

Failure Modes in Pavements

Flexible Pavement Distress Modes



FINDING A BETTER WAY

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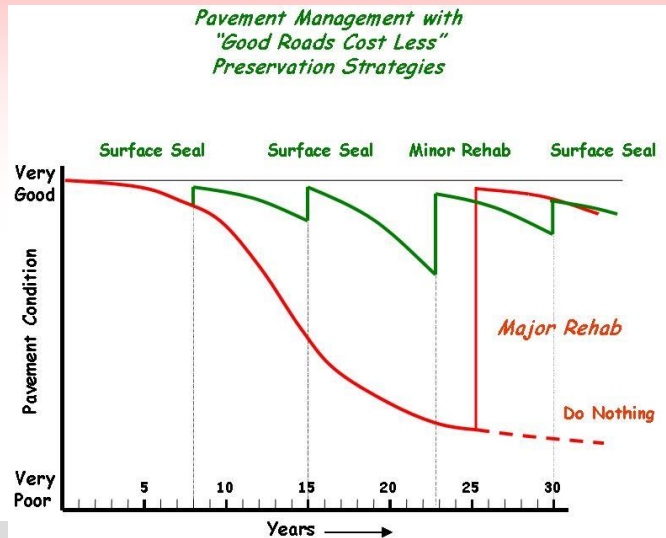
What is a failure of a pavement?



FINDING A BETTER WAY

- Failure of typical civil engineering structures is defined as break or fracture. This usually happens when applied load exceeds the maximum allowable value.
- The applied loading on pavements are usually much smaller than the strength of the material. Therefore one load application does not fail the pavement, but causes an infinitesimal amount of deterioration. This deterioration gradually increases until it reaches an unacceptable level.
- Surface distress is "Any indication of poor or unfavourable pavement performance or signs of impending failure; any unsatisfactory performance of a pavement short of failure"

Pavement conditions



Type of failure modes

- Rutting
- Cracking
 - Longitudinal
 - Fatigue cracking
 - Single crack in the wheel path
 - Alligator cracking
 - Seasonal (frost heave) cracks
 - Joint construction cracking
 - Edge (verge) cracking
 - Transversal (thermal) cracking
 - Pattern cracks
 - Block Cracking
 - Joint Reflection Cracking
- Potholes
- Bleeding
- Ravelling
- Stripping
- Corrugation and shoving
- Segregation
- Patching
- Polishing
- Depressions
- Slippage cracking
- Water bleeding and pumping

Rutting



- **Description:** Surface depression in the wheel path. Pavement uplift (shearing) may occur along the sides of the rut. Ruts are particularly evident after a rain when they are filled with water.
- **Problem:** Ruts filled with water can cause vehicle hydroplaning, can be hazardous because ruts tend to pull a vehicle towards the rut path as it is steered across the rut.
- **Possible Causes:** Permanent deformation in any of a pavement's layers or subgrade usually caused by consolidation or lateral movement of the materials due to traffic loading. Specific causes of rutting can be:
 - Insufficient compaction of pavement layers during construction.
 - Compression of unbound layers (base course, subbase)
 - Subgrade rutting (e.g., as a result of inadequate pavement structure)
 - Improper mix design or manufacture (e.g., excessively high asphalt content, excessive mineral filler, insufficient amount of angular aggregate particles)
- Ruts caused by studded tyre wear present the same problem as the ruts described here, but they are actually a result of mechanical dislodging due to wear and not pavement deformation.
- **Repair:** A heavily rutted pavement should be investigated to determine the root cause of failure (e.g. insufficient compaction, subgrade rutting, poor mix design or studded tyre wear). Slight ruts (< 8 mm deep) can generally be left untreated. Pavement with deeper ruts should be levelled and overlaid.

Fatigue Cracking



- **Description:** Series of interconnected cracks caused by fatigue failure of the HMA surface (or stabilized base) under repeated traffic loading. In thin pavements, cracking initiates at the bottom of the HMA layer where the tensile stress is the highest then propagates to the surface as one or more longitudinal cracks. This is commonly referred to as "bottom-up" or "classical" fatigue cracking. In thick pavements, the cracks most likely initiate from the top in areas of high localized tensile stresses resulting from tire-pavement interaction and asphalt binder aging (top down cracking). After repeated loading, the longitudinal cracks connect forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile.
- **Problem:** Indicator of structural failure, cracks allow moisture infiltration, roughness, may further deteriorate to a pothole.
- **Possible Causes:** Inadequate structural support, which can be caused by a number of things. A few of the more common ones are listed here:
 - Loss of base, subbase or subgrade support (e.g., poor drainage or spring thaw resulting in a less stiff base).
 - Stripping on the bottom of the HMA layer (the stripped portion contributes little to pavement strength so the effective HMA thickness decreases)
 - Increase in loading (e.g., more or heavier loads than anticipated in design)
 - Inadequate structural design
 - Poor construction (e.g., inadequate compaction)
- **Repair:** A fatigue cracked pavement should be investigated to determine the root cause of failure. Any investigation should involve digging a pit or coring the pavement to determine the pavement's structural makeup as well as determining whether or not subsurface moisture is a contributing factor. Once the characteristic alligator pattern is apparent, repair by crack sealing is generally ineffective. Fatigue crack repair generally falls into one of two categories:
 - *Small, localized fatigue cracking indicative of a loss of subgrade support.* Remove the cracked pavement area then dig out and replace the area of poor subgrade and improve the drainage of that area if necessary. Patch over the repaired subgrade.
 - *Large fatigue cracked areas indicative of general structural failure.* Place an HMA overlay over the entire pavement surface. This overlay must be strong enough structurally to carry the anticipated loading because the underlying fatigue cracked pavement most likely contributes little or no strength.

Transversal (thermal) cracking



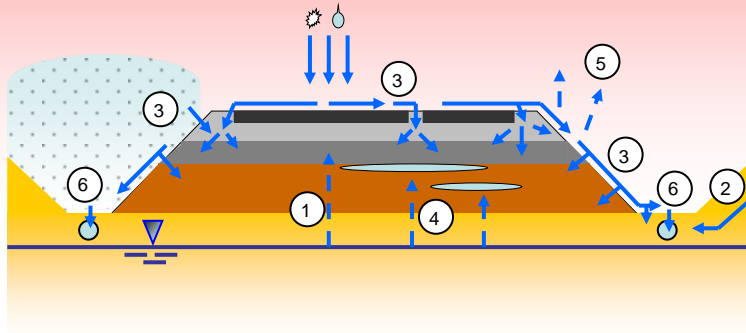
- **Description:** Cracks perpendicular to the pavement's centreline or lay-down direction. Usually a type of thermal cracking.
- **Problem:** Allows moisture infiltration, roughness.
- **Possible Causes:** Several including:
 - Shrinkage of the HMA surface due to low temperatures or asphalt binder hardening.
 - Reflective crack caused by cracks beneath the surface HMA layer.
 - Top-down cracking.
- **Repair:** Strategies depend upon the severity and extent of the cracking:
 - *Low severity cracks (< 12 mm wide and infrequent cracks).* Crack seal to prevent (1) entry of moisture into the pavement through the cracks and (2) further ravelling of the crack edges.
 - *High severity cracks (> 12 mm wide and numerous cracks).* Remove and replace the cracked pavement layer with an overlay.

Frost heave/thaw (action) cracking



- Frost action can be quite detrimental to pavements and refers to two separate but related processes:
 - Frost heave. An upward movement of the subgrade resulting from the expansion of accumulated soil moisture as it freezes.
 - Thaw weakening. A weakened subgrade condition resulting from soil saturation as ice within the soil melts.
- This problem occurs primarily in soils containing fine particles (often termed "frost susceptible" soils), while clean sands and gravels (small amounts of fine particles) are non-frost susceptible (NFS). Thus, the degree of frost susceptibility is mainly a function of the percentage of fine particles within the soil.

Frost heave/thaw (action) – cont.



Water intake

- ① Capillary rise
- ② Lateral transfer of moisture
- ③ Infiltration from precipitation
- ④ Frost action - capillarity

Moisture extraction

- ⑤ Evaporation
- ⑥ Drainage

Block cracking



- **Description:** Interconnected cracks that divide the pavement up into rectangular pieces. Blocks range in size from approximately 0.1 m² to 9 m². Block cracking normally occurs over a large portion of pavement area.
- **Problem:** Roughness, Allows moisture infiltration.
- **Possible Causes:** HMA shrinkage and daily temperature cycling. Typically caused by an inability of asphalt binder to expand and contract with temperature cycles because of asphalt binder aging.
 - Poor choice of asphalt binder in the mix design
- **Repair:** Strategies depend upon the severity and extent of the block cracking:
 - *Low severity cracks (< 12 mm wide).* Crack seal to prevent (1) entry of moisture into the structure through the cracks and (2) further raveling of the crack edges. HMA can provide years of satisfactory service after developing small cracks if they are kept sealed.
 - *High severity cracks (> 12 mm wide and cracks with ravelled edges).* Remove and replace the cracked pavement layer with an overlay.

Transversal/block/frost heave cracking



Potholes



- **Description:** Small, bowl-shaped depressions in the pavement surface that penetrate all the way through the HMA layer down to the base course. They generally have sharp edges and vertical sides near the top of the hole. Potholes are most likely to occur on roads with thin HMA surfaces (25 to 50 mm) and seldom occur on roads with 100 mm or deeper HMA surfaces.
- **Problem:** Roughness (serious vehicular damage can result from driving across potholes at higher speeds), moisture infiltration.
- **Possible Causes:** Generally, potholes are the end result of alligator cracking. As alligator cracking becomes severe, the interconnected cracks create small chunks of pavement, which can be dislodged as vehicles drive over them. The remaining hole after the pavement chunk is dislodged is called a pothole.
- **Repair:** Patching.

Joint Reflection Cracking



- **Description:** Cracks in a flexible overlay of a rigid pavement. The cracks occur directly over the underlying rigid pavement joints. Joint reflection cracking does not include reflection cracks that occur away from an underlying joint or from any other type of base (e.g., cement or lime stabilized).
- **Problem:** Allows moisture infiltration, roughness.
- **Possible Causes:** Movement of the PCC slab beneath the HMA surface because of thermal and moisture changes. Generally not load initiated, however loading can hasten deterioration.
- **Repair:** Strategies depend upon the severity and extent of the cracking:
 - *Low severity cracks (< 12 mm wide and infrequent cracks).* Crack seal to prevent (1) entry of moisture into the pavement structure through the cracks and (2) further ravelling of the crack edges.
 - *High severity cracks (> 12 mm wide and numerous cracks).* Remove and replace the cracked pavement layer with an overlay.

Corrugation and shoving



- **Description:** A form of plastic movement typified by ripples (corrugation) or an abrupt wave (shoving) across the pavement surface. The distortion is perpendicular to the traffic direction. Usually occurs at points where traffic starts and stops (corrugation) or areas where HMA abuts a rigid object (shoving).
- **Problem:** Roughness
- **Possible Causes:** Usually caused by traffic action (starting and stopping) combined with:
 - An unstable (i.e. low stiffness) HMA layer (caused by mix contamination, poor mix design, poor HMA manufacturing, or lack of aeration of liquid asphalt emulsions)
 - Excessive moisture in the pavement structure
- **Repair:** A heavily corrugated or shoved pavement should be investigated to determine the root cause of failure. Repair strategies generally fall into one of two categories:
 - *Small, localized areas of corrugation or shoving.* Remove the distorted pavement and patch.
 - *Large corrugated or shoved areas indicative of general HMA failure.* Remove the damaged pavement and overlay.

Depressions



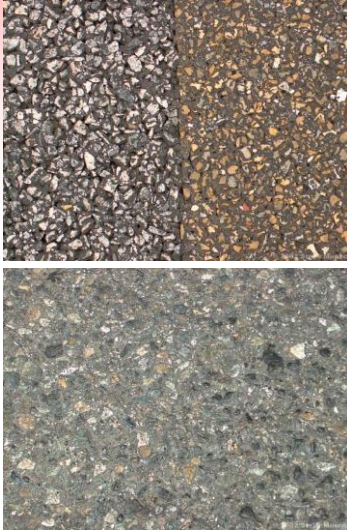
- **Description:** Localized pavement surface areas with slightly lower elevations than the surrounding pavement. Depressions are very noticeable after a rain when they fill with water.
- **Problem:** Roughness, depressions filled with substantial water can cause vehicle hydroplaning.
- **Possible Causes:** Irregular frost heave or subgrade settlement resulting from inadequate compaction during construction or poor quality (soft) subgrade.
- **Repair:** By definition, depressions are small localized areas. A pavement depression should be investigated to determine the root cause of failure (i.e., subgrade settlement or frost heave). Depressions should be repaired by removing the affected pavement then digging out and replacing the area of poor subgrade. Patch over the repaired subgrade.

Patching



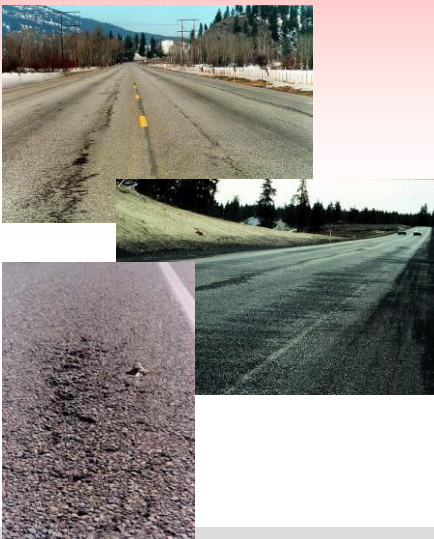
- **Description:** An area of pavement that has been replaced with new material to repair the existing pavement. A patch is considered a defect no matter how well it performs.
- **Problem:** Roughness.
- **Possible Causes:** Previous localized pavement deterioration that has been removed and patched.
- **Repair:** Patches are themselves a repair action. The only way they can be removed from a pavement's surface is by new either overlay.

Polishing (polished aggregates)



- **Description:** Areas of HMA pavement where the portion of aggregate extending above the asphalt binder is either very small or there are no rough or angular aggregate particles.
- **Problem:** Decreased skid resistance.
- **Possible Causes:** Repeated traffic applications. Generally, as a pavement ages the protruding rough, angular particles become polished. This can occur quicker if the aggregate is susceptible to abrasion or subject to excessive studded tyre wear.
- **Repair:** Apply a skid-resistant slurry seal or BST or overlay.

Ravelling



- **Description:** The progressive disintegration of an HMA layer from the surface downward as a result of the dislodgement of aggregate particles.
- **Problem:** Loose debris on the pavement, roughness, water collecting in the ravelled locations resulting in vehicle hydroplaning, loss of skid resistance.
- **Possible Causes:** Several including:
 - Loss of bond between aggregate particles and the asphalt binder as a result of:
 - A dust coating on the aggregate particles that forces the asphalt binder to bond with the dust rather than the aggregate
 - Aggregate Segregation. If fine particles are missing from the aggregate matrix, then the asphalt binder is only able to bind the remaining coarse particles at their relatively few contact points.
 - Inadequate compaction during construction. High density is required to develop sufficient cohesion within the HMA (paving in cold weather).
 - Mechanical dislodging by certain types of traffic (studded tyres, snowplow blades or tracked vehicles).
- **Repair:** A ravelled pavement should be investigated to determine the root cause of failure. Repair strategies generally fall into one of two categories:
 - *Small, localized areas of raveling.* Remove the ravelled pavement and patch.
 - *Large ravelled areas indicative of general HMA failure.* Remove the damaged pavement and overlay.

Stripping



- **Description:** The loss of bond between aggregates and asphalt binder that typically begins at the bottom of the HMA layer and progresses upward. When stripping begins at the surface and progresses downward it is usually called ravelling. The third photo show the surface effects of underlying stripping.

- **Problem:** Decreased structural support, rutting, shoving/corrugation, ravelling, or cracking (alligator and longitudinal).

Possible Causes: Bottom-up stripping is very difficult to recognize because it manifests itself on the pavement surface as other forms of distress including rutting, shoving/corrugations, ravelling, or cracking. Typically, a core must be taken to positively identify stripping as a pavement distress.

- Poor aggregate surface chemistry.
- Water in the HMA causing moisture damage

Repair: A stripped pavement should be investigated to determine the root cause of failure (i.e., how did the moisture get in?). Generally, the stripped pavement needs to be removed and replaced after correction of any subsurface drainage issues.

Slippage cracking



- **Description:** Crescent or half-moon shaped cracks generally having two ends pointed into the direction of traffic.

- **Problem:** Roughness, allows moisture infiltration.

- **Possible Causes:** Braking or turning wheels cause the pavement surface to slide and deform. The resulting sliding and deformation is caused by a low-strength surface mix or poor bonding between the surface HMA layer and the next underlying layer in the pavement structure.

- **Repair:** Removal and replacement of affected area.

Bleeding



- **Description:** A film of asphalt binder on the pavement surface. It usually creates a shiny, glass-like reflecting surface that can become quite sticky.
- **Problem:** Loss of skid resistance skid (when wet).
- **Possible Causes:** Bleeding occurs when asphalt binder fills the aggregate voids during hot weather and then expands onto the pavement surface. Since bleeding is not reversible during cold weather, asphalt binder will accumulate on the pavement surface over time. This can be caused by one or a combination of the following:
 - Excessive asphalt binder in the HMA (either due to mix design or manufacturing)
 - Excessive application of asphalt binder during BST application (as in the above figures)
 - Low HMA air void content (e.g., not enough room for the asphalt to expand into during hot weather)
- **Repair:** The following repair measures may eliminate or reduce the asphalt binder film on the pavement's surface but may not correct the underlying problem that caused the bleeding:
 - Minor bleeding can often be corrected by applying coarse sand to blot up the excess asphalt binder.
 - Major bleeding can be corrected by cutting off excess asphalt with a motor grader or removing it with a heater planer. If the resulting surface is excessively rough, resurfacing may be necessary.

Water bleeding and Pumping



- **Description:** Water bleeding (left two photos) occurs when water seeps out of joints or cracks or through an excessively porous HMA layer. Pumping (right-most photo) occurs when water and fine material is ejected from underlying layers through cracks in the HMA layer under moving loads.
- **Problem:** Decreased skid resistance, an indication of high pavement porosity (water bleeding), decreased structural support (pumping)
- **Possible Causes:** Several including:
 - Porous pavement as a result of inadequate compaction during construction or poor mix design
 - High water table
 - Poor drainage
- **Repair:** Water bleeding or pumping should be investigated to determine the root cause. If the problem is a high water table or poor drainage, pavement drainage should be improved. If the problem is a porous mix (in the case of water bleeding) a fog seal or slurry seal may be applied to limit water infiltration.

Pumping

