Loading to failure of an Archtec strengthened brick arch using Cintec Multi-bar anchors

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LOADING TO FAILURE OF AN ARCHTEC STRENGTHENED BRICK ARCH USING CINTEC MULTI-BAR ANCHORS

ABSTRACT

This report been produced by TRL Limited under contract to Cintec International Limited to describe a load test to failure on a three-ring brick arch bridge. The arch was constructed with layers of wet sand between the three rings to simulate ring-separation. The bridge was then strengthened using the new Multiple Bar Cintec Anchor System. The test was performed to determine the increase in load bearing capacity of the strengthened arch bridge.

The arch was loaded at one quarter-span position. The maximum load reached was 448 kN. At this load the maximum vertical displacement under the load was 21.9 mm. This point was defined as "failure". The load was then removed and later re-applied and continued under displacement control until the arch collapsed. The mechanism was the development of hinges at the quarter points and springings with some crushing of masonry and shearing at the springing nearest the load.

The results are compared with those obtained from two previous tests. Firstly on an unstrengthened arch bridge (Sumon, 1997), and secondly on an arch bridge strengthened using Cintec Archtec anchors (Sumon, 1998).

1. INTRODUCTION

A test rig was been built in the Structures Laboratory at the Transport Research Laboratory to investigate this. The rig enables the construction of a 5 m span, 2 m wide, three-ring-brick arch which can then be tested to failure.

The arch was constructed without spandrel walls and no road surface, which had been left out to reduce the number of parameters being studied. Type 2 sub-base backfill was then placed and compacted. The fill was retained by a steel box, which has been designed not to restrain movement of the arch ring. It was then strengthened (see Section 3) and tested under controlled environmental conditions.

The arch was constructed on 27-29 April 2001, strengthened between 14th and 28th May 2001 and tested on 28 June 2001.

2. ARCH CONSTRUCTION

The arch had layers of sand between the rings rather than mortar to simulate ring-separation (delamination). Ring-separation is one of the common defects found in many old arch bridges. A brief account of the construction of the arch is given below.

The procedure was to build one ring at a time, on a steel centring, working up from the springings to meet at the crown. Handmade bricks were used, which best simulated those used in pre 1900 arch bridges. The bricks were weak by modern standards and in some cases fissured and distorted. In accordance with current practice, cement, lime and sand were mixed to give a cement/lime mortar. The mortar was mechanically with the minimum amount of water added to give the required workability. The nominal width of mortar used in the joints was 10 mm though some tolerance was allowed near the crown to ensure that the arch was completed without the need to cut bricks. The edges of the sand-filled inter-ring joints were pointed with mortar and the whole of the exposed brickwork was painted white to highlight crack formation.

3. ARCH STRENGTHENED WITH CINTEC ANCHOR SYSTEM

Twelve Cintec multi-bar anchors were used to strengthen the delaminated barrel. Fill was excavated approximately 1.2 m from the west-end and 1.4 m from the east-end of the arch to expose the extrados. Then using a long drilling rig, mounted to a purpose built scaffolding fixed to the arch rig, twelve 55mm diameter holes were drilled into the barrel from above. The anchors contained 6xS10 multi-bar stainless steel bars (grade 460) to BS 6744 (Figure 3). All the anchors were installed in 55mm diameter holes and grouted using Cintec Presstec grout in a Cintec fabric sock. Figure 1 gives the general layout and dimensions of the arch bridge. The positions and angles of installation of the anchors are shown in Figure 2, and a cross sectional diagram of the anchors is shown in Figure 3.

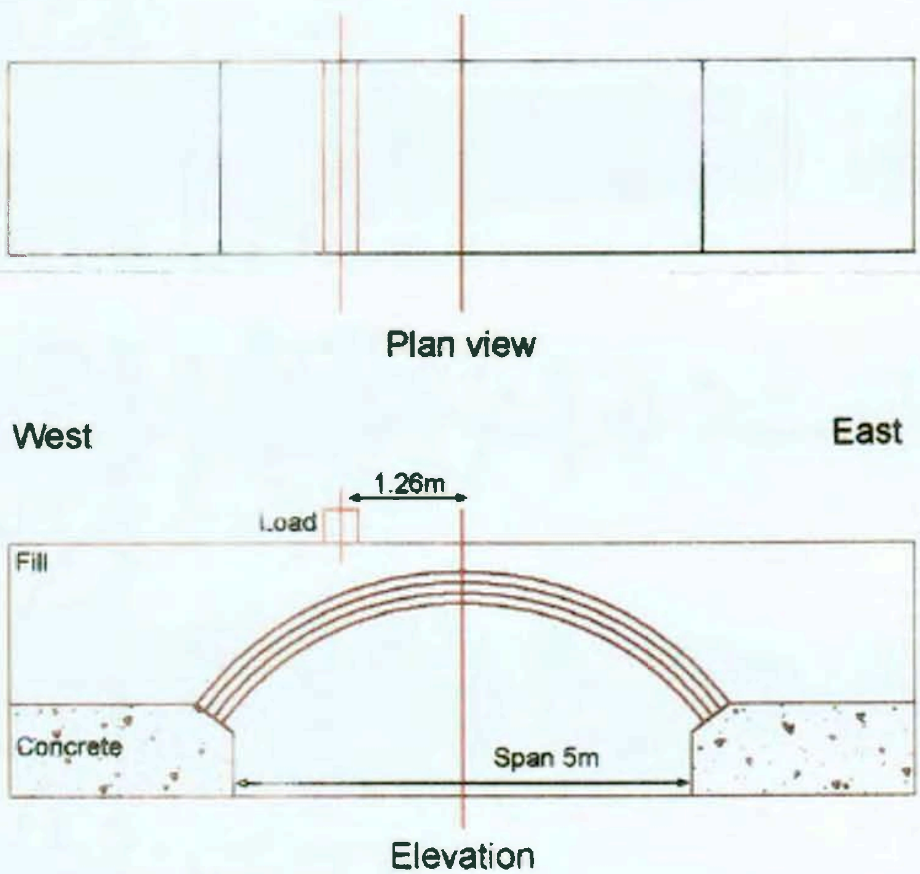

Figure 1. General layout of the arch bridge.

The anchors were arranged in three sets:

- three anchors were drilled and grouted into the abutment on the west side (Abutment Anchors),
- three anchors were drilled and grouted into under the east side third span point (Compression Anchors) and
- six anchors were drilled and grouted under the quarter point (Primary Sagging Anchors). One of the primary sagging anchors was equipped with electrical resistance strain gauges

4. MATERIALS USED

4.1 Bricks

Swanage Heathered Handmade type bricks were used. A mean compressive strength of 10 N/mm2 was obtained from the manufacture's literature.

4.2 Fill

The fill used for the back fill was a Type 2 sub-base material.

5. INSTRUMENTATION

5.1 Electrical resistance strain gauges

The second (of 6) Primary Sagging Anchor ("Smart Anchor") from the south side was equipped with strain-gauges. Twenty CEA-Series electronic resistance strain gauges were installed in pairs at 250mm intervals starting at 125mm from each end.

5.2 Displacement Gauges

Nine linear variable differential transformers (LVDTs); displacement transducers were attached to the arch soffit to measure vertical movement. There were three at each of the quarter-span crown (mid-span), and three-quarter-span positions. At each of these positions one gauge was attached on the longitudinal centre-line and one at each edge of the arch Solartron "B" series transducers were used. These have a stroke of ± 25 mm with a non-linearity of <0.25 %.

Table 1. Displacement gauge designations

	North	Centre	South
East ¼ point	1/4N	1/4C	1/4S
Mid span	1/2N	1/2C	1/2S
West ¼ point (load position)	3/4N	3/4C	3/4S

5.3 Data Recording Equipment

The vibrating wire strain gauge data was recorded using a Datataker system. The data from the LVDTs was acquired using an Orion 3350 data logger system. During loading of the arch data was acquired at approximately 2-second intervals. Data from both systems was transferred in real-time to an in-house logging program running on a PC. Selected data was plotted in real time and displayed simultaneously on four monitors, two for control of the test and two for informing the audience of test progress.

5.4 Crack monitoring

The formation and propagation of the cracks was highlighted on the south face of the structure in ink, on the south face only. The load at which each crack first appeared and its length were marked. These were recorded photographically (see accompanying CD). The arch ring voussoirs of the inner, central and outer rings of brickwork were numbered consecutively from 1 at the eastern end to 78, 81 and 85 respectively for identification

6. LOAD TESTS AND RESULTS

6.1 Load test to failure

The objective of this test was determine the load bearing capacity of the arch and the effectiveness of the applied strengthening method. The load was applied at the quarter-span on the west-end (see Figure 1) using a 3000 kN hydraulic jack. This bore on a 317mm wide 'I' section spreader beam that spanned the full width of the arch fill. The structure was loaded in approximately 10 kN increments. The resulting strains and displacements were recorded at each increment. The arch was loaded until it could not sustain any further increase in load. Initially the test was load-controlled. When the displacement began to increase more rapidly a switch to displacement feedback was made to give better control of the failure.

A plot of the load versus displacement from the LVDTs can be seen in Figure 3.

A comparison with results obtained from the unstrengthened arch and the previous Cintec arch tests are given in Table 2 below.

Table 2: Summary of load tests to failure

Test to failure	Load to failure (kN)	Factor	Max. disp. @ max. load applied (mm)	Max. disp. after load removed (mm)
TRL Arch	200	1.00	27.40	23.40
Previous Cintec Arch	410	2.05	16.50	11.40
Cintec Arch	448	2.25	21.93	17.95

The first cracks were recorded around the crown circumferentially between the top/middle, and middle/bottom rings at a load of 80 kN in the region of middle ring voussoir 74 which was between the load line (at outer ring voussoir 61) and the springing (85). Initially very little damage was observed under the load-line. Increasing ring-separation in the region of voussoir 74 was the most visible sign of damage throughout this phase of the loading.

Damage continued to occur as the load was increased and hinges began to form at the load-line, at the opposite quarter span point and nearer to the springings on the load-line side. The arch was loaded until significant creep and plastic deformation had occurred, and it could not sustain further load. The maximum load applied to the arch was 448 kN. The load was then removed and there was some elastic recovery but there was still considerable deformation (Figure 4). This suggests that the strengthening method had some elastic properties. The maximum displacement was 21.93 mm which dropped to 17 95 mm when the load was removed.

Table 3. Min and Max data for arch test to failure.

LVDT's

	kN	mm								mm
	Load	1/4N	1/4C	1/4S	1/2N	1/2C	1/2S	3/4N	3/4C	3/4S
Max	448.20	5.33	5.29	5.36	5.40	5.27	5.29	0.00	0.00	0.00
Min	-0.79	0.00	0.00	0.00	-0.30	-0.33	-0.30	-27.01	-26.48	-24.57

Electrical resistance strain gauges

	microstrain									
	ERG1	ERG3	ERG5	ERG7	ERG9	ERG11	ERG13	ERG15	ERG17	ERG19
Max	116.00	128.00	197 00	43.00	34.00	3.00	4.00	197.00	718.00	258.00
Min	1.00	0.00	1.00	78.00	-226.00	-406.00	-308.00	-94.00	-4.00	-1.00

	microstrain									
	ERG2	ERG4	ERG6	ERG8	ERG10	ERG12	ERG14	ERG16	ERG18	ERG20
Max	21 00	227 00	262 00	458 00	1310 00	2019 00	1163 00	156 00	4 00	29 00
Min	1.00	1.00	63.00	2.00	-1.00	-1.00	-3.00	-8.00	-299.00	-189.00

6.2 Test to collapse

All surface mounted instrumentation was removed prior to this phase of the test to avoid damage.

The arch was loaded to collapse under displacement control. The load was re-applied and reached a maximum of 421 kN before reducing steadily. The arch was pushed down at the load-line and up at the crown, and was breaking up internally as indicated by the rapid dropping of load. A high level of creep and plastic deformation was taking place. The ring separation in the region of voussoir 74 increased substantially. The arch remained held together by anchors until total collapse occurred by rotation at the hinges combined with some shearing at the western springing.

7. CONCLUSIONS

The following conclusions may be drawn from the test carried out:

- The load bearing capacity of the arch was increased by a factor of 2.24.

- The first crack and hinge did not occur under the load-line.
- The installed anchors delayed the formation of hinges.
- The anchors added considerable strength to the bridge.
- The arch failed in a gradual but a ductile manner.
- On unloading the structure recovered indicating some elastic behaviour.
- The bond between the anchor and masonry was found to be good.
- The strengthening was relatively easy to install.

8. REFERENCES

Sumon, S.K. 1997. Repair and Strengthening of Damaged Arch with Built-In Ring-Separation. Seventh International Conference on Structural Faults + Repair-97, held at Edinburgh, p. 69-75.

Sumon, S.K. 1998. Load test to failure on a ring-separated arch repaired using Cintec Anchor System. Unpublished Project Report PR/CE/61/98. Transport Research Laboratory, Crowthorne.

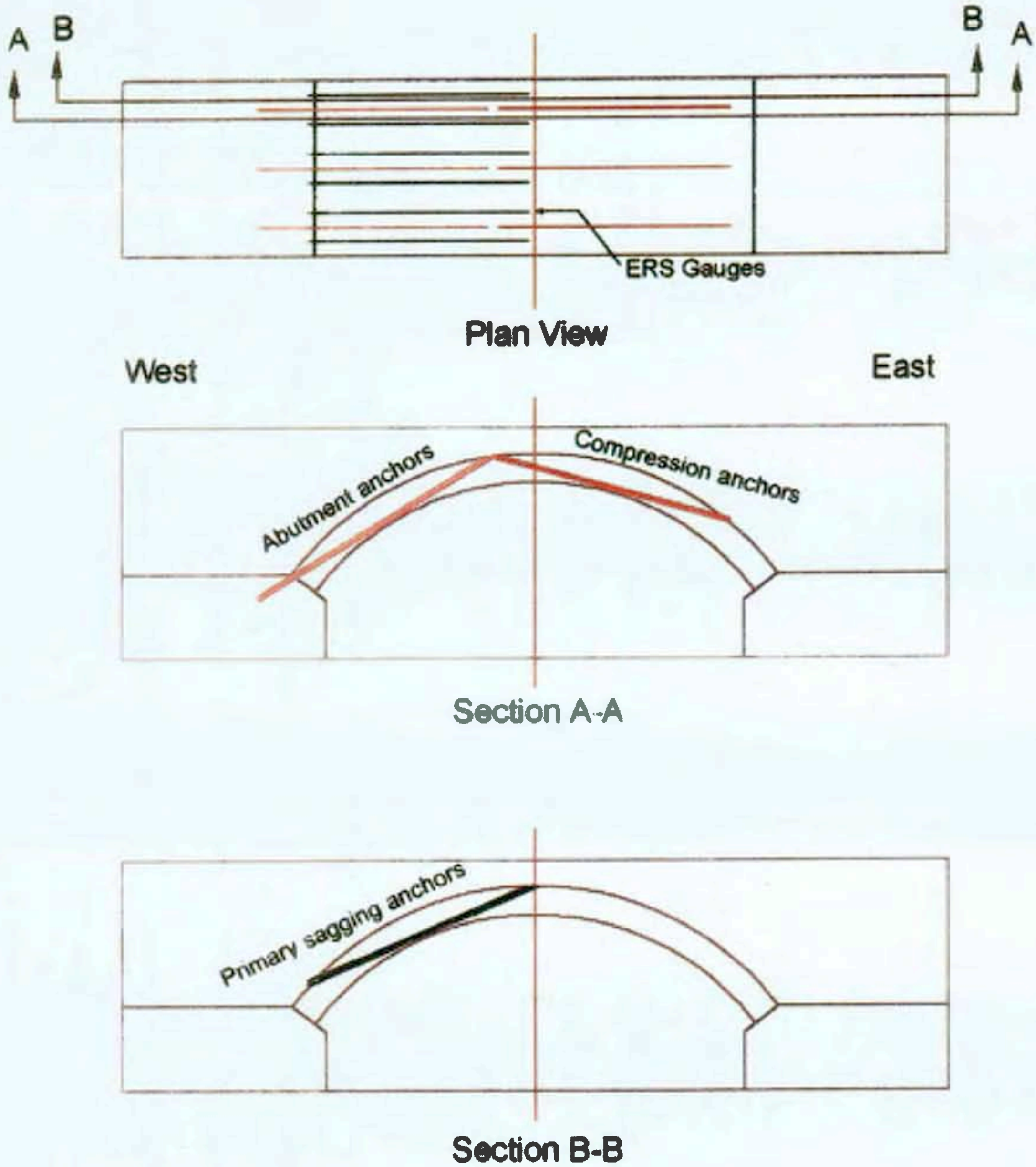

Figure 2. Layout and location of anchors.

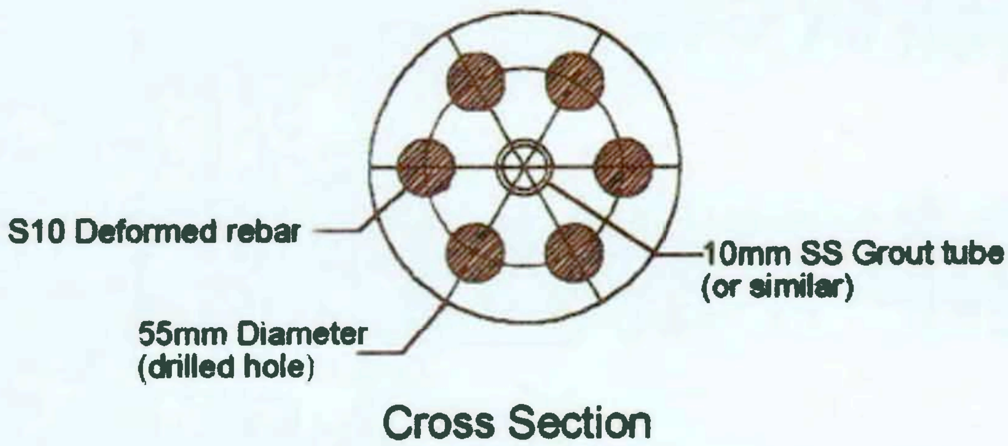

Figure 3. Cross Section of Cintec Multi-bar anchor.

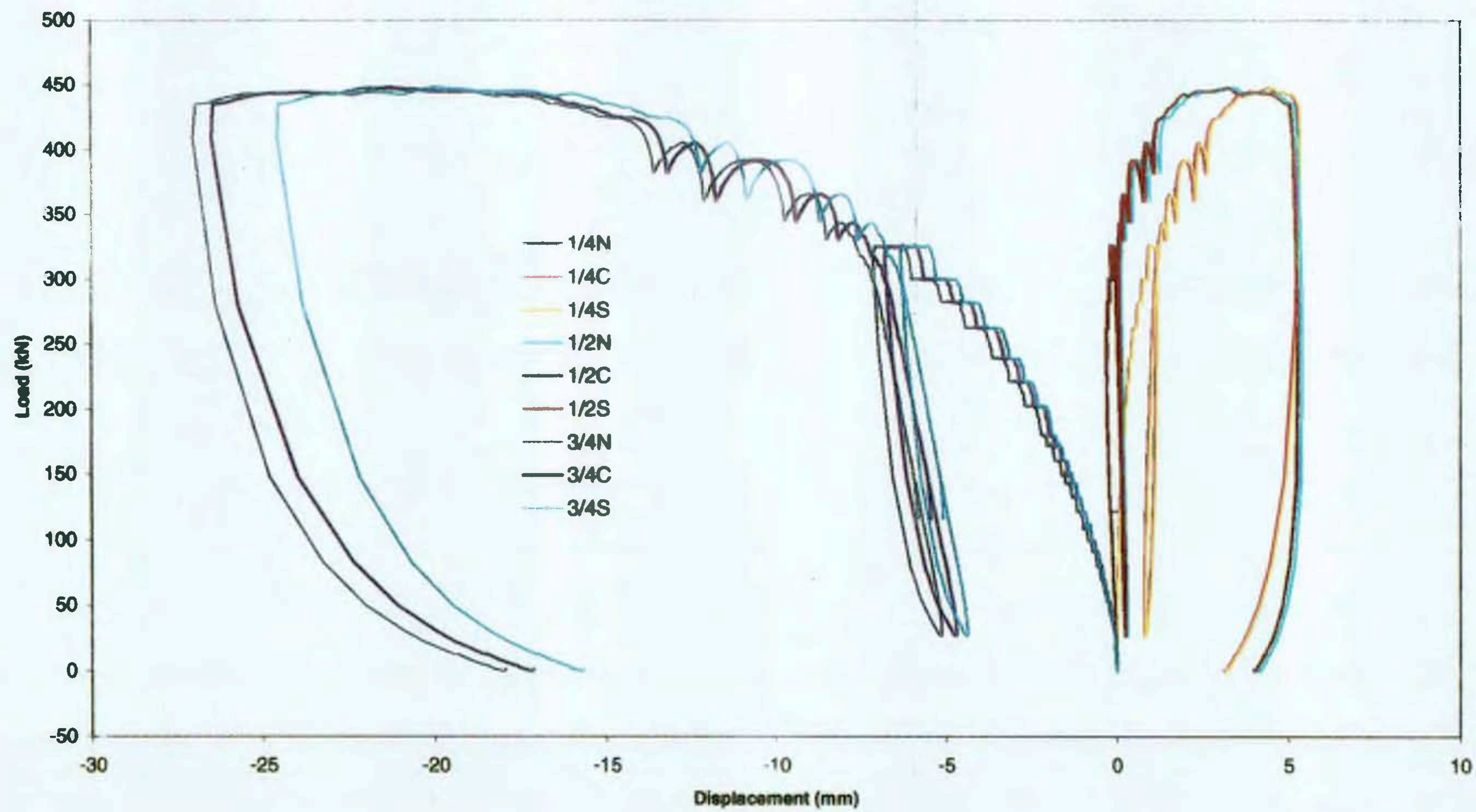

Figure 4. Load verses displacement for LVDT's attached opposite quarter span and under load-line