Use of Industrial By-Products in Economical Standard Low-Volume Road Pavements

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In Hungary, 50 percent of the urban and about 10 percent of the local rural roads are paved. The extremely limited amount of financial means available makes decreased costs for these low-volume pavements necessary. According to investigations by the Institute for Transport Sciences Ltd (KTI Rt) in Budapest, this goal can be attained by (*a*) utilization of relevant experience, (*b*) maximum possible use of industrial by-products and local materials with the appropriate techniques, (*c*) realistic design of pavements, and (*d*) staged construction of pavements. Use of various soil stabilization types, chemical treatments, and various wastes is discussed. Standard pavements and typical pavement cross sections are described.

In the 1950s and 1960s, based on the proposal of the forerunner of the present KTI Institute, Budapest, the base courses of about 150 low-volume roads were constructed using soil stabilization instead of the previously generally applied macadam base course. The slightly cohesive soils (silt and loess) were stabilized in situ using a cement binder. At that time, low-cost cutback binders were economical for the stabilization of fine sands. If nearby granular materials such as rock quarry wastes, silty gravel and sand, and slag were economically available, mechanical stabilization was preferred. The long-term behavior of these sections, some of which were considered experimental, was systematically monitored. The common experience gained from these sections was evaluated in 1987. These stabilization methods usually proved successful.

Early Experience with Pavements in Hungary

Cement Stabilization

A relatively thin asphalt surfacing on a cement-stabilized base course could endure a light traffic load for several decades. Major maintenance was necessary only if some construction fault, such as failure to apply cement, wetting of the subgrade (drainage deficiency), and construction in late autumn, occurred.

During the past 25 years, cement soil stabilization has become a widespread roadbuilding technique in Hungary. If local soils are used, the soil is generally milled on site; otherwise mixtures made in continuous-mixing plants are compacted using pneumatic-tire rollers.

Laboratory tests for the determination of the amount of cement needed have been developed and are included in standard specifications. The amount of cement used is important from technical and economical standpoints: a high cement content increases the strength unfavorably and is also uneconomical, whereas a low cement content does not provide the required bearing capacity and frost resistance.

The required cement rate is from 6 to 8 percent. Fine sand without silt, however, requires 10 to 12 percent cement content because of its high porosity. The quantity of cement can be reduced to 6 to 7 percent by mixing 15 to 20 percent silt with the material. The base courses of several low-volume streets in Budapest were constructed using cement-stabilized local sand.

Other Stabilization Techniques

Use of fine sand stabilized with cutback bitumen has proven successful for the base course of low-volume roads and was also economical because of the low bitumen prices. Currently, however, it cannot be considered a suggested technique.

As shown in Figure 1, a considerable part of Hungary is covered by silt (loess) and fine sand, which can be stabilized using various binders. Granular materials appropriate for mechanical stabilization are found only in a few areas of Hungary. If this technique is used properly, the results are favorable. In particular, wastes from rock quarries and gravel pits can be utilized advantageously for mechanical stabilization. Several rock wastes meet the grading requirements of mechanical stabilization. Other suitable materials are crushed blast furnace slag, burnt coal mine waste (red slag), coal and waste incinerator slag, and crushed debris from building demolition (*1*).

A paper by the author dealing in part with the location of quarry wastes and secondary materials suitable for road construction provides detailed information on the major sources of these materials. Favorable results have also been obtained from the rehabilitation, repair, and gradual development of unsurfaced roads using mainly mechanical stabilization (*2*).

Several experimental sections were constructed using slag from the Budapest Waste Incinerator Plant. On the basis of the results, technical guidelines on slag utilization were developed (*3*).

Lime stabilization was economically used where the low-volume road was on an acidiferous clay subgrade (for example, on a flood-prevention dam). The clay was not excavated, only loosened; the lime, either powdered slaked lime or a hydrated lime by-product, was admixed and, if necessary, wetted. The compaction was done by pneumatic-tire rollers or suitably guided loaded trucks.

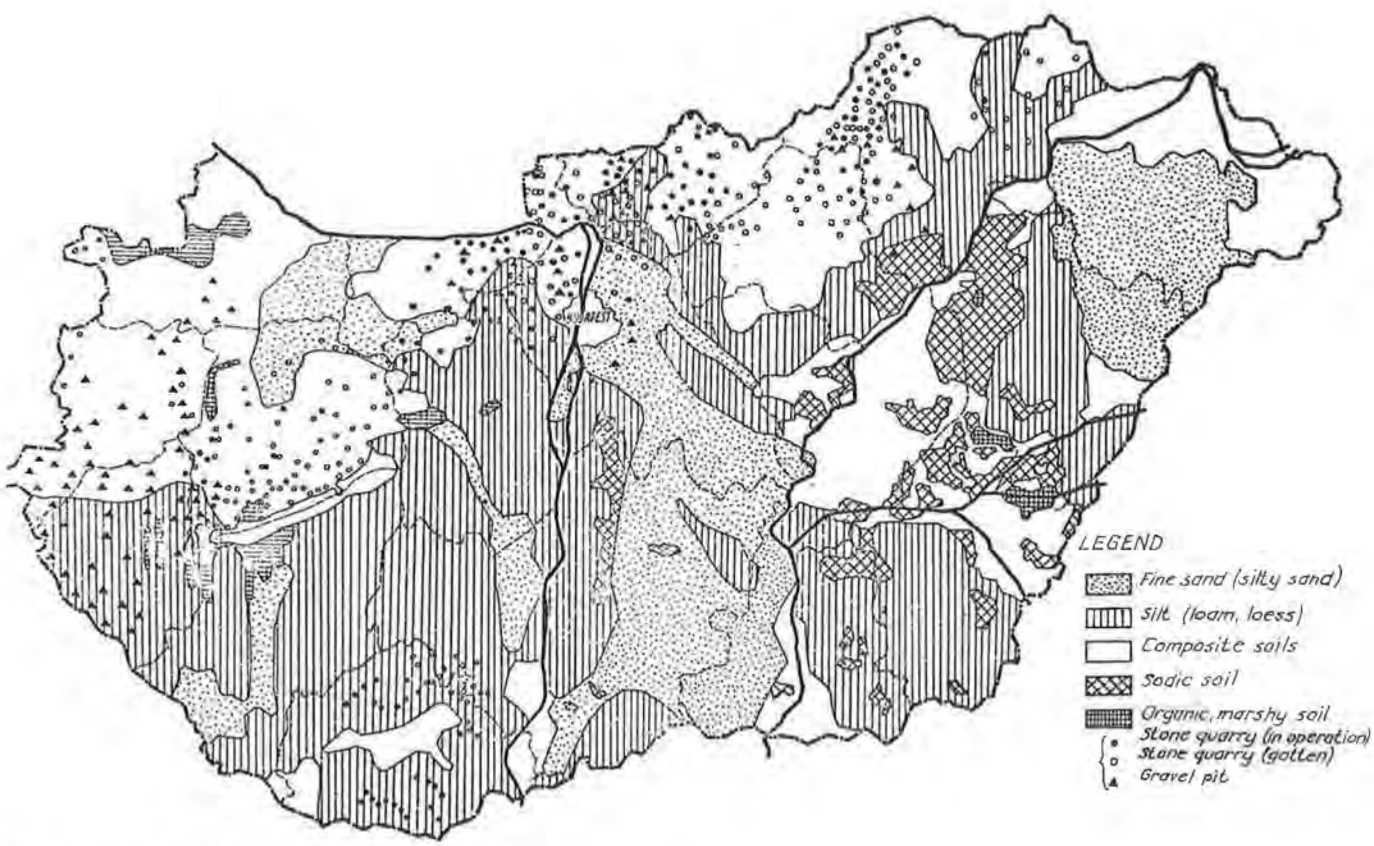

FIGURE 1 Schematic soil map of Hungary.

To determine the required lime rate, cement stabilization tests were used. Strengths at 28 and 42 days were considered critical because of the slower hardening.

Favorable results were obtained with the use of intermediate geotextiles when final or temporary pavement was constructed on a soft organic subgrade. When dirt roads were developed, surface and base courses were successfully replaced with geotextile impregnated with bitumen.

Fly-Ash-Bound Base Courses

Fly ash from thermal power plants proved an economical and appropriate substitute for cement binder in Hungary (based on French experience with this technique). The first three experimental sections were constructed in 1975. Favorable results caused development of the first technical directives, which have promoted the use of this technique. In Hungary, 5 million m^2 of fly-ash-stabilized base course have been constructed.

The majority of Hungarian power plants produce nonhydraulic fly ash that can be activated by the addition of lime. Instead of expensive lime, hydrated lime by-products and carbide caustic sludge can be used. Unused fly ash is transported to slime deposit areas where it settles down and dries. Wet fly ash activated by lime is also utilized as a binder.

When coal is burned with limestone waste, hydraulic fly ash with free CaO content of at least 18 percent is produced that becomes cement-like when mixed with water. This material can also be utilized for activating nonhydraulic fly ash. The fly-ash-bound mixtures bind slowly. This binding takes place in storage and makes for a longer compaction period for the mixture. The optimum binder rate is determined by laboratory tests that are the same as those for cement stabilization. The 60-day strength, however, is critical. The swelling of hydraulic fly ash during binding is compensated for by mixing it in an appropriate ratio with fly ash containing a high silica content. In a Hungarian power plant, various coal types of known composition were burned in a predetermined ratio to produce a hydraulic fly ash with the desired properties. To arrive at these ratios, Hungarian experts developed a new procedure to determine the equilibrium of fly ash–lime systems. A special device was established for the quick measurement of pozzolanic activity and active CaO content (*4*).

The construction cost of fly-ash base courses was 30 to 35 percent less than that of traditional cement variants when the hauling distance of the fly-ash and lime by-product was less than 60 km.

Technical directives for fly-ash base courses are being developed. Voids in low-quality crushed stone and blast furnace slag bases were filled successfully using cement or fly-ash mortar. This mortar ensured a waterproof base course.

Chemical Soil Treatment

In the 1970s, the local cohesive subgrades of several low-volume roads were treated with Reynolds Road Packer 235 (RRP-235) in regions of Hungary lacking granular materials. According to the manufacturer, on the basis of grading, condition limits, and compaction (Proctor) data of soils, the optimum chemical application rate as a function of soil particles smaller than 0.06 mm was determined to be 3 to 7 kg/100 m^2.

The upper 5-cm layer of leveled soil was loosened and the RRP-235, diluted with water, was sprayed in several applications. During the next 2 weeks, 20 to 30 mm of natural precipitation or sprinkled water made the chemical reach a few decimeters into the soil. Compaction was delayed until the moisture content of the treated soil approached the optimum compaction (Proctor) value. Too much rain sometimes made compaction difficult. One of the roads was treated in September 1970, but the compaction was carried out the following summer because of the rainy autumn and winter weather.

Chemische Bodenverbesserung (CBV) has been used in Hungary since 1977. The initial treatments proved successful; hence, laboratory tests were conducted using various soil types. These tests included measurement of the condition limits and the compaction dates of the untreated and the treated soils.

To obtain data on the waterproofness and bearing capacity of various soil types, the water absorption, swelling, and California bearing ratio (CBR) value of cylinders of various soil types subjected to 4-day capillary water action were measured. For some samples, the CBR value of the treated soils was more than 20 percent higher, and after the 4-day water action it was 5 percent lower than that of the untreated soils. For other samples, however, no improvement was observed. Based on these findings, the following conditions for the treatability of soils using chemicals were determined:

- Plasticity considerably decreases even under the influence of a few chemicals,
- The maximum dry (Proctor) density and the optimum compaction moisture content increase,
- The CBR value of the treated samples subjected to capillary water action is 15 to 20 percent higher than that of untreated soil, and
- The chemical soil mixture is acidic (pH less than 6).

It is important to treat only suitable soils using the appropriate procedures (*5*).

In the 1980s, more low-volume roads were constructed using chemical treatment. RRP-235 became available on the Hungarian market in the 1970s, and some test sections were constructed using it. Appropriate chemical soil treatment could result in considerable savings in areas having cohesive soils without granular materials.

Flexible Pavement Structural Design

In the early 1970s, a simple procedure was developed in Hungary using results of the AASHO Road Test and those of the Asphalt Institute for the structural design of flexible pavements (6). Pavements with various bearing capacities were compared on the basis of their H_e equivalent centimeter (ecm) thickness:

$$H_e = \Sigma\, e_i h_i$$

where e_i is the equivalency factor of each layer proportional to its load distribution capability, and h_i is the geometric thickness of each layer in centimeters.

The various pavement structural layer types were designated by letter symbols. The symbols for widespread stabilized base courses and their *e*-factors are as follows:

1. CK_t and PK_t, $e = 1.3$: cement and fly-ash-stabilized gravel (granular material), mixed in plant;
2. CK_h and PK_h, $e = 1.1$: the same layers as in 1, mixed in place;
3. CT_h and PT_h, $e = 0.8$: cement and fly-ash-stabilized soil, mixed in place; and
4. *M*50, $e = 0.8$: mechanically stabilized (D_{max} = max 50 mm).

Some asphalt pavement layers and surface dressings are as follows:

1. AB, KAB, HAB, EA, JU-20, $e = 2.2$: asphalt concrete, gravel asphalt concrete, cold asphalt concrete, emulsion asphalt, asphalt base course (partly crushed aggregate);
2. It-3, It-5, $e = 1.0$: penetration asphalt macadam layer; and
3. Fb_1 and Fb_2, $e = 0$: single and double surface dressing.

The bearing capacity of pavements has been characterized using the Benkelman beam since 1954. Later, Lacroix deflectographs and recently KUAB falling weight deflectographs have also been utilized.

Experimental Sections Under Controlled Traffic Load

In 1974, an experimental section was built on a fine sand subgrade as a part of a common program with the former German Democratic Republic to economically construct pavement for low-volume roads. The length of each type of pavement was 45 m, with the total length of the section being 1.7 km. One lane of the 6-m-wide roadway had surface dressing, whereas the other lane had an asphalt concrete course 2.5 cm thick. Underneath these surfaces were 35 different base course variants (for example, various cement stabilizations, bituminous base courses, and mechanical stabilizations). Periodically, loaded trucks passed over the experimental road. After each 2,500 passes, control measurements were made. The bearing capacity was characterized by deflection tests.

Based on evaluation of the results, the following observations were made:

- The bearing capacity of the fine sand subgrade (20 percent of the area of Hungary) is higher than had been supposed earlier: a minimum of 20 percent instead of 13 percent, and
- The thickness of the pavement can be considerably less than H_e = 20 ecm as specified in the Hungarian design guidelines (6).

The latter statement can be proved, for example, by the performance of a 12-km-long section of a main road constructed in 1971. A 65-cm layer of fine sand was placed on the cohesive clay subgrade. The upper 15 cm of this layer were stabilized by cement in situ. An asphalt pavement 11 cm thick was placed on top of the cement. According to the design guidelines (6), a much thicker pavement would have been necessary. Nevertheless, the road section still endures heavy traffic without major defects.

STANDARD PAVEMENTS

Local Soils, Bearing Capacity, and Base Courses

Local soil types have an important role in the design of pavements (subgrade bearing capacity) and in the design of base courses (stabilized soils). Figure 1 shows the distribution in Hungary of various soil types (such as silt, loess, fine sand, and clay) as well as sodic soil and organic and marshy soil.

For the design of low-volume roads, the following bearing capacity values can be used for the three main soil types:

- Clay, CBR = 5 percent;

- Silt (loess), CBR = 7 percent; and
- Fine sand, CBR = 15 percent.

It is important that the subgrade be constructed according to the relevant specifications and be well drained. Where this criteria cannot be met, the necessary subgrade bearing capacity should be attained using one of the following methods:

- Use of a granular protection layer,
- Lime treatment of wetted clay with an acidic chemical reaction, and
- Use of geotextile (as discussed in the section Other Stabilization Techniques).

Protection against spring thaw damage is needed according to the relevant specifications. In areas poor in granular materials, cement or fly-ash-stabilized base courses should be constructed using the local silt or fine sand and a mixed-in-place technique (ST_h or PT_h).

Industrial By-Products and Application Areas

Stone Quarry and Gravel Pit Wastes

Currently about 100 million tons of stone quarry and gravel pit wastes is available in Hungary. Yearly, about 1.6 million m^3 of gravel pit wastes and about 3.1 million tons of stone quarry wastes are produced. Figure 1 shows the regional distribution of the major stone quarries and gravel pits. Waste material from these can be utilized in the construction of MSO (M20) as well as CK and PK base courses. The utilization of these wastes is justified because of the savings of domestic rock resources as well as for economic and environmental reasons.

In addition to the big stone quarries and gravel pits, several hundred small pits are operated by agricultural firms, local councils, and forestry offices, among others. Waste material from these sources can often be obtained within a short hauling distance.

Other Granular Industrial By-Products

Crushed blast furnace slag can be substituted for natural granular aggregates in several areas of Hungary. In Ózd, crude iron is extracted from the old blast furnace slag waste site. The resulting crushed blast furnace slag should be utilized because repeated storage incurs significant costs. In Dunaújváros, not only crushed blast furnace slag but also crushed Siemens-Martin slag can be obtained, which can be used for surface dressings.

Slag from waste sites can be used for the construction of high-quality base courses if the uniform mixing of coarse and fine grains is ensured. The quantity of coal mine wastes exceeds 80,000 tons in Hungary. About half of it is red slag that burns as a result of spontaneous ignition. It can be used for the construction of high-quality mechanical stabilized bases. About 100,000 tons of waste incinerator slag produced in the Budapest Waste Incinerator Plant can be utilized for good mechanical stabilization because of its hydraulic fly ash content, which hardens slowly (*3*).

Mechanical stabilization can also be accomplished through use of boiler and grate slag, roof tile and brick fragments, as well as the debris from demolished buildings, if they meet the required specifications.

Fly Ash and Lime By-Products

Hungarian thermal power plants produce 5 million tons of fly ash a year. The following fly-ash-bound soils and gravels (granular materials) are found in the recommended pavement structures: PT_h, PT_t, PK_h, and PK_t (mixed in place or mixed in plant).

Design Parameters

In the gradual development of dirt roads, the pavement should usually be designed for a light traffic load, or Category A traffic. In this category, there should be several subcategories. The planned life cycle of the first step can be 5 years. Relatively light commercial vehicles with maximum weight of 60 to 80 kN run on these secondary roads. Regular bus traffic is usually IKARUSZ 250 buses with a total weight of 110 kN. During the first years, the actual load from these vehicles is generally under the maximum permitted value. Some two-thirds of the load falls on the rear dual-wheel axle. Thus, the standard axle load can be taken as 80 kN, supposing a 10-kN effective load.

When converting into F 100-kN unit axles, factors of 0.08, 0.16, and 0.30 are utilized for 60-, 70-, and 80-kN axles. Accordingly, the standard pavements should be designed according to the following traffic subcategories:

- A_1: 1,000 F100: no regular bus service, 4 to 5 commercial vehicles per day with a 60- to 70-kN load,
- A_2: 2,000 F100: twice the value of an A_1 load,
- A_3: 5,000 F100: 4 bus runs per day in addition to an A_2 load, and
- A_4: 10,000 F100: 14 bus runs and about 15 commercial vehicles per day.

Commercial vehicles under 60 kN (such as trailers towed by tractors) or passenger cars should not be considered in the design.

The width of the pavement is as follows:

- A_1 and A_2 traffic subcategories: 3.5 m and 4.0 m and
- A_3 and A_4 traffic subcategories: 6.0 m.

For the A_1 and A_2 traffic subcategories, the vehicle conversion factor is 1.0. That is, the loads of both traffic lanes should be taken into account. For the A_3 and A_5 subcategories, a factor of 0.7 is used when 5,000 and 10,000 F100 traffic loads are calculated.

The design bearing capacities of clay, silt, and sand-subgrades are CBR = 5, 7, and 15 percent, respectively.

Base and Wearing Course Materials

The base courses of the four standard pavements (T_1, T_2, T_3, and T_4) are as follows:

- T_1 M50 mechanical stabilization (e = 0.8): This base type can be constructed using a simple apparatus. It proves to be economical only if transportation costs are not too high.
- T_2 CT_h or PT_h cement or fly-ash-stabilized silt (loess) or sand mixed in place (e = 0.8): Use of these bases is economical if no local granular material is available. Site mixing can be considered efficient. The maximum layer thickness that can be mixed in a run is 20 cm. The mixed-in-plant CT_t and PT_t variants with e = 1.0 are rarely applied.
- T_3 CK_h or PK_h cement or fly-ash-stabilized gravel (granular material), mixed in place (e = 1.1): granular material in the vicinity increases the economy.
- T_4 CK_t or PK_t cement or fly-ash-stabilized gravel (granular material), mixed in plant (e = 1.3).

If suitable chemicals can be economically obtained, treatment of the cohesive soils with an acidic chemical reaction can also be used in areas with fewer granular materials.

Standard Pavement Variants

The following are the equivalent thicknesses of the 12 standard pavement variants, subgrade bearing capacity groups I through III and traffic subcategories A_1 through A_4:

F100 Subgrade CBR (%)	*H_e (ecm)*			
	A_1	A_2	A_3	A_4
Group I: 5	21	24	28	32
Group II: 7	18	21	25	28
Group III: 15	14	16	18	21

The favorable base courses of various standard pavements can be selected as a function of the local conditions as follows:

- Group T_1, e = 0.8, M50 mechanical stabilization;
- Group T_2, e = 0.8, CT_h or PT_h;
- Group T_3, e = 1.1, CK_h or PK_h; and
- Group T_4, e = 1.3, CK_t or PK_t.

Figures 2 and 3 present the standard pavements T_1, T_2, T_3, and T_4.

The CT_t and PT_t variants with e = 1.0 equivalency factors are rarely applied, and no special standard pavement group was designed for them. However, if preferred, the thicknesses of group T_3 (e = 1.1) could be modified as follows:

- A_1 I, II, III: 21, 18, and 14 cm, respectively;
- A_2 I, II, III: 21, 21, and 16 cm, respectively;
- A_3 I, II, III: 22, 22, and 18 cm, respectively; and
- A_4 I, II, III: 21, 22, and 15 cm, respectively.

Figure 4 illustrates the typical cross sections. Pavements in groups T_1 through T_3 are considered flexible, whereas the

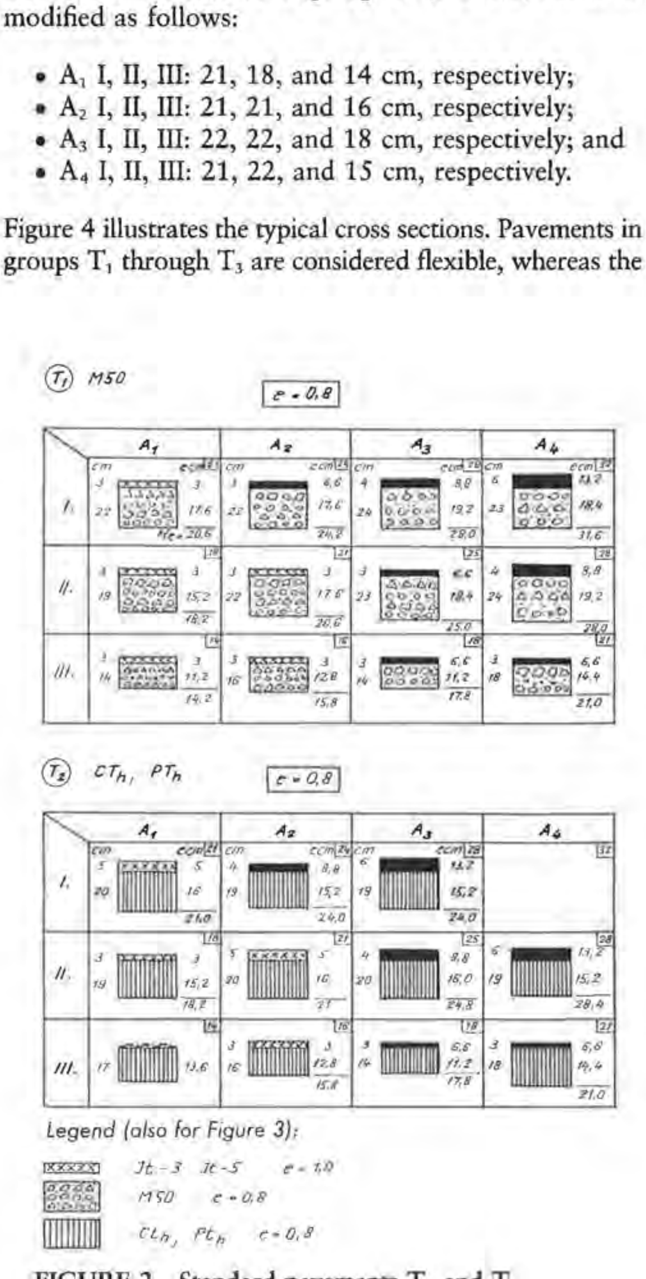

FIGURE 2 Standard pavements T_1 and T_2.

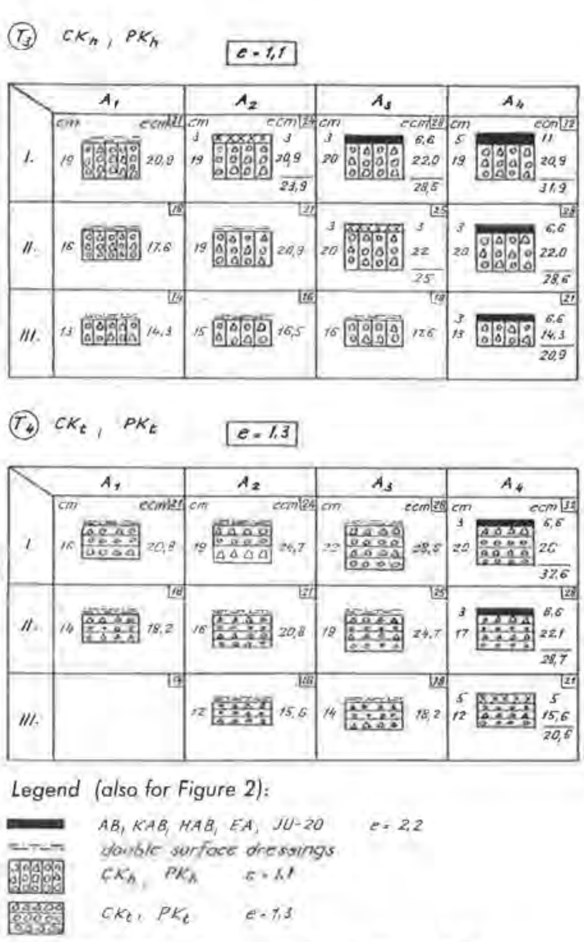

FIGURE 3 Standard pavements T_3 and T_4.

ones in group T_4 are semirigid variants. Accordingly, the allowable deflection values in 0.01 mm are as follows:

Group	A_1	A_2	A_3	A_4
T_1–T_3	300	270	230	190
T_4	250	220	180	150

Economic Analysis

When the optimum pavement type is being selected, it is expedient to investigate at least three favorable variants. Economy is considered the first criterion in ranking. Information about construction costs is enhanced by county (regional) costs in HUF/m²/ecm.

Another aspect is the machinery needed. Generally, short sections should be constructed using low standards because setting up a mixing plant would considerably increase construction costs. That is why the base courses of group T_1 made without mixing if low-cost granular material is available or the base courses of groups T_2 and T_3 produced by the mixed-in-place technique would be preferred.

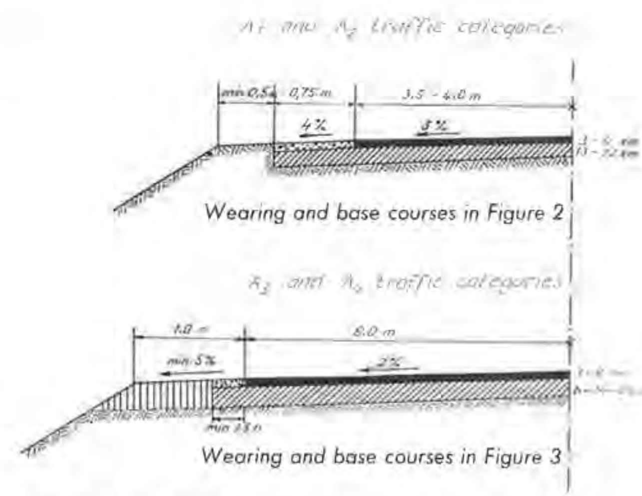

FIGURE 4 Typical pavement cross sections.

The equivalency costs of penetration asphalt macadam pavements are not favorable although their single machinery need can make the technique competitive, especially in the case of sealing of M50 base courses. The main advantages of HAB and EA cold asphalts are that they can be transported from a relatively long distance and can be stored for a long time.

The mixed-in-plant base courses (CK_t and PK_t or, rarely, CT_t and PT_t) and the hot-asphalt pavements (KAB, AB, JU + F_b) are preferred if a mixing plant operates close to the working site and the materials can be obtained economically from that plant.

It is expedient to use precoated chippings for surface dressings because the run would be very slow because of the low-volume traffic causing intensive raveling.

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