

# 材料強度設計第13時間目

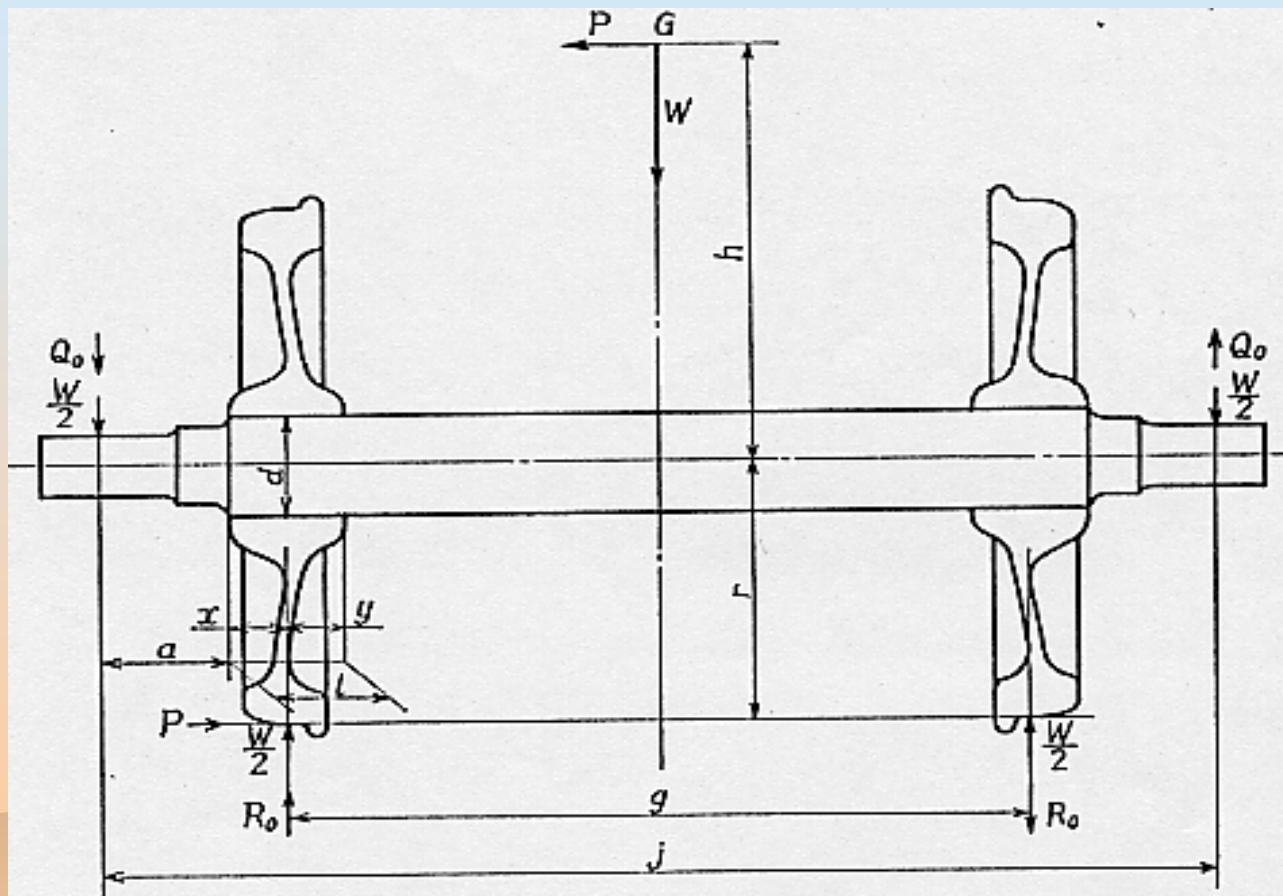
1. 鉄道用車軸の設計基準
2. リニアモーターカー用台車、  
部品の設計製作
3. 鍛鋼ブレーキディスクの開発



# 鉄道車両用車軸の強度設計方法

- ⌘ JIS E4501, 日本工業規格、鉄道車両用車軸の強度設計方法
- ⌘ 強度計算上考慮する事項：1軸上の重量、上下付加力と水平付加力、応力の割り増し係数、輪座（車輪がはめ合いされる部位）の疲れに対する許容応力、疲れ安全率などが規定されている。

# 記号



備考 図中の記号は、表1と対応する。

# 計算

$$Q_0 = \frac{h}{j} P$$

$$R_0 = \frac{h + r}{g} P$$

$$P = \alpha_L \cdot W$$

$$y = \alpha + l - \frac{j - g}{2}$$

$$l = x + y$$

$$M_1 = \frac{j - g}{4} W \dots\dots\dots$$

$$M_2 = \alpha_V \cdot M_1 \dots\dots\dots$$

$$M_3 = P \cdot r + Q_0(\alpha + D) - R_0 \cdot y \dots\dots\dots$$

$$\sigma_b = \frac{m(M_1 + M_2 + M_3)}{Z} \dots\dots\dots$$

$$n = \frac{\sigma_{Wb}}{\sigma_b} \dots\dots\dots$$



# 鉄道システム

表 2 上下付加力及び水平力の一軸上の重量に対する割合

鉄道システム	適用区分	$V$ km/h	$\alpha_V$	$\alpha_L$
システム 1	—	150 を超え 280 以下	$0.0027V$	$0.030+0.00085V$
システム 2	A	60 を超え 130 以下	$0.0027V$	$0.040+0.0012V$
		60 以下	0.16	0.11
	B	60 を超え 130 以下	$0.0052V$	$0.060+0.0018V$
		60 以下	0.31	0.17

# 疲労強度

表 3

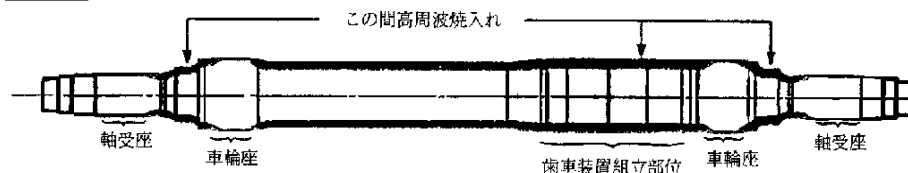
単位  $\text{kgf/mm}^2$  {MPa}

車軸の種類	$\sigma_{\text{Wb}}$
1 種	10.0 {98.1}
2 種	10.5 {103}
3 種	11.0 {108}
4 種	15.0 {147}

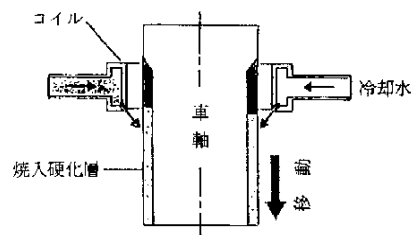
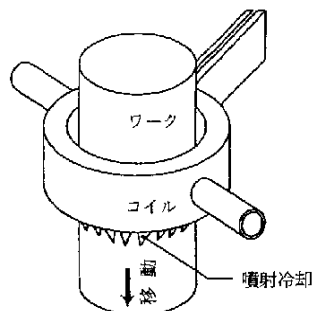


# 新幹線車軸の高周波焼き入れ

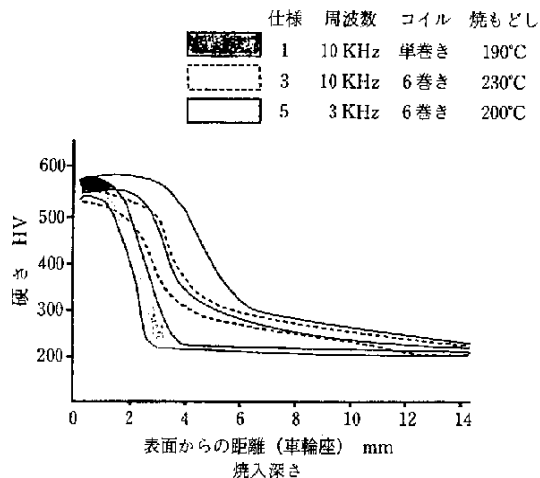
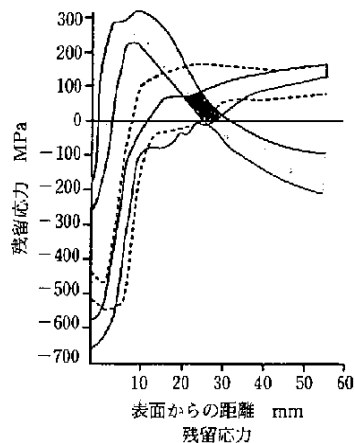
焼入部位



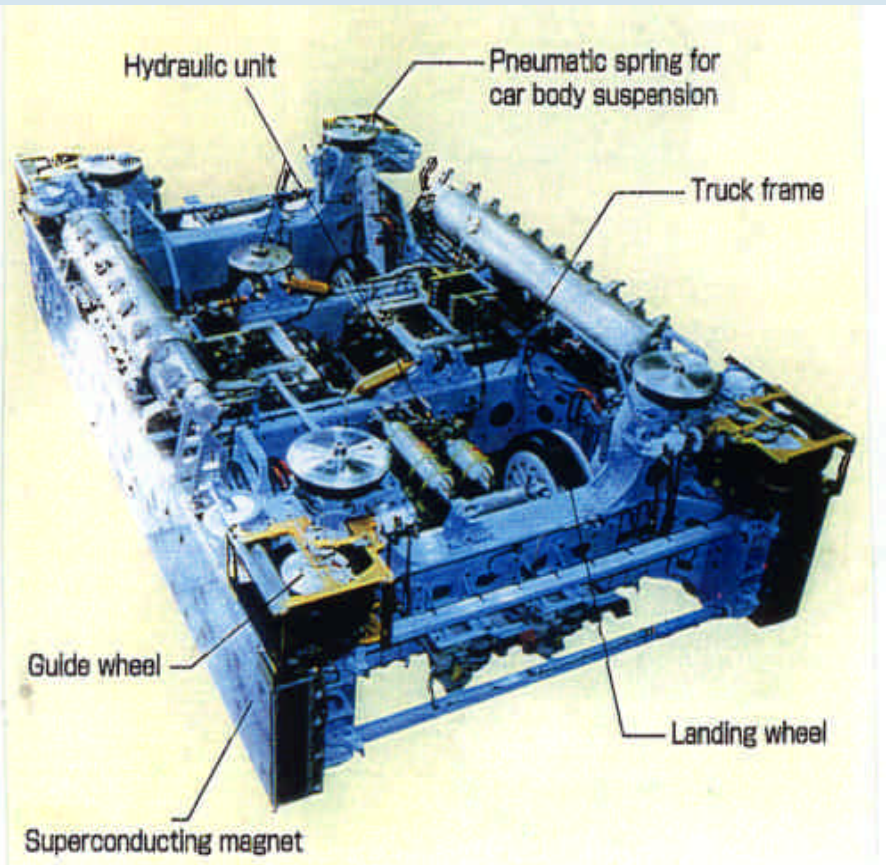
焼入方法



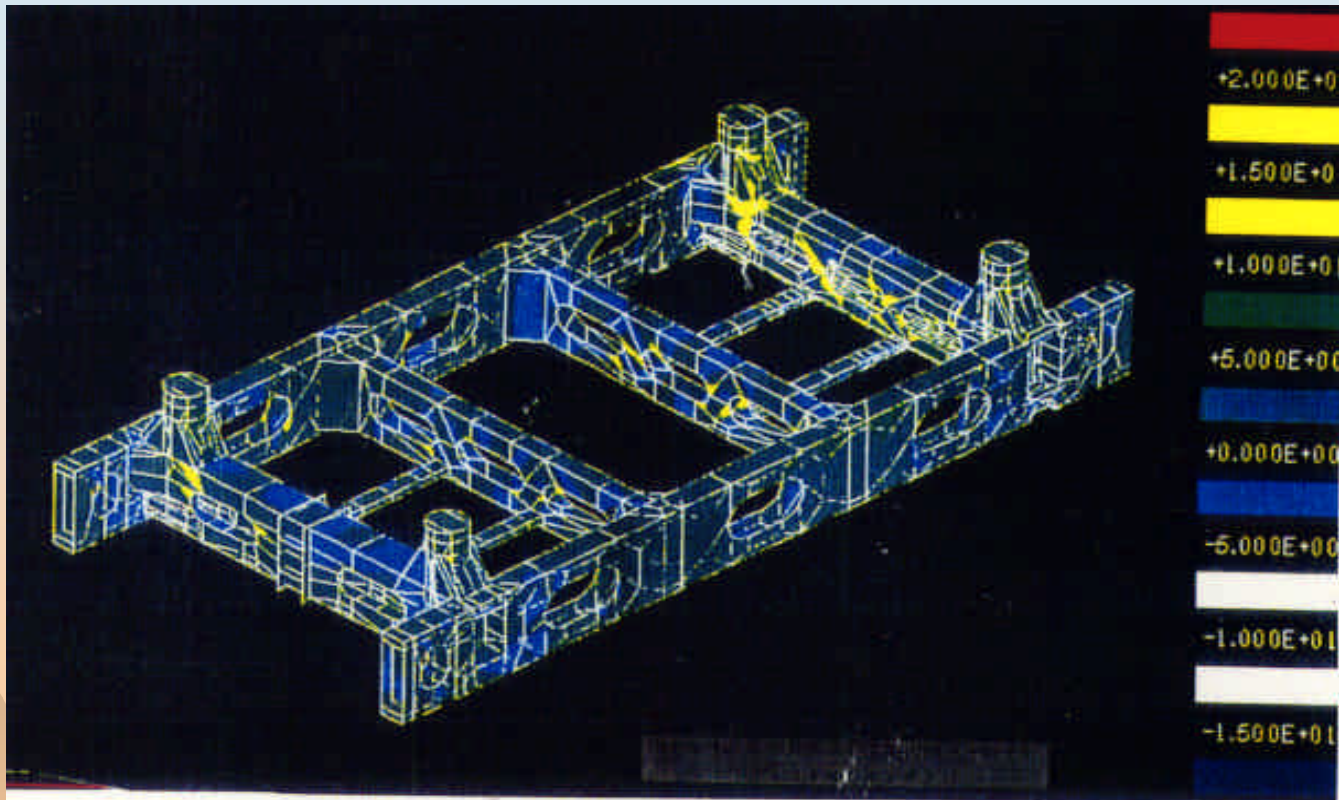
焼入条件と硬化深さ・残留応力の関係一例



# 浮上式鐵道車兩用台車



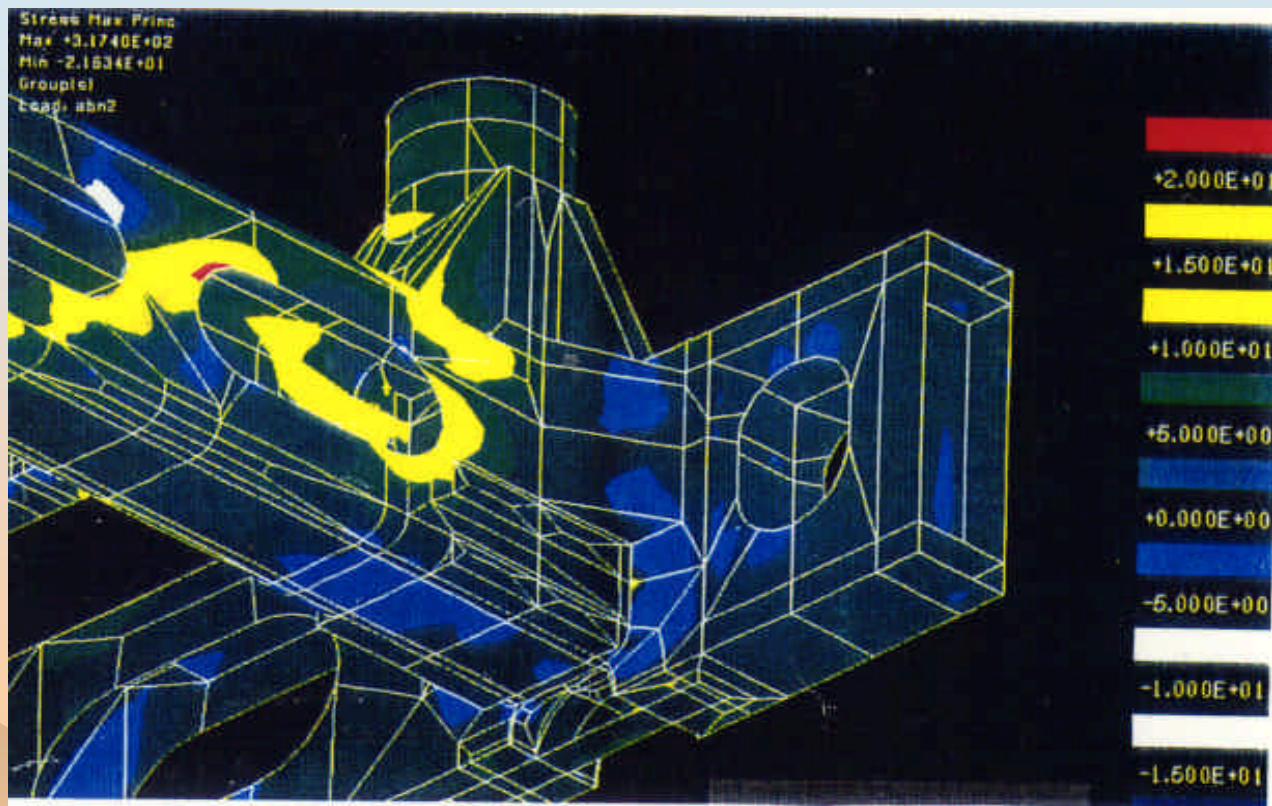
# アルミ台車枠の解析-1



(1) 全体図 (フリンジ図)

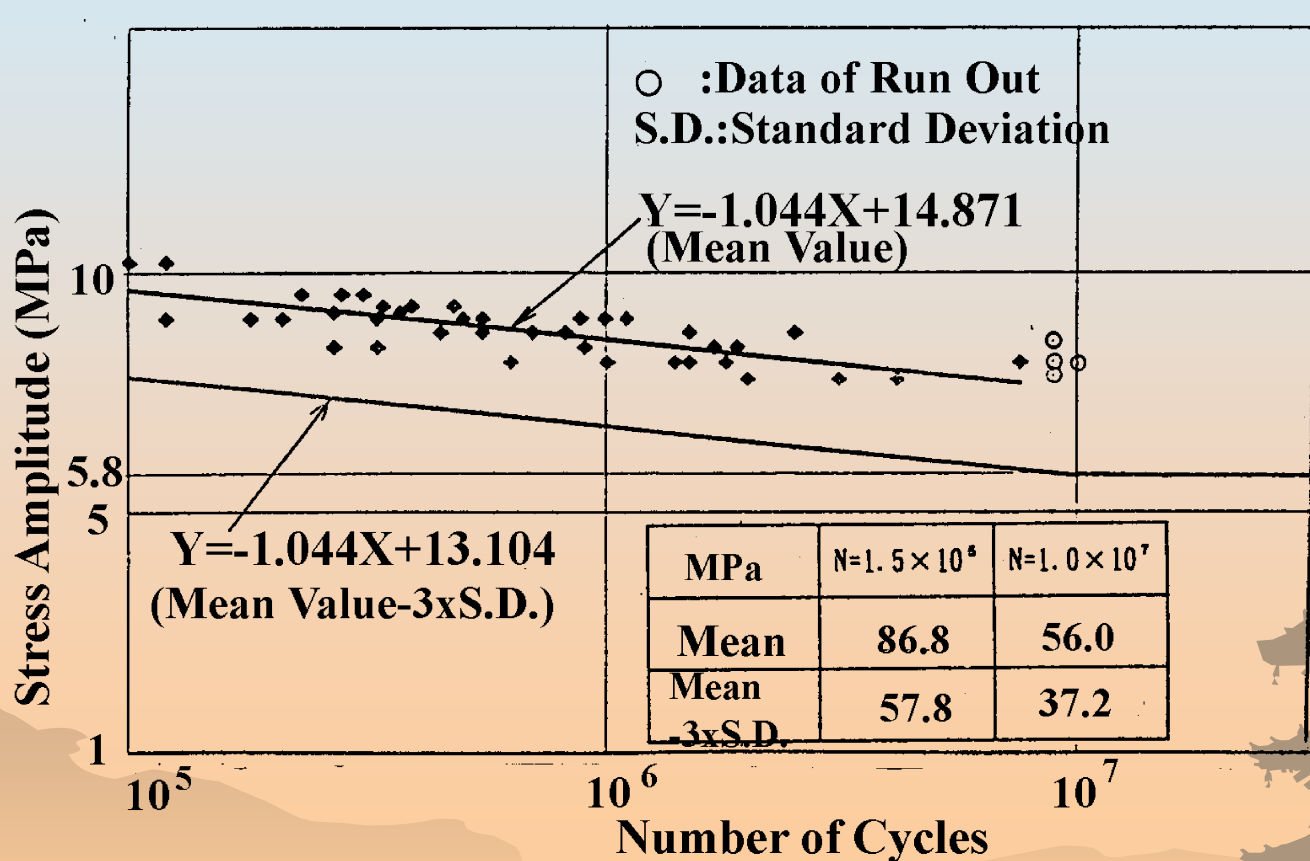


# アルミ台車枠の解析-2

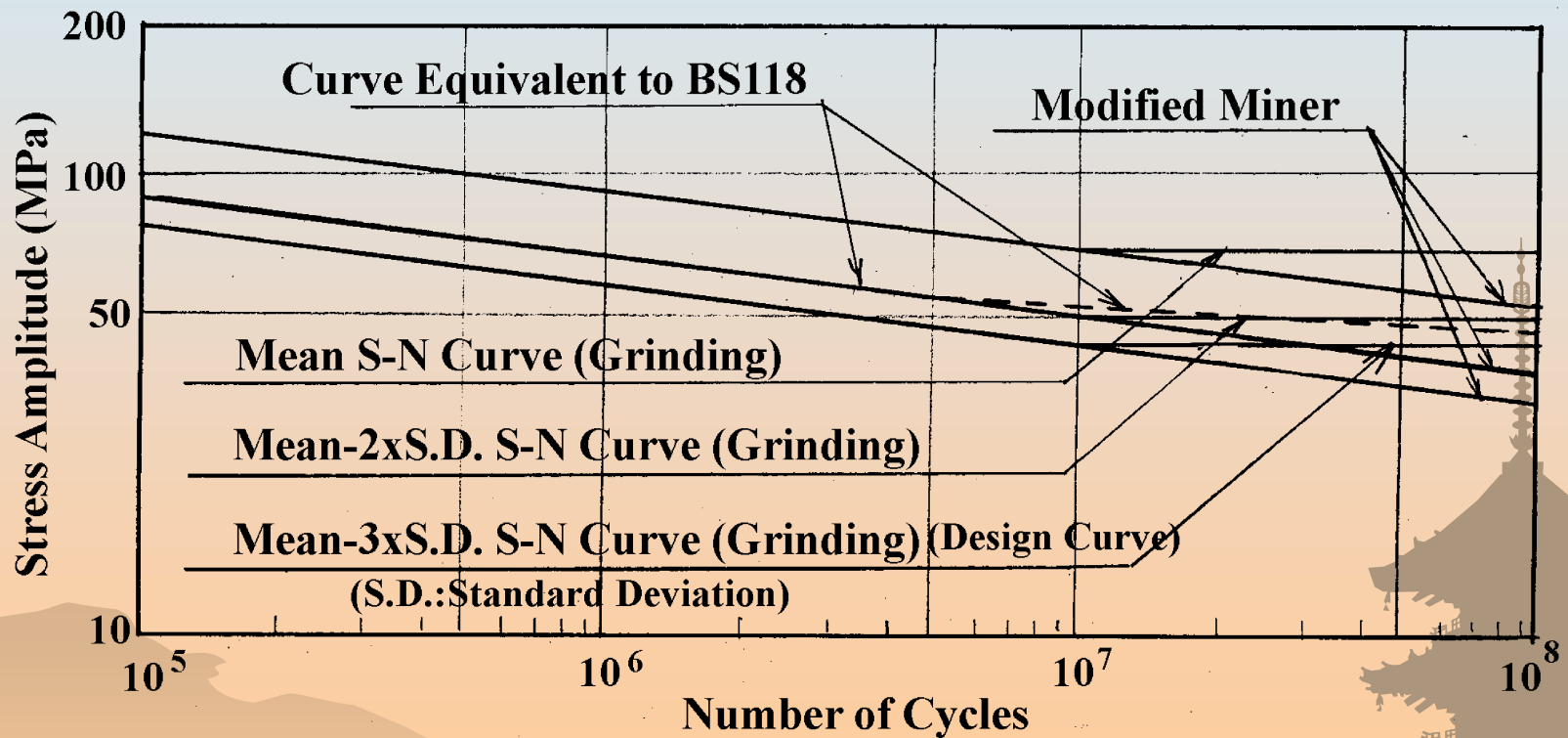


(2) 4隅ブラケット部拡大図 (フリンジ図)

# アルミ継ぎ手の疲労試験結果

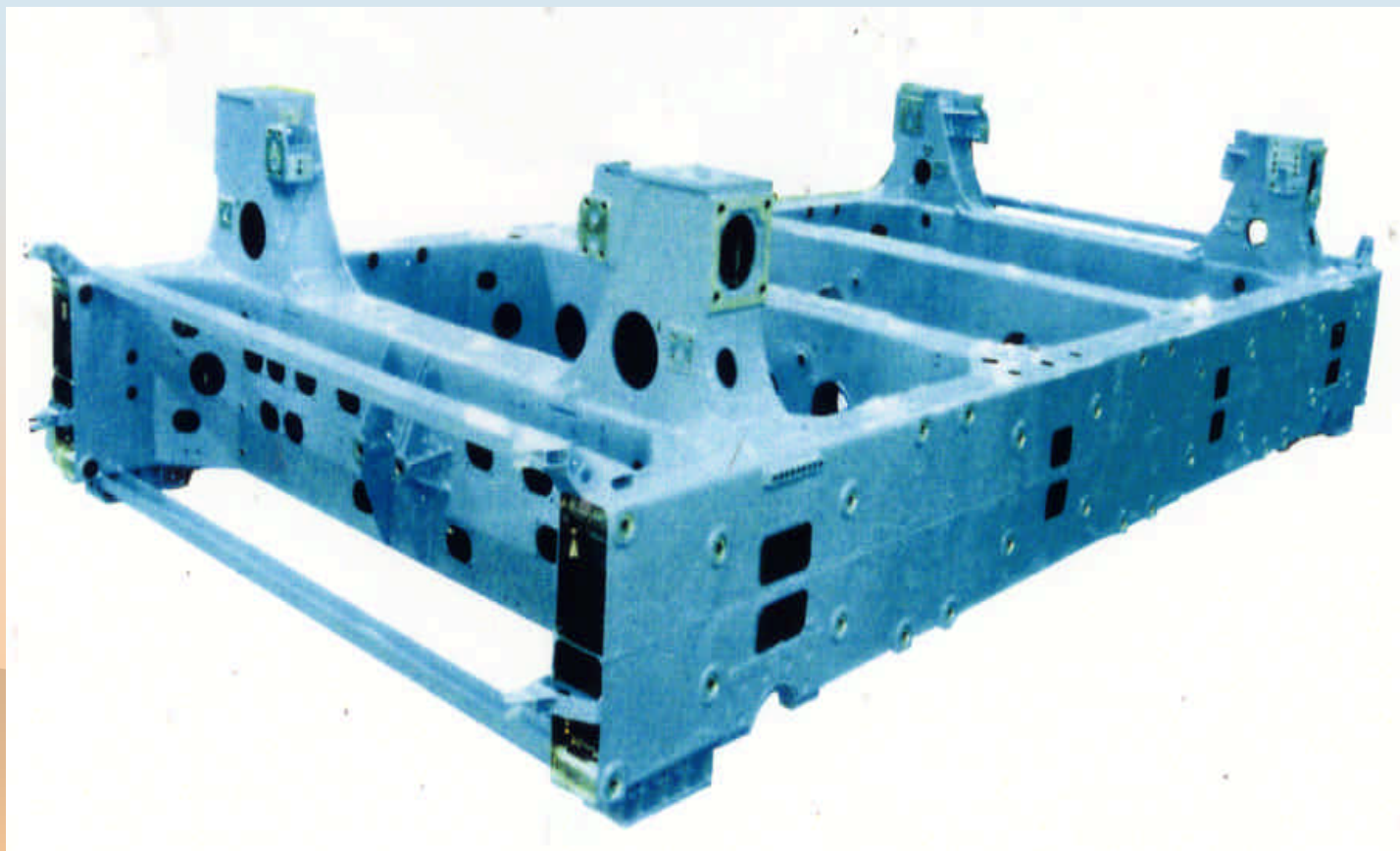


# 設計基準

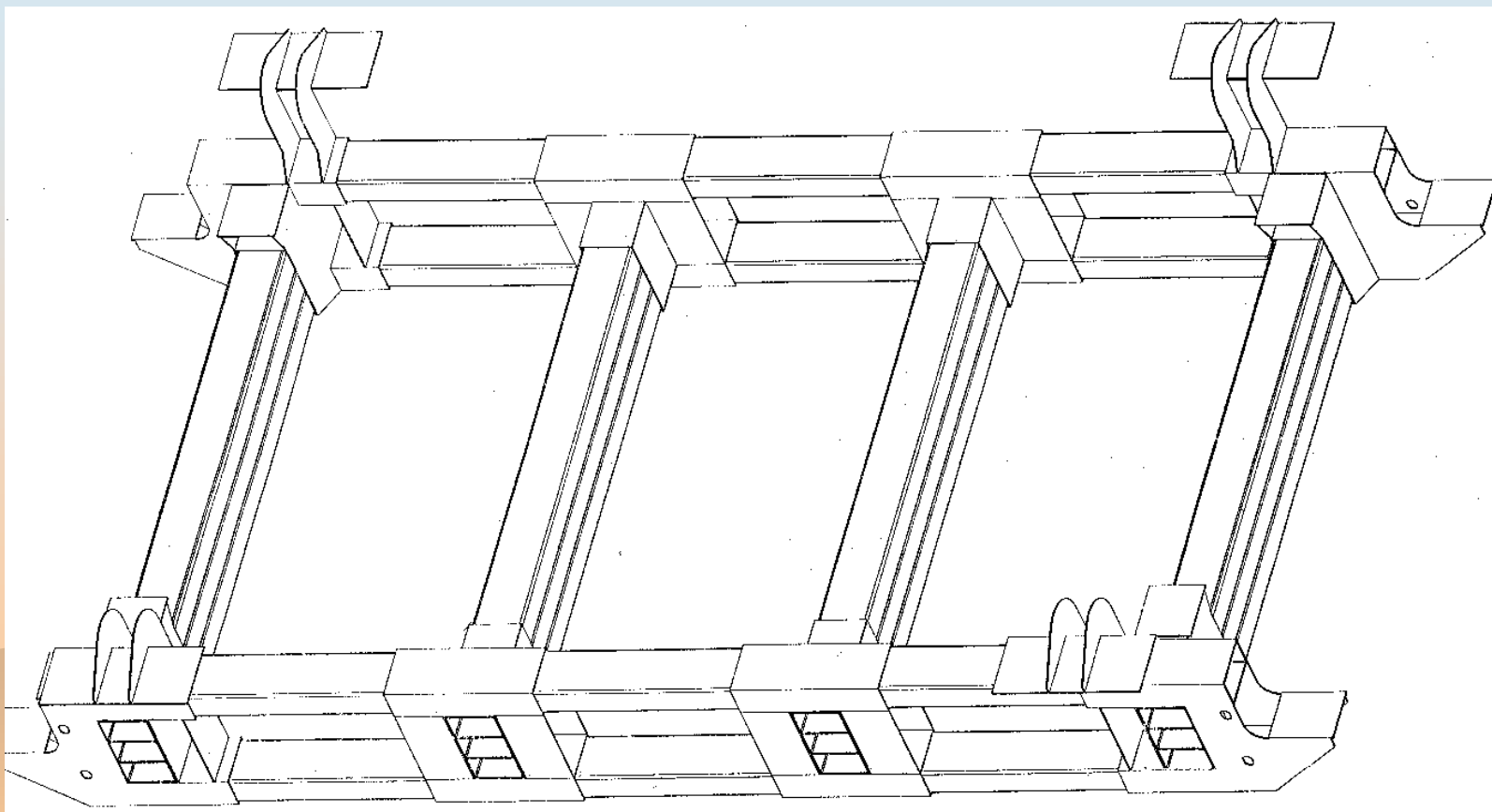




# 製作したアルミ台車枠



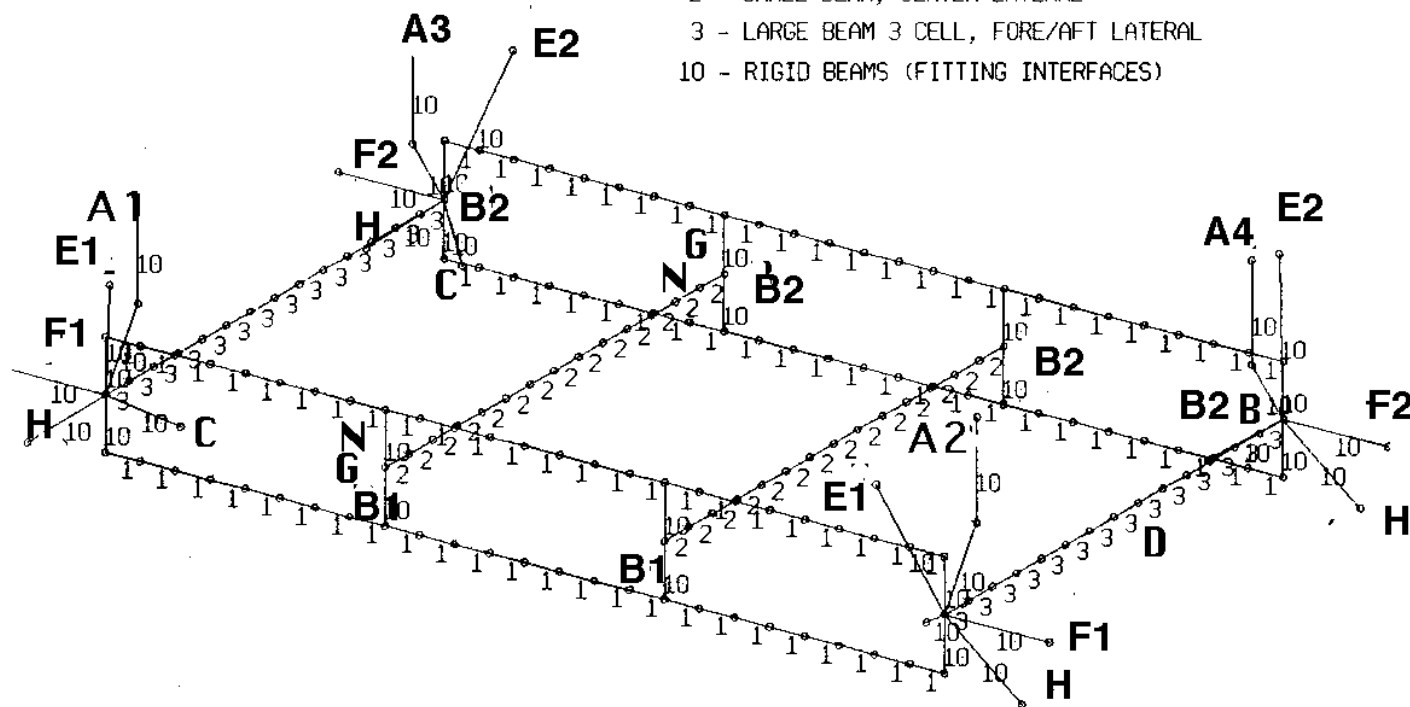
# FRP+アルミジョイントの台車枠



# ビーム解析

BEAM PROPERTY IDENTIFICATION NUMBERS:

- 1 - SMALL BEAM, LONGITUDINAL
- 2 - SMALL BEAM, CENTER LATERAL
- 3 - LARGE BEAM 3 CELL, FORE/AFT LATERAL
- 10 - RIGID BEAMS (FITTING INTERFACES)

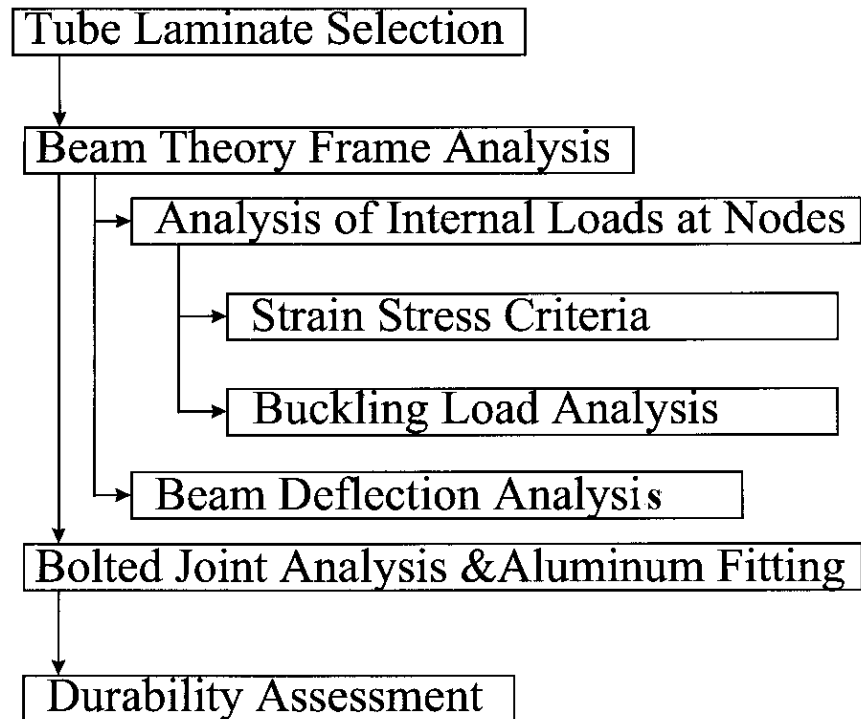


Case Loading Locations		Pattern 1	Pattern 2	Pattern 3	Pattern 4
		Normal Gears*1	Normal SCM*2	Abnormal Gears*1	Abnormal SCM*2
A1/A2/A3/A4:Secondary Air Suspension, Guide Gear, Damper, Stopper	X	+9/-9/-9/+9	+9/-9/-9/+9	+15/-15/-15/+15	+9/-9/-9/+9
	Y	+27/+20/R/R	+17/+8/+8/+17	+50/+41/R/R	+25/+16/+16/+25
	Z	-51	-51	-57	-51
B1/B2: SCM Support Link	X	/	0	/	0
	Y		+12/R		+68/0
	Z		0		-8/0
C: Landing Gear	X	0	/	0	/
	Y	0		0	
	Z	R		R	
D: Anchor to Car Body	X	R	R	R	R
	Y	0	0	0	0
	Z	-4	-4	-11	-4
E1/E2: Primary Upper Air Suspension	X	0	0	0	0
	Y	0	0	0	0/R
	Z	+5	R	+5	+72/+10
F1/F2: Primary Lower Air Suspension	X	0	0	0	0
	Y	0	0	0	0
	Z	-19	-19	+19	-19/-73
G: Anchors to SCM	X	+24	+24	+66	+24
	Y	0	0	0	0
	Z	0	0	0	0
H: Emergency Loading Gear Load	X	/	/	/	0
	Y				0
	Z				R

\*1: Running by landingh gears, \*2: Running by superconductivity magnets(SCM)

R=Reaction Force, Unit of Maximum Load=kN

# 解析プロセス



# FRPの構成

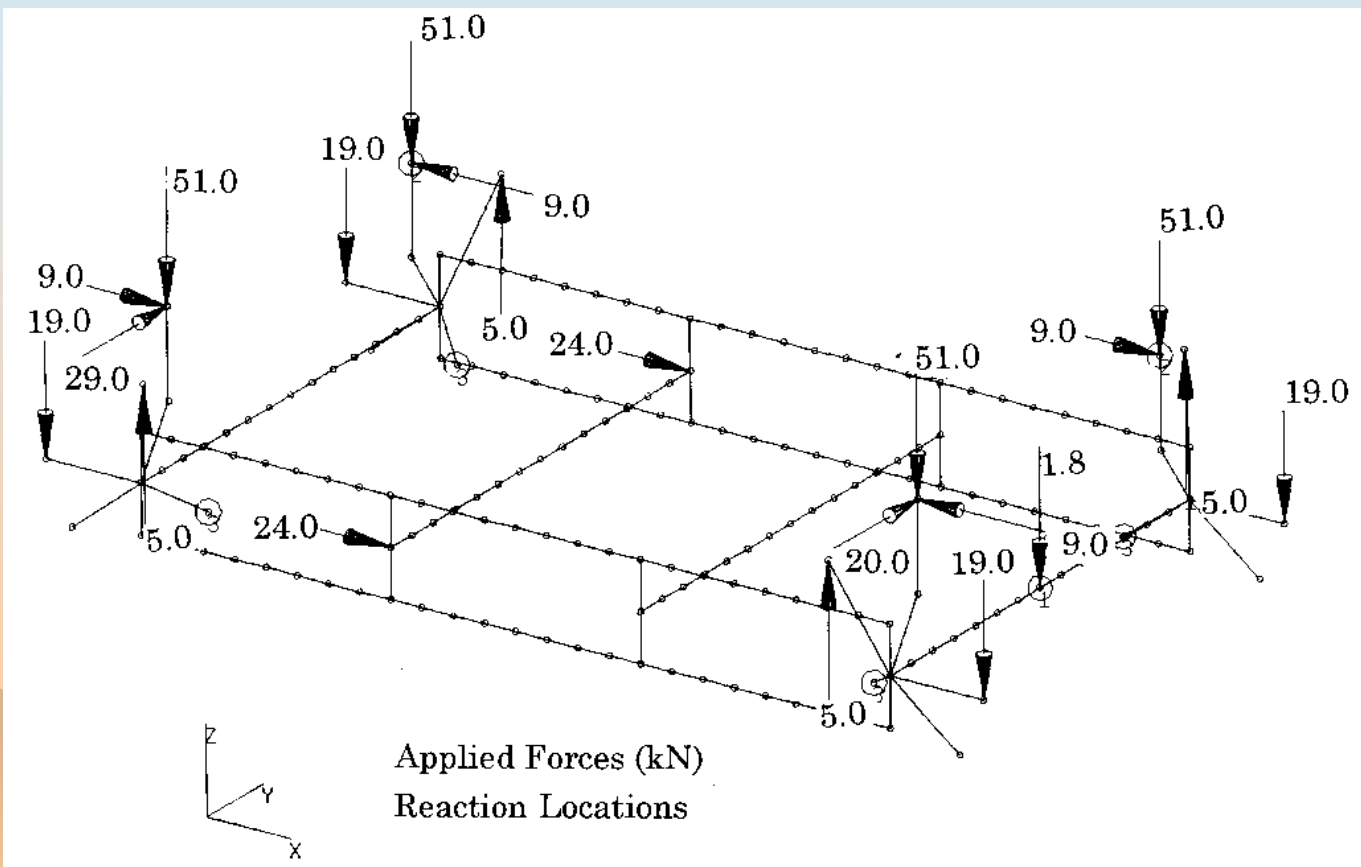
**Laminate: ( 0° / ±45° / 90° ) : ( 50% / 33% / 17% )**

Ply	Orientation	Fiber Areal Weight g/m <sup>2</sup>	Thickness mm	Target Fiber Volume
Polyester Veil	-	25	.038	.515
Eglass Mat	Random	153	.114	.515
Carbon	+45°/-45°/0°	180/180/383	.765	.54
Carbon	90°/+45°/-45°/0°	183/180/180/383	.953	.54
Carbon	90°/0°	183/288	.485	.54
Carbon	0°/90°	288/183	.485	.54
Carbon	0°/+45°/-45°/90°	383/180/180/183	.953	.54
Carbon	0°/+45°/-45°	383/180/180	.765	.54
Eglass Mat	Random	153	.114	.515
Polyester Veil	-	25	.038	.515
Total		Carbon 4280 Glass 306	4.710	-

# FRPの強度

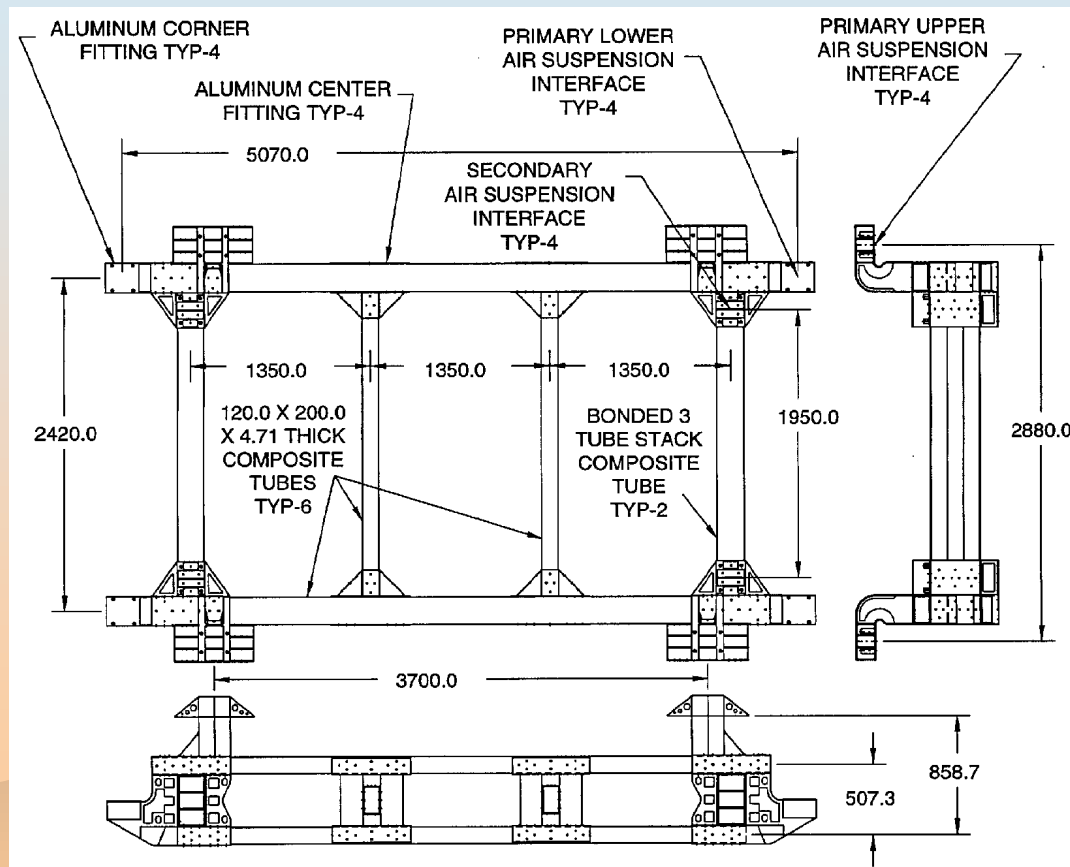
MATERIAL DIRECTION	LIMIT*		ULTIMATE**	
	STRAIN	STRESS (MPa)	STRAIN	STRESS (MPa)
E1	.0035/- .0027	-- / --	.0100/- .0077	-- / --
E2	.0035/- .0027	-- / --	.0100/- .0077	-- / --
E3	-- / --	12.4/-41.4	-- / --	38.6/-124.1
G12	.0054	--	.0154	--
G23	--	12.4	--	38.6
G13	--	12.4	--	38.6
V12	--	--	--	--
V23	--	--	--	--
V13	--	--	--	--
$\alpha 1$				
$\alpha 2$				
$\alpha 3$				
BEARING	--	144.0	--	414.0
* - Repeated Loading (Wet)      Material Type = Carbon/Glass 9310/9360 ** - Static Loading (Wet)        Density = 1.50 g/cc 1 - In plane direction            Fiber Volume = 54% 2 - In plane direction            Process = Pultrusion 3 - Out of plane direction        Environmental Condition = Wet				

# ひずみ解析モデル





# 台車枠寸法

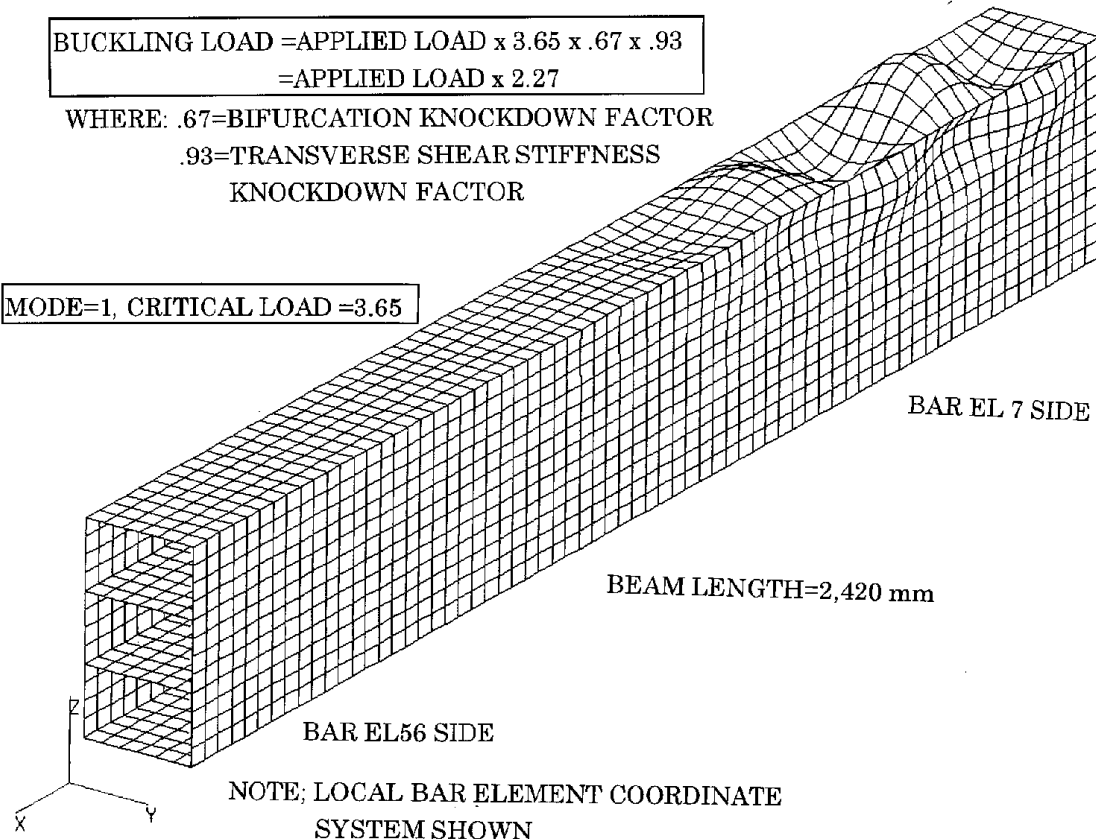


# 挫屈解析

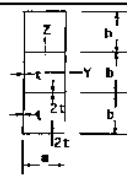
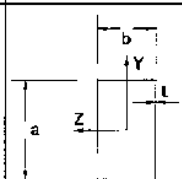
$$\begin{aligned}\text{BUCKLING LOAD} &= \text{APPLIED LOAD} \times 3.65 \times .67 \times .93 \\ &= \text{APPLIED LOAD} \times 2.27\end{aligned}$$

WHERE: .67=BIFURCATION KNOCKDOWN FACTOR  
.93=TRANSVERSE SHEAR STIFFNESS  
KNOCKDOWN FACTOR

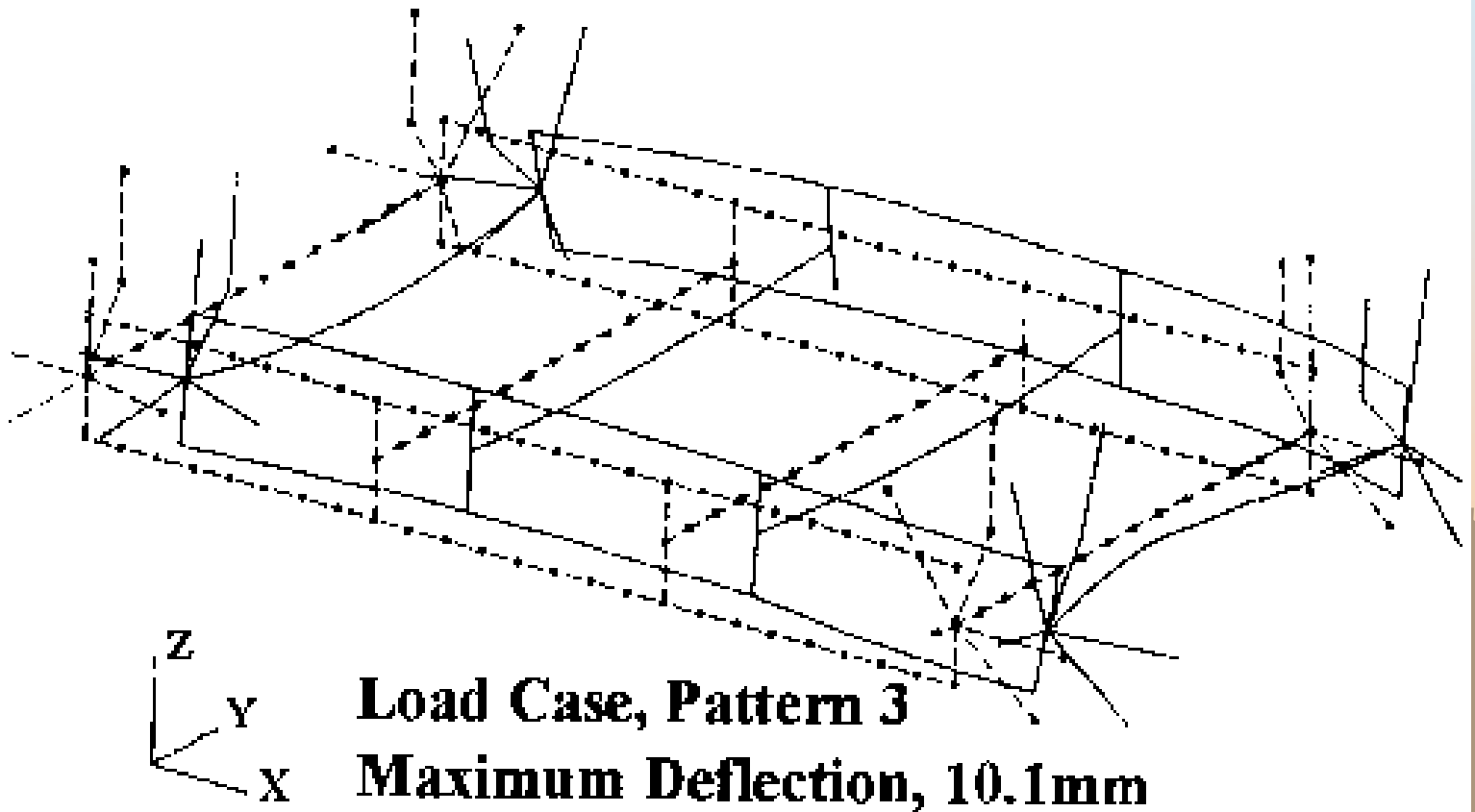
MODE=1, CRITICAL LOAD =3.65



# 荷重、モーメント解析結果

	Notation	Large 3-Cell Beam	Small Beam Lateral
Size (mm)	a	195.3	195.3
	b	120.4	115.3
	c	4.7	4.7
Force (kN)	Fx:Limit	29.6	12.0
	Fx:Ultimate	119.3	42.5
	Fy:Limit	25.5	0.4
	Fy:Ultimate	68.5	0.4
	Fz:Limit	8.4	0.06
	Fz:Ultimate	27.0	4.0
Moment (m.kN)	Mx:Limit	0.6	0.03
	Mx:Ultimate	0.9	0.04
	My:Limit	37.7	0.2
	My:Ultimate	105.2	4.9
	Mz:Limit	20.6	1.6
	Mz:Ultimate	56.7	3.3
			

# 变位解析



# 安全率結果

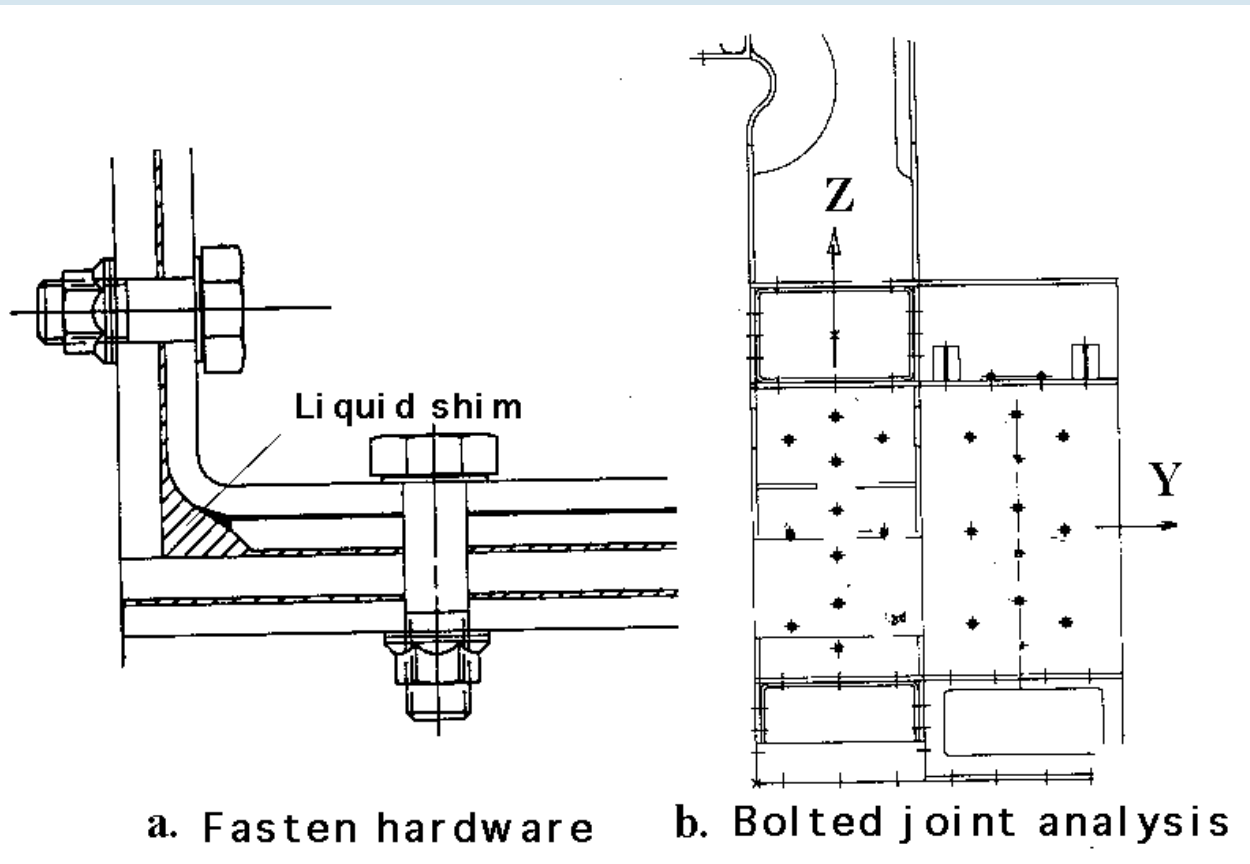
		Large Beam	Small Beam
Static Strength	Limit	+3.5	+2.4
	Ultimate	+3.3	+2.8
Crippling	Ultimate *	+0.39	+0.10
Buckling	Approxiamte	+0.18	-0.05 to +0.11
	FEM	+1.27	0.71
Bearing Strength	Limit	+0.42	Larger than
	Ultimate	+0.41	Large Beam

Unit: Margin of Safety Factor

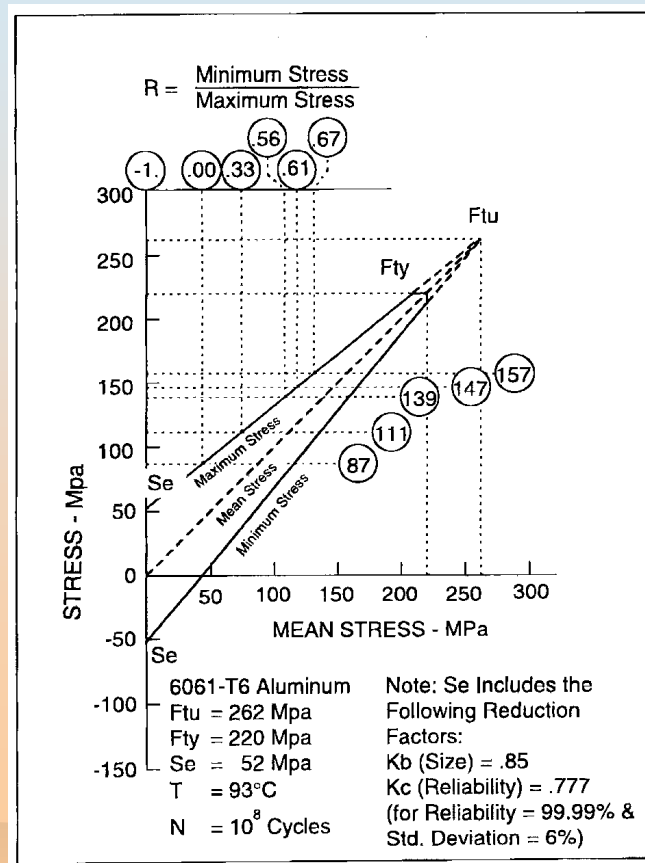
\*: One Edge Free Condition



# ジョイント部の解析



# 疲劳设计基準

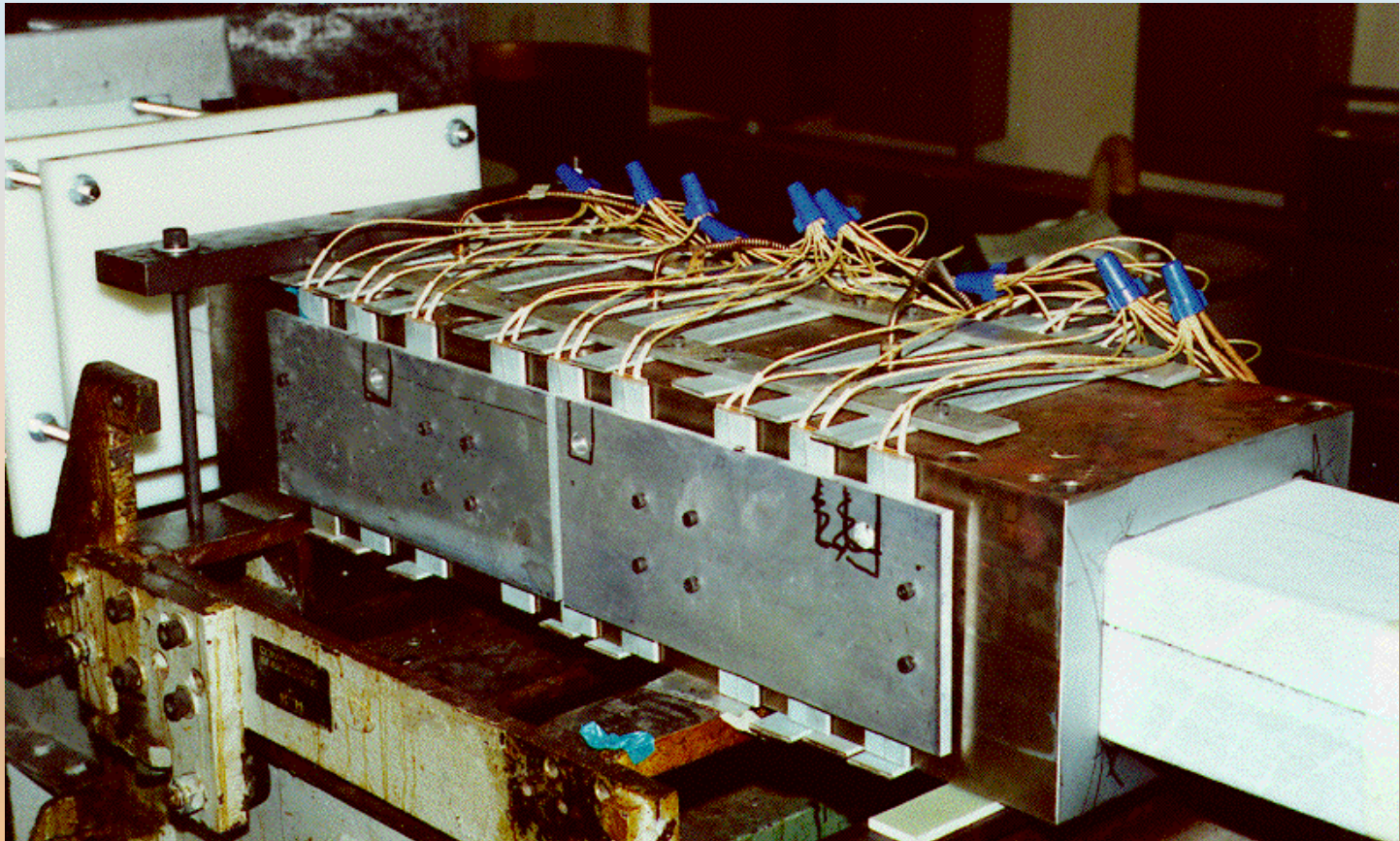


# ジョイント解析結果

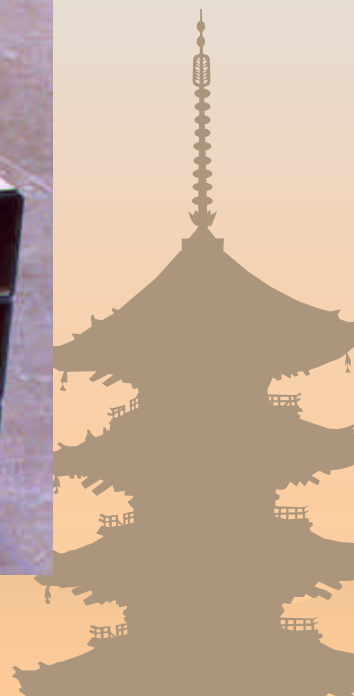
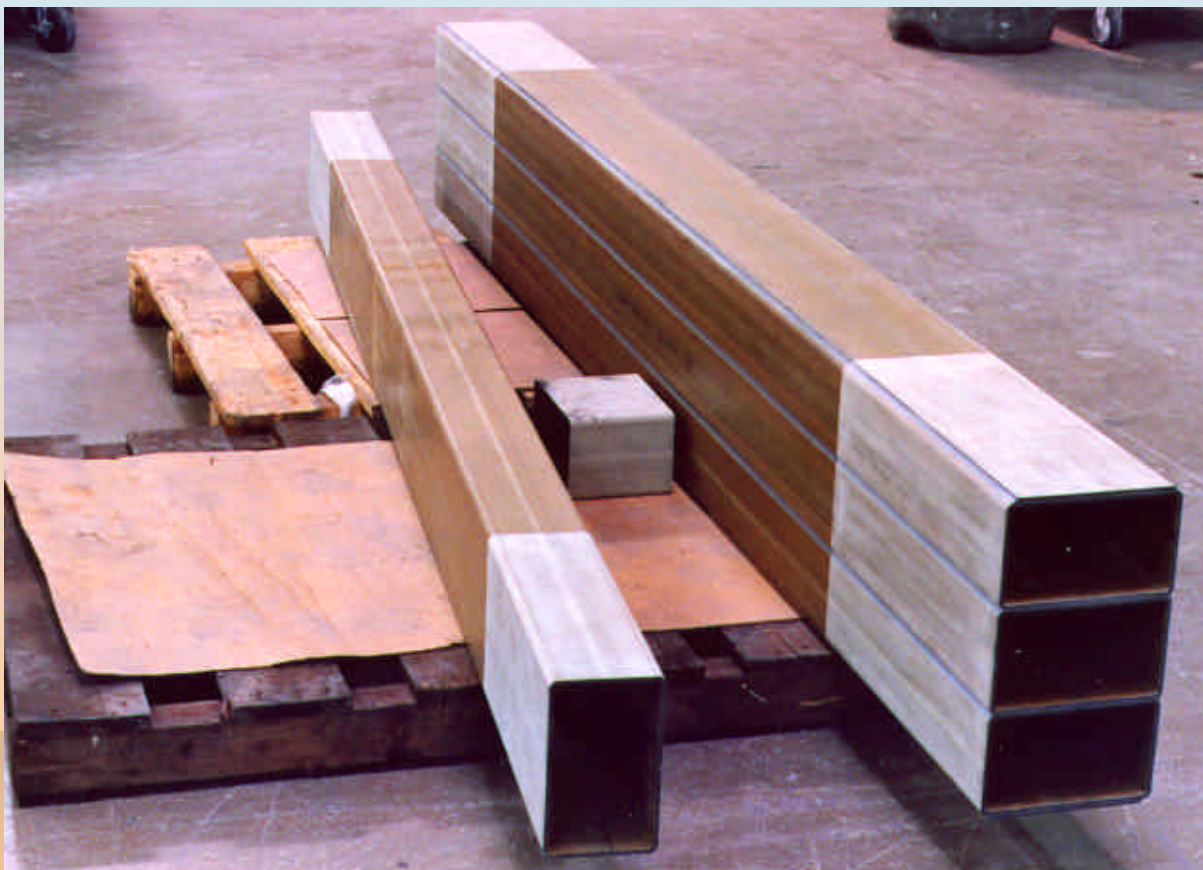
	Fitting Type	Wall Thickness / Hole Diameter mm	Max Stress $\sigma_{max}$ MPa	Stress Conc. Factor $K_t$	Stress Ratio $R = \sigma_{min}/\sigma_{max}$	Margin of Safety
Weld on Basic Wall	Corner	6.35 / --	67.7	1.4	.56	+1.05
	Center	4.76 / --	14.8	1.4	.56	+8.39
Bypass Load on Open Holes	Corner	6.35 / Ø9.53	79.1	2.5	.33	+40
	Center	4.76 / Ø9.53	17.3	2.5	.33	+5.42
Bearing Load Resulting in Peak Net Tensile Stress at Open Hole	Corner	6.35 / Ø9.53	77.6	1.2	.61	+89
	Center	4.76 / Ø9.53	18.1	1.2	.61	+7.12
Combined 1/2 Bypass and Full Bearing Load on Hole	Corner	6.35 / Ø9.53	--	--	--	+12
	Center	4.76 / Ø9.53	--	--	--	+4.00
Upper Air Spring Hook Radius	Corner	--	97.9	1.0	.67	+60



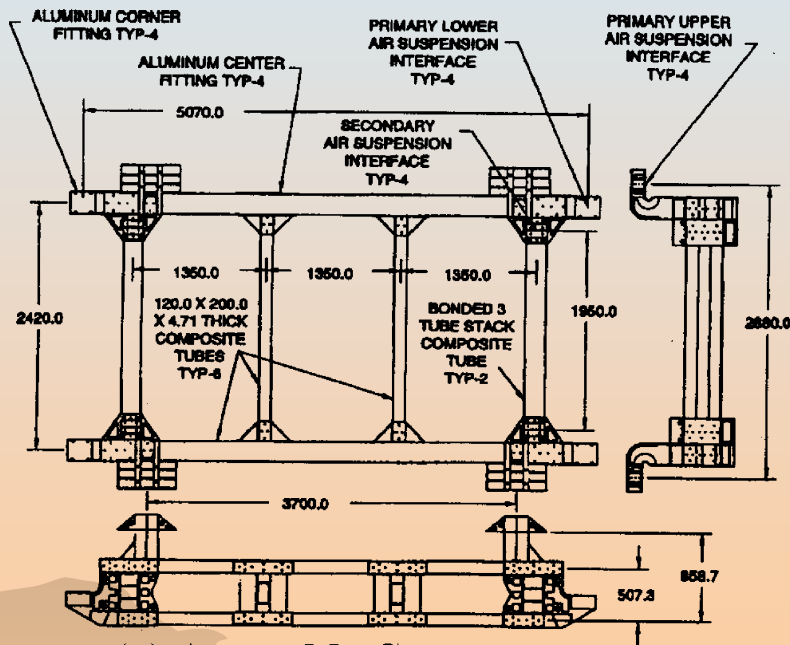
# 引き抜きFRPの製造



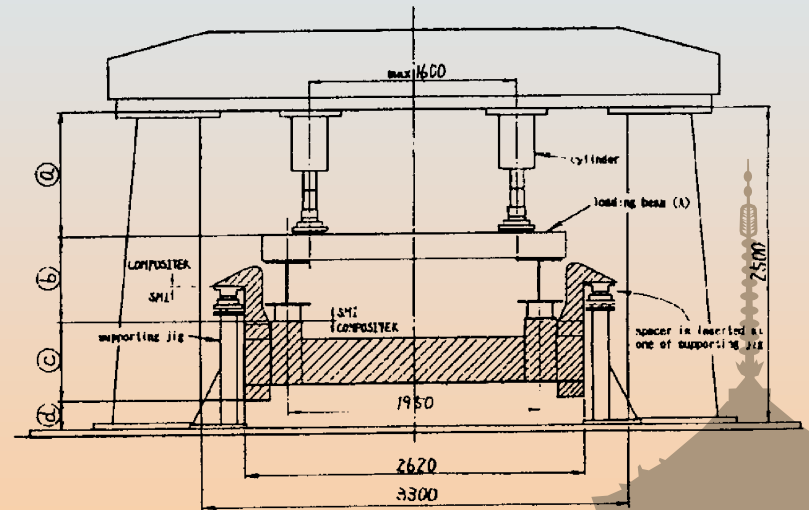
# 引き抜きFRP



# 疲労試験方法



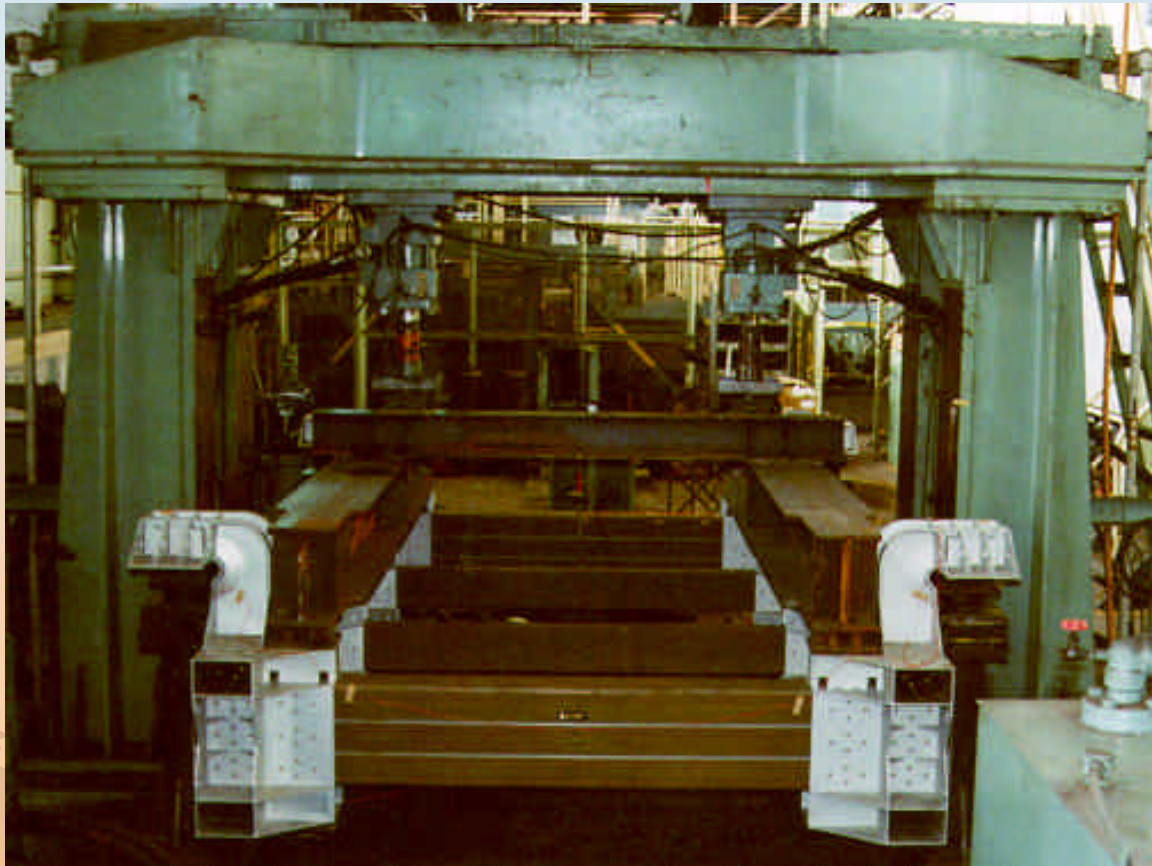
(a) Assembly Structure



(b) Test Rig



# 疲労試験セットアップ



# ひずみ測定結果

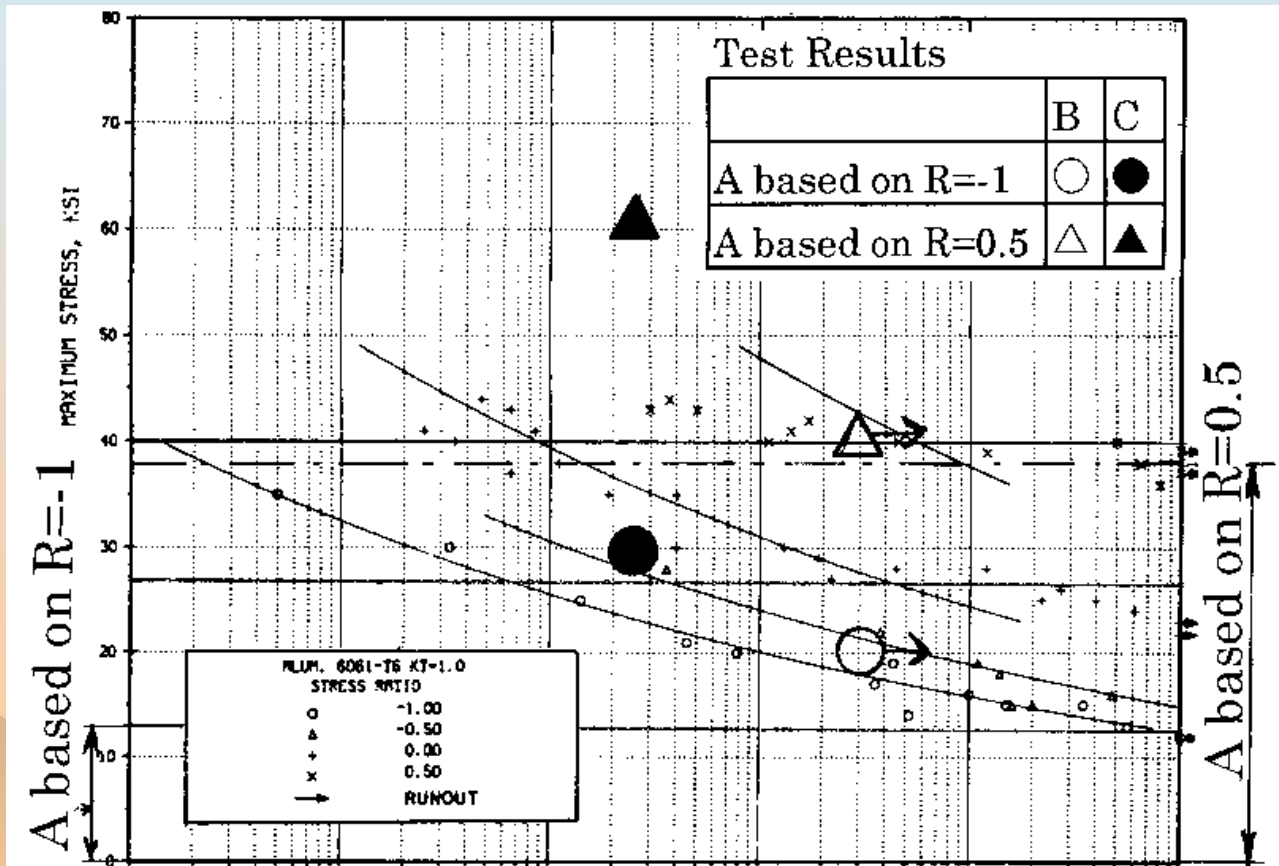
Load Condition =Test Condition"A" per Table 8  
(47 kN per Fitting X 4 Fittings)

Item	Location	Measured	Analysis Prediction
Large 3-Cell Beam Max. Strain	End of Beam Near Fitting	Top Strain=-415 $\mu$ s Bottom Strain=+335 $\mu$ s	Top Strain=-375 $\mu$ s Bottom Strain=+375 $\mu$ s
Large 3-Cell Beam Max. Deflection	Middle of Beam	Relative Z Direction Deflection = -1.61 mm	Relative Z Direction Deflection=-1.41 mm
Aluminum Joint	Inner Hook Radius	Strain=+1247 $\mu$ s	Strain=-773 $\mu$ s

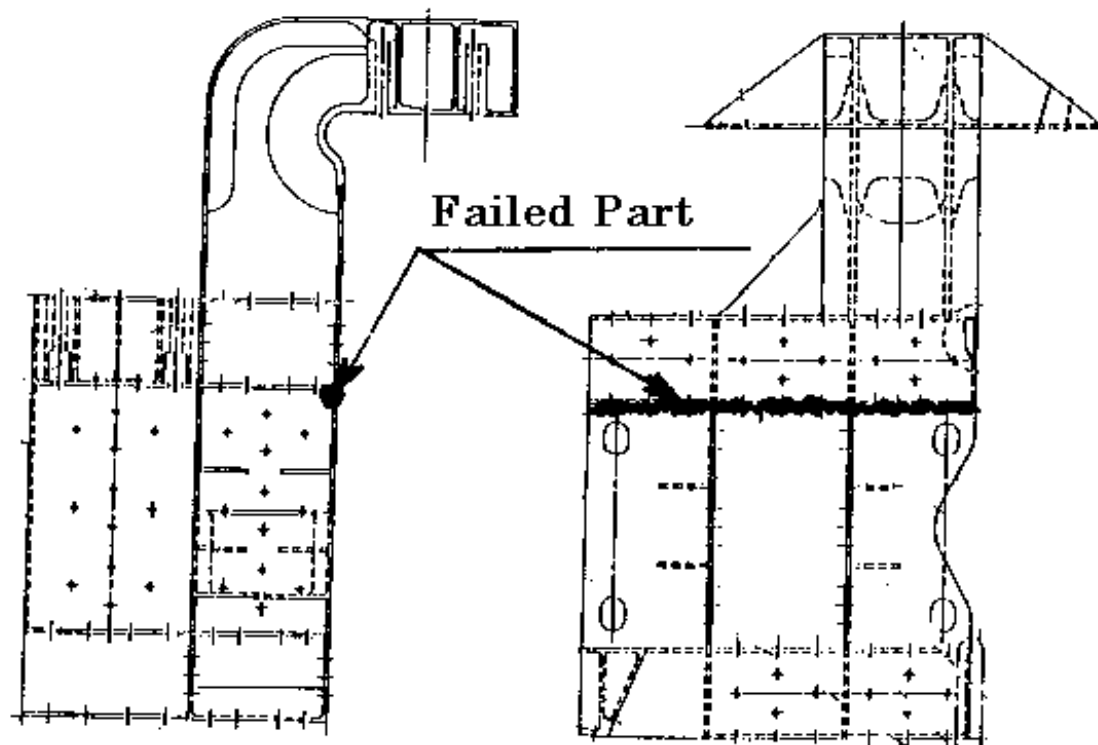
# 疲労試験条件

Condition	Loading Values (kN)	Remarks
A: Design Life for 10 years	$39.2 \pm 7.8$ (R=.67)	Normal Fatigue Life $>10^8$ Cycles
B: Fatigue Test, Step 1	$39.2 \pm 11.8$ (R=.54)	Accelerated; 1.5 x Variable Load of A
C: Fatigue Test, Step 2	$58.8 \pm 15.7$ (R=.54)	Accelerated; 1.5 x B

# 疲劳試驗結果



# 破断箇所





# 製作された台車枠

