Load test to failure on a ring-separated arch repaired using CINTEC Anchor System

by S K Sumon

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TRANSPORT RESEARCH LABORATORY

PROJECT REPORT
PR/CE/61/98

LOAD TEST TO FAILURE ON A RING-SEPARATED ARCH REPAIRED USING CINTEC ANCHOR SYSTEM

by S K Sumon

Prepared for:

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LOAD TEST TO FAILURE ON A RING-SEPARATED ARCH REPAIRED USING CINTEC ANCHOR SYSTEM

ABSTRACT

This report describes a load test to failure on a three-ring-brick arch bridge. The arch was constructed with a layer of wet sand between the three rings to simulate ring-separation (delamination). It was then strengthened using the CINTEC Anchor System. The test was carried out to find out the increase in load bearing capacity of the strengthened arch bridge.

Elastic tests were carried out by applying a series of 50 kN point loads and the maximum deflection was 2.2 mm, which was recorded on the edge of arch at the crown. The maximum load to failure, when the arch was loaded at quarter-span, was 410 kN. The arch failed in a gradually but ductile manner with crushing of the bottom brick at the crown which lead to the formation of the first hinge. During the loading to collapse the bottom ring fell away but the rest of the arch remained held together by the anchors. It was eventually collapsed after a further displacement of 200 mm at the load-line. The arch failed by crushing of masonry and a four hinge mechanism.

The results are compared with those obtained from a previous test on an arch that also had built in ring-separation but was not strengthened (Sumon, 1997).

1. INTRODUCTION

Many strengthening methods exist but they have never been tested and compared quantitatively. A test rig has 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 CINTEC arch was constructed without spandrel walls and no road surface, which had been left out to reduce the number of parameters being studied. Backfill was then placed and compacted. The fill was retained by a steel former 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 6-8 November 1997, strengthened on 23 December 1997 and tested on 27 January 1998.

2. ARCH CONSTRUCTION

The arch had a layer 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 working up from the springings to meet at the crown. Handmade bricks were used, which best simulated those used in pre 1900 arch bridges. They were weak bricks by modem standards and in some cases fissured and distorted. In accordance with current practice, cement, lime and sand were mixed to give a traditional lime mortar. The mortar was mixed using a cement mixer 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.

3. ARCH STRENGTHENED WITH CINTEC ANCHOR SYSTEM

Eight CINTEC anchors were used to strengthen the delaminated barrel. Drawing no. B0822A/001 gives the general layout and dimensions of the arch bridge. The positions and angles of installation of the anchors are shown in drawing no. B0822A/002. 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, eight holes were drilled into the barrel. Two anchors (A) were installed through the barrel and into the concrete abutment on the west end. A further four anchors (B) and two (C) were installed which were contained in the barrel; on the west-end and east-end of the arch respectively.

4. MATERIALS USED

4.1 MORTAR CUBES

Nine mortar cubes were obtained in batches of three from the various mixes during construction. The mortar was made and tested according to BS 5628:1978 (BSI 1978). The cement:lime:sand ratio was 1:3:12 and the mean cube strengths obtained were 0.42 N/mm2 and 0.71 N/mm2 at 12 and 28 days, respectively.

4.2 BRICKS

Swanage Heathered Handmade type bricks were used. Tests were executed to BS 3921 British Standard Specification for Clay Bricks (BSI 1985); Appendix D. A mean compressive strength of 10 N/mm2 was obtained from the manufacture's literature.

4.3 FILL

The fill used for the back fill was a Type 2 roadbase material.

5. INSTRUMENTATION

5.1 STRAIN GAUGES

Nine Gage Technique vibrating wire (VW) strain gauges (gauge length = 140 mm) were installed on the arch extrados. Small steel boxes were placed over the gauges to protect them from damage, and the fill material was placed and compacted. A further nine gauges were attached to the intrados on removal of the centring. These were to measure the longitudinal strain profile along the centre-line of the arch. The accuracy of the strain measurement was to within 1 micro-strain.

5.2 DISPLACEMENT GAUGES

Nine linear variable differential transformers (LVDTs); displacement transducers were attached to the arch soffit to measure vertical movement at the quarter-span, crown, and three-quarter-span. In each case one gauge was attached to the transverse centre-line and one at the edge.

Two additional transducers were attached horizontally to the monitor abutment movement. Solartron "B" series transducers were used. They have a stroke of + 25 mm with a non-linearity of less than 0.25 %.

5.3 DATA RECORDING EQUIPMENT

The vibrating wire strain gauge data was recorded using a Strainmanager ST1 system. The data from the LVDTs was recorded using an Orion 3350 data logger system. For consistency the same cabling system was used at all stages of testing.

6. LOAD TESTS AND RESULTS

6.1 ELASTIC TESTS (point load tests) Procedure

To determine the elastic behaviour of the arch a series of single 50 kN point loads were applied to the fill. The load was applied on one quarter of the arch through a loading foot which simulated the area of a heavy goods vehicle tyre. The loads were applied from east to west using a 200 kN hydraulic jack, in this case, from a-f, g-l and m-r, shown in Figure 1.

Two tests were performed one before and one after the strengthening. In the first test only local strain data was obtained, whereas in the second test both strain and displacements were recorded. Generally all gauges returned to their initial position after the removal of the load indicating structure tested in the elastic range. The strain data was not plotted. The influence lines plotted from the displacement data are shown in Figures 2a, 2b and 2c.

The maximum deflection of 2.20 mm was recorded on the edge of arch at the crown. The results from both arches are summarised in Table 1 below:

ELASTIC TESTS	Maximum displacement, at the crown, when applying 50 kN point loads along longitudinal axis (+ ve)		
Load positions:	at centre-line (c/l)	at 0.42 m from c/l	at the edge of arch
TRL Arch	1.61 mm	1.71 mm	3.37 mm
CINTEC Arch	1.05 mm	1.40 mm	2.20mm

Table 1: Values of maximum displacement

6.2 LOAD TEST TO FAILURE

The objective of this test was to find out the load bearing capacity of the arch and the effectiveness of the applied strengthening method. The arch was tested until either hinges had formed or severe damage had occurred. The load was applied at the quarter-span on the west-end (see Figure 1) using a 3000 kN hydraulic jack. The structure was loaded in approximately 10 kN increments. The resulting strains and displacements were recorded at each increment. The formation and propagation of the cracks were recorded. The arch was loaded until it could not sustain any further increase in load.

Again the strain data was not plotted. Plots of the displacement under the load-line, opposite quarter span and crown are given in Figures 3a and 3b. A comparison with results obtained from the unstrengthened arch tested previously are given in Table 2 below.

TESTS TO FAILURE	Load to failure (kN)	Factor	Max. disp. @ max. load applied (mm)	Max. disp. after load removal (mm)
TRL Arch	200.00	1.00	27.40	23.40
CINTEC Arch	410.00	2.05	16.50	11.40

Table 2: Summary of two load tests to failure

Discussions

The first cracks were recorded around the crown circumferentially between the top/middle, and middle/bottom rings on the north face at a load of 100 kN. Initially very little damage was observed under the load-line except the rings-separating mainly due to existing ring-separation. As the arch was loaded further crushing was observed on the bottom ring at the crown, which lead to the first hinge (at approximately 280 kN). The strengthening prevented the first hinge from forming under the load-line and delayed the formation of further hinges.

Damage continued to occur as the load was increased and further hinges formed at the load-line (at =320 kN), around the opposite quarter span (at = 350 kN) and nearer to the springings on the load-line side (at = 350 kN). Thus a four hinge mechanism had formed. 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 410 kN. The load was then removed and the arch sprung back but there was still considerably deformation (Figure 4). This suggests that the strengthening method had some elastic properties. The maximum displacement was 16.50 mm which dropped to 11.40 mm when the load was removed.

6.3 TEST TO COLLAPSE

All surface mounted instrumentation was removed and the knife edge was substituted with 'railway sleepers'.

Discussions

The arch was then loaded to collapse. It was difficult to maintain the applied load once the maximum load of 365 kN had been reached. Here the load could not be increased further as the structure had been considerably damaged during the test to failure. The arch was being pushed down at the load-line and up at the crown, and breaking up internally as indicated by the rapid dropping of load. At this point the loading system was switched over to displacement control. Following this as the displacement was increased the bottom ring started to crush at the crown. There was also high level of creep and plastic deformation taking place. This lead to the bottom ring falling away from the structure (the load at this point was only 11.50 kN), but the rest of the arch remained held together by anchors. Figure 5 and 6 shows the arch just before and just after the bottom ring fell away. This shows the exposed anchors, under the load-line, although considerably bent they are still holding the structure together.

The arch was eventually collapsed by a further displacement of 200 mm at the load-line.

7. CONCLUSIONS AND RECOMMENDATIONS

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

- The load bearing capacity of the arch was increased by a factor of 2.05.
- 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.

Although the test has been successful and a considerable strength increase has been obtained, it may be worth considering testing CINTEC Anchor System in conjunction with the following:

- A delaminated arch that has been stitched.
- An arch soffit that has been partially or completely repaired.
- An arch with no visible defect (for example arch with an imposed load restriction.)

8. ACKNOWLEDGEMENTS

The author would like to express his thank to Nigel Ricketts and the Civil Engineering Resource Centre (CERC) test-team for their involvement and contribution to the programme.

9. REFERENCES

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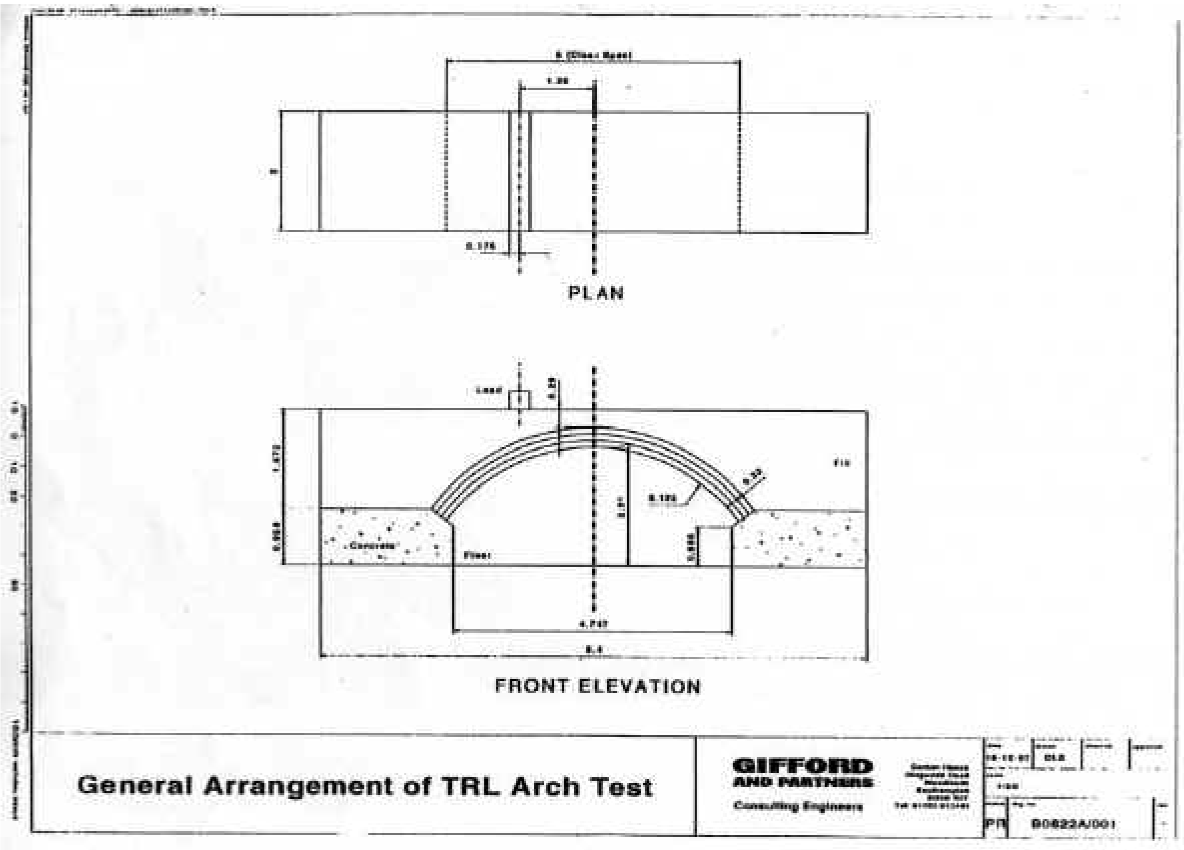
Sumon, S.K. 1997. *Repair and Strengthening of Damaged Arch with Built-In Ring-Separation.* Seventh International Conference on Structural Faults + Repair-97, held at Edinburgh, p. 69-75.



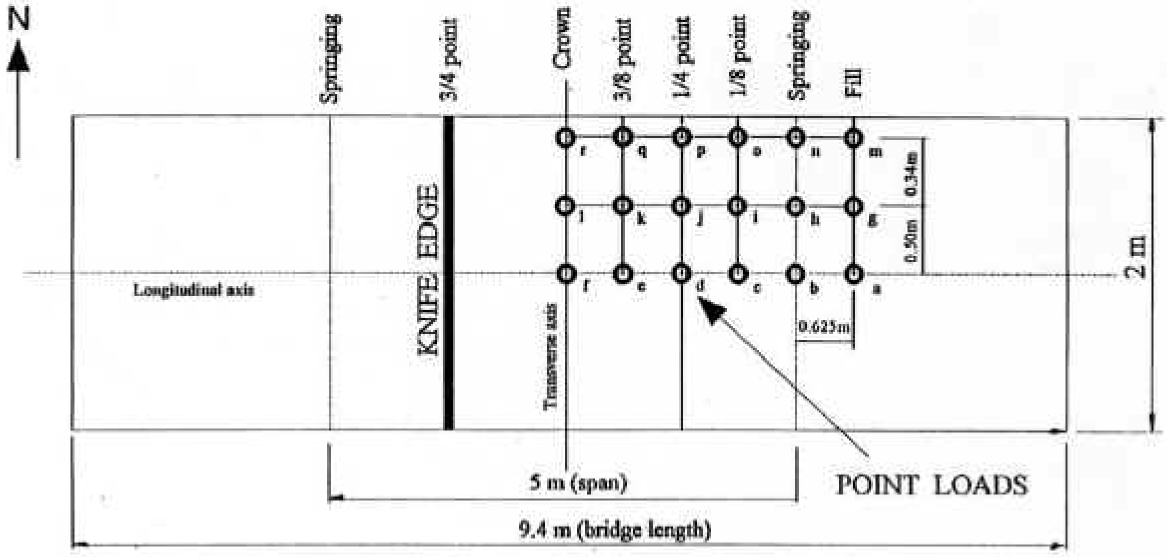
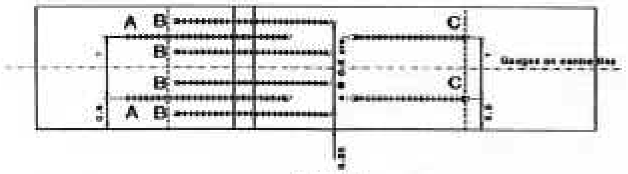
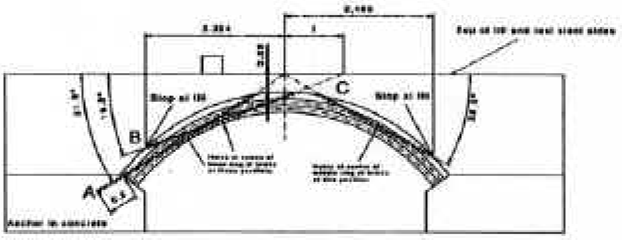


Figure 1: Plan view of arch loading positions



PLAN

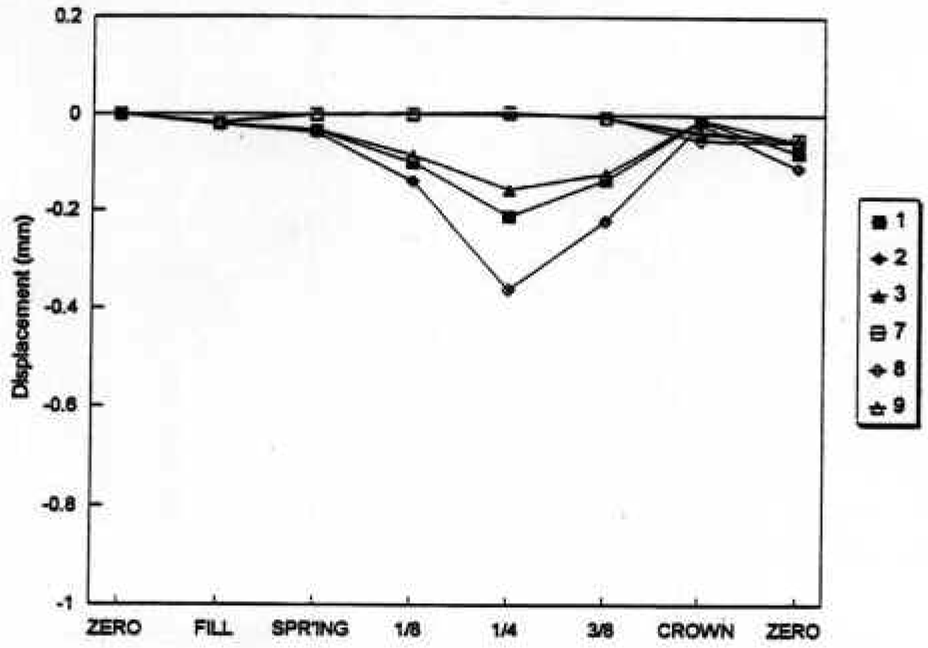


FRONT ELEVATION

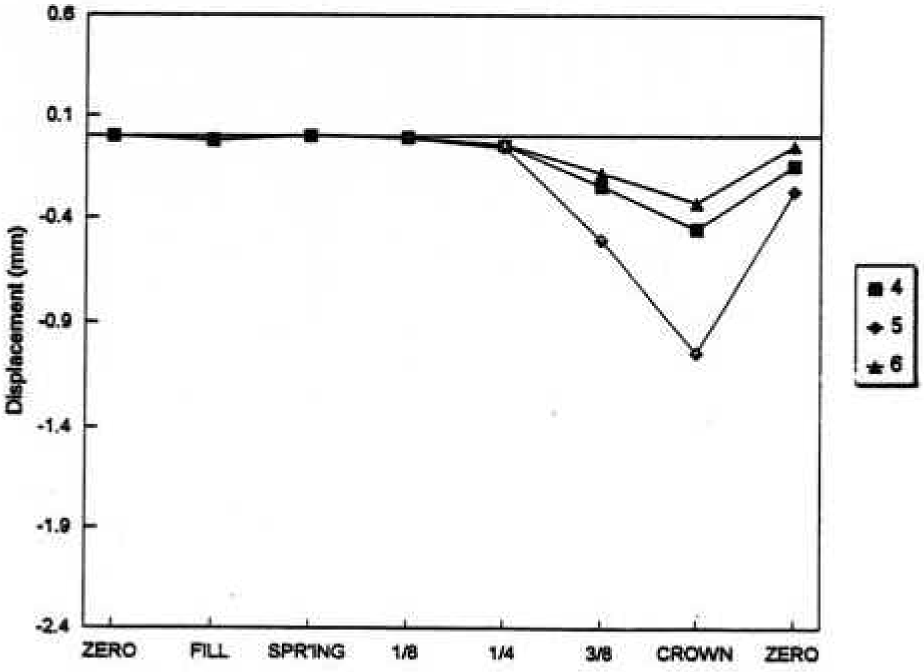
General Arrangement of CINTEC Anchors

GIFFORD
AND PARTNERS
Consulting Engineers

PR B0822A/002

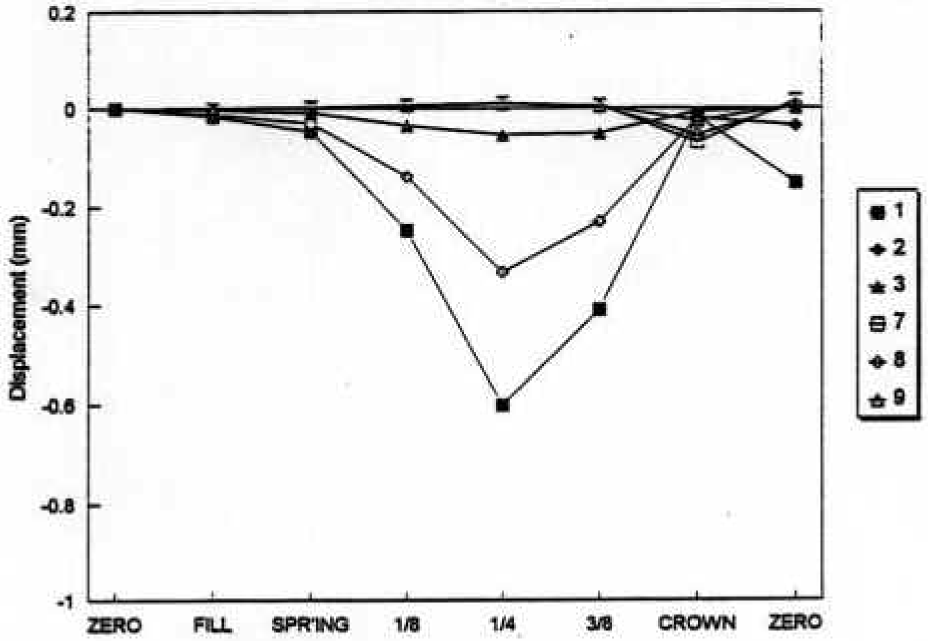


(i) LVDT gauges @ load-line and opposite load-line

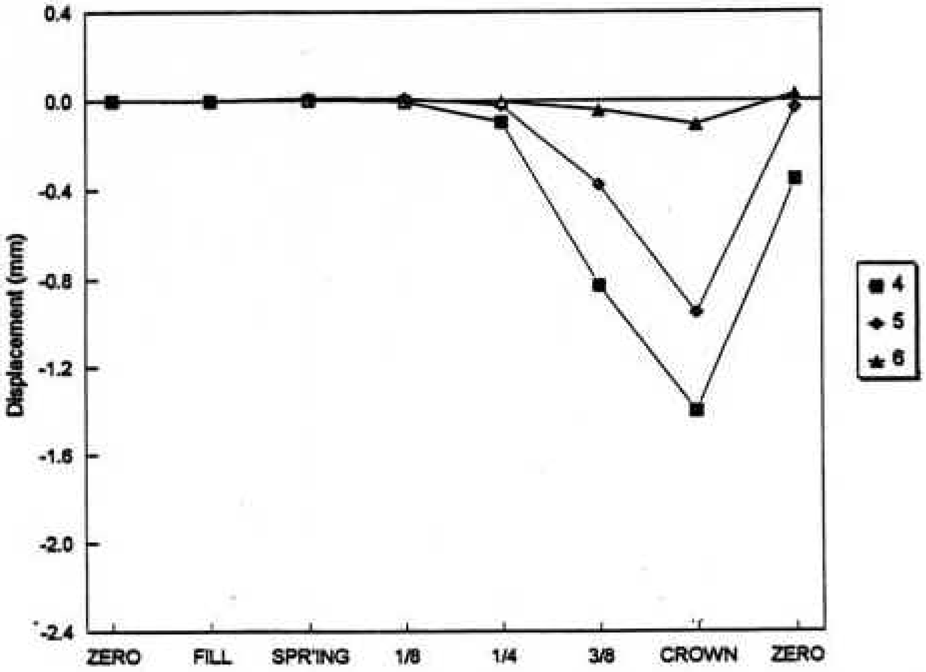


(ii) LVDT gauges @ crown

Figure 2a: Influence lines for displacement for 50 kN point loads applied along the centre-line

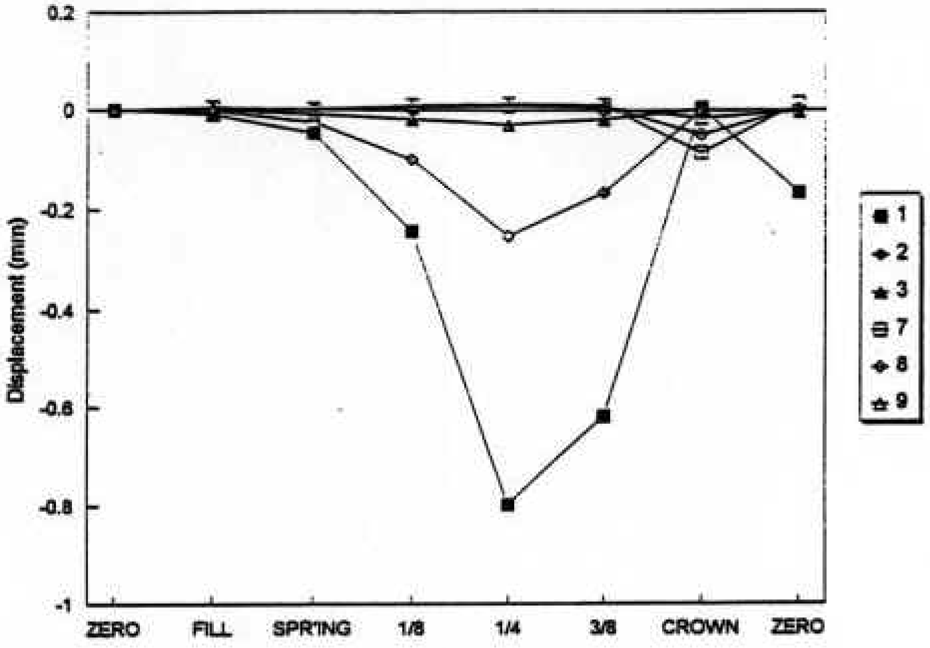


(i) LVDT gauges @ load-line and opposite load-line

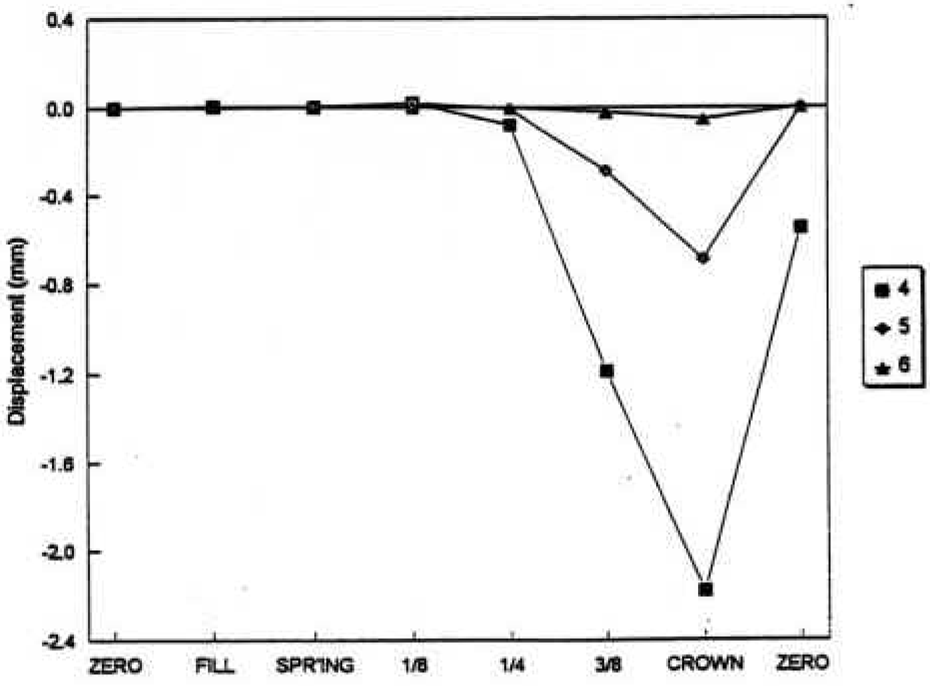


(ii) LVDT gauges @ crown

[illegible] Influence lines for displacement for 50 kN point loads applied [illegible]m from the centre-line



(i) LVDT gauges @ load-line and opposite load-line



(ii) LVDT gauges @ crown

Figure 2c: **Influence lines for displacement for 50 kN point loads applied along the edge of arch**

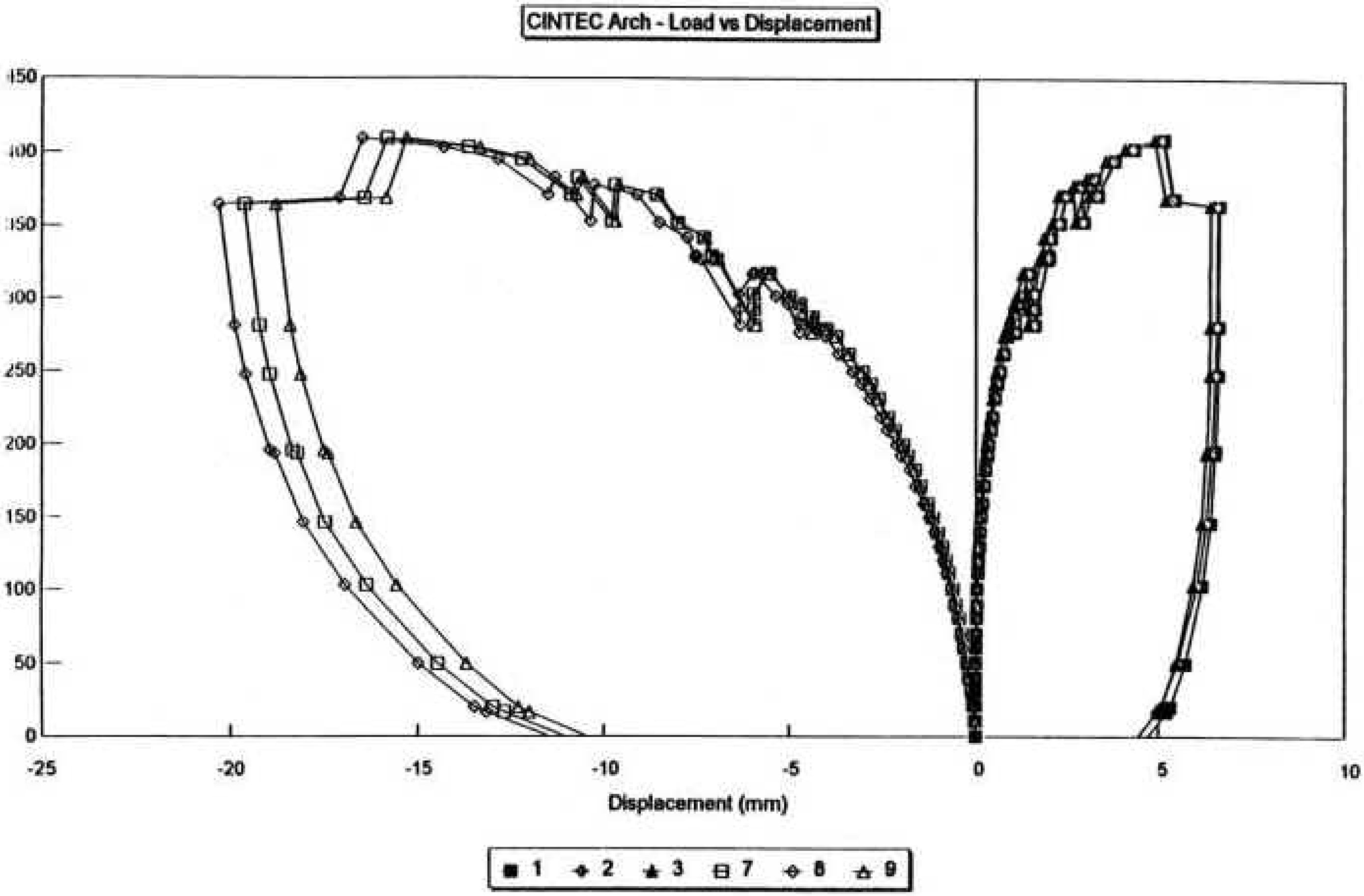


Figure 3a: Load vs displacement for LVDTs attached opposite quarter span (1,2,3) and under load-line (7,8,9)

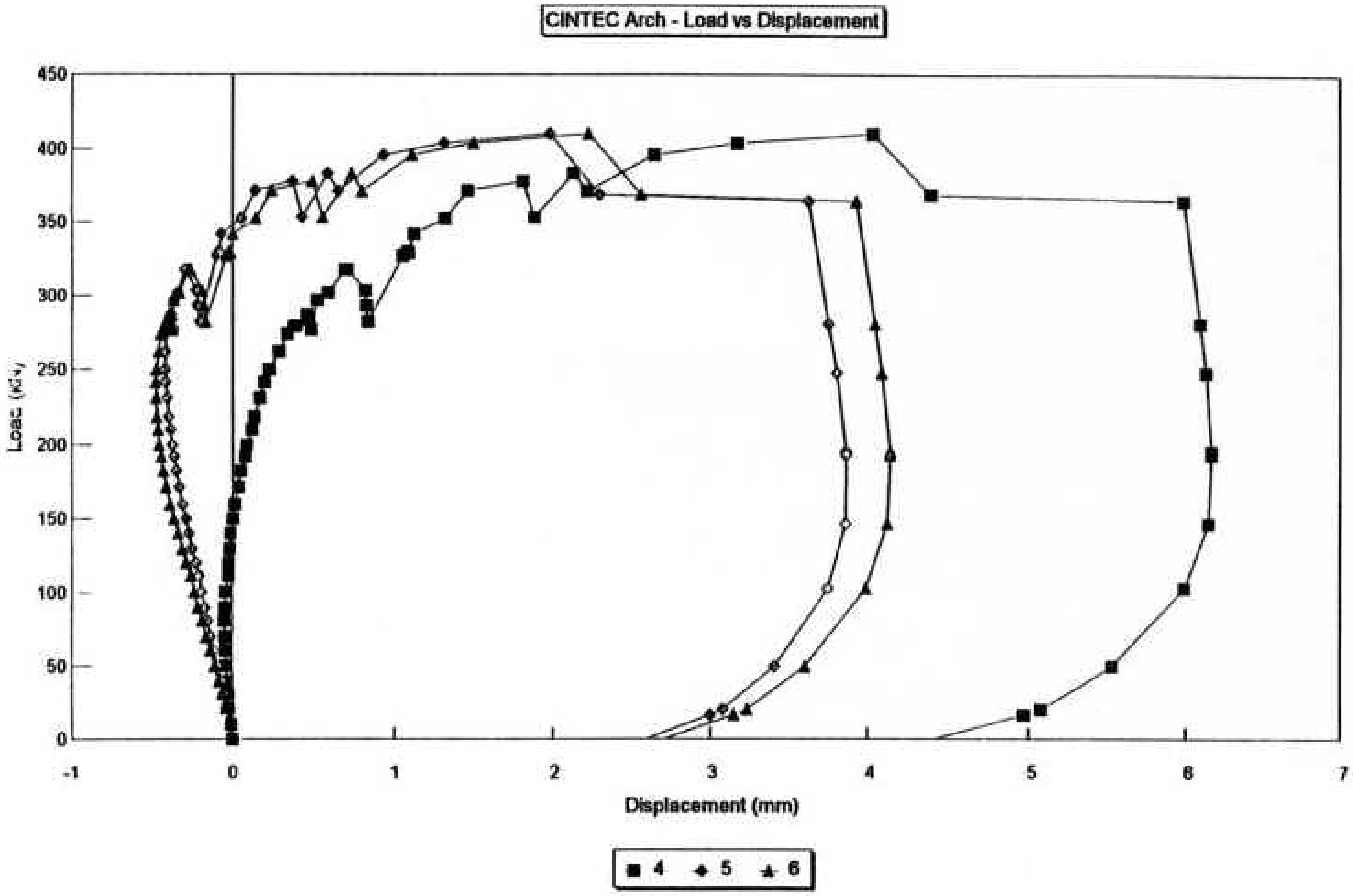


Figure 3b: Load vs displacement for LVDTs attached to the crown (5,6,7)

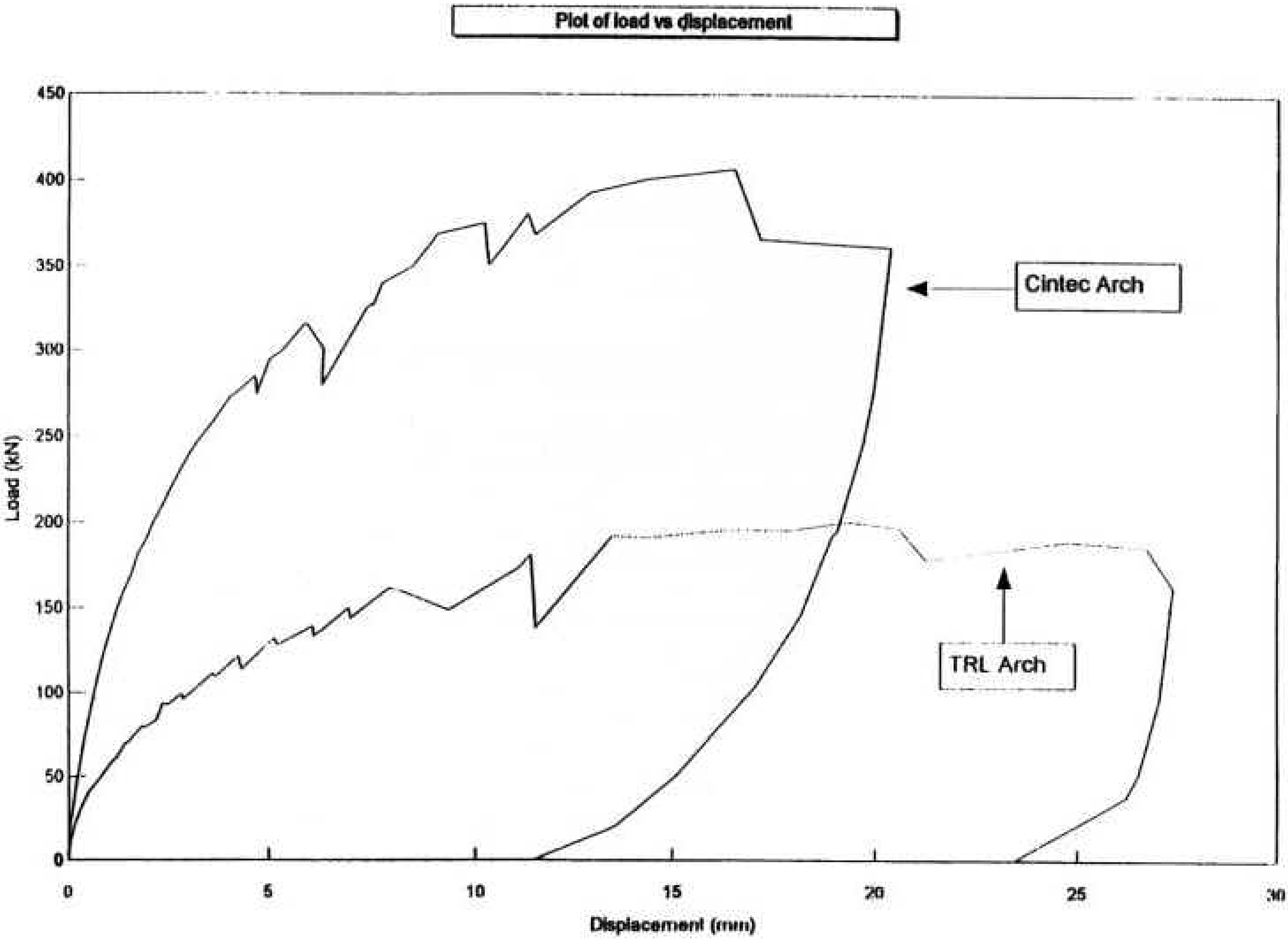


Figure 4: Comparison between Cintec and TRL arches

Figure 5: Arch just before bottom ring fell away

Figure 6: Arch after bottom ring fell away