演讲会・講演会・Lecture

2005年9月20日（September 20, 2005）

浙江大学建工学院交通工程研究所
College of Civil Eng. & Architecture
Zhejiang University


浙江大学


学术报告
题目：纤维桥梁的现状与展望
报告人：日本首都大学(原东京都立大学)
前田研一 教授
日本土木学会钢结构委员会FRP桥梁小委员会委员长
中村一史 博士
时间：2005年9月20日晚上6:30
地点：土木科技馆三楼多功能厅
(会场备有资料)
欢迎广大师生参加!

讲演题目·講演題目·Lecture Title

纤维强化塑料(聚合物)桥

FRP橋梁

Fiber Reinforced Plastic Bridge (Polymer)

定义·定義·Definition What is FRP ?

强化纤维·強化繊維 Reinforcement Fiber

〔非金属纤维 Non-metallic Fiber〕

玻璃纤维, 碳纤维, 芳族聚酰胺纤维

Glass Fiber, Carbon Fiber, Aramid Fiber

聚合物基础 Polymer Matrix 〔树脂·樹脂 Resin〕

Fiber－Matrix Bonding

纤维强化塑料(聚合物) Fiber Reinforced Plastics

GFRP, CFRP, AFRP (Polymers)

《复合材料·複合材料 Composite Material》

1. 材料 ・ Materials

1-1 特征・特徴 Characteristics

1）超轻量特性・超軽量性 Super Lightweight

密度 Density　FRP：Steel ≒ 1：5

特殊用途桥・特殊橋梁 Application to Special Use Bridge

应急的桥・应急橋 ・・・・Application to Emergency Bridge

浮体桥・浮体橋 ・・・・Application to Floating Body Bridge

可动桥・可動橋 ・・・・・・・・・・・・・・・・・・・・・・Movable Bridge

超长大桥・超長大橋 ・・・・・・・・・Super Long-Span Bridge

下部构造・下部構造 Effects on Substructure of Bridge

上部构造反力的减轻・上部構造反力軽減

・・・・・・Reduction of Superstructure Reaction Force

软弱地盘・軟弱地盤・・・・・・・・Adaptation to Soft Ground

抗震性・耐震性 Effects on Earthquake Resistance

质量减轻・質量軽減 Reduction of Superstructure Mass

现场施工性・現場施工性 Effects on Execution（Erection）

劳动力减少・省力化 ・・・・・・・・・・・・・・・・・・・・Labor Saving

不用重型机械・省重機械 ・・・・・Minimum Machine Power

（人力架設可能 ・・・・・・・・・・・・・・・・・Manpower Erection）

狭窄的现场・狭隘現場 ・・・・・Adaptation to Narrow Site

工期的缩短・工期短縮 ・・・・・・・・・Short Erection Period

劳动的安全・労働安全 Effects on Safety of Field Worker

人员的确保・労働者確保 Resolution of Worker Shortage

环境保护・環境保全 Effects on Environmental Preservation

自然环境・自然環境 ・・・・・・・・・・・・Nature Conservation

生活环境・生活環境 ・・Living Environment Maintenance

2）耐腐蚀性･耐食性 Corrosion Resistance

Resistance for 盐害･塩害 Salt Damage

酸害 Damage by Acid

维护管理性･維持管理性 Effects on Maintenance

沿岸的桥･沿岸橋 ・・・・・・・・Adaptation to Coast Bridge

火山地区、他 ・・・Adaptation to Volcanic Area & Others

减少寿命周期成本 ・・・・・・Reduction of Life Cycle Cost

3）着色形成性･着色成形性 Coloring Formability

设计多样性･設計多様性 Effects on Designability

景观设计･景観設計 ・・Application to Aesthetic Design

1-2 树脂/纤维・樹脂/繊維 Resin & Fiber

1）树脂・樹脂 Resin

热硬化性树脂・熱硬化性樹脂 Thermosetting Resin

主要的种类・主種類 Main Kinds of Resin

- 不饱和聚酯树脂 Unsaturated Polyester Resin
- 乙烯酯树脂 Vinyl Ester Resin
- 环氧树脂 Epoxy Resin

2) 纤维 Fiber

a. 连续纤维・連続繊維 Continuous Fiber

单纤维・単繊維 Filament（Φ 3～13μm）

1000～12000 pieces

Strand

Continuous Strand Mat
（Uni-Dir.）〔Glass Fiber〕

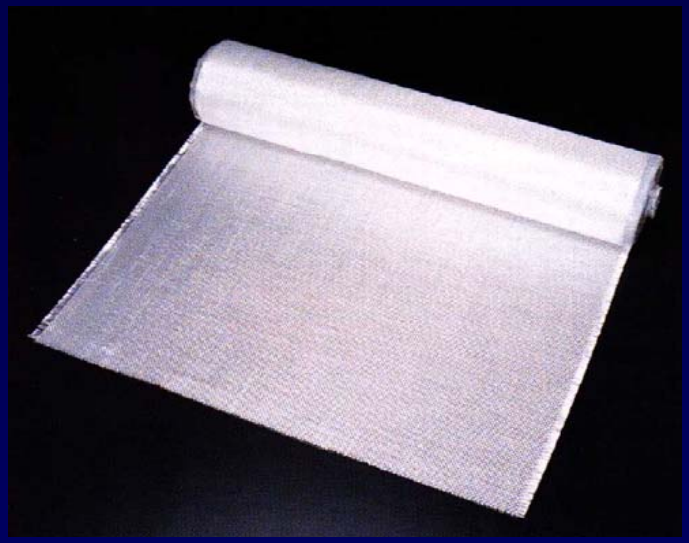
Roving
〔Glass Fiber〕

CSM：Chopped Strand Mat
（Random Dir.）

Tow〔Carbon Fiber, Aramid Fiber〕

b. 纤维织物·繊維織物 Fiber Fabric

◆ 织　布　Cloth （ Resin Direction　0°　，　90° ）



Roving Cloth
〔Glass Fiber〕

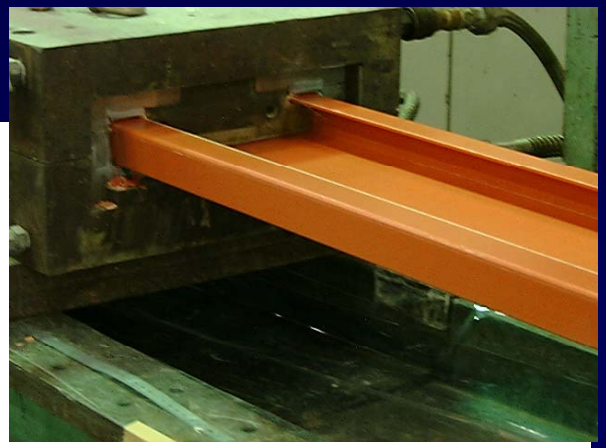
Carbon Cloth
〔Carbon Fiber〕

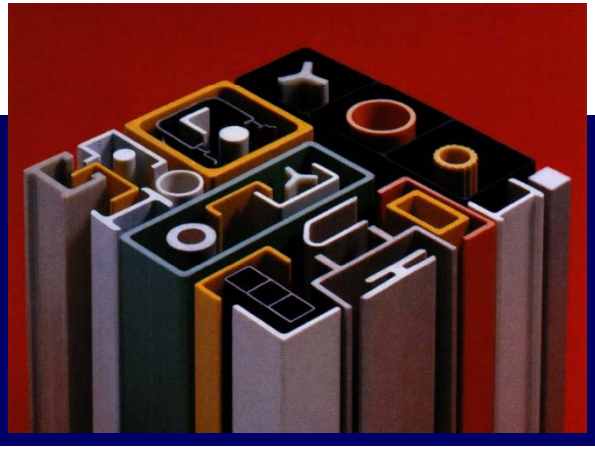
◆ 偏倚织　Bias （ Direction　0°　，　45°　，　90° ）

◆ 编织物　Knit Fabric　　（ Optional Direction ）

1-3 形成技术·成形技術 Molding Method

1) 抽擠形成·引抜成形 Pultrusion

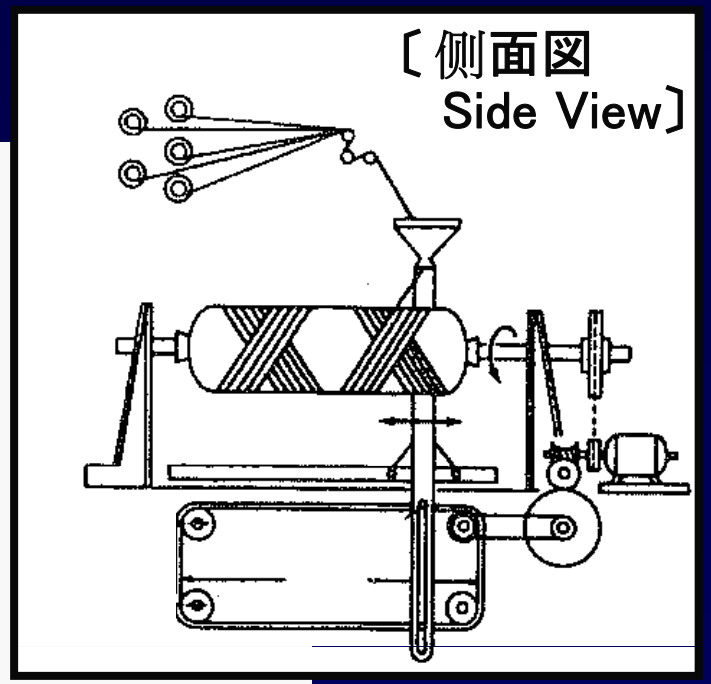


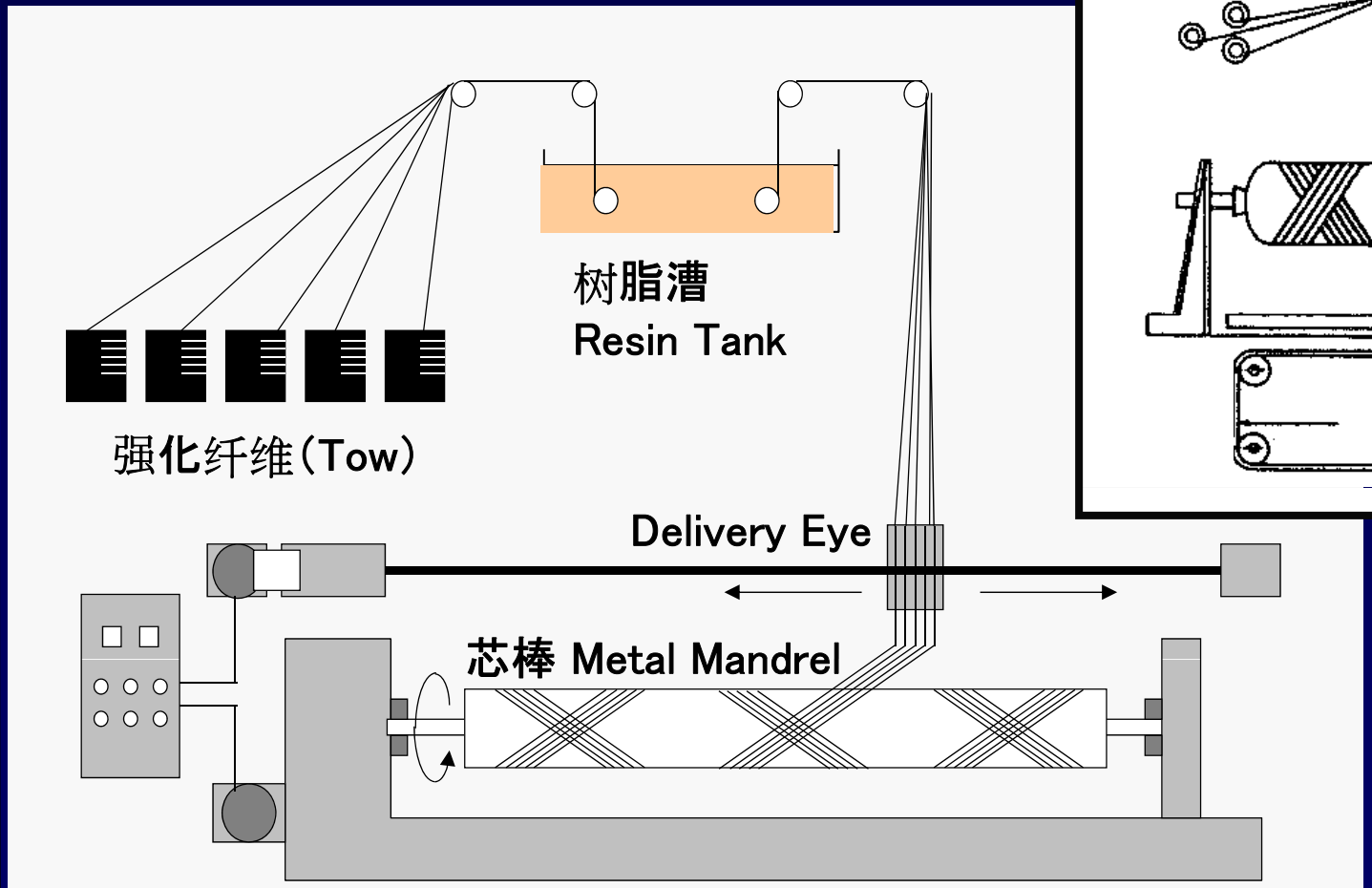


Pultrusion Profiles

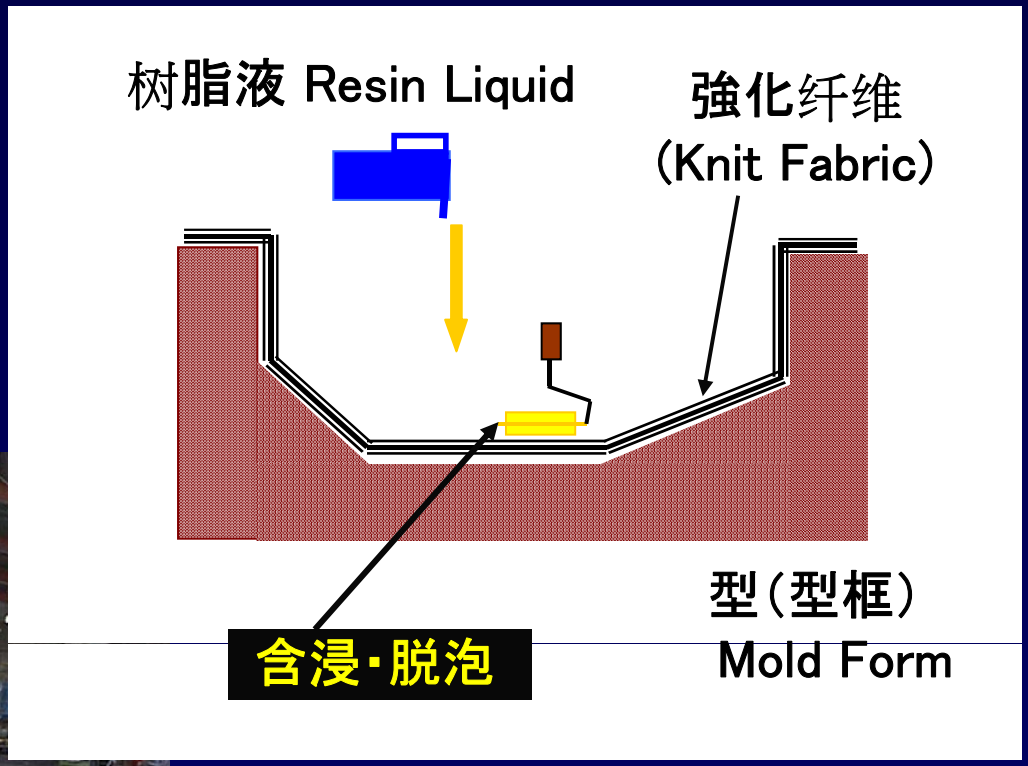
切断
Cutting

2）自动缠绕形成 Filament Winding (FW)





3) 手工铺叠形成 Hand Lay-up Molding (HLU)



1-4 材料的力学特性 Material Property

1）比较例子·比較例 Comparison Example

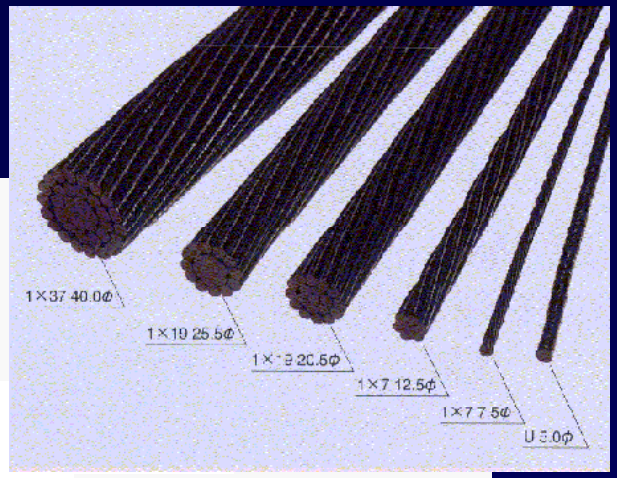
1方向強化材 Uni-Direction Reinforcement

	密　度 Density (kN/m^3)	张拉强度 引張強度 Tensile Strength (Mpa)	弹 性 率 Elastic Modulus (GPa)	线性膨胀率 線 膨 張 率 Thermal Expansion ($x10^6/℃$)
GFRP	20	1,200	42	8
CFRP	16	1,800	128	−0.7
AFRP	14	1,500	80	4
Steel	77	—	200	12

（纤维含有率 Content Rate of Fiber : 60 %）

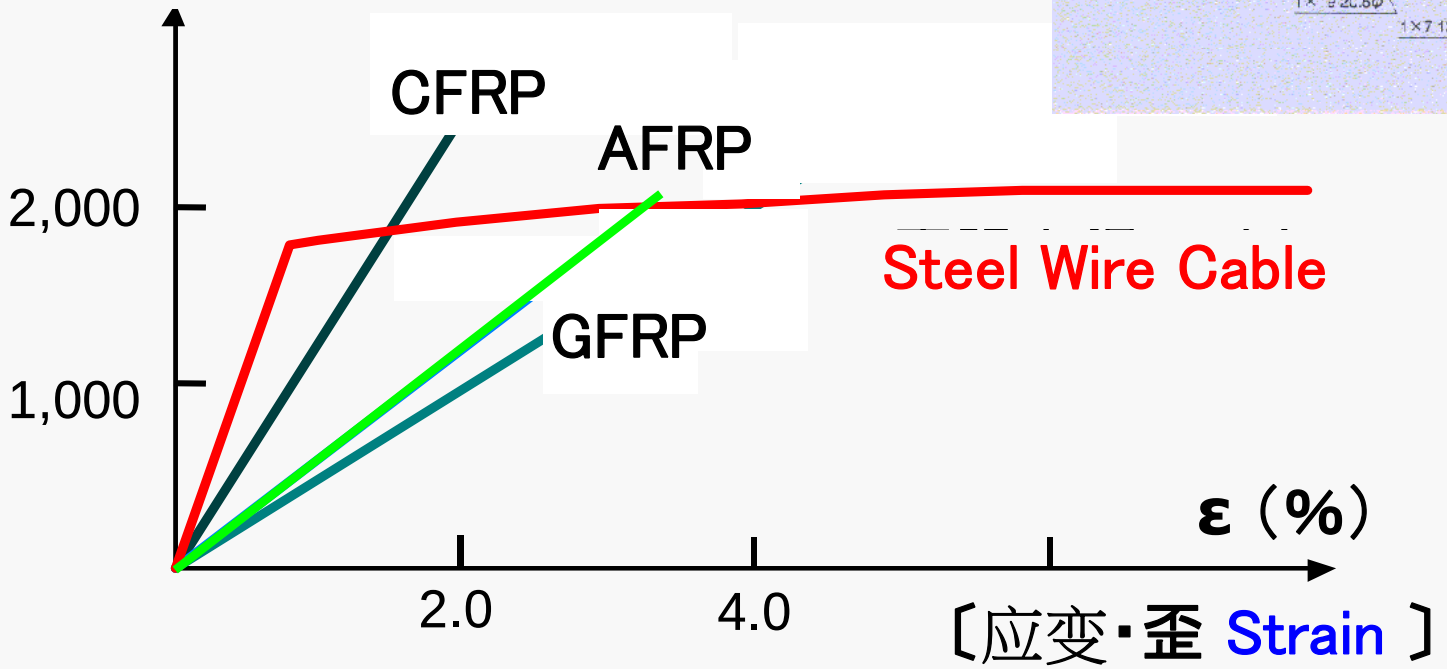
2) 应力-应变曲线･应力-歪曲線 σ - ε Curve

缆线 Cable Strand



〔张拉应力･引張応力 Tensile Stress 〕

σ (MPa : N/mm²)



2. 欧美桥的例子
欧米実橋例
Example in EU & US

2-1 玻璃纤维强化塑料桥 GFRP Bridges

1) 手工铺叠形成 Hand Lay-up (HLU)

Smith Road Bridge (TECH 21)
箱型桥 Box Girder Br.
USA, 1997

Length : 10 m Width : 7.2 m

〔形成费用
Molding Cost 〕

HLU >>> Pultrusion

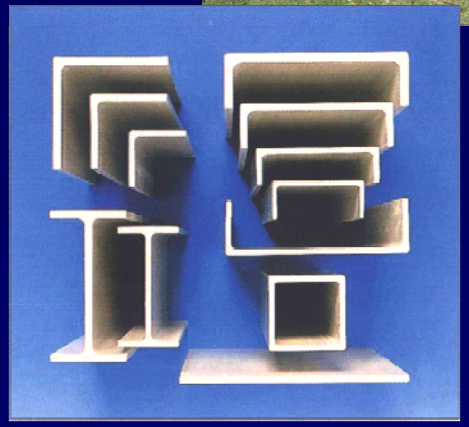
⇩

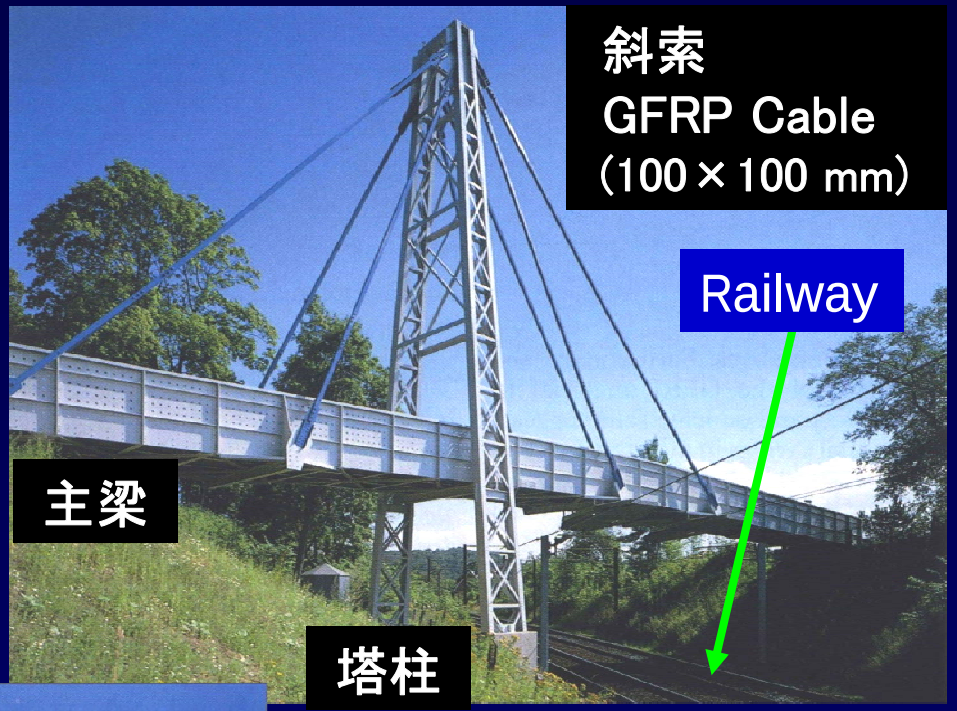
Pultrusion Profiles

2) 抽擠形成･引抜成形 Pultrusion

1. Kolding Bridge 斜拉桥
Cable-Stayed Bridge
Denmark, 1997

Span : 13 m + 27 m
Tower Height : 18.5 m
Width : 3.2 m Weight : 125 kN





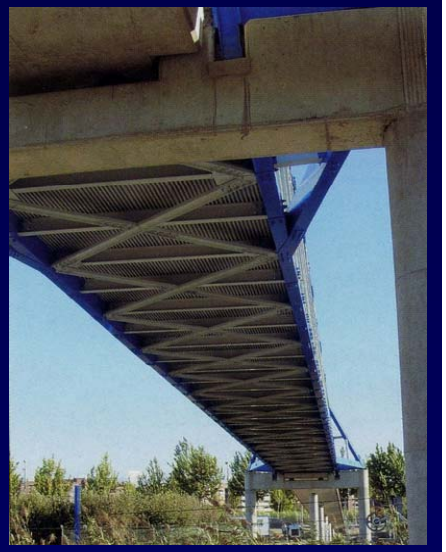
工期的缩短
Short Erection Period
→ 18 hours （ 3 night ）

→ Initial Cost + 5～10 %

2-1 玻璃纤维强化塑料桥 GFRP Bridges

2. Lleida Bridge Spain, 2001 拱桥 Arch Bridge

Length : 38 m Width : 3.0 m Weight : 19 ton



工期的缩短

Short Erection Period

Large Block Erection

→ 3 hours（1 night）

→ Initial Cost 325,000 US$

构件种类过多

Too Many Kinds of Members

Systematization

3. San Francisco National Park Bridge – Longspan Prestek System

USA, 1990's 悬索桥 Suspension Br. 系统桁架桥 System Truss Br.

Center Span : 21.4 m 〔Wood Deck〕

FRP Weight : 3 ton（Total : 5 ton）

Erection using Helicopter

自然环境·自然環境

Nature Conservation

盐害·塩害 Resistance for Salt Damage

≫ 100 Bridges

4. Middlebury Run Park Bridge & 5, Carey Avenue Bridge

USA, 2003 & 2005 – Longspan Prestek System

系统桁架桥 System Truss Bridge

Length : 17.7 m 〔Wood
Width : 3.05 m Deck〕

Length : 15 m 〔Wood
Width : 1.5 m Deck〕

永久荷载 Dead Load 3.2 ton << 9.1 ton (Steel Br.)

材料费用 Material Cost 53,400 US$

2-1 玻璃纤维强化塑料桥 GFRP Bridges

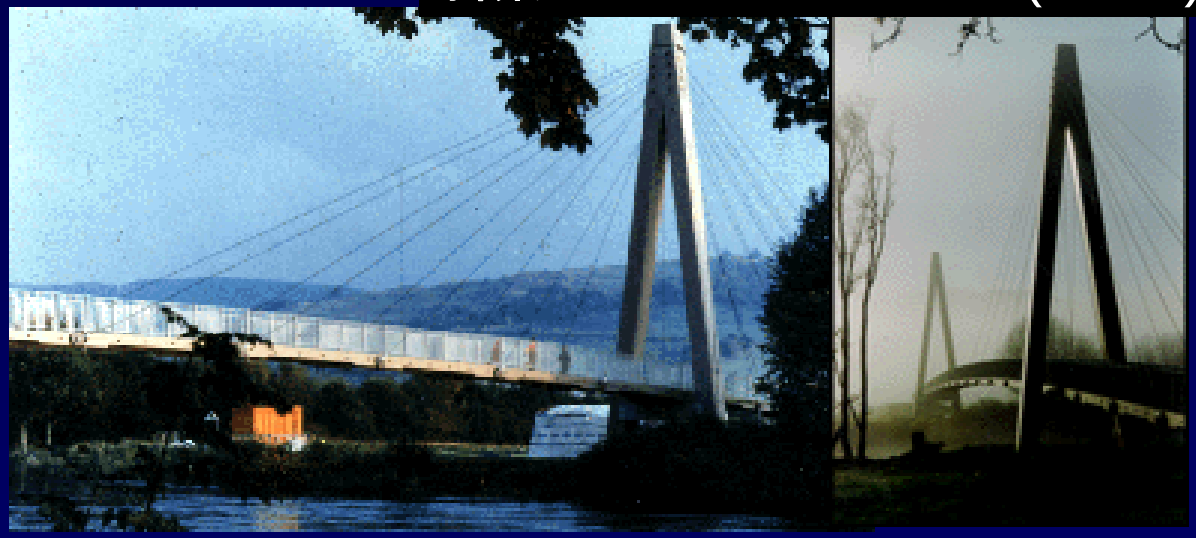
现场施工 Erection of Carey Avenue Bridge　3 Men × 3 hours

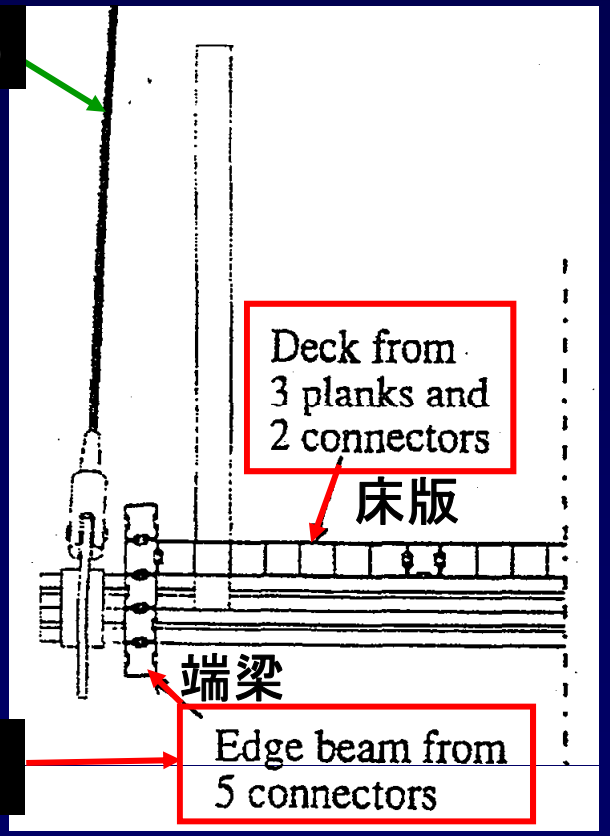
6. Aberfeldy Footbridge
斜拉桥 Cable-Stayed Bridge
UK, 1992

– ACCS（Advanced Composites Construction System）
系统桁桥 System Girder Bridge

Span : 25 m + 63 m +25 m Tower Height : 17.5 m Width : 2.2 m

斜索 Aramid Fiber Cable (Kevlar)



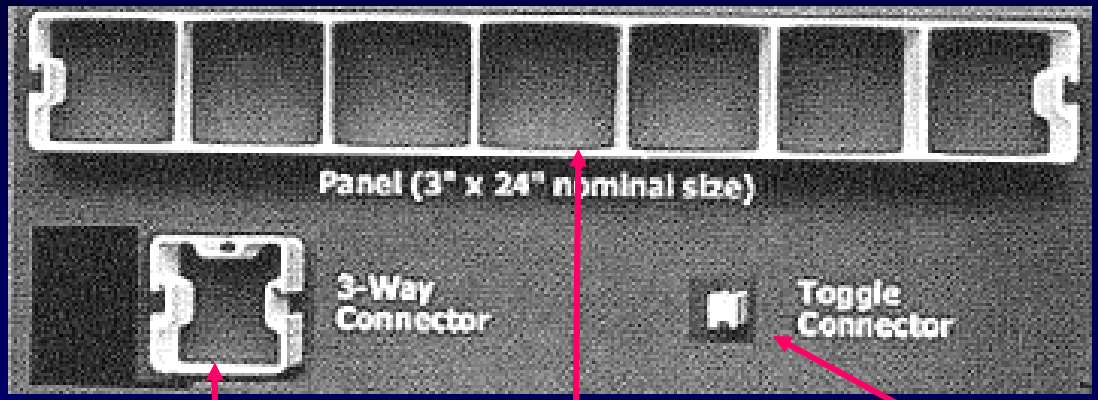


软弱地盘 Application to Soft Ground

塔柱 Tower、横梁 Cross Beam ← ACCS

Systematization → Low Cost Bridge

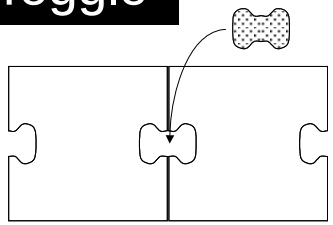
ACCS (Advanced Composites Construction System)



Connector
80mm × 80mm

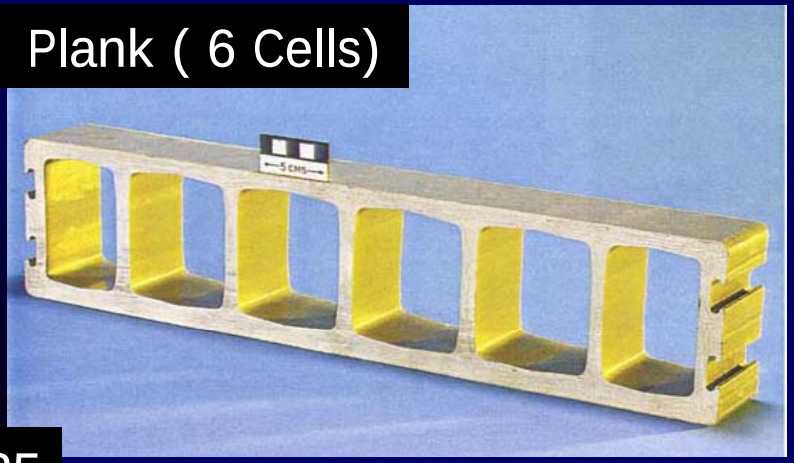
Plank (7 Cells)
600mm × 80mm

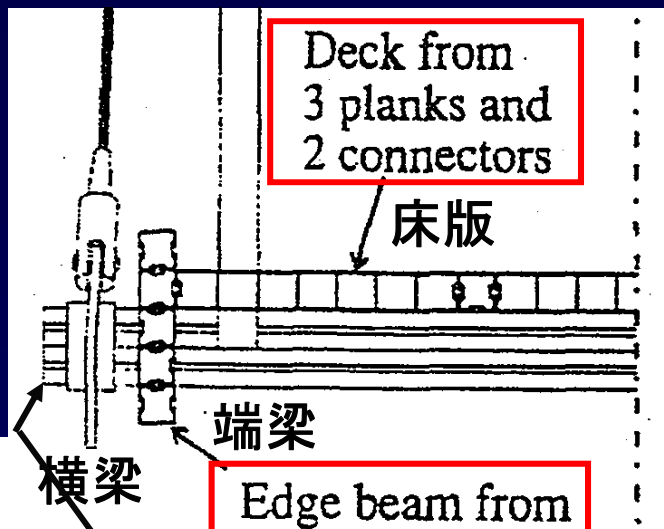
Toggle



(Dog Bone Joint)

Plank (6 Cells)





Edge beam from
5 connectors

Cross Beam from
4 connectors
160mm × 160mm

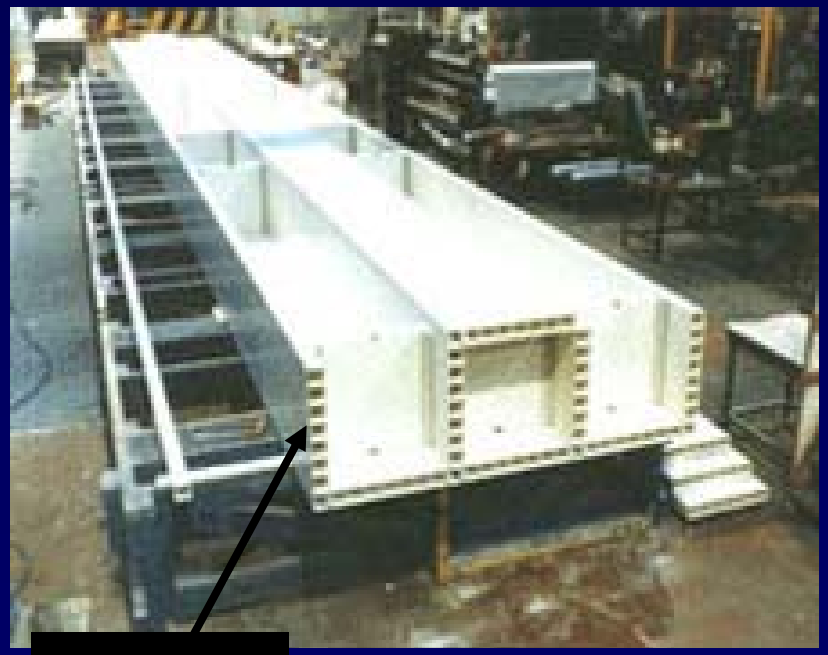
塔柱

Tower from
4 planks and
4 connectors
760mm × 760mm

7. Bonds Mill Lift Bridge
可动桥・可動橋
UK, 1994

– ACCS（Advanced Composites Construction System）
⇩
系统桁桥 System Girder Bridge

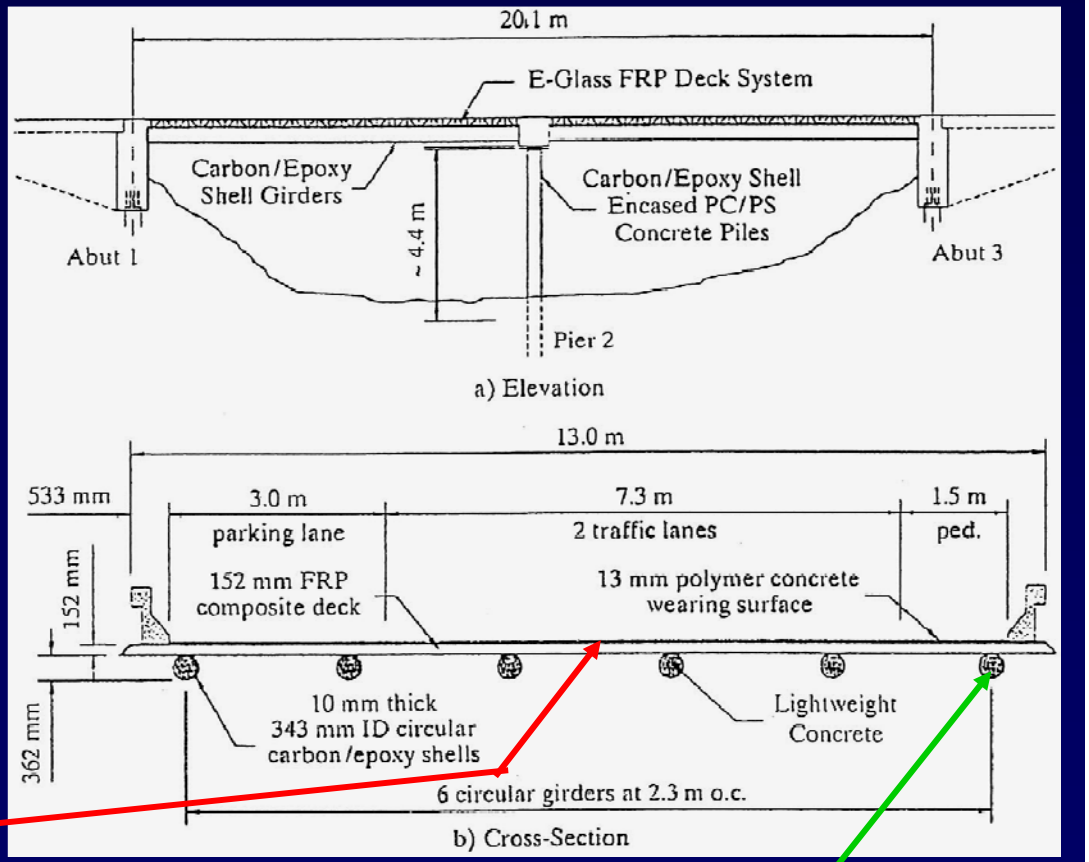
Length : 8.2 m Width : 4.3 m 〔Movable Road Bridge〕



2-2 碳纤维强化塑料桥 CFRP Bridges

Kings Stormwater Channel Bridge USA, 2000

Length : 20.1 m （ 2 Span ）
Width : 11.8 m 〔 Road Br.〕



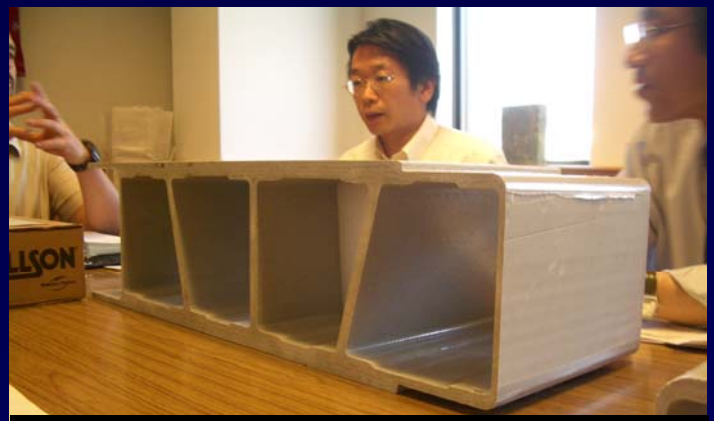
GFRP Deck System
- DuraSpan -

Carbon Shell Girder（混凝土填充 Concrete Filling ）

2. 欧美桥的例子·欧米実橋例 · Ex. in EU & US

GFRP Deck System in USA

– DuraSpan –



DuraSpan 766
Depth 195mm, Span 3.05m

DuraSpan 500
Depth 127mm, Span 1.52m

“Superdeck”

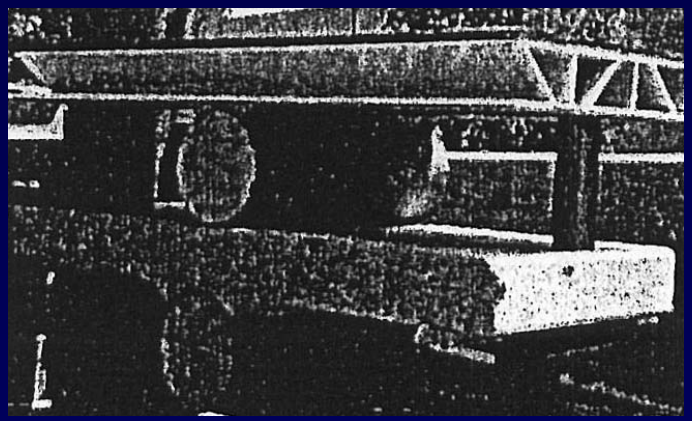
Depth 204mm, Span 2.74m

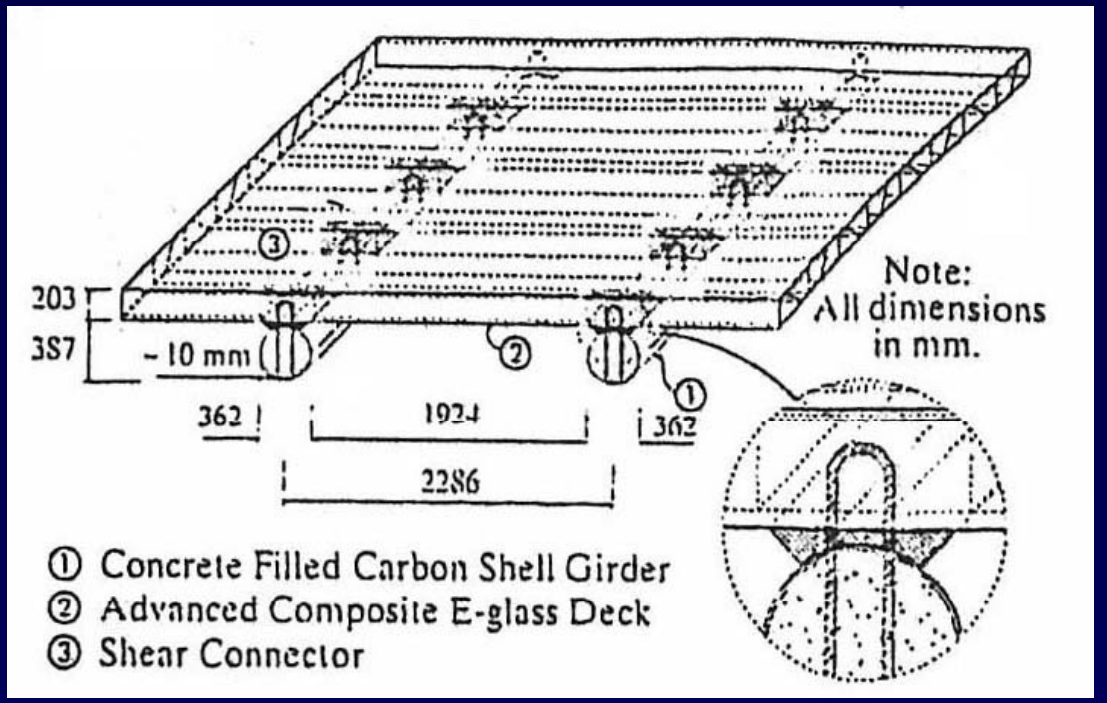
Width 1.143m

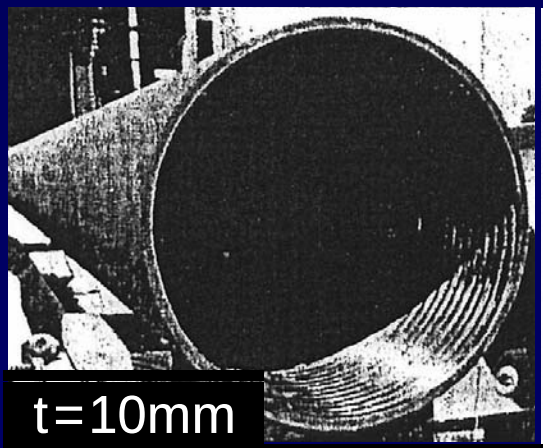
2-2 碳纤维强化塑料桥 CFRP Bridges

GFRP Deck System

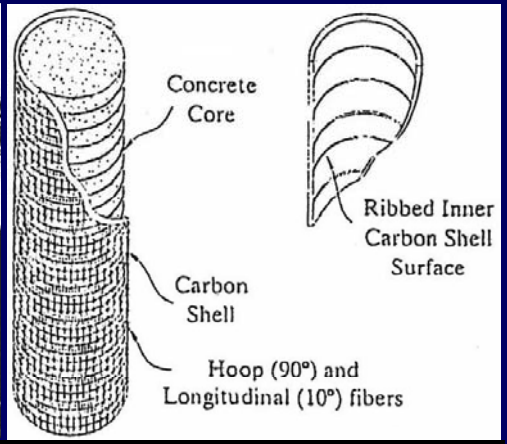
& Concrete Filled Carbon Shell Girder







t=10mm



Filament Winding (Inside Φ340mm)

〔材料費用
Material Cost〕

CFRP >>> GFRP

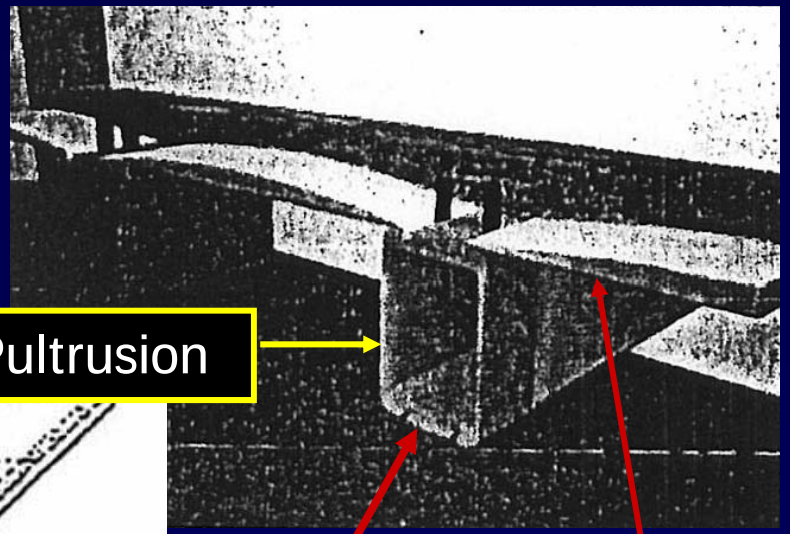
⇩

Hybrid Composite Material

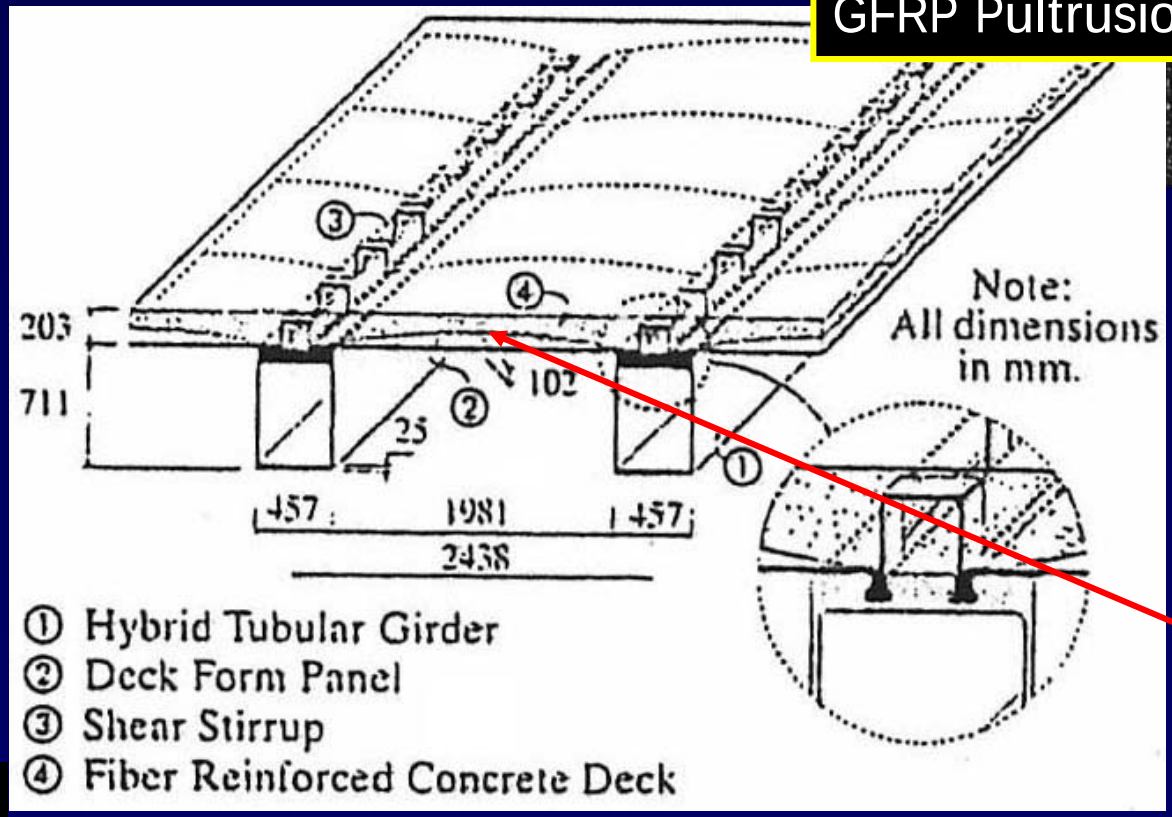
(G+C) FRP

2-3 混合桥 Hybrid Bridges

Hybrid Tubular Girder
(h = 711mm　t = 19mm : Web
t = 25mm : Lower Flg.)



GFRP Pultrusion



Uni-Directional
Carbon Strips

Carbon Membrane

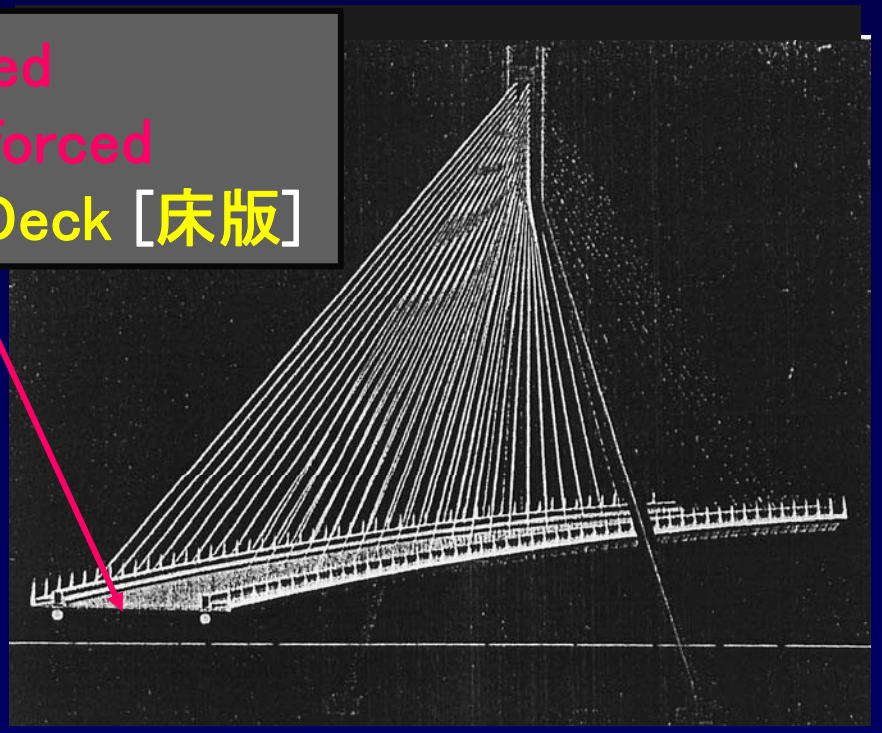
Arch Shaped
Fiber Reinforced
Concrete Deck

I-5/Gilman Advanced Technology Bridge　USA, ????

斜拉桥 Cable-Stayed Bridge

Length : 137 m (2 Span)　Tower Height : 58 m　Width : 14 m

Arch Shaped
Fiber Reinforced
Concrete Deck [床版]



Concrete Filled Carbon Shell
Main Girder [主梁]
(Inside Φ914mm　t = 10mm)

Hybrid Tubular Cross Girder
[横梁] (h = 711mm, t = 19mm
: Web,　t = 25mm : Lower Flg.)

Concrete Filled Carbon Shell
Tower [塔柱]
(Inside Φ1,520mm　t = 13mm)

3. 日本桥的例子
日本実橋例
Example in JAPAN

1) 人行天桥·横断歩道橋 GFRP Pedestrian Bridge

Okinawa Road Park Bridge　Japan, 2000

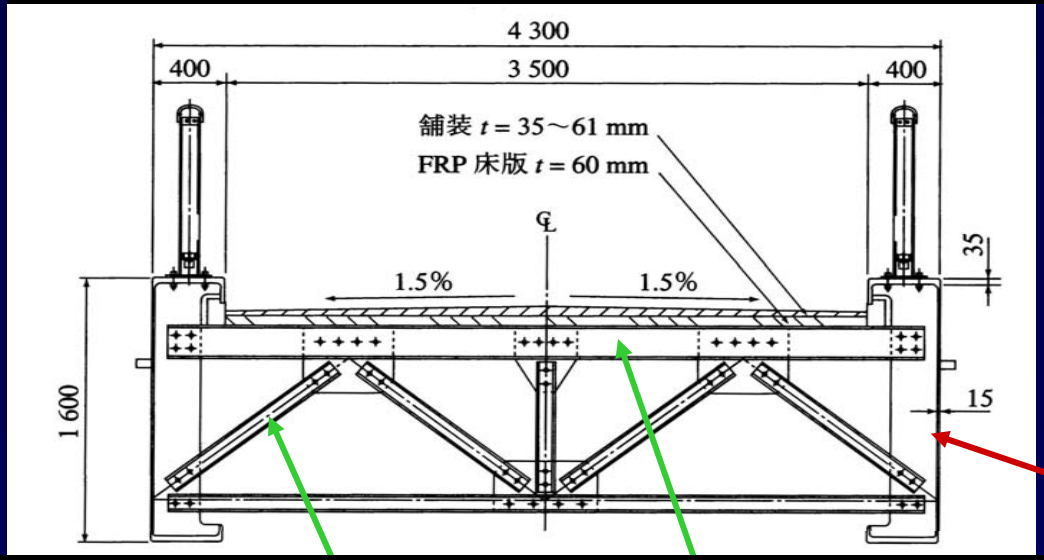
Span : 19.7 m + 17.2 m　Width : 3.5 m

盐害·塩害　Resistance for Salt Damage

→ Initial Cost + approx. 15 %　to PC Bridge

3. 日本桥的例子·日本実橋例 · Ex. in JAPAN

横断面 Sectional View of Okinawa Road Park Bridge



Secondary Member Pultrusion Profile

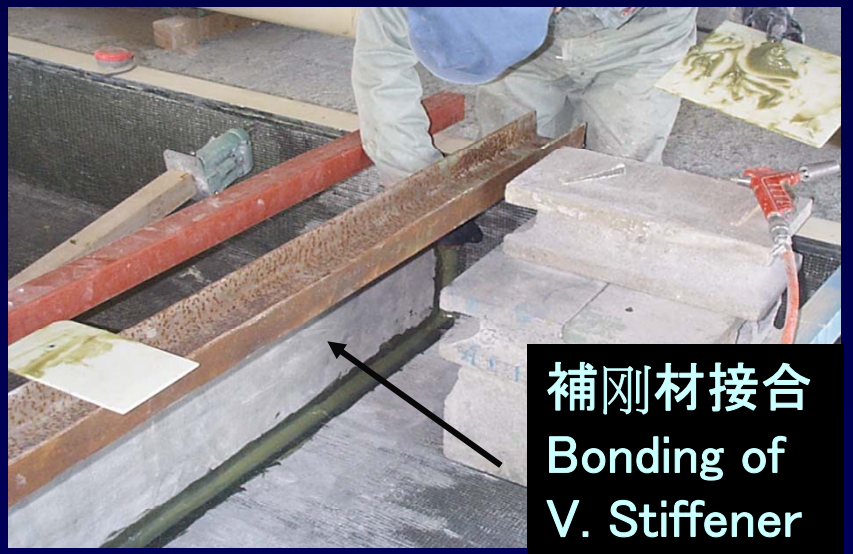
Main Girder
(Channel Section)
Hand Lay-up

材料特性 Material Property		张拉/压缩强度 T/C Strength (Mpa)	弹 性 率 E-Modulus (GPa)	线性膨胀率 T. Expansion (x10⁶/℃)
Main Girder	Flange	200/280	15	
	Web	200/220	13	
Secondary Member		400/550	32	0.7

→ 挠度限制
Deflection Limitation

施工 Fabrication and Erection of Road Park Bridge

Hand Lay-up of Main Girder

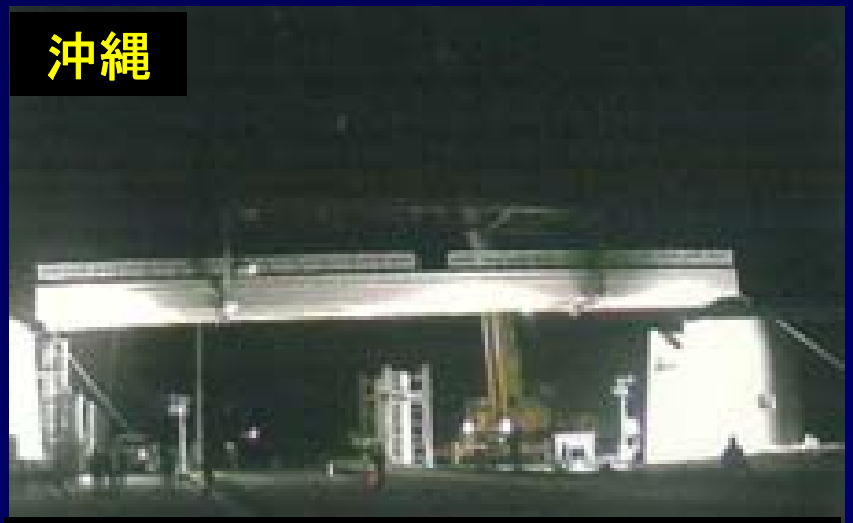


補剛材接合
Bonding of
V. Stiffener

東京

Shipping with Cargo Boat

沖縄



Large Block Erection at Site

2) 应急的桥·应急橋梁 GFRP Emergency Bridge

Asagiri Emergency Test Bridge Japan, 1998

Span : 8 m Width : 3 m 〔 Emergency Road Bridge〕

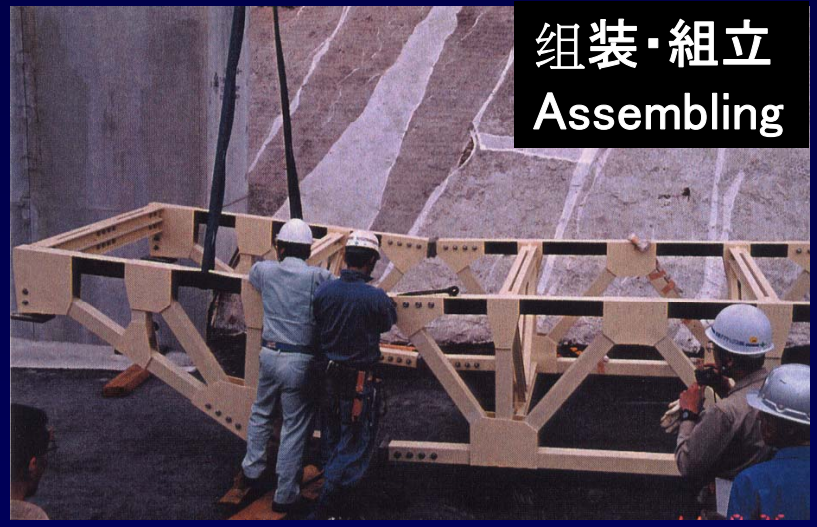
Design Assumed Run of 2ton Truck

材料特性 Material Property （ 主桁架 Main Truss）	张拉/压缩强度（ T/C Strength ） 518/430 MPa
	张拉/压缩弹性率（ E-Modulus ） 24/30 GPa

现场施工实验 Erection Test of Asagiri Emergency Test Bridge

抵达 Arrival of Truck (Start)

组装·組立 Assembling



Block Erection using 12ton Crane

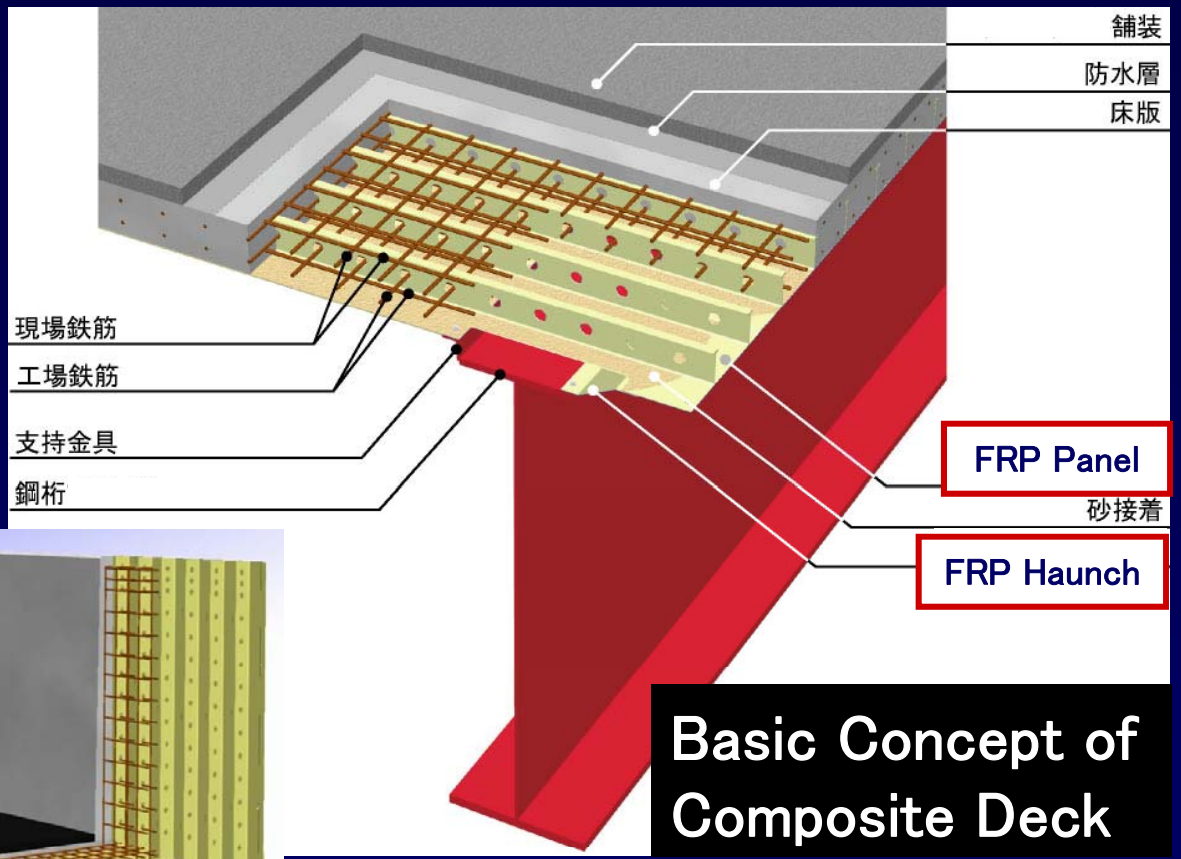
床版铺装 Floor Slab Construction

2 Men (+ 10 Assist) → 311 min (approx. 5 hour)

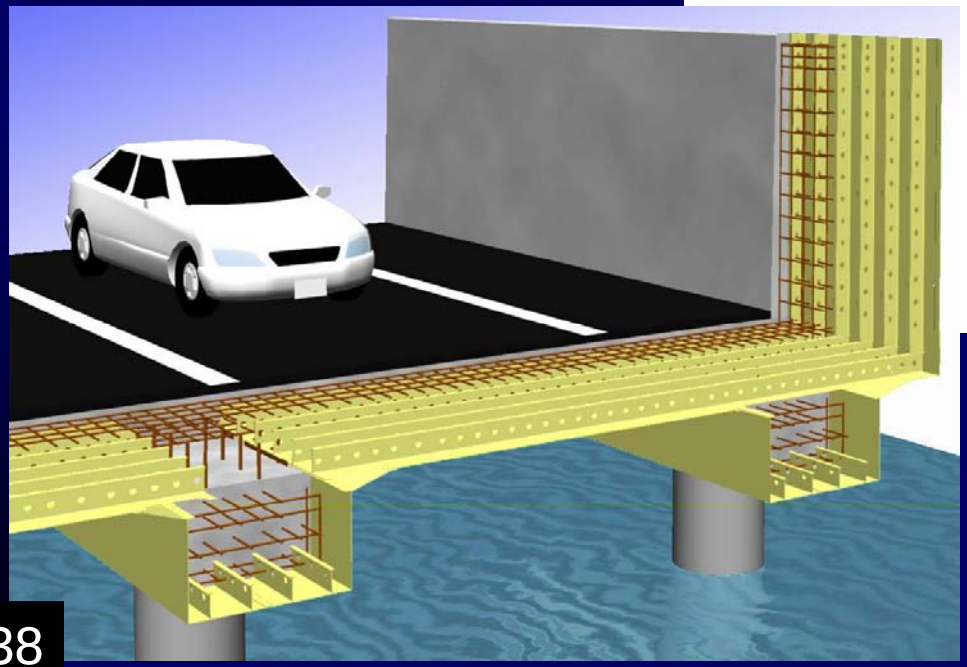
3) 塑料钢筋混凝土合成桥 GFRP & RC Composite Br.

Shiojinmachi Bridge
Japan
(under Construction)

Length : 83.2 m
Width : 22 m



Basic Concept of Composite Deck



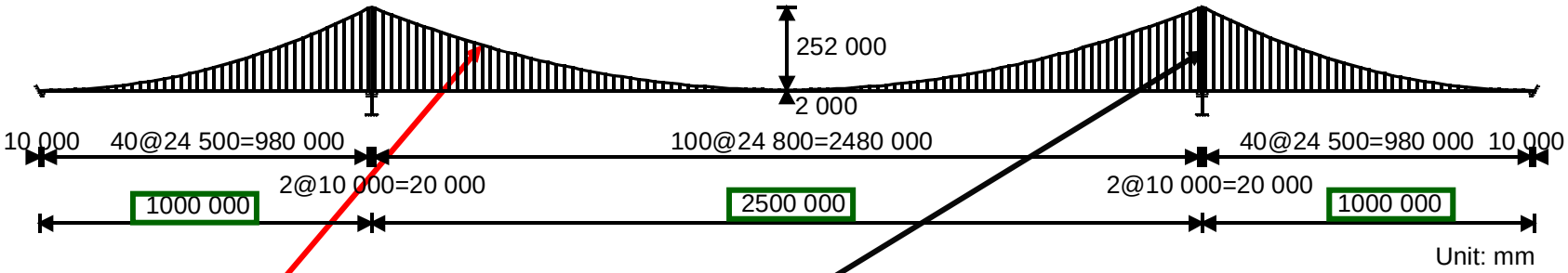
盐害·塩害 Resistance for Salt Damage

Systematization
→ Initial Cost + approx.10 %

4. 首都大学東京的研究
Studies in TMU

1) 长大悬索桥・長大吊橋 Very Long-Span Suspension Bridge with CFRP Main Cable

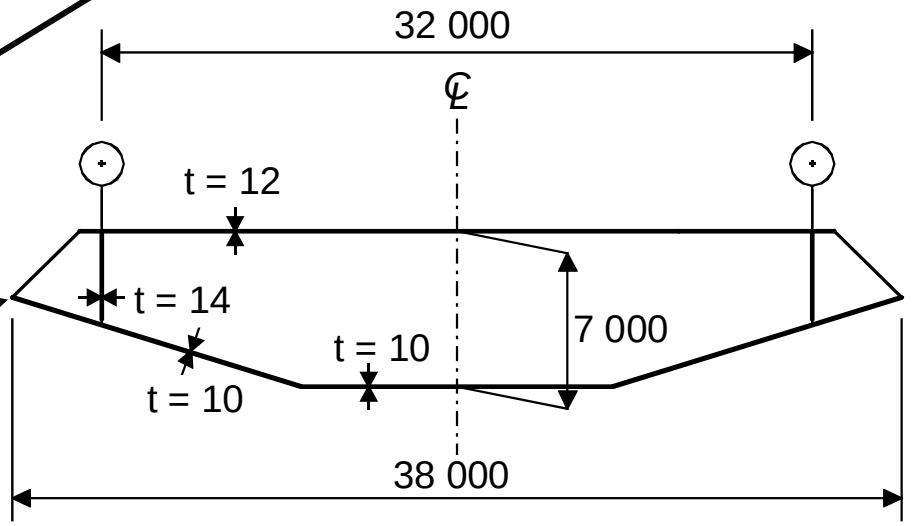
中跨・中央径間長 Center Span 2,500m 垂跨比 Sag Ratio 1/10



主索 CFRP Main Cable

主塔 Steel Main Tower

刚性梁（Height 7 m）
Steel Stiffening Girder



试行设计・試設計 Trial Design

材料特性 Material Prpperty	Steel Cable	CFRP Cable
密度 Density（ kN/m³ ）	77.0	16.0
弹性率 Elastic Modulus（ GPa ）	200	160
线性膨胀率 Thermal Expansion（ x10⁶/℃）	12.0	0.6
张拉強度・引張強度 Tensile Strength（ MPa ）	1,960	2,460
安全率 Safety Factor	2.0	2.5
容许应力・許容応力 Allowable Stress（ MPa ）	980	980
断面积・断面積 Sectional Area（m²/cable ）	0.5966	0.4540

初期费用比较 Comparison of Initial Cost

Material Cost (/kN)
CFRP / Steel < 20

＋

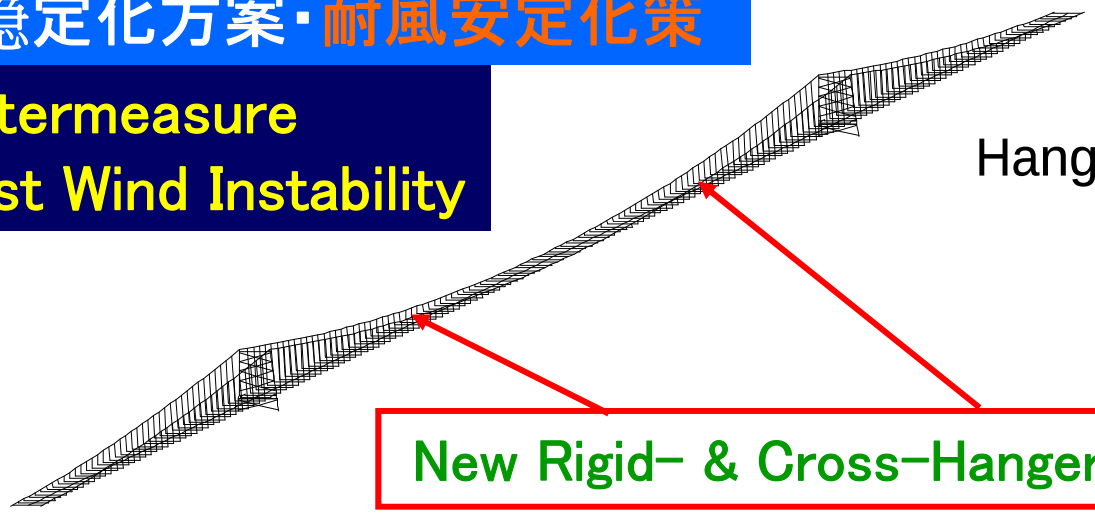
Erection Cost (/m³)
CFRP / Steel < 0.5

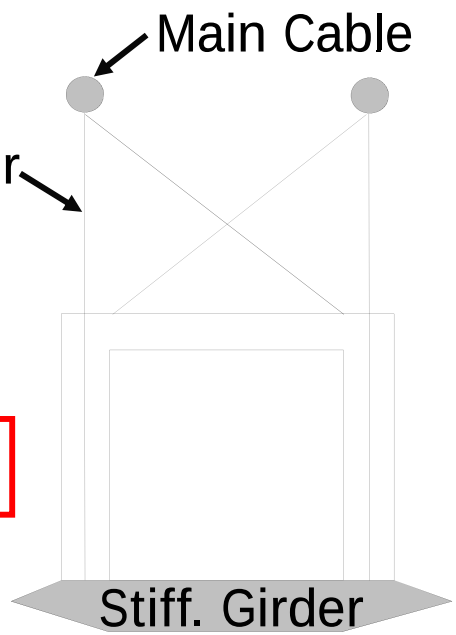
→

〔 Initial Cost 〕
CFRP < Steel

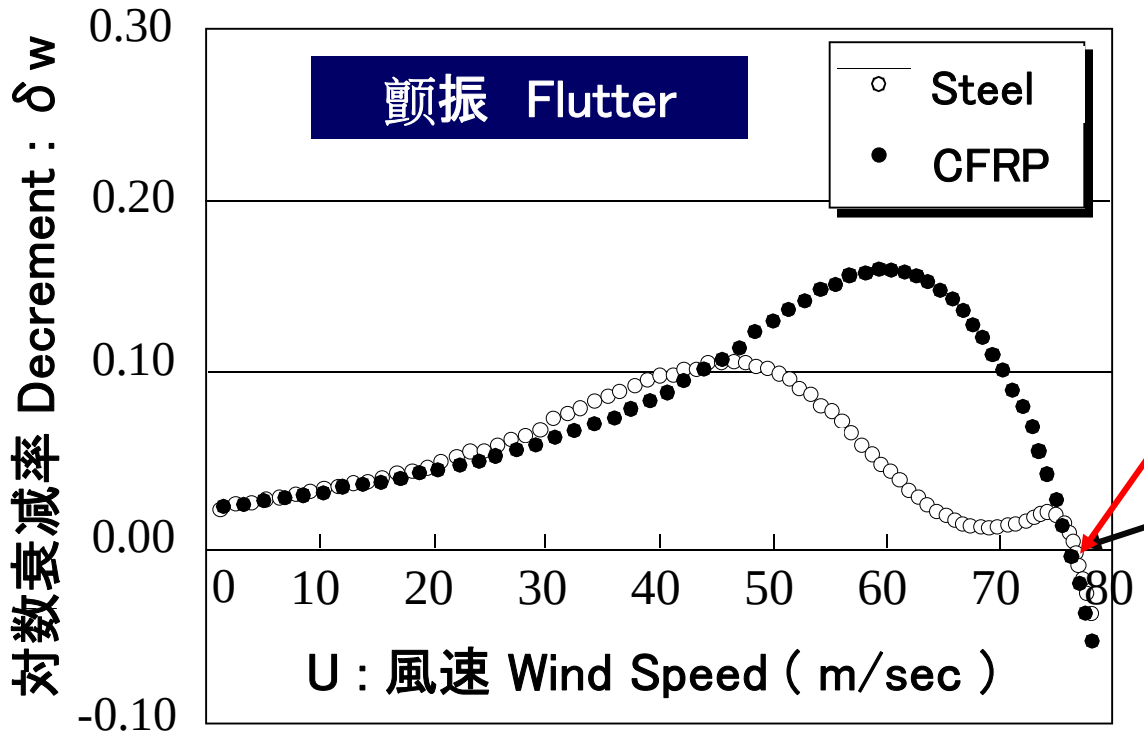
抗风稳定化方案・耐風安定化策

Countermeasure against Wind Instability





New Rigid- & Cross-Hanger



临界風速 Critical Wind Speed for Flutter

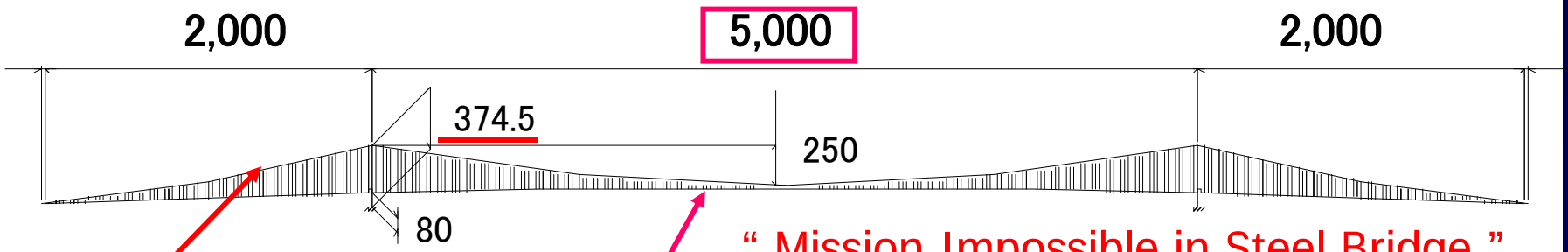
CFRP 76.2 m/sec
(55.8 m/sec)

Steel 76.5 m/sec
(61.5 m/sec)

(No Countermeasure)

2) 超长大悬索桥・超長大吊橋 Super Long-Span Suspension Bridge made of All FRPs

中跨・中央径間長 Center Span 5,000m 垂跨比 Sag Ratio 1/20

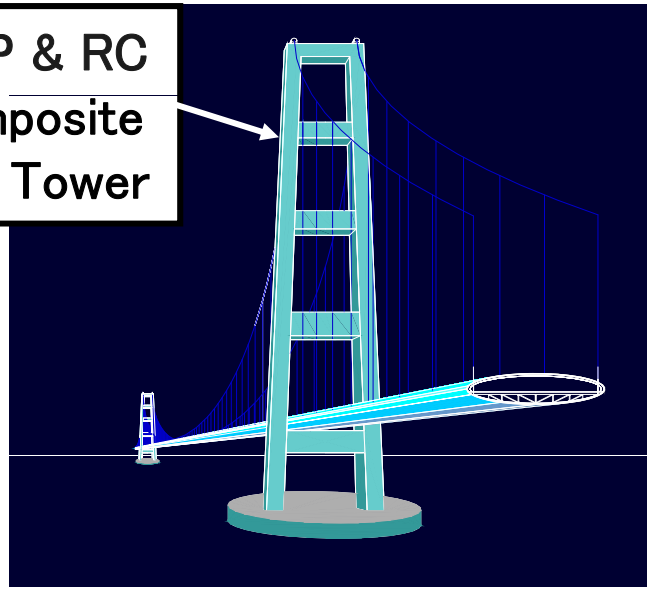


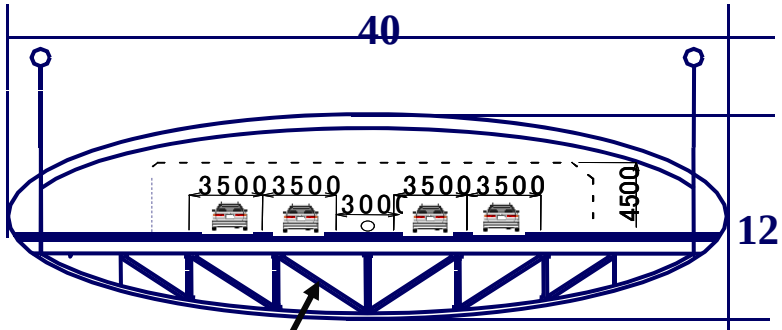
主索 CFRP Main Cable

刚性梁 CFRP Stiffening Girder

“ Mission Impossible in Steel Bridge ”

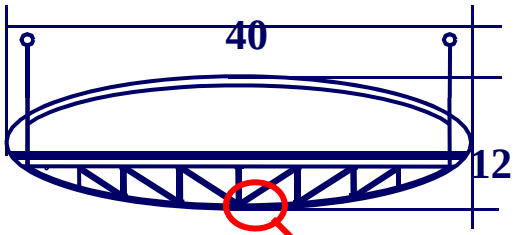
主塔 CFRP & RC Composite Main Tower





GFRP Secondary Member

试行设计・試設計 Trial Design

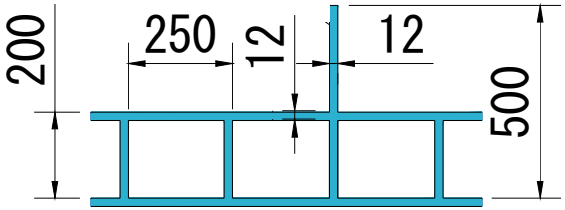


刚性梁
Stiff. Girder

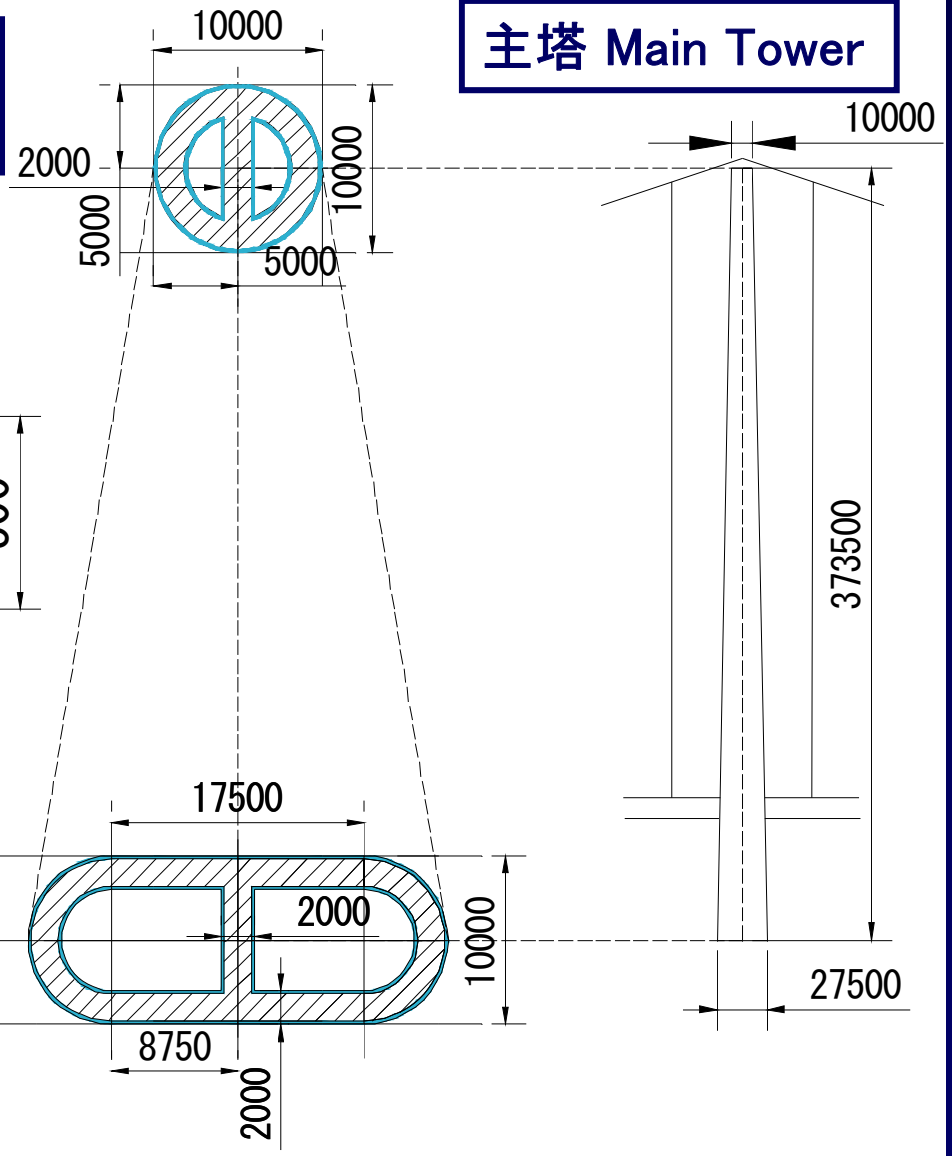
安全率
5.0

张拉/压缩强度
1000/500 MPa

弹性率
65 GPa



主塔 Main Tower



主索 Main Cable

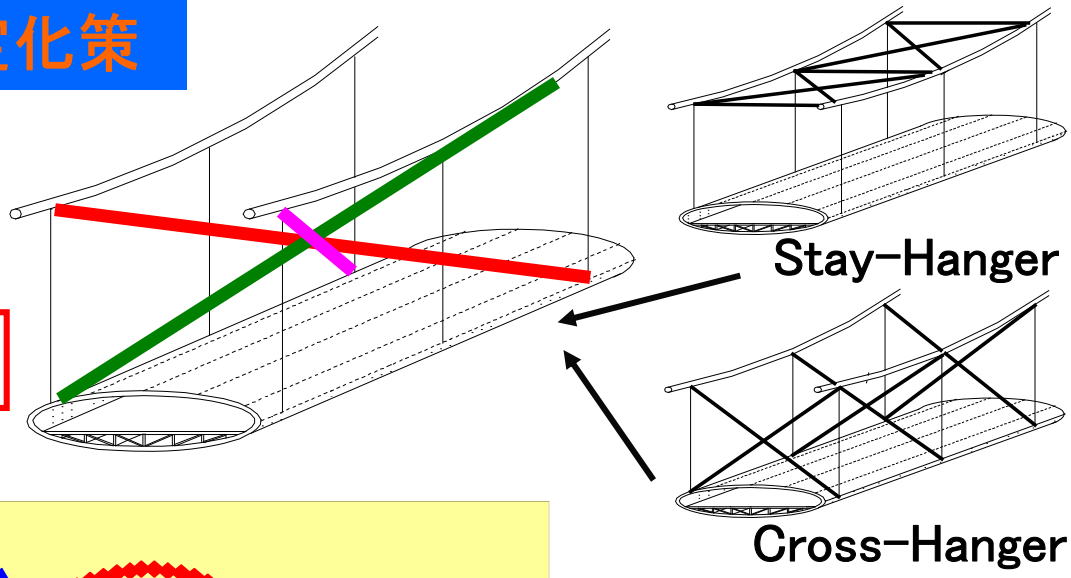
弹性率	安全率	张拉强度
160 GPa	2.5	2450 MPa

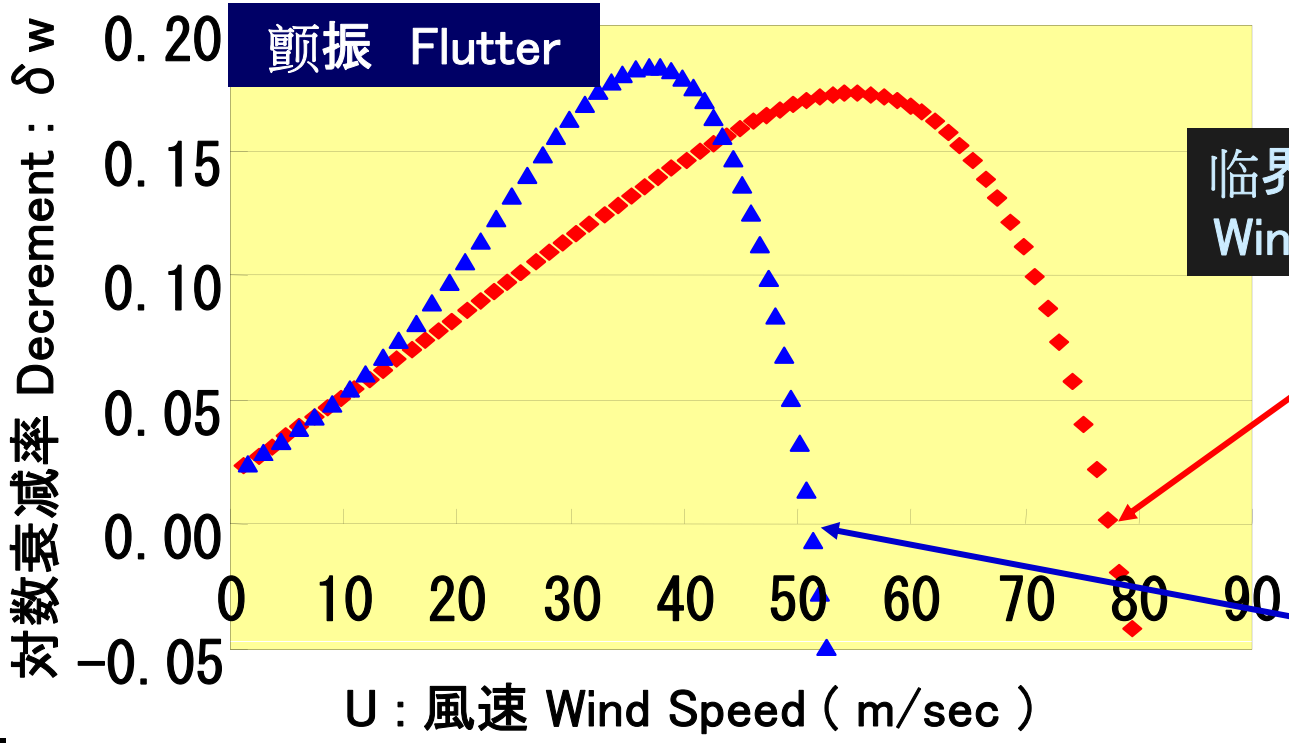
断面积・断面積 1.25 m^2/cable

抗风稳定化方案・耐風安定化策

Countermeasure against Wind Instability

New Spatial Cross-Hanger



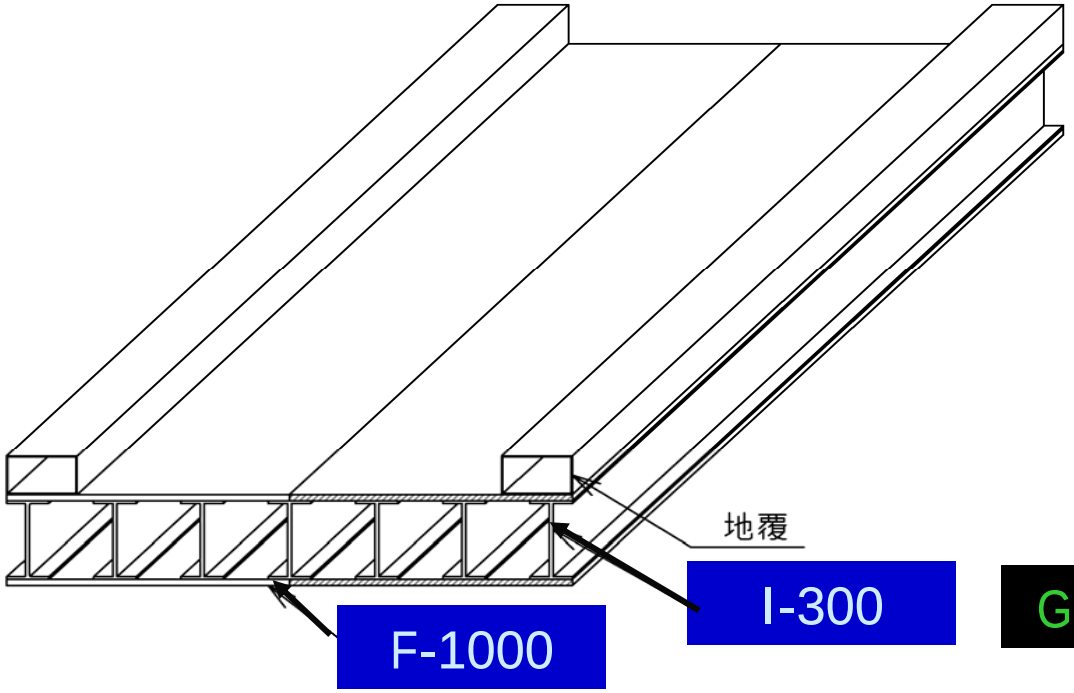


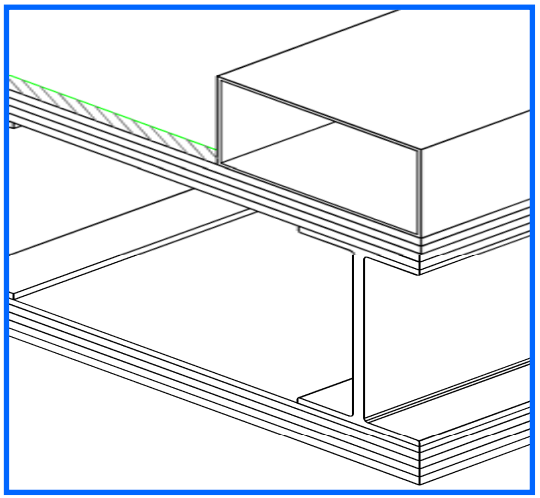
臨界風速 Critical Wind Speed for Flutter

All Span Countermeasure 79.6 m/sec

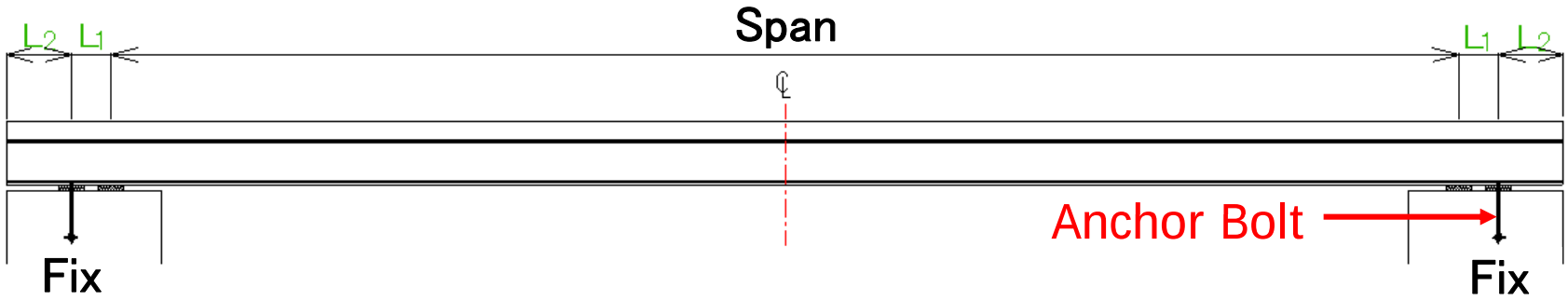
No Countermeasure 51.1 m/sec

3) 床版人行天桥 GFRP Slab Footbridge



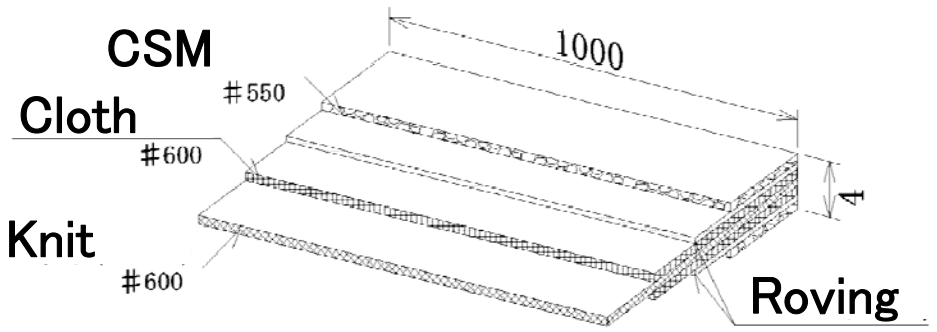


GFRP Pultrusion Profiles

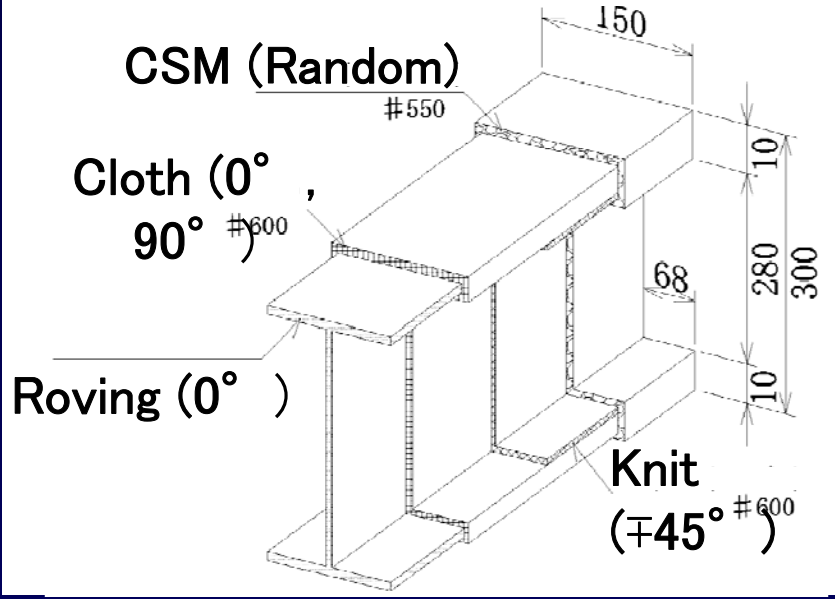


材料设计・材料設計

F-1000



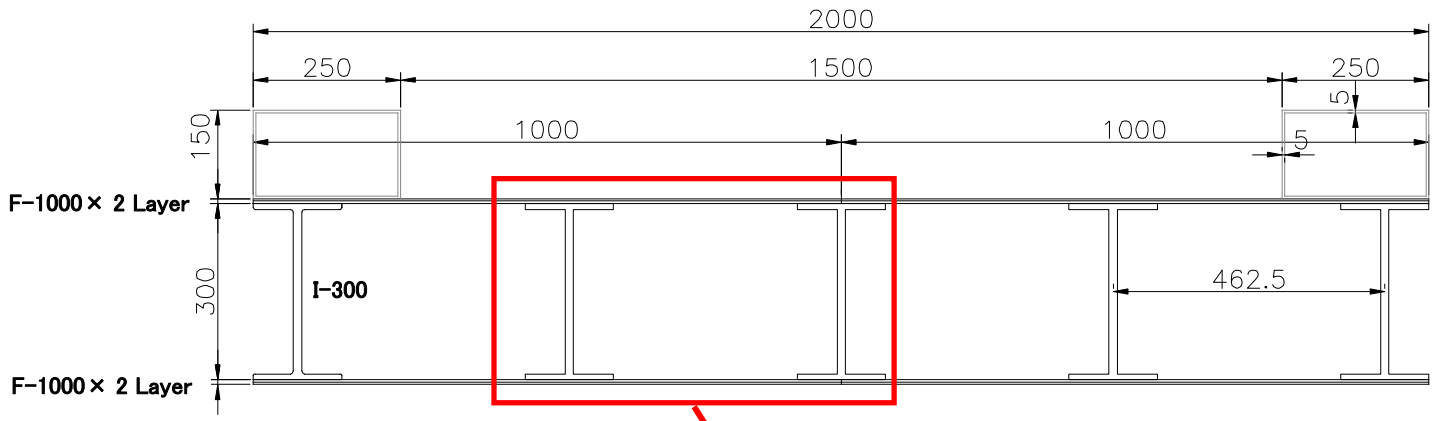
I-300



材料特性 Material Property		张拉/压缩强度 T/C Strength (Mpa)	弹 性 率 E-Modulus (GPa)	线性膨胀率 T. Expansion (x10⁶/℃)
I-300	Flange	over 420	34	0.7
	Web	over 350	25	
F-1000		over 400	29	0.7

→ 撓度限制
Deflection Limitation

试行设计・試設計　Trial Design　Span 16 m



荷载实验・載荷試験