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**STABILIZATION OF MARGINAL AGGREGATES WITH HYDRAULIC AND PUZZOLANIC BINDERS
BASED ON WASTE MATERIALS****STABILISATION DE GRANULATS MARGINAUX AVEC DES LIANTS A BASE DE DECHETS****HÖBEDA Peet *****Abstract**

Natural sand deposits and waste screenings from gravel pits and quarries are abundant in parts of Sweden. Investigations have been made to stabilize such materials with binders based on waste materials. Both laboratory work and test roads have been performed. In the latter case, mainly secondary roads have been strengthened with a plant-mixed bases.

Good results have been achieved with a binder made of milled granulated blast furnace slag, activated with lime or especially with both lime and waste gypsum. Sand and screenings from gravel often contain organic material, deleterious with the binders studied. In such cases, the gypsum addition also seems to counteract the negative effect of the organic material.

Fly ash has recently been available in Sweden. Tests made with fly ash-lime, as often used for stabilization abroad, have shown too slow binding for a rather cold climate. Addition of waste gypsum, calcium chloride, alkali-salts or use of an alkali-rich cement kiln dust instead of commercial lime can improve the binding properties. Different fly ashes, however, react in different ways. It is often more suitable to use fly ash-cement as a binder, especially with poorly graded aggregates. The fly ash, added in an optimum amount, work as a filler and high immediate stabilities can be achieved at a correct water content. The puzzolanic properties of the fly ash, at the same time, makes it possible to reduce the cement content considerably in comparison with the case when only portland cement is used as a binder.

Promising laboratory work has also been done with binders consisting of condensed silica fume or ash from fluidized bed coal combustion, both in combination with lime.

Résumé

Les dépôts de sables naturels et les rebuts de criblage de ballastières et de carrières sont abondants en Suède. Des recherches ont été faites pour stabiliser de tels matériaux à l'aide de liants à base de déchets. On a réalisé à la fois des essais de laboratoire et des tests sur chaussées, principalement sur renforcements de routes secondaires avec des couches de base variées.

De bons résultats ont été obtenus avec un liant de laitier de hauts fourneaux granulé et broyé, activé par de la chaux ou à la fois par de la chaux et un déchet gypseux. Les sables et les produits de criblage des gravières contiennent souvent de la matière organique, poison des liants étudiés. Dans de tels cas, l'addition de gypse semble contrecarrer l'action négative de la matière organique.

Des cendres volantes sont utilisables depuis peu en Suède. Des essais réalisés avec des cendres volantes-chaux, équivalentes à celles souvent utilisées en stabilisation à l'étranger, ont montré un durcissement trop lent pour un climat plutôt froid. L'addition de déchet de gypse, de chlorure de calcium, de sels alcalins ou l'utilisation de poussières de four à ciment riches en alcalins au lieu de chaux commerciale permet d'améliorer les propriétés des liants. Différentes cendres volantes réagissent cependant de manières variées. Il vaut souvent mieux utiliser des cendres volantes-ciment comme liant, en particulier avec les matériaux à granularité défavorable. Les cendres volantes ajoutées en pourcentage optimal se comportent comme un filler et on peut ainsi obtenir une haute stabilité immédiate avec une teneur en eau correcte. Les propriétés pouzzolaniques de la cendre volante permettent, en même temps, de réduire considérablement le pourcentage de ciment par rapport au cas où on n'utiliserait que du ciment portland comme liant.

Un travail prometteur a aussi été fait en laboratoire sur des liants obtenus à partir de fumées de silice condensées ou de cendres de construction du charbon en lits fluidisés, dans tous les cas en combinaison avec la chaux.

1. Introduction

Sweden is favoured with extensive resources of natural aggregates of good quality, originating both from gravels from glaciofluvial deposits and crystalline bedrock. Regional shortages exist, however, and the extraction of gravel has been made more difficult by environmental protection measures. The ambition to save natural resources and energy has initiated research in using marginal aggregates and binders, based on waste materials, in road constructions.

At the VTI, laboratory work has been performed and test roads built, mainly on contracts with the Swedish Road Administration. In connection with test roads, stabilized road bases have mainly been studied, often when strengthening unsurfaced secondary roads. In such cases a cheap surfacing e.g. surface dressing made with graded gravel, can be used. However, it is considered important to have an especially strong base in such cases.

Besides unbound bases only bitumen, and cementbound bases are currently standardized in Sweden. Cement stabilized bases have, however, been used to a minor extent when building new roads because thick asphalt bound layers have been considered necessary to prevent reflective

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cracks appearing in the road surface. Such cracks do not necessarily degrade the bearing capacity of the pavement.

The climatic conditions also prevent the pavement from being made frostproof because of the great thicknesses necessary to prevent frost penetrating the subgrade. Rigid stabilizations, made with hydraulic or puzzolanic binders, are less suitable than flexible ones when the subgrade soils are frost-susceptible. Because of these problems, it is necessary to study construction methods, already used abroad, in more severe climatic conditions in order to define the applications.

The marginal aggregates stabilized have mainly been sand and fine grained screenings from crushing gravel or rock. The aggregates have sometimes been contaminated by organic material that complicates the use of the binders studied. These have been based on either activated granulated blast furnace slag or fly ash, mixed with lime or cement. Other waste products have also been studied in laboratory tests. Granulated blast furnace slag, activated with a small amount of lime, cement, NaOH, gypsum etc. is, like portland cement, classified as a hydraulic binder. Fly ash, obtained from burning high rank coals, contains little lime and lime or cement must be added for a binding action. The binder is therefore classified as puzzolanic.

2. Blast furnace slag as a binder

At the beginning of the seventies an attempt was made in Sweden to use lime activated unground granulated blast furnace slag in stabilized road bases as first done in France [1]. Good results have often been obtained when water-cooled blast furnace slag was used as an aggregate and a ready-mix was introduced by a steel industry. The attempts to stabilize natural aggregates were, however not so successful, partly because of the rather "acid" nature of the slags which leads to poor binding properties. The aggregates are also mostly of granitic composition and consequently less suitable than e.g. limestone or air-cooled blast furnace slag. Also the asphalt surfacings used were comparatively thin, 4 cm asphaltic concrete as maximum.

The binding properties of the granulated slag can be improved if the specific surface is increased by grinding. In France, preground slag with a fines (< 0.08 mm) content of 10-15% has been introduced [2]. This binder can be stored for some time in a stockpile in the open air and is plant-mixed when an activating agent is added. In Sweden, however, the granulated slag has been ground to approximately cement fineness. This binder can be added in smaller amounts and can be bulktransported longer distances by truck. Existing equipment for handling cement can be used. The mixes have been made in a cement stabilization plant or in plant used for producing the oiled gravel surfacing used on secondary roads in Sweden. Also batch mixes in concrete plant have been made. Control of the binder content has, however, sometimes been inadequate. The ground slag has been activated with 10% lime, but it has later been learnt that the addition of waste gypsum can give considerably improved properties.

The first test road, Hissjö 1980, built with ground, lime activated slag, was made in late August near Umeå in northern Sweden, in connection with strengthening of road 363 with a 15 cm thick stabilized base [3]. Oiled gravel was used as surfacing. The average daily traffic with a large number of heavy lumbertrucks. The subgrade was a well drained sand.

The aggregate was varied, both a gravelly and a sandy grading being used (table 1). The binder content was

comparatively high, about 10%, but could not be controlled as carefully as desired. A test section was also laid without adding lime as activator. Also fly ash-lime was studied as a binder, see chapter 3.

Little time was available when laying the test sections and heavy rain caused problems. Oiled gravel was immediately laid on the compacted base and the road was opened to traffic. The mix made with gravelly material was observed to be more sensitive to a high water content than the sandy one. The deformations caused by heavy traffic were shaped with additional low binder content oiled gravel which became thicker than planned. The final surfacing was laid later.

The development of bearing capacity of the test sections was determined with the aid of a falling weight deflectometer. The deflection was measured at two points which enabled calculation of the layer modulus of the stabilized layers and modulus for the underlying unbound layers [4]. These values depend on environmental conditions e.g. the moisture contents in the materials. Cores were also extracted from the bound layers for determination of the compressive strength. This test was made according to the specification of the Swedish Road Administration, which means that rubber pads are used between the test specimens and steel plates of the loading machine. In this way a splitting type of failure is induced, which means that the strength value for a well-bound specimen with low slenderness (height/diameter) is reduced, e.g. with about 50% for a laboratory compacted Proctor-sized specimen. The influence of the slenderness is, however, minimal and the results seem to correspond to the compressive strengths obtained at a slenderness of 2.0, as recommended by PIARC [5].

In spite of the unfavourable weather conditions when laying the test sections, good results have been obtained with the slag stabilized materials. The sandy material has performed as well as the gravelly one. The slag binder seems to be less sensitive to a high water content than portland cement, a fact also observed when using slag cement in concrete [6]. The section with non-activated slag, in spite of the slow binding, has with time achieved layer modulus values of the same level as sections with the lime-activated binders. The modulus values, however, show some decrease, especially according to measurements made in spring 1983, which is probably due to increased cracking, not seen on the road surface. A good relationship between the compressive strengths of cores and layer modulus values can be observed before any significant reduction of the latter has occurred. Some transverse cracks have formed in the road surface, mostly in transitions between the test sections.

The freeze-thaw durability of the material compositions of the test sections has been studied in the laboratory by water saturation in vacuum of test cylinders and exposure to 10 freeze-thaw cycles in a frost cabinet. The samples which have been moist stored for 135 days have been embedded in moist sand. The freeze-thaw durability, evaluated by the expansion and strength reduction of the samples, is excellent for the well-bound materials. Self healing properties are also found when fitting cracked specimens together with rubber bands and storing them in a moist environment. The original strength can be obtained or even exceeded when storing specimens for a sufficiently long time. The importance of such autogenous healing can be disputed, in road conditions e.g. the transverse and longitudinal cracks formed mostly lack the stress conditions necessary for healing. Also this property probably declines with time.

Tab. 1 : Test road Hissjö 1980. Average values from falling weight deflectometer measurements (layer modulus of stabilized courses) and compressive strength of cores (values in brackets)

Test section	Aggregate and binder composition	Layer modulus, MPa (compressive strength of cores, MPa)					
		800930	810520	810917	820605	820906	830614
1	gravelly, 10 % slag 1 % lime	8800 (6.0)	20900 (10.2)	26200 (14.2)	29900 (12.2)	24300	14673 (15.7)
2	sandy, 10 % slag 1 % lime	10100 (5.1)	23300 (9.4)	32500 (12.9)	39500 (8.8)	18500	20494 (13.4)
3	sandy, 13 % slag	1200 —	10300 (4.9)	13500 (9.4)	27200 (10.3)	32100	19914 (11.4)
4	sandy, 16 % fly ash 4 % lime	530 —	680 —	4300 (3.0)	4400 (2.4)	8100	6715 (6.9)
5	sandy, 16 % fly ash 4 % lime 1 % CaCl ₂	1700 —	680 (3.3)	10600 (5.7)	14000 (5.9)	11400	6860 (9.3)
6	gravelly, 12 % fly ash 3 % lime 1 % CaCl ₂	2300 —	4500 —	13200 (7.9)	16800 (5.8)	11500	9848 (8.4)
7	gravelly, 12 % fly ash 3 % lime	800	980 —	7300 (6.1)	20800 (7.8)	26600	16940 (11.3)

Tab. 2 : Test road Sollebrunn 1981. Average values from falling weight deflectometer measurements (layer modulus of stabilized base) and compressive strength of cores (values in brackets)

Binder	Layer modulus, MPa (compressive strength of cores, MPa)							
	8106	8107	8109	8203	8204	8209	8304	8310
9 % milled slag	14400	20100 (7.9)	19500 (10.0)	15600 —	18800 (9.3)	18600 (11.4)	12200 —	16300 (14.7)
6 % port land cement	11500 (3.8)	13000 —	7800 —	2800 —	5900 (4.0)	2200 (3.8)	1100 —	1500 (3.7)

The next test with a slag binder was made in summer 1981 at Sollebrunn in south-west Sweden [7] in connection with strengthening of a minor unsurfaced road with a 15 cm thick stabilized base. The subgrade soil was a clay. The aggregate used was screenings 0-8 mm originating from the processing of gravel. 9 % lime-activated slag binder was used. The compacted base was sealed with cutback asphalt and later provided with a surface dressing made with graded aggregate. Transverse cracks occurred a short time after construction and further cracks appeared the following winter. Construction was performed during a long warm summer period and drying out of the sealed material has probably occurred.

Extracted cores show a strength gain during the 2 year long observation period (table 2). However, no such strength gain can be observed in the portland cement stabilized material, used for the rest of the road where the binder content is lower, 6 %. The layer modulus (table 2) has increased to a certain degree for the slag stabilized material and to a major extent for the cement stabilized one because of degradation. The cracking of the road surface is also

more severe for the cement stabilized than for the slag-stabilized sections. A similar degradation of a cement-stabilized Swedish road has been described earlier [4].

In August 1980 a test road was constructed at Gårdhem, near Trollhättan, not far from the former one [8]. The same aggregate was used, the traffic and subgrade soils are similar, as are the stabilized base layer thickness and surfacing. This time, however, the binder composition was varied and also low binder contents, 4, 6 and 8 % lime-activated slag binder, were studied. Sections with added waste gypsum (0.5, 0.75 and 1 % respectively) were laid for comparison (table 3). Test sections with flyash-cement were also laid, see chapter 3.

The construction of the test sections was performed in different weather conditions. The material, containing only 4 % slag binder, became unstable because of heavy rain and was strengthened the next day with a 10 cm layer containing 8 % slag binder. Material containing 4 % binder, and also 0.5 % gypsum, was laid in the same weather conditions but had gained some strength and was therefore

Tab. 3 : Test road Gärdhem 1982. Average values from falling weight deflectometer measurements (layer modulus of stabilized base) and compressive strength of cores (values in brackets)

Test section	Binder composition	Layer modulus, MPa (Compressive strength, MPa)			
		820902	820922	830414	831005
1	10.0% fly ash 2.0% cement	2400	3800 (1.7)	4000 (3.9)	7100 (7.3)
2	6.0% fly ash 3.0% cement	2300	3300 (1.6)	3250 (2.3)	6400 (5.7)
3	8.0% slag 4.0% slag*	700	6000 —	72700 (5.7)	110000 (6.8)
4	4.0% slag 0.5% gypsum	3500	10900 (2.5)	9000 (5.6)	13300 (5.9)
5	6.0% slag	2300	11300 (2.7)	8200 (5.2)	8900 (6.4)
6	8.0% slag	11800	16400 (4.5)	15000 (5.8)	18100 (8.5)
7	8.0% slag 1.0% gypsum	26000	22900 (11.5)	17900 (13.7)	17400 (16.6)
8	8.0% fly ash 6.0% slag	9200	15000 (4.5)	14300 (10.2)	15900 (11.1)
9	6.0% slag 0.75% gypsum	10500	16200 (4.4)	14300 (9.0)	14800 (10.1)
Reference	6.0% portland cement	—	—	—	5500 (4.5)

* Section with 4.0% slag strengthened with 10 cm material with 8% slag. Compressive strength determined on bottom layer.

not strengthened. CBR-tests, as performed in France, were made to control the immediate stability of the unbound materials (Fig. 1) and a good measure of agreement with the observations during laying of the test sections was achieved.

The falling weight deflectometer measurements show a continuous increase of the bearing capacity of the different test sections (table 3). Extracted cores show a strength gain, also for the material containing only 4 % binder (Fig. 2). The addition of waste gypsum has benefited the binding properties still more than observed in laboratory tests.

No transverse cracks were observed in the test sections after construction, contrary to the test road at Sollebrunn. The main difference has been the weather conditions ; the test road at Gärdhem was constructed later in the summer during wet weather conditions and no excessive drying and shrinkage of the material has occurred. It may be added, that in the Netherlands the importance of preventing moisture loss has been observed when applying cement stabilizations and the asphaltic surface is laid immediately after the stabilized base [9]. A few narrow transverse cracks were observed the following spring. However, more extensive cracking has occurred during the summer 1983, which has been extremely hot and dry. It cannot be excluded that the drying out of the clay subgrade under the pavement may have exerted an influence.

Fig. 1 : Immediate stability for material compositions in test road Gärdhem 1982. Water content 6.0 %.

Fig. 2 : Development of compressive strength, determined on cores drilled from test road Gärdhem 1982.

3. Fly ash-lime and fly ash-cement as binders

Coal has not been used as a fuel in Sweden for some decades because of the availability of low priced oil. However, in recent years, some coal-fired plants have been built, mainly for heating, although new plants are also planned for electricity generation. In the USA, France [10, 11] and some other countries, fly ash from high-ranked coals has been used in combination with lime for stabilization of pavements. Studies of this binder were taken up by the VTI in 1980. The laboratory tests showed that fly ash-lime compositions had very slow binding properties but the addition of a low content of waste gypsum, calcium chloride, sodium silicate etc, could improve the binder. Fly ashes, however, react in a different way and testing must be performed in each case.

Test sections were laid with fly ash-lime stabilized base in the test road Hissjö 1980 [3]. The binder contents were 12-16 % fly ash and 3-4 % lime. Test sections were also laid with the addition of 1 % calcium chloride (table 1). The dry fly ash was fed from a cement silo which caused some handling difficulties. Rainy weather in combination with heavy vehicles caused deformations in the unbound material and were adjusted with oiled gravel.

No cores were obtained when a first drilling attempt was made one month after construction. However, some bin-

ding could be observed in the calcium chloride activated materials. Next spring, cores were obtained only from these sections but in the autumn also from the unactivated materials. The falling weight deflectometer measurements show a faster increase of layer modulus values for the activated material sections, but with time the gravelly aggregate mixes get the highest values. The calcium chloride activated materials seem to have cracked to some extent because it has become increasingly difficult to obtain unbroken cores. However, no decrease in compressive strength can be seen for the unbroken cores tested. Some transverse cracks have appeared the second winter in the road surface.

As the slag stabilized materials, also the fly ash-lime stabilized ones have had good freeze-thaw durability after binding and also show autogenous healing.

Because of the slow binding action of the fly ash-lime binder compositions fly ash-portland cement binder has also been studied. This binder is favourable especially with poorly graded aggregates, e.g. sand. Good results were obtained in the laboratory with high fly ash and low cement content binders and two short test sections were constructed in the test road Gärnhem 1982 [8]. Moist, stockpiled fly ash was used this time in compositions with 10 % ash, 2 % cement and 6 % ash, 3 % cement (table 3). An unplanned test section was also laid with 8 % fly ash and 6 % slag binder, since these components were in excess. The fly ash, stored in a small stockpile, became quite wet in rainy weather and some difficulties arose in the mixing process. The fly ash tended to form rounded agglomerates a few cm in size that were also present after compaction. The stabilities of the unbound materials were however high and they resisted truck traffic well. Also the corresponding CBR-values in the laboratory were high, figure 1.

The short-term strengths according to cores were considerably poorer than that obtained in former laboratory tests, mainly because of the poor mixing (table 3). However, the compressive strengths improve with time (figure 2). The falling weight deflectometer measurements show the same tendency. It can also be observed that the test sections, containing fly ash-cement, have lower layer modulus values than the slag stabilized sections at the same level of compressive strength. It is assumed that the resilient characteristics of porous fly ash can exert an influence. The fly ash-slag treated section performed favourably and the slag content (the most expensive component) could have been lower.

According to freeze-thaw testing, the durability of the material, bound with 10 % fly ash and 2 % cement, is insufficient after 3 months hardening. However, no signs of degradation were observed during the first winter.

Because of the considerable interest in fly ash utilization, a test road was built in summer 1983 in the town of Västana. This time a new road was built, with a traffic volume of 12000 vehicles/day. The aggregates studied used in the stabilized base were a 0-32 mm gravel and 0-8 mm screenings respectively. The fly ash content was 6 % in the former and 10 % in the latter case because of the poorer grading. Dry silo ash was used. Cement contents of 2 % and 3 % were studied with both aggregates. Shorter test sections were also laid with cement-stabilized fly ash (10 % binder) as a base material and unstabilized fly ash (moist ash from stockpile) as a subbase material. The surfacing consisted of a 4 cm thick asphaltic concrete. The subgrade soil was a soft clay.

The road base materials were batch-mixed in a concrete plant. The sandy material was more easily handled than

the gravelly one because the latter was well graded and dense, and therefore sensitive to moisture content. Also it tended to segregate. The strength gain is fairly similar but the layer modulus values tend to be lower for test sections with the sandy material. The compressive strengths and layer modulus values, monitored the first year are considerably higher than from the test road Gärnhem 1982 for similar binder compositions and obviously the dry silo ash has worked better than the wet stockpiled fly ash. Both came from the same plant.

Narrow transverse cracks in the sealed surface occurred some days after construction, especially when the weather was sunny, and some have later penetrated the asphaltic concrete.

4. Stabilization with other waste materials

Laboratory tests have been made with other pozzolanic binders, e.g. condensed silica fume (of impure quality, unsuitable for concrete) ash from fluidized bed combustion of coal etc. These have been tested both with commercial lime and with waste lime. The results have often been better than with fly ash. Condensed silica fume especially is a good pozzolan and can be used in a lower content than fly ash. Also alkali-rich waste lime from a cement kiln has given excellent results, better than commercial lime.

5. Aggregates containing organic material

Marginal materials such as glacial tills and sands may be contaminated by organic material that retards or hinders the binding action of both hydraulic and pozzolanic binders. Standardized tests for aggregate quality are sometimes misleading, e.g. the commonly employed colorimetric test in NaOH-solution. Also the pH-values, both of the aggregate and hydrating mixtures have been measured, but the results are not always in agreement with the strength development of the materials. The strength gain of aggregate-binder combinations must therefore be evaluated in suspicious cases with different binders and additives.

There are various measures for counteracting the negative influence of organic contamination. Slag binder is particularly sensitive but can be improved by gypsum or alkaline salts. Road 626 near Kungälv for example was strengthened in 1981 with a base, made of screenings from a gravel pit, stabilized with lime-activated slag binder. According to laboratory tests, the strength development was very slow but the addition of waste gypsum or potassium sulphate improved the properties. For practical reasons, the latter was used in 0.3 % content when strengthening the road.

Laboratory tests were also made in 1983 in connection with strengthening of road 1175, not far from Vingaker. A natural sand, containing an active organic contaminant, was used as an aggregate. Various binders were studied in different contents in order to find the most suitable one [12]. Portland cement, slag-cement (70 % slag content) and a modified cement (delivered with 30 % fly ash) were studied and in addition also lime activated slag, fly ash-cement, fly ash-lime and silica-lime binders. Additions of different chemicals in low contents were also studied.

With portland cement, quite unsatisfactory results were achieved and no strength gain was observed after 7 days. Additions of calcium chloride, gypsum and alkaline salts gave no significant improvements. Better results were achieved with slag-cement and fly ash containing cements. The

short term strengths were low, but contrary to portland cement, a strength gain was observed. Lime-activated slag binder did not work until waste gypsum or calcium chloride was added; the short term strengths were low but significant strength gains were observed. The same thing can be said about fly ash-cement binder (moist fly ash was mixed with portland cement). Fly ash-lime did not work well, even with additives, but silica-lime was an efficient binder, especially in combination with alkali-rich waste lime.

The modified cement was used in a content of 7 % when strengthening the road. A test section was also made when besides 4 % cement also 10 % moist, stockpiled fly ash was added. The stability of the material in the unbound state was greatly improved. According to compressive strength-testing of on cores, taken one month after construction, the strengths of the both material compositions are equal. The layer modulus is, however, lower on the base, which is rich in fly ash.

6. Conclusions

Sandy materials have been successfully stabilized with different binders. The construction properties may under circumstances be better than with well-graded aggregates, because of a lower moisture sensitivity and lesser segregation when laying the material. However, adverse wet weather conditions must be avoided. The layer modulus values tend to be lower with sandy than gravelly aggregates.

Ground, lime activated, slag binder has given especially good results when waste gypsum has also been added. Also treatment of aggregates, contaminated by organic substances, seems to be possible with a binder of this type.

Fly ash-lime binder has shown unacceptably slow binding properties, but improvement is possible by adding e.g. waste gypsum or calcium chloride. Fly ash-cement is a more useful binder in Swedish conditions, the short-term strength is sufficient and the strength increases during a long period. An important beneficial effect of the fly ash addition is also that poorly graded sands show greatly improved immediate stability and can, when protected from wetting up, withstand traffic stresses even in an unbound state. The freeze-thaw durability may be low for a binder with high fly ash content, but low in cement or lime content, until sufficient strength is gained.

Good results have also been achieved with non-traditional binders consisting of condensed silica fume-lime, fluidized bed coal combustion ash-lime etc. Alkali-rich waste lime can give better results than commercial lime.

Sometimes a decrease of the layer modulus values of test sections have occurred, obviously because of cracking of the materials which is not always seen in the road surface. The compressive strength of cores may, however, be high. The stabilized material condition is best monitored by bearing strength measurements e.g. with a falling weight deflectometer. Mainly transverse reflective cracks have appeared after various times in the road surface and obviously because of different reasons.

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