

Restoration of the Morell Bridge, Melbourne

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SYNOPSIS

The Morell Bridge is a unique earth filled arch bridge, designed and built in 1899 by Sir John Monash's (Monash University) company, Monash and Anderson. The structure exhibited severe concrete spalling, displacement of side walls, one deflected arch, together with widespread drainage problems and poor aesthetics.

The restoration involved the total investigation of the structure, including corrosion and structural analysis incorporating dynamic surveys. Significant corrosion was identified in the arch reinforcement over a large portion of the soffit.

The project utilised an unique Cathodic Protection System, with 12 anodes placed in the soil below the footpath, permanently protecting all arch reinforcement, minimising the extent of patched concrete which would weaken the arch. The side walls were stabilised and the drainage improved, and a protective coating restored the heritage structure to its former glory. The project was carried out while the bridge remained in operation, allowing constant pedestrian, vehicular and river traffic over a nine month period to completion in April 1994.

1. THE BRIDGE

Morell Bridge spans across Melbourne's Yarra River in three graceful 33 metre arches. It is supported by end abutments and two concrete piers and is largely a reinforced concrete structure.

The bridge was constructed over dry land in 1899, at a cost of £6000. Documents revealed that this 96 year old bridge was designed for 50 years of service. Following the construction of the bridge, the Yarra was locally straightened and the bridge became one of Melbourne's best loved.

The reinforced concrete arches, which have an average thickness of 500 mm, support mass concrete gravity walls and soil filling which is contained by these walls.

The decorative render to these walls and the feature cast iron balustrades, greatly enhance the visual attraction of this structure.

However, at nearly twice its design life, a number of defects and problems had developed requiring attention. This led the City of Melbourne to commission Facade Technology to conduct a detailed condition study and structural assessment of the Bridge and its restoration.

2. CONDITION STUDY FINDINGS

The most notable defects were concrete spalling at the soffit of the arches due to corroding reinforcement, and outward movement of the side walls. (Refer Photos 1, 2 and 3). The latter resulted in spalling render and heavy staining due to water seepage. Both defects appeared to have developed over a period of time as evidenced by previous repairs which were only partially successful.

It became clear that the cause of these defects needed to be established in order to develop a more successful long term repair and restoration strategy.

Accordingly, the concrete arches were subjected to a range of tests which included covermeter readings, electric potential surveys to determine likely corrosion activity and resistivity tests. Furthermore cores were extracted and analysed for amongst others, concrete quality, depth of carbonation, and chloride content.

Surprisingly these revealed that the concrete strength which varied from 20 to 30 MPa lacked large aggregate. Partly as a result of this sandy mix, the soffit had carbonated to depths of up to 90mm, which is generally beyond the bottom layer of reinforcement. Elevated chloride levels were only local and attributed to contamination by the soil fill. The coincidence of spalling along edges and joints was therefore attributed to carbonation. The localised failure of the epoxy

patch repairs was a result of inadequate preparation and due to the creation of new anodic zones along their perimeters. Potential surveys carried out by Remedial Engineering indicated widespread corrosion activity.

Carefully located cores through the side walls confirmed the initial impression that these mass concrete walls were indeed moving outwards. It was considered that this was principally due to the dynamic traffic loading on the soil fill, the effects of which were translated laterally. Not surprisingly, it was also found that the bridge was holding water.

Of greater concern was the visual flattening of the northernmost arch and the corresponding and very visual handrail deflection. This and the need to reassess the capacity of the bridge, led to a structural assessment of the bridge.

The modelling of such a structure requires a range of assumptions to be made. To eliminate some of these, various analytical models were analysed. Six loading conditions were superimposed on these models including truck load combinations. It is of interest that the original bridge design was based on a 20 ton steamroller or a uniform 100 pound per square foot (20 Kpa) load.

Computations revealed that this old structure was being overstressed when subjected to today's loads. The Council accepted and adopted immediate load limits.

In order to verify the analytical findings, dynamic on-site tests were conducted by the then Victorian Road Authority. These involved the application of carefully placed strain gauges. Readings were logged following the passage of specially adopted trucks (in the early hours of the morning).

The results obtained verified Facade Technology's analytical conclusions and indicated that the principal cause of the northern arch flattening was abutment related. It was further discovered that whereas the stable southern arch was founded on rock, the moving northern arch was supported on piles in silt. This abutment is now being monitored.

It was also of interest that differential movement was recorded at the two longitudinal construction joints which divide the 9 metre wide bridge arch into three parallel sections.

However, the overall conclusion from the comprehensive condition study and structural assessment was that following the implementation of effective repairs, the application of a protective coating and the traffic load restrictions, the bridge could serve Melbourne well into the 21st century.

3. BRIDGE REPAIRS AND RESTORATION

Repair and restoration projects usually require a value engineering exercise involving the "could, should and must" items. Morell Bridge was no exception.

This process required a close interaction with the City of Melbourne Engineering Services Design Department to ensure that the final scope incorporated the Council's longer term maintenance strategy requirements. It was initially considered that the installation of a Cathodic Protection (CP) System was not suitable for this project. However, the introduction by Remedial Engineering of the "earth" anode system proved to be both cost effective and aesthetically acceptable for this historic structure.

The final scope of works was based on the following approach.

- Install an effective drainage system to prevent the future build up of water inside the bridge.
- Arrest further outward movement of the side walls through the installation of stainless steel dowels.
- Conventionally repair the concrete arches and create flexible joints to accommodate the differential deflection at the longitudinal construction joints (as detected by the strain gauges).
- Install the cathodic protection system.
- Coat the bridge soffit.
- Repair and re-coat the decorative render to the side walls, involving epoxy injection methods, priming, and the careful removal of unsuitable coating layers.
- Following additional strain gauging and structural modelling it was concluded that the handrails did not carry compressive loads. However, the cost of raising the deflected handrails proved prohibitive. Instead the edge of the bridge was re-profiled to visually minimise the effects of the deflection of the northern arch.

Following competitive tendering Remedial Engineering was awarded the contract. Their access platform which was suspended from the arches required engineering to nominate loading patterns and sequences. (Refer to Photo 4).

4. THE CATHODIC PROTECTION SYSTEM

A CP trial was conducted in one half of the Southern Arch before full scale installation. Technical assistance was provided by the Materials Department of Monash University, Melbourne. The results of the trial confirmed that CP could be used to successfully protect the reinforcing steel in the bridge.

Full scale repairs began in July 1993 and installation of the Soil Anode CP system was finished in April 1994. Final design of the system was based on the results of the trial.

Four Silicon iron rod anodes embedded in a coke breeze backfill were installed in each span, giving a total of twelve. The anodes were inserted into the earth backfill section under the footpath, as shown in Photo 5. The anode cables were individually connected via a 0.01 Ohm shunt to enable measurement of the current supplied per anode.

To control and monitor the system a Transformer/Rectifier-Control Unit was installed on the East Face of the South abutment. The Transformer/Rectifier consisted of a four independent modules power supply rated 4A/24V. Three outputs are used to control the current/voltage supplied to each span. Each of these outputs are fitted with two, 50 Ohm/50W, adjustable balance resistors used to control each layer of reinforcement; top and bottom mats. The fourth output is used to mitigate any adverse interference that the CP system may cause to foreign structures located near the bridge, viz. a Melbourne Water main, cable ducts and the bridge handrail. This output is fitted with three, 50 Ohm/50W, balance resistors; one per structure.

In order to monitor the performance of the CP system 12 Silver/Silver Chloride reference electrodes were embedded in the concrete in the arches, with four per span. In each span two reference electrodes are used to monitor the top mat and two to monitor the bottom mat. Eight Zinc reference electrodes were installed in the earth fill to monitor the foreign structures; the cable ducts and the water main. The design of the system is shown in Figure 1.

The system was commissioned in July 1994 and its performance has been assessed at three monthly intervals using internationally recommended criteria appropriately refined for the conditions at the bridge(1).

5. CONCRETE AND RENDER REPAIRS

With the use of Cathodic Protection to protect the reinforcement, a far reduced quantum of patch repairs were required. Only areas of spalled or delaminated concrete required exposure to, not behind, the reinforcement, with badly deteriorated reinforcement replaced.

The extensive delaminations along the outermost sections of the arches allowed easy access to the reinforcement, which was welded to ensure electrical continuity.

All repairs used no reinforcement primers or bond coats and the repair concrete was a simple sand/cement of low resistivity, closely matching the characteristics of the original concrete.

The extent of the required repair in the soffit of the arches and rendered sides of the bridge was extensive including:

- a) 200m² dry sprayed concrete spall repair;
- b) 700m of reinforcement replacement (R10+R6);
- c) 2000m² of decorative coating;
- d) 150m² of render pinning and injection rebonding.

All works were completed from a "hung" scaffolding system, with no disruption to vehicle, pedestrian or river traffic.

6. CP MONITORING RESULTS AND DISCUSSION

After six months of polarisation, a four day depolarisation test was carried out. The on potential, the instantaneous off potential, the 24 hour off and the four day off potentials were measured at each reference electrode location. The 24 hours decay, the four days decay and the shift values were then calculated from the monitoring. The results are presented in Table 1.

These results indicate that six months after the system was energised, protection of both top and bottom mats has been achieved according to the proposed criteria, ie. 100mV potential decay criterion. The amount of polarisation obtained was adequate regardless of the position of the reference electrode relative to the position of the anodes. This indicates that uniform current distribution was obtained with the anode system used. The results also indicate that both top and bottom layers of reinforcing steel are being adequately polarised.

The cathodic protection system installed in the earth backfill is successfully protecting both top and bottom layers of reinforcement of the concrete anodes of the bridge.

Interference testing was also carried out in the water main, the cable ducts and in the East and West side of the bridge handrail. The results indicated that these foreign structures have been beneficially affected by the CP system.

7. A LONG TERM SUCCESS

The immediate impact of this repair and restoration project is visual. Gone are the stains, spalls and misalignments. Instead a remarkably attractive 'as new bridge'. (Refer to Photo 6).

The long term impact is one of continued durability and serviceability due to effective drainage, the arrest of further outward movement, and the stabilisation of the corrosion process in the concrete arches.

The effective installation of a state-of-the-art cathodic protection system and the complimentary use of advanced structural engineering modelling and measuring techniques, makes this project an engineering success.

The uninterrupted function of this critical traffic link and its new long term lease of life, makes the restoration of Morell Bridge a total success.

8. ACKNOWLEDGMENTS

Remedial Engineering wish to acknowledge Professor Brian Cherry (Monash University) for his collaboration in this project. The authors wish to thank Melbourne City Council for their permission to publish this work.

9. REFERENCE

- (1) NACE Standard RP0290-90 Item No. 53072, "Recommended Practice Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures", 1990.

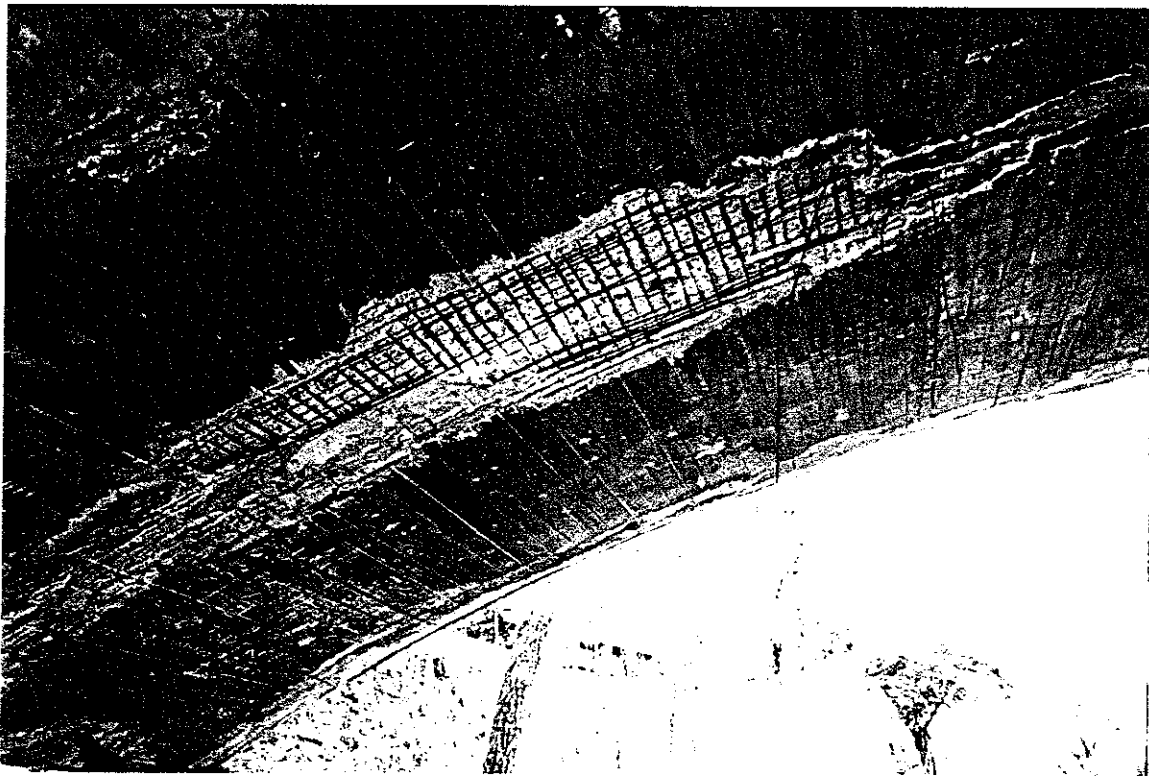
| Arch | Reference Electrode | Natural Potential (mV) 14/7/94 | Instantaneous Off (mV) 2/2/95 | 24 h Decay (mV) | 4 days Decay (mV) | Shift (mV) |
|--------|---------------------|-----------------------------------|----------------------------------|-----------------|-------------------|------------|
| North | 1 b | -125 | -227 | 88 | 108 | -102 |
| | 2 t | -193 | -339 | 90 | 106 | -146 |
| | 3 b | -120 | -113 | 35 | 40 | +7 |
| | 4 t | -223 | -492 | 219 | 249 | -269 |
| Centre | 1 t | -240 | -418 | 130 | 141 | -178 |
| | 2 b | -140 | -361 | 163 | 210 | -221 |
| | 3 b | -152 | -335 | 125 | 160 | -183 |
| | 4 t | 178 | -359 | 137 | 154 | -181 |
| South | 1 b | -224 | -620 | 278 | 320 | -396 |
| | 2 t | -184 | -294 | 81 | 94 | -110 |
| | 3 b | -330 | -752 | 207 | 314 | -422 |
| | 4 t | -312 | -652 | 228 | 260 | -340 |

t - top, b - bottom mat

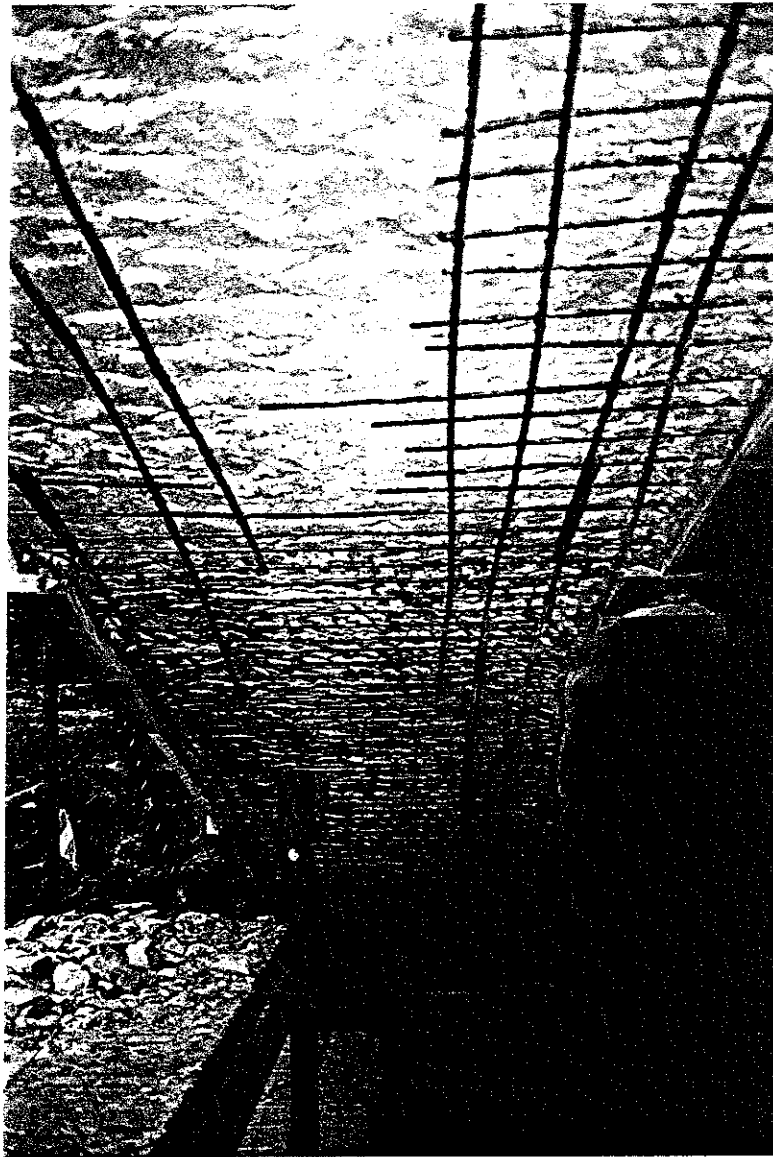
Table 1: The natural potential before polarisation, the instantaneous off potential, the 24 hours and the 4 days decay values obtained at 6 months.



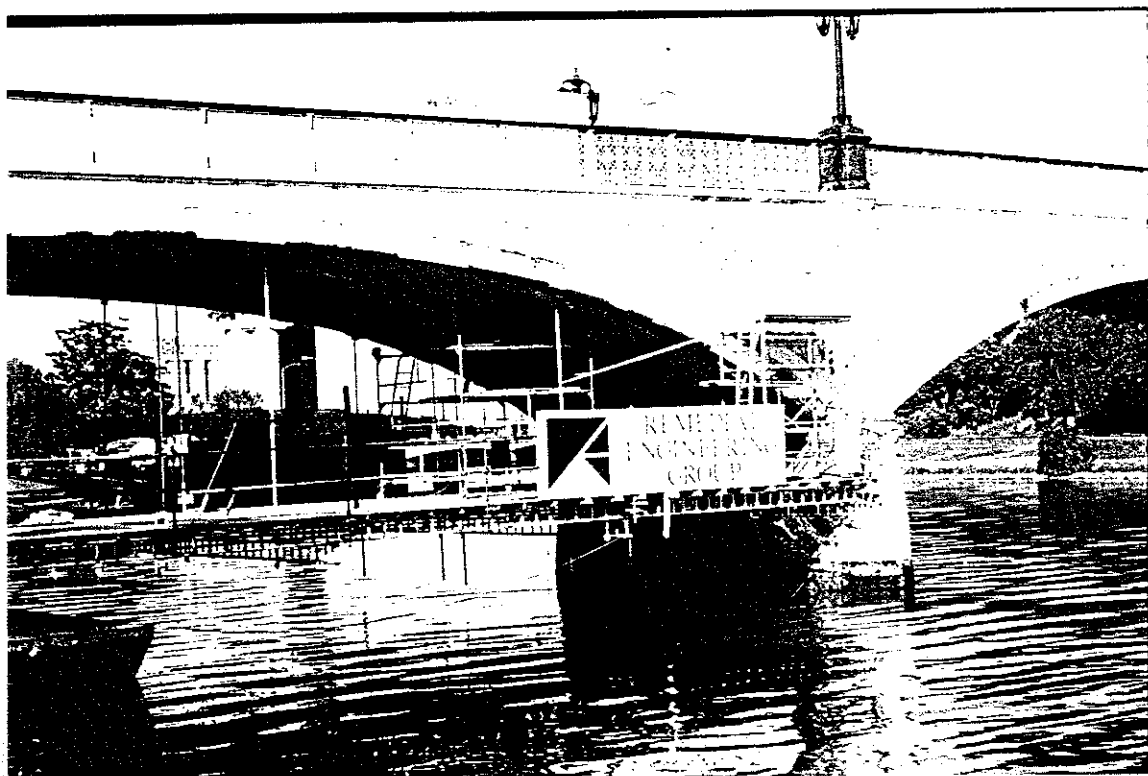
Photograph 1: Condition of Morell Bridge before restoration



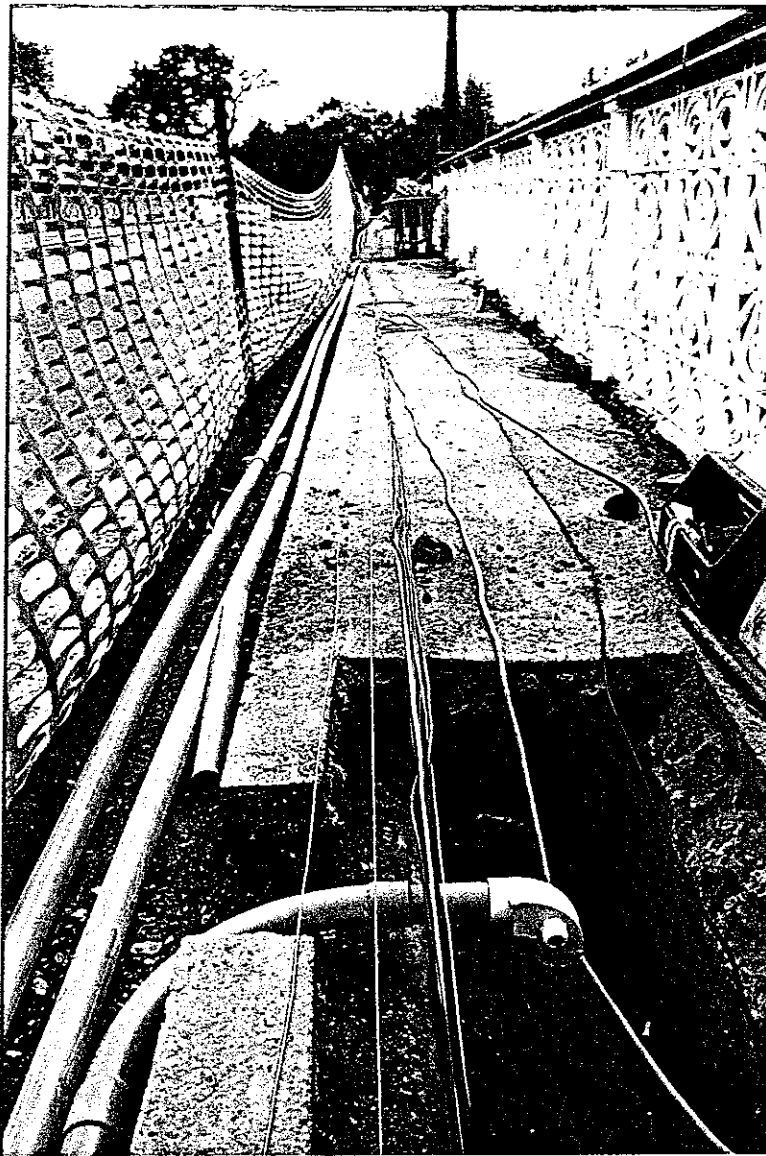
Photograph 2: Concrete spalling at the soffit of the arches



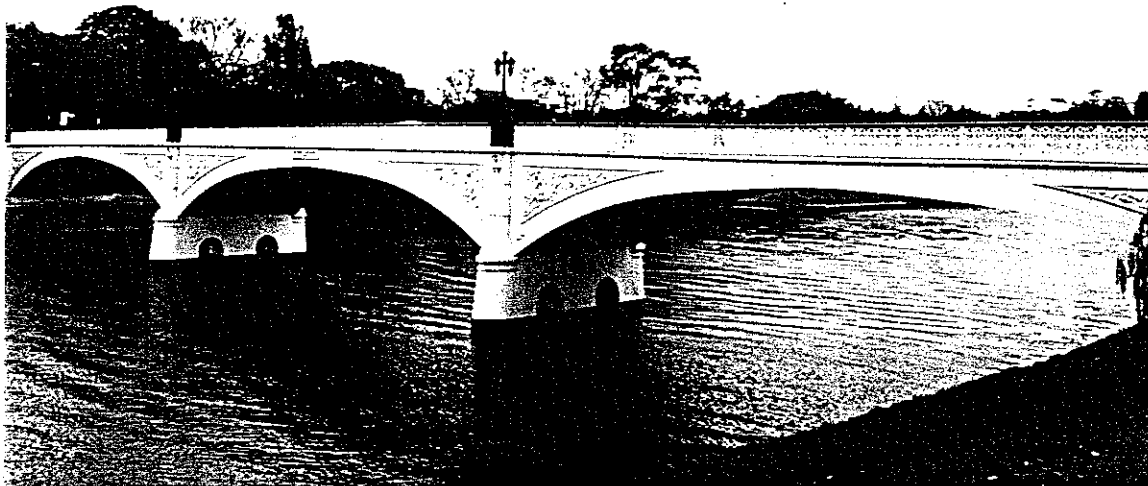
Photograph 3: Extent of concrete removal - North arch



Photograph 4: Access platform suspended from the arches



Photograph 5: Location of soil Anode



Photograph 6: Morell Bridge after restoration