Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 78 (1998)

Artikel: Rehabilitation of two existing tunnels in West Malaysia: a case study

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DOI: https://doi.org/10.5169/seals-59073

Rehabilitation of Two Existing Tunnels In West Malaysia: A Case Study

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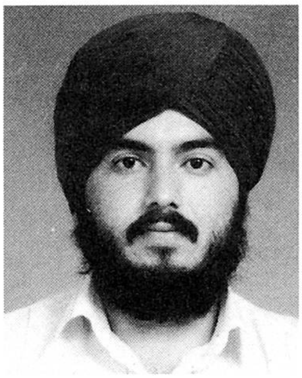

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Summary

The Meru and Menora tunnels situated along West Malaysia's North-South Expressway were recently rehabilitated after more than 10 years in service. As part of the rehabilitation scheme an investigation programme was carried out to determine the nature and extent of defects in the ten year old concrete lined tunnels. Two main types of deterioration were investigated namely cracking and faulty expansion joints. The most widespread type of defects observed in the lining of the two tunnels was cracking. After having carried out the investigation programme a rehabilitation scheme was implemented to reinstate the existing defects. This paper highlights findings of the investigation programme including details of the overall rehabilitation scheme. It also makes recommendations for future maintenance and suggests long term monitoring of functionality and durability of the tunnel structure based on local Malaysian practice.

1. Introduction

The North-South Expressway linking the entire length of Peninsular Malaysia from the northern border with Thailand and Singapore in the south was completed in 1995. The entire road network measuring approximately 850km was designed to serve increased user demand and exceptionally high annual traffic growth rate. With her present 8% rate of economic growth, the need for a modern infrastructure of road networks is essential for Malaysia's development. In 1988, the Government of Malaysia awarded a Concession to finance, design, construct, manage, operate and maintain the entire stretch of the North-South Expressway. The Concessionaire is expected to operate and maintain the highway for 30 years before handing it over to the Government by mid 2018. The highway consists of a two-lane dual carriageway with an emergency lane on each bound for certain stretches and a three-lane dual carriageway with an emergency lane on each bound for the rest. Almost 79.5% of the expressway pavement is paved with asphalt whilst the rest is made of concrete. Between the Jelapang Toll and Changkat Jering Toll, the expressway was built on hard rock. Close to the Jelapang toll, two tunnels were built after boring through hard granite rocks. The Meru Tunnel (north bound) and Menora Tunnel (south bound) were constructed between 1984

Fig. 1 Route map

and 1986. The Meru Tunnel measures approximately 821 metres whilst the Menora Tunnel is almost 832 metres in length. The climate of the site is tropical with a relative humidity range of between 70% to 100%. Average temperature of about 27°C is experienced throughout the year. The climate is generally characterised by a small seasonal variation of temperature, high relative humidity and pronounced wet and dry seasons. The average yearly rainfall is approximately 1,914mm. The months between January and March are generally marked by dry spells followed by moderately wet months of April and May. June, July and August are moderately dry months whereas September to December are marked by rainy seasons. After almost 10 years in service , a number of defects were observed in the concrete lining of both the tunnels. Cracks were observed in the concrete linings along the length of the tunnels. Severe signs of seepage and leaching were apparent in the cracked concrete linings.

Expansion joints which are spaced at every 6 metres along the length of the tunnels also showed signs of aging. Apart from the above defects, a faulty drainage system and fire hydrant system was also noted by the Maintenance team during a routine inspection in 1995. Following the routine inspection, a detailed investigation was carried out to determine the extent and type of defects in the tunnels.

2. Assessment Programme

A preliminary investigation was carried out to identify the existing defects and their extent in the different locations of the tunnel. A photographic survey was carried out to classify the different defects according to their severity. Existing drawings and past records related to the construction of the tunnels were reviewed to obtain useful data for detailed testing. At this stage, a preliminary scheme was drawn to ascertain the types of test and method of conducting these tests to suit site conditions. A traffic management scheme was prepared to ensure minimal disruption to traffic flow during the course of the investigation works.

2.1 Visual Survey

A detailed visual inspection carried out on the cracked concrete did not reveal signs of rust or corrosion of rebars. Localised break-outs were carried out to confirm the absence of rebar corrosion. Leaching of cement through wet cracks was evident in cracks located above the spring line of the tunnel. A detailed crack mapping exercise was carried out to document the extent and pattern of cracks in the lining. This was done by dividing the entire length of the tunnel into chainages and marking individual cracks according to their chainage. The total length of cracks measured for both the tunnels was close to 8500 metres. Most of these cracks were between 0.3mm to 3mm wide.

A detailed inspection was also carried out to determine the extent of damage in the existing expansion joints. It was noted that most of the sealant in the expansion joint was loose and damaged. A separate inspection was carried out to check on the efficiency of the existing fire hydrant system. The inspection confirmed that a section of the existing fire hydrant system in the north bound tunnel was faulty. Further inspections were carried out on the existing drainage system along side the kerbs. This was to ensure that water collected behind the concrete lining could be effectively conveyed into the drainage system via the existing weep holes.

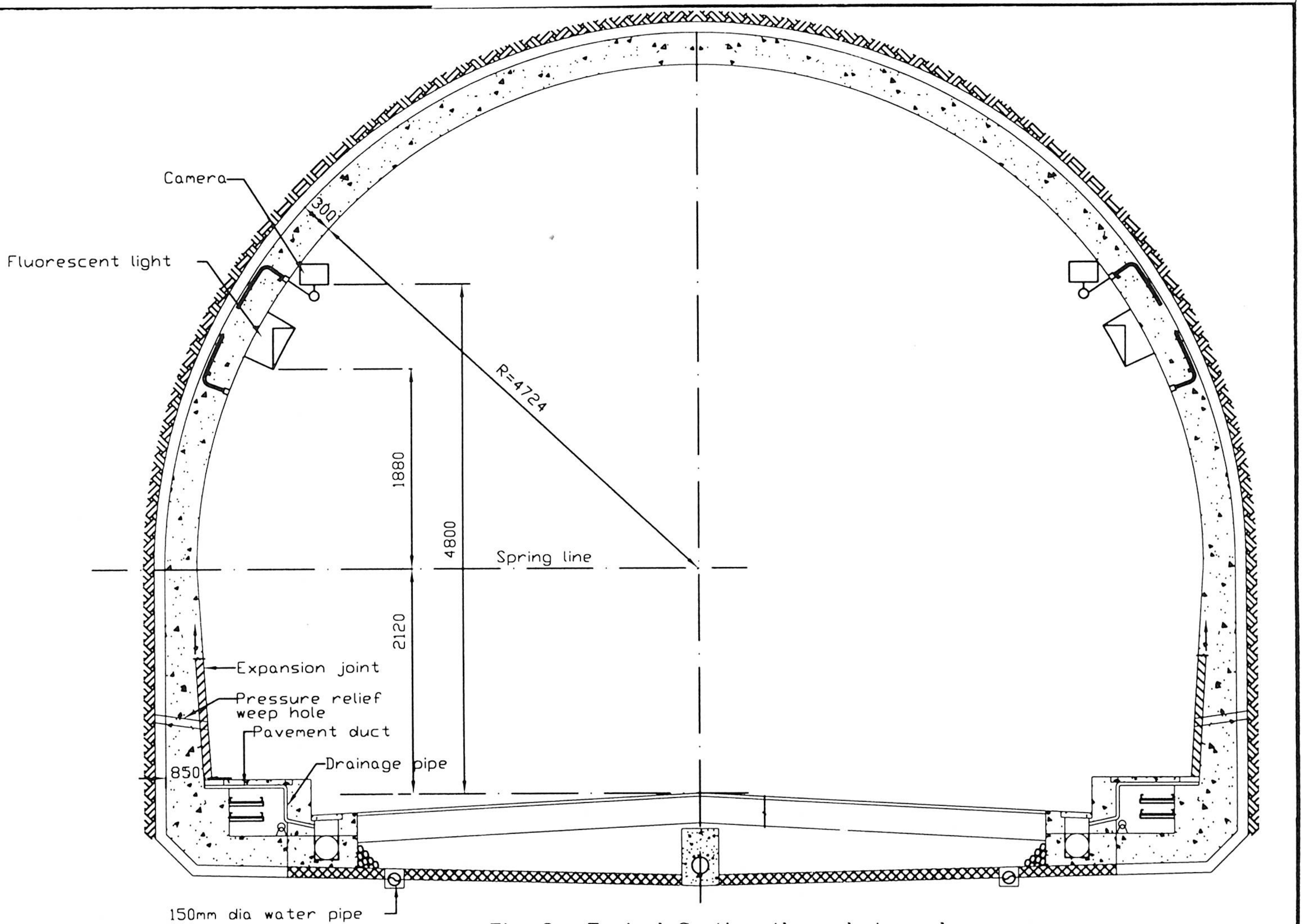

Fig. 2. Typical Section through tunnel

2.2 Detailed Tests

Based on the findings of the preliminary investigation a series of test were conducted to determine in-situ condition of concrete in the tunnel linings. As a means to determine surface hardness, Rebound Hammer test was carried out at selected locations after installing a mobile working platform. One lane of the dual carriageway was closed to traffic during the testing works. In order to determine the extent of cracks in the concrete a number of 50mm diameter core samples were extracted at cracked locations of the concrete. In most core samples the depth of cracks were observed to be in excess of 300mm. In some core samples the cracks were observed to have a series of smaller width cracks branching from the main crackline. Most of the cracks examined under a magnifying glass showed signs of contamination by dirt. An attempt was made to determine the depth of cracks using the indirect method for Ultrasonic Pulse Velocity test in areas where core sampling could not be conducted. This test served as a complementary test to compare sound concrete with cracked concrete by non-destructive methods. A hammer test was also conducted to check for weak spots in the concrete. This test was performed as a guide to differentiate between "ring" sound (often indicative of good concrete) and a 'hollow" sound for loose or cracked concrete. Carbonation test was carried out on selected locations by spraying phenolphthalein indicator on freshly exposed concrete. At most test locations the depth of carbonation was noted to be close to 5mm.

3.0 Rehabilitation Scheme

Following the detailed investigation programme a rehabilitation scheme was prepared to reinstate the existing defects in the tunnels. The scope of the rehabilitation programme was focussed primarily in the following areas:-

- i) Repair of dry and wet cracks in the tunnel linings.
- ii) Reinstatement of faulty expansion joints
- iii) Rehabilitation of the drainage systems
- iv) Upgrading of the fire hydrant system

3.1 Repair of Dry and Wet Cracks

The appearance of cracks in the tunnel lining of both the tunnels was generally of concern to most motorists using the tunnels. However, from the detailed investigation carried out during the assessment programme it was noted that the pattern of cracks was typical of map cracks as shown in Fig. 3. The dry crack pattern was typical for both tunnels and core samples obtained from cracked concrete generally gave details of depth of cracks. Fig. 4 shows typical crack depths as seen in six 50mm core samples obtained from the tunnel linings. A detailed crack mapping exercise was carried out to locate the extent and severity of the cracks according to established chainages along the total length of the tunnels. The cracks were further divided into two main types; dry and wet cracks. Almost seventy percent of the 8500 metres length of cracks measured for both the tunnels fell under the dry crack category. Most of these cracks were contaminated with dirt particles. The remaining cracks were typically wet owing to their depth and location which was close to faults in rocks. The thickness of the tunnel lining varied between almost 850mm at the base

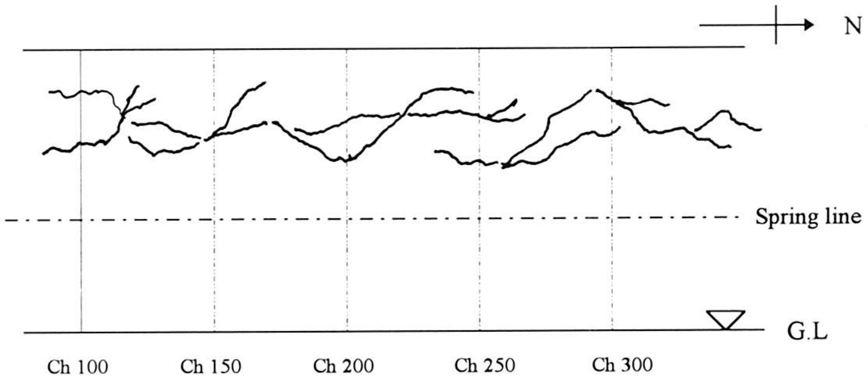

Fig.3 Typical map cracks observed in linings of north bound tunnel

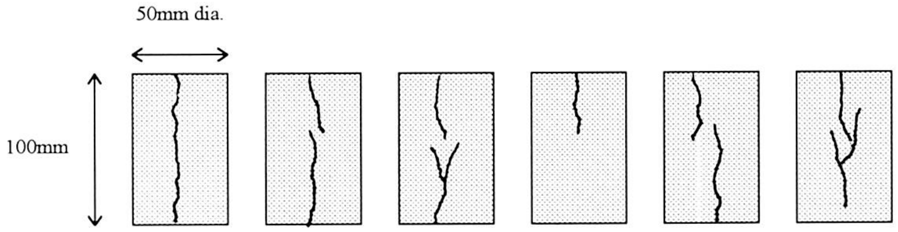

Fig.4 Section through 50mm diameter core samples

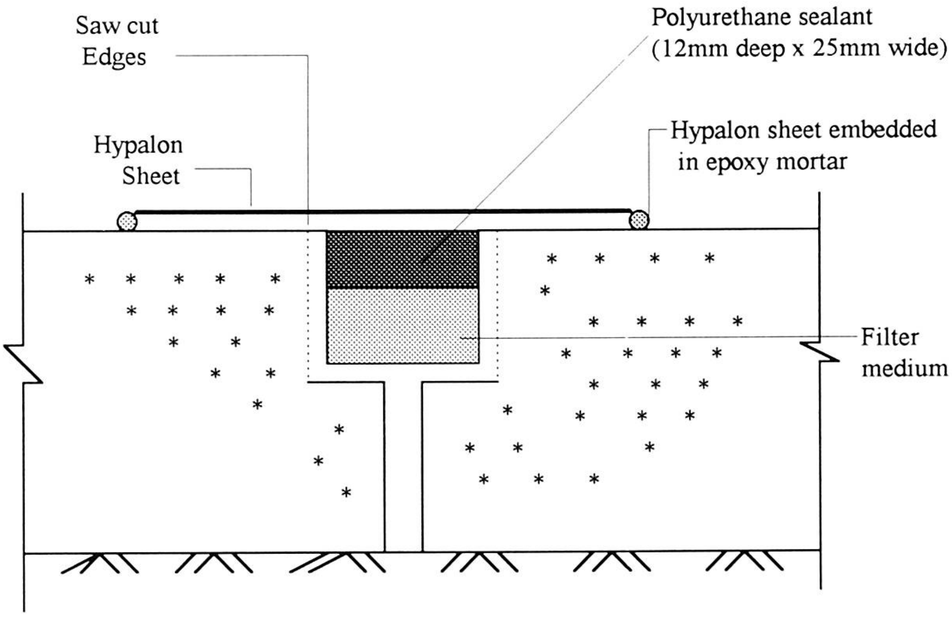

Fig.5 Section through expansion joint

of the tunnel to nearly 300mm at the crown. Most of these wet cracks were contaminated with lime salt deposits.

The dry cracks were first cleaned with a high pressure (1000 p.s.i) water jet using potable water. This was to ensure that the cracked surface was properly prepared prior to the crack repairs. A temporary seal was applied along the length of the cracks leaving masking seals along regular intervals. The temporary seal is an epoxy compound which serves as a barrier to prevent the flow of epoxy from the interior to the surface of the concrete during injection. As soon as the temporary seal was cured, the masking strips were removed exposing cracked concrete at regular intervals which served as entry ports for epoxy injection. The epoxy injection system used for sealing the dry cracks consisted of a low viscosity two component (resin & hardener) epoxy resin which is injected into the cracks using a high pressure, high speed, electromechanical handgun. The primary advantage of this electromechanical system is its ability to mix accurately the two components of the epoxy i.e resin and hardener in the desired ratio eliminating the possibility of inaccurate mix ratios. The epoxy resin is dispensed into the crack via a rubber nipple mounted onto the nozzle of the hand gun. The rubber nipple is pressed against the entry port to allow the entry of the epoxy into the crack. As soon as the epoxy is seen emerging from the adjacent entry port, the flow of the epoxy is temporarily halted by rubbing dry candle wax into the oozing port. Epoxy injection is continued until it appears in the successive entry port. The above steps are repeated until all the entry ports are injected with the epoxy.

The procedure for repairs to wet cracks differs a little from the dry cracks. For wet cracks, 8mm diameter holes are drilled along regular intervals of the crack length to serve as entry ports. Six mm diameter copper tubes approximately 75mm long are inserted into the holes. A temporary epoxy seal is applied to the surface of the cracks to seal off the crack surface between entry ports. The procedure for injection is repeated from the lower most entry port until all successive entry ports are completely injected using the hand gun. The sealing of the cracks using epoxy ensures that the cracks are structurally bonded and free from leaks.

3.2 Reinstatement of Faulty Expansion Joints

The main defect observed in faulty expansion joints was loose and hardened sealant which had debonded from the existing groove. Some of the joints were affected by seepage of water from behind the tunnel lining. The defective sealant was completely removed to ensure the affected expansion joint was free from loose and debonded material. A chase measuring 25mm wide and 50mm deep was cut along the length of the faulty expansion joint using a diamond saw. The joint was cleaned with a high pressure water jet to prepare the surface for remedial treatment. A filter medium was then installed along the length of the expansion joint to convey trapped water into an adjoining uPVC pipe which was connected to the existing drain. The surface of the expansion joint was then sealed with a 12mm thick polyurethane sealant to prevent seepage of water from the filter membrane. As a protection to the exposed sealant, a hypalon sheet was installed along the length of the joint as shown in Fig. 5.

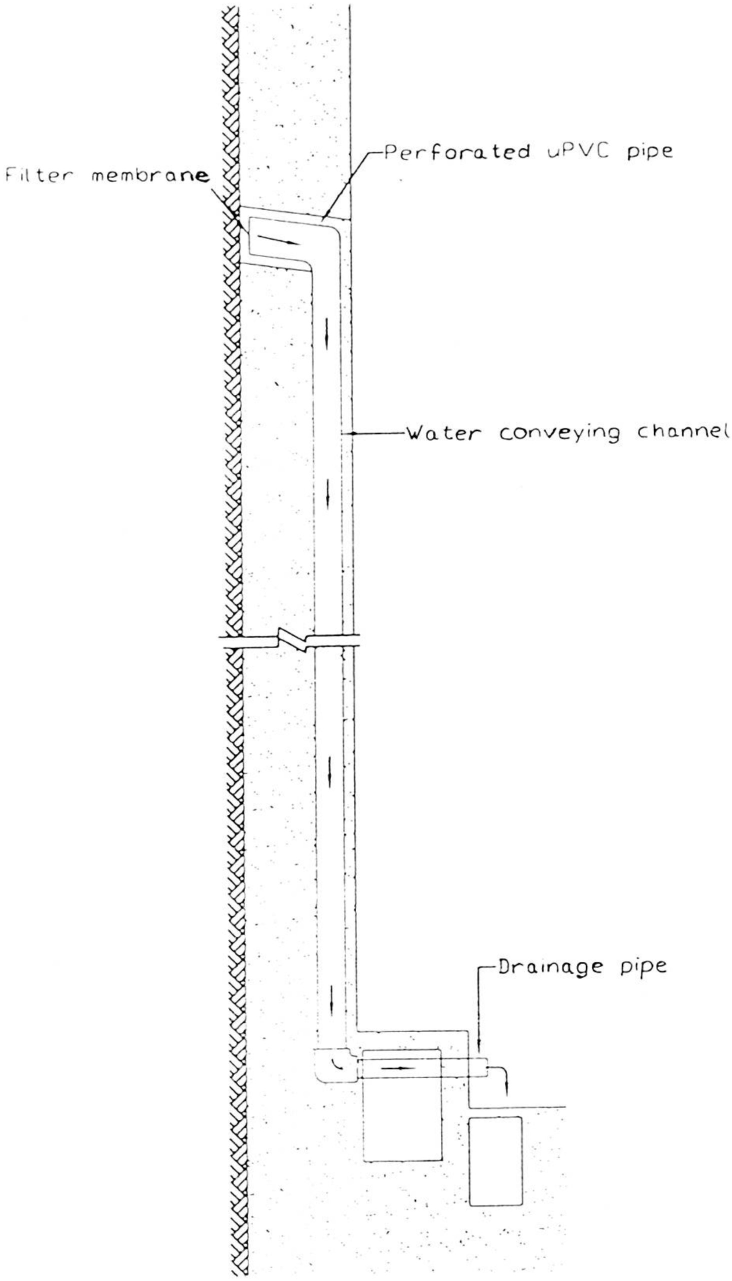

Fig. 6 Section through expansion joint showing drainage system

3.3 Rehabilitation of the Drainage System

In expansion joints where excessive seepage of water occurred, additional water relief holes were drilled into the existing concrete lining. A 30mm diameter uPVC perforated pipe was inserted into the concrete lining after cutting a chase. The perforated section of the uPVC pipe was covered with a geotextile to prevent entry of contaminants into the perforations. Water collected in the uPVC pipe was then directed into the existing drains which were located on either sides of the tunnel. The side drains were thoroughly cleaned to ensure these were free form blockages. Fig. 6. shows a typical section of the modified drainage and water relief system.

3.4 Upgrading of the Fire Hydrant System

Based on the findings of the inspection programme it was confirmed that the fire hydrant system located at the north bound tunnel was not functioning to its original serviceability level. In order to ascertain the "most probable" location of the fault, a pressure test was performed prior to the repairs. The fault was believed to have lied at a joint between the existing 150mm diameter pipe and a "Y" flange close to the elbow connection near the hose reel. Since the affected joint was buried underground, a section of the kerb had to be hacked to gain access to the faulty joint. The faulty joint was removed and replaced with a new pipe and joint system including new fittings. A final pressure test was conducted to check on the efficiency of the reinstated fire hydrant prior to backfilling with new concrete.

3.5 Suggestion for Future Maintenance and Repair

The once held belief that concrete is a durable material and requires minimum maintenance is a thing of the past. Recent cases of premature deterioration of concrete in existing structures which have been reported locally also involve other civil engineering structures such as bridges, dams, jetties and tunnels. The need for periodic inspection to check for defects related to premature deterioration is essential in order to overcome repetitive and costly repairs to rectify such defects. Recent advances in the field of concrete testing and assessment has enabled specialist engineers to diagnose defects related to concrete strength and durability. Maintenance personnel should be trained to monitor functionality and durability of concrete in existing structures on a routine basis. Data obtained from the monitoring can be analysed to identify the most cost effective maintenance strategy.

4. Project Management and Traffic Control

The rehabilitation scheme commenced in July 1995 and was completed in October 1995. During the sixteen weeks period proper traffic control measures were taken to ensure smooth flow of traffic through both the tunnels. Safety cones and traffic signage were placed at designated spots within the tunnels. Safety cones were placed at 7m apart spacing in the tunnel and at 4m spacing for a distance of 150m before the entrance and 150m after the exit point. Blinkers were placed at 7m spacing to ensure motorists could slow down well in advance of the working area in the tunnel. Rehabilitation works were carried out simultaneously in both the tunnels by closing each half of the tunnels in turn thus ensuring a free flow of traffic in both directions. However, during the course of the works a total of five working days were lost due to heavy flow of traffic during a festive season in middle of October and a minor accident which occurred outside the north bound tunnel. The rehabilitation works were carried out between 7am to 7pm on weekdays. During the course of the works, the client's project management team liaised closely with the specialist contractor to ensure smooth progress of the works. Quality control procedures stipulated in the contract were implemented by the client's representative.

5. Conclusion

This paper has attempted to highlight findings of an assessment programme carried out in two concrete lined tunnel of Malaysia's North-South Expressway which had to be rehabilitated after 10 years in service owing to the presence of defects. Both dry and wet cracks which were discovered during the assessment stage were reinstated using a proprietary epoxy injection system. A modified version of the expansion joint was introduced to provide additional protection to the sealant in some faulty expansion joints. Additional relief holes were introduced in leaking expansion joints to convey trapped water into the existing side drains. Faulty fittings in a section of the fire hydrant system for the north bound tunnel were replaced with new fittings. The overall rehabilitation scheme was successfully completed in sixteen weeks under tight supervision and a well planned traffic management system. Early indications are that no new cracks have developed in the tunnel linings and all sealed cracks do not show signs of leaking.

6. Acknowledgements

The author would like to thank the Management of L&M Corporation Malaysia Bhd for their kind permission to publish this paper and Ms Lee Bee Ling for typing this manuscript.