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REHABILITATION WORKS IN QUEENSLAND USING FOAMED BITUMINOUS STABILISATION

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ABSTRACT: Adapting foamed bitumen stabilisation is considered as the most cost effective approach in Queensland to expedite the rehabilitation works, especially after the major flood devastation in 2011. This paper presents the key changes made as well as the recent practices adapted during a road rehabilitation work to increase the return from the investment. In this process, initially, the designed width for subgrade lime stabilisation has been modified to minimize the moisture entry into the pavement. The dry modulus, three days soaked resilient modulus and retain modulus were used to identify the suitable base material for construction. In addition, a trail site was used to examine the bulking effect on base layer when adding lime as secondary agent, which helped to estimate the exact depth for foamed stabilisation. A few innovative techniques such as a two-layer compaction to effectively condense stabilised subgrade, was used to improve the quality of the outcome were also highlighted.

Keywords: Foamed bitumen, Flexible pavement, Pavement Rehabilitation, Stabilisation

1. INTRODUCTION

In Queensland, foam bitumen stabilisation (FBS) is becoming popular and widely accepted as a long term economic treatment for the base and sub-base layers in road rehabilitation works. Although the foam bitumen stabilisation method was introduced in Australia in 1960s, it never really gained acceptance until 1990s with the introduction of new reclaimers and the use of more experienced contractors [1]. In 1997, the first foam bitumen works was carried out in Queensland; however it is still new area for the road engineers especially when it comes to identification of suitable material as well as filed testing that need to be carried out during construction to ensure quality outcomes. More specifically, a full depth reclamation works using foam bitumen still require a good knowledge-based approach and better specifications to achieve a quality outcome.

Traditionally, the most of the Queensland roads have been rehabilitated using the locally available material together with few (2~3%) adhesive agents. It was found that adding cement for unbound pavement change the properties of the pavement layer and become as bound/rigid pavement. When unbound gravels are strengthened by cementing, the particles that were stuck together raised a significant tensile strength, resulting in an unavoidable shrinkage effect, hence causing cracking of the pavement [2]. In contrast foamed bitumen provides a much more flexible pavement layer which reduces shrinkage cracks when using lime as secondary additive. Foamed bitumen stabilised pavement also act as a water proof layer and improve the plasticity and the stiffness of the unbound pavement material. In consideration of similar advantages into account, currently foam bitumen stabilising is known as an environmental friendly, economical and innovative treatment for rehabilitation works compare to the other form of stabilisation works.

This paper discusses the steps taken from the design stage to completion of a rehabilitation work to a flexible pavement project in Oakey, Queensland. Specially, after the project was awarded to the contractor, the expertise from both client and contractor revisited the design, material specification and construction process to improve the quality of the outcomes. Thus, the aim of this paper is to highlight the technical changes made, analysis and testing adapted, and the follow-up actions undertaken on site to increase the return from investment.

2. FOAM BITUMEN STABILISATION

Foamed bitumen is produced by injecting air and water droplets under high pressure into hot bitumen. In this process, as the water turns into steam, bitumen changes from the liquid state into foam [3]. When this foamed bitumen mixed with the suitable pavement materials it then helps to coat the fine particles within the material to make a bond between larger particles. This bonding is also sometimes referred as welding action between pavement partials.

2.1 Advantages of using FBS

The advantages and disadvantages of using foam bitumen stabilising compared to other type of stabilising techniques are highlighted by several researchers [6][7]. The key advantages of using FBS are listed below:

- Significantly reduce or eliminate shrinkage cracks
- Increased resilient modulus for flooding/water entry areas
- Strong and flexible layer against fatigue failure
- Increased shear strength and reduced moisture susceptibility of granular material
- Reduced binder and transportation costs compared to other type of cold mixing.
- Foamed bitumen layers can be constructed in adverse weather such as light rain without affecting any conditions for workability.
- Energy conservation due to the only heating bitumen when stabilizing (no need to dry or heat the material)
- Reduced environmental and other side-effects resulting from the evaporation
- Reduced wastage as the existing material can be used with the imported material
- No risk of binder run off or leaking
- Saving in curing time as the traffic can be allowed as soon as compacted

2.2 Key Requirements

The success of a foamed bitumen stabilisation is highly dependent on material characteristics, moisture content of the existing/imported material, bitumen class, characteristics of the foaming agent, tight quality process during the construction including use of correct equipment/machineries. Other factors which affect foaming properties of bitumen are foaming temperature, anti-foaming agents, foaming water content and bitumen chemical composition [4].

It is noted by several studies that when bitumen at a stage of foamed, it doesn't completely coat all aggregate surfaces but has an affinity for finer particles, those of 75 microns or less. This action with the fine particles forms a mortar or glue which effectively bonds with the other pavement materials together [5]. It has also been highlighted that the quality of fine is critical rather than the quantity. Therefore expected quality and chemical property of the fine particles should be well specified from the laboratory testing methods.

When foamed bitumen breaks and mixes with tiny particles the moisture contents within the tiny particles influences the strength of the created bond between the particles, so it is necessary to maintain a suitable moisture content for this purpose. If the imported/existing material for foamed bitumen works contain too much moisture or clayey then particles create lumps before the application of bitumen and foam will not be distributing evenly to create a strong bond. A moisture level that is too high lengthens the curing time, reduces the strength and density of the compacted mix, and reduces the coating of the aggregates [6]. On the other hand, insufficient moisture reduces the workability of the mix which could result in inadequate dispersion of the binder. Therefore optimum moisture content should be maintained throughout the construction process.

Time required to mix the foam with the pavement material is critical in foamed bitumen works. Producing foam by adding water and air to a hot bitumen is an easy task than maintaining the foamed stage. Therefore appropriate expansion ratio and half-life should be used during the construction process. Expansion ratio is defined as being the ratio between the maximum achieved volume of the foamed bitumen and the original volume of the non-foamed bitumen [8]. Half-life of the bitumen is defined as time taken for the volume of foamed bitumen to settle to half of the maximum volume [7]. The type of foam most effective is one which has an expanded volume of 10 to 15 when injecting one to two percent of water to the hot bitumen[12].

Wirtgen Stabiliser (WR 2400, WR 2500) with the mixing chamber in the middle is the most suitable machine currently available for foamed bitumen stabilising work [13]. The selection of the roller and rolling pattern is critical for compaction works. Experienced final trim operator is also critical to provide quality product within the specified tolerance.

3. PROJECT DISCRIPTION

The project is on Oakey-Pittsworth two-lane undivided highway which is located 40 km from Toowoomba. A 2.6 km section of the highway has been identified for rehabilitation works which was severely affected by flood in 2011 and 2013. Since its location subject to floods, a proper treatment is required to stand against future flood/rain events. The rehabilitation works had been awarded to RoadTek.

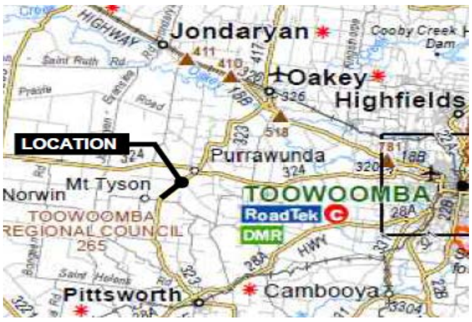

Fig.1 Locality Map (Source: RoadTek)

3.1 Proposed Design

The Department of Transport and Main Roads (DTMR) has carried out the initial design where mechanistic design approach was carried using a pavement design software namely CIRCLY. The following traffic and materials parameters were used in the preliminary design: Maximum vertical design modulus for lime stabilised layer was 200MPa; Maximum design modulus for foam bitumen layer was 1200 MPa; Bitumen content for foam was 7% by volume; Strength of post cracked phase was 500MPa with Poisson's Ratio of 0.35, Project Reliability was 90%, Design Traffic was 1.8 x 10^6 ESAs, and other design loading and subgrade rutting criteria as per Austroads 2004[11].

The initial design considered the use of existing base and sub-base pavement material or replacing it with suitable material. During the initial stage the moisture condition of existing pavement was considered critically when proposing mix design for foamed bitumen. As a result, it proposed to replace unsuitable material (250mm top) with imported Type 2.5 material as per specification given in Main Roads Technical Specification (MRTS) [11]. Further lime stabilising (300mm) was proposed to improve the strength of subgrade to eliminate the undesirable characteristics of the expansive soil. Lime demand test was conducted, and it was proposed to use 9% by mass that is 40kg/m2 hydrated lime to stabilise the subgrade. The optimum bitumen content was also identified through MATTA testing done in laboratory. As a result, the initial proposed FBS layer design was to use 3% bitumen and 2% General Blend cement (GB) by mass as primary and secondary stabilising agents respectively.

4. DIRECTING IMPROVED QUALITY

After the contract was awarded, the following changes were undertaken jointly by the client and the contractor to improve the quality of the works. In this process, the team has revised initial design, identified proper sources for material and implemented additional control measures to ensure the quality outcomes from foam bituminous stabilisation process.

4.1 Changes to subgrade design

Subgrade of this rehabilitation work has been identified as expansive soil. Expansive soil will expand during the wet season and shrink in dry season; therefore the base layer would fail on the expansive subgrade if not properly treated. In Queensland, lime is normally applied to modify expansive soils to improve strength characteristics, because lime improves the plastic properties, flocculating particles and it allows drying the material. In addition lime stabilising increases load bearing capacity and achieves long term strength retention [13]. Initial design for this work was to use lime (9% by volume) to stabilise the subgrade. The lane width of 4.8m (including median width) for a direction is proposed for subgrade stabilisation, however the design has been changed to stabilise 6.0m wide to include the additional 1.2 m road section below the shoulder. This action was aimed to reduce the lateral moisture movements to the pavement. While expanding the width along the road it was noted that some of the sections contained small rocks and sandy soil which has to be treated with suitable process. In this process, encountered rocks have been removed and the area containing sandy soil had been treated by mixing with expansive soil. Although, initially it was decided to use triple blend, in order to maintain consistency across the road, later it has been decided to cross blend and stabilise the layers with lime. The lime demand test has been carried out to identify the actual lime requirement.

4.2 Material Identification from Mix Design

With the foamed bitumen stabilisation it is essential that adequate fines must be available for the bitumen to bind with [7]. As per the material classification in Main Roads Technical Specification (MRTS), Type 2.5 and Type 2.3 material with 'C' grading can satisfy the requirement of a foam stabilisation works [11]. Therefore, undertaking initial investigation on available materials as well as carried out mix design out of these materials were considered as critical steps.

A number of samples were prepared for varying amount of primary and secondary stabilising agent, that is the samples were prepared for a total of 16 different type of materials. These materials were taken from three different quarries. The following key tests were carried out in Herston Laboratory, Queensland (DTMR laboratory) to identify the suitable material for this rehabilitation work:

- Indirect tensile test to identify initial modulus after three hour curing at 25°C. A minimum expected strength of 700 MPa was set as target according the specification [13].
- Dry modulus was obtained after placing the specimen for three days at 40°C. Previously dry modulus were obtained after curing the sample at 60°C. However it has been modified considering softening point of the bituminous binder which allows its mobilisation and possible absorption into the aggregate [12].

Therefore currently, the DTMR, Queensland has been using 40°C as curing temperature.
- Three days soaked modulus was obtained after specimens soaked in water in vacuum chamber for 10 minutes at maximum pressure of 95 kPa.

When it comes to material selection, MRTS recommends the use Type 2.5 material as it can achieve high soaked modulus in mix design; however, there is no specific requirement for a minimum CBR value for type of materials that can be used. Therefore, the requirement for this project has been modified to achieve a minimum strength (CBR=45) for the base layer material.

Testing results revealed few issues when identifying the right material as the field soaked modulus was not achieving the minimum requirements. However this paper is only concentrating the construction issues. Therefore the detail technical issues will be discussed in elsewhere. In overall it was found that using material having finer particles increase the soaked and retained modulus more than material having more coarse particles.

4.3 Changes to Base Layer Design

Initial design proposed adding 2 % cement as secondary stabilising agent. However, experience from as a similar site on the Warrego Highway showed that using cement as secondary agent would results in crack failures. The actual reasons for the failures are currently under investigation. Therefore, experts argued that using lime instead of cement would defiantly increase working time. Furthermore, using lime has the following advantages [7]: stiffens the bitumen binder, acts as anti-stripping agent, increases the initial strength of the material, and has a longer working time (up to 24 hours if need to rework). Therefore with the consultation of design engineers, lime has been proposed as a secondary agent.

5. CONSTRUCTION PROCESS

The conduction works in this entire job has been equally divided into four sections, namely Lot 1, Lot 2, Lot 3 and Lot 4, as shown in Figure 2. This segmental approach allows a continuous passage of traffic in one lane with proper traffic control in place. Manual of Traffic Control Devices (MUTCD Part 3) was used to develop the traffic management plan. Additional safety measures had been implemented on site during the construction based on various risk assessments.

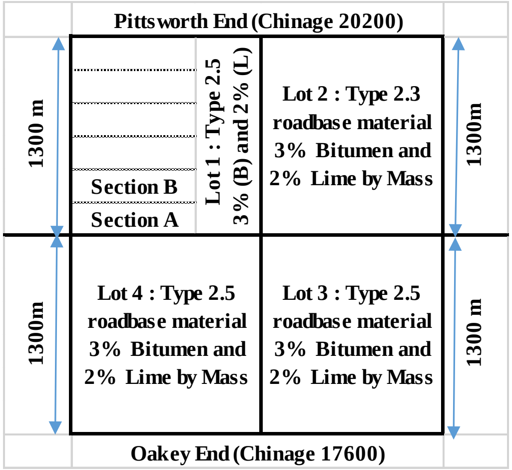

Fig.2 Site plan for segmental construction

After clearly dividing the lot's activities into the project plan, the following the construction works were carryout for each lot, separately:
- Removing 250mm unsuitable material using profiler
- Lime stabilising 300mm underneath foam bitumen layer
- Import 250mm layer of new base material
- 250mm depth of foam bitumen stabilising
- Primer sealing, allowing traffic and monitoring
- Spray sealing

5.1 Subgrade Stabilisation

Initially, an entire lot (eg., Lot 1) was milled out using profiler and existing material and was stockpiled away from site to use it for another project by the contractor.

Fig.3 Boxed-out section for lime stabilising

The lime stabilising method has been used to improve the subgrade. The lime demand test has been carried out and mix design showed the subgrade is to be treated with the lime at the rate of 40 kg/m2, which is equivalent to 9% hydrated lime by mass. Initially, the construction process has been planned to use 13~14 kg/m2 spread rate in three runs. Matt/tray test has been carried out on-site to ensure the spread rate. However it was found that spreader operator encountered problem on maintaining consistence spread rate. As the hydrated lime is added with water it turned out to be bonded so the spread rate had been reduced to 10-11 kg/m2. Therefore number of run increased to 4 runs which has been increased the cost and the project duration.

Fig.4 Matt Test carried out on site

Design has also been modified on site by increasing stabilsing width by 6m instead of original design of 4.8m for one direction. Each Lot has been further divided to five 260m sections to make the safer construction process (example, Sections A & B in Figure 1). Hydrated lime was spread for each section of 260m length, and subsequently mixed using stabiliser in three strips: two 2.4m sections (width) and one 1.2m section to achieve a total of 6m width. The lime stabilisation work has been carried out in two days in two adjacent sections (say Sections A & B). For example, subgrade lime stabilisation took two days in the following sequences: day 1 for 3 dry run in section A and 2 dry runs in Section B, and day 2 for 1 dry run in section A and 2 dry run in section B followed by wet run. The water truck was connected with stabiliser and proceeded with the wet run to both section A and section B.

Fig.5 Subgrade lime stabilising works (Dry run)

The Section A and Section B were left over the night to cure and after second day sand replacement tests were carried out in these two sections to check the subgrade density with the required specification.

The MRTS-07A clause 8.4.16 [11] specifies the minimum requirement for the rollers to be used. Accordingly, 21 Tonne Smooth drum and Padfoot rollers were used to compact 300mm lime stabilised layer. However the compaction at site has been carried out in two stages.

In this process, after completing lime applications, mixing and wet run the 150mm depth of material was removed using grader and bottom layer (150mm) was compacted using a 21 Tonne Padfoot roller. This initial layer was compacted by eight passes with full vibration. The next 150mm layer brought back and compacted using the same roller through 6 passes with full vibration. This segmental compaction process reduces the risk of failure, especially from not achieving the required ‘Relative Dry Density (RDD) of 97% (standard compaction) as specified in MRTS 11.07A clause 8.5.2 [11]. Once subgrade (300mm) was compacted, a grader was used to cut all Padfoot marks and trim the section within the tolerance specified in MRTS 11.07A [11]. Finally, smooth drum followed by multi tyred roller (12 Tonne) compacted the trimmed sections (3 passes with full vibration and three passes with half vibration). The sand replacement tests were carried out together with Dynamic Cone Penetration (DCP) tests on a few sections to ensure the required compaction. Both results show a satisfactory results, therefore at a later stage, DCP testing process has been adapted to speed up the construction process. According to the design, the stabilised subgrade should have a minimum California Bearing Ratio (CBR) value of 10. The test results show an average CBR values between 20 and 30.

5.2 Foamed Bitumen Stabilisation

As soon as the completion of subgrade works and granular material (identified from the mix design) was delivered to the boxed out sections, the required tip rate for delivering material was calculated and provided to the supplier. Based on the test results, Type 2.5 material was used for Lot 1, Lot 3 and Lot 4, and Type 2.3 material was used to Lot 2.

The material was delivered to the site with 65% to 70% of moisture content. As success of a foam bitumen stabilising work is heavily dependent on the moisture content of the material, the contractor has been informed about the high penalty for delivering material outside the tolerance level for the moisture content. As the materials were delivered, the moisture content has continuously been monitored closely on site. Then material were spread and compacted to 100% Relative Dry Density (RDD) as per the requirement of MRTS11.05 [11]. Then the section was compacted using a smooth drum (22 Tonne) with 12 passes and trimmed to the required level prior to commence the FBS. Once the section was trimmed to the required level the roller was used to tighten the material with back watering process using a water truck. The compaction process was carried out to ensure the section got the right amount of material (by mass) prior to commencing stabilising works.

A local contractor was appointed to supply the hot bitumen to the site, and the contract includes: load, cart, heat and supply at the required temperature. The bitumen has been supplied from Pinkinbar BP plant in Queensland, and it took 3 hours to transport the bitumen to the site from the plant.

The Class 170 bitumen has been loaded at 160 degrees. It is normal that when the bitumen is loaded into a road tanker, the temperature dropped by about 5°C-10°C and continues to fall by a further one or two degrees per hour while in transit [14]. In consideration of these facts, as soon as the bitumen arrived on site the supplier starts to heat the bitumen, and it generally took an average of 3 hours to reach 180 degrees (heating rate 10 degrees per hour). When refining/transporting bitumen, anti-foaming agent (e.g. silicone oil) was added to reduce surface tension, as per guidance given in Shell Bitumen Handbook [4]. As the success of the foam bitumen stabilising relies on half life time and expansion ratio, a foaming agent (Terric 311) was added 30 minutes prior to the stabilising, ie., a 100 liters (0.5% by mass : ie 0.005 x 20,000 kg) of foaming agent was added for each 20 Tonne bitumen tanker.

Prior to commence foam bitumen stabilising (adding bitumen) the secondary agent (hydrated lime) was spread and mixed with the base materials. The use of hydrated lime helped to maintain the required right moisture before commencing the foam bitumen stabilisation. The quantity of the hydrated lime varies with the density of the road base material. As per the design, for the sections A & B, an application rate of 11.5 ~ 12 km/m^2 hydrated lime was used on site (~2% by mass). In this process, lime was dropped in two 2.4 m run to achieve 4.8m width. The Matt/tray test was carried out to ensure the drop rate is achieved as per the design requirement. As soon as spreader dropped the lime the water truck connected with the stabiliser and commenced the mixing the lime with granular base material. The moisture was controlled when mixing hydrated lime with granular material. In the construction process of FBS, the DTMR has introduced a term “Lower Reference Level (LRL)” which is the reduce level or bottom level of the foam bitumen stabilised layer. The material has been mixed to a depth 30mm above the lower reference level (in this case 220mm instead of 250mm) to ensure the stabliser is not mixing subgrade with the existing base material when mixing lime. A smooth drum (22 Tonne) compactor followed the stabiliser and provide two passes with the full vibration and the grader was used to correct any irregularities on the mixed surface to ensure the surface is smooth just before staring the foam bitumen stabilisation. Then the trimble was used to check the surface level at different local points.

Fig.6 Depth control (manual measurement using trimble)

It should be noted as soon as add the lime, the material will bulk (about ~30mm) due to the change of volume, not the mass. Therefore a trail section was prepared to identify the bulking depth due to the lime stabilising. Then bulking depth was added to the design depth to identify the stabilising depth for foam bitumen stabilisation. Hence the final stabilising depth was calculated to include about 20mm of stabilised subgrade to ensure the compaction achieved was well below the lower reference level. In this case the full depth of foam bitumen stabilising was calculated to be 300mm as follows: 30mm bulking + 250mm actual stabilising + 20mm subgrade.

Foam bitumen stabilising continues straight after mixing the lime using a purposely made machine namely Wirtgen WR 2500 (see Figure 7). Within its chamber a small quantity of water injected into hot bitumen make the bitumen to expand, then at a correct timing this expanded bitumen foam injected into the mixing drum to mix with the base materials where the bitumen droplets are attracted by the finer particles of pavement material [15]. The injection system in WR2500 consists of a microprocessor-controlled metering unit, an eccentric pump and an injection bar with 16 nozzles and feeding device. The pump delivers the liquid agent (e.g. water) from a tanker truck to the injection bar [8]. Test jet system of the Wirtgen 2500 was used to ensure correct bitumen expansion and half-life time during the foam bitumen stabilisation work.

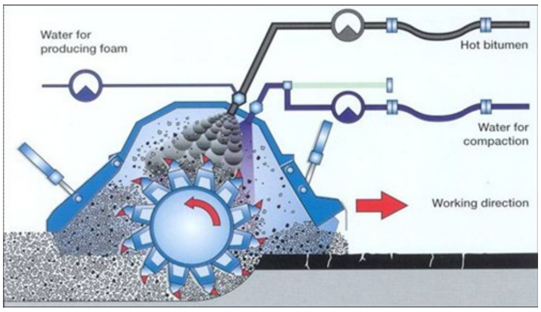

Fig.7 Foamed Bitumen mixing process [5]

Previous works showed that the reducing the depth of the stabilisation shorten the life of the pavement. Therefore, depth of the stabilising layer is important to be achieved to the design depth. Once commence the foamed bitumen stabilising work the stabilisng depth was measured using dummy level and Trimble to ensure the bitumen stabilising has been done to the designed depth. Further the temperature was constantly checked across the pavement behind the stabiliser to ensure all nozzles are working properly. The visual inspections were also carried out by squeezing stabilised material by hand to identify the bitumen has spreaded properly.

Fig.8 Foam bitumen stabilizing work

5.3 Final compaction and trimming

Soon after completing the mixing process, initial compaction was carried out using padfoot roller (22Tonne) with 6 passes. The project team ensured that the stabilized pavement achieved required compaction and wasn’t over-stiffening the pavement. Then a grader cut the padfoot mark, and trimmed the surface to the required level, followed by it a multi rubber tyred roller (24 Tonne) used to bring the final surface. At all times during the compaction process, it was monitored to eliminate any laminated layer due to the variation of vibration between layers.

Fig.9 Foam bitumen stabilising work

5.4 Sealing

The full width spread seal will not commence till complete entire job, but a primerseal was carried out to protect the pavement from adverse weather. The traffic was not allowed on the stabilised pavement until the primerseal was complete and 24 hours to cure before allowing traffic. In this project Class 320 bitumen and 10mm aggregate was used for primerseal.

Initially, a Double/Double PMB seal with 14/7mm aggregate was designed for full width as final seal. However, the experts commented that transverse cracks might be appeared if a fabric was not used. In addition, Fyfe (2010) has highlighted a similar modification to the design, and the following were documented as justified advantages when using fabric seal: waterproof layer, bridging shrinkage crack, acts as a stress absorbing interlayer, and pro long surfacing life span [16]. Therefore, in this project, Type II-B geotextile was used. Finally, a fabric seal with tackcoat was carried out on top the primerseal before a double/double seal with 14/7 mm aggregate.

Fig.9 Final Product after sealing and linemarking

6. CONCLUSION

After the severe floods in 2011 in Queensland, the application of foamed bitumen stabilisation technique in rehabilitation works has been recorded with several success stories. This paper outlines the steps taken to improve outcomes while rehabilitating 2.6 km section of Oakey-Pittsworth road, Queensland. In this process of construction the stabilisation width of sub-grade layer increased, available materials were tested to maintain the required specification, a suitable secondary agent as a filler for FBS is introduced, and continued testing were undertaken to improve the quality of the outcome. A highly motivated collaborative relationship between DTMR (client) and RoadTek (contractor) provides a good platform to identify these key changes to improve the quality in this project. The documented scenarios highlight the recent approaches that could be applied for similar construction sites. This project could be considered as experiment for making changes to the specification by the road authories.

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