Triangle Tech Tips
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Understanding Delayed Ettringite Formation (DEF)

What DEF Means for Concrete Durability

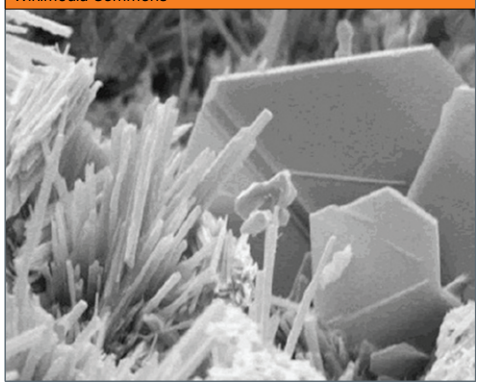
Delayed Ettringite Formation (DEF) is a hidden but potentially serious durability concern in concrete structures. DEF is one of those issues that doesn't show itself right away — but when it does, the consequences can be significant. This article explains what DEF is, how it develops, how to identify it, and what steps can be taken to prevent it — especially in high-heat or mass pour situations. Understanding DEF is key to ensuring long-term performance and protecting your investment in concrete construction.

Ettringite: What is it?

Ettringite was first identified in 1874 by a scientist named J. Lehmann. It was discovered near a volcano called the Ettringer Bellerberg in Ettringen, Germany. The mineral is usually found in limestone that has changed due to heat and pressure, especially when it's close to melted rock that pushed up from deep underground.

Ettringite is a complex hydrated calcium sulfoaluminate mineral with the chemical formula $Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$. In the context of Portland cement hydration, ettringite forms rapidly when tricalcium aluminate (C_3A, a reactive component of cement clinker) reacts with calcium sulfate (typically introduced as gypsum). The controlled formation of ettringite is crucial for the proper setting and hardening of concrete.

Figure 1: Fractured hardened cement paste, showing thin hexagonal plates of portlandite and needles of ettringite.
Source: US Department of Transportation, Public domain, via Wikimedia Commons



Ettringite is a natural byproduct of the cement hydration process. When Portland cement reacts with water, it undergoes a series of chemical changes. One of these reactions involves sulfate (from gypsum in the cement) combining with calcium aluminate compounds to form ettringite.

In normal conditions, ettringite forms early — while the concrete is still fresh and pliable. This early formation does not cause problems and is simply part of the curing process.

In simple terms: *ettringite is a harmless mineral that normally forms when cement and water mix. It forms during the early stages of setting and doesn't cause issues when it forms on time.*

What Is Delayed Ettringite Formation (DEF)?

Delayed Ettringite Formation occurs when the normal formation of ettringite is suppressed — usually due to high temperatures during the initial curing phase of the concrete. In mass concrete or precast applications, internal temperatures can rise above 158°F, which prevents ettringite from forming when it normally would.

Later, when the concrete has hardened and is exposed to moisture (such as rain, groundwater, or internal humidity), the previously delayed ettringite begins to form — this time inside the ***hardened*** matrix. Because the concrete has already set and hardened, the expansion caused by the newly formed ettringite creates internal stress, which can result in cracking and structural damage.

In simple terms: *DEF is what happens when heat delays the formation of a normal mineral in concrete. When that mineral finally forms later, it does so inside hard concrete and causes it to crack from within.*

Causes of DEF

1. **High early-age temperatures:** Often due to heat of hydration in mass pours or accelerated curing methods (like steam curing).
2. **High sulfate content in the mix**.
3. **Excessive alkalis in the cement**.
4. **Prolonged exposure to moisture after hardening**.

Effects and Visual Cues

The effects of DEF may not appear until months or even years after the concrete is placed. Visual and structural signs can include:

- **Surface or internal cracking,** especially map or pattern cracking.
- **Swelling or warping** of slabs or elements.
- **Loss of strength** and reduced load-carrying capacity.
- **In severe cases,** spalling or delamination.

Concrete affected by DEF may show a network of fine cracks, especially near joints or edges where moisture ingress is more likely.

DEF in Mass Pours

Mass concrete pours — such as foundations, retaining walls, or bridge piers — are particularly susceptible to DEF. The larger the volume, the greater the heat generated during hydration. If internal temperatures exceed 158°F, the risk of DEF increases significantly.

To protect against DEF in mass concrete:

- Use a low-heat cement or supplementary cementitious materials (SCMs) like fly ash or slag to reduce peak temperatures.
- Implement thermal control plans, including the use of cooling pipes, insulation, or scheduling pours during cooler weather.
- Monitor internal temperatures with embedded sensors during curing.
- Limit the maximum allowable temperature rise and maximum internal temperature as specified in ACI guidelines.

Prevention and Best Practices

The best way to deal with DEF is to prevent it entirely. At Triangle Ready Mix, we work closely with contractors, engineers, and project managers to reduce risk through smart mix design and temperature management. Recommended strategies include:

1. **Control temperature rise:** Avoid peak internal temperatures above 158°F.
2. **Use SCMs:** Materials like fly ash or slag help moderate heat and reduce sulfate content.
3. **Optimize mix designs:** Select cements with lower C_3A (tricalcium aluminate) and alkali content.
4. **Moisture management:** Protect hardened concrete from prolonged moisture exposure, especially in the early service life.
5. **Testing and monitoring:** Implement in-place temperature and humidity monitoring during curing for critical elements.

Figure 2: Delayed Ettringite Formation at the joining surfaces of aggregates and hardened cement causes fracturing due to the expanding forces of the ettringite.