Flexible arch system for constructing sustainable concrete arch bridges and tunnels

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MASONRY ARCH BRIDGES

- AESTHETIC
- DURABLE
- STRONG

BASIS OF NEW CONCEPT

TRANSPORT & INSTALLATION

FLAT PACK

EASILY LIFTED

BUT

REQUIRES

- Precast
- Polymeric reinforcement
- Individually cast voussoirs

NO CENTRING

CENTERING £
Basic Concept

Quote from Senior Bridge Engineer

“Most significant advance in Arch Construction since early 1900’s”
Why are there no new arch bridges?

Challenge: Produce an Innovative solution

- Develop an arch with all the desirable characteristics of a Traditional Masonry Arch but less labour intensive and without the need for centring
- Must be as good as a Masonry Arch to make concept more acceptable as few of us like to be 1st to use a new product
Centring Details
Is there a market?
- Over 60,000 arch bridges in UK
- Many need repair, strengthening or replacement

Solution may be simple but required:
- 12 years of laboratory research leading to a patent
- 5 years of R&D with a selected prefabricator
- Attention to detail/quality but cost competitive
Method of Construction

(a) Construction of arch unit using precast individual voussoir concrete blocks

(b) Monolithic Construction of arch unit using precisely made wedges
Method of Construction

(a) Construction of arch unit using precast individual voussoir concrete blocks

- Concrete durability
- Accurate voussoirs
- Reinforcement location
- Two stage process

(b) Monolithic Construction of arch unit using precast wedges

- One stage process
- Wedges impracticable
- Concrete quality
- Reinforcement displaced
- Formwork removal
Concept influenced by Experience

- **Bridge Design – Fenco, Toronto**
  - Concrete hinges – Articulation

- **Structural Research – QUB**
  - Shear in reinforced concrete
  - Aggregate interlock – Shear transfer

- **Durability Research – QUB**
  - Quality – precast concrete
  - No corrodible reinforcement
Concrete Hinge
Shear in compression zone

Aggregate Interlock

Dowel Action
Experimental Validation

- Full scale tests – deformations/strains
  - Stability: 5 x 2, 15 x 3. (meters)
  - Strength: 5 x 2, 10 x 2, 15 x 3. Max 74t (concrete)

- Model tests
  - Third scale: 5 x 2, 10 x 2.
  - Conventional backfill vs Concrete
  - Loading to ultimate, over 74t on conventional backfill
Load test on arch unit
Full scale test
Sequence of pours

Actual

Preferred
Load vs deflection; Third point loading of composite system

- Load (psi)
- Deflection (mm)

- Vert 3rd right
- Perp 3rd right
- Mid point
- Vert 3rd left
- Perp 3rd left
Single unit test
Analysis using ‘ARCHIE’

- Arch unit
- Thrust line
- Loading
- Passive pressure
- Backing material
Stress distribution using FEA


Step: "apply load", third load 80kN
Increment 175; Step Time = 0.9344
Primary Var: S, Mises
Deformed Var: U Deformation Scale Factor: +1.000e+00
## Paragrid material tensile strength details

### Table: Tensile Strength of Paragrid Materials

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Tensile strength of material from manufacturer (kN/m)</th>
<th>Tensile strength of material from test results (kN/m)</th>
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<tr>
<td>150/15</td>
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<td>100/15</td>
<td>100</td>
<td>43.6</td>
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</table>
Acceptable Factor of Safety for polymeric reinforcement during lifting

‘FlexiArch’ stable under concrete and granular backfill

Analytical predictions conservative
Tievenameena Bridge
Tievenameena Bridge
Tievenameena Bridge
Tievenameena Bridge
Tievenameena Bridge
Tievenameena Bridge
Tievenameena Bridge
Newtownabbey
Newtownabbey
Reclaimed brickwork
Advantages of ‘FlexiArch’

- Cast horizontally, flat pack delivery to site
- Simply / speedy installation as no centring
- Durable / precise precast conc. voussoirs
- No corrodbile reinforcement
- Cost competitive with RC alternatives
- Watercourse / track not disturbed during construction
Anticipated applications

Road Widening

Flexi Arch
Anticipated applications

Multi-Span
Anticipated applications

Longer Spans
Skew ‘FlexiArch’
Skew ‘FlexiArch’
Skew ‘FlexiArch’
Skew ‘FlexiArch’
Increase range of spans

- Initially 3m to 10m
- Successfully constructed 15m x 3m
  - Tests completed 2009
- Consider 20m plus achievable if:
  - Adequate crane capacity
  - Suitable transport
‘FlexiArch’ precast concrete lining

- Formed to fit inside arch soffit
- 1 m widths placed on extended sill beam and jacked horizontally into position
- Gap between grouted
- Non circular geometry viable
- No corrosion risk – sustainable!
- Reduced flow area – minimum thickness!
Pseudo elliptical ‘FlexiArch’
Concluding Remarks

Capital vs Life Cycle vs Whole Life Costs

- Traditional Masonry Arch
- Stone Clad FlexiArch
- Concrete Finish FlexiArch
- Beam Alternative

- Time:
  - 40 years
  - 80 years
  - 120 years

- Cost

Repair
Concluding Remarks

- Precise arch geometry without centring
- Assembly of precast bridge units << 1 day
- Minimal disruption to river / track
- Comparable initial capital cost
- Very durable, no corrosible reinforcement
- Minimum total life cycle cost
- ‘FlexiArch’ can greatly enhance use of short / medium span arch bridges
- Ideal for retrofit and strengthening
‘FlexiArch’
Research & Innovation
Prof. Adrian Long
To promote entrepreneurship in the workplace you must have freedom to pursue your own ideas

Staff 15% of time on own ideas!

If you put fences around people you get sheep!

Tolerant attitude to mistakes!
Innovative Process

- Identify/Encounter problem
- Apply relevant knowledge/experience
  (Engineers ideal as thrive on problems)
- Innovative solution/opportunity
Asking Key question helps identify the problem

- G. Millington – Flight to Belfast
- Why are there no new arch bridges?
  - Strong horses – lorries
  - Aesthetic
  - Durable > 2000 years
  - Low maintenance
- Gordon identified the problem
10 years later patented a Flexible concrete arch which did not need centering

After further 5 years, R&D with Macrete 15 ‘FlexiArch’ bridges (4m–14m) built in UK/Ireland

Identify problem– invention– commercialisation
Innovation is not an initiative that can be easily copied
Takes time & effort to establish
Even more effort to practice
Fragile
May take decades to build but only months to destroy
Technical personnel who understand the technology and were in close contact with customer applications were the main catalyst to deliver innovation.
Delivering Innovation

- Stubborn persistence, courage, curiosity and patience
- Creative use of failure – revisiting old ideas
- Supportive & hands-on management (sponsors)
- Individual initiative (product champions) together with cross functional teams
Thank you for your attention