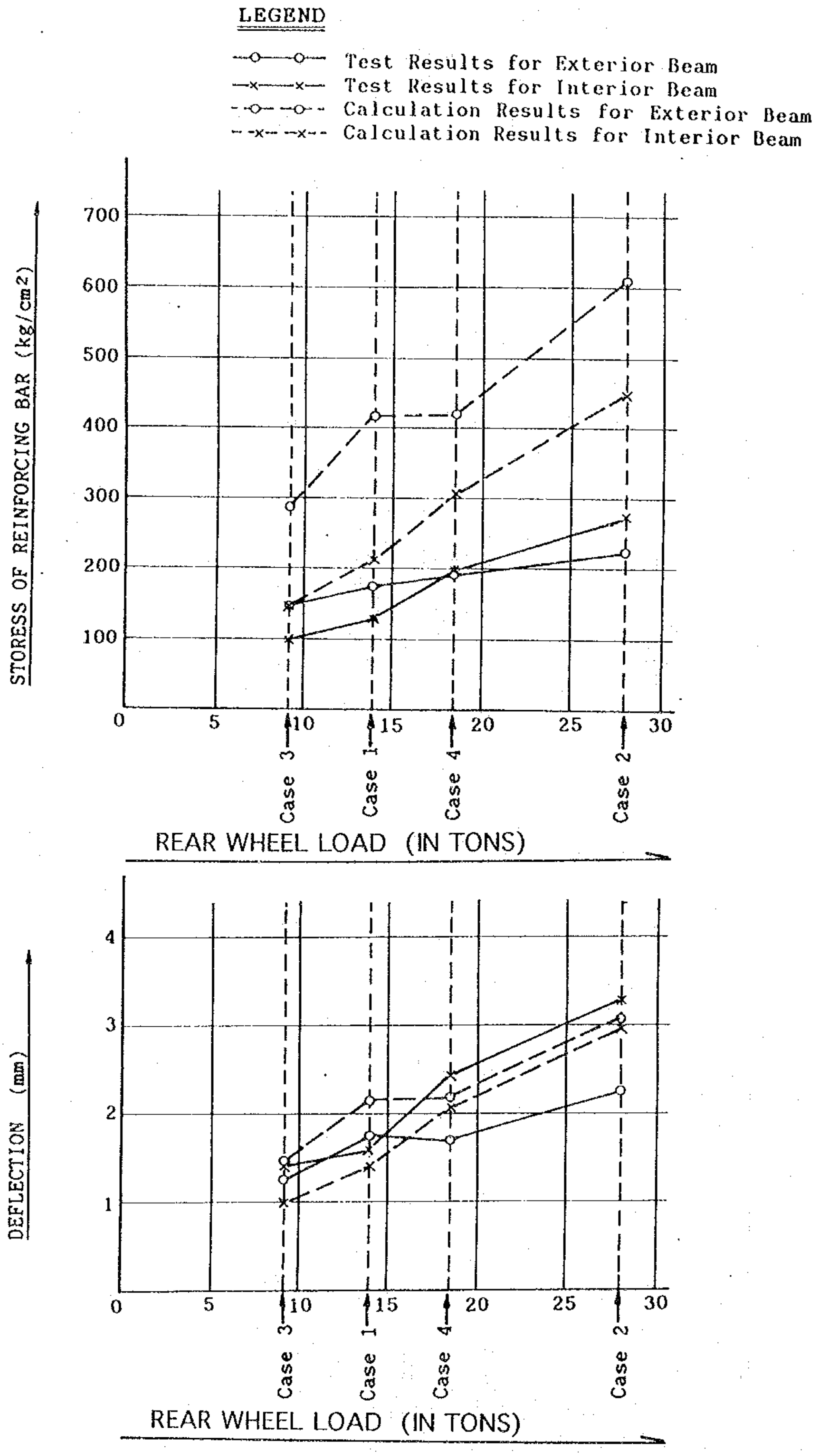


CASE 4 LINE LOADING(29.2TON)

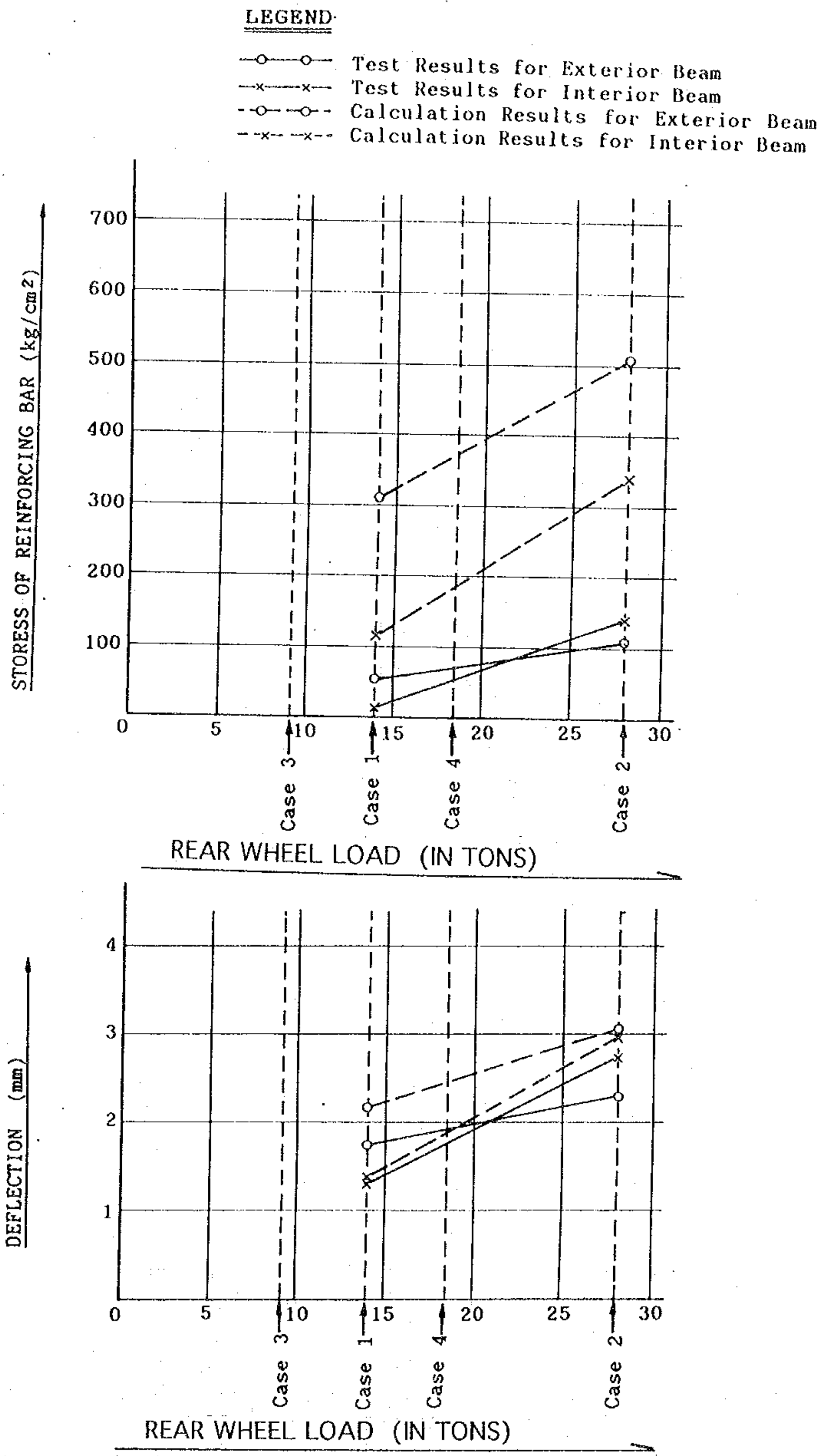
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. 7.3-2 Loading Case for Calculation (PC Br.)**



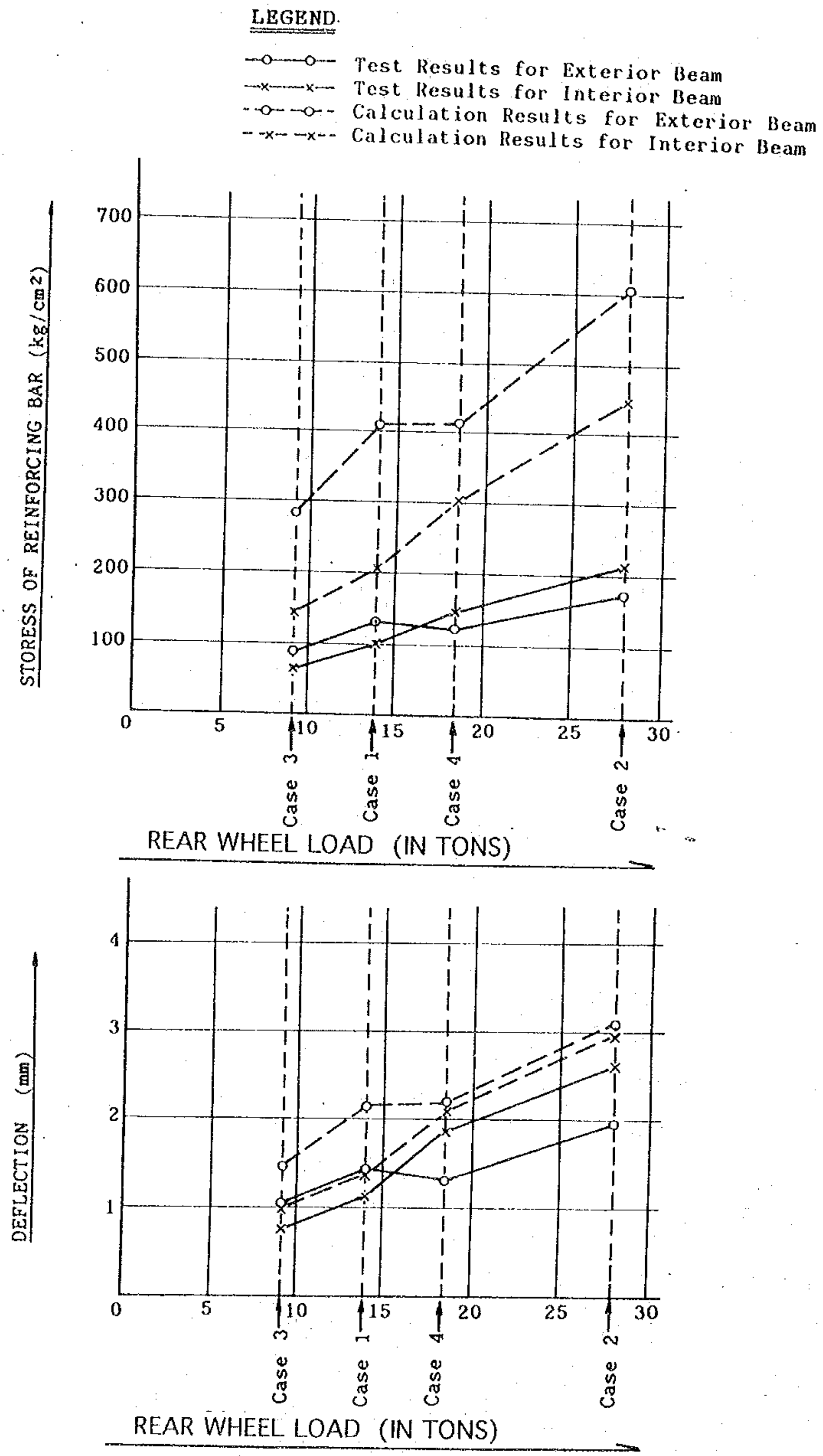
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. 7.4 Relation between Live Load & Stress, Deflection for Br. No. 1 (RC)**



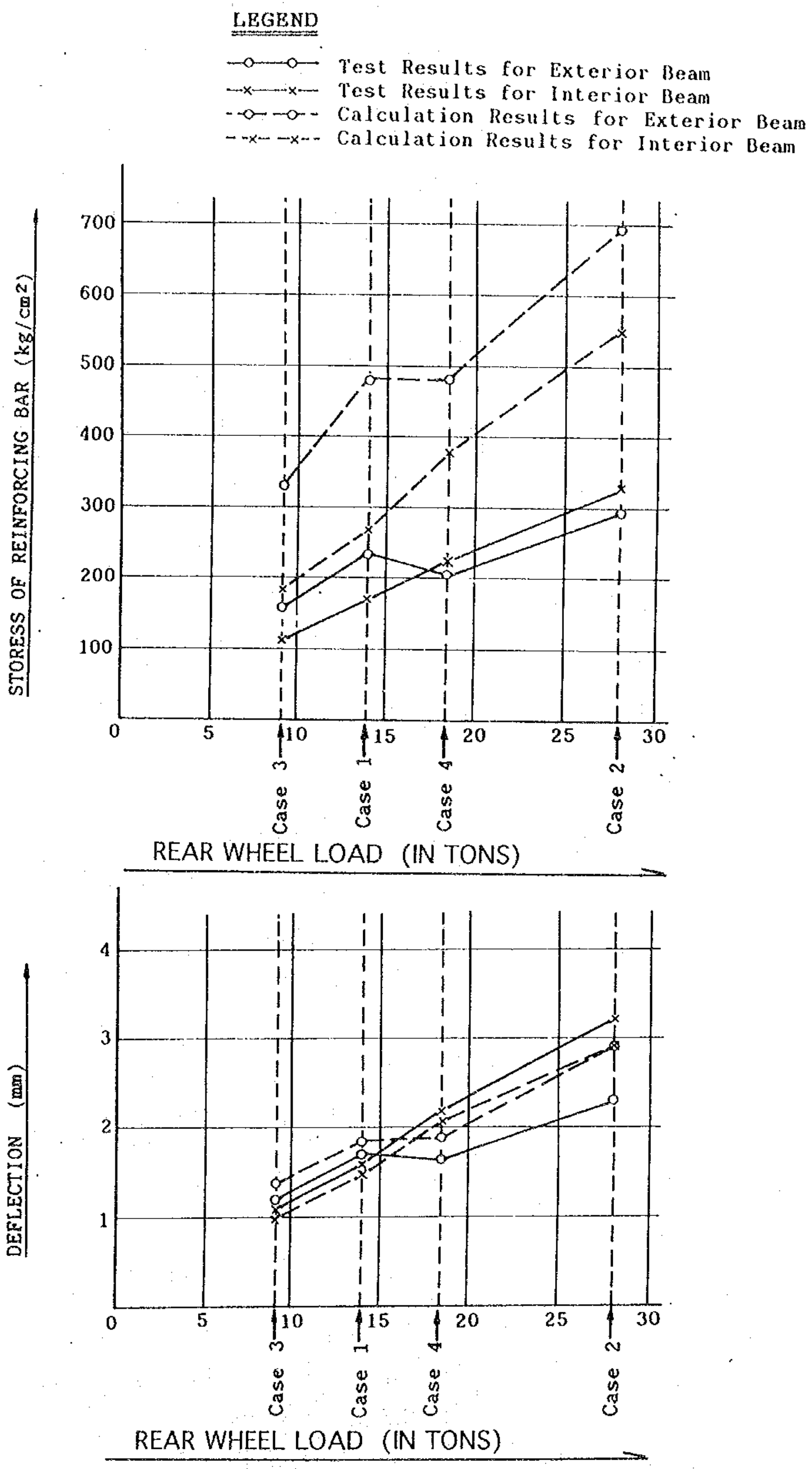
THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. 7.5 Relation between Live Load & Stress, Deflection for Br. No. 2 (RC)**



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. 7.6 Relation between Live Load & Stress, Deflection for Br. No. 3 (RC)**



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. 7.7 Relation between Live Load & Stress, Deflection for Br. No. 4 (RC)**



THE STUDY ON ROAD DEVELOPMENT PROJECT	JAPAN INTERNATIONAL COOPERATION AGENCY	**Fig. 7.8 Relation between Live Load & Stress, Deflection for Br. No. 5 (RC)**

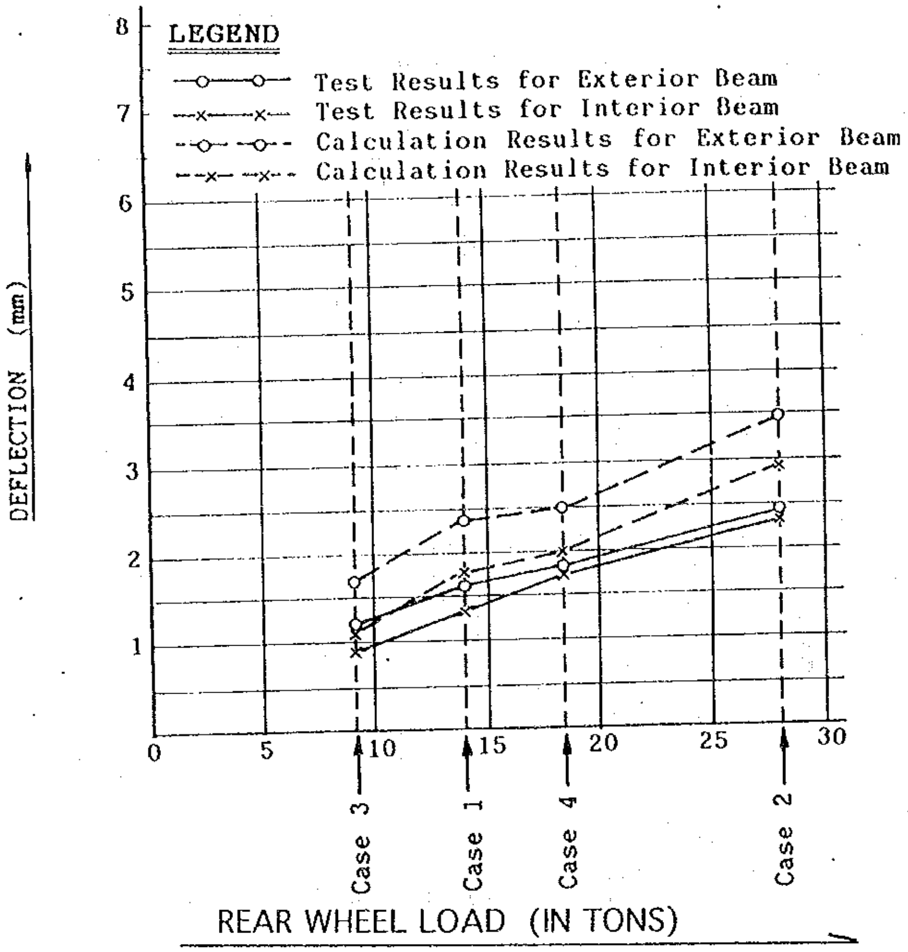


Fig. 7.9 Relation between Live Load & Stress, Deflection for Br. No. 6 (PC)

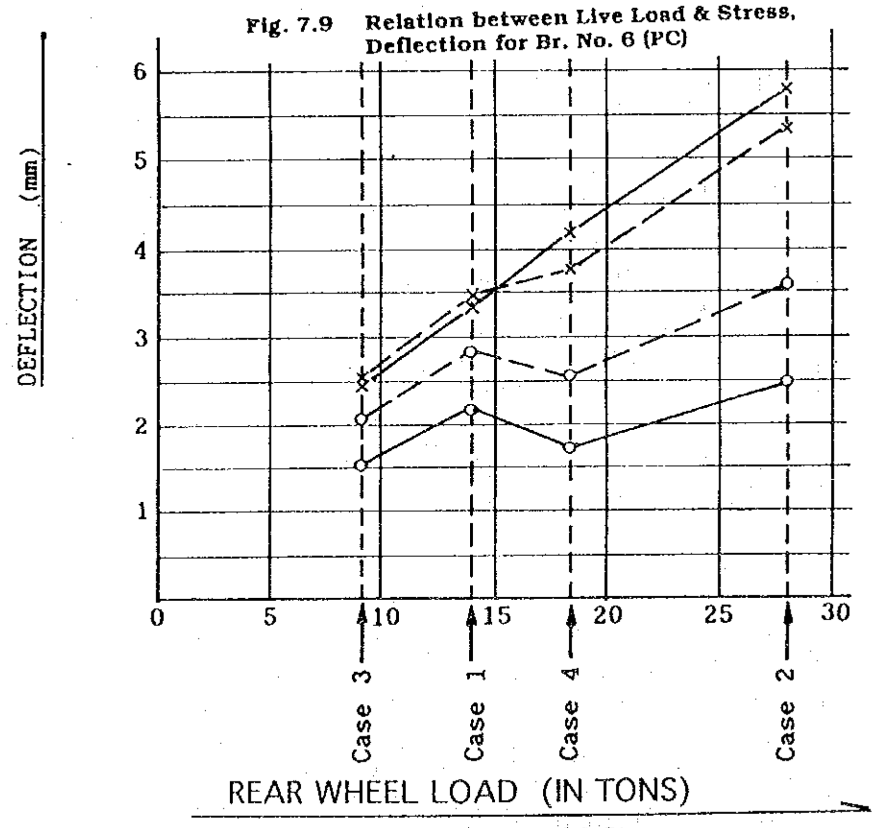
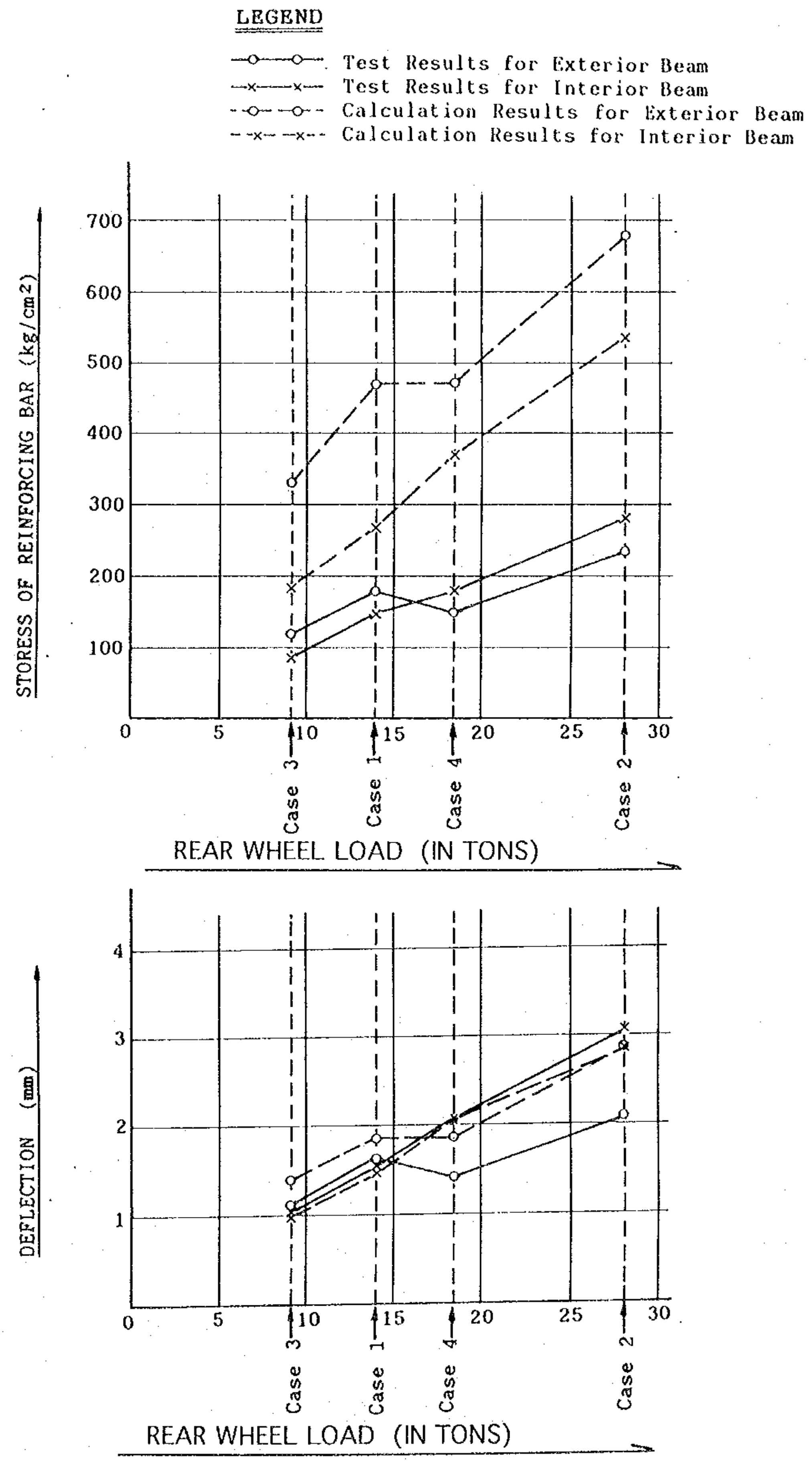


Fig. 7.10 Relation between Live Load & Stress, Deflection for Br. No. 7 (PC)

Fig. 7.9 Relation between Live Load & Stress, Deflection for Br. No. 6 (PC)

Fig. 7.10 Relation between Live Load & Stress, Deflection for Br. No. 7 (PC)


LEGEND
Test Results for Exterior Beam
Test Results for Interior Beam
Calculation Results for Exterior Beam
Calculation Results for Interior Beam
STORESS OF REINFORCING BAR (kg/cm2)
700
600
500
400
300
200
100
0
5
10
15
20
25
30
Case 3
Case 1
Case 4
Case 2
REAR WHEEL LOAD (IN TONS)
DEFLECTION (mm)
4
3
2
1
REAR WHEEL LOAD (IN TONS)

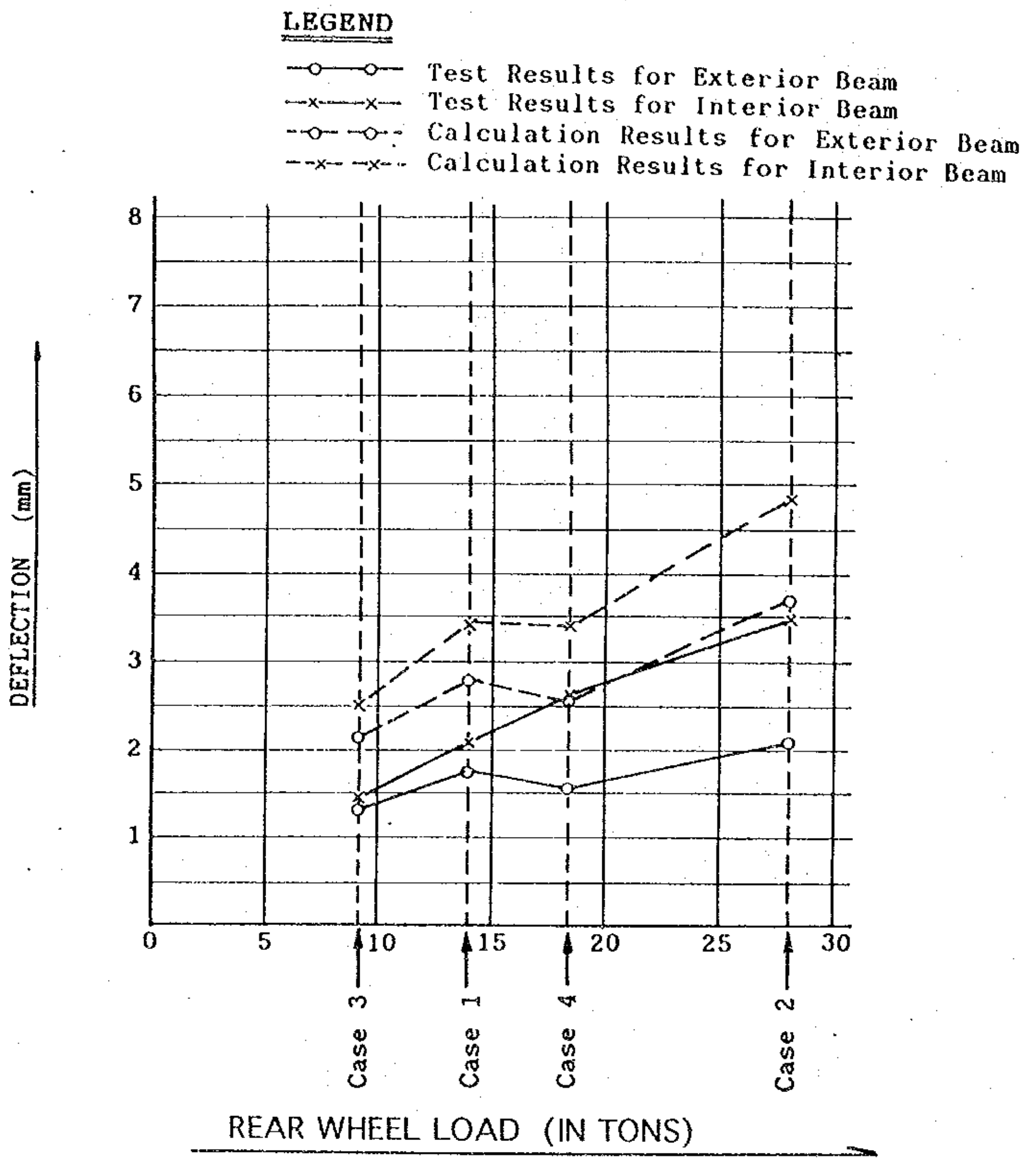


Fig. 7.12 Relation between Live Load & Deflection for Br. No. 9 (PC)

Table 7.13 f-Value (Calculation/Measurement)

Bridge No.	Deflection Calculation/ Measurement	Stress Calculation/ Measurement	f Value	Max Case
1	1.7/1.23 = 1.38	486/180.6 = 2.69	2.69	Case 2 Int. (G_2)
2	3.0/3.32 = 0.90	449/277.2 = 1.62	1.62	Case 2 Int. (G_2)
3	3.0/2.81 = 1.07	449/245.7 = 1.83	1.83	Case 2 Int. (G_2)
4	3.0/2.62 = 1.15	449/218.4 = 2.06	2.06	Case 2 Int. (G_2)
5	2.9/3.22 = 0.90	555/333.9 = 1.66	1.66	Case 2 Int. (G_2)
6	3.5/2.43 = 1.44	–	1.44	Case 2 Ext. (G_1)
7	5.4/5.86 = 0.92	–	0.92	Case 2 Int. (G_5)
8	2.9/3.09 = 0.94	555/298.2 = 1.86	1.86	Case 2 Int. (G_2)
9	5.4/3.50 = 1.54	–	1.54	Case 2 Int. (G_5)

Note: Applied Maximum Value of Span Center

Table 7.14 Summary of Bending Moment by Tested Load (RC Br.) (Grid Analysis)

Bridge No.	Case No.		Bending Moment (t • m) Dead Load	Live Load	Total	(Live Load) Deflection (mm)	Remarks
1	Case 1	G1	81.6	31.8	113.4	1.28	
		G2	82.8	19.3	102.1	0.75	
	Case 2	G1	81.6	45.1	126.7	1.83	
		G2	82.8	39.5	122.3	1.54	
2 (3.4)	Case 1	G1	104.8	33.1	137.9	1.85	
		G2	75.8	15.8	91.6	1.24	
	Case 2	G1	104.8	48.2	153.0	2.71	
		G2	75.8	32.8	108.6	2.57	
	Case 3	G1	104.8	22.7	127.5	1.29	
		G2	75.8	10.8	86.6	0.86	
	Case 4	G1	104.8	33.2	138.0	1.89	
		G2	75.8	22.3	98.1	1.79	
5 (8)	Case 1	G1	104.2	30.7	134.9	1.70	
		G2	75.4	16.2	91.6	1.26	
	Case 2	G1	104.2	44.1	148.3	2.46	
		G2	75.4	32.6	108.0	2.53	
	Case 3	G1	104.2	21.1	125.3	1.19	
		G2	75.4	11.1	86.5	0.88	
	Case 4	G1	104.2	30.4	134.6	1.71	
		G2	75.4	22.2	97.6	1.76	
6	Case 1	G1	313.7	54.4	368.1	2.38	
		G2	330.8	40.0	370.8	1.75	
	Case 2	G1	313.7	78.9	392.6	3.46	
		G2	330.8	65.6	396.4	2.87	
	Case 3	G1	313.7	38.7	352.4	1.70	
		G2	330.8	28.4	359.2	1.24	
	Case 4	G1	313.7	56.0	369.7	2.45	
		G2	330.8	46.6	377.4	2.04	
9	Case 1	G1	83.4	15.2	98.6	2.94	
		G2	87.7	18.3	106.0	3.54	
	Case 2	G1	83.4	18.9	102.3	3.65	
		G2	87.7	24.8	112.5	4.80	
	Case 3	G1	83.4	10.7	94.1	2.07	
		G2	87.7	12.8	100.5	2.48	
	Case 4	G1	83.4	13.3	96.7	2.57	
		G2	87.7	17.4	105.1	3.36	

Table 7.15 Calculation Results (Grid) by Tested Loading (Br. No. 1)

Beam	Case No.	Compressive Strength for Concrete (kg/cm2)				Tensile Strength for Re-bar (kg/cm2)				Deflection (mm)		Remarks
		Dead Load σ_{cd}	Live Load σ_{cl}	Total σ_c	Allowable σ_{ca}	Dead Load σ_{sd}	Live Load σ_{sl}	Total σ_s	Allowable σ_{sa}	*Live Load σ_l	Allowable σ_{la}	
Exterior Beam (G1)	Case 1	24.1	9.4	33.5	$\sigma_{28}=270kg/cm^2$ $\sigma_{ca}=90kg/cm^2$	1010	394	1404	Yield>40kg/mm^2 $\sigma_{sa}=1800kg/cm^2$	1.3 (1.5)		
	Case 2	24.1	13.3	37.4		1010	559	1569		1.8 (2.1)		
	Case 3	–	–	–		–	–	–		–		
	Case 4	–	–	–		–	–	–		–		
Interior Beam (G2)	Case 1	21.5	5.0	26.5		1020	238	1258		0.8 (0.9)		
	Case 2	21.5	10.3	31.8		1020	486	1506		1.5 (1.7)		
	Case 3	–	–	–		–	–	–		–		
	Case 4	–	–	–		–	–	–		–		

* Figure in ( ) indicates correction for the difference of Young's modulus (y = 3.25/2.85 = 1.14)

Table 7.16 Calculation Results (Grid) by Tested Loading (Br. No. 2, 3, 4)

Beam	Case No.	Compressive Strength for Concrete (kg/cm2)				Tensile Strength for Re-bar (kg/cm2)				Deflection (mm)		Remarks
		Dead Load σ_{cd}	Live Load σ_{cl}	Total σ_c	Allowable σ_{ca}	Dead Load σ_{sd}	Live Load σ_{sl}	Total σ_s	Allowable σ_{sa}	*Live Load σ_l	Allowable σ_{la}	
Exterior Beam (G1)	Case 1	52.5	16.6	69.1	σ_{28}=270kg/cm^2 σ_{ca}=90kg/cm^2	1321	417	1738	Yield>40kg/mm^2 σ_{sa}=1800kg/cm^2	1.9 (2.2)		
	Case 2	52.5	24.1	76.6		1321	607	1928		2.7 (3.1)		
	Case 3	52.5	11.4	63.9		1321	286	1607		1.3 (1.5)		
	Case 4	52.5	16.6	69.1		1321	418	1739		1.9 (2.2)		
Interior Beam (G2)	Case 1	61.1	12.8	73.9		1037	217	1254		1.2 (1.4)		
	Case 2	61.1	26.5	87.6		1037	449	1486		2.6 (3.0)		
	Case 3	61.1	8.7	69.8		1037	148	1185		0.9 (1.0)		
	Case 4	61.1	18.0	79.1		1037	306	1343		1.8 (2.1)		

* Figure in ( ) indicates correction for the difference of Young's modulus (y = 3.25/2.85 = 1.14)

Table 7.17 Calculation Results (Grid) by Tested Loading (Br. No. 5, 8)

Beam	Case No.	Compressive Strength for Concrete (kg/cm2)				Tensile Strength for Re-bar (kg/cm2)				Deflection (mm)		Remarks
		Dead Load σ_{cd}	Live Load σ_{cl}	Total σ_c	Allowable σ_{ca}	Dead Load σ_{sd}	Live Load σ_{sl}	Total σ_s	Allowable σ_{sa}	*Live Load σ_l	Allowable σ_{la}	
Exterior Beam (G1)	Case 1	55.3	16.3	71.6	σ_{28}=270kg/cm^2 σ_{ca}=90kg/cm^2	1640	484	2124	Yield>40kg/mm^2 σ_{sa}=1800kg/cm^2	1.7 (1.9)		
	Case 2	55.3	23.4	78.7		1640	695	2335		2.5 (2.9)		
	Case 3	55.3	11.2	66.5		1640	332	1972		1.2 (1.4)		
	Case 4	55.3	16.2	71.5		1640	479	2119		1.7 (1.9)		
Interior Beam (G2)	Case 1	65.1	14.0	79.1		1281	276	1557		1.3 (1.5)		
	Case 2	65.1	28.2	93.3		1281	555	1836		2.5 (2.9)		
	Case 3	65.1	9.5	74.1		1281	188	1469		0.9 (1.0)		
	Case 4	65.1	19.1	84.2		1281	377	1658		1.8 (2.1)		

* Figure in ( ) indicates correction for the difference of Young's modulus (y = 3.25/2.85 = 1.14)

Table 7.18 Calculation Results (Grid) by Tested Loading (Br. No. 6)

Beam	Case No.	Bending Moment (t • m)		Composite Stress (kg/cm^2)		Deflection by Live Load (mm)	Remarks
		Dead Load	Live Load	Upper Edge of Beam	Lower Edge of Beam		
Exterior Beam (G1)	Case 1	313.7	54.4	73.4 *132.0	0.0 *-13.2	2.4	$\sigma_{28} = 340\ kg/cm^2$
	Case 2	313.7	78.9	76.5 *132.0	-6.0 *-13.2	3.5	
	Case 3	313.7	38.7	71.5 *132.0	3.9 *-13.2	1.7	
	Case 4	313.7	56.0	73.6 *132.0	-0.4 *-13.2	2.5	
Interior Beam (Max G2)	Case 1	330.8	40.0	78.9 *132.0	-2.6 *-13.2	1.8	
	Case 2	330.8	65.6	82.1 *132.0	-8.9 *-13.2	2.9	
	Case 3	330.8	28.4	77.5 *132.0	0.3 *-13.2	1.2	
	Case 4	330.8	46.6	79.8 *132.0	-4.2 *-13.2	2.0	

Note: * indicates the allowable stress by Japan Design Standard

(By ACI Committee $\sigma_{28} = 340\ kg/cm^2$ $\sigma_{cu} = 153\ kg/cm^2$ $\sigma_{cl} = -29.3\ kg/cm^2$
$\sigma_{28} = 315\ kg/cm^2$ $\sigma_{cu} = 142\ kg/cm^2$ $\sigma_{cl} = -28.2\ kg/cm^2$)

Table 7.19 Calculation Results (Grid) by Tested Loading (Br. No. 7, 9)

Beam	Case No.	Bending Moment (t • m)		Composite Stress (kg/cm^2)		Deflection by Live Load (mm)	Remarks
		Dead Load	Live Load	Upper Edge of Beam	Lower Edge of Beam		
Exterior Beam (G1)	Case 1	83.4	15.2	57.6 *124.0	25.3 *-12.4	2.9	σ_{28} = 325 kg/cm^2
	Case 2	83.4	18.9	59.2 *124.0	21.9 *-12.4	3.7	
	Case 3	83.4	10.7	*124.0	29.3 *-12.4	2.1	
	Case 4	83.4	13.3	*124.0	27.0 *-12.4	2.6	
Interior Beam (Max G2)	Case 1	87.7	18.3	*124.0	13.5 *-12.4	3.5	
	Case 2	87.7	24.8	*124.0	7.6 *-12.4	4.8 (5.4)	( ) G4 max
	Case 3	87.7	12.8	*124.0	18.4 *-12.4	2.5	
	Case 4	87.7	17.4	*124.0	14.3 *-12.4	3.4 (3.8)	Max $\sigma G4$ = 5.4 mm ( ) G4 max

Note: * indicates the allowable stress by Japan Design Standard

(By ACI Committee σ_{28} = 340 kg/cm^2 σ_{cu} = 153 kg/cm^2 σ_{cl} = -29.3 kg/cm^2
σ_{28} = 315 kg/cm^2 σ_{cu} = 142 kg/cm^2 σ_{cl} = -28.2 kg/cm^2)