Transport Scotland

AN APPROACH TO COLD RECYCLING OF BITUMEN AND TAR BOUND ROADS

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INTRODUCTION

1 INTRODUCTION

1.1 BACKGROUND

Driven by a desire to make more prudent use of natural resources, the recycling of existing pavement materials has become a viable option for maintaining roads. The concept of using cold recycling has evolved over many years and is now a recognised form of road construction. Following the introduction of a design guide in 2004 (D Merrill *et al*, 2004), both *in situ* and *ex situ* recycling techniques have been used to reconstruct and maintain roads. Advantages of cold recycling over traditional construction methods include reduced amounts of energy, fuel and material consumption. Currently pavement designs in the UK (CD 226) are permitted to contain cold recycled base materials for roads that carry up to a design traffic of 30 million standard axles (msa).

1.2 ROAD TAR

Road tar is processed from coal tar and it was commonly used as a binder for road materials up until the mid-1980s. Commonly known as tarmacadam, this material comprised a mixture of road tar and graded aggregate and was used in all the pavement layers. Coal tar-based binders were also commonly used to seal and maintain the surface of roads using a traditional method known as surface dressing.

Coal tar became out-dated in the 1980s and was largely replaced with bitumen, a product of crude oil production. Subsequently it has been shown that road tar can contain carcinogenic compounds and is highly toxic to aquatic life. As such, tar bound road planings are considered to be a waste with hazardous properties, known as special waste in Scotland. For those who manage and regulate waste, it is classified as waste code ‘17 03 01 bituminous mixtures containing coal tar’ if the level of coal tar is 0.1% or more (WM3, 2018). When a road has been identified as containing coal tar, strict requirements apply to the removal and disposal of the material, as it can present potential risks to the environment or human health. This presents the road industry with a challenge when a road pavement that contains road tar is deemed to require replacement.

1.3 COLD RECYCLING

One approach to dealing with materials contaminated with road tar is to reuse them on site. This involves pulverising the coal tar contaminated material and using the arisings to produce a dense, non-permeable material, as specified by national standards. Contaminated arisings are encapsulated as part of the recycling process. Typically, the existing road materials are processed in situ or nearby (*ex situ*) at an ambient temperature and stabilised with the addition of binding agents. The national specification for controlling the quality of cold recycled base materials and ensuring that the mix design is achieved in the permanent works is covered in the “Specification for Highway Works”, Clauses 947 and 948 (MCHW). Additional guidance can also be found in TRL report TRL611 (Merrill, 2004) where designs incorporate a hydraulic binder.

1.4 PURPOSE OF THE GUIDE

The Scottish Environment Protection Agency (SEPA), need to ensure that waste management is carried out without endangering human health or the environment. Currently in Scotland regulatory approval to recycle an existing road contaminated with road tar is given on a site-by-site basis, i.e. approval is scheme specific.

It is intended that this guide will provide a protocol or approach to cold recycling of bitumen and tar bound roads. It contains procedures and rules that provide a framework for warranting technical approval from Transport Scotland and will assist SEPA to review individual scheme proposals. In particular, it provides an approach to treat tar bound road arisings to ensure that:

- A site is suitable for recycling;
- hazardous contaminants are encapsulated, making them harmless to the environment and human health;
- recycled base materials comply with the Specification for Highways Works, Clauses 947, Clause 948 and TRL611; and
- the end-performance properties demonstrated at the design stage are achieved in the permanent works.

The guide does not provide information on sampling or testing strategies to identify the presence of road tar, but advice on this aspect can be found in the guidance note Managing Reclaimed Asphalt (ADEPT, 2019).

The guide does not include information on assessing the prioritisation and Value for Money aspects of any scheme that is developed. This is managed through other processes embedded within the Operating Company term maintenance contracts.

1.5 SCOPE AND DEFINITIONS

The guide gives summary descriptions of:

- *in situ* recycling;
- *ex situ* recycling;
- evaluating site suitability;
- SEPA compliance requirements;
- quality plan and mix design; and
- demonstrating compliance.

Cold recycled bound material (CRBM) - base and binder courses produced by one of two methods: *In situ* CRBM where the material is produced by the pulverisation and stabilisation of all, or part, of an existing road structure at ambient temperature; and *Ex situ* CRBM where material is produced and processed in a fixed or mobile mixing plant from arisings taken from an existing road at ambient temperature.

Quick Hydraulic (QH) - a binder that contains cement as the main component and excludes bituminous binders.

Slow Hydraulic (SH) - hydraulic binders that exclude bituminous and Portland Cement. Common examples include pulverised fuel ash (PFA) and lime, granulated blast furnace slag (GBS) and lime, and ground granulated blast furnace slag (GGBS) and lime.

Quick Visco-Elastic (QVE) - bituminous binder as the main component but also includes Portland Cement.

Slow Visco-Elastic (SVE) - bituminous binder as main component but excludes Portland Cement.

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AN APPROACH TO COLD RECYCLING OF ROADS - NOTES FOR GUIDANCE (NG)

PUBLIC

2 AN APPROACH TO COLD RECYCLING OF ROADS - NOTES FOR GUIDANCE (NG)

NG 2.1 COLD RECYCLING

Over the last two decades several techniques have been developed that allow existing road materials, such as asphalt and concrete, to be recycled and reused as part of maintenance and new road construction. The driving force to these developments has been to increase the sustainability of road construction by reducing the use of virgin aggregates, energy use, disposal of waste, transport movements and impacts on the environment.

Originally developed as an *in situ* technique, the method has been extended to include a wide range of binders, including combinations of hydraulic and visco-elastic binders, and to *ex situ* applications. There are advantages and disadvantages to using both techniques and these are described below.

NG 2.1.1 IN SITU COLD RECYCLING

As part of the cold *in situ* (or in place) recycling process, the existing road material that is to be recycled does not leave the construction site. It is treated in place through a mechanical process that involves various stages: pulverisation to produce a granulate to the desired depth of existing material; mixing with binding agents; and finally repaving and compaction. A new standard surface course is required on top of the recycled material. A typical cold recycling machine is shown in Figure 2-1.

Figure 2-1 - Cold recycler (*courtesy of SPL*)

The cold recyclers use a large rotating drum fitted with picks or cutters. The process is shown in Figure 2-2 and typically involves the following stages:

- Milling
    - The upper layer of the pavement is normally removed; an increased depth may be required where finished levels are fixed, e.g. urban areas or restricted headroom.
- Pulverisation
    - The remaining bound pavement, and possibly foundation platform, is pulverised to create a granulated aggregate.
- Stabilisation
    - Dependent on the recycled mixture design, cement or hydraulic binder is pre-spread on the granulated layer.
    - Pre-determined quantities of water and bitumen (if specified) are injected via injection bars contained within the recyclers mixing chamber (see Figure 2-2).
    - The final part of the stabilisation process involves compaction.
- Surfacing
    - On completion of compaction the stabilised materials are sealed with a bond coat prior to being surfaced with a layer of new asphalt. The minimum thickness of asphalt surfacing will be dependent on the design traffic loading.

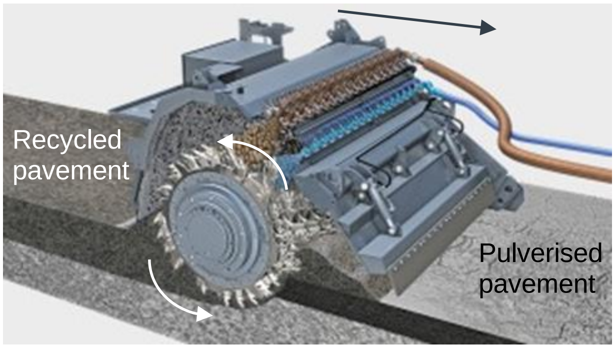


Figure 2-2 - In situ stabilisation process (*courtesy of Wirtgen*)

The majority of machines use an up-cut process as shown in Figure 2-2, where the drum rotates opposite to the direction of travel. Some larger machines use a down cut process where the drum rotates in the same direction of travel and the picks come down onto the surface being cut. Recycled base materials using the down cut process should comply with the Specification for Highways Works, Clause 949 (draft under development) and currently requires a Departure from Standard approval obtained from by Transport Scotland.

Advantages of using *in situ* cold recycling include:

- a recycled mix that encapsulates any hazardous contaminants in place;
- a fast process that reduces construction time and consequential traffic disruption;
- reduced risk of exposure of the lower pavement layers to inclement weather and construction traffic; and

- reduced energy, including a reduction in the amount of construction traffic to and from the site.

Limitations of the *in situ* cold recycling are likely to revolve around its use in urban areas where the risk to the damage of shallow underground services or structures is assessed to be a problem. Previous research (Milton and Earland, 1999) also suggested that the *in situ* recycling process should be limited for traffic levels up to 20 msa to ensure a satisfactory recycled pavement. *In situ* cold recycling has limited ability to address localised variations in pavement material thickness and condition, meaning a conservative approach is required. It is also contended that there is a practical thickness limit of around 300mm, above which, adequate compaction of a single, thick lift of recycled material would be too difficult to achieve. Recycling using a two-layer process is feasible, but the need to temporarily stockpile the top layer whilst recycling the bottom layer, would reduce the energy saving and advantage gained by the in-situ recycling process.

NG 2.1.2 EX SITU RECYCLING

Ex situ cold recycling typically involves the use of a mobile plant to produce a cold recycled bound material (CRBM). The existing pavement layers are broken out in a similar manner to the *in situ* technique. However, the arisings milled from the road are transported to the mobile plant where they are crushed and screened (see Figure 2-3), before being mixed with the relevant binding agents under controlled conditions. The recycled material is then taken back to the site and placed with a conventional paver. A new surface course will be required on top of the recycled material and dependent on the scheme design, a binder course may also be required.

The plant needs to be located close enough to the site to enable placing and compaction of the material within the appropriate setting time, which is dependent on the binding agents used. It is important to identify a suitable compound for the plant that comprises a hard-standing area and that permits safe access for heavy vehicle movements.

The *ex situ* technique allows for better control of the materials going back into the pavement. The risk that design stiffnesses will not be achieved is reduced and generally the recycled material is laid in thinner layers compared to the *in situ* method. However, *ex situ* does require the need for temporary sites, for both storing and processing the arisings, which can be difficult.

Figure 2-3 - Crushing and screening of arisings (*courtesy of BEAR NE*)

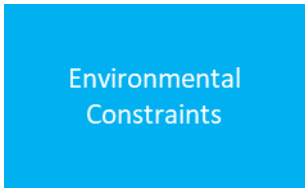
NG 2.2 DETERMINING THE SUITABILITY OF A SITE FOR RECYCLING

The flowchart shown in Figure 2-5 is intended to assist the process of determining whether a site is suitable for cold recycling and deciding the most appropriate option, i.e. *in situ* or *ex situ*. The suitability of cold recycling will depend on a large number of factors that in some instances will require information to be collected and questions to be answered. The concept behind the questions or steps in the flowchart are described below.

NG 2.2.1 DESIGN TRAFFIC

The design traffic for the road scheme needs to be determined. The calculation of design traffic is set out in the Design Manual for Roads and Bridges (DMRB), Volume 7, Part 2 (CD 224). The DMRB (CD 226) restricts pavement designs containing cold recycled base material up to a design traffic of 30 msa or less. This may be extended as more confidence and knowledge in the process is gained. Transport Scotland will review each scheme proposal independently. It should be noted that cold recycled materials can often rely upon their internal mechanical stability to resist damage in their early life. It is therefore essential that the materials have gained sufficient strength, prior to opening to traffic. The latter is particularly important if the recycled pavement is reopened to heavy traffic shortly after construction, i.e. sites designed to carry traffic at the upper permitted range (20 to 30 msa).

NG 2.2.2 ENVIRONMENTAL CONSTRAINTS



The environment in which the cold recycling technique will take place needs to be considered and the following factors should be taken into account:

- Rural or urban setting?
  - In an urban environment the use of the pulveriser and large compaction plant need to be considered, e.g.:
    - likely depth of recycling;
    - presence of shallow underground services or structures that could be damaged; and
    - generation of dust needs to be assessed.
- Headroom
  - *In situ* recycling can be useful in an urban setting where existing levels need to be maintained.
- Seasonal/Climatic conditions
  - Consideration should be given to the timing of the works and the likely weather conditions during construction.
  - Winter conditions, particularly sites located at high altitude, will influence the curing rate of binding agents.

NG 2.2.3 CURRENT DRAINAGE (DRAINAGE PATHS)

Current drainage (Drainage paths)

Often referred to as the 'Cinderella' of road pavements, the true value of drainage often goes unrecognized. An appropriate drainage system should always be in place to prevent water from penetrating the pavement structure. Drainage improvements may need to be carried out prior to the recycling works commencing. It is essential that the existing drainage and site conditions are appraised in order to:

- Protect the life of the recycled pavement
  - In rural areas arrange for grips to be checked or new ones cut, and ensure ditches are cleared and functioning properly.
  - Where subsurface drainage systems have been installed, ensure that they are working correctly to prevent excess water entering the pavement foundation.
  - If the carriageway is to be widened, care should be taken to ensure that the drainage paths under the old and recycled pavements, including tie-ins, are maintained.

NG 2.2.4 THICKNESS OF BOUND AND UNBOUND LAYERS

Thickness of bound and unbound layers

The thickness of the existing pavement materials is of paramount importance to both the suitability and subsequent design of cold recycled bound material. The selection of a site will normally depend on whether there is sufficient thickness of existing pavement to accommodate the design thickness, although the required pavement thickness may be achieved using imported secondary aggregate if the *ex situ* method is being used. However, the cost of cold recycling can increase if raw materials are required to be transported over long distances. It is preferable if the in situ pulverisation depth is with the bound layers, although some of the foundation platform can be pulverised if deemed to be of suitable quality.

In the first instance, construction information will normally be available through Transport Scotland's pavement management system and/or from a recent pavement investigation report.

An allowance for bulking should be made as part of the recycling process. The excavation or pulverisation of road material is accompanied by an increase in material volume. Consideration needs to be given to this excess material, such as movement, storage on site, or removal from site.

NG 2.2.5 NETWORK RESTRICTIONS

Network Restrictions

Dependant on the location of the proposed scheme, the following factors will need to be considered:

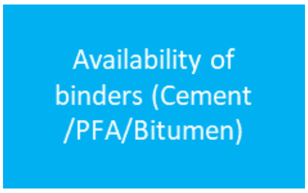
- Traffic management
  - Closure of a carriageway or traffic lanes will be required.
  - Contraflow working or a pre-planned alternative route may be needed.
  - Owing to the nature of the Scottish road network, it is possible that no practicable diversion route will be available.

- Site Access
  - Availability of suitable location for *ex situ* plant in proximity of site.
  - The need to provide access to residents and service traffic.

NG 2.2.6 SIZE OF SCHEME

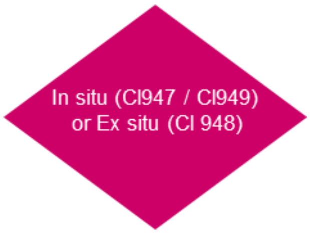
Cold recycling involves the mobilisation of a substantial amount of specialist plant and trained personnel, and the size of the scheme will have a strong influence on whether this technique is economically viable. Ideally the scheme should be greater than 3000 m^2. However, particular circumstances, such as the presence of road tar could lead to excessive disposal costs. Where schemes can be grouped, smaller scale cold recycling projects may still offer an environmental and cost effective solution.

NG 2.2.7 AVAILABILITY OF BINDERS



When selecting binders as part of the design process, thought should be given to its local availability to the site that is being considered. For example, pulverised fuel ash (PFA), a by-product from burning of fuels in power stations, may need to be transported over long distances.

NG 2.2.8 IN SITU OR EX SITU?



Following careful consideration of the steps described in 2.2.1 to 2.2.7 above, the decision on whether cold recycling by *in situ* or *ex situ* is feasible will become clearer**.** Figure 2-4 summarises some of the information that needs to be considered. However, it should be borne in mind that the preferred method of cold recycling may change following the collection of more detailed information, i.e. pavement investigation stage**.**

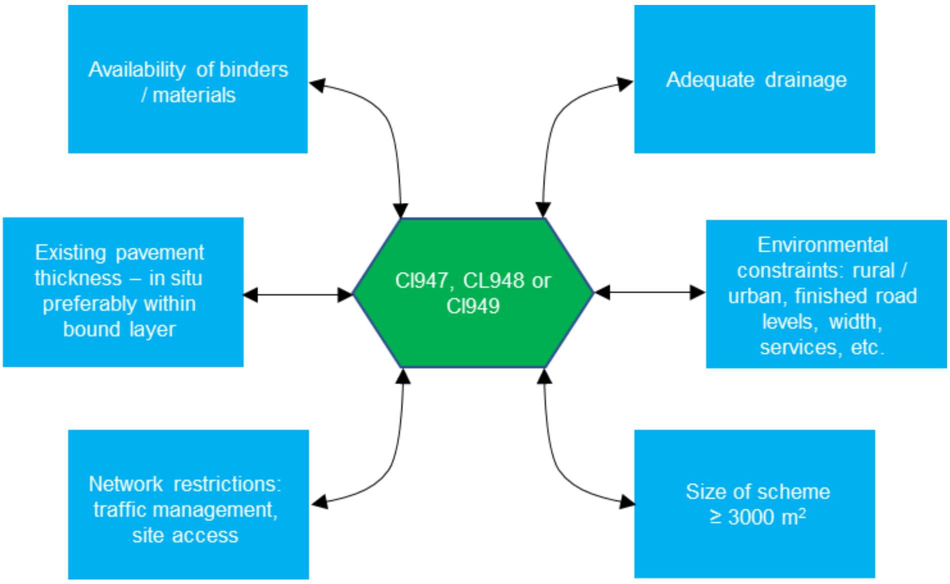


Figure 2-4 - Gathering information to select *in situ* or *ex situ*

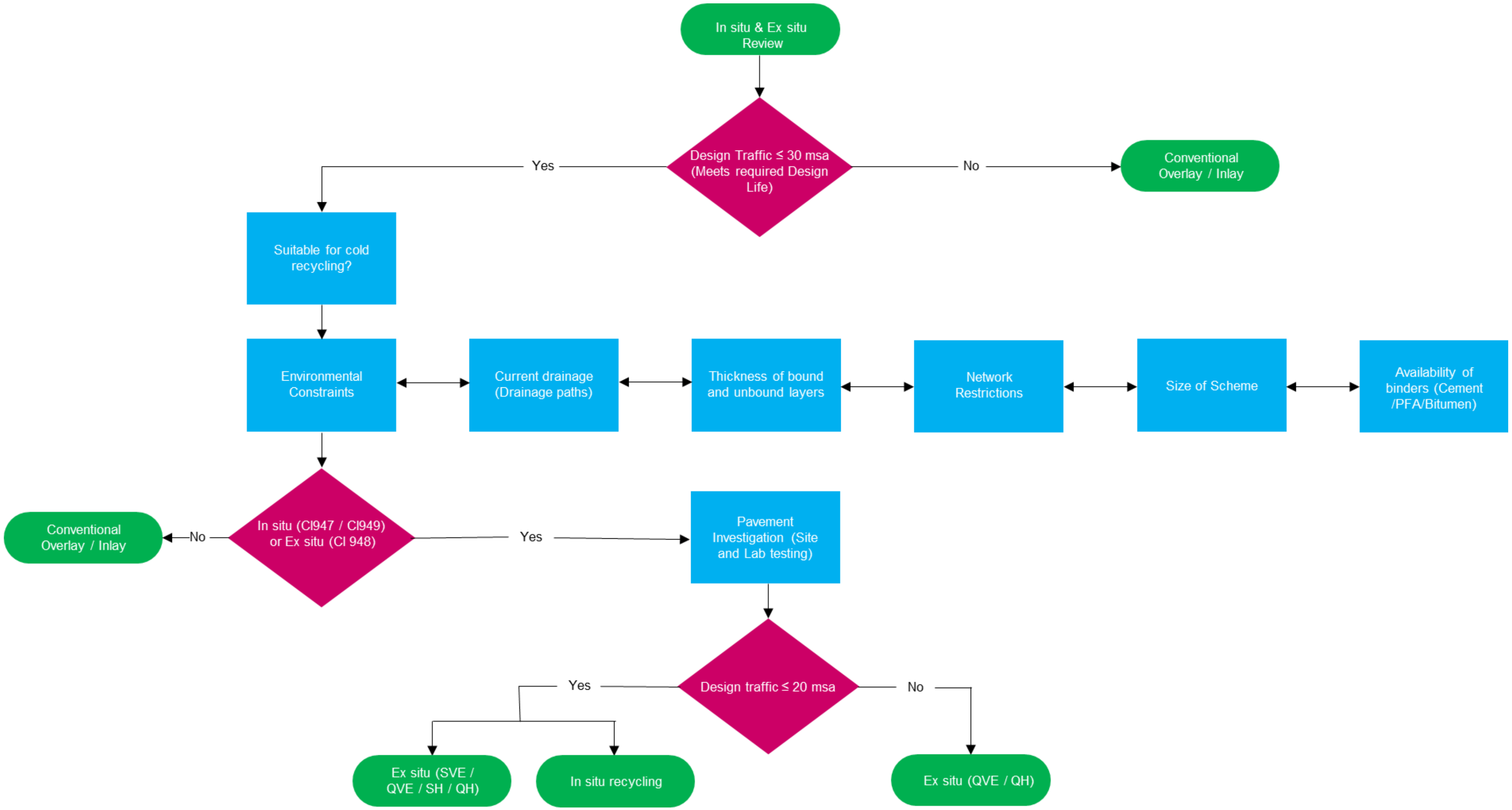


Figure 2-5 - Determining site suitability for cold recycling

NG 2.3 PAVEMENT INVESTIGATION

The purpose of the pavement investigation is to collect information on the existing pavement materials to determine whether they are suitable for treatment using the *in situ* or *ex situ* technique. The location, condition and construction of the existing pavement will have a significant bearing on the pavement design process and it is essential that adequate samples of the existing road are obtained throughout the site.

A typical cross-section of a road showing the main layers in a pavement structure is shown in Figure 2-6. The actual layers encountered on a site will depend on a range of factors, such as age, underlying ground conditions (subgrade), road type (traffic intensity) and construction type (flexible or flexible-composite). Both the foundation and bound pavement layers may comprise materials based on outdated specifications (e.g. tar bound) and include both bound and unbound materials of varying consistency and quality. It is therefore paramount that the pavement investigation collects detailed information on the existing materials so that their properties can be taken into account in deciding on the suitability of the site and the subsequent design process.

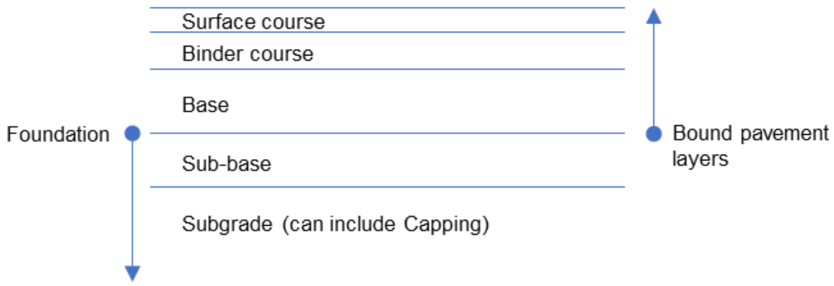


Figure 2-6 - Typical pavement structure

NG 2.3.1 DATA COLLECTION

The pavement investigation is carried out to assess the pavement support and existing bound pavement layers as shown in Figure 2-7.

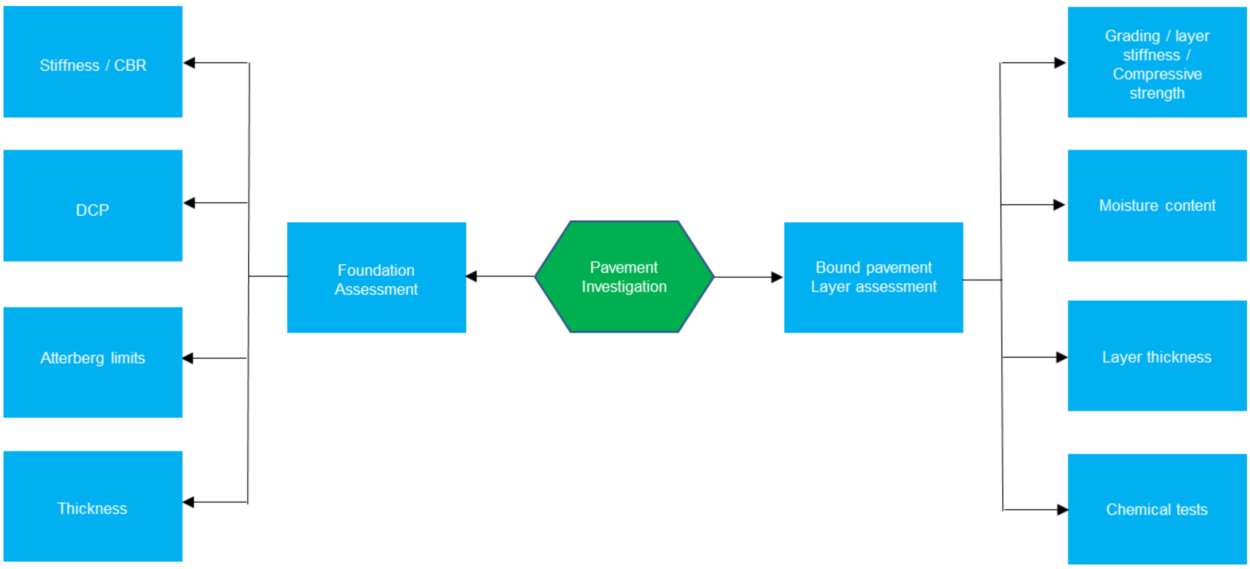


Figure 2-7 – Data collected as part of pavement investigation

NG 2.3.2 SITE SAMPLING

Trial pits or 300 mm diameter cores, or a combination, should be positioned at a minimum frequency of one per 750 m^2 or approximately one every 200 lane metres. Samples extracted from the road are required to determine material properties and any variations along the site. At least 100 kg of material will be required to develop a mixture design, i.e. job standard mixture. Figure 2-8 represents a small idealised scheme which is 0.5 km long by 7.3 m wide (3,650 m^2) and indicates where sampling points could be located. The sampling locations will depend on the site conditions, and additional sampling points should be considered to cover features such as obvious changes in construction or condition. A minimum of four sampling points is required for any one scheme.

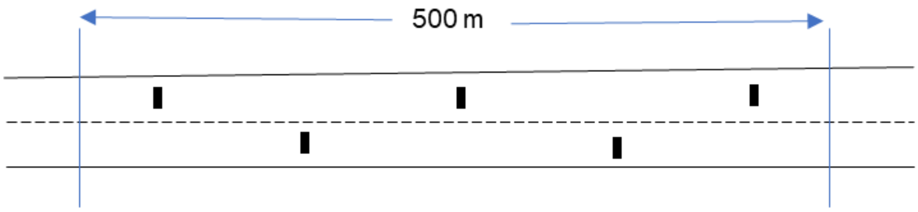


Figure 2-8 - Locating trial pits

As pavement investigations can be carried out well in advance of a scheme start date, samples should not be taken in wheel tracks to limit further damage to the pavement structure.

NG 2.3.3 USE OF TESTING DATA

A combination of trial pits, visual assessment and non-destructive testing such as falling weight deflectometer (FWD) and ground penetrating radar (GPR), can be used to establish the consistency of the pavement layers throughout a site. The collection of the data is likely to be undertaken in two phases, as follows:

- Phase 1 - Demonstration of recyclability

  In situ and ex situ

  - Establish material layer thicknesses, composition and consistency to identify what parts of the existing road structure can be cold recycled to form the main structural layer and possibly foundation platform of the new road pavement.

- Phase 2 - Design process

  In situ

  - Exposing the foundation to assess the pavement support to determine the Foundation Class.
  - Provide samples of representative material that will permit the development of a mixture design in accordance with Clause 947 (MCHW) or TRL 611.

  Ex situ

  - Assessment of the pavement support to determine the Foundation Class.

- Provide samples of representative material that will permit the development of a job standard mixture that meets one of the grading zones in Table 9/25 and demonstrate compliance with the requirements of Table 9/27 of Clause 948 ((MCHW).

NG 2.4 SEPA COMPLIANCE REQUIREMENTS

As a regulatory body, the main role of SEPA is to protect and improve Scotland's environment. The starting point for most Regulators in the UK, is that arisings from construction processes should be regarded as waste and producers and users need to possess the appropriate permits and licences. However, if it can be demonstrated that a material has been fully recovered, i.e. ceases to become a waste, SEPA may permit an exemption (Paragraph 13 exemption) that is specific to that individual project or scheme. Useful guidance on the production of fully recovered asphalt road planings can be found at the SEPA web site (www.sepa.org.uk/regulations/waste/). It should be noted that this guidance is not applicable to tar bound aggregates. Waste with hazardous properties which is considered to be harmful to human health or the environment is called "special waste" in Scotland.

NG 2.4.1 TAR BOUND ROAD MATERIAL

Ideally tar bound material should be left in place if it is assessed to be sound and located at a pavement depth that does not require to be renewed. However, tar bound material by its nature will be old and is known to be susceptible to oxidation and weathering. A pavement investigation may also conclude that owing to a weak foundation the pavement requires strengthening to a depth that contains tar bound material.

If the tar bound material needs to be disturbed, then it can be reused as a CRBM using the *in situ* or *ex situ* method. The *in situ* method has been recognised as a technique that can be used to repair roads containing tar bound material as the contaminated material is treated in place, i.e. the process involves the material being pulverised, stabilised, recompacted and resurfaced without being removed from the road. For the *ex situ* method, the tar bound material is removed from the road and is treated through a process of crushing, screening and mixing to meet the requirements of Clause 948 (MCHW).

NG 2.4.2 OBTAINING SEPA APPROVAL

The Environmental Protection (Duty of Care) (Scotland) Regulations 2014 (SSI No. 4, 2014) means that everyone has a legal duty of care to keep waste safe. This requirement is also echoed under the Construction (Design and Management) Regulations 2015 (SI No. 51, 2015), where those involved in the design of a scheme have a duty to highlight and minimize construction hazards. As Scotland's principal environmental regulator, SEPA ensures that any proposal to reuse tar bound material in an individual road scheme is properly assessed prior to approval. Information needs to be provided to demonstrate that a scheme has been carefully designed and that the treatment of any tar bound material does not lead to pollution or environmental damage. The most efficient way of submitting the required information is through the use of a pro forma.

NG 2.4.2.1 Pro forma

A pro forma document should be prepared at least 28 days from the commencement of any proposed scheme start date. The pro forma should summarise the scheme and provide enough information to enable both SEPA and Transport Scotland to assess the proposed treatment. An example of a pro forma, which includes sites details and controls, is provided in Appendix A.

Individual proposals to produce a CRBM will be different but the pro forma should contain the following information as a minimum.

- A summary of the scheme proposal
  - A description of the scheme including location, size and planned treatment, i.e. *in situ* or *ex situ* method.
  - Details of how the treated material will only be used in bound sub-surface layers, e.g. at the sub-base, base or binder course.
  - Confirmation that no treated material will be used in surface applications.
  - Reference to relevant specifications and design guides, e.g.:
    - Clause 948, Ex Situ Cold Recycled Bound Material (MCHW);
    - Clause 947, In Situ Cold Recycled Bitumen Bound Material (MCHW); and
    - TRL Report TRL 611 (Guidance and specification for *in situ* method using hydraulically bound cold recycled material).
- Risk assessment
  - A description of how the work will be carried out safely, focussing on the identification of any environmental risks and how they will be managed and minimised.
  - Detail specific measures put in place to avoid cross contamination with other materials, e.g. how material prepared using the *ex situ* method will be crushed, screened and stored.
- Waste Framework Directive
  - A statement to the effect that the treatment or reuse of the tar bound material meets the relevant objectives of the Waste Framework Directive

NG 2.5 MATERIAL DESIGN

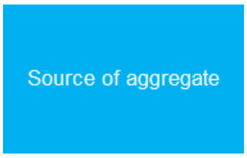
In general, the information collected as part of the pavement investigation will determine whether the existing pavement structure can provide a sufficient quantity and quality of material that can be used to produce a cold recycled bound material (CRBM). Whether the *in situ* or *ex situ* method is selected, it is essential that the material used in developing the design mixture is based on representative samples taken from the site. Key factors that are likely to influence the design process include:

- Nature and consistency of available material
  - The existing material along a site can be highly variable in nature and it may not be practical to develop an *in situ* mixture design even with splitting the scheme into several sections.
  - High compressive strengths of existing base material, e.g. lean concrete base, may rule out the material being planed or pulverised.
  - The design process will rely on site samples that are crushed in the laboratory rather than those obtained from pulverisation. Modern pulverisers and planers can produce aggregates of finer grading when compared to laboratory crushing methods and separate guidance from the recycling plant manufacturer may be necessary.
- Condition of foundation
  - The quality of the existing support can require a higher quality or thicker material to be placed to achieve the design life, i.e. this may be difficult to achieve with the *in situ* method.
- Design life
  - The *in situ* process is currently restricted to schemes with a design traffic of 20 msa or less. The nature of the *in situ* method means that there is a practical material thickness limit of around 300 mm that can be stabilised. Material layers thicker than this are unlikely to receive adequate compaction to ensure the material stability required to withstand deformation under traffic.
- Scheme design
  - Dependant on the scheme details, i.e. construction depth, condition and traffic levels, the CRBM will need to be designed to achieve an end performance property. For QVE and SVE type CRBM, the performance requirements are given in terms of indirect tensile stiffness modulus (ITSM), Material Classes B1 to B4. The material performance requirements for QH and SH are given in terms of flexural strength and dynamic stiffness, Zones H1 to H9 (see NG 2.5.1.3).
  - Experience to date has shown that it is difficult to consistently produce the high stiffnesses required for B4 materials. Currently Transport Scotland will only approve Material Classes up to B3.

NG 2.5.1 QUALITY PLAN

The quality plan is an important document for any cold recycling scheme as it sets out the stages involved in both designing and producing an *in situ* or *ex situ* CRBM. The flowchart shown in Figure 2-10 describes the typical stages that should be covered in a quality plan. In addition, the quality plan should refer to any standards, specifications, and quality objectives. The stages and steps shown in Figure 2-10 are described below.

NG 2.5.1.1 Source of aggregate

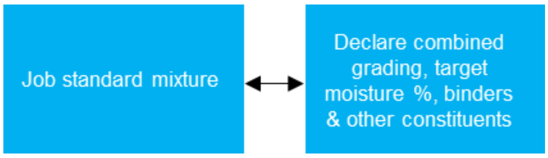


Details of all aggregates to be used in the CRBM should be provided, including any aggregate or filler from other sources. Emphasis should made on ensuring that the material to be recycled does not contain clay lumps or badly weathered aggregate.

NG 2.5.1.2 Processing of aggregate

Where the *ex situ* method has been selected, information needs to be given on how arisings will be processed, crushed, screened and stockpiled to enable consistent production of the CRBM. In particular, the plant should be capable of achieving controlled batching by weight or volume and possess appropriate hoppers and tanks to store the materials to be mixed. The location of the plant should be stated with respect to ensuring there is enough time to lay and compact the material within the relevant setting time.

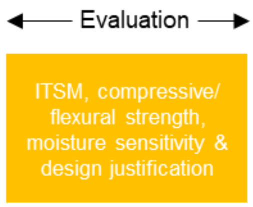
NG 2.5.1.3 Job standard mixture and constituents



The job standard mixture needs to be declared and include the following information:

- Source, origin and proportion of all aggregate constituents.
- Source and origin of binder(s), e.g. bitumen, cement, Lime, PFA, etc. Information on any other constituents such as setting and hardening agents needs to be declared.
- The particle size distribution (PSD) of the job standard mixture, i.e. aggregate together with other constituents, needs to comply with one of the zones in Table 9/25 (MCHW).
- Target moisture content.

Mix design evaluation



Whether the *in situ* or *ex situ* method is proposed, a mix design evaluation is normally required. Aggregates and binders that are to be used in the finished works should be mixed and prepared in the laboratory or on a pilot basis (*ex situ*) using full scale plant.

The required test results are dependent on the binders proposed in the design, as follows:

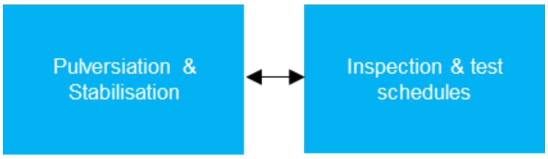
- QVE and SVE binders should be cured and tested in accordance with Clause 948 (MCHW) to determine the indirect tensile stiffness modulus (ITSM). The average results should be considered as indicative only but can be used to classify the design stiffness of the material in accordance with Table 9/27(MCHW), i.e. Class B1 to B4.
- QH and SH binders should be cured in accordance with Clause 948 (MCHW) to determine the dynamic modulus and flexural strength; where these values are not directly measurable, the prescribed alternative tests and transfer functions described in TRL 611 may be used. The average results should be considered as indicative only but can be used to classify the design stiffness and strength of the material in accordance with Figure A4.1 (TRL 611), i.e. Classes H1 to H9.

- In order to assess moisture sensitivity additional sets of specimens can be prepared and tested after 24 hours soaking in water; the modulus or strength values should be at least 75% of the un-soaked values.
- The proposed design should be justified with appropriate reference to design charts or an analytical pavement design.

It is important to recognise that the results of laboratory tests are influenced by the curing regime of the test specimens. These conditions will not be similar to those experienced on site, but the results permit comparisons and assist in the process of optimising the mixture design process.

Owing to costs, timescales and the size of a scheme, there has been a trend to use mix designs based on previous works. This is regarded as acceptable if the constituents used in the previous mix design can be demonstrated to be representative of the site materials and possess similar properties. However, the geographical location of a site is important and will invariably reflect the underlying geology and aggregate sources used in the area. For example, a design developed in England or Wales, where the principle source of aggregate is limestone, may not be suitable for a site located in Scotland where dominant sources include igneous rocks such as basalt in the central belt and granite in the north east. For instance, experience in Scotland has shown that stripping problems can occur owing to some aggregates having a poor affinity to bitumen and care needs to be taken in developing a QVE design to ensure a bitumen emulsion is compatible with an aggregate.

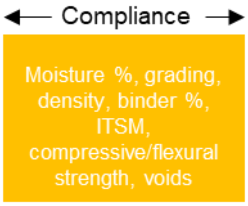
NG 2.5.1.4 *In situ*: pulverisation & stabilisation



The production and quality of the *in situ* CRBM by pulverisation and stabilisation needs to be carefully controlled and monitored. The quality plan should include a flow diagram showing how the in situ CRBM will be produced and monitored, including information on the following:

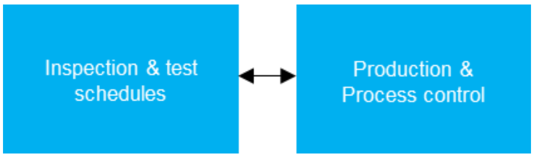
- Pulverisation phase
  - The depth and pattern of pulverisation, including overlaps, to ensure that it covers all areas of the road.
  - Measures to deal with any obstacles, such as kerbs and gullies.
  - A schedule of inspection and test frequencies, with appropriate reference to specifications and standards, to assess the condition and quality of the pulverised material, including collecting bulk samples to determine:
    - Moisture content of pulverised material, including corrective action if the pulverised aggregate is outside ±2% of the optimum moisture content for bitumen bound material, or 0% to +4% of optimum moisture content for cement bound mixtures.
    - The bitumen content of the pulverised aggregate, if appropriate.
- Stabilisation phase
  - A procedure should be provided for dealing with extreme weather to ensure construction does not proceed if the road materials are frozen or excessively wet.
  - Method of spreading and measurement of filler and/or adhesion agents, e.g. use of mechanical spreader, trays, mats, etc.

- Monitoring the rate of bitumen binder (where appropriate) and any other fluids to the stabilising plant.
- The collection of samples following stabilisation, but prior to compaction, to determine the refusal density of the stabilised material and to provide additional material samples for compliance testing, such as grading zone, ITSM (QVE & SVE), flexural strength (QH & SH), air voids, etc.



- Measurement of in situ bulk density using an indirect density gauge.
- Method statement describing laying, compaction and sealing of CRBM
  - The surface should be sealed using a sprayed membrane complying with Clause 920 (MCHW).
  - Where a surface is to be open to traffic, the sealing membrane should be blinded with fine aggregate or sand.

NG 2.5.1.5 *Ex situ*: Production and process control



The production and quality of the *ex situ* CRBM should be subject to continuous monitoring. Figure 2-9 shows an aerial view of an *ex situ* mobile plant where arisings milled from a scheme are crushed and screened, before being mixed with the relevant binding agents under controlled conditions. A quality plan should include a flow diagram showing how the *ex situ* CRBM will be produced and monitored, including information on the following:

- Plant
  - The location of plant to be used, including transportation of material and expected average time between mixing and laying.
  - A description of how the CRBM will be produced in accordance with the specification.
  - Plant calibration schedules and measures to avoid problems caused by extreme weather, e.g. feedstock becomes frozen or excessively wet.
- Inspections and testing
  - Schedule of inspections and test frequencies in accordance with Table 9/28 of Clause 948, which includes gradings and moisture contents on aggregate stockpiles, combined mixtures, and any binders used.
- Installation
  - Plant should be capable of laying the material without significant segregation and to the required thickness across at least one lane width.
  - A procedure for making longitudinal and transverse joints, appropriate to the type of CRBM being laid.
  - Method statement describing laying, compaction and sealing of CRBM.
    - Following final compaction, the measurement of in situ bulk density should be carried out using an indirect density gauge.
    - The surface of the recycled layer should be sealed using a sprayed membrane complying with Clause 920 (MCHW)

- – Where a surface is to be open to traffic, the sealing membrane should be blinded with fine aggregate or sand.

- Compliance testing

  ← Compliance →

  Moisture %, grading, density, binder %, ITSM, compressive/flexural strength, voids

  - Samples should be taken either at the mixing plant (*ex situ*) or from site to determine the refusal density of the stabilised material and to provide additional material samples for compliance testing.
  - Testing will be dependent on the type of CRBM and specification, but will include tests such as grading, ITSM (QVE & SVE), flexural strength (QH & SH), air voids, etc.

Figure 2-9 - *Ex situ* process (*courtesy of Eurovia Roadstone*)

NG 2.5.1.6 End product performance testing

← End product →

LWD ≤ 24 hrs
FWD ≥ 270 days

Most of the testing described above for *in situ* and *ex situ* CRBM is used for quality control and specification compliance, and also to provide information on whether adjustments to the production process should be made. End product performance tests relate more to the desired performance of the recycled pavement and are carried out on the completed pavement layer or structure. Guidance on end product testing is provided under NG 2.7.

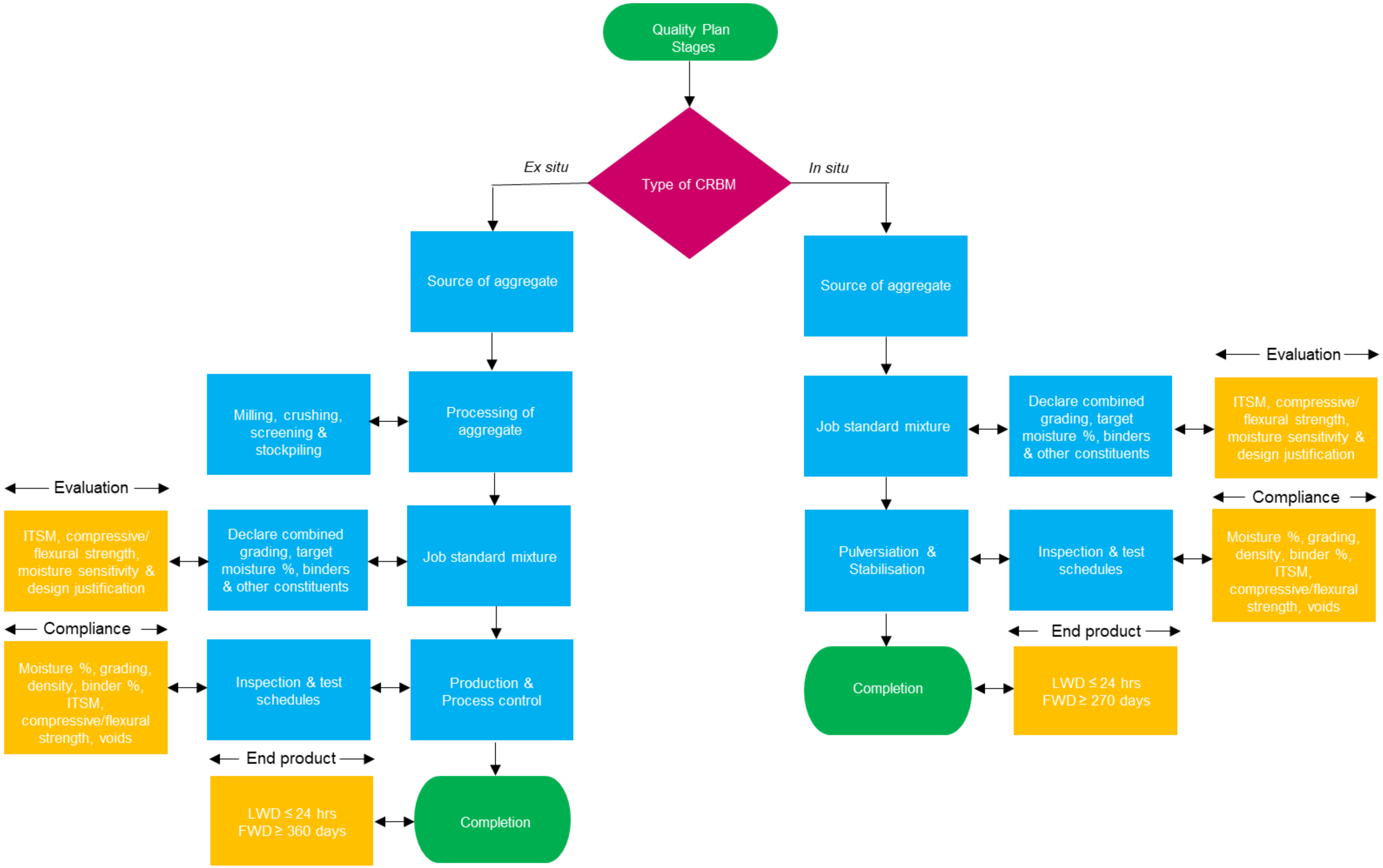


Figure 2-10 - Quality plan stages

NG 2.6 MATERIAL CONSTRUCTION ON SITE

NG 2.6.1 *IN SITU* METHOD

The construction stages are shown in Figure 2-11, along with the initial stages required in the *in situ* recycling process. The steps that relate to construction are described below.

NG 2.6.1.1 Pulverisation, grading and trimming

Pulverisation

The plant needs to be capable of uniformly pulverising the existing road structure to the depth and tolerances stated in the quality plan. Appropriate overlaps should be made between end-to-end passes and neighbouring passes of the machine. Material that cannot be reached by the recycling machine, e.g. excavated along hard edges such as kerbs and gullies, should be placed in the path of the machine until a uniformly pulverised aggregate is achieved. Care should be taken to ensure pulverised material is not contaminated by material drawn from adjacent verges.

Review

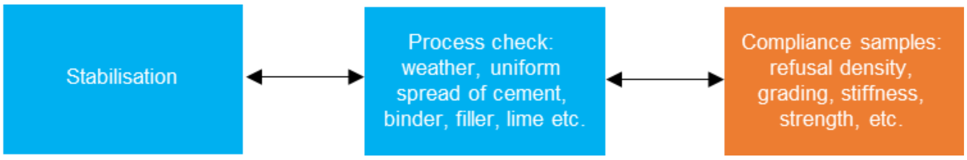
It is essential to monitor the depth of pulverisation and to take regular samples to ensure that the grading of the resultant mixture compares with the grading used for the job standard mixture, prior to the addition of binders. The moisture content of the pulverised material needs to be measured prior to stabilisation and any necessary adjustments made to achieve ± 2% of the optimum moisture content for the unstabilised aggregate. Corrective action should be carried out either by:

- Reducing moisture content
  - Aeration of the affected area is achieved by full depth passes of the recycling machine to disturb and loosen the material and assist the evaporation of excess moisture.
- Increasing moisture content
  - The controlled addition of water, through the recycling plant's adjustable spray bar system, in conjunction with full depth passes will uniformly increase moisture throughout the layer.

Grading

Grading and level control are important to form the CRBM base layer and avoid unnecessary regulating with asphalt at a later stage. This is mainly achieved through the skill and expertise of the grader operator and regular dipping from a string line held tightly from kerbs or pins. Once grading has been completed to the required profile the surface is nominally compacted in preparation for stabilisation.

NG 2.6.1.2 Stabilisation



Stabilisation

The stabilisation should be carried out to the required depth in a similar pattern to that used for the pulverisation process, with an overlap of at least 150 mm between adjacent passes of the machine. As described above, the moisture content of the pulverised material should be measured immediately prior to stabilisation and any necessary adjustments made.

Process check

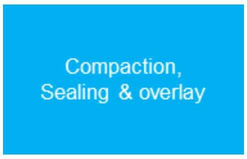
Excessive moisture will compromise the stability of the layer under compaction or trafficking and stabilisation should not commence if weather conditions change, e.g. a period of heavy rainfall. Stabilisation of frozen materials is not permitted.

Prior to stabilisation, any cement binder, filler and/or adhesion agent should be spread uniformly over the full width of the layer with the aid of a mechanical spreader. Whether the primary binder is bitumen or cement, their addition demands attention to ensure that the resultant mixture compares with the job standard mixture. For the hydraulic binder application, it is important that the spreader is regularly calibrated, and its outlet is adequately skirted and shielded to minimise dust emissions. Similarly, the bitumen binder - introduced as a foamed bitumen - should be distributed directly through the plant’s spray bar system into the rotor and mixing box. The binder will be supplied to the spray bar from an on-board tank or from a tanker moving in tandem with the recycling machine. The rate of supply of the bitumen and any foaming agent should be controlled and monitored to achieve the target binder content.

Compliance

Dependent on the job mixture design, samples will be taken to assess the condition and quality of the pulverised and stabilised mixture to ensure compliance with the specification.

NG 2.6.1.3 Compaction, sealing and overlay



For the *in situ* method, compaction is a critical part of the construction process that requires specific care. This is particularly the case for thick layers greater than 225 mm where the lower part of the layer does not achieve the same density as the upper surface. This effect may be minimised through commencing compaction at the earliest time using heavy vibratory compaction to meet the minimum in situ density specification requirements. The stabilised layer should not shove, rut or exhibit transverse cracking during compaction or under subsequent construction traffic.

Sealing and overlay

The timing of sealing and any asphalt overlay will be scheme specific. The surface should be sealed as per the specification and if the surface is to be opened to traffic prior to being overlaid it should be blinded with fine aggregate or sand.

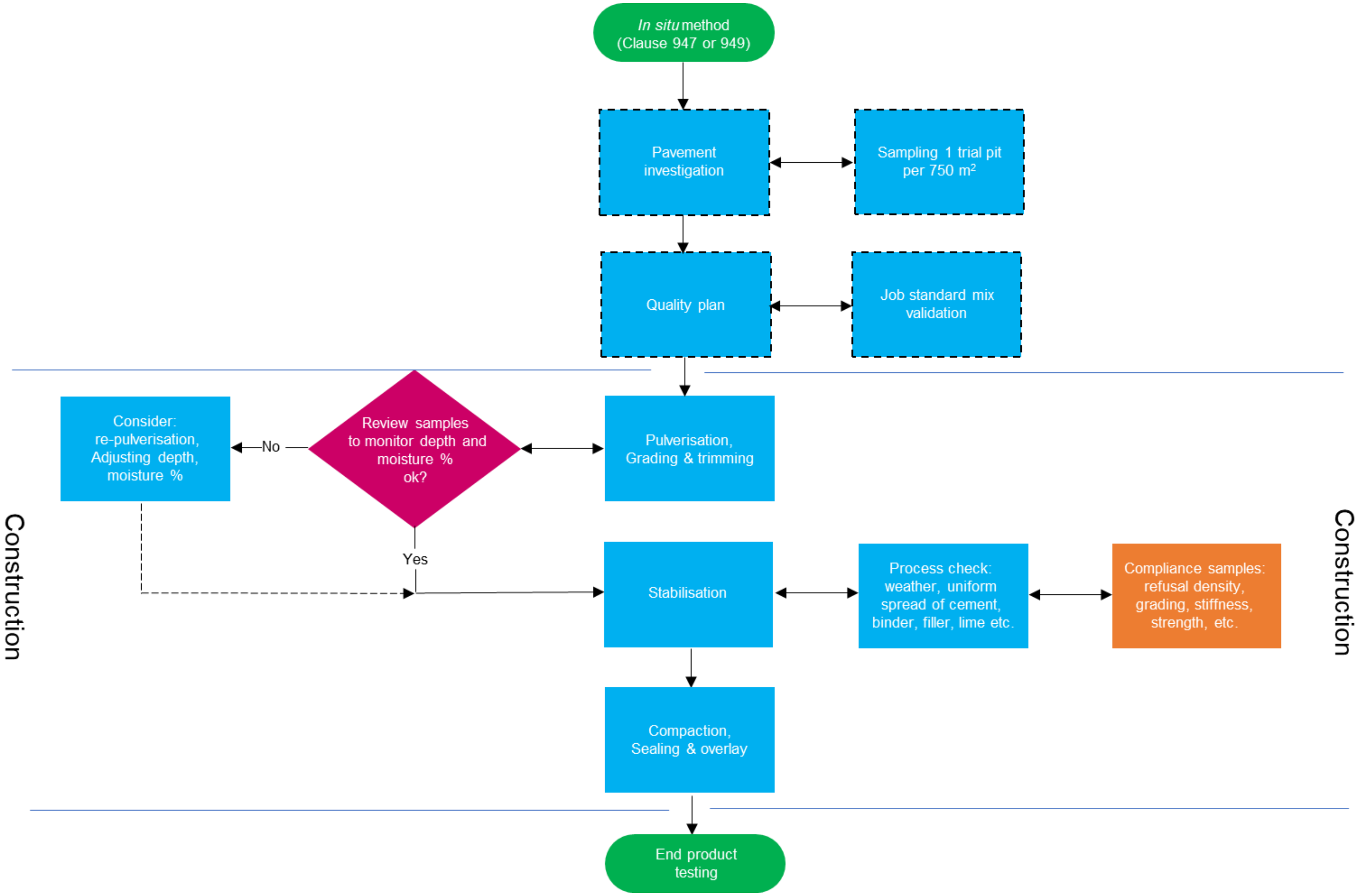
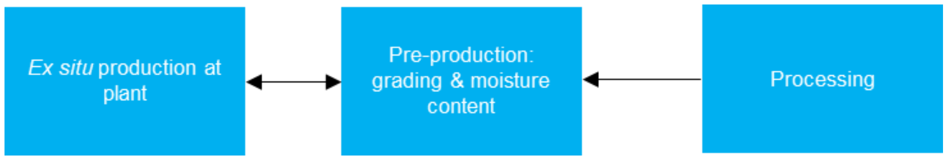


Figure 2-11 - *In situ* construction

NG 2.6.2 *EX SITU* METHOD

The *ex situ* construction stages are shown in Figure 2-12 and are described in more detail below.

NG 2.6.2.1 Processing, pre-production checks and mixing



Processing

It is important that the arisings from the site to be recycled - and any other secondary sources - are crushed, screened and stored in a way that will enable the consistent production of the CRBM type in line with the job standard mixture. This is particularly important if the processed aggregate contains different road materials, i.e. stored separately and measures taken to avoid cross contamination with other materials. Emphasis should be made on being vigilant to ensure no deleterious materials, such as clay or badly weathered aggregate are used in the production of the *ex situ* CRBM.

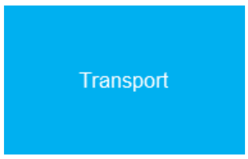
Pre-production checks

Consistent grading checks on aggregate stockpiles and combined grading of the mixture are of paramount importance. It is important that the CRBM does not contain too high a proportion of fine material, and this is particularly important in the production of bitumen bound CRBM. Similarly, the moisture content has a large influence on the workability, mixing and degree of compaction that can be achieved.

Ex situ production

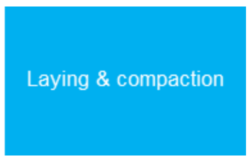
The plant used for mixing the components of the *ex situ* CRBM should be detailed in the quality plan, including the methods for controlling the addition of the components outlined in the job standard mixture.

NG 2.6.1.2 Transport



It is important that the travelling time between mixing, transportation and compaction of material to the site allows for the curing rate of the binders used in the CRBM. Ideally, both a preferred and an alternative route for the transportation of the material should be declared to allow for possible delays due to congestion or accidents.

NG 2.6.1.3 Laying and compaction



The plant used for placing *ex situ* CRBM should be capable of laying the material without segregation, evenly and to the required thickness. The compaction of each layer should be carried out using a defined rolling pattern until the required in situ density is achieved and the layer presents a stable, dense and tight-knit surface appearance. The stability of the layer should be such that it does not shove, rut or exhibit cracking under the load of traffic. The method for the making of longitudinal and transverse joints should be appropriate to the type of CRBM being laid. Open edges should be protected from traffic.

NG 2.6.1.4 Compliance

Dependent on the job mixture design, samples will be taken to assess the condition and quality of the pulverised and stabilised mixture to ensure compliance with the specification.

NG 2.6.1.5 Sealing

Sealing

Following non-destructive end performance testing for early-life material properties (see NG 2.4.1), the surface should be sealed using a sprayed membrane of Class C40B4 bitumen emulsion complying with Clause 920 (MCHW). The bitumen emulsion should be sprayed at a rate of 1 to 1.5 l/m^2 to achieve a uniform and continuous seal to the surface of the layer. Where the surface is opened to traffic, the sealing membrane should be blinded with fine aggregate or sand applied at a rate of 5.5 to 7.0 kg/m^2.

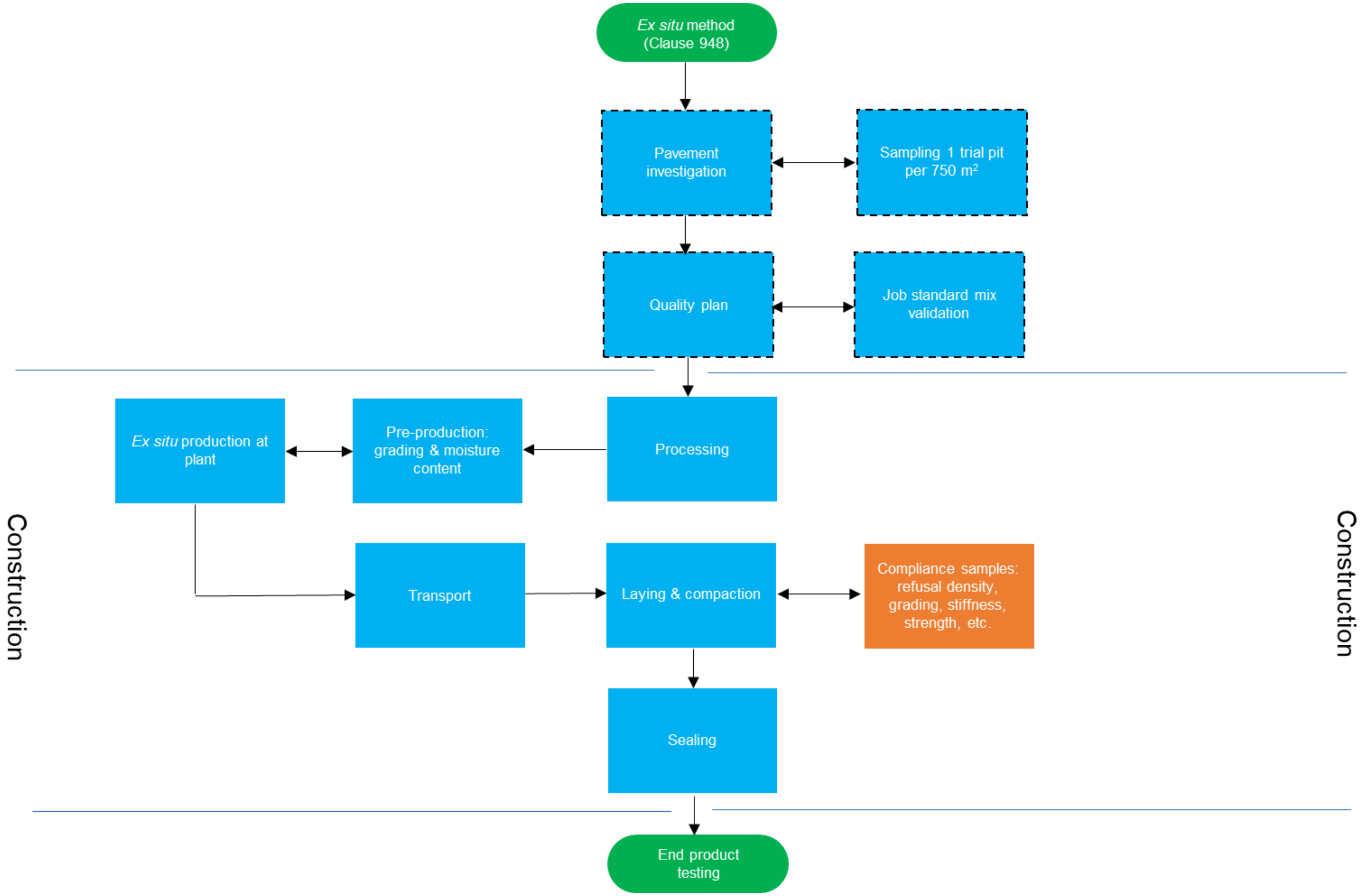


Figure 2-12 - *Ex situ* construction

NG 2.7 END PRODUCT PERFORMANCE TESTING

The testing of CRBM described under Material Design (NG 2.5), produced by either the *in situ* or *ex situ* technique, is targeted at assessing the quality and condition of the material and meeting the relevant specification. They are known as process control tests and the information gathered also permits adjustments to be made to the production process. In contrast, end product performance tests are carried out on the completed pavement layer or structure. As such, they relate more to the desired performance of the recycled pavement. End product performance tests can be both non-destructive and destructive, although the latter tend to be used following concerns regarding the performance of the pavement.

Historically, material designs have been developed in a variety of countries that experience different climates and geology. These 'recipe' methods and specifications have served the road industry well, but end product performance tests allow the development of performance targets that facilitate material innovations and provide confidence in the use of CRBM. For example, as they measure mechanical properties, such as stiffness, they can provide useful information on curing and how the material performs in service.

NG 2.7.1 IN-SERVICE STIFFNESS

Early life material properties

The recently installed performance of the CRBM should be assessed using a Light Weight Deflectometer (LWD). It is important that the LWD can demonstrate a satisfactory correlation with an agreed reference test method, i.e. the Falling Weight Deflectometer (FWD). Two options are permitted for LWD correlation (BS 1924-2, 2018): a site-specific correlation trial, or an annual correlation certificate.

The performance of the final stabilised layer should be evaluated using a calibrated LWD within 24 hours of final compaction. Dependant on weather conditions testing could commence immediately, but in some instances a small rest period may be required. The final stabilised layer should meet the following criteria:

- The minimum surface modulus measurement should be ≥ 50 MPa within 2 hours of installation; or ≥ 100MPa within 24 hours of completion of installation.
- Where this criteria is not met, consideration should be made to delaying final surfacing to allow further curing and stiffening of the layer to occur. Alternatively, a repeat of all or part of the recycling process should be undertaken until a compliant surface modulus is achieved.

In-service material properties

After 270 days of completion of an *in situ* scheme, or after one year for an *ex situ* scheme, FWD surveys should be carried out in accordance with CS 229 (DMRB) and meet the following criteria:

- The FWD surveys should be carried out when the pavement temperature, at a depth of 100 mm, is within the range 15 to 25ºC.
- The FWD results should be analysed with the pavement modelled as a two-layer system: Layer 1 should represent the combined design thickness of the bound materials and Layer 2 the unbound foundation layer of infinite depth.

- Compliance is achieved when the calculated stiffness of Layer 1, uncorrected for temperature, using the rolling mean of 10 results is:

  Recycled layer containing QVE & SVE

  - Not less than 2500 MPa and no individual result is less 2100 MPa.

  Recycled layer containing QH & SH

  - Not less than 5000 MPa and no individual result is less than 4200 MPa.

In the event that these performance standards are not achieved using the FWD then core testing should be considered as a final course of action when the pavement is one year old. However, consideration should be given to repeating the FWD survey, assuming no surface defects are visible, towards the end of the contract maintenance period. This would maximise the success rate for the extraction of cores and offer the best opportunity for obtaining suitable test specimens and achieving the required ITSM values given in Table 9/27 and 9/24 (MCHW) or requirements given in Figure A4.1, TRL611.

NG 2.8 REFERENCES

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APPENDIX A

Pro Forma for Cold Recycling of Tar Bound Material (including site details and controls)	
Contact Details	
Name of Business:	
Address of Business:	
Primary Contact Name:	
Email Address:	
Phone Number:	
Scheme Information	
Scheme Location:	
Scheme NGR:	
Recycling Process to be Utilised:	
Recycling Plant Location:	
Recycling Plant Location NGR:	
Recycling Plant PPC(s)	
Production Site Licence / Exemption	
Evidence of Landowner Consent:	
Scheme Dimensions:	
Estimated Volume of Tar Bound Planings:	
Provide details of how the treated material will only be used in bound sub-surface layers e.g. at the sub-base, base or binder course:	
Provide reference to relevant specifications and design guides, for example: - Clause 948, Ex Situ Cold Recycled Bound Material (MCHW); - Clause 947, In Situ Cold Recycled Bitumen Bound Material (MCHW); and - TRL Report TRL 611 (Guidance and specification for in situ method using hydraulically bound cold recycled material).	
Stockpiling and Subsequent Reuse of Excess Tar Bound Material	
Excess Material Stockpile Location:	
Excess Material Stockpile NGR:	
Proposed Stockpile Volume:	

Proposed Duration for Storage:	
Stockpile Environmental Control Measures:	
Evidence of SEPA approval for stockpile location:	
Details of Sites where Stockpiled Material will be Reused:	
Site Environmental Management Plan	
Provide details of how the work will be carried out safely, focussing on the identification of any environmental risks and how they will be managed and minimised:	
Provide details of specific mitigation measures to be put in place:	

Declaration:			
I ***(insert name)*** confirm that no treated material will be used in surface applications.			
I ***(insert name)*** confirm that the treatment and reuse of the tar bound material meets the relevant objectives of the Waste Framework Directive.			
Signed:		Date:	
Completed pro forma to be issued to Transport Scotland and SEPA at least 28 days prior to any scheme start date.			

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