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On-Site Recycling of Trench Arisings for Pavement Reinstatement

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ABSTRACT

A new, environmentally friendly and more economical trench reinstatement process aimed at recycling on-site waste material as usable aggregate is being developed for a project called "Zerowaster". This project is a collaboration between the University of Nottingham, a water company, two utility supports and a plant manufacturing company. When a trench opening (usually in connection with maintenance of utility assets) needs to be reinstated in a road, the UK performance requirements effectively dictate that newly quarried aggregate replaces the excavated soil. In recent years it has been shown that appropriately selected and treated recycled aggregate is perfectly suitable for backfill, despite being considered a low quality material. Recycling the trench arisings directly on-site would not only save material, but also reduce transport costs and time. The output of this project is to produce a device that should be able to handle and allow recycling of at least 70% of the excavated material.

INTRODUCTION

One of the major requirements of utilities such as water, gas and telecommunication companies is to maintain old and install new assets. As many pipes and cables run below roads and pavements, work often involves highway excavations. The reinstatement of these excavations needs to be both strong enough to sustain traffic and long lasting. Failure of the completed work would mean that a new reinstatement would need to be done by the utility. For this reason, utility companies follow the published guidelines [SROH, 2002] that define the rules for good reinstatement. The specifications do not require refilling of the holes with virgin material from quarries, although, in practice, this has been their effect because, to date, they have effectively prevented alternative, recycled materials from being employed except by off-site processing and lengthy demonstration trials. Thus, the trench arisings, considered waste material, must be taken to landfill.

However, in recent years, landfill taxes have increased enormously, putting pressure on the industry to reduce the amount of material it sends to landfill, in so doing reducing environmental pollution. Due to these pressures, and for environmental reasons, recycled aggregate is now well accepted and even recommended in the UK, provided that good performance can be assured. As a consequence, recycling centres have arisen. Trench arisings are transported to these depots, where they are separated according to particle grading. Material passing the 0.062 mm sieve size is often considered waste, and thus sent to landfill. The rest is re-mixed in proportions that give a grading curve in accordance with the specifications, and treated if needed.

Unfortunately, these recycling centres are located at centralised depots, while excavations can occur anywhere, and so it is not always advantageous for the utility companies to use a recycled material as transportation costs still remain a big issue. In U.K. every year more than 6 million tonnes of trench arisings are excavated and more than half of this material is taken to landfill, for an overall industry that is worth around £100m, and the cost is going to increase due to the rise in landfill taxes. Therefore, an initial study has been performed to assess the potential for recycling of trench arisings into good reinstatement material directly on-site. Clearly, this has many advantages. Firstly, the material is recycled, which means its base cost is almost zero. Secondly, it is environmentally friendly, because it is not extracted from quarries. Also, the arisings do not need to be taken to landfill anymore, meaning no landfill taxes are paid. The transport of virgin material and of the arisings to landfill is avoided, with consequent decrease in pollution and in cost to the utility companies. The fact that the recycling process will take place on-site instead of in centralised recycling centres means a reduction of congestion on the roads, and a further reduction of the costs. Lastly and most importantly, the reinstatement process will be faster, and the road can soon be re-opened to traffic - an important consideration in the UK in light of the Traffic Management Act, TMA. The present paper will describe the study and the tests performed in order to assess whether an on-site recycling is possible, analysing the different phases necessary for the process.

Present specifications in the U.K.

In the U.K., two main guidelines are followed when reinstating road excavations. These are the Specification for the Reinstatement of Openings in Highways [SROH, 2002] and the Specifications for Highway Works [SHW, 2007]. Both promote the use of recycled material. A third guideline has recently been developed by the Waste and Resourced Action Programme [WRAP, 2007].

The SROH treats recycled aggregates as Alternative Reinstatement Materials, ARMs, in Appendix A9. The SHW introduces the recycled aggregates in SHW series 800 (“unbound, cement and other hydraulically bound subbase mixtures”). Part of the requirements is that the recycled material needs to be tested in accordance with SHW Clause 710. According to this clause, the material excavated can be used as backfill, unless it is contains plastic clay, which is classified as a “Class E” material. However, Class E material can be improved and subsequently used if treated with a hydraulic binder. It is also stated that the asphalt content shall not exceed 50%, while other foreign materials shall not exceed 1%. The WRAP guideline is a quality protocol for the production of aggregate from inert waste, and has also been created to give a quality management scheme to be followed when processing materials from trench excavations.

In the everyday reinstatement practice, the quality of a reinstatement is checked after compaction using a Clegg hammer [ASTM D5874, 2007] to give an Impact Value (IV) that is strictly correlated to the California Bearing Ratio value [Al-Amoudi et al., 2002]. The fourth IV measurement has to be around 22 for a footway and 30 for a carriageway. If these values are not reached, the reinstatement material needs to be compacted more to reach these thresholds. If this cannot be done, it is not a suitable material, in which case the reinstatement needs to be excavated and refilled with a stronger material. It is important to avoid such an eventuality not only because of the cost of a second reinstatement but also to avoid the fine that the law allows the road owner to impose.

EVALUATING REQUIREMENTS FOR ON-SITE RECYCLING

General description of required modification of trench arisings

Excavation arisings that are commonly extracted by utility companies include bound material (such as asphalt and concrete), unbound granular sub-base material (such as gravel and crushed rock), fine sub-grade material (such as sand, silt and clay) and foreign material (metal, plastic, brick and organic matter). These foreign materials are typically the remains of previous backfill and of pipework/cables and often include bricks. Figure 1 shows a schematic of the material types involved. Asphalt is a relatively precious material, because it is expensive and can be recycled to become new asphalt pavement. For this reason it is common practice to separate it from the rest of the material during the excavation phase – particularly on larger excavations, although this is not always the case. The rest of the material needs to be separated and handled according to its grading.

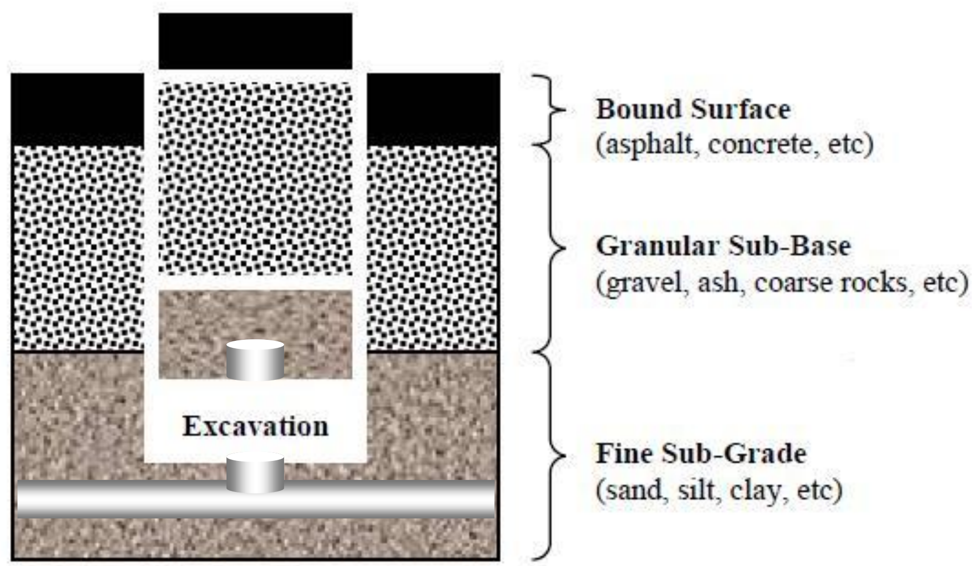

Fig. 1. Schematic of an excavation

A study of the best means to obtain a good reinstatement material from trench arisings, which is ready to be put back into the trench, has been undertaken. A small-scale reproduction of the large-scale process followed by the recycling centres was investigated. Such processes followed in recycling centres typically consist of the following main steps:

- Separation of the material based on the particle size
- A crushing stage for the larger rocks
- Re-blending of the single grain size particles in order to obtain the particle size distribution requested by the specifications

- Addition of hydraulic binders when the resulting material does not satisfy the strength requirements.

It quickly became apparent that it was impractical to attempt the same level of separation and re-blending on site as might be achieved at a recycling centre. For one reason, there would not be the space to store all the different sizes of arising. Also, at any one trench there would likely be certain sizes absent or available in excess. Therefore, it was decided only to differentiate between small and large particle sized aggregate. Large blocks could then be crushed to an acceptable size, unless they were of poor quality, in which case they would be disposed. The finer material would be analysed for its moisture content and grading, and then treated appropriately. Finally, the two different gradings could be used separately or re-mixed, ready to be used as reinstatement material.

The grading separation process

A classification process is necessary to separate the small particle size material from the large one that needs crushing. Many different types of separation equipment were looked at; most of them showed problems when dealing with clayey soils. Industrial screening arrangements usually work best on completely dry or completely wet materials [Wills, 1997]. They are not good at handling balls of clay as they tend to get stuck. For this reason, drying technologies were initially hypothesised. The thermal drying processes considered involved the use of medium infra-red waves, radio frequency, micro-wave and convection ovens. However, this idea was ruled out because of the high energy consumption and the time length of the processes involved. Washing processes were not considered because of the large amount of water needed at site and because very wet material is not advisable for trench reinstatement in roads. For these reasons, it was finally decided to attempt to deal with soil at its excavation water content. It should be noted that, when a Water utility company performs an excavation, a large percentage of the time the reason is to fix a leakage problem. Consequently this will cause the soil to be very wet and large quantities of water may be expected to come out from the excavation. If there is gas leakage, on the other hand, it is possible that the soil will be slightly drier than its natural state.

A number of techniques were investigated for the separation of arisings at excavation moisture content values – brushed grills, finger screens, shredders, etc.. The main problems encountered during the screening process are due to the presence of clay. When a clayey material is wet, it sticks together to form a clod that cannot be broken with a classic sieve. Even worse, these lumps of clay can dry out and become very strong, sometimes with the appearance of rock. These materials are troublesome for two reasons. The first is that they need to be broken up into pieces small enough to provide sufficient surface area for any subsequent mixing with binders. The second is that they tend to foul and block the screen and, if they are treated as the “large grading” aggregate (the “oversize”), the can block typical crushing equipment.

Eventually, a separation equipment built by Pearson Separation, which is an adaption from technology originally developed for agriculture, was selected. It is able to handle almost all the types of soils that can be excavated, thanks to a dynamic rotating screen that is able to break and crumble the material. Tests have been performed with many different types of soils, and the results have been very satisfactory. The speed and grading threshold can be varied in order to obtain the optimum separation. During the setting phase, the separation between large and small aggregates was adjusted taking the maximum size accepted by the recycling centres as a reference. For this purpose, tests were conducted in a recycling depot where a large range of different materials, both in their natural state and already separated, was available. Figure 2 shows an example of the different gradings obtained from a single excavation. It can be seen from the picture on the left that the “large size” material contains not only rocks, but also bricks, larger pieces of asphalt (although they are not commonly encountered) and other foreign material such as organic material.

Fig. 2. Trench arisings separated by size: on the left the larger material that will need to be crushed, on the right the finer material

The crushing phase

The control of the grading includes the size reduction of any coarse particles; this is done by means of a crusher. The crushing process has also the benefit of improving the shape of the aggregate by making them very angular and thus creating better interlocking. It is important to try to avoid the production of fines, as they tend to decrease the compaction performance of the final material. Thus, a study of the available crushing methods was also instigated. As the recycling process has to be done on site, the employment of a crusher with a low power draw and small dimensions is necessary. Also, in the eventuality of small quantities of clods of clay or asphalt being present (material that can stick), the machine should not get blocked.

Different types of crushers were taken into consideration including gyratory crushers, impact crushers, roll crushers and jaw crushers. A jaw crusher was selected for its high operational reliability, robustness and low maintenance requirements. It can also be cleaned of blockages rather easily. The quantity of material to be processed is usually small, and therefore high capacity was not a requirement.

Some tests were performed to assess its performance. The crusher selected, despite its small dimensions, was able to deal with medium-large blocks (maximum average diameter about 25 cm). The machine was also tested with a large piece of concrete, approximately 30 x 10 x 10 cm. The result was satisfactory, even though the concrete dimensions were at the limit that could be accepted by the machine: the concrete was completely broken into pieces of adequate dimensions, and a small amount of fines was produced. Trials were made with an oversize material that contained a large quantity of clay. The result was that the clay stuck to the sides of the jaw crusher and needed to be removed by hand.

A particle size analysis of the resulting crushed material is shown in Figure 3. The grading range required for UK highway unbound mixtures is also shown [SHW, 2007: clause 803]. It can be seen that the material obtained by crushing the oversize material with the jaw crusher is acceptable.

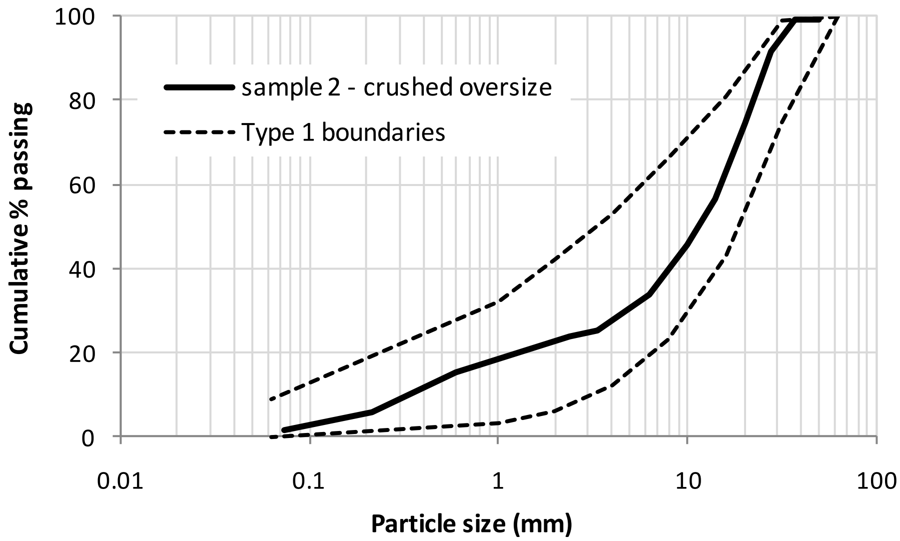

Fig. 3. Example of grain size grading curve obtained from crushed oversize

Initially, the authors intended to treat the crushed rock and the “undersize” material as two separate products for reinstatement. The crushed rock would be a well graded granular material to be used as a granular sub-base material, and the “undersize” a hydraulically stabilized fine material for the substitute subgrade. However, despite the good particle size distribution from the laboratory and field tests, it was decided that the two gradings would be blended to obtain a single type of material. This decision was for two reasons. Firstly, the quality of the crushed rocks cannot be assured on site; Aggregate Impact Value (AIV) tests were made on the materials crushed, and the resulting AIVs were sometimes above the limit of 30%. Secondly, during the field tests it was noticed that a rather small quantity of medium-large aggregate is typically encountered in a trench arising and such small quantities are insufficient to assure enough material for the subbase layer.

From the field tests, it became clear that it was not always possible or beneficial to crush, and then use, the coarse material. This can be easily understood from Figure 2. Sometimes the coarse aggregate is mainly composed of big clods of sticky clay, which can even be very hard. In addition to the problems these may give the crusher, they do not give strength to the final recycled material. Other times, the coarse aggregate was found to be composed of a large proportion of bricks. Although they can be crushed without any problem, bricks tend to suffer frost heave, so only small quantities should be allowed. For these reasons, an assessment of the suitability of the oversize material should be done by an operator before the crushing stage. If it is judged to be unsuitable, it should be discarded.

The soil grading and moisture content

The finer portion of material can be composed of gravel, sand, silt, clay and topsoil. Although typical trench arisings contain all different particle sizes, usually one of them is more prevalent. This is the first aspect that needs to be assessed on site, as good performance is associated with a broad grading, while clayey soils usually do not perform well. The moisture content of the material is another important issue, especially when it comes to compaction. If the soil is too wet or too dry, it cannot be compacted to its optimum. The consequence of this is that further compaction will be generated after the road is built, leading to consequential distress and loss of performance. Also, a very wet material can be rather weak because of the reduced suction forces and the eventual reduction in effective strength.

During this project, tests were made using material dug from excavations performed by Yorkshire Water. This material varied in moisture content, often being very wet as a consequence of having been dug from around a leaking pipe. In these excavations it was unusual to encounter dry material. However, if the soil excavated is mostly of a sandy-gravelly nature, it will rarely contain an excess of water, because it drains quite quickly. But the quantity of excess water can increase as the silt and, especially, the clay content increases, resulting in a very weak material unable to sustain any substantial stress. At worst, it can take the consistency of mud. It is clear that a rough assessment of the dominant particle size and moisture content of the arisings is important. From this description, an assessment has to be made as to whether the soil needs to be treated and what the best treatment is.

An approximate idea of the grading of the excavated material can be made simply by observation, without need of a measurement device. This can be done by the trench arisings work team. Also the presence of excess water can be quite easily assessed by eye. However, a second judgement of the soil water content, especially in those cases in which it is not clear whether the soil needs to be treated or not, will be based on a direct or indirect measurement. The direct measurement can be performed by means of (e.g.) a microwave moisture sensor.

Treatment additives and mixing phase

In almost all cases, due to their poor mechanical characteristics, the fine arisings will not be suitable for re-use without some form of stabilization. Thus, the effects of different additives have been investigated in order to improve clayey, silty and sandy types of materials. Particular attention was given to the use of waste material additives (or by-products) for their environmental advantages, as it has already been widely demonstrated that some by-products can bring benefits such as hydraulic binding and drying.

The stabilisation additives investigated in this project were:

- Cement
- Hydrated lime
- Gypsum
- Various waste by-products including ashes and slags (air-cooled blast furnace slag, granulated blast furnace slag and steel slag).

However, no particular benefits were seen in order to justify the cost and/or availability issues of gypsum and of the slags, so they have been discounted almost immediately.

Sub-bases and road-bases that are suitable for cementitious binders are granular materials such as sand and gravel. It is not possible to get an effective bonding action in cohesive soils due to the much higher specific surface area, although some mineralogical modification resulting in soil stabilization is possible. Such stabilization can better be achieved by hydrated lime which, in the presence of water, reacts with any pozzolanic materials (materials that contain silica and alumina such as clay) to provide a slow strength gain, perhaps over a period of several months.

As many ashes are pozzolanic, their use is beneficial because it brings cost savings and less landfill pollution. However, this property is not automatically associated with the origin, as shown in Figure 4. This figure illustrates the assessment of one waste-derived proprietary product, an ash tested with unconfined compression strength (UCS) tests to see if it provided any cementitious or pozzolanic properties. No pozzolanic action was observed in the short period over which it was tested. Other ashes, instead, did show pozzolanic properties.

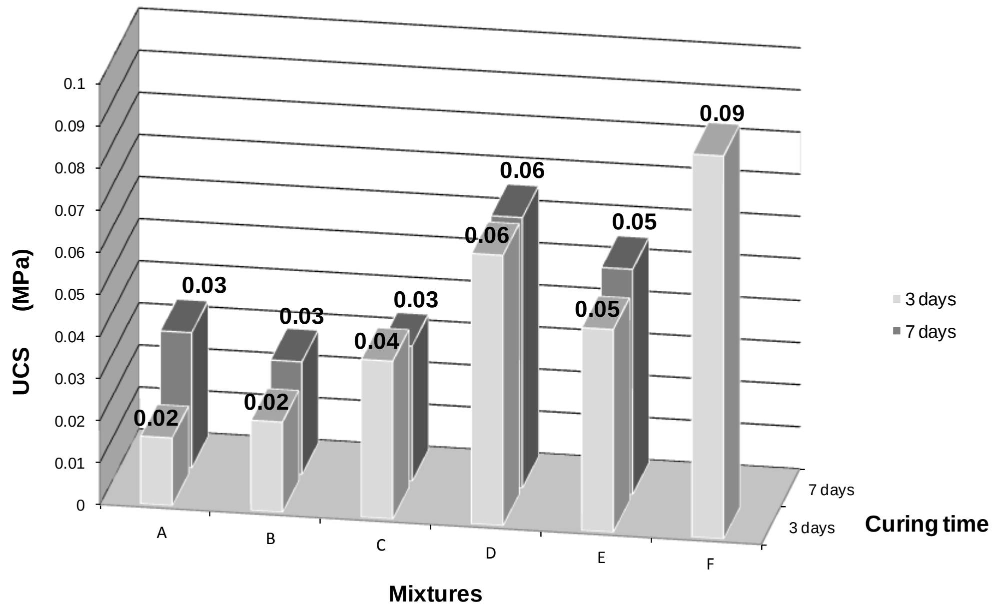

Fig. 4. Strength of trench arising mixtures treated with lime (samples A, B and C) or cement (D, E and F) and with varying percentages of the waste-derived by-product at 3 days and at 7 days: no significant increase of strength with time could be observed.

Initially, cement was chosen as a binder for more sandy materials and hydrated lime for clay-type materials. However, despite the potential strength that lime could give, it was decided not to use it as a binder. The main reason is that the strength gain process takes a long time compared to cement, whereas the road needs to be open to traffic as soon as possible. A second reason was that the maximum strength that will be reached is more difficult to predict. Even though it is easy to avoid the problem of producing too weak a subgrade by adding a larger amount of hydrated lime, this can then risk the hydraulically bound material becoming too strong, which has consequent problems if it ever needs to be retrenched. These two observations can be seen in Figure 5 where the immediate unconfined compressive strength of the material treated with cement (M15) is much higher than that of the material treated with lime (M17), yet the long-term strength does not increase significantly.

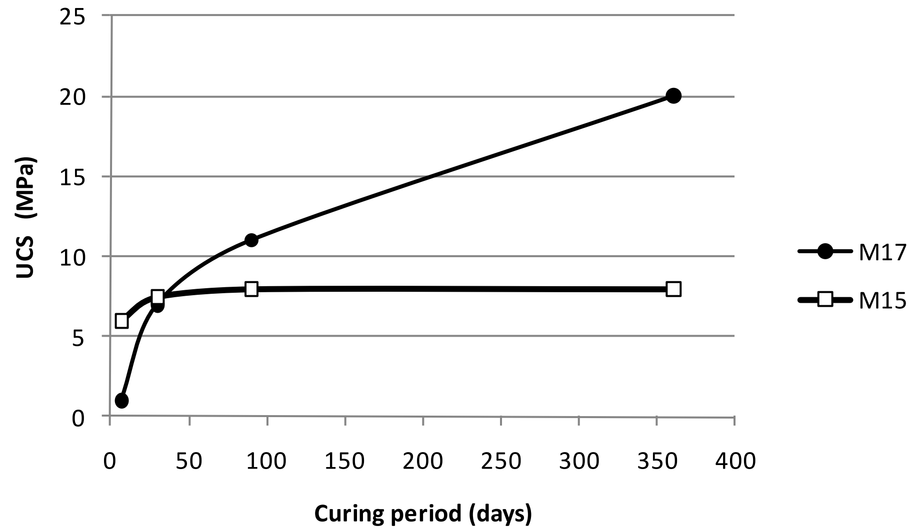

Fig. 5. Compressive strength of Type 1 granite treated with cement plus other additives (M15), and with hydrated lime plus other additives (M17)

Even though cement was not found to be as efficient at stabilization of clay as the lime, it still gave reasonable results with clay, so it was decided to use it as a hydraulic binder. The addition of an ash with pozzolanic properties as a partial cement replacement gave good results while having the potential to reduce costs.

The proprietary by-product assessed earlier (see Figure 4), although not having any pozzolanic properties, showed a very strong drying effect. This led to an increase in immediate strength (tested with California Bearing Ratio tests, Figure 6) and its addition to clay-like soil increased the friability, which facilitates compaction.

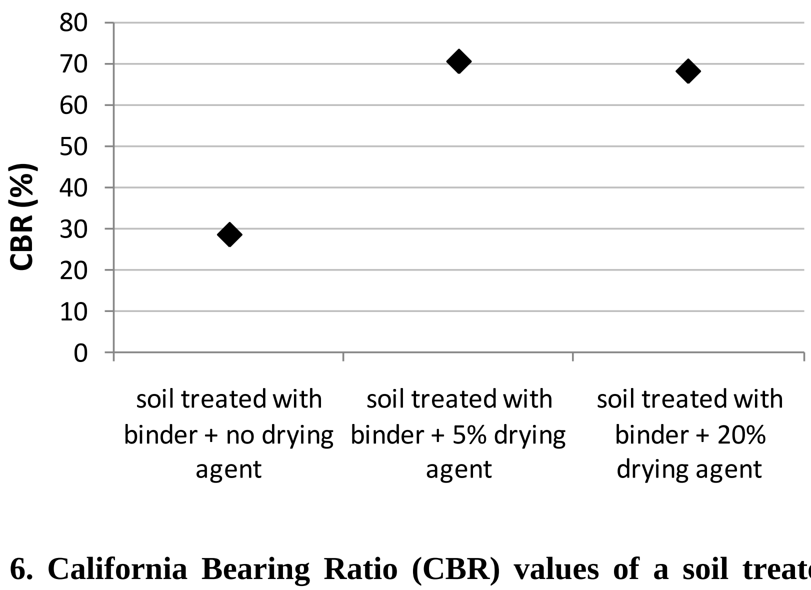

Fig. 6. California Bearing Ratio (CBR) values of a soil treated with different quantities of a proprietary by-product used as drying agent

Although the precise quantification of the different additives still needs to be optimised, it was found that the trench arisings give good results if treated with binder (mix of cement and pozzolanic ashes) in different percentages according to the initial soil strength, and if dried with the drying by-product when the quantity of water largely exceeds the optimum moisture content. It should be noted that tests performed on very clayey material at high moisture content demonstrated that, if treated with the binder and with the drying agent, the soil can reach a reasonable strength, but the compaction process is very troublesome (see Figure 7) as the compaction device tends to sink into the material. When large quantities of crushed coarse oversize material are to be added (see below), the composite material might be recyclable even though the fine component is very clayey. However, in practice, those excavations yielding clay fines were found to be the ones with very low quantities of coarse materials that can be blended. Thus, it is not usually practical to recycle these types of arisings.

Fig. 7. Very clayey soil, not suitable for compaction

The upper limit to binder addition is dictated by the fact that a high quantity would result in a very strong material, causing difficulties in the case of need to re-excavate. Some material tested on-site was overdosed in treatment and gave a Clegg hammer IV reading of 62 after just 6 days. Its subsequent removal turned out to be very difficult even with a mechanical digger.

Conventional mixing plant that is available at a size suitable for using on-site was used to blend the soil with binders/drying agent. Once mixed, the final stage of the recycling of the arisings is to blend the “undersize” material to the crushed oversize material, if any, to obtain the final backfill product.

FINAL ASPECTS

As has been shown in the previous section, very clay-like material represents the physical limit for recycling at the trench; if such material is encountered, the device is not able to deal with it, and new material must be imported. However, it should be noted that clay is usually discarded even by the recycling centres. Such a badly performing soil was encountered only once during this project, so it is envisaged that on-site treatment of at least the 70% of excavated trench arisings is achievable.

The frost heave problem might be encountered when dealing with natural soils. Frost heave is mostly linked to the presence of fines in the soil. However, when the excavated material is not well graded, the problem is usually a high fines content, and such material will be treated with cement. As cement-based bonding reduces the frost heave sensitivity of the soil, this treatment should eliminate any problems. For example, WRAP [2007] states that hydraulically bound materials with a compressive strength over 3 MPa can be considered resistant to frost heave.

CONCLUSIONS

In order to make the trench reinstatements in roads more economically and environmentally efficient, the feasibility of recycling trench arisings in-situ has been investigated. Excavated material has been taken through an on-site process to make it suitable to be used as a recycled material for back-filling. This process will involve treatment with hydraulic binders in most the cases and, if necessary, with drying agents. Laboratory tests and site trials were performed with trench arisings in their natural state which showed that recycling of almost all types of excavated material, returned an aggregate with satisfactory strength and quality. The only limitation encountered was the treatment of very wet, plastic clay, because of the difficulties in compaction. However, such a material is seldom encountered. The treatment methods, according to soil type and moisture content, still need to be optimised and a way to categorize the quality of the recycled material for back-fill still needs to be implemented.

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