Economics of FRP for Reinforcing and Prestressing Concrete

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"I'm going to tell you a fairy story …"

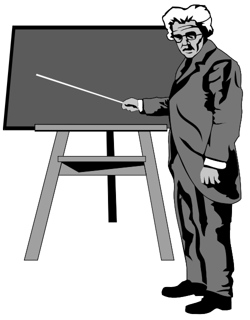
"Once upon a time …

there was a young man …

who was looking for a new research topic."

An ancient professor said:-

"Do you want to do research on plastic prestressing tendons?"



Plastic?

- Plastic coffee in plastic cups
- Didn't seem like an engineering material to me!

"How strong are they?"

"21 grams per denier."

But, 21 grams per denier > 2000 MPa

- Stiffness comparable with steel
- Very little creep
- Durable
- Light
- Already in production

So we were talking about a serious engineering material

Rust!

Ynys-y-Gwas

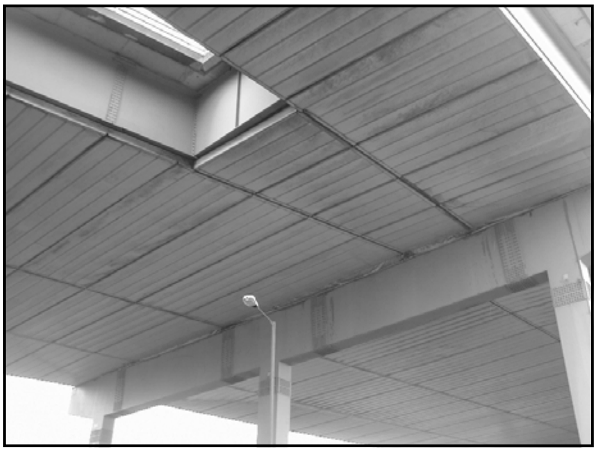
Fibres for Composites

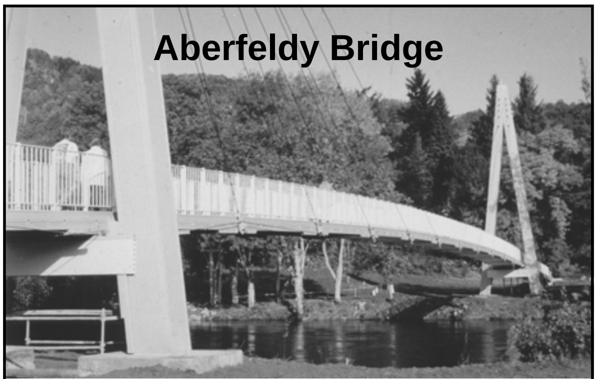
- Carbon
- Glass — Low modulus but cheap
- Aramid
- UHMP — Cheap but creeps
- PBO — Good but expensive
- Polyester — Low modulus & creeps

Naval Minehunters

Hull made from composites

High Speed Train cab unit made from GFRP





Aberfeldy Bridge

Will FRPs *ever* be economic in concrete?

Cost/unit force - 2004

Prestressing steel	1	7-wire strand
Reinforcing steel	3	plus bending
GFRP pultrusion	6	straight
Aramid fibre	4	fibre only
Aramid rope	12	+ terminals
AFRP pultrusion	12	straight
CFRP pultrusion	12	straight
PBO	15	fibre only

Carbon

- **Expensive**
- **Very brittle**
- **Cannot be used without resin**
- **Anchoring very difficult**
  - **No reliable, simple and cheap system exists**

Box Lane Footbridge

First bridge with all stay cables made from CFRP

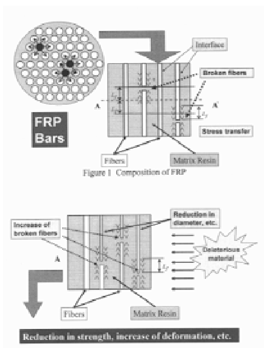
Dintelhaven Bridge

Concrete box girder with a main span of about 185 m, four (external) tendons each with 91 carbon fibre reinforced wires (5 mm diameter).

In tests at TNO anchorage failed due to stress-rupture in resin at 65% breaking load

Glass

- **Cheap(er) so first to be adopted**
- **Stress rupture remains main problem**
- **Alkali attack in concrete**
- **Fatigue in fibre**



Failure mechanism
Involves both matrix and resin

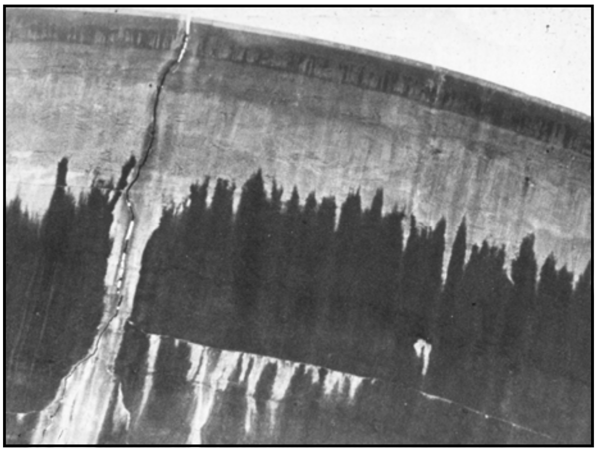
Aramid

- Looks to have disadvantages

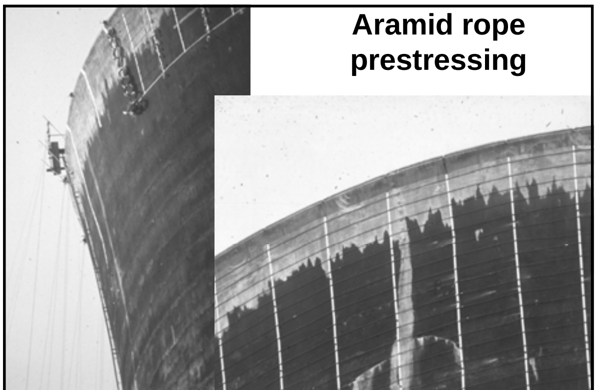
but:-
Tougher, so doesn't need resin
Anchorage can be fully effective
Several varieties exist

Aramids can be anchored without resin

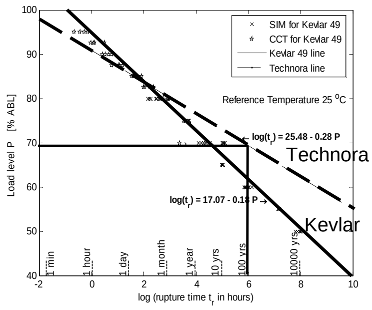
Thorpe Marsh Power Station



Aramid rope prestressing



Stress Rupture results

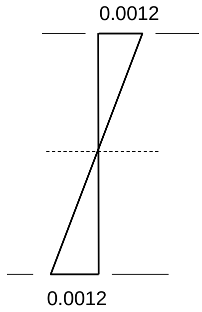


Internal flexural reinforcement?

- **GFRP not stiff enough**
- **AFRP – durability concerns**
- **CFRP – too expensive**

Niche application for GFRP where durability is a prime concern and stiffness not needed

- **exposed sea structures**
- **some ground structures**

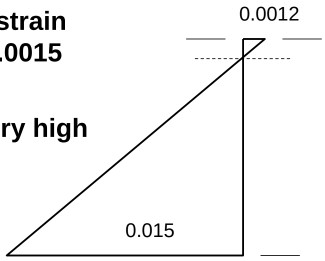


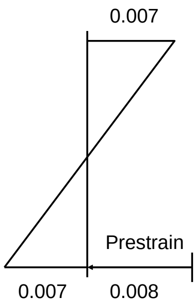
Concrete reinforced with steel reinforcement

Gives good strain distribution.

Beam reinforced with an FRP with strain capacity of 0.0015

Neutral axis very high





Section prestressed with FRP
and enhanced concrete strain capacity

"Let's do the simple thing first"

- **Reinforcing is easy**
- **Prestressing is hard**

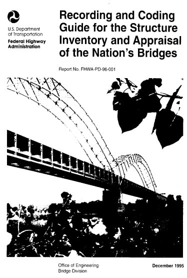
"Let's build a prototype in reinforced concrete"

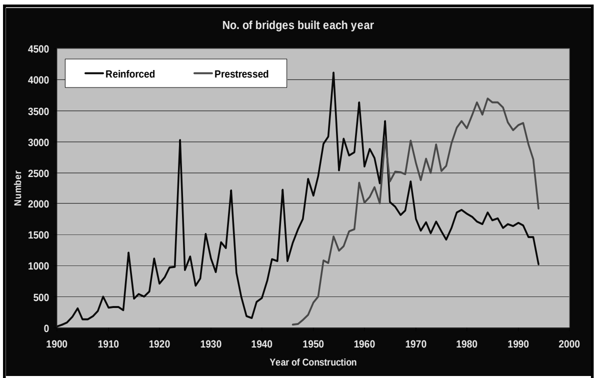
- **But FRPs are not sensible materials for reinforcing**
- **So the prototypes look like silly structures**
- ~~**Therefore FRP produces silly structures**~~

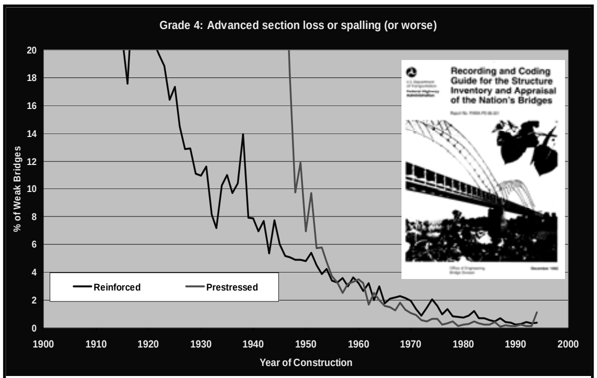
~~**"FRPs are not worth using"**~~

Study of the US Bridge Stock

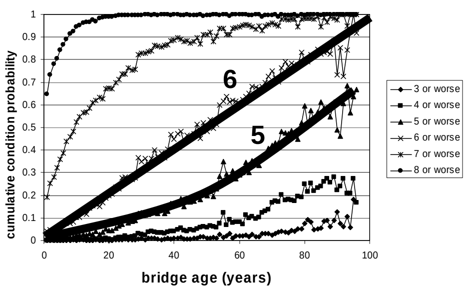
- Bridge condition assessment data (2002) from US Federal Highway Administration
- Sample consists of 257,235 concrete bridges
  - 137,961 RC
  - 114,795 PSC
- Condition of bearings, joints, paint etc. excluded from the data.
- Scale 0-9
  - 9 for excellent
  - 0 for failed condition



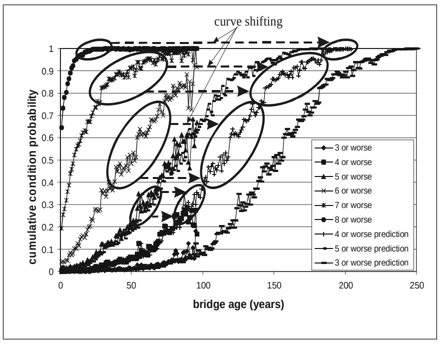




Project onto condition probability scale

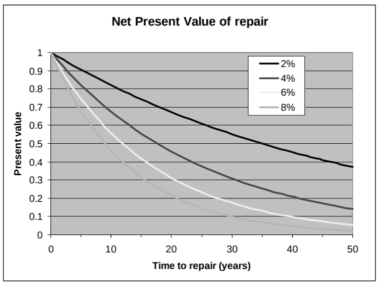


Predict the future



A condition-6 bridge is a condition-4 bridge waiting to happen!

Whole life costing



Discount rate is crucially important in determining current value of future repair

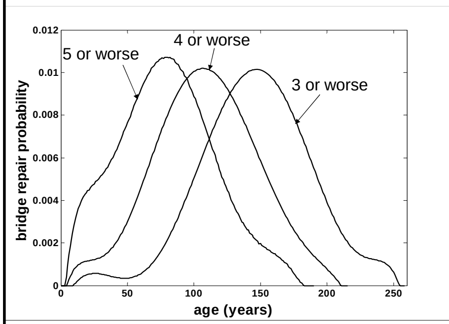
Should be interest rate less inflation

Discount Rates set by Governments

- **Discount rates often chosen much higher than real interest rates, or inflation**
- **Has the effect of making "cheapest first cost" appear also to be "cheapest whole-life cost"**
- **Politically acceptable since it keeps down taxes now**

"Of course we use whole-life costing!"

Bridge repair probabilities



Most bridges won't need replacing for 50 years.

Not even whole life costing justifies use of FRP!

What costs to include?

- The actual repair costs are usually small
- Traffic delay costs are huge
- These costs overwhelm all other costs if taken into account properly

Traffic-Model Observations

- **User-delay costs**
  - **largest portion of the life-cycle-costs**
- **Justify much higher initial costs**
  - **even when they occur much later**
- **Choice of repair method**
  - **should be based on time, rather than cost**
- **User-delay-costs can be high for any road type**
- **Decisions depend on "Who pays for traffic costs?"**

Who pays for this?

Contractor?
Driver?
Road owner?
Society?
State?

Economic?

Even when using most effective materials in most logical way

FRPs only economic if:-

- Used for prestressing
- Whole-life costing is adopted
- Realistic discount rates used
  - < (inflation + 2%)
- Traffic delay costs taken into account

Conclusions

- **Considerable present value in adopting strategies that make bridges more durable**
- **The additional costs of using FRP would be small in comparison to the total cost**
- **Asymmetry of time:-**
  - **We won't spend money in 2009 to save money in 2039**
  - **But we grumble about people not building durable structures in 1979**

“What is the principal selling point?”
  “Durability”
“When do I spend the money?”
  “Now”
“When do I get the benefit?”
  “30 years time”
“Forget it”