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References/ Notes

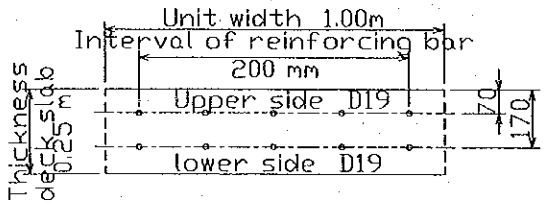
③Deck Slab "S3"

・Examination of shearing force capacity of ultimate limit state

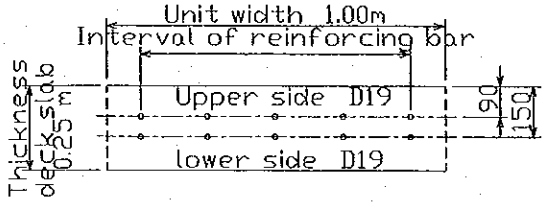
		unit	Ordinary Parallel	Ordinary Vertical
reinforcing bar			D19	D19
number of reinforcing bar			5	5
area of reinforcing bar	A_s	cm^2	14.33	14.33
width of member	b_w	mm	1,000	1,000
effective depth	d	mm	170	150
axial compressive force	N'_d	kN	0	0
A_w		mm^2	2.534	2.534
α_s		°	90	90
s		mm	200	200
V_{cd}		kN	97.98	90.12
V_{sd}		kN	56.19	49.58
V_{yd}		kN	154.17	139.70
V_d		kN	46.82	61.51
Examination result ($\gamma_i \cdot V_d / V_{yd}$)			0.364	0.528
Judgment			O.K	O.K

・Dimension of an examination section

The parallel direction to the face line



The vertical direction to the face line



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			26/07/2002		08/08/2002

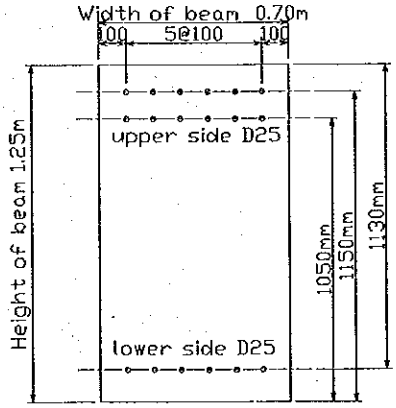
(ii) Beam

①The vertical direction beam to the face line

・Examination of shearing force capacity of ultimate limit state

		unit	Ordinary	Wheel Load (Truck)	Earthquake
reinforcing bar			D25	D25	D25
number of reinforcing bar			6	6	6
area of reinforcing bar	A_s	cm^2	30.40	30.40	30.40
width of member	b_w	mm	700	700	700
effective depth	d	mm	1,130	1,130	1,130
axial compressive force	N'd	kN	0	0	0
A_w		mm^2	3.972	3.972	3.972
α_s		°	90	90	90
s		mm	100	100	100
V_{cd}		kN	226.81	226.81	226.81
V_{sd}		kN	1,170.88	1,170.88	1,170.88
V_{yd}		kN	1,397.69	1,397.69	1,397.69
V_d		kN	426.69	626.66	591.19
Examination result ($\gamma_i \cdot V_d / V_{yd}$)			0.366	0.538	0.423
Judgment			O.K	O.K	O.K

・Dimension of an examination section

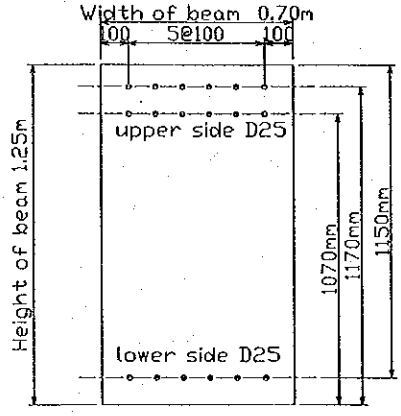


②The parallel direction beam to the face line

・Examination of shearing force capacity of ultimate limit state

		unit	Ordinary	Wheel Load (Truck)	Earthquake
reinforcing bar			D25	D25	D25
number of reinforcing bar			6	6	6
area of reinforcing bar	A_s	cm^2	30.40	30.40	30.40
width of member	b_w	mm	700	700	700
effective depth	d	mm	1,150	1,150	1,150
axial compressive force	N'_d	kN	0	0	0
A_w		mm^2	5.730	5.730	5.730
α_s		°	90	90	90
s		mm	100	100	100
V_{cd}		kN	224.30	224.30	224.30
V_{sd}		kN	1,644.26	1,644.26	1,644.26
V_{yd}		kN	1,868.56	1,868.56	1,868.56
V_d		kN	406.22	542.03	633.54
Examination result ($\gamma_i \cdot V_d / V_{yd}$)			0.261	0.348	0.339
Judgment			O.K	O.K	O.K

・Dimension of an examination section



③Other beams (Cantilever (Beam 4)、Beam of the Direction of Slant (Beam 7))

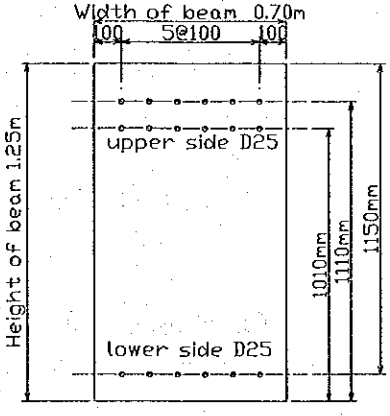
・Examination of shearing force capacity of ultimate limit state

		unit	Cantilever	Beam of the Direction of Slant
reinforcing bar			D25	D25
number of reinforcing bar			6	6
area of reinforcing bar	A_s	cm^2	30.40	30.40
width of member	b_w	mm	700	700
effective depth	d	mm	1,130	1,150
axial compressive force	N'_d	kN	0	0
A_w		mm^2	3.972	3.972
α_s		°	90	90
s		mm	100	100
V_{cd}		kN	226.81	228.61
V_{sd}		kN	1,170.88	1,191.60
V_{yd}		kN	1,397.69	1,420.21
V_d		kN	384.01	674.57
Examination result ($\gamma_i \cdot V_d / V_{yd}$)			0.330	0.570
Judgment			O.K	O.K

・Dimension of an examination section

Dimension of section of cantilever is the same as the vertical direction beam to the face line.

Beam of the Direction of Slant



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(2) Examination of Serviceability Limit State

Design load is computed using the following formulas.

$$S_k = k_p \times S_p + k_r \times S_r$$

where

S_k : characteristic value of load for examination of the serviceability limit state

S_p : characteristic value of permanent load

S_r : characteristic value of variable load

k_p, k_r : constants to represent the effects on crake widths and the corrosion of steel by the permanent load and variable load, respectively. It may be taken that k_p is 1.0 and k_r is 0.5.

a) Examination of Flexural Cracks

Flexural crack width (w (mm)) is computed by the following formulas.

$$w = k \cdot \{4c + 0.7 (Cs - \phi)\} \cdot \left(\frac{\sigma_{se}}{Es} + \varepsilon'_{csd}\right)$$

k ; constant indicating the effect of the bonding properties of the steel material, which may usually be taken as 1.0 in the case of deformed bars.

c ; covering(mm)

Cs ; distance between centers of steel materials(mm)

ϕ ; diameter of steel materials(mm)

ε'_{csd} ; constant introduced to represent the increase of crack width caused by creep and drying shrinkage of concrete (this can be o under seaweter, and elsewhere 150×10^{-6})

σ_{se} ; increased stress on reinforcement $(=M_e/(A_s\, j\, d))$

Es ; Young's modulus of reinforcement $(=2.00 \times 10^5\ N/mm^2)$

M_e ; bending moment

A_s ; area of reinforcing bar (mm^2)

j ; Distance between stress (mm)

d ; effective depth (mm)

Permisible crake width is computed by the following formulas.

・Permisible crake width upper side reinforcing bar $w_a = 0.0040\ c$ (mm)

lower side reinforcing bar $w_a = 0.0035\ c$ (mm)

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References/ Notes

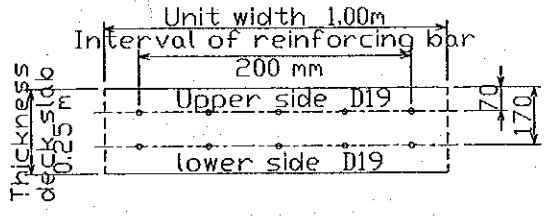
(i) Deck Slab

①Deck Slab "S1" : the parallel direction to the face line

・Examination of flexural crack of serviceability limit state

		unit	Ordinary		Wheel Load (Distribution)		Wheel Load (Partial distribution) Vertical to the face line		Wheel Load (Partial distribution) Parallel to the face line	
			upper	lower	upper	lower	upper	lower	upper	lower
reinforcing bar		mm	D19	D19	D19	D19	D19	D19	D19	D19
diameter	ϕ	mm	19	19	19	19	19	19	19	19
covering	c	mm	60	70	60	70	60	70	60	70
distance between centers of bar	C_s	mm	200	200	200	200	200	200	200	200
moment (permanent load)	M_e	kN・m	7.60	3.45	7.60	3.45	7.60	3.45	7.60	3.45
moment (variable load)	M_e	kN・m	25.32	11.49	26.50	12.02	21.06	21.06	26.94	26.94
moment (design load)	M_e	kN・m	20.26	9.20	20.85	9.46	18.13	13.98	21.07	16.92
area of reinforcing bar (tension)	A_s	cm^2	14.33	14.33	14.33	14.33	14.33	14.33	14.33	14.33
effective depth	d	mm	180	170	180	170	180	170	180	170
increased stress on reinforcement (design load)	σ_{se}	N/mm^2	82.26	40.46	84.65	41.63	73.61	61.52	85.55	74.45
increased stress on reinforcement (permanent load)	σ_{se}	N/mm^2	30.86	15.18	30.86	15.18	30.86	15.18	30.86	15.18
flexural crack width (design load)	w1	mm	0.206	0.143	0.210	0.146	0.190	0.186	0.212	0.212
flexural crack width (permanent load)	w2	mm	0.112	0.092	0.112	0.092	0.112	0.092	0.112	0.092
permisible crake width	w_a	mm	0.240	0.245	0.240	0.245	0.240	0.245	0.240	0.245
Examination result (design load)			$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K
Examination result (permanent load)			$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K

・Dimension of an examination section



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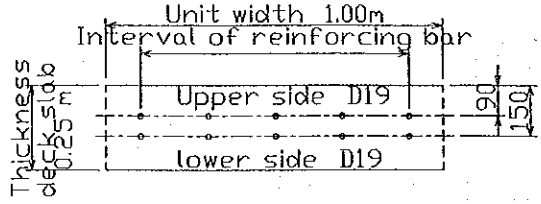
②Deck Slab "S1" : the vertical direction to the face line

・Examination of flexural crack of serviceability limit state

		unit	Ordinary		Wheel Load (Distribution)		Wheel Load (Partial distribution) Vertical to the face line		Wheel Load (Partial distribution) Parallel to the face line	
			upper	lower	upper	lower		upper	lower	upper
reinforcing bar		mm	D19	D19	D19	D19	D19	D19	D19	D19
diameter	ϕ	mm	19	19	19	19	19	19	19	19
covering	c	mm	80	90	80	80	80	90	80	90
distance between centers of bar	C_s	mm	200	200	200	200	200	200	200	200
moment (permanent load)	M_e	kN・m	6.12	1.94	6.12	1.94	6.12	1.94	6.12	1.94
moment (variable load)	M_e	kN・m	20.41	6.47	21.36	6.77	20.52	20.52	14.83	14.83
moment (design load)	M_e	kN・m	16.33	5.18	16.80	5.33	16.38	12.20	13.54	9.36
area of reinforcing bar (tension)	A_s	cm^2	14.33	14.33	14.33	14.33	14.33	14.33	14.33	14.33
effective depth	d	mm	160	150	160	150	160	150	160	150
increased stress on reinforcement (design load)	σ_{se}	N/mm^2	65.39	22.81	67.30	23.47	65.61	53.78	54.22	41.24
increased stress on reinforcement (permanent load)	σ_{se}	N/mm^2	24.52	8.55	24.52	8.55	24.52	8.55	24.52	8.55
flexural crack width (design load)	w1	mm	0.213	0.129	0.217	0.130	0.214	0.204	0.188	0.173
flexural crack width (permanent load)	w2	mm	0.122	0.094	0.122	0.094	0.122	0.094	0.122	0.094
permisible crake width	w_a	mm	0.320	0.315	0.320	0.315	0.320	0.315	0.320	0.315
Examination result (design load)			$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K
Examination result (permanent load)			$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K

・Dimension of an examination section



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			26/07/2002		08/08/2002

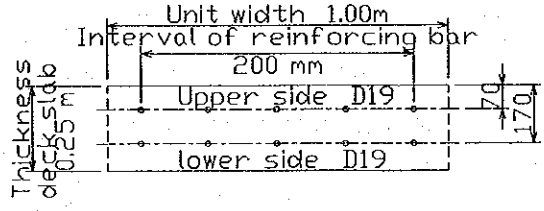
③Deck Slab "S3"

・Examination of flexural crack of serviceability limit state

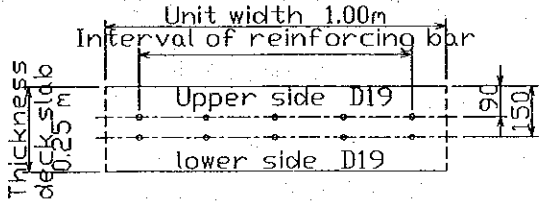
		unit	Ordinary Parallel		Ordinary Vertical	
			upper	lower	upper	lower
reinforcing bar		mm	D19	D19	D19	D19
diameter	ϕ	mm	19	19	19	19
covering	c	mm	60	70	80	90
distance between centers of bar	C_s	mm	200	200	200	200
moment (permanent load)	M_e	kN・m	5.16	—	2.02	0.28
moment (variable load)	M_e	kN・m	17.19	—	6.73	0.92
moment (design load)	M_e	kN・m	13.76	—	5.39	0.74
area of reinforcing bar (tension)	A_s	cm^2	14.33	14.33	14.33	14.33
effective depth	d	mm	180	170	160	150
increased stress on reinforcement (design load)	σ_{se}	N/mm^2	55.85	—	21.57	3.26
increased stress on reinforcement (permanent load)	σ_{se}	N/mm^2	20.95	—	8.09	1.23
flexural crack width (design load)	w1	mm	0.157	—	0.115	0.081
flexural crack width (permanent load)	w2	mm	0.093	—	0.085	0.076
permisible crake width	w_a	mm	0.240	—	0.320	0.315
Examination result (design load)			$w1<w_a$ O.K	—	$w1<w_a$ O.K	$w1<w_a$ O.K
Examination result (permanent load)			$w2<w_a$ O.K	—	$w2<w_a$ O.K	$w2<w_a$ O.K

・Dimension of an examination section

The parallel direction to the face line



The vertical direction to the face line



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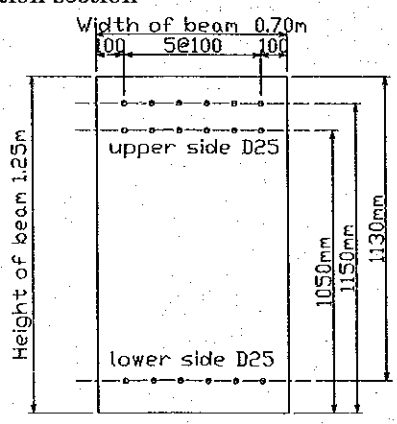
(ii) Beam

①The vertical direction beam to the face line

・Examination of flexural crack of serviceability limit state

		unit	Ordinary		Wheel load (Truck)	
			upper	lower	upper	lower
reinforcing bar		mm	D25	D25	D25	D25
diameter	ϕ	mm	25	25	25	25
covering	c	mm	90	110	90	110
distance between centers of bar	C_s	mm	100	100	100	100
moment (permanent load)	M_e	kN・m	475.52	102.67	475.52	102.67
moment (variable load)	M_e	kN・m	171.62	98.76	335.28	304.08
moment (design load)	M_e	kN・m	561.33	152.05	643.16	254.71
area of reinforcing bar (tension)	A_s	cm^2	60.804	30.402	60.804	30.402
effective depth	d	mm	1,100	1,130	1,100	1,130
increased stress on reinforcement (design load)	σ_{se}	N/mm^2	98.39	47.77	112.73	80.03
increased stress on reinforcement (permanent load)	σ_{se}	N/mm^2	83.35	32.26	83.35	32.26
flexural crack width (design load)	w1	mm	0.265	0.192	0.294	0.271
flexural crack width (permanent load)	w2	mm	0.234	0.153	0.234	0.153
permisible crake width	w_a	mm	0.360	0.350	0.360	0.350
Examination result (design load)			$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K
Examination result (permanent load)			$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K

・Dimension of an examination section



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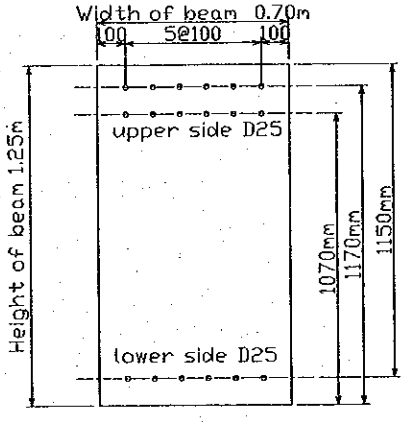
②The parallel direction beam to the face line

・Examination of flexural crack of serviceability limit state

		unit	Ordinary		Wheel load (Truck)	
			upper	lower	upper	lower
reinforcing bar		mm	D25	D25	D25	D25
diameter	ϕ	mm	25	25	25	25
covering	c	mm	70	90	70	90
distance between centers of bar	C_s	mm	100	100	100	100
moment (permanent load)	M_e	kN・m	475.52	36.36	475.52	36.36
moment (variable load)	M_e	kN・m	106.68	58.35	204.95	338.05
moment (design load)	M_e	kN・m	528.86	65.535	578.00	205.39
area of reinforcing bar (tension)	A_s	cm^2	60.804	30.402	60.804	30.402
effective depth	d	mm	1,120	1,150	1,120	1,150
increased stress on reinforcement (design load)	σ_{se}	N/mm^2	90.60	20.17	99.02	63.21
increased stress on reinforcement (permanent load)	σ_{se}	N/mm^2	81.46	11.19	81.46	11.19
flexural crack width (design load)	w1	mm	0.200	0.103	0.214	0.192
flexural crack width (permanent load)	w2	mm	0.185	0.085	0.185	0.085
permisible crake width	w_a	mm	0.280	0.315	0.280	0.315
Examination result (design load)			$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K
Examination result (permanent load)			$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K

・Dimension of an examination section



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③Other beams (Cantilever (Beam 4)、Beam of the Direction of Slant (Beam 7)、 Fender attachment part (apron))

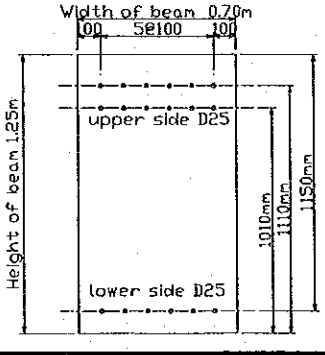
・Examination of flexural crack of serviceability limit state

		unit	Cantilever		Beam of the Direction of Slant		Fender attachment part	
			upper	lower	upper	lower	upper	lower
reinforcing bar		mm	D25	D25	D25	D25	D19	D19
diameter	ϕ	mm	25	25	25	25	19	19
covering	c	mm	90	110	130	90	70	90
distance between centers of bar	C_s	mm	100	100	100	100	100	200
moment (permanent load)	M_e	kN・m	288.41	—	114.24	57.12	0.00	0.00
moment (variable load)	M_e	kN・m	621.18	—	447.68	299.15	188.70	71.85
moment (design load)	M_e	kN・m	599.00	—	338.08	206.70	94.35	35.93
Axial Load (permanent)	N	kN	0.00	—	0.00	0.00	0.00	-48.00
area of reinforcing bar (tension)	A_s	cm^2	60.804	30.402	60.804	30.402	28.65	14.325
effective depth	d	mm	1,100	1,130	1,060	1,150	420	400
increased stress on reinforcement (design load)	σ_{se}	N/mm^2	104.99	—	61.57	63.87	86.50	86.66
increased stress on reinforcement(permanent load)	σ_{se}	N/mm^2	50.55	—	20.80	17.65	0.00	89.72
flexural crack width (design load)	w1	mm	0.278	—	0.262	0.194	0.196	0.284
flexural crack width (permanent load)	w2	mm	0.166	—	0.145	0.098	0.000	0.291
permisible crake width	w_a	mm	0.360	—	0.400	0.315	0.245	0.315
Examination result (design load)			$w1<w_a$ O.K	—	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K	$w1<w_a$ O.K
Examination result (permanent load)			$w2<w_a$ O.K	—	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K	$w2<w_a$ O.K

・Dimension of an examination section

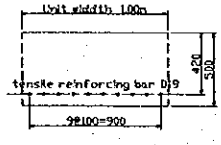
Dimension of section of cantilever is the same as the vertical direction beam to the face line.

Beam of the Direction of Slant

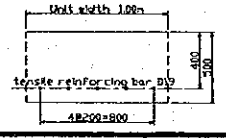


Fender attachment part

Horizontal reinforcing bar



Vertical reinforcing bar



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b) Examination of Shear Cracks

For members subject to shear forces, it may not be required to examine shear cracks when the design shear force, Vd, is smaller than 70% of the design shear capacity of concrete, Vcd. When examination for shear crack is necessary, the stress in shear reinforcement due to permanent load is confirmed smaller than the limiting value for the increment in stress in ordinary reinforcement due to permanent load.

$$\sigma_{wpd} = \frac{(Vpd + Vrd - k_2 \times Vcd) \times s}{Aw \times z \times (\sin\alpha s + \cos\alpha s)} \times \frac{Vpd + Vcd}{Vpd + Vrd + Vcd}$$

wher 、 σ_{wpd} : design stress in shear reinforcement due to permanent load

Vpd : design shear force produced by permanent load

Vrd : design shear force produced by variable load

Vcd : design shear capacity of concrete
(see examination of shearing force of ultimate limit state
It considers as $\gamma b = \gamma c = 1.0$)

Aw : area of one unit of shear reinforcement

s : spacing of shear reinforcement

z : distance from compression resultant to centroid of tension reinforcement (=d/1.15)

d : effective depth

αs : angle between shear reinforcement and axis of member

k_2 : The factor for taking into consideration the influence of the frequency of change load (=0.5)

The limiting value for the increment in stress in ordinary reinforcement due to permanent load " σ sp" uses the following values. (see "Standard Specifications of Concrete (in Japan))

When a upper side reinforcing bar steel rod is examined $\sigma sp = 100\ N/mm^2$

When a lower side reinforcing bar steel rod is examined $\sigma sp = 80\ N/mm^2$

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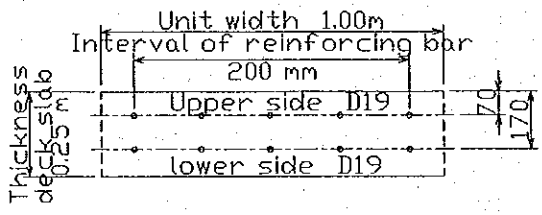
(i) Deck Slab

①Deck Slab "S1" : the parallel direction to the face line

・Examination of shearing crack

		unit	Ordinary	Wheel Load (Distribution)	Wheel Load (Partial distribution) Vertical to the face line	Wheel Load (Partial distribution) Parallel to the face line
reinforcing bar			D19	D19	D19	D19
number of reinforcing bar			5	5	5	5
area of tension reinforcing bar	A_s	cm^2	14.33	14.33	14.33	14.33
width of member	b_w	mm	1,000	1,000	1,000	1,000
effective depth	d	mm	170	170	170	170
compression force of an axis	N'_d	kN	0	0	0	0
design shear capacity of concrete	V_{cd}	kN	139.02	139.02	139.02	139.02
design shear force	V_d	kN	31.21	32.12	28.23	24.05
Examination result (V_d/V_{cd})			0.225	0.231	0.203	0.173
Necessity for examination of shear crack			without necessity	without necessity	without necessity	without necessity
σ wpd			—	—	—	—
σ sp			—	—	—	—
Judgment			—	—	—	—

・Dimension of an examination section



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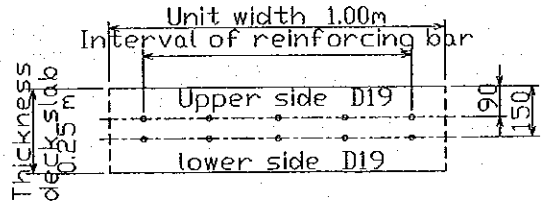
②Deck Slab "S1" : the vertical direction to the face line

・Examination of shearing crack

		unit	Ordinary	Wheel Load (Distribution)	Wheel Load (Partial distribution) Vertical to the face line	Wheel Load (Partial distribution) Parallel to the face line
reinforcing bar			D19	D19	D19	D19
number of reinforcing bar			5	5	5	5
area of tension reinforcing bar	A_s	cm^2	14.33	14.33	14.33	14.33
width of member	b_w	mm	1,000	1,000	1,000	1,000
effective depth	d	mm	150	150	150	150
compression force of an axis	N'_d	kN	0	0	0	0
design shear capacity of concrete	V_{cd}	kN	127.86	127.86	127.86	127.86
design shear force	V_d	kN	34.14	35.13	25.15	29.33
Examination result (V_d/V_{cd})			0.267	0.275	0.197	0.220
Necessity for examination of shear crack			without necessity	without necessity	without necessity	without necessity
σ wpd			—	—	—	—
σ sp			—	—	—	—
Judgment			—	—	—	—

・Dimension of an examination section



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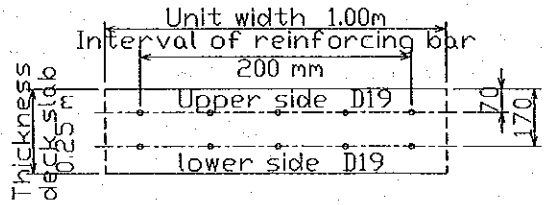
③Deck Slab "S3"

・Examination of shearing crack

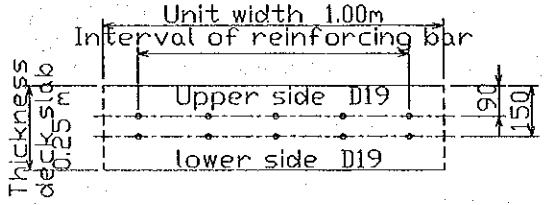
		unit	Ordinary Parallel	Ordinary Vertical
reinforcing bar			D19	D19
number of reinforcing bar			5	5
area of tension reinforcing bar	A_s	cm^2	14.33	914.33
width of member	b_w	mm	1,000	1,000
effective depth	d	mm	170	150
compression force of an axis	N'd	kN	0	0
design shear capacity of concrete	V_{cd}	kN	139.02	127.86
design shear force	V_d	kN	24.48	32.16
Examination result (V_d/V_{cd})			0.176	0.252
Necessity for examination of shear crack			without necessity	without necessity
σ wpd			—	—
σ sp			—	—
Judgment			—	—

・Dimension of an examination section

The parallel direction to the face line



The vertical direction to the face line



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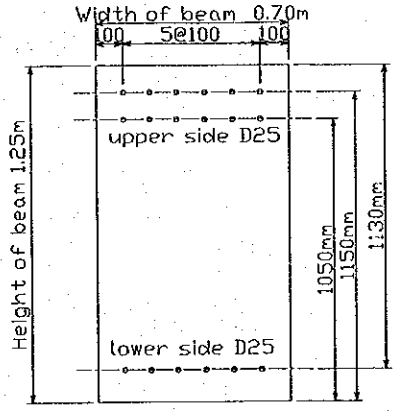
(ii) Beam

①The vertical direction beam to the face line

・Examination of shearing crack

		unit	Ordinary	Wheel Load (Truck)
reinforcing bar			D25	D25
number of reinforcing bar			6	6
area of tension reinforcing bar	A_s	cm^2	30.402	30.402
width of member	b_w	mm	700	700
effective depth	d	mm	1,130	1,100
compression force of an axis	N'd	kN	0	0
design shear capacity of concrete	V_{cd}	kN	321.80	321.80
design shear force	V_d	kN	367.01	424.46
Examination result (V_d/V_{cd})			1.140	1.319
Necessity for examination of shear crack			with necessity	with necessity
σ wpd			58.46	70.41
σ sp			80.00	80.00
Judgment			O.K	O.K

・Dimension of an examination section

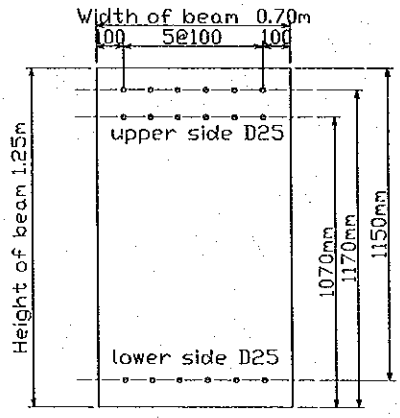


②The parallel direction beam to the face line

・Examination of shearing crack

		unit	Ordinary	Wheel Load (Truck)
reinforcing bar			D25	D25
number of reinforcing bar			6	6
area of tension reinforcing bar	A_s	cm^2	30.402	30.402
width of member	b_w	mm	700	700
effective depth	d	mm	1,150	1,150
compression force of an axis	N'_d	kN	0	0
design shear capacity of concrete	V_{cd}	kN	318.23	318.23
design shear force	V_d	kN	466.36	566.29
Examination result (V_d/V_{cd})			1.465	1.779
Necessity for examination of shear crack			with necessity	with necessity
σ wpd			57.53	70.15
σ sp			80.00	80.00
Judgment			O.K	O.K

・Dimension of an examination section



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③Other beams (Cantilever (Beam 4)、Beam of the Direction of Slant (Beam 7))

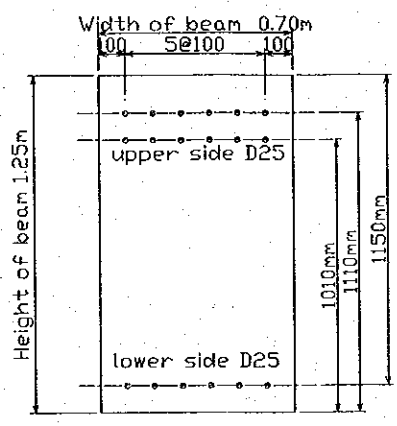
・Examination of shearing crack

		unit	Cantilever	Beam of the Direction of Slant
reinforcing bar			D25	D25
number of reinforcing bar			6	6
area of tension reinforcing bar	A_s	cm^2	30.402	30.402
width of member	b_w	mm	700	700
effective depth	d	mm	1,130	1,150
compression force of an axis	N'd	kN	0	0
design shear capacity of concrete	V_{cd}	kN	321.80	324.35
design shear force	V_d	kN	234.40	335.23
Examination result (V_d/V_{cd})			0.728	1.034
Necessity for examination of shear crack			with necessity	with necessity
σ wpd			30.71	48.72
σ sp			80.00	80.00
Judgment			O.K	O.K

・Dimension of an examination section

Dimension of section of cantilever is the same as the vertical direction beam to the face line.

Beam of the Direction of Slant



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(3) Examination to Fatigue Limit State

An examination case is set to Wheel Load (Truck). The fatigue life (number of times of a wheel load action) is as follows.

The number of car loading per car carrier : 650

The number of times of car carriers entry into port per year : 33 times / year

Lifetime of Berth : 50 years

Fatigue Life $650 \times 33 \times 50 = 1,072,500$ times

The unloading of the car is equally carried out at platforms 1 and 2. Therefore, lifetime per platform becomes as follows.

$N = 1,072,500 / 2 = 536,250$ times $\rightarrow$ 540,000 times

a) Examination of Fatigue Limit of Bending

(i) Examination of reinforcing bar

The safety to the fatigue limit state of the reinforcing bar is checked by the following formulas.

$$\gamma i \times \sigma sed / (fsrd / \gamma b) \leqq 1.0$$

where

σsrd : stress in reinforcement due to variable load (N/mm^2)

γi : structure factor

γb : member factor

fsrd : design fatigue strength for a reinforcing bar

$$fsrd = 190 \times \frac{10^{\alpha}}{N^{k}} \times \left(1 - \frac{\sigma sp}{fud} \right) / \gamma s$$

$\alpha = k_0 \times (0.81 - 0.003 \times \phi)$

$k = 0.12$

ϕ : diameter of reinforcing bar (mm)

k_0 : factor concerning α (=1.0)

fud : design tensile strength of steel (N/mm^2) (=fuk / γs)

$=490 / 1.05 = 466.67$ N/mm^2

fuk : characteristic value for tensile strength of steel (N/mm^2)

γs : material factor for steel

σsp : stress of a reinforcing bar due to permanent load (N/mm^2)

N : fatigue life

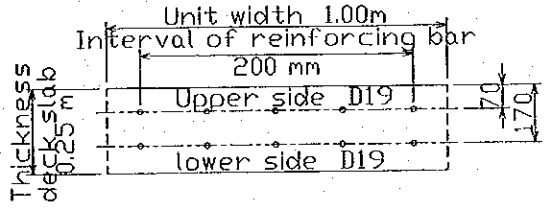
①Deck Slab

①－1 Deck Slab "S1" : the parallel direction to the face line

○Examination of fatigue limit of reinforcing bar (deck slab)

	unit	Wheel Load (Distribution)		Wheel Load (Partial distribution) Vertical to the face line		Wheel Load (Partial distribution) Parallel to the face line	
		upper	lower	upper	lower	upper	lower
α		0.753	0.753	0.753	0.753	0.753	0.753
k		0.12	0.12	0.12	0.12	0.12	0.12
diameter φ	mm	19	19	19	19	19	19
k_θ		1.0	1.0	1.0	1.0	1.0	1.0
design tensile strength of steel fud	N/mm²	466.67	466.67	466.67	466.67	466.67	466.67
bending moment (permanent load) Mpd	kN・m	7.60	3.45	7.60	3.45	7.60	3.45
bending load (variable load) Mrd	kN・m	26.50	12.02	21.06	21.06	26.94	26.94
σsp	N/mm²	30.86	15.18	30.86	15.18	30.86	15.18
fatigue life N	times	540,000	540,000	540,000	540,000	540,000	540,000
design fatigue strength for a reinforcing bar fsrd		196.32	203.38	196.32	203.38	196.32	203.38
stress in reinforcing bar due to variable load σsrd		107.59	52.89	85.51	92.67	109.38	118.54
Examination result γi・σsrd/(fsrd/b)		0.55 O.K	0.26 O.K	0.44 O.K	0.46 O.K	0.56 O.K	0.58 O.K

・Dimension of an examination section



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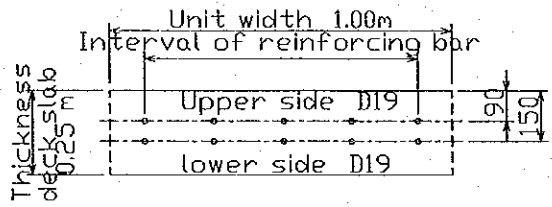
①－2 Deck Slab "S1" ：the vertical direction to the face line

○Examination of fatigue limit of reinforcing bar (deck slab)

	unit	Wheel Load (Distribution)		Wheel Load (Partial distribution) Vertical to the face line		Wheel Load (Partial distribution) Parallel to the face line	
		upper	lower	upper	lower	upper	lower
α		0.753	0.753	0.753	0.753	0.753	0.753
k		0.12	0.12	0.12	0.12	0.12	0.12
diameter ϕ	mm	19	19	19	19	19	19
k_0		1.0	1.0	1.0	1.0	1.0	1.0
design tensile strength of steel fud	N/mm²	466.67	466.67	466.67	466.67	466.67	466.67
bending moment (permanent load) Mpd	kN・m	6.12	1.94	6.12	1.94	6.12	1.94
bending load (variable load) Mrd	kN・m	21.36	6.77	20.52	20.52	14.83	14.83
σ sp	N/mm²	24.52	8.55	24.52	8.55	24.52	8.55
fatigue life N	times	540,000	540,000	540,000	540,000	540,000	540,000
design fatigue strength for a reinforcing bar fsrd		199.18	206.37	199.18	206.37	199.18	206.37
stress in reinforcing bar due to variable load σ srd		85.56	29.84	82.20	90.46	59.41	65.37
Examination result $\gamma i \cdot \sigma srd/(fsrd/b)$		0.43 O.K	0.14 O.K	0.41 O.K	0.44 O.K	0.30 O.K	0.32 O.K

・Dimension of an examination section



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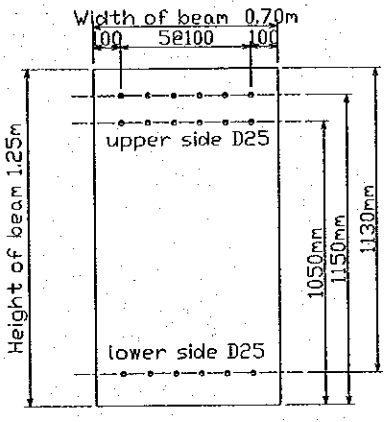
②Beam

○Examination of fatigue limit of reinforcing bar (beam)

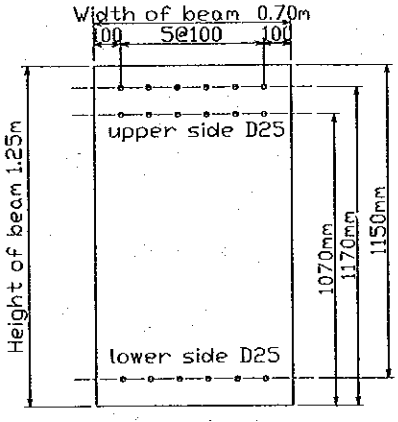
	unit	The vertical direction beam to the face line		The parallel direction beam to the face line	
		upper	lower	upper	lower
α		0.735	0.735	0.735	0.735
k		0.12	0.12	0.12	0.12
diameter φ	mm	25	25	25	25
k_0		1.0	1.0	1.0	1.0
design tensile strength of steel fud	N/mm²	466.67	466.67	466.67	466.67
bending moment (permanent load) Mpd	kN・m	475.52	102.67	475.52	36.36
bending load (variable load) Mrd	kN・m	335.28	304.08	204.95	338.05
σsp	N/mm²	83.35	32.26	81.46	11.19
fatigue life N	times	540,000	540,000	540,000	540,000
design fatigue strength for a reinforcing bar fsrd		165.67	187.74	166.48	196.85
stress in reinforcing bar due to variable load σsrd		58.77	95.54	35.11	104.03
Examination result γi・σsrd/(fsrd/b)		0.35 O.K	0.51 O.K	0.21 O.K	0.53 O.K

・Dimension of an examination section (Beam)

The vertical direction beam to the face line



The parallel direction beam to the face line



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③Other beams (Cantilever (Beam 4)、Beam of the Direction of Slant (Beam 7))

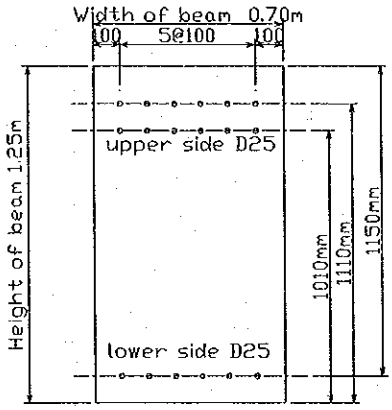
○Examination of fatigue limit of reinforcing bar (beam)

	unit	Cantilever	Beam of the Direction of Slant	
		upper	upper	lower
α		0.735	0.735	0.735
k		0.12	0.12	0.12
diameter φ	mm	25	25	25
k_0		1.0	1.0	1.0
design tensile strength of steel fud	N/mm^2	466.67	466.67	466.67
bending moment (permanent load) Mpd	kN・m	288.41	114.24	57.12
bending load (variable load) Mrd	kN・m	621.18	447.68	299.15
σsp	N/mm^2	50.55	20.80	17.65
fatigue life N	times	540,000	540,000	540,000
design fatigue strength for a reinforcing bar fsrd		179.84	192.70	194.06
stress in reinforcing bar due to variable load σsrd		108.88	81.53	92.45
Examination result γi・σsrd/(fsrd/b)		0.61 O.K	0.42 O.K	0.48 O.K

・Dimension of an examination section

Dimension of section of cantilever is the same as the vertical direction beam to the face line.

Beam of the Direction of Slant



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(ii) Examination of Concrete

The safety to the fatigue limit state of concrete is checked by the following formulas.

$$\gamma i \times \sigma' ced / (frd / \gamma b) \leqq 1.0$$

where

$\sigma' crd$: stress in concrete due to variable load (N/mm^2)

γi : structure factor

γb : member factor

frd : design fatigue strength for concrete (N/mm^2)

$$frd = k_1 \times fd \times (1 - \frac{\sigma p}{fd}) \times (1 - \frac{\log N}{K})$$

$k_1 = 0.85$ 、 K=17

fd : design compressive strength of concrete (N/mm^2) (=f'ck / γc)

$fd = 24 / 1.3 = 18.46\ N/mm^2$

f'ck : basic strength for design (= 24 N/mm^2)

γc : material factor for concrete (=1.3)

σp : stress of concrete due to permanent load (N/mm^2)

N : fatigue life

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①Deck Slab

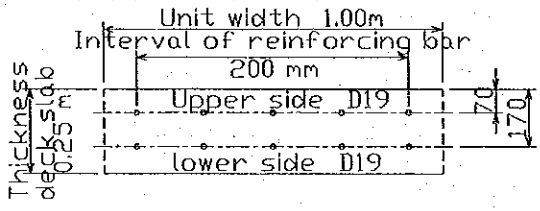
①－1 Deck Slab "S1" : the parallel direction to the face line

○Examination of fatigue limit of bending of concrete (deck slab)

	unit	Wheel Load (Distribution)		Wheel Load (Partial distribution) Vertical to the face line		Wheel Load (Partial distribution) Parallel to the face line	
		upper	lower	upper	lower	upper	lower
design compressive strength of concrete fd	N/mm²	18.46	18.46	18.46	18.46	18.46	18.46
k1		0.85	0.85	0.85	0.85	0.85	0.85
K		17	17	17	17	17	17
stress of concrete due to permanent load σp	N/mm²	1.36	0.68	1.36	0.68	1.36	0.68
fatigue life N	times	540,000	540,000	540,000	540,000	540,000	540,000
design compressive strength of concrete frd		9.63	10.02	9.63	10.02	9.63	10.02
stress in concrete due to variable load σ'crd		4.75	2.35	3.77	4.12	4.83	5.27
Examination result γi×σ'crd/(frd/γb)		0.49 O.K	0.23 O.K	0.39 O.K	0.41 O.K	0.50 O.K	0.53 O.K

※Section force is the same value as what was used by examination of reinforcing bar.

・Dimension of an examination section



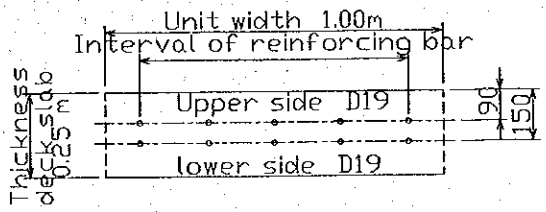
①－2 Deck Slab "S1" : the vertical direction to the face line

○Examination of fatigue limit of bending of concrete (deck slab)

	unit	Wheel Load (Distribution)		Wheel Load (Partial distribution) Vertical to the face line		Wheel Load (Partial distribution) Parallel to the face line	
		upper	lower	upper	lower	upper	lower
design compressive strength of concrete fd	N/mm²	18.46	18.46	18.46	18.46	18.46	18.46
k1		0.85	0.85	0.85	0.85	0.85	0.85
K		17	17	17	17	17	17
stress of concrete due to permanent load σp	N/mm²	1.29	0.46	1.29	0.46	1.29	0.46
fatigue life N	times	540,000	540,000	540,000	540,000	540,000	540,000
design compressive strength of concrete frd		9.67	10.14	9.67	10.14	9.67	10.14
stress in concrete due to variable load σ'crd		4.51	1.61	4.34	4.87	3.13	3.52
Examination result γi× σ'crd / (frd / γb)		0.47 O.K	0.16 O.K	0.45 O.K	0.48 O.K	0.32 O.K	0.35 O.K

※Section force is the same value as what was used by examination of reinforcing bar.

・Dimension of an examination section



②Beam

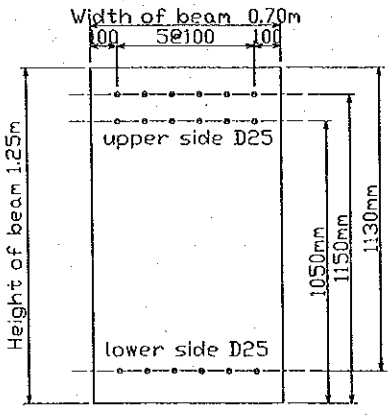
○Examination of fatigue limit of bending of concrete (beam)

	unit	The vertical direction beam to the face line		The parallel direction beam to the face line	
		upper	lower	upper	lower
design compressive strength of concrete fd	N/mm²	18.46	18.46	18.46	18.46
k1		0.85	0.85	0.85	0.85
K		17	17	17	17
stress of concrete due to permanent load σp	N/mm²	2.89	0.76	2.78	0.26
fatigue life N	times	540,000	540,000	540,000	540,000
design compressive strength of concrete frd		8.77	9.97	8.83	10.26
stress in concrete due to variable load σ'crd		2.04	2.26	1.20	2.38
Examination result γi× σ'crd / (frd / γb)		0.23 O.K	0.23 O.K	0.14 O.K	0.23 O.K

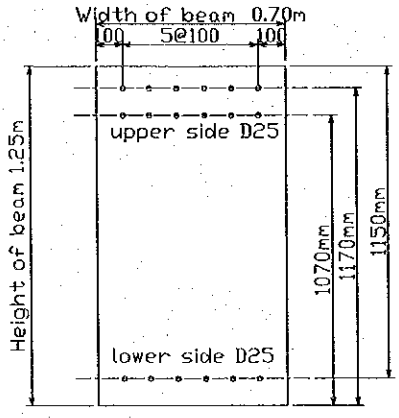
※Section force is the same value as what was used by examination of reinforcing bar.

・Dimension of an examination section

The vertical direction beam to the face line



The parallel direction beam to the face line



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③Other beams (Cantilever (Beam 4)、Beam of the Direction of Slant (Beam 7))

○Examination of fatigue limit of bending of concrete (beam)

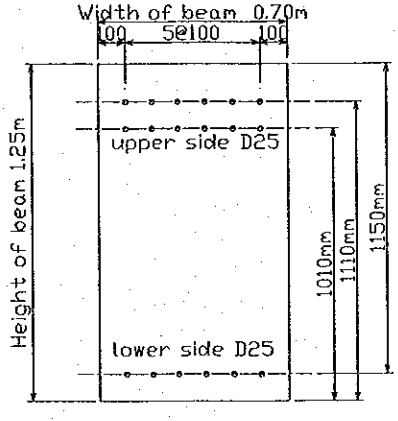
	unit	Cantilever	Beam of the Direction of Slant	
		upper	upper	lower
design compressive strength of concrete fd	N/mm²	18.46	18.46	18.46
k1		0.85	0.85	0.85
K		17	17	17
stress of concrete due to permanent load σp	N/mm²	1.75	0.73	0.43
fatigue life N	times	540,000	540,000	540,000
design compressive strength of concrete frd		9.41	9.99	10.16
stress in concrete due to variable load σ'crd		3.78	2.86	2.26
Examination result γi× σ'crd / (frd / γb)		0.40 O.K	0.29 O.K	0.22 O.K

※Section force is the same value as what was used by examination of reinforcing bar.

・Dimension of an examination section

Dimension of section of cantilever is the same as the vertical direction beam to the face line.

Beam of the Direction of Slant



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b) Examination of Fatigue Limit of Shear

Examination of fatigue limit of shear checks the safety of only a concrete portion. When design shear force exceeds design shear fatigue capacity of a concrete portion, the stress of shear reinforcement is examined.

Examination of fatigue limit of shear of a concrete portion checks the following formulas.

$$\gamma i \times Vrd / Vrcd \leqq 1.0$$

$$Vrcd = Vcd \times (1 - Vpd / Vcd) \times (1 - \log N / 11)$$

where、 Vrd : design shear force produced by variable load

Vrcd : design shear fatigue capacity of member without shear reinforcement

Vcd : design shear capacity of concrete

(see examination of shearing force of ultimate limit state)

N : fatigue life

Vpd : design shear force produced by permanent load

When not filling the above-mentioned formula, the following formulas examine shear reinforcement.

$$\gamma i \times \sigma wrd / (fwrd / \gamma b) \leqq 1.0$$

design stress in shear reinforcement due to permanent load

$$\sigma wpd = \frac{(Vpd + Vrd - k_2 \times Vcd) \times s}{Aw \times z \times (\sin \alpha s + \cos \alpha s)} \times \frac{Vpd + Vcd}{Vpd + Vrd + Vcd}$$

design stress in shear reinforcement due to variable bad

$$\sigma wrd = \frac{(Vpd + Vrd - k_2 \times Vcd) \times s}{Aw \times z \times (\sin \alpha s + \cos \alpha s)} \times \frac{Vrd}{Vpd + Vrd + Vcd}$$

design fatigue strength for reinforcing bar (shear reinforcement)

$$fwrd = 190 \times \frac{10^{\alpha}}{N^{k}} \times (1 - \frac{\sigma wpd}{fud}) / \gamma s$$

where、 Aw : area of shear reinforcement within distance "s"

s : spacing of vertical shear reinforcements

z : distance from compression resultant to centroid of tension reinforcement (=d/1.15)

d : effective depth

αs : angle between shear reinforcement and axis of member

fud : design tensile strength of steel (=490 / 1.05 = 466.67 N/mm^2)

N : fatigue life

$\alpha = k_0 \times (0.81 - 0.003 \times \phi)$ ($k_0 = 1.0$、 ϕ : diameter of reinforcing bar)

$k = 0.12$ 、 $k_2 = 0.5$

Since shear reinforcement has the bent portion, design fatigue strength, fwrd, is taken as 50% of value of a calculation result.

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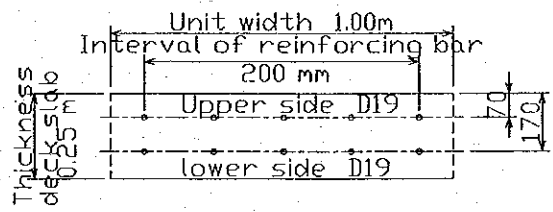
(i) Deck Slab

①Deck Slab "S1" : the parallel direction to the face line

	unit	the parallel direction to the face line		
		Wheel Load (Distribution)	Wheel Load (Partial distribution) Vertical to the face line	Wheel Load (Partial distribution) Parallel to the face line
Vpd	kN	11.70	11.70	11.70
Vrd	kN	40.83	33.06	24.69
Vcd	kN	127.38	127.38	127.38
Vrcd	kN	55.40	55.40	55.40
Examination result γi・Vrd / Vrcd		0.737	0.597	0.446
Necessity for examination of shear reinforcement		without necessity	without necessity	without necessity
α		—	—	—
k		—	—	—
diameter of reinforcing bar φ	mm	—	—	—
k_0		—	—	—
design tensile strength of steel fud	N/mm²	—	—	—
design stress in shear reinforcement due to permanent load σwpd	N/mm²	—	—	—
fatigue life N	times	—	—	—
design fatigue strength for reinforcing bar fwrd		—	—	—
design stress in shear reinforcement due to variable load σwrd		—	—	—
Examination result γi・σwrd / (fwrd / b)		—	—	—

・Dimension of an examination section



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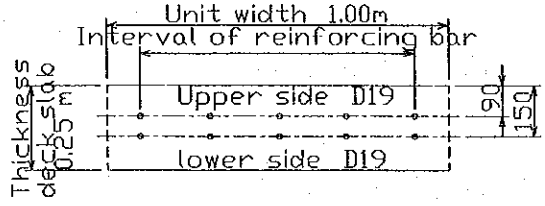
②Deck Slab "S1" : the vertical direction to the face line

	unit	the vertical direction to the face line		
		Wheel Load (Distribution)	Wheel Load (Partial distribution) Vertical to the face line	Wheel Load (Partial distribution) Parallel to the face line
Vpd	kN	12.80	12.80	12.80
Vrd	kN	44.65	24.69	33.06
Vcd	kN	117.15	117.15	117.15
Vrcd	kN	49.97	49.97	49.97
Examination result γi・Vrd / Vrcd		0.894	0.494	0.662
Necessity for examination of shear reinforcement		without necessity	without necessity	without necessity
α		—	—	—
k		—	—	—
diameter of reinforcing bar φ	mm	—	—	—
k0		—	—	—
design tensile strength of steel fud	N/mm²	—	—	—
design stress in shear reinforcement due to permanent load σwpd	N/mm²	—	—	—
fatigue life N	times	—	—	—
design fatigue strength for reinforcing bar fwrd		—	—	—
design stress in shear reinforcement due to variable load σwrd		—	—	—
Examination result γi・σwrd / (fwrd / b)		—	—	—

・Dimension of an examination section



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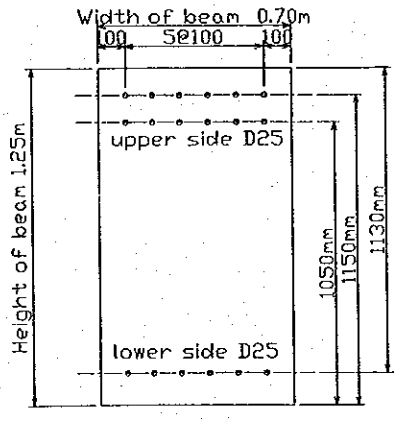
(ii) Beam

①The parallel and vertical direction to the face line

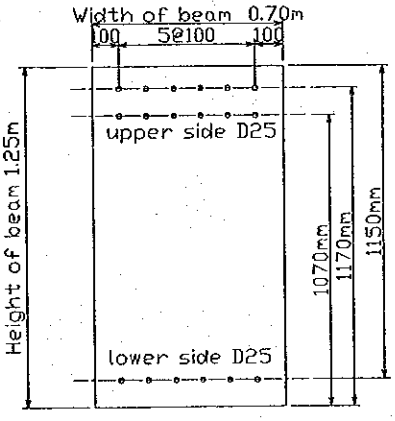
	unit	The vertical direction beam to the face line	The parallel direction beam to the face line
Vpd	kN	271.52	370.87
Vrd	kN	305.88	390.83
Vcd	kN	294.86	291.58
Vrcd	kN	11.18	0.0
Examination result γi・Vrd / Vrcd		6.686	Vpd > Vcd
Necessity for examination of shear reinforcement		with necessity	with necessity
α		0.771	0.771
k		0.12	0.12
diameter of reinforcing bar φ	mm	13	13
k0		1.0	1.0
design tensile strength of steel fud	N/mm²	466.67	466.67
design stress in shear reinforcement due to permanent load σwpd	N/mm²	71.53	70.68
fatigue life N	times	540,000	540,000
design fatigue strength for reinforcing bar fwrd		92.76	92.97
design stress in shear reinforcement due to variable load σwrd		38.63	41.70
Examination result γi・σwrd / (fwrd / b)		0.42 O.K	0.45 O.K

・Dimension of an examination section

The vertical direction beam to the face line



The parallel direction beam to the face line



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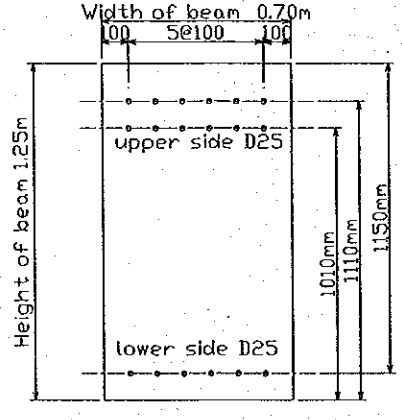
②Other beams (Cantilever (Beam 4)、Beam of the Direction of Slant (Beam 7)

	unit	Cantilever	Beam of the Direction of Slant
Vpd	kN	137.34	99.49
Vrd	kN	194.12	471.47
Vcd	kN	294.86	297.19
Vrcd	kN	75.43	94.67
Examination result γi・Vrd / Vrcd		2.573	4.980
Necessity for examination of shear reinforcement		with necessity	with necessity
α		0.771	0.771
k		0.12	0.12
diameter of reinforcing bar φ	mm	13	13
k0		1.0	1.0
design tensile strength of steel fud	N/mm²	466.67	466.67
design stress in shear reinforcement due to permanent load σwpd	N/mm²	32.54	48.59
fatigue life N	times	540,000	540,000
design fatigue strength for reinforcing bar fwrd		101.92	98.15
design stress in shear reinforcement due to variable load σwrd		14.61	57.75
Examination result γi・σwrd / (fwrd / b)		0.14 O.K	0.59 O.K

・Dimension of an examination section

Dimension of section of cantilever is the same as the vertical direction beam to the face line.

Beam of the Direction of Slant



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7） Design of Pile Head

Because the thickness of the concrete above the pile heads is small in pier, the embedment length of pile is calculated on the assumption that there is no punching shear of concrete and the loads are transmitted from the beams to piles only through the bonding between the pile circumference and concrete without assistance of shear strength of concrete against punching

（1） Section Force

Maximum axial force Sd = 1,084.0 kN

(Earthquake parallel direction to the face line)

Maximum pile head moment M_0 = 1,202.2 kN・m (Earthquake Sea→Land)

（2） Examination to pile head moment

The necessity embedding length to pile head moment computes from the following formulas.

$$L = \sqrt{(6 \times M_0 / (B \times f'ad))} \times \gamma b \times \gamma i$$

where L : necessity embedding length to pile head moment (mm)

M_0 : pile head moment (= 1,202,200,000 N・mm)

B : diameter of the pile (= 800 mm)

f'ad : design bearing strength of superstructure

(The same value as the design compression strength of concrete)

(= 24 / 1.3 = 18.46 N/mm^2)

γb : member factor (=1.15)

γi : structure factor (=1.0 (earthquake condition))

$$L = \sqrt{(6 \times 1{,}202{,}200{,}000 / (800 \times 18.46))} \times 1.15 \times 1.0 = 803.7 \text{ mm}$$

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(3) Examination to axial force

The necessity embedding length to axial force computes from the following formulas.

$L = P / (\phi \times fbod / \gamma b)$

where P : calculated value of axial force acting on pile in design
(=Sd=1,084,000 N)

ϕ : outer perimeter of the cross section of pile (diameter : 800 mm)

fbod : design bond strength between the pile and concrete
$(=0.11 \times f'ck^{2/3} / \gamma c = 0.11 \times 24^{2/3} / 1.3 = 0.704\ N/mm^2)$

f'ck : characteristic compressive strength of concrete

γc : material factor for concrete

γb : member factor

$L = 1,084,000 / (800 \times \pi \times 0.704 / 1.0) = 612.7$ mm

(4) Determination of the embedding length of piles

The embedding length to superstructure of a steel pipe pile does as follows from the above-mentioned examination result.

L = 850 mm

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8) Examination of welding of reinforcing bar and steel pipe pile

The lower reinforcing bar of a beam is welded to the plate attached in the steel pipe pile. The diameter and number of lower reinforcing bar of the parallel and vertical directions beam to the face line are as follows.

Diameter : D25 、 Number : 6 pieces

(1) Examination of thickness of plate

The thickness (t) of a plate is calculated by the following formula.

$t = T / (L \times \tau_{ta})$ (mm)

where T : Action tension (N)

$T = As \times \sigma_{sa} \times n$

As : cross-section area of reinforcing bar (mm^2) (D25 As = $506.7mm^2$)

σ_{sa} : allowable stress of reinforcing bar (SD345 : =176 N/mm^2)

n : number of reinforcing bar (=6 pieces)

L : Welding length of a plate

τ_{ta} : allowable tensile stress for steel at welded zone

(SM490 =140 N/mm^2)

・Welding length of a plate

The outer perimeter of steel pipe pile is 800mm, and a plate is divided into four.

$L = \pi \times 800 / 4 = 628$ m

・Action tension

$T = 506.7 \times 176 \times 6 = 535{,}075$ N

・Thickness of plate

$t = 535{,}075 / (628 \times 140) = 6.1$ mm → 9.0mm

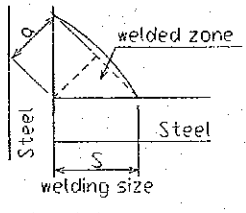
(2) Examination of the welding of steel pipe pile and a plate

Welding size is made into what satisfies the following formulas.

$\tau_{ts} = T / (a \times L) \leqq \tau_{ta}$

The sign of an upper formula is shown in the right figure.

where $a = 0.7 \times a$



Welding size is set to 9mm.

$\tau_{ts} = 535{,}075 / (0.7 \times 9 \times 628) = 135.2$ $N/mm^2 \leqq 140$ N/mm^2 O.K

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(3) Examination of the welding of a plate pile and reinforcing bar

The welding length of reinforcing bar computes by the following formulas.

$$l = \sigma_{sa} \times As / (\sqrt{2} \times \lambda \times \tau_{sa})$$

where λ : welding size (=D / 3 D : diameter of reinforcing bar)

τ_{sa} : allowable shearing stress for steel at welded zone (= 80 N/mm^2)

$$l = 176 \times 506.7 / (\sqrt{2} \times (25 / 3) \times 80) = 94.6 \text{ mm}$$

Therefore, welding length is set to $l = 100$ mm.

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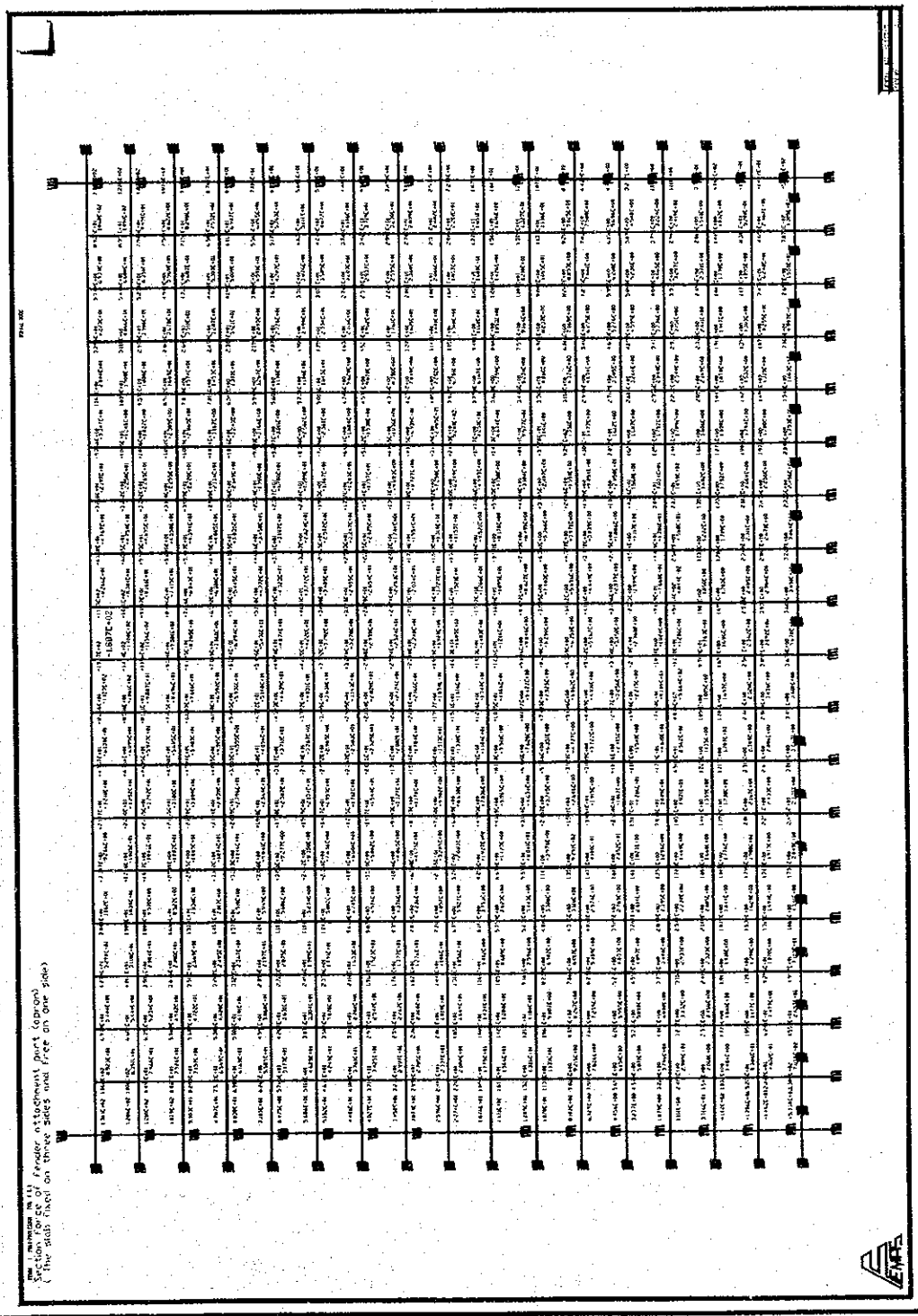
<Appending Data>

Section Force of Fender attachment part (apron)

(1) The case where Reaction force of the fender acts on lower end (Bending Moment)



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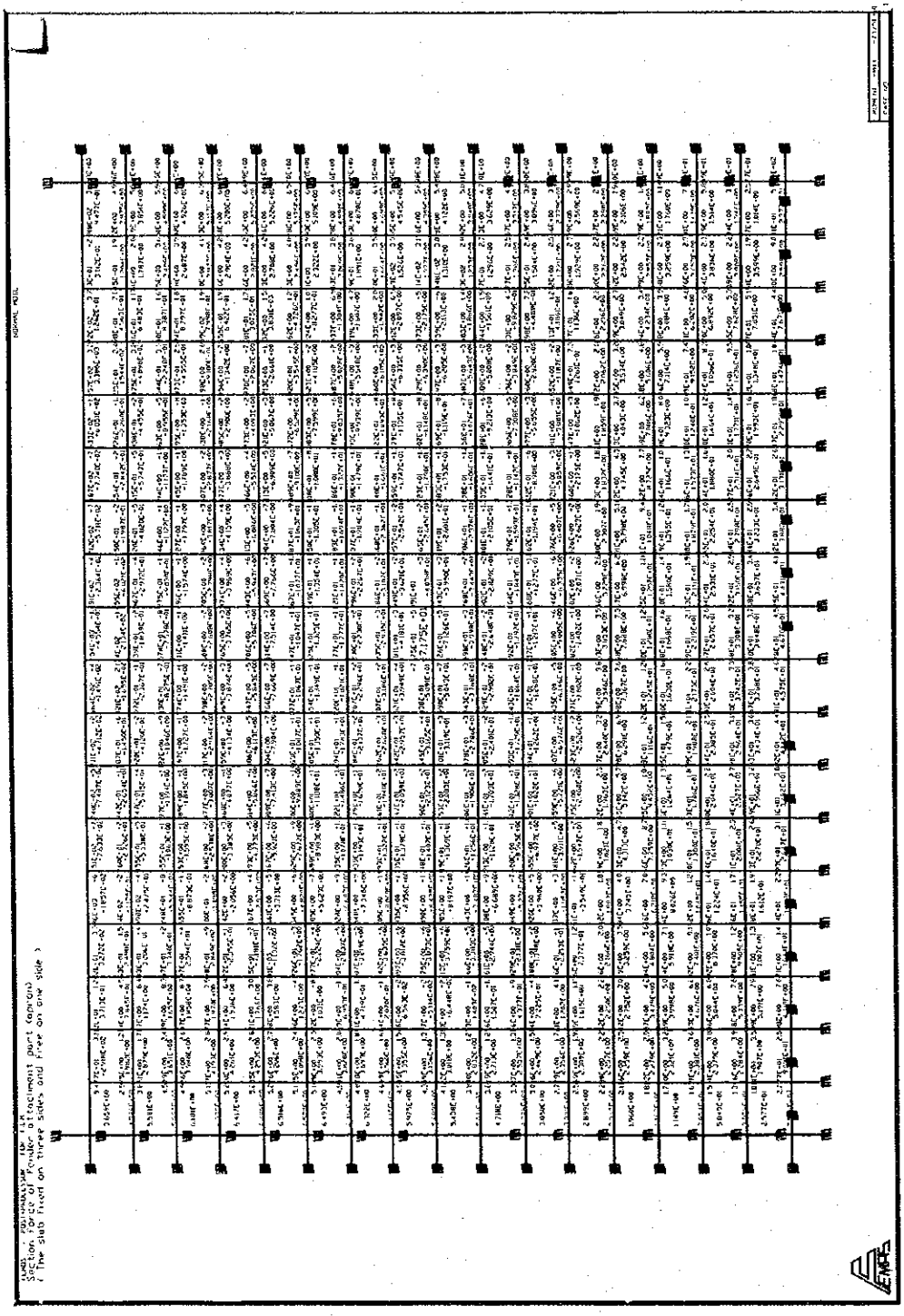
(2) The case where Reaction force of the fender acts in the center

(Bending Moment)



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	Y. Ando	R. NISHIMURA
	26/07/2002	08/08/2002