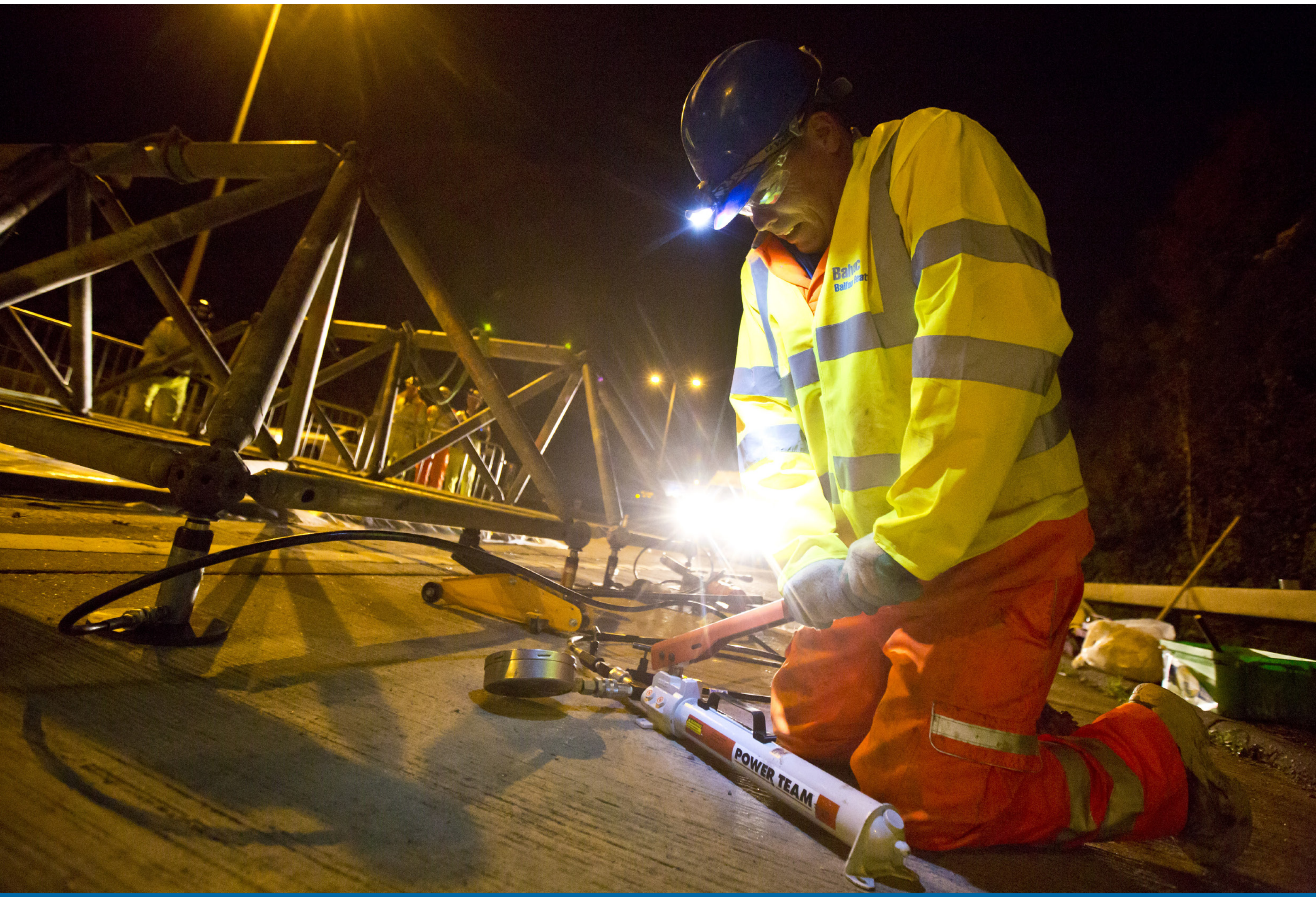


Tried, Tested, Proven

Vacuum Void Grouting

November 2019

Balvac
Balfour Beatty

Foreword

The strategic road network (SRN) includes some of the world's busiest roads. It is vital to the UK economy and to the daily lives of millions of people and businesses. Keeping it in good working order is essential. But it must also be ready to cope with significant forecasted traffic growth, new technologies and a range of climate-related environmental challenges. On top of all this, those operating and maintaining the SRN have to ensure the reliable journey times and low levels of disruption that the road user deserves and expects, whilst keeping a weather eye on value and cost.

This combination of requirements has rightly led to a new focus on preventative maintenance – keeping the roads in good shape rather than waiting until they need to be repaired – something in which Balvac has significant expertise. And after years as the poor cousin of capital spend on large schemes, preventative maintenance is now seeing improved levels of investment and long-term delivery plans.

In 1973 Balvac invented a vacuum impregnation process – a process so innovative that it featured on BBC's Tomorrow's World. By the late 1970s, this had been developed into a portfolio of specialist applications, including vacuum void grouting, which was used to stabilise concrete based pavements. Since then, Balvac has invested significantly in technique and technology, honing the process over the past 40 years – and continuing to do so up to the present day as we look to how we can incorporate the benefits of new technologies such as 3D ground penetrating radar.

Balvac remain leaders in the field. Our bespoke, leading approach of combining modern testing and survey techniques with vacuum void grouting provides highways engineers with the confidence that they are treating the worst joints at the optimum time, allowing them to realise considerable cost savings. In our experience, this technique can extend the life of the asset by up to 20 years[1], holding at bay the need for bigger, more disruptive repair and refurbishment programmes.

Vacuum void grouting does not involve digging large holes in the road or lengthy road closures. All work can be done off-peak at night and in very short working windows, always with the option of fully reopening the road within minutes if necessary. This translates into a better, more reliable service for the road user and ultimate customer, and better value for the taxpayer. Concrete repair and protection also has a significantly reduced environmental impact when compared with the alternatives of demolition, reconstruction or demise. Indeed, the Balvac vacuum void grouting process has an embodied carbon broadly in the region of 1/10th of that of replacing the concrete slab.

All of these benefits in many ways make vacuum void grouting a "no brainer".

Used extensively throughout the UK on both the SRN and local authority roads, this technique to stabilise slabs is today being discovered by a new generation of pavement engineers keen to realise the benefits it has to offer.

With its considerable track record of success, Balvac's approach to vacuum void grouting is a tried, tested and proven technique. This short, technical piece sets out the benefits of the process and Balvac's leading, specialist approach.

Richard Bailey
Director, Balvac

[1] Depending on the routine maintenance applied going forward

What lies beneath

Many of the UK's highways have a concrete base, typically slabs, even where that base has subsequently received a flexible overlay.

On roads with a concrete base, the sealant between joints requires regular routine maintenance. Where the sealant is poorly maintained, water can enter the joint. This leads to a softening of the foundation (subbase and/or subgrade) just at the point (edge of slab) where vehicle loading puts the construction under the most stress.

Repeated deflection of the overlying slab into this softer area forms a minor void which water can collect in. Subsequent deflections force this water back up the joint. As the water is pushed up, it brings grains of material from the foundation with it, slowly increasing the size of the void. As the void gets bigger, this scouring action becomes more destructive, further eroding the material around the joint. This means that the rate of deterioration accelerates with time. While even a small void can result in rocking slabs, left unchecked the rocking slabs will eventually fail, usually through transverse cracking. This is because around 80% of the strength of a pavement comes from the foundation, rather than from the concrete slab. Re-establishing full support at the optimal time is therefore vital.

Movement in the concrete base results in an unstable road. Where concrete roads are overlaid without checking for and treating any slab instability, the overlay is likely to fail prematurely due to reflective cracking coming through from the underlying rocking slabs. This will typically result in potholes as the overlay breaks up. Simply renewing the failing overlay is a false economy as it does not address the root cause of the problem.

In the late 1970s, in conjunction with the Department for Transport and the Transport Road Research Laboratory, Balvac developed and successfully trialled a vacuum void grouting process specifically designed to stabilise rocking concrete slabs. The 'Balvac Process', which has been honed and developed in the intervening period, uses vacuum assistance to fill the void matrix beneath the slabs with a resin grout in order to stabilise the pavement.

In addition to its use on concrete based roads, the Balvac Process is equally applicable to any concrete based pavement. For example, Balvac has used it successfully at airports and ports, as well as outside and inside industrial warehouses and distribution centres.

Prevention is better than cure

While the economic benefits of new infrastructure schemes have been widely acknowledged in recent years, the importance of infrastructure maintenance is less frequently spoken about. Yet maintaining existing infrastructure, ensuring that it is being used as efficiently as possible and that it is continuing to play its role in underpinning economic growth is equally as important and, in many ways, has a more immediate impact on those using it.

Money spent on infrastructure maintenance, ensuring it works safely and well, is money well spent, especially taking increasing usage due to population growth, into account. It helps to extend the life of the assets we rely on. This is something which will become increasingly important as the amount of infrastructure we use to support our daily lives grows and the need to use resources responsibly becomes a priority for environmental reasons. The inclusion of ring-fenced funds for preventative maintenance in Highways England's RIS2 (Road Investment Strategy 2020-2025) is therefore extremely welcome.

Preventative maintenance is also a key way of reducing the carbon footprint of the country's roads. Indeed, research has found that extending pavement life through preventive maintenance can reduce greenhouse gases by up to 2%, enabling responsible agencies to cut spending by between 10-30% and helping drivers save between 2-5% in fuel consumption, tire wear, vehicle repair and maintenance costs due to smoother surfaces[2]. Specifically in relation to Balvac's vacuum void grouting process, our calculation is that it has an embodied carbon broadly in the region of 1/10th of that of replacing the concrete slab.

While the importance of planned cost-effective long-term preventative maintenance programmes as part of overarching strategies is now better understood, in the past there have been long periods of under-investment in some of the UK's assets, including concrete based roads. In spite of its importance, infrastructure maintenance is often deferred due to budgetary pressures and funds earmarked for maintenance are redeployed elsewhere. Infrastructure owners and managers come under understandable, but often competing demands to reduce the costs involved in inspection and maintenance while keeping critical transport routes open. In particular, undertaking maintenance in a live environment such as on roads, means that it is more difficult and takes longer, which, in turn has an impact on how expensive it is to undertake.

As a consequence of these periods of under-investment, much of this vital infrastructure is in desperate need of rehabilitation. However, in Balvac's experience of both maintenance and of undertaking repair work on a range of assets, deferring maintenance is a false economy.

Vacuum void grouting is a quick and effective preventative maintenance technique. It means that, rather than breaking up and replacing the road slabs at significant expense, their useful working life can instead be extended by up to 20 years. This cost-effective option also significantly reduces the need for the traffic disruption and expense involved in repair or replacement.

Vacuum void grouting is most effective when used as a preventative maintenance tool to intervene and stabilise slabs before they break up and/or subside. In the past, uncertainty has been a barrier to scheme development due to a limited ability to investigate where the most 'at risk' joints are; and limited funds for preventative maintenance.

However, depending on the nature of the break up and/or subsidence there are occasions when Balvac's vacuum void grouting process, possibly in conjunction with our Slablifting capability, can still be used to extend the life of the pavement.

[2] Hao Wang, Israa Al-Saadi, Pan Lu, Abbas Jasim. Quantifying greenhouse gas emission of asphalt pavement preservation at construction and use stages using life-cycle assessment. International Journal of Sustainable Transportation, January 2019

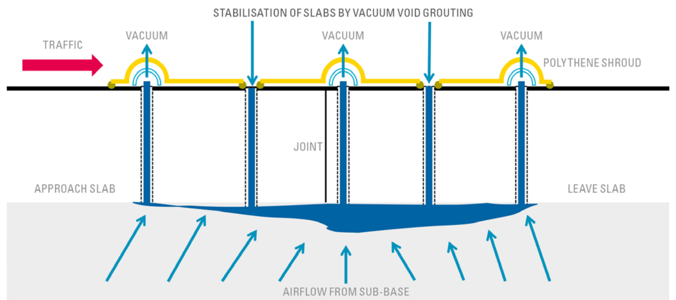
How it works: The Vacuum Grouting Process

The vacuum void grouting process specifically targets the small voids that have developed between the concrete and the underlying foundation, with the aim of reinstating full slab support. It is not a process which seeks to treat deeper issues such as poorly consolidated ground, where injection of material to 2, 3 or more metres in depth is required. Even though this means the drilling of injection and vacuum holes only needs to be to sufficient depth to penetrate the bound layers (i.e. the PQC and/or any underlying CBGM), in the interests of safety the areas to be treated should be scanned and the location of any underground services marked prior to any drilling works commencing. In further consideration of health and wellbeing, the drilling operation must be carried out using rig-mounted drills or similar so the operator is not subjected to tool vibration. It must also be fitted with a vacuum attachment that removes dust at source for subsequent safe disposal.

A standard vacuum void grouting injection treats a single slab width transverse joint to 2m either side of the joint. Five rows of holes are drilled through the concrete on a nominal 1m grid, amended locally if required to avoid drilling down directly over buried services. The centre row of holes should be drilled just on to the leave side of the joint, as that is where there will be the best access to the void matrix, and these will be covered by a vacuum duct. The rows of holes 1m either side of this will be grout feed points and a sealant is applied individually around each hole. The rows of holes 2m either side of the central row will be covered by vacuum ducts and a sealant applied around the perimeter of the whole area. Covering the area with a polythene shroud, creating an effective seal, and attaching the vacuum unit to the duct with hoses completes the preparation phase.

Over the years, Balvac has continued to invest in advances in vacuum technology and the current bespoke vacuum units are the 4th generation. This can allow up to 3 individual joints to be treated simultaneously provided they are in close enough proximity to make this practicable.

When the vacuum unit is engaged, it starts to draw air from the sub-base and, when the polythene is removed from the grout feed holes, air is also drawn down them. This latter flow is then replaced with resin grout, which is drawn into and through the void matrix. The initial dose of grout will be neat, to ensure material can be drawn into the finest voids, and experienced operatives will then closely monitor the drawdown rate and add an appropriate amount of filler to the resin as required.



The drawdown rate is also an indicator of where the largest and easiest access to the void matrix has been achieved. It is also important to acknowledge that the grout will generally travel more easily and more rapidly along the larger interconnections within the void matrix and consequently appear at one of the vacuum holes well before it has been drawn to all corners of the injection. It is for this reason that each duct has at least two connections to the vacuum source, enabling the operatives to reduce (or even turn off) the direct vacuum pull at one point, thus still maintaining the vacuum overall but pulling slightly harder towards the remaining corners so that the whole area can be effectively treated.

If the void contains water at the outset, this is drawn out by a combination of the applied vacuum and the fact that the resin grout is denser and thus pushes the water ahead of it as it is drawn through the void matrix. Water drawn off in this manner is collected in a separator trap on the vacuum unit.

Once the grout has been drawn to all corners and/or no more grout is being taken, the vacuum unit is reduced to tick-over for the final 5 minutes, at which point some further topping up of holes is likely to be required. This is because under full throttle the vacuum unit effectively applies a load to the pavement, potentially deflecting it slightly in to the void until the vacuum induced load is removed. Once the injection is complete the hoses, polythene and ducts are removed and the holes beneath the ducts are topped up so that all holes finish flush with the carriageway surface.

Identifying the ‘at risk’ joints

A key challenge for Highways Engineers is identifying the most ‘at risk’ joints. This is a two-stage process whereby the raw data is processed by the Falling Weight Deflectometer (FWD) survey supplier to provide a single set of data for each joint, normalised to 50kN. This requires the bespoke setting up of the geophones, which is quite different to the normal FWD set up for flexible pavement testing. This raw data provides nine parameters of joint condition, each of which is a pointer towards the probability of voids being an issue, with some ‘pointers’ being more important than others. This relevant importance is addressed by the second stage of processing which assigns a penalty score to each parameter, from a series of weighting tables, based on the actual value of that parameter. Added together, these provide a total penalty score for each joint which facilitates the prioritisation process. It is important to ensure such a ranking process does not override the designer’s decision-making process, it is merely a tool to assist the designer who should ensure any visual condition information, other test results, and practical operational considerations are also considered when finalising which joints to treat.

The nine parameters derived from the normalised FWD data are as follows:

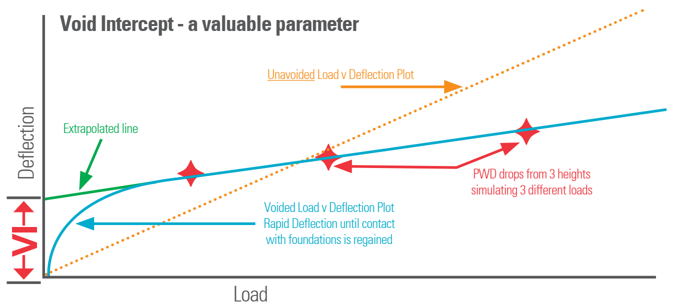
1. Absolute Deflection (Approach) – indication of the strength of the foundation under the approach slab.
2. Absolute Deflection (Leave) – indication of the strength of the foundation under the leave slab.
3. Relative Deflection – the difference between Approach and Leave Absolute Deflections provides an indication of any asymmetrical loading.
4. Load Transfer Efficiency (Approach) – indication of LTE from approach to leave slabs.
5. Load Transfer Efficiency (Leave) – indication of LTE from leave to approach slabs.
6. Void Intercept (Approach) – indication of potential voiding beneath the approach slab.
7. Void Intercept (Leave) – indication of potential voiding beneath the leave slab.
8. Slab Curl (Approach) – nature and extent of approach slab bending indicates support / voiding issues.
9. Slab Curl (Leave) – nature and extent of leave slab bending indicates support / voiding issues.

With the exception of Relative Deflection, the above parameters pair up due to testing both the approach and leave slabs. The additional accuracy of joint assessment provided by taking this ‘belt and braces’ approach does make a difference when selecting the most ‘at risk’ joints for injection. This is because whilst in most cases leave values will be worse than approach values for slabs that need stabilising, occasionally it is the approach values that trigger the need for treatment. It also provides an increased level of confidence that maintenance is being most effectively targeted when the engineer can contrast the results from both sides of the joint.

Treating the right joints at the right time delivers compelling results and more than offsets the costs of large-scale FWD condition surveys on future schemes.

Deflections and LTE are familiar terms but Void Intercept and Slab Curl (sometimes called slab rotation) may be less so and warrant further explanation.

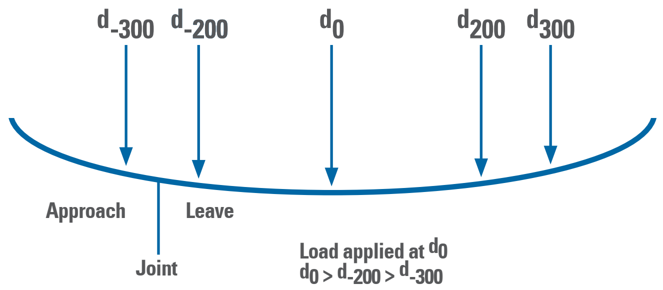
Void Intercept – The FWD survey makes 3 drops from different heights to simulate 3 different loads. When no voids are present, extrapolation of those 3 points on a load v deflection graph will pass through the origin (zero deflection for zero load). When voids are present, initial loading of the pavement will cause relatively high deflections as the slab is deflected in to the void. Only once the deflecting slab comes into contact with the underlying foundation is the main strength of the pavement engaged and much greater force needed to deflect it. This means that Void Intercept (VI) is a valuable parameter in assessing joint performance and, if present, the Leave VI will usually be greater than the approach VI.



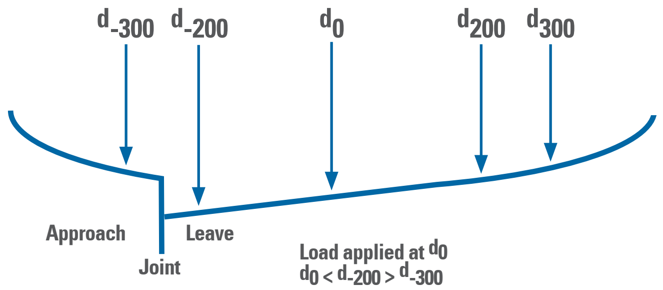
Measuring success

Slab Curl (Slab Curvature) – When the FWD makes a drop on to the loading plate the geophones record deflections under the plate d_0, and at varying distances from that point, eg d_{-300}, d_{-200}, d_{200}, d_{300}, etc. If the leave slab is well supported the shape of the deflection bowl will be typical with the maximum deflection at d0 and less deflection at d_{-200}, with less again at D_{-300} so slab curl will be positive. If, however, there is a void present the loaded slab will be cantilevered over that void. Consequently when d_0 is loaded d_{-200} will be pushed down into the void, recording a greater deflection than d_0, and slab curl will be negative. The more negative, the greater the void.

Fully Supported Deflection Bowl (+ve slab curl)



Voided Deflection Bowl (-ve slab curl)



As outlined, the main objective of vacuum void grouting is to extend the life of existing pavements. The durability (life) of the repair depends on both the condition of the foundation, and the future routine maintenance of the road.

The key way in which success is proven is through data from the pavements where the Balvac vacuum void grouting process has been used and where the need for subsequent repair or replacement has been delayed for up to 20 years. Due to the general lack of ongoing monitoring, hard evidence of previous success is difficult to come by, but where such evidence exists, the durability of the process is compelling.

Just as FWD testing is used to help prioritise the most 'at risk' joints, repeating that test can be used to verify the level of improvement gained from the injection work. Exactly what sort of post-grout testing regime is instigated will depend upon the client, and how much importance, and indeed funding, they attach to this aspect of the project. However, Balvac recognises the value of pre-grout and post-grout testing to provide an efficient targeted treatment, but also the value in periodic routine testing in the years that follow.

It is extremely rare that an opportunity to actually see what has occurred below the concrete pavement post vacuum void grouting presents itself. However, where this has happened, notably in a test which saw Balvac add a bright red colouring agent to the grout to facilitate post-grout investigations, post-grout testing by Ground Penetrating Radar (GPR) confirmed that the voids had gone, and the FWD reported the slabs were now fully supported. To confirm this the slabs either side of the joint were sawcut into quarters, fitted with lifting hooks, and physically lifted out for examination.

Where next for vacuum void grouting?

Over the last 40 years Balvac has continued to invest in improving the vacuum void grouting process. This has included significant evolution of the vacuum units (now 4th generation) and the testing methodologies used to identify the worst performing joints so that limited maintenance funds can be targeted where they will deliver the best value for money.

Our aim is to continue this process of improvement by taking advantage of new technologies as they come on line.

The main focus will be in the use of new technologies to help Highways Engineers identify with increased accuracy exactly where the problem lies, in order to allow even better targeting of activity. With instability of the road joints and the subsequent development of a void happening beneath the road slabs, out of sight, the first indication of a problem is often surface distress, which is long after the optimum time to intervene.

Since the invention of the vacuum void grouting process, Balvac has worked with a variety of companies to improve accuracy, speed and reliability of data collection.

The Falling Weight Deflectometer (FWD) has long been, and still is, a major tool in the testing of flexible roads. In conjunction with a manufacturer and operator of the FWD, Balvac achieved a breakthrough in the mid-nineties by repositioning the geophones to facilitate testing both sides of the joints on roads constructed with concrete slabs. This not only enabled the reporting of Absolute and Relative Deflections as defined in the original HA6/80 advice note, but also provided several other useful joint condition parameters. More importantly it did this much faster, more accurately, and with greater repeatability than previous testing methods. However, our aim is to build upon the numerous developments achieved over the last 40 years to continue to improve on this success.

While GPR can be used to identify some of the issues associated with pavement conditions, it has so far had only limited success in establishing where the voids are, due to the fact that they are often only a few millimetres in size.

The very latest GPR technology, using ultra-wide step-frequency radar, may provide a breakthrough and Balvac is working closely with specialists in this field to ascertain if it can assist their current methods of locating the most 'at risk' joints.

Looking further forward, Artificial Intelligence and machine learning will drive increased use of predictive maintenance, which relies on precise data and predictive analytics to provide a deeper understanding of asset condition. This, in turn, will support engineers in better determining maintenance priorities, facilitating a cost-effective approach focussing on those assets where maintenance is most needed, first.

Effectively leveraging transformational new technologies as they come online will ultimately lead to increased reliability and less disruption for the road user, and better value for the taxpayer.

Conclusion

The case for vacuum void grouting is extremely strong. A well-established process with a proud track record of success, it is one which will continue to go from strength-to-strength as technological advances come online.

By working closely with the client, and leveraging its specialist capabilities and knowledge to the project, Balvac helps clients realise efficiencies in preventative maintenance and extend the life of their existing assets.

Vacuum void grouting is a process which provides significant benefits for the road user in terms of increased reliability and a reduced need for road closures for lengthy repairs. It also presents the taxpayer with an excellent value for money option and is therefore recommended to infrastructure owners and operators.

About Balvac

Part of the Balfour Beatty Group, Balvac is a leading specialist contractor undertaking repair, strengthening, protection and refurbishment of civil and building structures throughout the UK.

With extensive expertise and experience, Balvac delivers innovative, value-engineered solutions for its customers in numerous sectors including highway and rail infrastructure, marine and coastal, power, water and waste water, and commercial buildings and multi storey car parks.

Balvac also carries out post-tensioning installation works to bridges, tunnels and circular tanks. Its complete service combines project management, specialist skills, survey and design works to deliver complex structural repairs, operating either as a principal or specialist contractor on projects ranging from £100k to £10m in value.

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