Cold In-Place Recycling on Low-Volume Roads in Austria

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Modern methods for road maintenance should involve used construction materials, take account of environmental compatibility, and eliminate road damage economically and durably. Regarding these basic requirements, attention should be paid to cold in-place recycling of damaged asphalt layers using cement stabilization. Within the last few years, cold in-place recycling has become an appropriate alternative for the rehabilitation of low-volume roads in Austria. In the course of documentation carried out at the Institute for Traffic and Transportation Engineering of the Vienna University of Bodenkultur, the individual steps of construction were analyzed. The advantage of the described procedure is that none of the old pavement need be hauled to a special repository. An innovative method for cold in-place recycling on low-volume roads using cement stabilization is described. The first step of this method contains a detailed analysis of the section to be restored, including bearing capacity measurements and the determination of the grading curves of existing unbound layers. Grading curves are also determined for the existing asphalt layer after trial milling in order to consider refinement by milling. This analysis forms the basis for adding material before milling in order to achieve a well-graded aggregate. On the construction site, the necessary additional aggregate is spread over the existing pavement. In the next step, the cement binder is distributed on the road surface. A soil stabilizer breaks up the existing road structure and mixes it thoroughly with the aggregates and binder that were distributed beforehand. The leveling and compaction are done with a grader and a vibratory roller. An after-treatment with a vibratory roller is carried out up to 3 days later to create microcracks and prevent the appearance of open stress-caused cracks at greater intervals. The paper also describes in detail the analysis of existing pavement before milling, including bearing capacity measurements. Existing results and statements describing achievable quality level are given. Results showing increased and homogenous bearing capacity conditions after milling and cement stabilization are shown. Concluding remarks also show that this way of reconstruction is an economic means of conserving raw materials and protecting the environment.

The low-volume rural road network in Austria consists of all roads that are neither federal nor provincial and that render access to the rural areas of the country. This low-volume road network consists of all local roads outside the villages, farm roads and forest roads. Its total length amounts to about 160 000 km (approximately 99,300 mi). Traffic volume on these rural roads amounts to a maximum of 250 vehicles per day on an annual average.

Since the responsibility for construction and maintenance of this road network is split up between private persons and public authorities, there is no exact documentation on the condition and length of these roads. In practice until now, maintenance was neglected in many cases and adequate new reconstruction techniques have been increasingly needed.

Within the last few years, cold in-place recycling has become an appropriate alternative for reconstruction of low-volume roads in Austria. The advantage of the described innovative method is that all of the existing material can be used within the new construction. Many tests during the last 10 years were carried out with cold in-place recycling using bituminous stabilization and cement stabilization as well. Especially for rural roads with normally poor bearing capacity and poor-quality existing pavement material, cement stabilization was found to be the more appropriate solution.

In the course of documentation carried out at the Institute for Traffic and Transportation Engineering of the Vienna University of Bodenkultur, each step of construction was analyzed critically (*1*). This forms the basis for the further improved application of this construction method.

CONSTRUCTION PROCEDURE

Cement stabilizations mixed in-plant have been used for reconstruction and overlays on rural roads since 1984 (*2*). These experiences form the basis for use of cement stabilization with the in-place recycling method at the beginning of the nineties. In summer 1993, this construction method was applied at seven sites using the experience of the last several years. At these sites the construction process was documented extensively (*1*) in order to describe the random conditions, preconditions and special requirements for the use of this construction method. The total length of these sites is 5.88 km, with an average width of 3 m. Thus the treated area is approximately 17 600 m^2.

General Remarks

The described method for cold in-place recycling can generally be divided into the analysis of the existing pavement, the adding of necessary unbound material, the distribution of cement binder on the surface, the milling by means of a soil stabilizer, the leveling with grader, the compacting with vibratory rollers and the after-treatment procedure.

Within this method for cold in-place recycling, the unbound subbase layer and the wearing course are milled together with added material and portland cement binder, resulting in a cement-stabilized layer. An additional surface layer is necessary. In most cases a bituminous surface dressing will be enough. Very often asphalt concrete surface layers (with a thickness of about 40 to 60 mm) are used.

The following advantages and benefits can be achieved by using the presented method:

- Economical and durable elimination of damage;
- Increased and homogenous bearing capacity;
- Frost sustainability;
- Total recycling of existing subbase and wearing course material;
- No waste material for deposit;
- Minimized environmental impacts, including no use of raw materials, minimal use of resources such as gravel, and little or no additional transportation of materials; and
- Brief traffic interruptions during construction.

Preliminary Examinations

Thickness Investigation

According to a design catalogue for rural roads in Austria (*3*) the necessary thickness of the cement-treated layer can be determined in relation to the existing design traffic. A preliminary investigation of the thickness of the existing pavement must show that it is possible to reach the necessary thickness of the cement treated layer with sufficient certainty. If the existing pavement shows insufficient thickness it is necessary to place additional unbound material (natural gravel or reclaimed granular asphalt) on the road surface before milling. The choice of this method should be made taking into account the aspects of the optimum grading curve shown in the next section.

Unbound Layer Examination

In general, subbase materials of existing minor rural roads in Austria with an age of approximately 30 years show grading curves with a high percentage of material less than 0.02 mm, thus showing a rather high frost susceptibility; and maximum particle size between 32 and 56 mm, amounting to between 5 and 10 percent by mass.

In most cases it is necessary to make some corrections of the grading curve of the existing material before stabilization to achieve a good result. The necessary preceding investigation must consider not only the existing unbound base material, but the material that results from the milling process, including base material and milled asphalt material. This is the reason why this investigation should be made after a trial milling on site. In cases where such a trial milling is not possible for organizational and economic reasons, the investigation of the unbound layer should be made after adding a respective amount of reclaimed granular asphalt in the laboratory.

The aim of the correction of the grading curve is a gradation to reach a good stability and compactability of the layer. An orientation for this gradation can be derived from the grading curves for unbound base layer materials as given in the respective Austrian specification (*4*), shown in Figure 1.

For cement stabilization, it is not necessary to restrict the content of particles smaller than 0.02 mm to 3 percent by weight, which also means that slightly frost-susceptible material can be used. With respect to the following treatment with cement, it is possible to allow higher amounts of fines (< 0.02 mm). But it has to be taken into account that a content > 10 percent results in a rather high necessary cement content to reach frost sustainability of the cement aggregate mixture (see section entitled "Suitability Test"). This high cement content normally leads to a high strength of material and increases the possibility of shrinkage cracking.

Another point is the sand content (0.06 to 2 mm) because these sand particles are of great importance for the mortar filling the voids between the bigger particles and increasing the stability of the mixture. If the sand content is lower than 10 percent, it is necessary to add sand to avoid too coarse an aggregate.

Suitability Test

With the unbound materials composed along the lines of the previous section, the suitability test must be performed in the laboratory to find the appropriate mix design, that is, the necessary cement content.

This test follows the Austrian specification RVS 8.05.13 (*5*), taking into account two different requirements, compressive strength and frost sustainability.

For these tests, specimens with different cement contents compacted at optimum water content are made using a proctor cylinder. These specimens are damp-storaged for 7 days at a temperature of +20°C. Compressive strength after this time should not be less than 3 MPa. Experiences also show that this value should not exceed 5 MPa because higher compressive strength brings much higher risks of wide reflective cracking (package cracking).

Frost susceptibility testing, which also starts after these 7 days, is carried out according to the ASTM Method D 560-57. The height difference between the first and twelfth frost cycle must not exceed 1 percent.

The minimum cement content is normally fixed with 90 kg/m^3 of compacted mixture. In cases of coarse aggregate this value could create compressive strength that is too high. This limit can therefore be undercut if necessary.

Construction

Stabilization Procedure

Before milling is performed, the additional unbound material, if necessary, is spread over the surface of the existing pavement that needs reconstruction. The cement binder is distributed by means of a spreader immediately before milling.

In the next construction step, a soil stabilizer breaks up the existing old road surface as well as the subbase

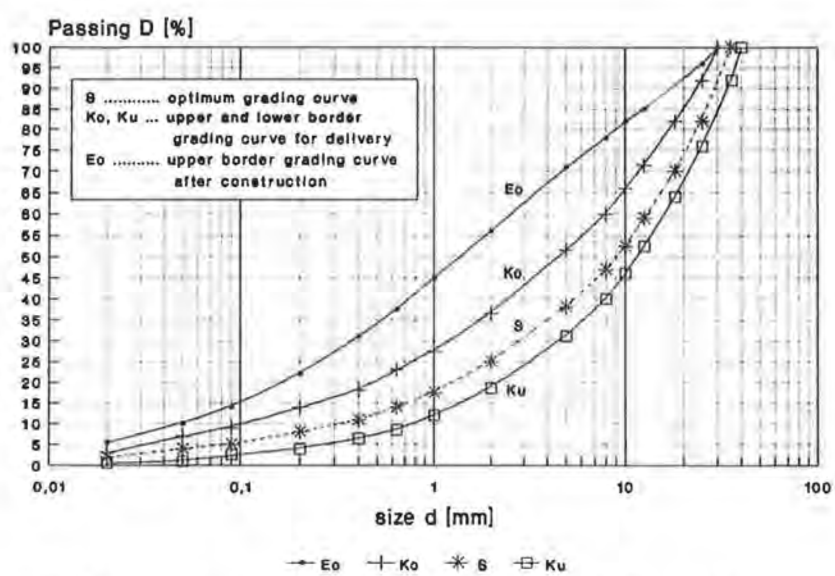

FIGURE 1 Grading curves for base material, grading 0/35 mm (*4*).

layer and mixes it thoroughly with the aggregates and the cement binder distributed beforehand. Practice has shown that a maximum milling depth of about 30 cm can be achieved.

A truck with a tank is connected to the soil stabilizer to provide the necessary water for the mixing process. The necessary moisture content for setting and compaction is achieved through a batching unit in combination with an injection beam integrated in the soil stabilizer. A moisture content of about 6 percent of the milled material has proven ideal.

For control purposes it is advisable to take samples of the fresh mixture to analyze the effective gradation at greater intervals. A comparison with the grading curve used at the suitability test could sometimes lead to small corrections of the mixture design.

After milling and mixing, the material is leveled by a grader, considering the projected necessary transversal gradient. Compaction is conducted by 100 kN-vibratory steel rollers with a small amplitude. Following the respective Austrian specifications, the compaction rate (dry density of the layer versus proctor dry density) has to be $\geq$ 100 percent on average with no value < 97 percent in the whole section.

To prevent the stabilized layer from drying out too fast, the surface is kept wet for between 3 and 5 days according to climatic conditions. Another possibility is to place a bituminous surface dressing (chipping size $^2/_4$ or $^3/_5$ mm) soon after construction of the stabilized layer. This brings the additional advantage of better bond between the cement stabilized base and the surface course placed later.

Immediately after construction the new pavement can be opened for slight traffic. Truck traffic is normally permitted 24 hours after construction.

Aftertreatment

As a result of tensile stress caused by shrinkage during setting and changes of temperature, transverse cracks often occur at regular intervals of about 15 to 20 m. To avoid or minimize the development of shrinkage cracking, the compressive strength is limited at the design process (see section entitled "Preliminary Examinations"). Furthermore a special procedure for aftertreatment has been developed and applied successfully.

The cement stabilized layer is loaded through several passes with vibratory rollers after a timespan of between 24 and 72 hr, thus creating a microcrack structure in the stabilized layer.

Practical experiences show that five roller passings lead to satisfactory results and the created microcrack structure prevents the development of larger stress-caused cracks successfully. Thus reflective cracking in overlying asphalt courses does not appear.

Measurements on Test Sites

In addition to the routine investigations and tests necessary at test sections, bearing capacity measurements before and after construction were made. These measurements were carried out with a modified Benkelman beam with automatic data collection under a wheel load of 50 kN.

Figure 2 illustrates a series of deflection diagrams measured on one of the test sections at various times:

- On the existing pavement before reconstruction,
- After reconstruction (stabilization) and before microcrack creation,
- After microcrack structure creation, and
- Three weeks after construction.

Table 1 shows as a result of statistical calculations the mean values, the standard deviations, and the representative deflections (mean value + 1.3 × standard deviation) for these measurements.

It can generally be stated that increased and homogenized bearing capacity takes place. The mean deflection of the measurement on the existing pavement before milling was 1.63 mm, whereas this mean value is reduced to 0.72 mm 3 weeks after construction. The standard deviation before treatment had a value of 0.55 and 3 weeks later this value has been reduced to 0.27. Accordingly the representative deflection is reduced from 2.35 to 1.07 mm during this time.

A comparison between deflection measurement before and after microcrack initiation shows an increase of the mean values (from 1.09 to 1.32 mm). Nevertheless, this increase of the mean values has been reduced in the course of the setting process 3 weeks later by approximately 50 percent.

In addition to the standard deflection measurement, deflection basins at single measuring points have been determined on all test sections. The deflection basins were determined by measuring the deflections in various distances from the actual loading point using an interval of 30 cm up to a distance of 3 m with a concluding measurement at 4 m distance.

The backcalculation of E-modulus was performed following the method proposed by Yang (*6*). Backcalculations from measurements conducted approximately 28 days after construction showed the following results for the E-modulus of the cement-stabilized layer:

- Maximum value: 6300 MPa
- Minimum value: 2800 MPa
- Mean value: 4500 MPa

This mean value corresponds very well with the value of 5000 MPa, which is used normally for analytical calculations in Austria (*3*).

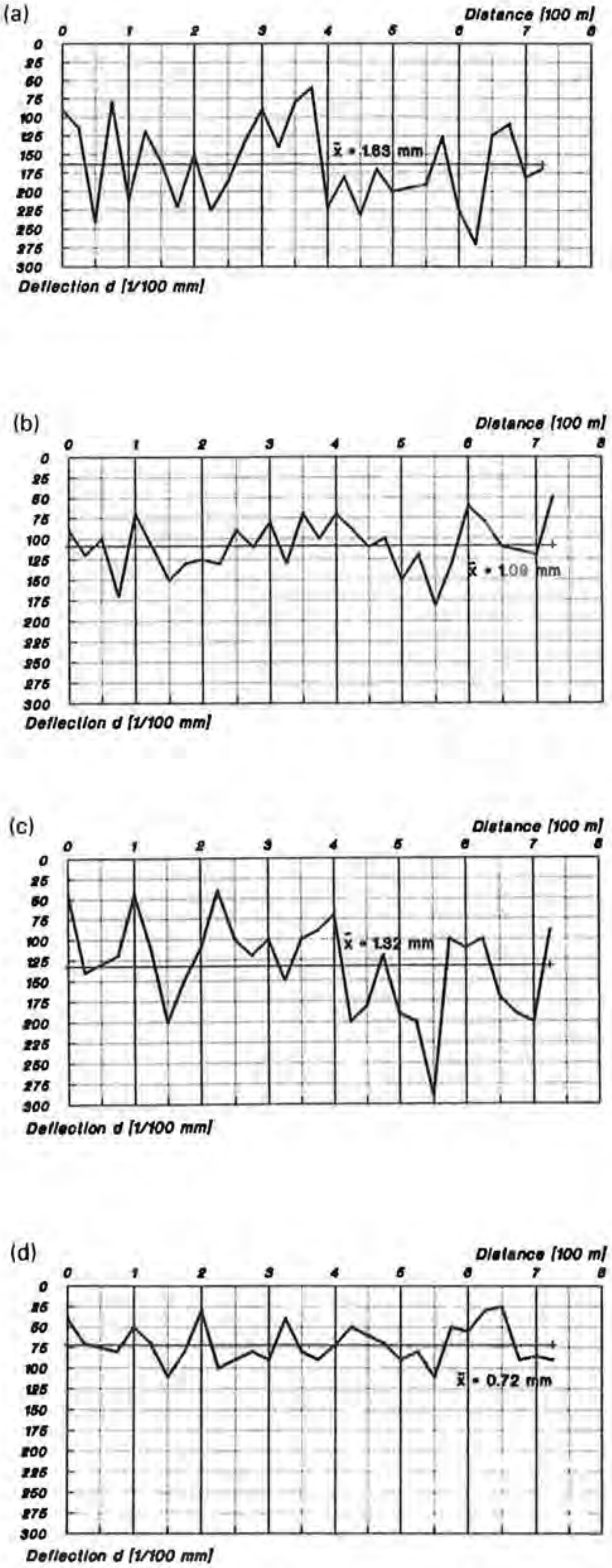

FIGURE 2 Deflection diagrams: (*a*) on existing pavement before reconstruction, (*b*) after reconstruction (stabilization) and before microcrack creation, (*c*) after microcrack structure creation, and (*d*) 3 weeks after construction.

ECONOMIC EVALUATION

As a basis for economic evaluation of cold in-place recycling under Austrian conditions, a comparison was made with the generally used reconstruction method of excavating the frost-susceptible old pavement down to formation level and placing a new unbound base layer and asphalt wearing course. The cost comparison also accounted for transport and deposit of the excavated material. For this method one must calculate a cost of approximately ATS 250/m^2, whereas cement stabilization mixed in place costs about ATS 150/m^2.

Thus calculations show that costs for cold in-place recycling per square meter of pavement are about 50 to 70 percent of the costs of the traditional method of reconstruction.

These figures only show the range of the possible reduction. One must take into account great differences in local conditions. For instance in cases where the material which must be added before stabilization is very expensive, the application of this cold in-place recycling method can become uneconomical.

GENERAL CONDITIONS AND HINTS FOR APPLICATION

The described method is applicable primarily to old pavements with coarse aggregates. For roads with only thin unbound layers or with very large aggregates this method cannot be used economically.

Furthermore one must take into account that reconstruction by recycling in place is restricted to the width of the existing pavement and thus to cases where this width is sufficient. If widening of the cross section is necessary a total reconstruction is normally better.

Regarding the fact that in most cases additional material is necessary (to improve the grading or to reach the necessary thickness of the stabilized layer) the surface of the new pavement lies at a higher level than that of the old pavement. Therefore this method cannot be used in cases where there are serious height restrictions.

Besides all these technical aspects concerning the pavement itself, it should be pointed out that in connection with reconstruction measures such as recycling in place, an improvement or reconstruction of the drainage facilities also must take place. To pay attention to the pavement alone without improving the drainage conditions in many cases will bring distresses after a short time.

SUMMARY

The presented method for cold in-place recycling using cement stabilization has in practice proven to be a good

TABLE 1 Comparison of Deflection Measurements at Various Times

	a) existing pavement	b) after reconstruction	c) after micro-crack creation	d) after three weeks
mean [mm]	1.63	1.09	1.32	0.72
standard deviation	0.55	0.31	0.56	0.27
representative deflection [mm]	2.35	1.49	2.05	1.07

way for reconstruction of existing heavily damaged pavements on rural roads, provided that the necessary preliminary examinations and laboratory tests for mixture design are performed.

The results of deflection measurements before and after construction illustrate that an increase and homogenizing effect in bearing capacity can be achieved. This makes this method an economical solution to the increasing reconstruction demand, especially on low-volume rural roads. The economic benefit depends to a very high degree on local conditions such as the costs of material, transportation, and materials deposit.

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