An Analysis of and Remediation of Cracks in Bridges in a Trunk Highway

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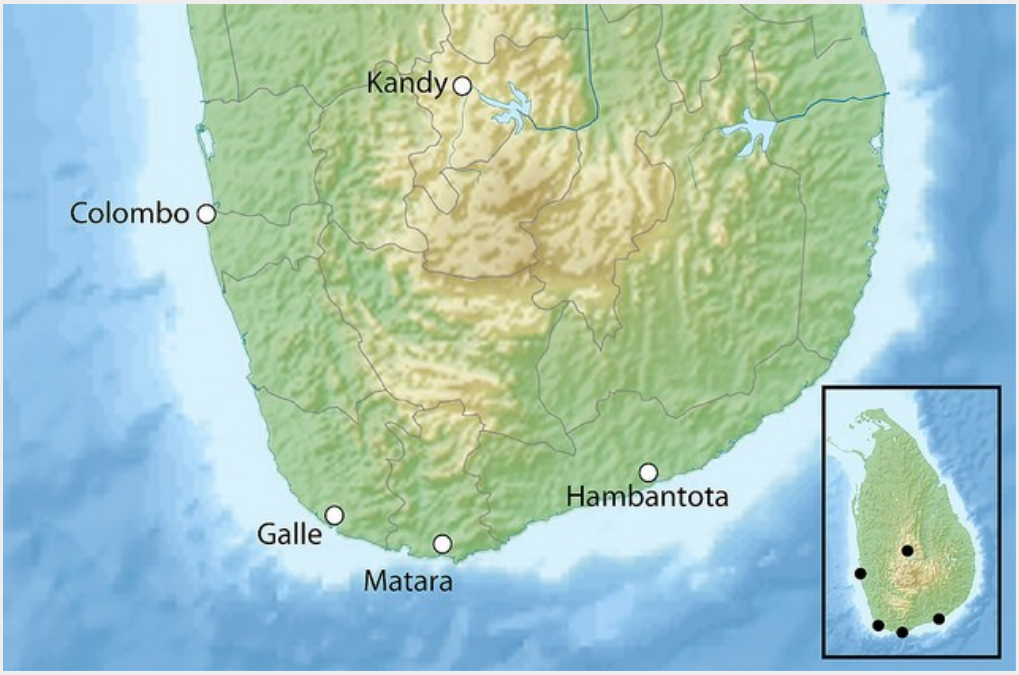
Sri Lanka's E01 Expressway

The E01 Expressway

When the E01 opened, the atmosphere was carnival-esque. 6,000 vehicles travelled the highway in the first 18 hours, generating a toll income of 1.5 million Sri Lankan Rupees

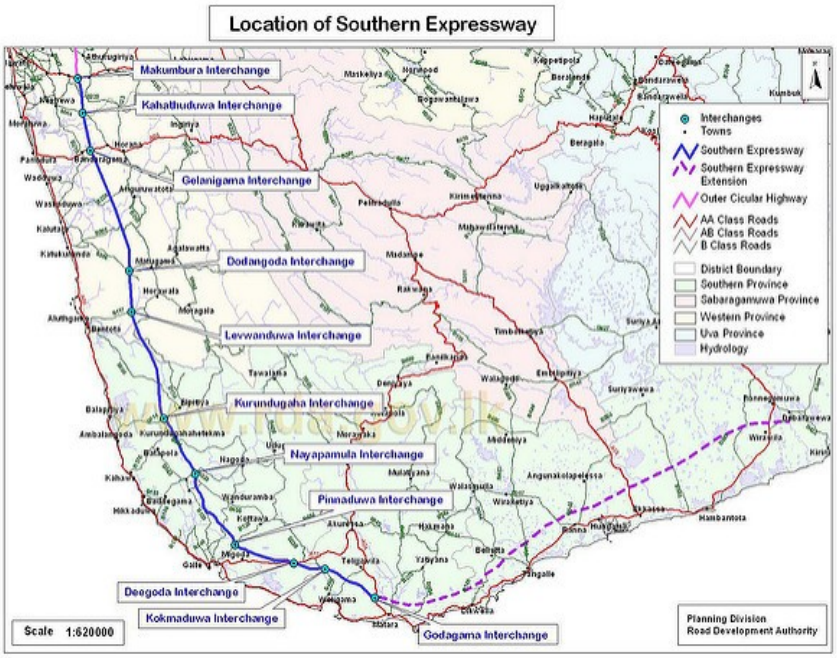
(approximately US $13,225), while an estimated 8,000 cars travel the length of the Southern Expressway each day.



Map of southern Sri Lanka

The E01 is the first of a planned network of expressways designed to link major cities in the island. It currently connects the western capital of Colombo with the southern city of Galle. When the 128 km highway is completed, it will stretch to Matara, located at the southernmost tip of the island. There are proposals in the works to extend the highway to the port city of Hambantota, which will be a boon to those travelling to and from the recently completed Mattala International Airport in the area.

The expressway replaces the A2 highway, which is colloquially known as the Galle Road, as the major connector to the south. The drive along the Galle Road from Colombo to Galle is actually slightly shorter in length at approximately 120 km. You wouldn't know this when travelling, of course. While the speed limit on the Galle Road is 70 kmph, with 50 kmph in towns, actual speeds are much slower during most hours of the day owing to congestion. The beauty of the access-controlled E01, for Sri Lankans, at least, is that it enables them to drive, for the first time, at steady speeds of 80-110 kmph – no more rush hour or school traffic to contend with. An added bonus is the fact that the E01 is a particularly picturesque expressway, flanked by rice paddies and plantations of coconut and rubber.



E01 trace denoted in blue; Galle Road denoted in red (Source: Road Development Authority, SL)

And yet, a cursory glance at the numbers demonstrates that data alone can't capture what the highway signifies in Sri Lanka. After all, what are 8000 vehicles a day to an American, or a highway that is still only 80 miles long? But not only is the E01 a start of something new (and beginnings are always exciting) it signals a change in mindset. Perhaps the real excitement is that Sri Lankans can appreciate, for the first time, how small their island nation is. Getting to the south via the Galle Road would take up to four hours; on the E01, the journey is roughly one and a half hours, despite the bottlenecks caused by exits that spill into narrow and winding highways that are still in the process of being developed. The new expressway has shrunk Sri Lanka from a seemingly sprawling landmass into the island it really is.

Perhaps the E01 is a source of pride not only because it enables Sri Lankans to fly like birds from coast to coast, but also because of what it symbolises to them. The thirty-year Sri Lankan Civil War, which ended in 2009, is still fresh in the minds of the island's inhabitants. To many, the surge of infrastructural development projects – including the E01 – is a sign of reconstruction and rebuilding. Amidst efforts to reconcile, the expressway physicalises the act of connecting people and bringing them closer to one another. Shaped like a bulging teardrop, Sri Lanka spans a length of only about 270 miles from north to south. Limited access to the north during most of the conflict, however, meant that many Sri Lankans have never made that journey. The completed highway network can make that journey a reality, and perhaps being able to "see things for oneself" may help to shatter a few stereotypes. It is, of course, optimistic to place one's hope in a highway as a catalyst for peace, but it is clear that the E01 is a symbol with the potential to connect a fragmented nation, promising a journey that extends beyond a mere commute or highway trip.

The novelty of being able to take a spontaneous drive down south is unlikely to wear off any time soon. Journeys that required a weekend now take less than a day. But the highway is a blessing not only to those who would like to jaunt down south for a dip and a seafood lunch. One of the great advantages of the highway is the options it gives people to commute. Colombo is very small for a capital city, only about twice as big as Cambridge, Massachusetts, USA. The E01 will ease a great deal of congestion while making it feasible to consider taking some of the commerce and industry out of the city itself.

Health of a Highway

It is not exactly known who was the first engineer to use the term 'health' to a highway or in which year this term was first used. While it is not important to get the year in which it was first used, it would be interesting to know who used it the first time. The engineer, who used the term 'health' of highways for the first time, somewhere deep within, believed in highways having 'life'. The word health of a highway is perfectly in blend with this philosophy hence an alternate word like, 'safety condition level' or 'performance reliability level' etc do not perfectly and completely describe the meaning when compared to 'health' of a highway.

Health of a highway and that of a human being are comparable. A genetically healthy human being will live longer and so will a highway that is well designed and constructed. A healthy human being will perform better, just like a structure. A human being can have minor illnesses like cough/cold/ fever et cetera in day to day life. The same can get into serious illnesses if not attended to in time, with appropriate type & dose of medicine. Similarly, a highway can have minor illnesses which would aggravate to health hazards if not attended to from time to time. To understand a highway, it is important to understand the meaning of the term 'health' of a highway in totality and not just its literal meaning.

Canowin Arcade on the E01

There is an array of new services and amenities available to users of the highway

Highways are either - 1. Well designed and well constructed; 2. Well designed and poorly constructed; 3. Poorly designed and poorly constructed. The first type of highway will give a long trouble-free life to the user. The second type of highway would attract a lot of maintenance. The third type of highway would require great maintenance/ repairs in early part of its service life. There is a fourth type of highway too; poorly designed but well constructed. These types of highways generally provide a reasonable service life and do not need maintenance in early part of the life.

The E01 Expressway Project in Sri Lanka

A good approach to investigating failures is given below:

1. Do not assume any cause of a failure until all information is obtained, reviewed and verified.
2. Seek independent information from sources not initially used or thought to be

important.
3. The wider the range of information about an event, the more likely the accuracy of the event will be determined
4. Do not be confined to a single investigative path during failure analysis by pre-judging the cause of the failure.

Cracks in Bridges of the E01 Expressway, their Analysis and Remediation

Bridges on the E01 Expressway Project in Sri Lanka developed fairly wide cracks (0.7 mm) at the root of the cantilever of the pier cap on its tension side. Considering the Sri Lankan context, several design and construction failures have occurred in engineering projects in the past. However, such failures have increased in the last decade. Forensic investigations of these failures were carried out in several cases to identify the actual reasons for these catastrophes.

Concrete bridges have a design life of 100 years. This implies that with periodic inspection and maintenance, the structure would be serviceable for the intended purpose for that duration. However, premature deterioration, damage or requirement of capacity upgradation can require interventions of varying magnitude during the design life of concrete bridges. The longevity of concrete bridges also depends on prompt attention to repairs, rehabilitation and retrofitting. Remediation of bridge structures is an art as well as a science. The engineer must have the knowledge and creativity to select and adapt any of several remedial techniques or combinations thereof to fix the problem.

The process of remediation often takes the following route:

1. Visual inspection.
2. Evaluation of condition, preferably by non-destructive testing.
3. Analysis of root-cause of problem.
4. Formulation of remedial strategy.
5. Evaluation of magnitude and disruption of existing traffic.
6. Costing of various alternatives.

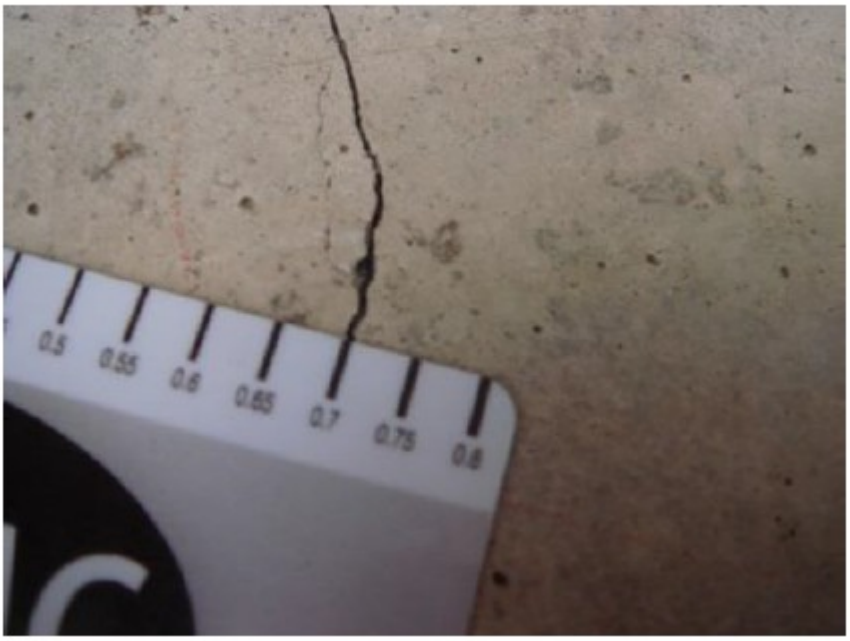
The most frequently used techniques of remediation of bridges employ traditional materials like concrete, steel reinforcement and plates and, prestressing. Chemical admixtures, pre-packaged mortars and similar proprietary products are also in frequent use. Drilled rebar connections to make the parent concrete act in unison with the material used for repairs often forms an integral part of the remediation

In recent years, FRP (fibre reinforced polymers) have opened up a completely fresh avenue for remediation strategy. This strengthening technique may be visualised as one in which FRP laminates or wraps of small thickness are bonded with an epoxy adhesive to the concrete structure to improve its strength and behaviour. FRP systems offer many advantages over the traditional methods of remediation because they are lightweight, easy to install, do not corrode and can be installed while the structure is still in use. These systems are normally used as supplementary measure for enhancing strength and ductility of concrete structures. The “wonder material” called FRP must be employed with great finesse remembering that it has drawbacks like brittle failure, low resistance to UV and also to high temperatures. Since it covers the affected structural part, the same is no longer amenable to visual inspection.

The reliability of remediation strategy is strongly dependent upon the correct assessment and diagnosis of the root-cause of the problem. It must also be remembered that the whole objective of the exercise is to augment the existing strength and ductility

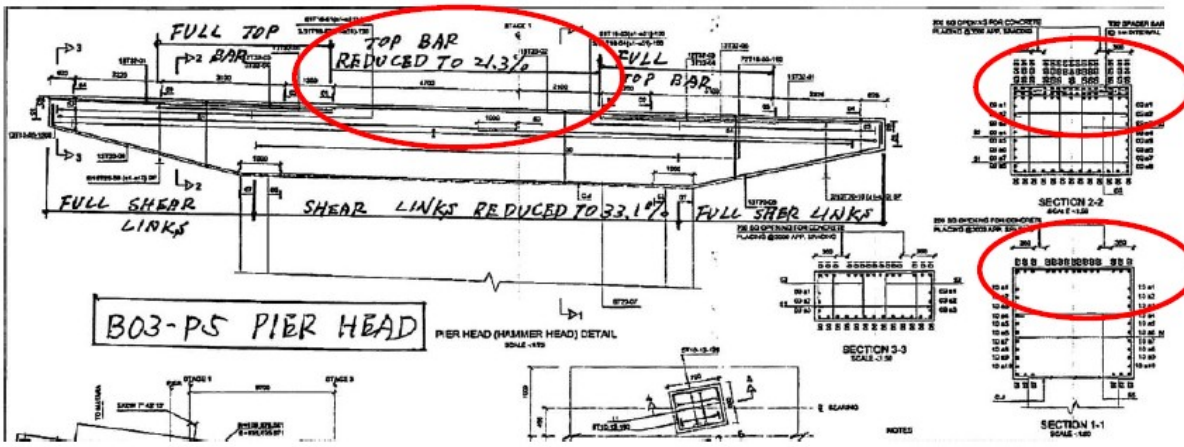
of the structure. If the structure has been damaged or deteriorated beyond a certain point remediation may be an altogether wasted effort.

Important qualifications of an investigating engineer are expertise in the subject under investigation and possession of the values of fairness, impartiality and ethicality.



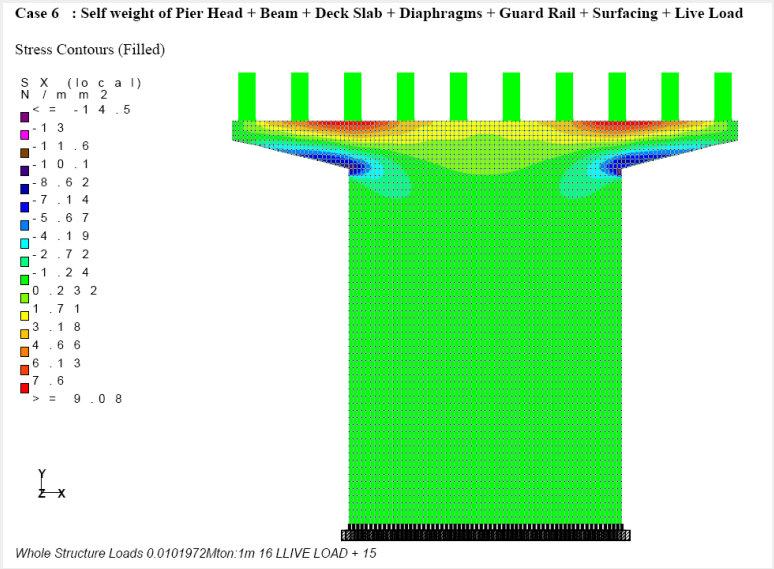
Pier cap cantilever crack 0.7mm at root of cantilever

A study of the drawings of the bridges finally revealed the problem. The cantilever reinforcement (at top surface of pier cap) had been curtailed prematurely to 21.3% of the value provided at the interface of pier cap and pier. The sections shown on below show the abrupt and drastic reduction of the reinforcement at the top face.



Premature and abrupt curtailment of tension reinforcement (at top)

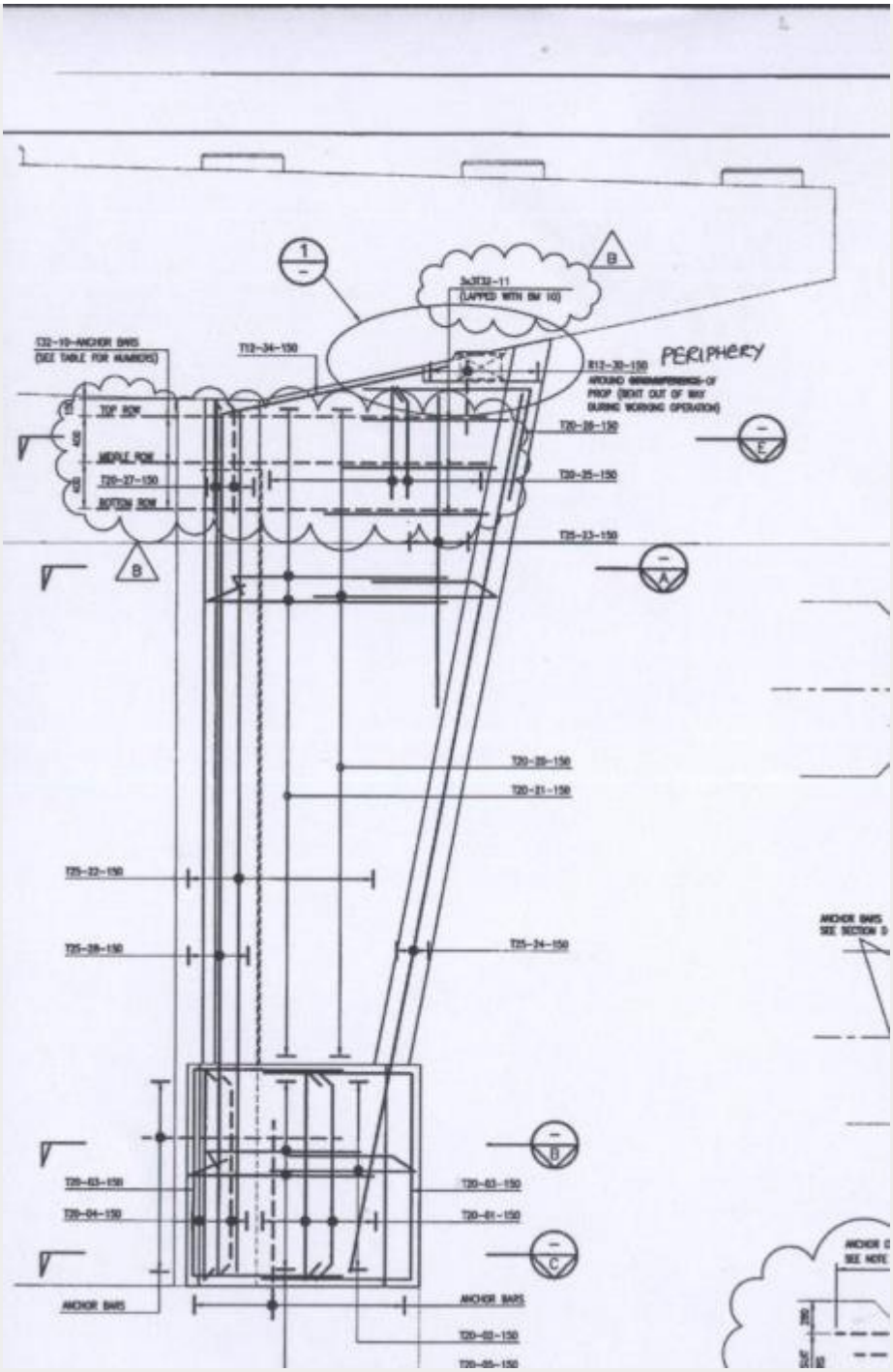
A Finite Element analysis was carried out and the results confirmed the same. The value of tensile stresses developed at the interface of pier/pier cap actually travel quite a distance inwards before petering out.



Results of the Finite Element analysis

The remedial scheme shows enlargement of the pier support by concrete to reduce the cantilever and hence also the moments and the requirement of reinforcement. The additional concrete was connected to the parent concrete by providing dowels after drilling into the parent concrete.

MultiSpectra Consultants White Paper



Remedial Scheme

Visual inspection is the first and the most important step in health assessment process. It must be carried out by only an expert in the subject with proven ability and track record of carrying similar exercise on similar highways successfully in the recent past. Several techniques of visual inspections like naked-eye, binoculars, infrared camera, Endoscopic inspection, drones et cetera are available.

Advanced techniques like drones reduce the cost of access for underside of bridges. infra-red Cameras and binoculars are particularly useful for remote inspections, and for assessing defects like seepage et cetera. Equipments like endoscopes are very useful in difficult to access areas like cavities in bridge bearings, expansion joints, concrete, prestressing tendons et cetera. A visual inspection is grossly incomplete without this

set of basic inspection kit. Only a few of the consultants possess these and carry out a half-hearted health assessment in their absence. It is observed that many laboratories/ engineering consultants carry out health assessment and use only the NDT equipments that they possess. Most laboratories possess Rebound Hammer, Ultrasonic Tester. Little better equipped laboratories possess core testing, cover meter and half cell potentiometer. Most of the laboratories do not possess some of the very important NDT/ assessment equipments like RADAR, Endoscope, Petrography, IR camera, durability test equipments such as PERMIT, LAMPIT and AUTOCLAM et cetera.

Most of the laboratories do not have chemical laboratories in-house and rely on engineering college labs. Though these labs do have a complete range of chemical analysis facilities, it invariably brings in a great time delay in the assessment. Also, the cost of the assessment shoots up, which tempts the consultant to reduce the number of tests and carry out lesser than adequate number of tests.

The type of the NDT to be deployed will depend on the nature of damage and the number of the NDT will depend on the extent and expanse of the damage.

Health of a highway will encompass several virtues of a highway. To enumerate a few; a highway will be needed to be crack-free, seepage-free, collapse-free, settlement-free etc to be certified as 'healthy'. The highway with leakage, seepage, cracking, settlement etcetera. can be safe but will surely be not healthy & is sure on the path of being unsafe progressively.

For monitoring the health of a highway, an engineer must carry out quantitative assessment initially, of all the distresses observed in the highway. Several Non Destructive Testing (NDT) techniques are available to carry out quantitative assessment of the damage/distress to a highway. Nothing though, can substitute for "a trained" eyesight. An expert must and can carry out qualitative assessment of the health of highway before deploying the NDT team to decide on the following:

1. The type of NDT techniques needed by the highway. This will depend on the type and extent of distress in the highway.
2. The quantity of NDT tests and the location of each type of test needed by the highway.
3. The nature of visual inspection technique/s to be deployed to make available the correct and complete data about the damage to highway.
4. Any special requirements of the highway.

Use of drones to monitor health of the underside of a bridge deck

Deflection Monitoring of large span bridge using thedolite and prism

Schmidt Rebound Hammer test

Half Cell Potentiometer

Rebar location being carried out using a profometer prior to extraction of cores from RCC members

Endoscopy being done to access the embedded portion of the steel girder

Finally, it must be said that "Prevention is better than cure". A proactive approach can deliver appropriate concepts that ensures that repairs, rehabilitation and retrofitting are either minimised or can be implemented in a safe, sound and economical manner if and when the need arises.

Even though a highway may be a symbol of better things to come, there is always a hidden cost to development, and the E01 is no different from other large-scale development projects. There are issues of inequality: several smaller vehicles like three-wheeled taxis and motorbikes are barred from entry, so the E01 is only accessible to the few who have access to a car or van.