A Flexible Concrete Arch System

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Abstract

Masonry arch bridges have been used for 4000 years and today they still play an important role in the road network of the UK and Ireland. The rapid rise in the labour cost associated with their construction has made them less cost effective than their reinforced and pre-stressed competitors. However, many of these relatively recent concrete bridges have had to be repaired due to corrosion or replaced due to lack of load carrying ability to meet European loading standards [1, 2].

In the repair and replacement of bridges, environmental and aesthetic consideration must also receive special attention and account taken of the design and durability advice given in the UK by the Highway Agency [3] and other European standards. The arch form, plain structural elements and the elimination of corrodbile reinforcement is recommended.

This paper describes the development of a novel flexible concrete arch system which requires no steel reinforcement in the long-term or centring in the construction phase. The arch is constructed from a ‘flat pack’ system by use of a polymer reinforcement for carrying the dead load but behaves as a masonry arch once in place.

Keywords: Arch, Concrete, Precast, Un-reinforced
INTRODUCTION

Masonry Arch bridges are one of the oldest types of bridge construction and have been around for thousands of years. They were originally built of stone or brick but are now built of reinforced concrete or steel. The introduction of these new materials allows arch bridges to be longer with lower height and can either be cast on site or manufactured as precast. However, a common problem with such bridges is corrosion to reinforcement, which further leads to their high repair and maintenance cost. Therefore, a bridge with no or low amounts of reinforcement is a matter of special attention for Civil Engineers. Such an arch bridge is being developed under a Knowledge Transfer Partnership (KTP) between Queen’s University and Macrete with planned completion in two years. The prototype arch unit has been manufactured in Macrete and lifted successfully. The unit was analysed for actual loading conditions using the software package ARCHIE [4]. The commercial feasibility, construction and analysis of the prototype are discussed in this paper. Furthermore, details of a full scale arch bridge unit are also highlighted.

2.0 A MARKET NEEDS ANALYSIS

A market needs analysis was completed for the commercial feasibility of the proposed bridge arch system with the help of the sales and marketing team at Macrete Ireland Limited. It was found that the DRD, NI (Department of Regional Development, NI), the UK highways Agency and railways are the potential clients. Almost 3500 bridges need to be replaced throughout the UK, which is equivalent to a cost of £80M. This suggests that there is a potential market for replacement arch bridges using this method.

3.0 DETAILS OF ARCH SYSTEM

Construction of a masonry arch bridge involves centring, resulting in huge labour costs and slow progress. The method of construction of precast reinforced concrete (RC) arches is more straightforward. However, deterioration of the structure due to corrosion and difficulties in transportation are practical problems in the construction and maintenance of existing precast RC arch bridges. Queen’s University Belfast (QUB) in collaboration with Macrete Ireland Limited is developing an arch bridge made only of precast concrete un-reinforced blocks. The two proposed forms of construction are shown in Figure 1.
The precast concrete blocks can be cast individually or together with the insertion of a wedge former. The blocks are held together by a Polymeric Reinforcement which supports the dead load of the system to permit lifting of the flat cast blocks into an arch unit. This is then positioned onto foundations or anchor blocks. Furthermore, the arches can be easily transported to site flat on trailers. This arch system does not have any main steel reinforcement and will not be subject to corrosion.

The project was started by manufacturing a trial arch (5m clear span and 2m rise) using precast concrete blocks of 0.35m width and 200mm deep with a 40mm in-situ screed. For the next unit, the width of arch unit was increased from 0.35m to 1.0m wide precast concrete blocks to improve the lateral stability and robustness of the individual arch unit. The 1.0m wide arch is described as the first prototype arch in this paper. The polymeric reinforcement used in for manufacture the arch was Paragrid® [5]. Control samples have been tested for all the components of the arch unit, that is, the concrete and polymeric reinforcement material properties.

3.1 Finalisation of the Paragrid material

The manufacturer’s data sheet indicates that the material code gives the longitudinal and transverse tensile strength in kN/m. Thus 100/15 material has a tensile strength of 100kN/m. Table 1 summarises the data for material tests carried out at Queen’s University. The differences between target and actual strengths may be accounted for by the use of BS EN ISO 10319:1996 Standard Test Method for Tensile Properties of Geotextiles by the wide strip (200mm nominal) method used for data sheet strengths where as the tensile tests were carried out in QUB on a long sample (900mm) and having a width smaller than 200mm, which was double folded at the end for gripping. The first 0.35m wide trial arch used the 100/15 material but the 1m wide prototype used the 150/15 to improve the overall factor of safety during the construction phase.

3.2 Precast Concrete Blocks

Moulds were prepared for manufacturing the concrete voussoir blocks and a standard C50/20 concrete mix was used. The cube test results of the mix are presented in Table 2.
Fig. 2 Sample of Paragrid Material

Table 1: Paragrid properties from the test results at QUB

<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>
</tr>
</thead>
<tbody>
<tr>
<td>a 100/15</td>
<td>100</td>
<td>43.6</td>
</tr>
<tr>
<td>b 150/15</td>
<td>150</td>
<td>72.2</td>
</tr>
</tbody>
</table>

Table 2: Cube Test Results of the Mix used for the Manufacture of Precast Concrete Blocks

<table>
<thead>
<tr>
<th>Nr of days</th>
<th>Compressive strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>28</td>
<td>55</td>
</tr>
</tbody>
</table>

3.3 Manufacture of Arch Unit

Thirty-five concrete blocks were made. Twelve concrete blocks were used to make two test beams and the remaining blocks, twenty-three in total, were used to make a 5m clear span arch unit. The test beams and arch unit were made as the procedure described earlier. The aim of the test beams was to obtain information about the strength of the actual arch unit cantilevered during lifting and particularly the advantages of the stronger Paragrid®. The beams were tested in QUB and results are summarised in Table 3. The results were found satisfactory and therefore, the prototype arch unit was lifted in Macrete as shown in Figures 3.

Table 3: Ultimate Load Test Results for the Test Beams

<table>
<thead>
<tr>
<th>Arch Load Test No.</th>
<th>Applied Ultimate Load (Excluding the self weight) (kN)</th>
<th>Ultimate Moment (including the self weight) (kNm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.0</td>
<td>7.5</td>
</tr>
<tr>
<td>2</td>
<td>16.0</td>
<td>8.3</td>
</tr>
</tbody>
</table>
Fig. 3: Lifting procedure for the prototype arch

a. Arch Unit before Lifting

b. Arch Unit during Lifting

c. Arch Unit after the lifting
3.4 Detailing Requirements

A 1m wide prototype arch was manufactured and a few problems were encountered at the time of testing of material and lifting of arch unit.

Positioning of the end blocks of the arch unit was found to be difficult at the time of the trial erection. Therefore, it was decided to provide steel hooks on the top of the end blocks, which can be pulled outwards horizontally using chains for final alignment of arch unit. Furthermore, it was decided to make a wedge shaped seating (Figure 4) for the arch unit that has the same seating angle as the end voussoirs, which will help it to provide and maintain its design geometrical shape.

The Paragrid material was found to be stretched between the precast concrete joints, which may explain the deformation in the shape of the arch unit at some locations during lifting. Therefore it was suggested that the arch unit should be designed with some dimensional tolerance to accommodate the stretching of Paragrid material rather than assuming the joint is a rigid hinge.

Therefore the top layer of the prototype was chipped off and recast by considering all the points mentioned above. The second lift of the arch was completed 2 weeks after the casting and it was successful (Figure 4). Hence, planning for stability testing during the construction phase and a full scale bridge test under live traffic load is on going and due for completion early next year.

![Fig. 4 Second Lift of Arch Unit Using Tapered Seating Units](image)

3.5 Analysis of Arch Unit

Analysis of the arch unit was conducted using ARCHIE, a numerical analysis package which allowed for interaction with the arch backfill. It is important to note that this software is also used by the DRD Road Service for load assessment analysis of their arch bridges [6, 7]. Therefore, validation of the manufactured arch unit using ARCHIE was an important task in this project. The arch unit was analysed under different wheel loading conditions and various observations were made. A typical case of arch unit analysis is shown in Figure 5. An arch unit of the required geometry can be created and loaded with the standard wheel loads. A line of thrust is indicated in Figure 5. Under design loading, the position of the thrust line in the arch unit gives information about the stability of the unit. Furthermore, it was found that the
thrust line is affected by the application of Passive Pressure (PP) and Backing Material (BM) at the springing level (Figure 5). Therefore, for a particular loading condition, using a suitable value of PP and BM, the required thickness of the arch unit can be found.

![Fig.5 Analysis of Arch Unit using ARCHIE Software](image)

### 4.0 FUTURE AIMS

#### 4.1 Stability Test

A test to check the stability of the arch during the backfill operation is scheduled at the end of November 2005. The arch unit will be set on the specially designed Anchor blocks (Figure 6). The arch will be shuttered all around using retaining wall units and the backfilling will be completed using either granular backfill or a lean concrete mix. The performance of the unit will be assessed by monitoring the strain and deflections at various positions along the arch profile.

#### 4.2 Full Scale Arch Bridge Test

A full scale arch bridge test (5m wide bridge) will be constructed in Macrete Ireland Limited after the stability test and is currently scheduled for early next year. The proposed arch bridge system is shown in Figure 7. It will comprise of five arch units, two spandrel wall units and standard L retaining wall units. Loading will be via truck of known load moving over the bridge. The performance of arch bridge will be assessed by monitoring the strain and deflection of the arch and spandrel walls. It is also intended to carry out a finite element analysis prior to testing and compare predicted behaviour with actual behaviour.
References

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