Effects of Climate Change Temperature and Water on Pavements in India

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Abstract:
Climate change is already beginning to have an influence on Indian roads, for example drier summers causing more incidences of subsidence and wetter winters creating greater frequency of flooding. These extreme events are likely to occur more frequently in the future. There are also less obvious effects on pavement deterioration from increased average temperatures and changes in rainfall patterns. Climate has always presented a hazard to the condition of pavements, being one of the prime causes of deterioration, particularly in footways. The extent to which a pavement is vulnerable to climate is dependent on factors such as pavement type and condition, but also on other location-specific factors such as geology, proximity to water courses and traffic flow. This guidance identifies how climate, temperature and water impacts on the different types of pavement most commonly found on local authority highway networks: asphalt, rigid and modular pavements.

Keywords: climate change, temperature, water, pavement deterioration, pavement type

Introduction

Even if we make a significant reduction in greenhouse gas emissions tomorrow, we will need to cope with a changing climate for the next 40 or more years, as a result of past emissions. It is therefore important to plan for and adapt to the climate predicted for the future, rather than basing decisions on historic climate. This is particularly important when planning infrastructure, such as highways, that is designed to have a long lifetime. Current highways and their maintenance are designed based on historic climate. However, as the climate changes, they could be subjected to very different climatic conditions over their design life. The cost of not adapting could be vast in terms of disruption to traffic, public safety and infrastructure repairs. Climate change is already beginning to have an influence on Indian highways - for example, drier summers causing more incidences of subsidence in South India and wetter winters creating greater frequency of flooding. This kind of weather event will become more frequent in the future.

Climate has a large influence on pavement construction and maintenance. Currently, past climate is used to plan construction and maintenance activities. However, changes in climate mean that practices currently used may not be appropriate for the future climate and therefore for the full life of the pavement. New highways are generally designed and constructed for a nominal design life of up to 40 years, with the expectation that periodic replacement of the surface course will occur every 10 to 15 years. Ensuring that highway construction and maintenance carried out now is suitable for the future climate is essential in preventing premature deterioration over time. The climate has always been one of the primary factors that affect the performance of both carriageway and footway pavements. However, the extent to which climate affects the pavement also depends on many other factors, such as the characteristics of the pavement (materials, structure and condition), drainage, underlying geology, topography and traffic. Each of these may itself present a hazard to the pavement. In general, the consequences of these hazards are deterioration of the surface, underlying layers and structure of the pavement and, occasionally, in the event of extreme weather, catastrophic failure. The hazards are also inter-linked, for example rutting due to heavy traffic increases at high temperatures. In general, climate change will not introduce new consequences for the pavement, but may increase the likelihood and scale of deterioration or catastrophic failure occurring as a result of the range of hazards presented. For example, there has always been a risk of rural roads on clay soils cracking as a result of shrinkage; however, the increased likelihood of hot dry summers following wet warm winters magnifies both the likelihood and scale of damage occurring.

Pavement characteristics

There are three fundamental pavement types: asphalt, rigid and modular. The majority of local authority roads are asphalt or concrete, but modular surfaces are increasingly used in shopping centres and residential areas. Footways and cycle tracks can be modular, thin flexible or thin rigid or, occasionally, unbound. Thin flexible or thin rigid footways are constructed similarly to road pavements, but without the structural layer, as they are not designed to take heavy vehicular traffic (although they may be designed to withstand vehicle over-run). Many local authority roads were originally constructed before modern design standards came about, and their subsequent maintenance has often been little more than adding a new thin asphalt surface when required. As a result, the structure of many of these roads has evolved over time and is unlikely to conform to existing standards.
1.1 The effects of climate on asphalt pavements
Asphalt pavements have several layers which all play a different role. Currently, these are referred to from the top surface as: surface course, binder course, base, sub base, capping and subgrade. The surface course and the binder course are often referred to collectively as the surfacing. The base is the main structural layer, although the binder course provides significant contribution. The subbase, capping and subgrade are together known as the foundation.

There are two main types of asphalt pavement: fully flexible (the most common form of construction in the UK, particularly local authority roads) and flexible composite. The hydraulically bound base of a flexible composite pavement is usually concrete, but can include secondary component materials such as pulverised fuel ash or blastfurnace slag.

The performance of asphalt pavements is affected by climate, in particular temperature and moisture. The climate impacts on the materials within the pavement, from the asphalt surface course, through the main structural layers down to the subgrade. These functions are interdependent, because structural failure of the base will affect the surface layers, and damage to the surface layers can lead to deterioration of the lower layers.

1.2 Effects of water
Water can have the following impacts on the materials and structure of asphalt pavements:

Binder stripping
Stripping is the separation of asphalt binder film from the aggregate surface due to the action of moisture and is exacerbated by traffic. Stripping tends to begin at the base of the susceptible asphalt layer and is usually well advanced before there are any visible signs on the surface. Stripping can lead to localised areas of deterioration and eventually total disintegration of the asphalt layer. Stripping is accelerated by warm moist conditions.
Freeze-thaw
Once water enters the structure of the pavement, it is prone to damage from freeze-thaw cycles. The water expands when frozen and shrinks when melted, generating tensile stress in the pavement. This process can create cracks, which propagate through the structure with each freeze-thaw cycle. The vulnerability of the pavement depends on the characteristics of material, such as its permeability and the condition, i.e. the presence of surface cracks. In addition, frost-heave freezing draws up water from the subbase, increasing the amount of water in the pavement.

1.3 Effects of temperature
The temperature profile can influence the deterioration of asphalt pavements in the following ways:

Age hardening
Age hardening increases the viscosity of the binder and depends on temperature, time and the bitumen film thickness. The hardening process will progress faster with higher pavement temperatures and greater porosity of the asphalt mixture. Excessive age hardening can result in brittle binder with significantly reduced flow capabilities. This hardening produces both negative and positive effects. In thin asphalt pavements, age hardening is not desirable, as it will decrease the ability of the pavement to flex under traffic loads. In addition, premature cracking will result from thermal and traffic induced stresses and strains. Hardening of the base and binder course materials of thick asphalt pavements increases their stiffness modulus and hence improves their load-spreadability ability. Higher average temperatures increase the rate of oxidative age hardening and will therefore accelerate the appearance of surface cracks.

Cracking
Observations in the UK have shown that the majority of the cracks in fully flexible and flexible composite pavements initiate at the road surface and propagate downwards. Oxidation and the action of UV radiation cause excessive hardening of the asphalt close to the pavement surface and the material to become brittle over time. In this condition, thermal and load-induced stresses can cause crack initiation and propagation. Hotter weather speeds up the oxidation process and makes the material more vulnerable to cracking, while cooler diurnal temperatures generate thermal tensile stresses that can cause crack initiation and propagation.

Stiffness
The base layer is the main load-spread layer in a fully flexible pavement, and the stiffness modulus is a measure of its load-spread ability. The higher the temperature, the lower the stiffness modulus and the greater the risk of fatigue cracking in the asphalt base layer and structural deformation in the subgrade.

Rutting
The resistance to rutting of the asphalt surfacing depends on road temperature as well as the traffic load. At high temperatures, asphalt becomes more susceptible to deformation, and rutting is more likely to occur, particularly on highly trafficked roads and at low traffic speeds. Research has found that the majority of rutting in the asphalt surfacing occurs on a few days of the year, when the temperature of the road surfacing exceeds 45°C.

2.1 The effects of climate on rigid pavements
Rigid pavements comprise a concrete layer, the main structural element, laid onto a bound or unbound subbase layer. Below the base is a similar foundation to flexible pavements.
There are four types of rigid pavements: jointed unreinforced concrete (URC), jointed reinforced concrete (JRC), continuously reinforced concrete pavement (CRCP) and continuously reinforced concrete base (CRCB). For the CRCB there is a requirement of a 100 mm thick asphalt surface course. Concrete footways are normally not reinforced. Jointed pavements, URC and JRC, comprise a series of concrete bays separated by expansion or contraction joints. They mainly suffer from progressive defects occurring at the joints, resulting in increased, ongoing maintenance costs to joints and bays. Whilst local authorities are unlikely to lay new URC or JRC pavements (in general, these are no longer permitted by the Highways Agency for use on motorways and trunk roads), existing jointed pavements generally maintained with asphalt overlays. CRCP and CRCB were developed to overcome problems associated with joints. They contain continuous reinforcement along the line of the road with intermediate expansion or contraction joints. Thermally induced transverse cracks can relieve tensile stresses. The elimination of joints within the slab enhances the structural integrity of the pavement, as well as reducing the need to construct the JRC layer on top of a bound or unbound subbase. For the CRCB there is a requirement of a 100 mm thick asphalt surface course. Concrete footways are normally not reinforced. Jointed pavements, URC and JRC, comprise a series of concrete bays separated by expansion or contraction joints. They mainly suffer from progressive defects occurring at the joints, resulting in increased, ongoing maintenance costs to joints and bays. Whilst local authorities are unlikely to lay new URC or JRC pavements (in general, these are no longer permitted by the Highways Agency for use on motorways and trunk roads), existing jointed pavements generally maintained with asphalt overlays. CRCP and CRCB were developed to overcome problems associated with joints. They contain continuous reinforcement along the line of the road with intermediate expansion or contraction joints. Thermally induced transverse cracks can relieve tensile stresses. The elimination of joints within the slab enhances the structural integrity of the pavement, as well as reducing the need to construct the JRC layer on top of a bound or unbound subbase.

2.2 Effects of water
Concrete is generally regarded as impervious to water. However, water can enter the underlying layers from the surface through poorly maintained joint seals or wide-cracks. The likelihood of water penetration is increased by inadequate/poorly maintained drainage systems and in road cuttings with steep sides. The effects of water under a slab are: weakening of the foundation and subgrade by reducing the stiffness of the layers vertical movements at joints leading to stepping; erosion of the unbound subbase and/or subgrade material leading to voiding and decreasing structural support. Flooding of an asphalt surface on a rigid pavement can lead to the textured asphalt surface becoming clogged with detritus and difficult to reinstate to satisfactory skid resistance and noise characteristics. An exposed aggregate concrete surface (EAS) used as surface texture is easily cleaned and will mitigate this problem. Water penetration can lead to loss of subbase support and accumulation of detritus in the joint gap, which will impair thermal movement of the joint and could lead to the situation known as a compression failure or colloquially as a ‘blow-up’.

2.3 Effects of temperature
Thermal gradients in concrete pavements can create uneven internal stresses which can then give rise to curling or warping, sometimes called hogging, of the slabs. These can be compounded by loading from passing traffic. Large changes in temperature generate thermal contraction and
expansion of the slabs which, if not taken into consideration at the design stage, can generate unacceptably large longitudinal internal stresses and excessive movements at joints. With the requirement to cover concrete surfaces with asphalt, higher temperatures in the underlying concrete may be created. The specific effects on concrete of an overlying layer at a higher temperature have yet to be assessed. The coarse aggregate has the greatest volume of the concrete constituents, and so its coefficient of expansion greatly influences the thermal properties of the concrete. The tensile stresses which develop in reinforced concrete slabs can be relieved by thermally induced transverse cracks. This feature is the modus operandi of a CRCP. The transverse cracks are kept tightly closed by the reinforcement, which ensures structural integrity, good load transfer and little surface water reaching the foundation. The spacing of the transverse cracks is a function of the climatic condition at the time of paving.

3.1 The effects of climate on modular pavements
Modular pavements are an alternative for asphalt and concrete for low traffic roads and shared use areas and footways - they are not generally used for cycle routes. Modular footway surfacing may be concrete or brick pavers, or slabs; slabs are not recommended as surfacing where there will be any vehicular traffic. In some historic town centres and prestigious streetscape projects, natural stone in the form of flagstones, sets and cubes is commonly used. On footways, the modular surfacing material is generally laid on bedding sand directly on subbase material, and sand is also used as jointing material, to fill in the gaps between adjacent blocks or slabs. Without this gap, the modular surface would be liable to crack and deform as it expanded. However, on older footways, slabs may be laid on hydraulically bound material. In areas that see vehicular traffic, such as pedestrianised town centres or housing estate roads, there is usually a bound base, which can be asphalt or concrete, underlying the bedding sand and modular surfacing, to provide a sufficiently strong loadbearing layer. Defects in modular pavements include rutting, missing paving units, rocking paving slabs, trips between slabs, and cracked slabs. Weed growth in cracks, between slabs/modules and at the backs of footways, can be a problem.

3.2 Effects of water
Most modular surfacing is porous in the short term, i.e. following construction, but largely impermeable in the long term. On footways, water can drain through the surface into the subbase and underlying soil. On modular roads the water may drain through to the underlying bound base layer, which should be cambered to allow this water to escape to the road drainage. Non-water-susceptible bedding sands (single sized) are commonly used in road constructions to permit the flow of water in the pavement's early life. Water can affect modular surfacing by removing the bedding and grouting sand. Excessive water, such as frequent torrential rain or flooding, may wash out grouting and bedding sand. Removal of jointing in footways will result in gaps large enough to trap shoe heels. Further removal of bedding sand will result in paving modules being unevenly supported, leading to rocking slabs and deformation in the paving surface, and thus to trip hazards. In trafficked areas the removal of jointing will allow paving modules to move horizontally and vertically. This is especially likely to happen where the traffic is turning and braking. Once vertical interlock has been lost, the pavement will cease to behave as a composite layer and traffic loads will be carried independently by blocks transmitting very high stresses into the bedding layer. The opening-up of joints will also permit the access of water, which will accelerate the breakdown of the bedding material below.

3.3 Effects of temperature
When a slab becomes hot at the surface, the slab will warp: the top surface will expand more than the underneath of the slab, causing it to become slightly concave at the side in contact with the bedding sand. However, the sand has some give, and will continue to provide some support to the entire slab. If slabs are laid directly on concrete, support would only be provided to the edges, with the concave centre of the slab unsupported. Slabs on concrete or other rigid bases become very susceptible to cracking with expansion and contraction, particularly if there is any vehicular traffic loading the unsupported centre of the slab. This effect will increase with larger slabs. Indeed, there have been incidents of "blow-up" where no allowance for the expansion of slabs under hot conditions has been made. This type of failure typically occurs in squares and public spaces where slabs are locked or restrained between buildings; lack of expansion joints results in lifting and cracking of slabs. When the temperature cools, the reverse happens: the surface cooks more quickly than the underneath side of the slab and the slab becomes concave on its top surface. This results in the edges of the slab curling up slightly, again making them susceptible to cracking if loaded, and possibly causing trips. Continual heating and cooling, causing expansion and contraction, can cause slabs to crack even if no vehicle loading occurs. Concrete modules laid in close proximity without chamfered edges are prone to spalling when they expand in hot weather - the expansion causes the edges to butt hard against each other, causing edge deterioration. The use of spacers to provide sufficient gap and grouting sand to fill this gap (rather than a rigid cement grouting) mitigates this problem. Problems due to temperature changes, especially where there may be vehicular use of the pavement, are more pronounced for large paving slabs than for smaller slabs or concrete blocks. New modular pavements should be designed with small element modules, not large slabs, as surfacing.

Maintenance practices
The change in seasons predicted may have implications. In particular, it may affect the conditions under which maintenance activities are undertaken, both with regard to the effect on the pavement and to avoid health and safety issues for workers as a result of temperatures, storms and winds.

Maintaining asphalt pavements
Actions that will help to minimise potential problems that can arise when laying hot asphalt material in adverse hot weather conditions are summarised as follows:
Selection of deformation-resistant mixtures.
1. An asphalt mixture delivery temperature just high enough to achieve the required workability. This is constrained by the mixing temperature (which again
is dependent on the grade and type of binder used), and the length of time the mixture is contained in thermally insulated lorries during transport.

2. Flexible contract specifications to allow thinner layer thickness to be used in hot weather and thicker in cold weather. Use of a relatively light roller for initial compaction in hot weather would diminish the risk of non-compliance with texture depth requirements (whilst still aiming to achieve adequate compaction).

3. Laying during the evening and night in hot weather to enable the substrate to cool more rapidly and therefore reduce the cooling time required for subsequent hot overlay or opening to traffic.

4. Cessation of laying during the hottest part of the day, say when the road surface temperature exceeds 45°C, will not only help the contractor to minimise problems in achieving asphalt compliance in terms of profile and texture depth, but will also enable the surface to cool sufficiently to enable the resumption of laying in the evening.

5. The season may need to be moved to allow for thicker layers to cool prior to opening to traffic.

6. Consider changes in the surface dressing season to accommodate climate changes.

### Maintaining rigid pavements

If paving has to take place during wet weather, special care should be taken to protect the surface from rain. Paving should be restricted to cooler periods of the day during higher temperatures in summer. It may be necessary to adjust the paving season to avoid high summer and exploit the warmer winters. Newly paved concrete may need more protection from solar heat during the initial curing period. Concrete mixture designs could be modified by using selected additives to achieve suitable workability and setting times during the period of paving and curing. Consider using concrete mixtures made with aggregates with a low coefficient of thermal expansion. Special care is required during the replacement of defective joints (in jointed pavements) throughout periods of high and rising temperatures.

### Maintaining modular pavements

Jointing and bedding sands should be neither too dry nor saturated to facilitate compaction. During paving, the sand should not be left for extended periods, as this makes it vulnerable to moisture content changes from rain and evaporation; if necessary, sands should be lifted and replaced from a covered stockpile.

### Recommendations

The key recommendation to come out of this work is that, as a matter of urgency, each highway authority should assess the vulnerability of its highway network to climate change. In doing so authorities should make full use of their local knowledge of their network and how it has been affected by extreme weather events in the past. Whilst each authority’s risk assessment and solution will be unique, authorities would benefit from recording and sharing their experiences of climate effects on their networks. Specific recommendations are:

- Prepare the risk assessment with the full engagement of members and staff. This is likely to include reviewing existing maintenance and management strategies and plans in the light of the risks posed by climate change.
- Undertake a sustainability audit of maintenance and management plans, including ensuring that the practices used to adapt to climate change are not themselves contributing to climate change.
- Record and monitor weather effects on the local highway network and share the lessons learnt with other local authorities.
- Keep to maintenance schedules and hence avoid small defects becoming major repairs. Well-maintained roads are less vulnerable to climate effects. This includes ensuring adequate drainage provision and maintenance of gullies.
- Support the Department for Transport in developing a mechanism to report the effects of climate on maintenance backlog, possibly through Local Transport Plans.
- Support the Department in reviewing pavement designs, specifications and practices used in those countries which have climatic conditions likely to be experienced in the India.
- Aid the Roads Board in identifying priorities for further climate change research.

### REFERENCES