CONSOLID UK

## 1. PAVEMENT COMPONENTS AND THEIR FUNCTIONS

Figure 1 shows a cross section through a pavement. The pavement consists of the higher quality (usually imported/borrowed) materials above the sub-grade, including the wearing coarse the base course, and the sub-base. The function of these materials is to protect the sub-grade from traffic loads and weather. Their quality and thickness requirements will be determined by the sub-grade conditions and the traffic loading. In many instances, it particularly depends on sub-grade conditions and the weather.

**Any road is built in layers, which are from top to bottom:**

Wearing course: Asphalt carpet, concrete layer, or soil macadam

Base course: Crushed rock, gravel, asphalt soil concrete, stabilised soil

Sub-base: Gravel, crushed rock, stabilised soil

Sub-grade: In-situ soil – stabilised or non-stabilised.

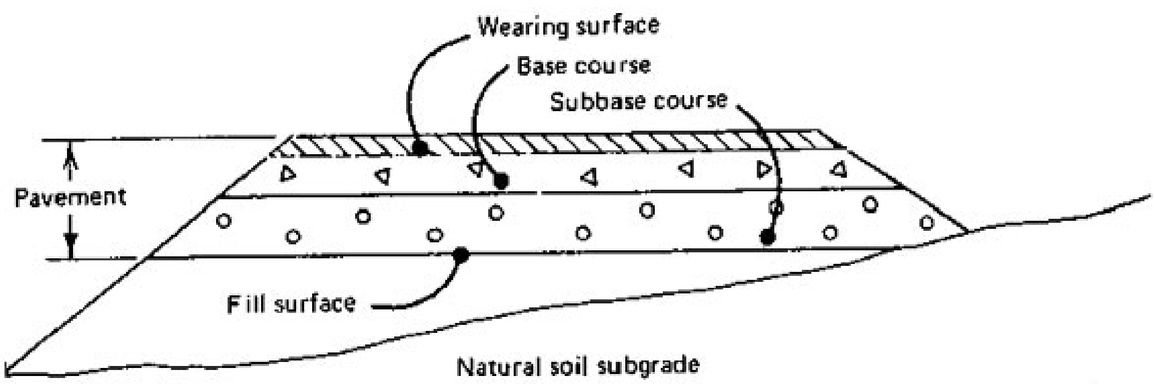



**Figure 1** Pavement section (standard)

The wearing course on any road should be the highest quality material in the pavement structure, except in those instances when the sub-grade consists of hard, durable intact rock. On permanent roads, it usually consists of asphalt, concrete or stabilised aggregate. It must be sufficiently strong to resist compressive stresses from wheel loads and mechanically stable enough to withstand traffic abrasion.

The base course is usually the major structural element in a pavement, except for those surfaced with Portland cement concrete. It consists of a comparatively thick, highly stable layer of well-graded, clean, coarse, crushed aggregate. Uncrushed aggregate is sometimes used when suitable natural gradations are available. The quality of the sub-base is intermediate between base course and sub-grade, due to the fact that lower layers do not need the same high loading capacity as the base course.

In contrast of standard road construction, **CONSOLID SYSTEM uses in-situ soil**.

## 2. SUBGRADE MATERIALS AND STRENGTH REQUIREMENTS

The general suitability of various soils as sub-grade materials may be inferred from soil classifications. Beyond general suitability, sub-grade strength is evaluated by methods used in con-junction with various pavement design procedures. Most of the methods used for pavement design are empirical or semi-empirical. Each requires complex equipment and tests to deter-mine sub-grade strength and each employs strongly specialised analytical procedures. **With the CONSOLID SYSTEM, a simple laboratory test shows exactly what you can aspect at the roadside**. A reasonably good understanding of pavement analysis methods and sub-grade material strength requirements can be acquired. Figure 2 provides a summary of the necessary definitions. Table 1 gives some examples of wheel loads for typical construction vehicles.

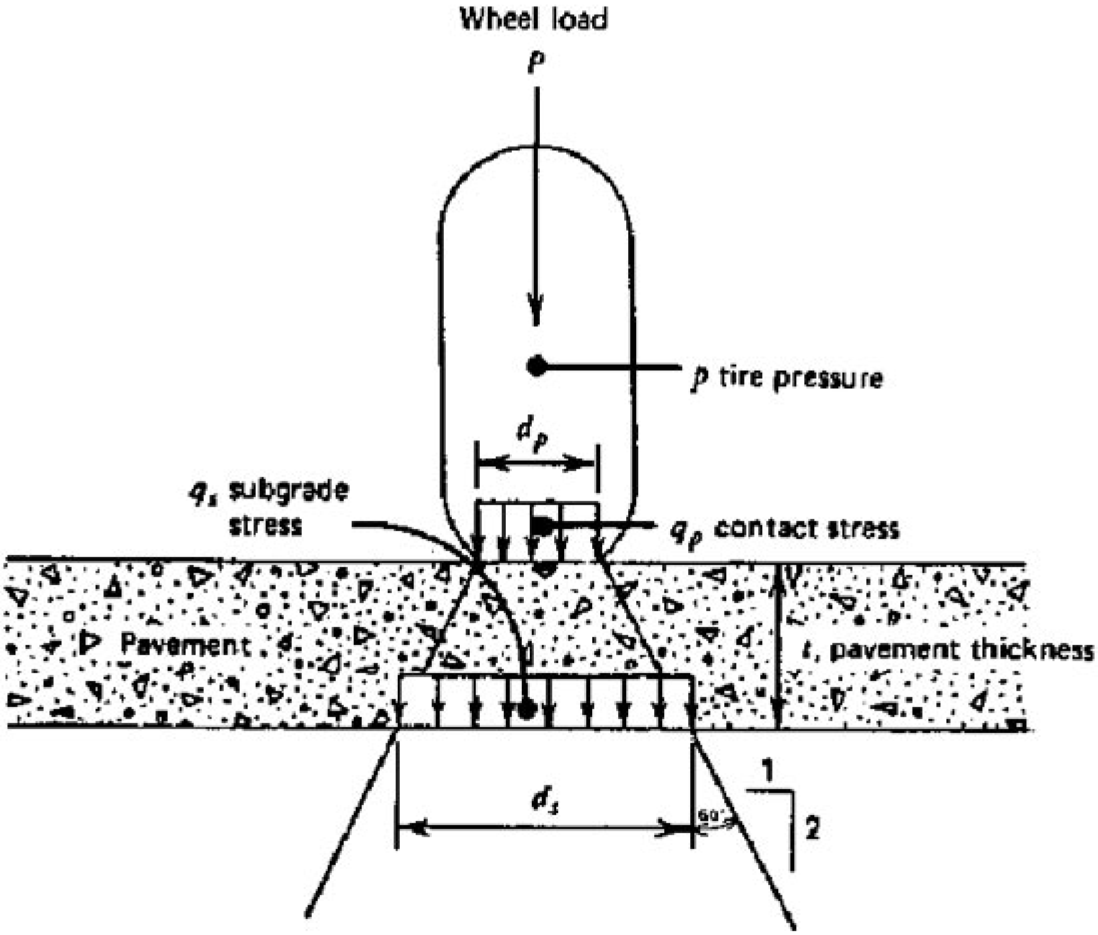



**Figure 2** Definition of term describing wheel load transfer through pavement to subgrade.

| Vehicle | Maximum Axle Load (ton) | Maximum Wheel Load (ton) | Tire Pressure* (bar) |
|---|---|---|---|
| Highway truck, legal, single axle, dual tires | 8 - 9 | 4 - 5 | 4 - 6 |
| Highway truck, maximum, single axle, dual tires | 14 | 7 | 4 - 9 |
| Front loader, light | 13 | 7 | 3.4 - 6 |
| Front loader, heavy | 54 | 27 | 3.4 - 6 |
| Off highway truck, light | 30 | 15 | 3.4 - 6 |

| | | | |
|---|---|---|---|
| Off highway truck, heavy | 39 | 20 | 3.4 - 6 |
| Scraper, light | 14 | 7 | 3.4 - 6 |
| Scraper, medium | 26 | 13 | 3.4 - 6 |
| Scraper, heavy | 43 | 21 | 3.4 - 6 |

* Tire pressures are varied to optimise performance for given loadings and road conditions.

**Table 1** Typical Wheel Loads for Construction Vehicles

The load on top of a road – the static pressure – is distributed to the depth of the embankment and with increasing depth, the loading stress becomes reduced substantially. This distribution is spread into the depth in an angle of 60° for material, which is not well balanced in the sieve curve and in an angle of 90° for well-graded material. Based on this formula, the figure 3 shows you the formula for the calculation of the required loading capacity in the depth, shown in an increased depth by 10 cm to 10 cm steps. It allows a comparable basis check against the real figures of the existing in-situ soil and the available loading factor for this soil or any soil mix based on the in-situ soil. This reduction can also be expressed in the actual requirement of the CBR value in each layer.

With the depth of an embankment, the loading from the top will be reduced to lower figures and consequently also the requirement for a certain strength. This static reduction can be calculated and is shown in figure 3.

Plate area = * ð ; Reduction Factor: $^2$ * ð : $^2$ * ð
Plate r = 15 cm; = surface; = radius in the layer with 10 cm steps

Axle load 20 tons = 15 kg/cm2

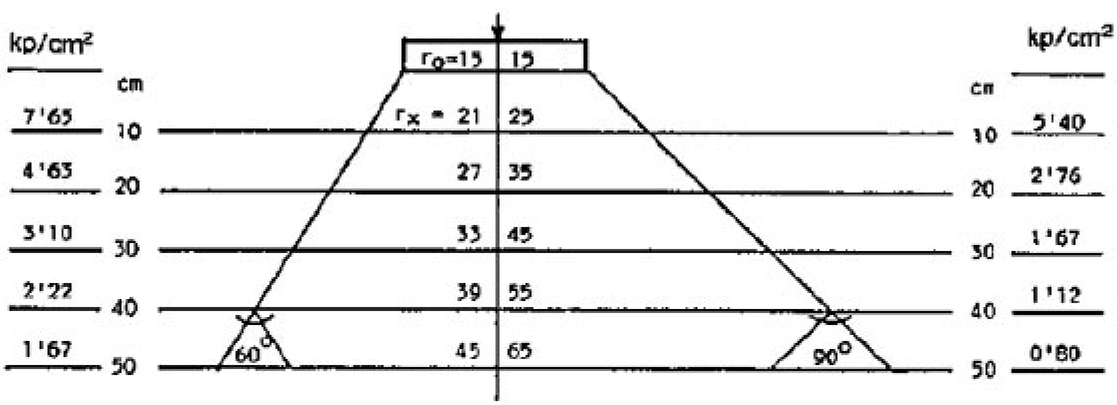



**Figure 3** Distribution of Pressure in the Depth of an Embankment

In this way, any improvement of the soil layers added by the **CONSOLID SYSTEM** can be fully respected in the design. By improving the soil, adding missing fractions, any soil can be upgraded to be material with good compatibility (90°).

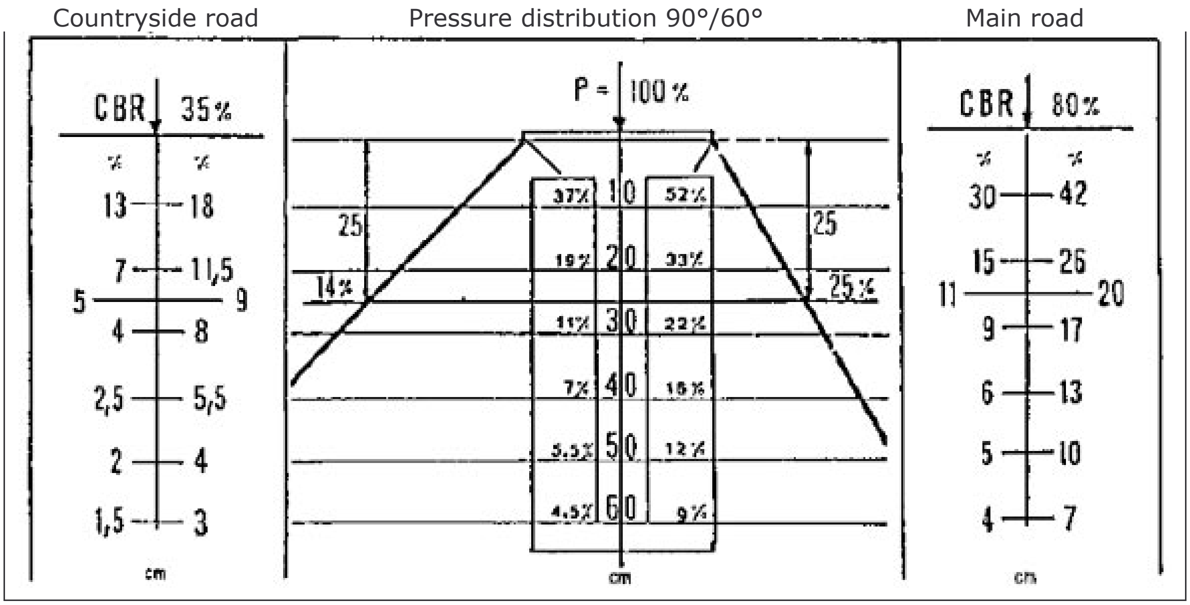



**Figure 4** shoes approximately the required CBR values for deeper soil layers

This formula is used to approximate the required CBR values for deeper soil layers in the base, sub-base, and sub-grade. From the treatment **with the CONSOLID SYSTEM you can expect at least 3 to 5 times the soaked CBR value** of the same, untreated material, but in more than 50% of all cases you will get more than 5 times this CBR value.

**Important is that this improvement can easily be shown and corrected in the laboratory before you start any field application – you can be sure that you get what you want.**

Besides the static stress, the dynamic stress to the road must also be fully respected, but this is another issue.

**2.1 SUBGRADE IMPROVEMENT (STANDARD)**

If pavement analysis shows that the pavement is not suitable, two options are available**.** The first is to use a thicker pavement, and the second is to improve or strengthen the sub-grade. Sub-grade improvement can be accomplished by compaction or by chemical stabilisation.

For cohesiveness sands, the angle of internal friction can be related approximately to the relative density. As a result of compaction, we obtain an angle of internal friction increase from about 30° to about 37°. One can see that the bearing is more than doubled. Obviously, compaction has a beneficial effect on sub-grade strength.

Mixing with chemicals may increase the cohesive strength of some fine soils, and cohesion may be developed in sands and gravels by the addition of cement or lime.

**2.2 SUBGRADE IMPROVEMENT with the CONSOLID SYSTEM**

The **CONSOLID SYSTEM** deals in most cases with the in-situ soil in the sub-grade and up-grades this soil with the treatment so that it can be used in the sub-base as well as in the base course to prevent borrowed material as far as possible.

To replace borrowed material with **CONSOLID** treated in-situ soil is possible because the treatment **changes the soil behavior** dramatically towards much higher loading capacities. The **CONSOLID SYSTEM keeps the softening effect of water out of the**

**treated soil.** The plate bearing pressure (CBR or any other measurement referring to the loading factor) in-creases substantially up to 3 to 5 times to that of the untreated soil. In more than 50% of applications, the loading factor increases more than 5 times. This fact makes it possible to substitute such borrowed material with the treated in-situ soil or to reduce the use of borrowed material substantially.

The road design is not changed. What you change is the behavior of the in-situ soil so that you can use much more or the entirely in-situ soil for the single layers. This saves you soil exchange, transportation and disposal costs.

It depends on the quality of the in-situ soil if it is necessary to add clayey fines to too sandy soils or cut down the plasticity and shrinkage/swelling in clays by adding sand or coarse material. **The smoother the sieve curve, without gaps or missing fractions, is the better the starting conditions for the CONSOLID SYSTEM**. It costs the same to treat a soil with poor composition as an improved one, but you obtain a much better effect with an adjusted soil.

**Increase of soaked CBR in %**

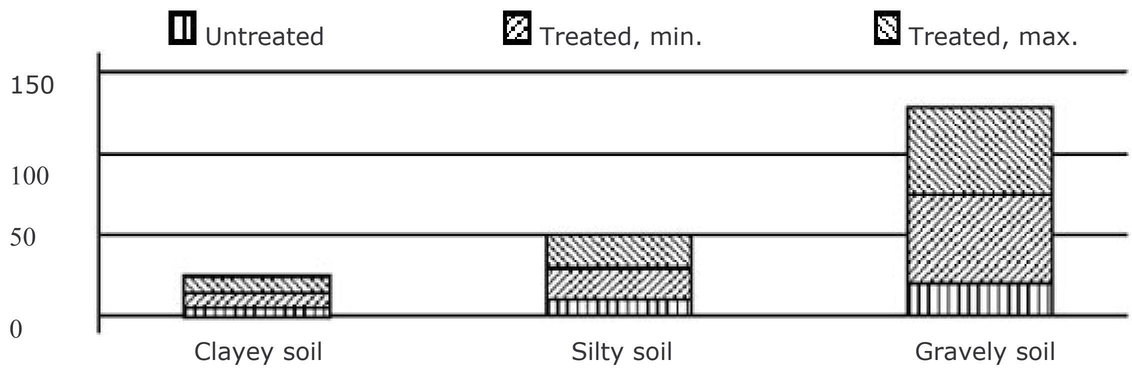



**Figure 5** Adding missing fractions makes the soil mix mechanically more stable

Figure 5 shows the improvement by adding missing fractions to make the soil mix mechanically more stable and gives with the CONSOLID SYSTEM much better results. Thus, the in-situ soil can be used in most cases entirely or in larger parts in all layers of the embankment.

The improvement of the soil composition is an economical step towards increasing the value of a road construction and should be considered in every single case. Due to the fact that the CONSOLID SYSTEM keeps the water out of the treated layers, the road base course and sub-base will be no longer be destroyed by water.

It is easy to determine the proper soil composition because the **simple and informative tests** in a soil laboratory indicate very accurately what is recommendable in respect of the improvement of the soil composition as well as the proper treatment with the CONSOLID SYSTEM. **In this way, any soil parameter can be tailored to the requirement** (density, compressive strength, CBR, water resistance, etc. etc.). **You will obtain exactly the same good results on the site.**

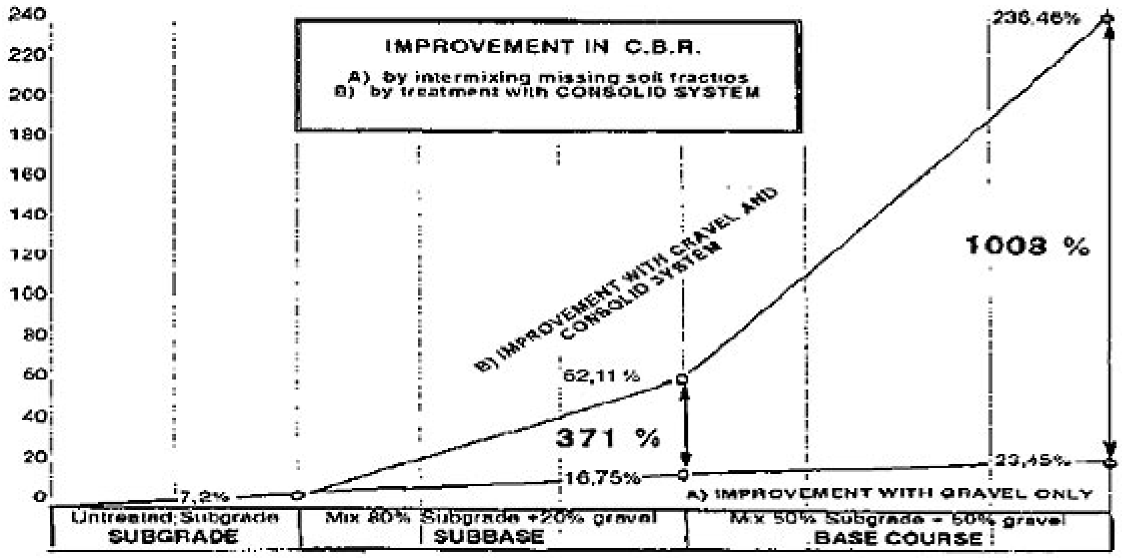
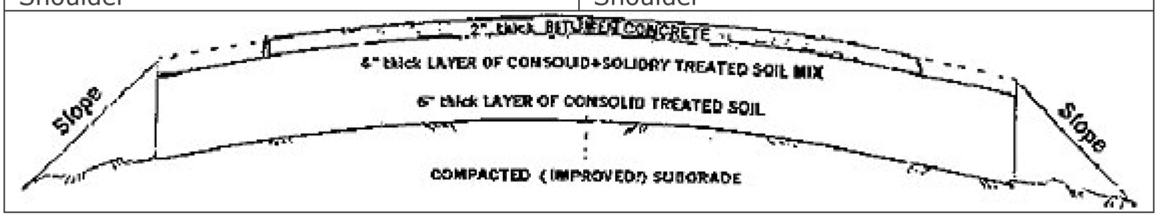



**Figure 6** shows the improvement of CBR constructed without and with the CONSOLID SYSTEM

The following graphic figure 7 is a design which respects the above mentioned facts and shows that in-situ soils in the range up to CBR 25% are suitable to be improved in their CBR value up to 100%+ if properly treated with the **CONSOLID SYSTEM**.

| Shoulder | Shoulder |
|---|---|




2 – 5 cm thick layer of asphalt concrete
10 cm thick layer of soil mix treated with CONSOLID + SOLIDRY (2/3)
15 cm thick layer of CONSOLID + SOLIDRY (1/3) treated soil
COMPACTED and IMPROVED SUBGRADE, where necessary

**Figure 7** shows a cross section of a road constructed with the CONSOLID SYSTEM

The best specification for earthwork for treatment with the **CONSOLID SYSTEM** is for:

| Type "A" | | Type "B" | |
|---|---|---|---|
| Clayey soil (0 – 0.2 mm min. 15% <0.006 | 25-35% | Clayey soil | 50-75% |
| Sands (0.2 – 2 mm) | 30-40% | Sands | 25-50% |
| Gravel (2 – 200 mm) | 25-45% | | |

SUBGRADE: in-situ cohesive soil or sand compacted to min. 98% mod. AASHTO

| CBR 35% + for country roads required for each layer: | CBR 80% + for main roads required for each layer: |
|---|---|

| untreated | before treated | | untreated | before treated |
|---|---|---|---|---|
| | | 2-5 cm wearing course | | |
| CBR 35 | CBR 10 | 10 cm base course | CBR 80 | CBR 25 |
| CBR 15 | CBR 5 | 15 cm sub-base | CBR 35 | CBR 10 |
| CBR 10 | CBR 3 | sub-grade | CBR 15 | CBR 5 |

**Table 2** These low CBR values are required for the single layers before the CONSOLID treatment.

CONCLUSION: **Any road design method can be used.** There is no need to change the design, only the material. In-situ soils properly treated with CONSOLID SYSTEM can replace borrowed material without any risk. But be aware that soil is never a uniform construction material and requires on the site a fast adaptation to the changing soil compositions. How-ever, even this is much easier if the CONSOLID SYSTEM is used for the upgrading of the conditions in an embankment. The simple laboratory soil test shows you when upgrading is needed.

**3. Pavement Structure and Base**

Pavements have usually an asphalt mixtures or concrete layers surface. However, the preparation for surfacing involves the construction of the sub-grade, sub-base base course. The design of these components depends on the materials used and the conditions which the pavement must meet.

**3.1 Pavement Design**

The function of the pavement structure is to distribute imposed wheel loads over a large area of the natural soil. If vehicles were to travel on the natural soil itself, shear failures would occur in the wheel path in most soils and ruts would form. The shear strength of the soil is usually not high enough to support the load. In addition to its load distribution function, the surface course of a highway or airport pavement structure must provide a level to a safe travel-ling surface.

Pavements are classified as "rigid" or "flexible", depending on how they distribute surface loads (Figure 8). Rigid pavements are surfaced by concrete slabs. These act as beams, and distribute the wheel loads fairly uniformly over the area of the slab. Flexible pavements, which include asphalt concrete, stabilised or bound granular material, or granular material only, distribute the load over a cone-shaped area under the wheel, reducing the imposed unit stresses as depth increases. The rate of stress reduction varies with the properties of the layers, and is difficult to estimate accurately.

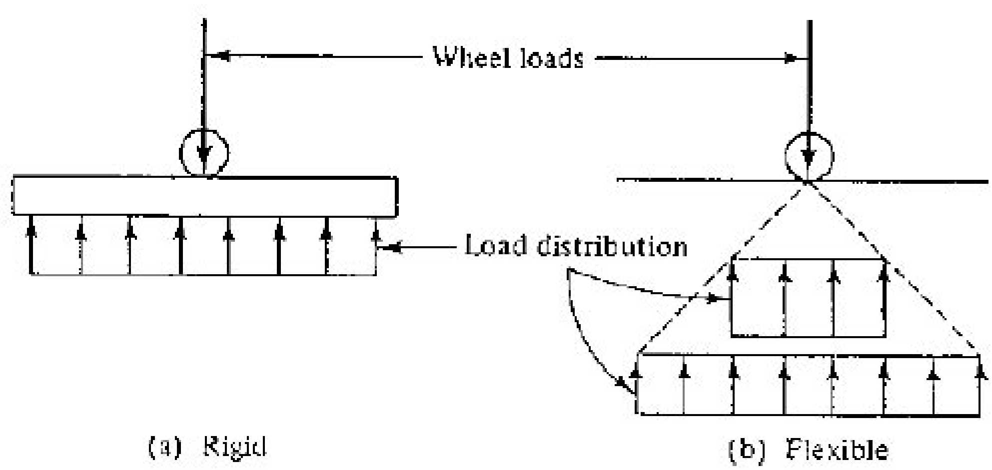



**Figure 8** Types of surface pavement.

Major components of a pavement structure are:
1. Surface .
2. Base . Pavement
3. Sub-base .
4. Compacted sub-grade
5. Natural sub-grade

**3.2 Typical pavement structures**

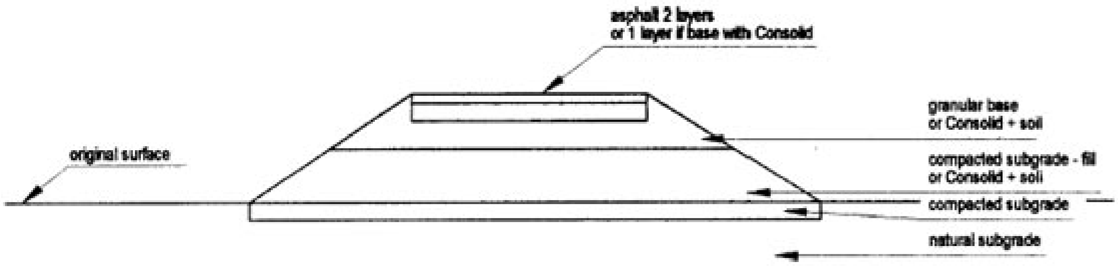



**Figure 9a** Typical structure for a flat area

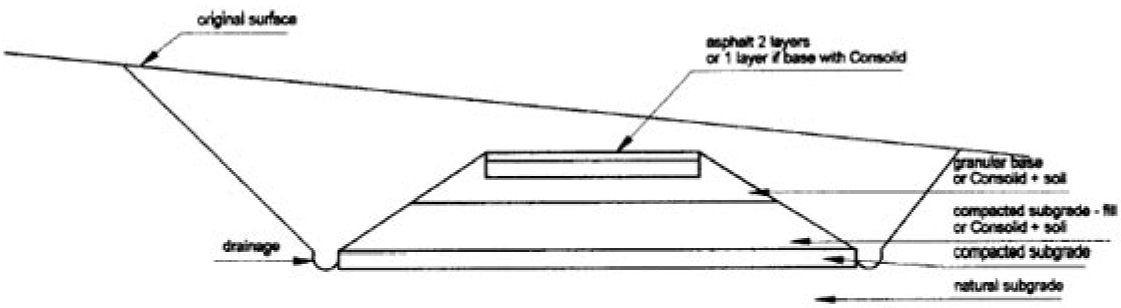



**Figure 9b** Typical structure for a hilly area – cut section

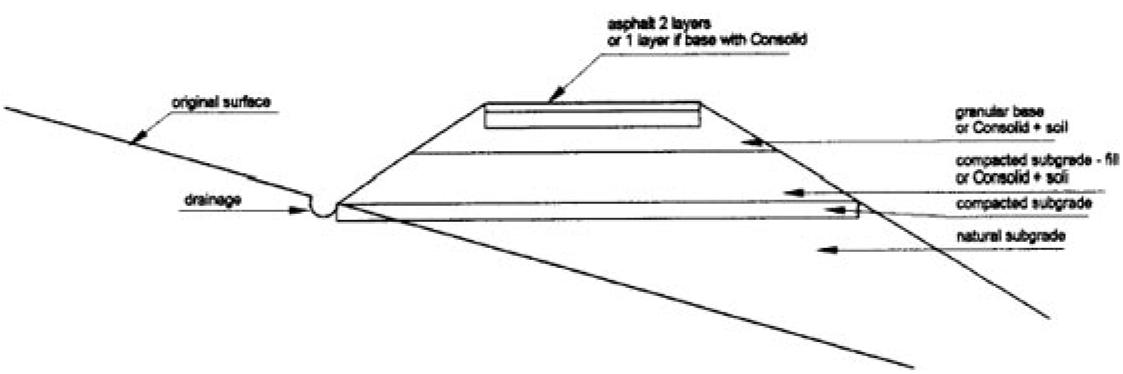



**Figure 9c** Typical structure for a hilly area – fill section

Bases and sub-bases are usually granular material or aggregates. The sub-base, which is lower in the structure, does not require such high-quality material as the base, then loads are reduced considerably. **With the CONSOLID SYSTEM, you use the in in-situ soil.**

The main function of the pavement is to reduce the high unit stresses imposed by vehicles on the surface to stresses on the sub-grade that are low enough to be carried without failure due to rutting, excessive settlement, or other types of distress. The magnitude of the stress reduction is mainly a function of the thickness of the pavement structure. Therefore, the main variable in the design of the pavement structure is the thickness. The major factors involved in design of the pavement thickness are:

1. The magnitude of imposed loads
2. The strength of the sub-grade soil

Many different methods of measuring the imposed load, the sub-grade strength values, and the required pavement structure have been suggested and used. Among pavement design organisations, there is little agreement on the test method. The problem is complex. Wheel loads vary from light passenger cars to heavy transports with dual tandem wheel configurations. Load applications vary from a few thousand to millions per year. Pavements may be designed to last for various lengths of time. Economics must be considered, whether it is more economical to construct lower-strength pavements and reinforce them frequently, or to construct relatively maintenance-free highways at high original costs. Soils may vary considerably along a proposed highway route, but the pavement structure can not be changed continually because of the construction problems that would result. **Such variations of soils are much easier to handle if you use the CONSOLID SYSTEM.**

Many authorities involved with specifications for pavement structures have standardised their designs, based on their experience with structures that have performed adequately in the past. For example, a City design standard might be:

| | | |
|---|---|---|
| Arterial roads | 75-mm | asphalt concrete |
| | 150-mm | granular base |
| Local roads | 40-mm | asphalt concrete |
| | 150-mm | granular base |
| | 150-mm | granular sub-base |
| Rural roads | 150-mm | granular base with an asphalt seal coat |
| | 150-mm | granular sub-base |

**With the CONSOLID SYSTEM** you will need for the above roads an asphalt layer or a bitumen coat with crushed stones of about 10 mm in diameter and 250 mm base and sub-base layers treated with the CONSOLID SYSTEM.

These are typical examples only. Actual design standards vary considerably, depending on the types of material locally available and the experience the design department has had with maintenance and failure of local roads. **The CONSOLID SYSTEM can handle almost all kind of soils and the prospected result is shown in the lab tests before the road is built.**

However, many larger pavement design organisations – such as state and provincial highway departments, airport construction agencies, military construction departments, and associations representing engineers or manufacturers of paving materials – have suggested thickness design formulas so that the pavement structure may be more closely related to the type of load to be imposed and the quality of the sub-grade.

There are numerous methods of measuring the imposed load-AADT (average annual daily traffic), maximum wheel loads allowed, number of trucks and buses using roads, EWL (equivalent wheel loads), DTN (design traffic number, the average daily number of equivalent 80 tons [80 kN] single axle loads), and others.

Methods used to measure soil quality include those based on soil classification, soil index properties, and soil strength tests of various types.

**The CONSOLID SYSTEM allows you to test the in-situ soil and compare the result with other tests.**

### 3.3 Drainage

The big enemy of every road is the water. Through the capillaries water soaks in to the road and the road swells. Through the pressure and vibration of the vehicles, the soil becomes plastic. In areas subject to freezing temperatures, the moisture in the soil forms ice lenses.

Another problem is the surface water running along the road, the water over the road down-hill and the erosion of the shoulders along the road. First, the surface water washes the fines away and afterwards the sand acts as a grinder to the soil particles. The water increasingly flushes the soil away until the road is heavily eroded. The same occurs with dusting under dry conditions.

There is a constant fight against the influence of water, because water softens soil and makes it plastic. The incorporation of water in cohesive soils is always related to a more or less remarkable swelling effect, which destroys the density and therefore the compressive strength.

To respect the importance of water in an embankment, it has to be considered that for different reasons, caused by moisture contents in the embankment of a road, it tends to concentrate in the middle under a hard surface. The highest moisture contents is just there where it causes the greatest problems, and only by preventing the capillary rise of water and the soaking-in of surface water, by reducing the permeability of soils, this problem could be solved or remarkably reduced with the **CONSOLID SYSTEM**.

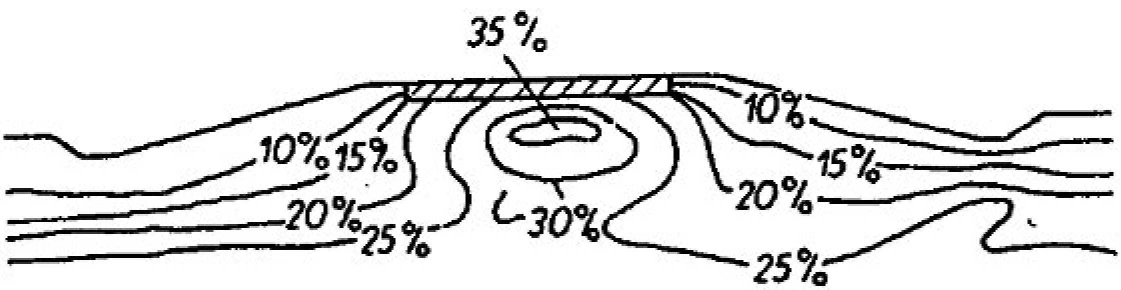



**Figure 10** The moisture tends to concentrate in the middle under a hard surface.

The surface water must be drained away from every road. In flat areas, the water flows into the surrounding land. The flow rate is not high, but it may stay aside of the road and soften the base and sub-base. The road must be higher than the surrounding land and a ditch has to carry the water away from the In hilly areas, the flow speed is high. We must deal not only with the surface water of the road, but also with the water from downhill (figure 9a – 9c). On the uphill side, the water washes the soil away and may under wash the road. On the downhill side, the flushing water from the hillside flows over the road and washes the rim away. There-fore, we need a ditch on both sides of the road to drain the water away to a point required without damages. Drainage under the road is needed all the way from the uphill side to the downhill side. The downhill side where the water flows out must be well prepared to prevent the slope from washing out.

Frost damage to pavement is another serious cause of pavement structure failure in climates subject to freezing conditions. The common occurrence in roads, known as "spring break-up", is caused mainly by frost action in susceptible soils.

Capillary rise in soils is a major factor in frost damage. Water rises in capillary tubes above the water table by a distance that varies inversely with the average size of the pores in the soil structure.

As a freezing front descends in the soil during the fall and winter, the water in the larger pores freezes. However, the capillary water in adjacent, smaller pores does not freeze, due to the depression of the freezing temperature in these very small volumes of water. This super-cooled water moves to the previously formed ice crystals and freezes on the crystal. If the capillary water is replaced while the freezing front remains stationary, an ice lens builds up in the soil. Under conditions favorable to lens development, the ice lens – consisting mainly of excess water brought up from the groundwater table – may grow to 5 to 10 cm or more in thickness. As the freezing front penetrates farther into the soil, more ice lenses are formed and cause a heave in the road surface. Soil heaves of more than 30 cm have occurred. Vertical cuts in these heave areas reveal a series of ice lenses made up of relatively clear ice, with the total thickness equaling the amount of heave.

During thawing of a heaved soil, pavement break-up may occur, as illustrated in Figure 11. «Frost boils» or wet potholes are formed on the surface as the roadbed thaws due to the excess water and loose condition of the roadbed.

The source of free water is usually groundwater, although seepage from higher areas may soak in.

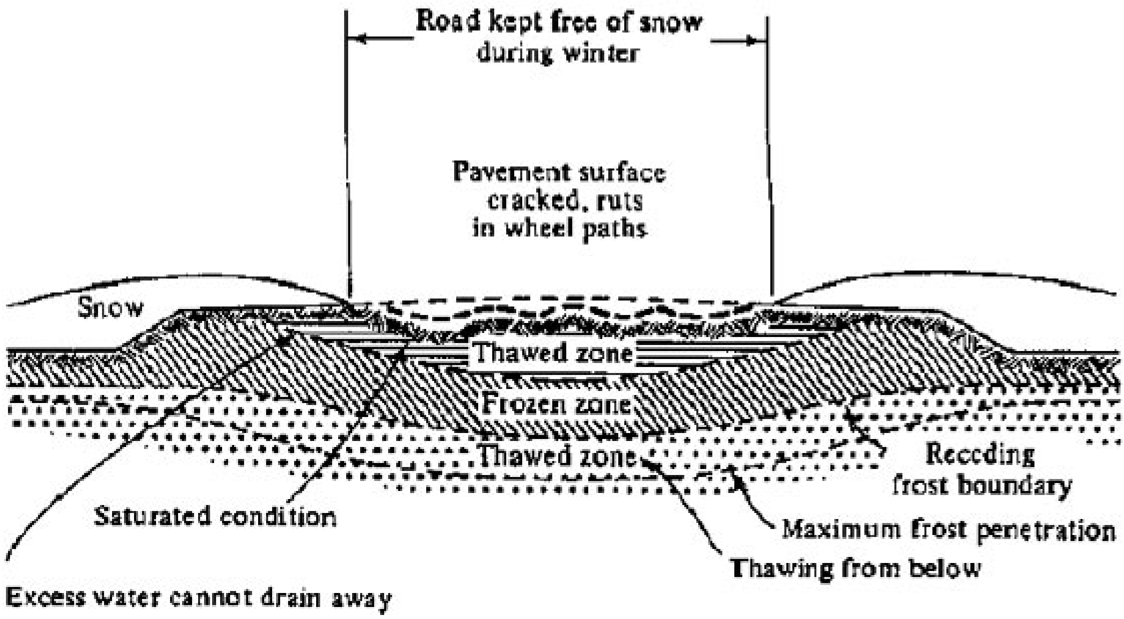



**Figure 11** Typical road surface damaged by water and ice

Frost damages caused by the sensitivity of the soil can be fully controlled because the CON-SOLID SYSTEM allows to reduce the capillary rise of water as well as the seepage of surface water into the soil close to zero. **Soil treated with the CONSOLID SYSTEM becomes impermeable and avoids seepage.**

The potential for frost action is substantially reduced if an in-situ soil is properly treated with the CONSOLID SYSTEM. If the water presence is reduced **the frost problem is sharply reduced or does even not exist any more**. Practical experiences in the last 20 years in areas exposed to heavy and deep frost, like the Alps, the Midwest of the USA or Canada, have con-firmed that otherwise frost-susceptible soils are absolutely unharmed by frost.

In conventional construction the base course as well as the sub-base is built as well draining layers, where water can go through easily. Here too many fines would block the drainage and cause friction, swelling, and frost damages. **Completely different are the aims of the CON-SOLID SYSTEM** – we fill the voids in the base and sub-base with as much fines as possible to get a very dense packing and the desired impermeability to preserve the dry shear strength as far as possible and make it a design factor.

Pavement pumping (vertical movement) can be caused by saturated base and sub-base as well as sub-grade layers, which are even possibly built first with granular material layers. Already during construction (rolling) the construction material degradation starts and continues under traffic. Soil layers even with high contents of fines will never start pumping as a form of plasticity when the moisture content is kept stable at a low level under the OMC. The treated soil becomes increasingly a mineral concrete with the CONSOLID SYSTEM. **Water can no longer penetrate.**

**4. Conclusion**

It is necessary to be aware of the fact that there is a great difference between theories and the practice of realising a project on the site. This makes it so eminently important that any action in altering a conventional design method must be fully reliable. When dealing with soils you deal only on the surface with the "cheap" in-situ material, which, if inappropriately used, turns out very fast to be the most expensive factor in a failing road construction. The CON-SOLID SYSTEM can reduce this problem substantially due to the fact that it enables a dramatically improvement of a treated soil without being too dependent upon to a uniform soil material. It will work under nearly all circumstances, also with changing soil compositions, and in most cases with the same quantities of additives, as long as the sieve curve of the in-situ soils is more or less in balance. **We have never learnt of a complete failure of an application, even if the products were not used very accurately.**

The **CONSOLID SYSTEM** reduces the demand for heavy wearing courses as the treated soil can adopt the "bridging" task, which otherwise has to be taken over by heavy wearing course layers. The in-situ soil is always the weak link in an embankment and keeps changing its performance under the changing conditions of the weather as well as the traffic. Take in consideration that any road design is overtaken by more and heavier traffic over time than that respected in the design. **Any improvements of the soil layers with the CONSOLID SYS-TEM is permanent**, increases over time and yields a valuable contribution to a better performance and durability of a road.

Portland cement is a binder used for soil stabilisation. But cement is sensitive to organic mat-ter in the soil and restricted to certain sandy/coarse kinds of soil. The effect is poor due to the fact that the soil cement mix leads to a kind of soil concrete, but it is no quality concrete; it is a weak, rigidly bound mass which easily cracks under the dynamic forces of the traffic, lead-ing to floating slabs. Once broken, it will not bind again.

One fact, which presents an enormous difference to any other method of soil stabilisation, has not been mentioned so far: The **CONSOLID SYSTEM** allows not only to treat any in-situ soil "in place", **it is also possible to treat any soil mix "in plant".** The treated material can be stockpiled without timely limits and used from stock at any time without loss of effective-ness. The only action required is to bring the pre-mixed soil material close to the OMC before compaction. In this way it becomes possible to prepare always the same soil mix with known characteristics and use the time for premixing when construction work in the field is not possible (during rainy, moist seasons).

**Source:**

Publications of CONSOLID AG, Switzerland

Highway Materials, Soils, and Concretes, 3rd Edition, by Harold N. Atkins, PE, published by Prentier-Hall, Columbus, Ohio, USA (Prentier-Hall l'natl., (UK) Ltd., London; ISBN 0-13-2128624 (a book we highly recommend to add to your technical library).