An asphalt road disappears into flood water in Snoqualmie Valley, Wash.

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ASPHALT PAVEMENT RESILIENCE

The ability to survive and recover from extreme events

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RESILIENCE IS A WORD most often associated with people. Individuals who endure hardship, withstand unexpected challenges and recover with strength and purpose are admired. In many ways, pavements face the same expectations. They are subjected to increasingly extreme conditions that include heavier traffic loads, more intense rainfall, prolonged heat waves, flooding, freeze–thaw cycles and constrained maintenance budgets.

Just as with people, truly resilient pavements are not defined by avoiding stress altogether, but by their ability to survive extreme events and recover quickly with no long-term damage.

In the context of asphalt pavements, resilience can be defined as the ability to survive and recover from extreme events. This definition emphasizes two equally important components, which are durability during the event and rapid recovery thereafter.

A resilient pavement may experience distress under severe conditions, but that distress is limited, predictable and repairable.

This makes it possible to return the pavement to service rapidly and cost-effectively.

Asphalt pavements are uniquely well-suited to meet this definition when properly designed, constructed, preserved and maintained.

DESIGNING FOR SURVIVAL

The first pillar of asphalt pavement resilience is the ability to survive extreme events without structural failure. Survival begins with structural design. Asphalt pavements can be engineered to carry exceptionally heavy loads over long service lives by adjusting layer thickness(es), material quality and structural composition.

Unlike rigid pavements, asphalt systems offer flexibility in design and response, allowing them to distribute loads efficiently while accommodating minor movements without cracking, faulting or buckling.

Modern mechanistic-empirical design approaches enable engineers to tailor asphalt pavement structures for site-specific conditions including traffic loading, foundation characteristics, climate and moisture sensitivity. When heavy loads are anticipated (e.g., for freight corridors, ports, intermodal facilities, energy infrastructure, military applications, etc.) thicker asphalt layers, stiffer structural layers, targeted innovation or a combination of these approaches can be utilized to reduce strains at the bottom of the asphalt and extend fatigue life.

Material selection plays a critical role in the design process. High-quality aggregates, durable asphalt binders and well-designed mixtures provide the starting point for resilient pavements. In particular, the use of innovative mixtures such as highly modified (HiMod) asphalt has gained attention for applications where extreme loading or structural efficiency is required.

HiMod mixtures are typically characterized by low air voids and high binder contents using high-polymer (HP) asphalt binders. The result is a dense, crack resistant, rut resistant and durable asphalt layer(s).

When properly designed and constructed, HiMod mixes improve rutting resistance, enhance fatigue performance and increase overall structural capacity. These are all key characteristics of pavements expected to survive extreme loads and environmental stressors.

PERPETUAL PAVEMENTS

One of the most compelling examples of asphalt pavement resilience is the perpetual pavement concept. Perpetual pavements are not experimental or theoretical; rather, they are a proven design strategy that has been successfully implemented for decades.

A perpetual pavement is engineered so that the structural layers are never expected to experience fatigue failure under normal traffic conditions. By limiting critical strains through proper thickness and material selection, the pavement's foundation remains intact indefinitely.

Distresses are intentionally confined to the surface layer(s), which can be preserved, maintained and rehabilitated in a manner that protects the structural integrity of the pavement. Perpetual designs may be thicker than conventional asphalt pavement, but they don't have to be. Innovations like HiMod mix, rich bottom layers, stabilization, etc., can be used to build perpetual pavements at thicknesses that can actually be thinner.

Perpetual pavement design aligns perfectly with the resilience definition of surviving and recovering from extreme events. When subjected to unusually heavy traffic, extreme temperatures or moisture intrusion, a properly designed perpetual pavement may exhibit minor surface distress, but the underlying structure survives.

A Wisconsin asphalt highway in the winter with snow on the roadsides.
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Recovery is achieved through shallow rehabilitation, such as milling and resurfacing, rather than full-depth reconstruction. This dramatically reduces user disruption, construction time, cost and environmental impact.

However, it is important to emphasize that perpetual pavements are optimally resilient when they are designed correctly, built correctly, preserved correctly and maintained correctly. Inadequate thickness, poor construction practices, insufficient density or delayed maintenance can undermine performance.

Preservation strategies (e.g., fog sealing, crack sealing, surface treatments or timely overlays) are essential to slow the aging process, prevent moisture infiltration and protect the permanent underlying structure.

RECOVERY MATTERS

Resilience does not end with survival. Rapid recovery from extreme events is equally critical. Agencies and owners must restore service quickly after extreme events. Asphalt pavements offer distinct advantages in this regard. They are fast to construct, adaptable to staged construction and can often be reopened to traffic within hours rather than days, weeks or months.

Shallow rehabilitation techniques that are central to perpetual pavement strategies allow damaged surface layers to be removed and replaced with minimal impact on traffic and adjacent infrastructure.

This capability is especially valuable in emergency response situations, where maintaining mobility is essential for public safety, commerce and recovery operations. For example, hurricane recovery in coastal areas is not possible without a serviceable roadway infrastructure.

From a sustainability perspective, asphalt pavements further enhance resilience through recyclability. Reclaimed asphalt pavement (RAP) can be incorporated into new mixtures, reducing material demand and environmental footprint while maintaining performance through proven innovations like balanced mix design (BMD) and warm mix asphalt (WMA).

The ability to reuse materials during recovery operations reinforces asphalt's role as a resilient, circular construction material.

Taken on Nov. 1, 2024, this North Carolina road was destroyed by Hurricane Helene.
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DESIGNING FOR THE ENVIRONMENT

Extreme weather events increasingly include intense rainfall and flooding, requiring pavements that can survive prolonged exposure to water. While no pavement is immune to flooding, asphalt systems can be designed to better tolerate moisture when appropriate materials, drainage strategies and construction practices are employed.

An illustrative example is South Bowers Road, a specialty asphalt pavement application designed to withstand recurring flooding conditions. Located in South Bowers, Del., a low-lying coastal environment, this roadway is routinely exposed to storm surge and tidal flooding.

Rather than treating flooding as an anomaly, the pavement design acknowledged it as a recurring condition.

The design incorporated robust asphalt layers, careful attention to mixture durability and construction practices focused on achieving mix stability as well as permeability. The objective was not to prevent water exposure, but rather to ensure that the pavement structure could survive repeated inundation without deterioration.

Projects like South Bowers Road demonstrate that asphalt pavements can be purposefully designed for extreme environmental conditions when resilience is prioritized from the outset.

BUILDING IT RIGHT

Even the best pavement design cannot achieve resilience without quality construction. Important details, such as mix proportioning, mat compaction, longitudinal smoothness, surface slope/super elevation, etc., are all essential to achieving the intended performance of resilient asphalt pavements. Low permeability, achieved through adequate density and well-designed mixtures, is particularly important for resisting moisture damage and preserving structural integrity during extreme weather events. Likewise, safety in extreme weather is a function of both mix properties and surface geometry.

Technologies like intelligent compaction (IC), improved quality assurance programs (QAP) and performance-based specifications offer opportunities to further enhance resilience by reducing variability and ensuring that pavements are built as designed.

Resilient pavements are not accidental. They are the product of intentional design, disciplined construction, proactive preservation, well-timed maintenance and strategic rehabilitation.

RESILIENCE BY DESIGN

As extreme events become more disruptive to the motoring public and more costly to the taxpayer, pavement resilience must move from abstract concept to mainstream application.

Defining resilience as the ability to survive and recover from extreme events provides a clear and practical framework for decision-making. Through proven strategies, such as perpetual pavement design, successful innovations like HiMod, and specialty applications tailored to harsh environments, asphalt pavements offer a resilient solution that aligns with modern infrastructure needs.

Like people, pavements cannot avoid stress. A good foundation, a fulfilled sense of purpose and continuous renewal are the universal keys for survival. With thoughtful design, quality construction and strategic intervention, asphalt pavements can endure extreme challenges, recover efficiently and continue providing mobility for the motoring public long after extreme events have passed. **R&B**

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