SAPIENZA
UNIVERSITÀ DI ROMA

STONE ROAD PAVEMENTS

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Reference

Preface

First of all, I would like to thank Professor Paola Di Mascio for suggesting me the topic of this thesis and for guiding me in writing it.

This work treats stone pavements that are representative of many of roads in the historical downtown of Italian cities. The focus of the study is on current techniques used for pavements considering also what has been used in the past, particularly during the Roman period.

A summary description of function of the pavement along with a list of the main types is presented; afterwards a description of stone pavements used during Roman times have been carried out, reporting some details on the main roads.

After some sketches of lithology, various types of pavements (cobblestones, tile stone, flag stone) are described in detailed with a brief description of sidewalks; this part represents the core of the work. Various type of road drainage systems is presented before treating in detail stone materials and their mechanical properties (i.e. compressive strength, hardness, mass density).

Finally, a project example has been considered; the design methods which have been focused on in this work, are empirical (Design guidance for lightly trafficked roads from I.D. Cook and J. Knapton and the AASHTO method).

Fig. 1.1. Generic road

1. ROAD PAVEMENTS

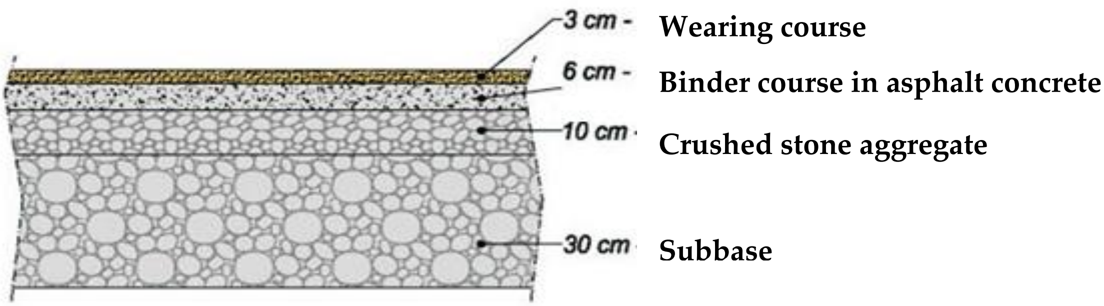


Fig. 1.2 Scheme of pavement for minor road

We begin our thesis making a sort of introduction and then giving a general definition of pavement. Later we will discuss the various types: flexible, rigid and semi-rigid.

1.1. Definition

The road pavement is the structure that separates the tires of the vehicles from the subgrade, which is the upper layer of the soil in the embankment or in the trench that makes up the road. It can be also the concrete or a steel bridge deck, or still the tunnel invert.

A pavement is formed by a succession of layers consisting of materials of different physical and mechanical characteristics, chosen according to the function that fulfill these layers within the structure and depending on the prevailing type of stress to which they are subject by traffic loads.

Such a composition is derived from economic considerations: each layer is constituted by the most suitable material to respond to the stresses induced by traffic, that decreases from the top downwards.

The reduction of the stresses with the depth depends on the stiffness and thickness of each layer.

In general the pavements perform three different tasks:

• to reduce tensions transmitted to the subgrade at a level compatible with its load-bearing capacity so that the soil does not undergo excessive deformation;

- to form a stable, durable and little deformable structure able to withstand the repeated loads applied by vehicles and such as to ensure an adequate driving comfort;
- to ensure the safety of traffic in relation to the skid resistance in the presence of contaminants (water, mud, snow, ice, rubber deposits).

1.2. Types of pavements

Upon variation of the materials used and of the order with which they are arranged in structure, we can distinguish the following types of pavements:

1.2.1. Flexible pavements

It mainly consists of the following layers:

- surface course in bituminous concrete consisting of two layers: the wearing course and the binder;
- base course made of asphalt concrete, or of crushed stone , crushed slag, or other untreated or stabilized materials;
- subbase in granular materials or recycled materials;
- subgrade

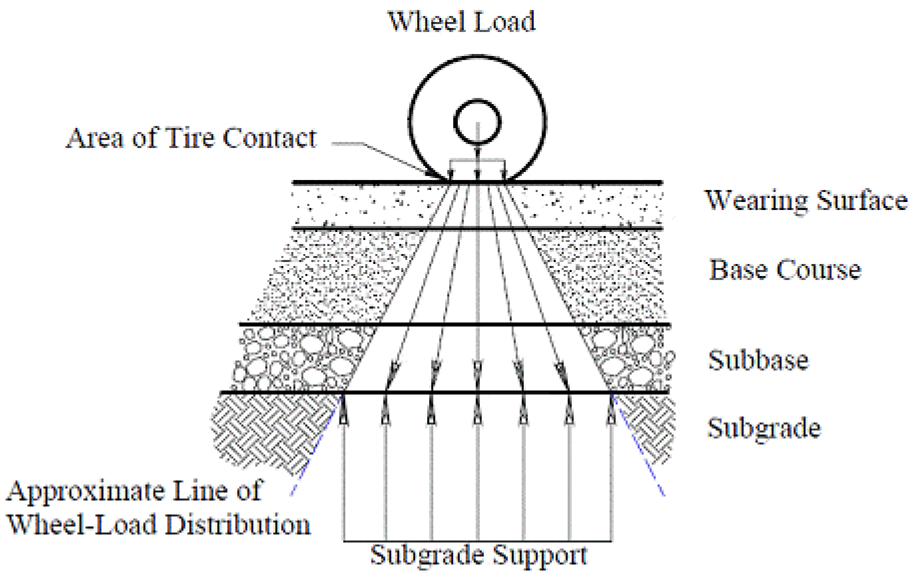


Fig. 1.3. Scheme of a flexible pavement

1.2.2. Semi-rigid pavements

Constituted by a succession of layers similar to that of the flexible pavements, but the base layer is bonded with cement (cemented aggregate).

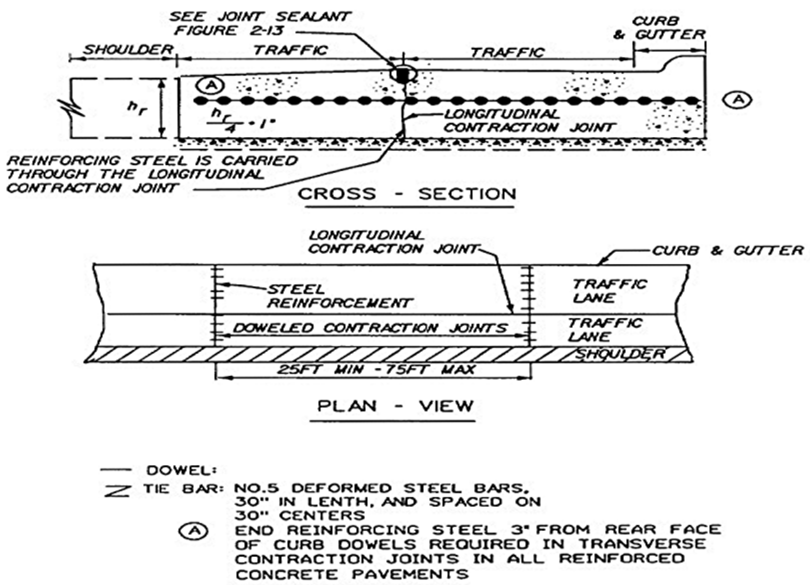


Fig. 1.4. Scheme of a semi-rigid pavement

1.2.3. Rigid pavements

A rigid pavement is constructed from cement concrete or reinforced concrete slabs. Grouted concrete roads are in the category of semi-rigid pavements. The design of rigid pavement is based on providing a structural cement concrete slab of sufficient strength to resists the loads from traffic. The rigid pavement has rigidity and high modulus of elasticity to distribute the load over a relatively wide area of soil.

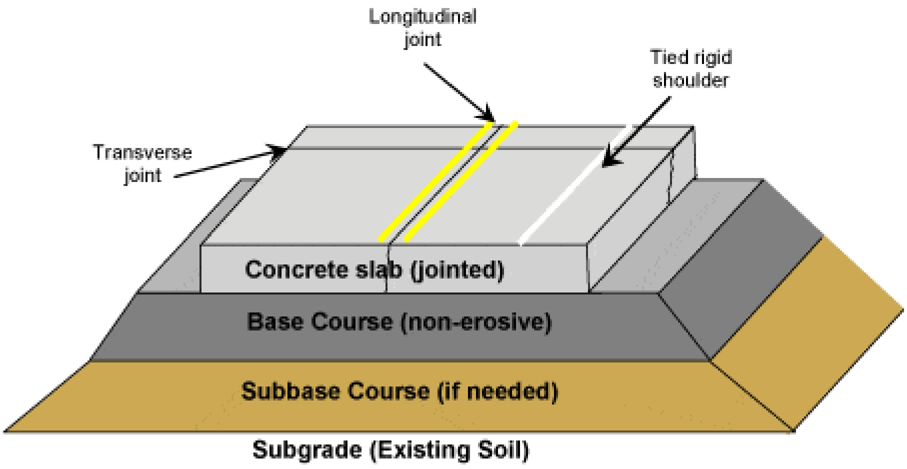


Fig. 1.5. Scheme of a rigid pavement

1.2.4. Composite pavements

Constituted by a rigid pavement covered with a layer in bituminous conglomerate.

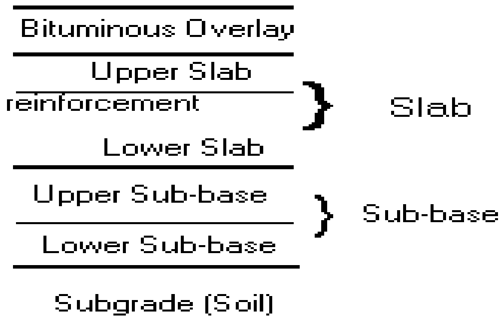


Fig. 1.6. Scheme of a composite pavement

1.2.5. Modular pavements

Constituted by natural or artificial stone elements (brick, concrete, etc.) resting on a bed of sand or cement mortar, a base layer and a subbase.

This work deals with the modular pavements and in particular with natural stone pavements.

2. ROMAN ROADS

Fig. 2.1. Roman road

It seems appropriate to spend a few lines on the topic about those routes which are still used today, because these roads are almost entirely made of stone (Appia Antica or Aurelia Antica).

2.1. History

Legend attributes to Heracles the paternity of the first major communication route, from the Guadalquivir delta to southern Italy. By leading, from the far west, the sacred cows of Geryon, he would be stopped to rest in the place where Rome would be founded later and from there he continued his journey to south. The route of the "Via Eraclea", mythical transposition of ancient streets of commerce and transhumance, will be taken up in historical times by Roman roads (via Augusta, via Domitia, Via Aurelia, Via Labicana or via Latina). The paths survival is a constant in almost the entire Mediterranean basin.

During the Republic, Rome began to structure and organize a road network of largely frequented routes: just think of the famous Via Appia, which in its initial section connected Rome to Alba Longa before the road reconstruction by the censor Appio Claudio in 312 BC.

Some of the most famous streets in the Italian peninsula date back the III-II century BC: the Via Flaminia from Rome to Rimini (between 223 and 219 BC), the Via Emilia (187 BC) backbone of communications in northern Italy, the via Postumia (148 BC) from Genoa to Aquileia, the via Aurelia along the Tyrrhenian coast (between 241 and 109 BC), whose upper section took the name of via Emilia Scauri, from the name of the consul who had commissioned in 115 BC.

Gradually, the road network extends to the provinces: thus the way Domitia in Narbonne Gaul (118 BC) or the Via Egnatia in the Balkans (146

BC). By definition isolated from the road network on the continent, a road was built on the east coast of Corsica, at the end of the Republic, around 50 BC.

The impressive road network of over 120000 km. will end with the extension to the Mediterranean basin and much of Europe and will be renewed and boosted during the empire. For Augustus initiative will build the Via Giulia Augusta, which from Tortona, in Liguria, reached Narbonne, instead through the mountain passes of the Great and Little St. Bernard it will conduct the so-called Via delle Gallie.

Fig. 2.2. Typical roman road

The interest in a properly functioning system of communication, in Italy and in the provinces, is deeply felt by all subsequent emperors, until the late Empire and Justinian.

2.2. Street names

The names of the oldest streets remind the trade of essential products (Via Salaria), or peoples, places and cities of ancient origin (via Latina, Via Nomentana, Via Tiburtina,); afterwards they take the magistrate's name - usually a consul or a censor - who takes care of the construction, such as C. Flaminio, C. Domitius Ahenobarbus, Egnatius G. and S. Postumius Albino, who call respectively the Via Flaminia, the Via Domitia, the Via Egnatia, the via Postumia.

During the empire, they will be precisely the emperors to tie their memory even the streets as the Via Severiana, the Via Erculea and Via Augusta, for example built for initiative of Septimius Severus, Maximian Eracleo and Augustus.

The roads also gave the names to the door of a city where they came.

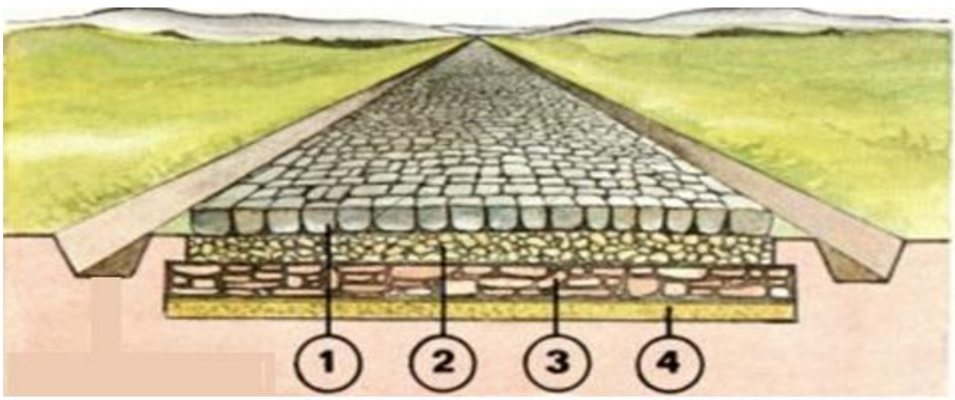


Fig. 2.3. Scheme of a roman road

2.3. The Roman road construction

Contrary to what one would have expected, no information is available about the existence in technical literature of Romans road engineering.

This deprives us of the opportunity to know directly not only the multiple aspects of the technical details of the road construction, but also the complex of the "system" tested and refined over the course of seven/eight centuries of practical implementation by which the Roman engineers faced the arduous task of building roads. More concretely, it prevents us to know in depth the ways in which they proceeded in the various field operations, from preliminary surveys to delineating, by the construction of embankments to the pavement; not to mention the organization of work, the tools and the technical means, the subdivisions of skills and specializations, testing etc.
Most of our knowledge of Roman road engineering is derived from the study of what it is available, which is abundant; it seems that there is the presence of certain constants; it is worthwhile to mention those of the straight line, the path detected and the altitude, which must be indicated. The feature of the straight line derived by the absolute priority given to more rapid achievement of "headline." This of course prevented the deviations for the connection of the intermediate urban centers and then forced to the frequent construction of side streets or siding. The tendency of the straight lead to the need for overcoming many natural obstacles and face very steep slopes. As to the detected path (that is, at an artificially higher level than that of the surrounding ground), it was dictated by safety requirements, considering both the danger associated to ambushes and the danger caused by natural phenomena.

On roads detected, it was in fact easier to control with good visibility a fairly large territory and avoid ambushes or surprise attacks, even if only by robbers and bandits. On the other hand it was equally easy (even for the purpose of regular maintenance) to avoid or at least limit the damage in case of flooding or heavy rains because the water, in this case, could more easily flow out to the sides of the roadway. Always to security, the other feature of the stay at altitude needs answered: it was to avoid as much as possible the valley floor, the depressions and hollows, if necessary with the use of long detours and even to sudden interruptions of straights and direction changes. It is clear that, in order to respect these characteristics, the builders had to face several problems and overcome a lot with the implementation of "arts" of various types such as embankments, bridges, tunnels: they are examples of the Carmona bridge (Via Augusta), the Julien (via Domitia), Highland (via Iulia Augusta), Narni (via Flaminia).

A special case is the bridge-aqueduct said Pondel (Via dei Passi), imposing private work that revolves in a major transalpine transport corridor.

But we must remember that the Romans resorted to these works only when it was absolutely necessary or when their implementation could allow, with the overcoming of an obstacle for itself also preventable, a more rational and rapid development of the entire project.

Although it is impossible to try to outline a unique model for the construction of Roman roads, given the infinite dependent variables also from the construction area, we can see in every street three basic technical elements: a basic ballast, an intermediate "elastic" core and an outer coating.

The work procedure is described in principle afterwards.

The roadbed was a deep layer, from 30 to 60 cm, called statumen: it consists of large flakes of hard stone and eventually topped by another 25-30 cm layer (Rudus or ruderatio) made of smaller stones and kept compact with lime and pozzolana. The intermediate core or nucleus was a layer of sand and crushed stone (or gravel and pot shards and rubble), level with a specific keystroke and passage of heavy rollers. For the outer coating, called agger or pavimentum, the most characteristic and universally known was realized with the use of large stone slabs made through polygonal paving stones (silica or limestone, depending on the availability of the place) sunk in a sand bed and well connected to each other, also with the aid of smaller stones (or "wedges") inserted as a link in wider commissures.

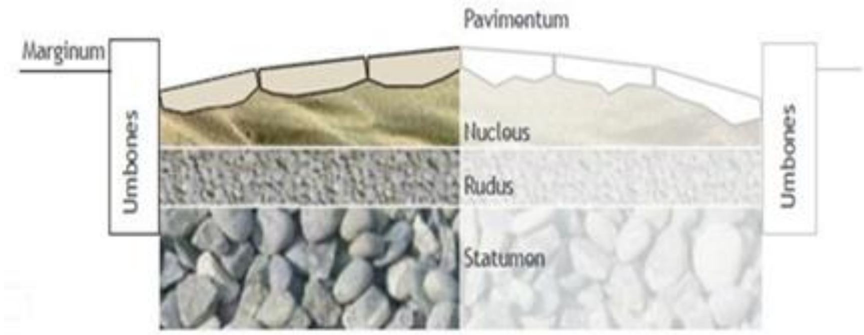


Fig. 2.4. Viae lapidibus stratae

These paving stones were mainly composed of leucitites, which are a group of effusive rocks essentially composed of leucite and clinopyroxene.

Large stones (umbones) were put vertically in the soil, marking off the sidewalks to contain the pavement. Stone blocks called “gomphis” were wedged at regular distances along the roadsides, to ease the riders’ remounting into the saddle without aid. The track width of Roman roads was normally arc curved, that is, dual slope built, with the highest point in the center and slopes toward the two sides. This is to prevent the stagnation of rain water and to ease its flow towards the ditches of laterally open drain, at a certain distance. The same track width was defined, and at the same time clamped on both sides by a border (umbo) or cord of stones embedded vertically in the ground and protruded upward and often flanked by pavements; it was not uncommon that, in the sides of the paved roads, there were side tracks reserved for riders, pedestrians and animals.

Concerning the execution of the work, this was usually carried out by the army; Via Appia, for example, at least in part, follows a route that indicates the path of legions returning from the first Samnite war.

The progressive distances, generally from Rome, were reported in miles (1,000 steps) on stone columns, which became known as milestones; in addition to that political messages have been proclaimed. These are usually dedications to the emperors as a demonstration of loyalty towards the sovereign.

Every 7-12 miles some stations (stationes) and the guard posts destination for couriers and postal services were, which were often accompanied by mutationes, buildings reserved to change horses.

After around one day of travel, there were real small towns called mansiones, which included accommodation for refreshment and rest, stables, doctors, blacksmiths and temples.

Fig. 2.5. Viae glareatae stratae

2.4. The main roads

Via Appia

Date: 312 BC

Manufacturer: censor Appio Claudio

Path: Rome, Capua, Benevento, Taranto, Brindisi

Via Aurelia and Via Emilia Scauri

Date: 241 BC and 109 BC

Manufacturers: Consuls Caio Aurelius Cotta and Marcus Aemilius Scaurus

Path: Rome, Civitavecchia, Tarquinia, Vetulonia, Scarlino (Aurelia) - Scarlino, Luni, Genoa, Vado Ligure (Emilia Scauri)

Via Cassia

Date: 171 BC

Manufacturer: Gaius Cassius Longinus consul

Path: Rome, Chiusi, Arezzo, Florence, Bologna

Via Flaminia

Date: 220 BC

Manufacturer: Gaius Flaminius Nepos

Path: Rome, Narni, Terni, Foligno, Fano, Rimini

Via Emilia

Date: 187 BC

Manufacturer: Lepidus

Itinerary: Rimini, Faenza, Bologna, Modena, Reggio Emilia, Parma, Piacenza

3. HINTS OF LITOLOGY

Fig. 3.1 Grand Canyon

In this chapter we will discuss the types of minerals and rocks used for the various materials used in the construction of the stone pavement; they are divided into: igneous or magmatic rocks (intrusive and extrusive), sedimentary and metamorphic.

3.1. Minerals and rocks

It is called the lithosphere (or crust) the surface and solid part of the Earth consisting of minerals and rocks.

A mineral is a compound (or object): natural, inorganic, solid state and in the stable-crystalline situation.

A compound is a homogeneous body obtained by mutual combination of two or more chemical elements, or two or more molecules or an element and a molecule or transforming, for example with a temperature rise, a molecule in another; in the body thus obtained properties of individual elements are no longer detectable.

The quality of "natural", "inorganic" and "crystal" are required for the development of minerals.

The attributes " natural " and " inorganic ", respectively, want to point out that the object is found in nature and excludes all organic crystals.

In addition a mineral must be present in the stable and anisotropic solid state form, that is crystal one.

The anisotropy is a feature that relates to the bodies whose physical properties have variable behavior with the different directions. In a more rigorous way: if a property of the body only varies with the direction, it is located to the anisotropic state; instead if all the physical properties of a body does not depend on the direction, it is said to be in the isotropic state: distinguishes the gas, most part of the liquid and some glassy metastable condition solid.

It follows that the anisotropy is essential to the determination of the crystalline state, instead the isotropy qualification to the amorphous.

In other words, for crystal, we mean that solid homogeneous and physically anisotropic having not only a polyhedral outer shape, which can sometimes lack neither for irregular growth nor for other extraneous factors, but especially a well defined structure.

The crystalline state is therefore characterized by the association of atoms, which are distributed in rows that form the three-dimensional crystal lattice. Some substances, however, have no crystal structure, that is, their particles are arranged in disorder and they are called amorphous.

The amorphous state is distinguished by crystal one precisely to the disorder of his atoms. The amorphous substances are isotropic, that is, their physical properties are the same in any direction. Crystalline substances instead are anisotropic: in them the physical properties (thermal and electrical conductivity, refractive index, etc.) are a function of direction.

Ultimately, for the definition of mineral, the natural characteristics of an inorganic crystal are taken separately, but not necessary and sufficient.

It is called *rock* a conspicuous mass of the earth's crust, formed by a mineral or an aggregate of two or more minerals.

The rocks constituted by only one element will say simple mineral, such as calcite (mineral consisting of calcium carbonate in white rhombohedral crystals) and chalk; compound (they are the most numerous), those formed by more minerals, such as granite which is made from quartz, mica and orthoclase.

3.1.1. Remarks

A pure solid substance (not mixed with other substances) melts if heated, instead the exact opposite occurs in the case in which it is melted and cooled to solidify. This process is called change of state and occurs at a constant temperature, despite having to respectively administer and remove heat, as a result of absorption or emission of the so-called latent heat of transformation.

The change of state, in certain conditions of pressure, occurs at a well-defined critical temperature: consequently it can be said that, at certain pressures, temperature differences are defined in that place in which an unchanged substance maintains its physical state.

If a substance is taken, through appropriate procedures, to maintain a well-defined physical state, it is in a typical range of temperature and pressure of another state, that is, this is a metastable equilibrium phenomenon: it is enough just one occasion recently to alter it.

Entering a bit more into detail, if we consider a substance in the molten state and the temperature is reduced up to the solidification point, three different conditions may occur:

1) the substance begins to solidify, releasing heat and preserving the critical temperature for the duration of the process;

2) the substance remains liquid while reducing the temperature below the critical value, positioning in a metastable situation. If this condition is altered, for example by inserting a small solid part of the same substance, the temperature rises immediately up to the critical level and so begins the solidification phase; his process is called over-cooling;

3) After reaching the critical temperature, the fluid is in a metastable situation and buy a certain viscosity, which further increases through the cooling; the higher density does not match the solid state but a simple vitreous structure. It is the glassy metastable condition: the situation in which the apparently solid substances are in fact amorphous, that is non-crystalline (the possibility of reciprocal motion of the particles that constitute them has virtually disappeared).

3.1.2. The externality of minerals

The minerals are present or may appear under polyhedral forms and therefore lend themselves to be treated as three-dimensional geometric models. The well-defined directions of the faces of a crystal show directly the anisotropy of the mineral, consequent to its internal structure. Generally the appearance of a natural body is not the same as the ideal model: this derives from environmental conditions and specifically to an irregular growth of the crystal, due to mechanical obstructions.

That is the case, for example, of the crystals that are formed in the fractures and protrude from them; or those which are originated within the cavities, where the geometric shape belongs to the only part not belonging to the wall. Finally, by analyzing the magmatic solidification process, we notice that the crystals formed earlier assumed their forms, instead those that developed later were forced to undergo appropriate configurations to available space.

The cleavage is a property of many minerals, linked to their appearance. The natural crystals, subject to certain stress, break with efforts and consequences which are variables with directions. For example, for actions not coincident with the preferential directions of cleavage fracture, manifests itself in any way and follows a much higher stress.

The cleavage is the result of the internal crystal shape and corresponds to dense planes of particles of the crystal lattice. There are however also of the cleavage-free crystals, and this always is due to the internal structure. For example, the quartz has the characteristic of breaking down in an asymmetrical way.

We must keep in mind that the cleavage is one of the aspects of the crystalline state anisotropy. Furthermore, a crystal face does not always coincide with a cleavage plane, instead the latter is still a face, at least potentially.

As for the attitude of the rocks and their origin, they can be divided into three major groups: igneous, sedimentary and metamorphic.

3.2. Igneous rocks (or endogenous, or magmatic)

Fig. 3.2. Igneous rock

They are formed by solidification, due to the cooling of the volcanic magma coming from the deep layers of the lithosphere. Igneous rocks are also defined endogenous rocks, because the magma usually reaches temperatures above 900° C. Igneous rocks have a different composition and appearance related to the physical and chemical quality of the magma and the site where they become dense.

The magma is a high-temperature mass (700° C - 1200° C), partly or completely melted, consisting of a mixture of mineral (silicate), with the presence of other cations, gases and steams, first of all the water.

The main element of the magma is represented by silica (SiO_2), the same substance of the quartz, which is found in varying percentages: from a minimum of 40% (very rare 35%) to a maximum of 75% (rare 80%), in a weight percentage. The second element in order of quantity is alumina (Al_2O_3), present between 10% and 20% in weight. Follow, in quantities less than 10%, various iron oxides, manganese, magnesium, sodium, etc. Also relevant is the presence of gases and vapors, in the form of water (H_2O), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrochloric acid (HCl) etc. The totality of these gaseous products may reach 5% of the entire molten mass.

The viscosity of the magma is influenced by the presence of silica because it has the ability to originate long polymer chains (compounds with multiple molecular weight with respect to those of departure). Usually, a magma with low percentages of silica is quite fluid and frees easily its gas, instead a magma with considerable percentages of silica is more viscous and thus presents a turbulent degassing process, sometimes explosive.

The magmas with low silica content (less than 52%) give rise to rocks which are generally calls basic. The basalts, among the most common volcanic rocks, are in fact basic.

The magmas with high silica content (more than 65%) produce the so-called acidic rocks.

The magmas with silica content between 52% and 65% generate the so-called intermediate rocks.

The basalt rocks have a color from dark gray to almost black, because the scarce presence of silica is associated with a large amount of iron, which tends to make them darker; instead acidic rocks are of a lighter gray, due to a lower proportion of iron, and those intermediate are characterized by a medium gray.

Among the different methods of classification of magmatic rocks is that of geological interpretation, which distinguishes them in intrusive and effusive.

3.2.1. Intrusive rocks (or depth massive)

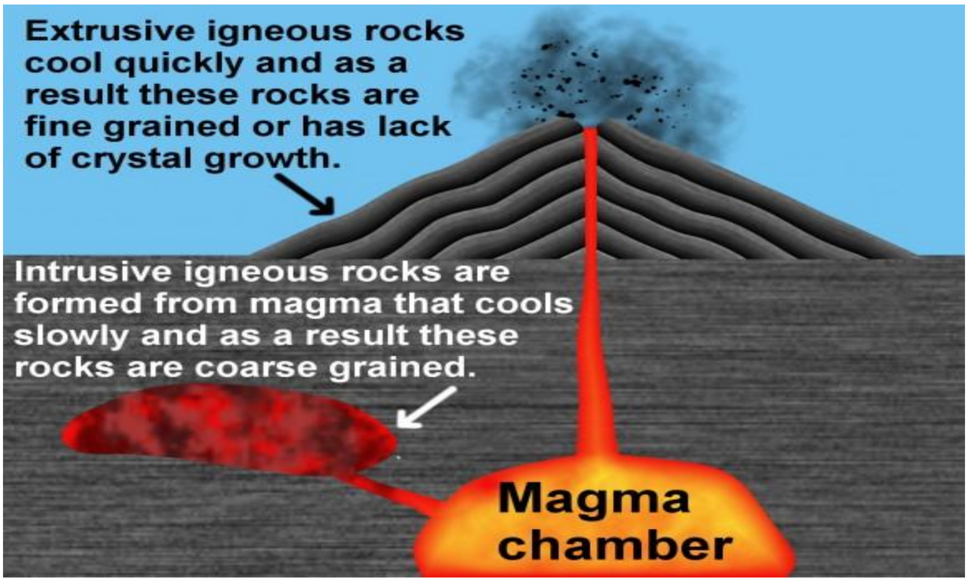


Fig. 3.3. Formation of extrusive and intrusive rocks

If we assume the presence of a significant molten mass at significant depths (usually not less than 5 km), it cools very slowly; in the period of millions of years. Pressure remains high for a long time, even reaching thousands of atmospheres. Being the silica very viscous, in a such situation the magma crystallizes in an ideal manner, especially since there are vapors and gases which help improve the thermodynamic conditions at which crystallization takes place.

It can be assumed that a crystal is formed in the following manner: the elements with greater binding energy, at a certain temperature, tend to get together converging at a defined point generating a microcrystal. The subsequent growth is caused by the addition on the external surface of further ions; this phenomenon is greatly eased by the existence of gases and vapors, which affect the melt silicates by reducing their viscosity.

The intrusive rocks have holocrystalline structures, because the glassy parts are completely missing. The environment in which crystals begin to form, being isotropic in practice and not troubled, favors a development in which they assume proper forms, because they are not bound by any mechanical duress. These crystals are therefore hydiomorphus: show regular polygonal contours. At lower temperatures other minerals crystallize, which are limited in growth by the structures already formed earlier, and thus they are deprived of their forms (crystals allotriomorphus).

Finally, if two different sets of crystals are formed simultaneously, we will have prevalence of one upon another in different areas, with allotriomorphismus and hydiomorphismus phenomena, variously combined.

It is then to generate a granitic structure, that is, crystals of a certain size and of different nature.

3.2.2. Effusive rocks (or volcanic)

Fig. 3.4. Effusive rock

In this case the magma is received on the outer surface of the crust that it compresses, through the consequent fractures to the movements of the same or to the internal pressure of the gases.

The earth's crust, thin layer and heterogeneous, is the upper part of the lithosphere.

The magma extends to a lesser or greater extent according to the temperature and viscosity, of course hyposilicata lavas are more fluid than hypersilicata ones. The latter having high percentages of silica are more viscous, they tend to trap their gas and they are therefore characterized by a degassing tumultuous process, sometimes explosive, with slag launches all around, accompanied by flows that flow more slowly.

At the same time, new gases and vapors are free, the pressure falls to 1atm and the temperature falls suddenly, as the heat directly radiates into the air. Therefore, the crystallization conditions are very poor.

In fact, in the worst situations, for considerable viscosity, contemporary fall of pressure and temperature to completely vitrify the magma give rise to obsidian. In the best conditions, the ions of the magma do not have the time to arrange themselves into crystals, but give rise to an amorphous paste, such as glass, which may be formed in the small, sometimes incomplete, crystals. In the most favorable circumstances the structure is microcrystalline.

If the magma is cooled before going out, because the leakage is slow (for example, for the narrowing of the chimney) and the crystallization has begun, it is present in the fluid of the already formed crystals. These are called phenocrystals, because they appear larger than the other and therefore distinguishable from the rest of the rock; instead the effusive part of the magma will form, solidifying, a matrix (or critical mass) of microcrystalline type. This structure is called porphyritic.

3.3. Sedimentary rocks (or exogenous)

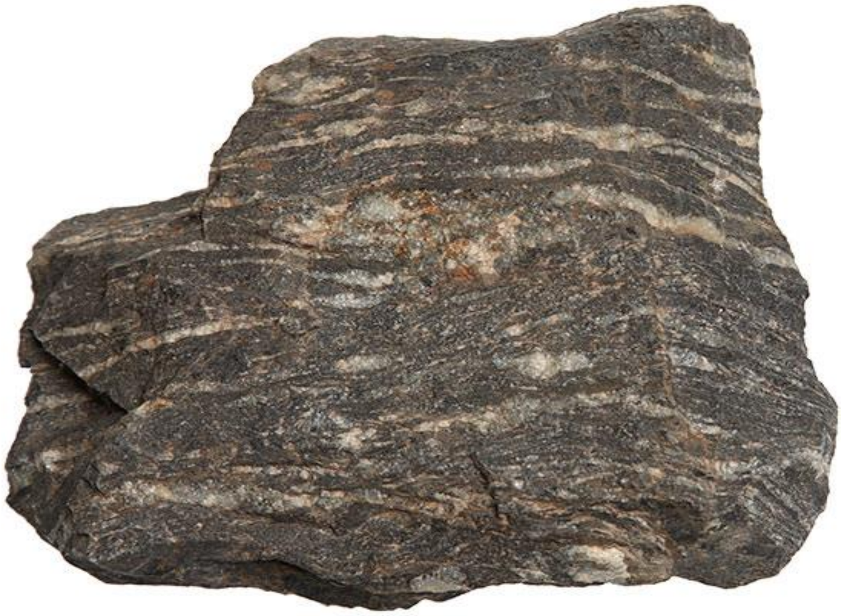


Fig. 3.5. Sedimentary rock

Deriving from the sedimentation of the chemical degradation products (alteration and physical disintegration) of pre-existing rocks and also from deposits of organic origin.

The main causes of deterioration and disintegration of igneous, metamorphic and sedimentary rocks are the combined actions of isolated glaciers, running waters, air, sea, volcanoes and living organisms (biological action).

3.3.1. Glaciers action

The exaration is the erosive and abrasive action exerted on the rocks by moving glaciers (movements of the order of a few millimeters per year).

The modification (modeling) of the surfaces of the valleys and the furrows marked in the valley walls, called glacial striae, are due precisely to the exaration.

The accumulation of rocky material dislodged from the valley walls, transported and deposited by glaciers at the edges or on their forehead, is called moraine.

The action of glaciers has a dual effect of demolition and construction.

3.3.2. Water Action

It is the erosive action of rain or torrential waters on rocks and sloping soils (leaching), due to the continuous transport of scree, ie incoherent rocks originated by exogenous changes in non-stratified heaps.

The sharp edges initially present on the fragments from the disintegration of the rocks (scree) are then rounded by the action of streams and rivers. The latter with their drive energy, move downstream and towards the sea considerable amounts of eroded material, more and more rounded. When the slope and the speed decrease, the energy is reduced and the current is no longer able to carry all the solid parts and sediments.

Sedimentation is also caused by other factors of an organic or chemical-physical nature.

Stalagmites, formed by the deposit of limestone contained in that drips from the vaults of the karst caves and slowly evaporated, are crystalline concretions of column-shaped calcite (mineral consisting of calcium carbonate in whitish rhombohedral crystals) or cone calcite which rises from the floor of the caves.

Limestone is also formed for the rapid evaporation of water in the waterfalls.

Even the waters therefore have a dual action of demolition and construction.

3.3.3. Atmospheric action

Freezing and thawing, temperature fluctuations and marine salinity are the main physical agents that break the rocks. While the most important of mechanical ones are the rain, wind and hail. Then there are the chemical and physical-chemical agents such as oxygen and water, carbon dioxide and water and, in the last few decades, air pollution which acts everywhere by acidic precipitation, pollutants carried by winds etc.

3.3.4. Action of the sea

The increasing abrasion, that is the denudation (erosion) and the break-up of the rocky coasts to wave effect of sea water, leads to a progressive retreat of the coastline. It follows that the ribbed rocky portions collapse giving rise to deposits on the spot, or at a distance in the case of fine-grained material such as sand. The pebbles, forming the above-mentioned deposits, are presented rounded, flattened and smoothed by the waves.

3.3.5. Volcanoes action

We preferred to classify the rocks formed by the accumulation and cementation of lava material and escaped from volcanoes, called pyroclastic, as sedimentary, being originated by layers of sediment; even if the treatise writers usually do not.

Initially inconsistent, the pyroclastic deposits may be subject to storage, in the empty spaces, and substance dragged from the water such as calcium carbonate and hydrated silica (limestone and volcanic tuffs, consistent lapilluses, etc.) with subsequent cementation processes.

3.3.6. Biological action

Living things (plants and animals) also playing a double role: destructive and constructive.

The biological destructive action, that of living organisms, is accomplished by the lower plants (lichens and mosses): it is chemical, physical and mechanical.

Constructive action is based substantially on the ability having certain kinds of microorganisms to deposit defined chemical substances, completing the formation process of shells and skeletons. They arrange themselves in layers in significant deposits giving rise to the sedimentary rocks of this kind.

Indirectly and directly, a considerable amount of limestone representing 5% of the sedimentary rocks was produced by the biological action.

3.3.7. Diagenesis of sediments

The complex of physico-chemical transformations, through which sediments loose it up into compact rock masses, is called diagenesis (changes of the structure, the texture and chemical composition).

By diagenesis of sediments, the scree or moraines may generate brecciated texture rocks (conglomerates with fragments of different nature); a gravel deposit can give rise to the pudding; siliceous kidney can generate sandstones, calcareous sands and tuffs containing calcium carbonate (limestone or sandstone).

3.3.8. Sedimentary rocks of chemical origin

The formation of these rocks (travertino, limestone and alabaster gypsum) is due to the deposition of salts dissolved in water; they are used in pavements (travertino), in the floors and walls.

The travertinos are formed by calcium carbonate ($CaCO_3$) fallen by calcareous waters during their evaporation.

The calcareous alabasters are rocks formed by limestone water evaporation on the soil surface, or in underground cavities. Thus forming on the walls some micro-crystalline deposits that continue to overlap, the stalactites formed by the roof, while the conical stalagmites get up from the floor and join together to form the columns; with the passage of time, these grow in diameter and join together with the walls; the cavity slowly fills and thus a large block of alabaster forms.

Last, gypsum alabasters are rocks formed by chemical deposit and consist of bi-hydrated calcium sulphate ($CaSO_4$-$2H_2O$).

3.4. Metamorphic rocks

Fig. 3.6. Metamorphic rock

They are volcanic origin rocks (magmatic) or sedimentary who are profoundly transformed, due to the continued evolution of the lithosphere and then due to the intervention of special physical-chemical factors, without coming their complete fusion: usually, these transformations take place in the solid.

Such a process is called metamorphism and the rocks derived from it, metamorphic.

Often, the above transformations are of such consistency that the nature of the original rock is almost indistinguishable.

Frequently the mutations cause the appearance of different minerals, new types of weaving (in part schistose) and a distinct crystalline form, even with recrystallization processes and therefore of neo-structure.

Individual action or, more often, contemporary action of different kinds of factors with the predominance of one over the other is the cause of metamorphism.

These factors are of chemical, mechanical and thermal reason; the chemical nature developments may occur with substances already incorporated in the original or new contribution rocks.

The reasons that lead the sedimentary rocks (exogenous) and magmatic (endogenous) in metamorphic processes are linked to specific geological phenomena of a different nature and therefore, in accordance with such differences, we have three types of metamorphism: dynamic (or torque control device metamorphism), load and contact (or depth, or regional).

The dynamic metamorphism appears in the areas affected by orogenic phenomena (mountain ranges of the generators).

The considerable pressure, faced upwards, acting on the earth's crust, origin of its corrugation, undergo stresses to the igneous and sedimentary rocks which are transformed so adapting to the new state. In the metamorphism of this type we must change the clay into slate (used for roof tiles), the marly clay in whiteboards (slates), limestone or dolomite in marble, etc.

The contact metamorphism is due to the action of new magmatic formations in the consolidation process and manifests itself on rock walls that are affected by temperatures of about 400° C - 600° C and pressures that do not exceed 2000 bar.

In this type of processing the limestones are very sensitive and, in relation to the composition and purity, are changed into marble, in calciferous (containing lime) and in cipollines (species of veined marble in more colors that are hollowed in the mountains of Carrara and elsewhere, used for floors, columns, etc.).

The load metamorphism, far more important than the previous one, is caused by temperatures from 400° C - 750 ° C, with very high pressures, of the order of 6-7 kilobar.

The regional metamorphism is caused by changes due to thermal, chemical and pressure effects, and not the consequences of a magma, which are originated at different depths in the earth's crust, and are found usually associated with changes due to same crustal movements. Please note that this phenomenon takes place in the deep rock layers, and therefore older, through the action of compression resulting from the most recent overlying mineral aggregates.

In function of the depth, and in relation to the different conditions of pressure and temperature, there are three metamorphic zones:

a) cata-area (or lower zone) in which the pressure is hydrostatic and temperatures are high (mica gneiss brown)

b) meso-area (or average area) in which the pressures are mainly oriented type and with lower temperatures of the preceding

c) epi-area (or the area above) in which the pressure is almost exclusively oriented and temperatures are low.

4. TYPES OF MATERIALS USED IN STONE PAVEMENT LAYERS

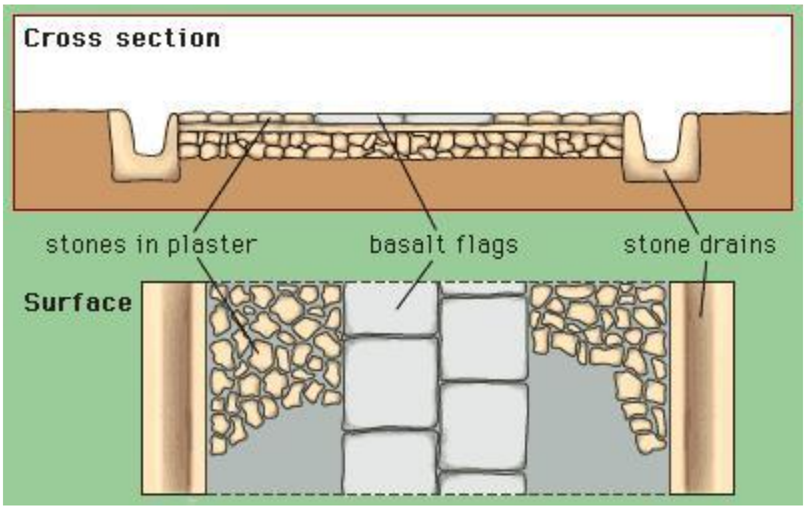


Fig. 4.1. Pavement cross section

4.1. Generality

Thanks to EU funding, from some years, the various municipalities are gradually engaging in the recovery, maintenance and enhancement of what remains of the historic paving stone in urban centers.

We currently use again albeit in a modern way, technologies are often wrongly considered outdated and no longer being able to meet the properties required for pavements.

It has been observed that a pavement is well performed when the lower layers (subbase and subgrade) offer sufficient resistance to the complex stresses transmitted from the upper and basic layers.

If the surfaces of the subgrade were to present the significant irregularities with respect to the floor of the pavement, we will have to follow, as appropriate, the procedures illustrated below.

Dealing, for example, with mortar bed pavements, the drawback is overcome with appropriate compensation through the same layer of mortar.

While for the sand bed pavements (tile or flag stone), in the case when the subgrade has altimetries more than necessary, it is possible to accept a certain difference if, upon completion of compression, the sand bed is not reduced to less than 3 cm - 4 cm. In the opposite case there is the possibility to match the difference with sand, provided that, in occurred compaction, the layer is not major than certain heights: for example 5 cm - 6 cm in pavements that use cubes 4/6 and 6/8.

If these differences were not accepted the profile of the subgrade is changed: in the first case the road must be discharged and recharged in turn. This situation must be avoided because additional effort, cost and time are required.

From this brief discussion, it appears clear that, for a road, the top surface of the subgrade must offer an appropriate transverse profile; while in the case of large areas, such as the squares, it must have the same inclinations of the finished pavements. The slopes are foreseen to allow the outflow of rain or washing water, in relation to the drainage system.

Let us examine the most common traditional stone pavements that may, in relevance to the elements size and shape used, be traced to the following main types: the cobblestones, the tile stones and the flag stones.

4.2. The cobblestones

Fig. 4.2. Cobblestone

The cobblestones are constituted by pebbles to edges almost rounded and already available in nature. They were spread in the '700, mainly in the cities, to ensure the roads a partial drainage of rainwater and more comfortable use of pedestrian and vehicular routes.

We recall in this regard that even the cities of some relief had in general dirt roads, while those equipped with pavement were only the main streets.

In that time, the cobblestone certainly was an appropriate technology and also gave dignity to urban spaces.

Now, to counter the considerable waterproofing caused by urban extensive bituminous surfaces, it sometimes is used in the cobblestones, because of its permeability. Lands adjacent to trees and shrubs, parks and city gardens are a classic example of where this is done to ensure breathability.

Once these pavements were very popular ; nowadays they are inadequate because they give certain inconvenience for traveling, such as they are muddy in winter, dusty in summer and very expensive.

To realize the cobblestones, we use oblong stones, easily found in the waterways of the rivers, at sea or in caves. Generally, the minor axis dimensions are between 6,5 cm - 8 cm, while the major axis ones between 9 cm – 15,5 cm. In some particular jobs, major pebbles called "boccelle " are also used.

After being properly washed to remove possible soil or saline parts (in case of marine pebbles) and selected these elements are ready for installation. Resistant rocks such as granite and porphyry present in the

Italian Alps generate rounded pebbles; elements which are characterized by flat shapes until the truncated cone which is made of stratified rocks, such as limestone and siliceous sandstone come from the Apennine area.

The different behavior of the rocks in the dynamic rolling action is influenced a lot by the figuration of city pavements, in their peculiar qualities of the place determined by the different equipment, colors and textures.

The cobbled polar patterns are characteristic of the seventeenth and eighteenth century, while the star designs mostly come later.

The cobblestone is often used in conjunction with typical elements of other pavement models (for example beads, plates etc.), used to perform driveways guides, panes, etc.

4.2.1. Achievement of dry cobblestone

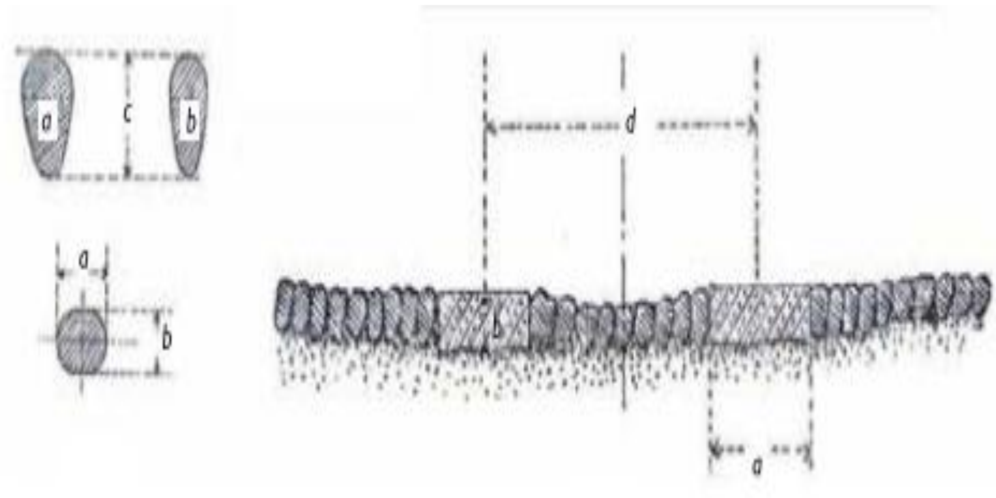


Fig. 4.3. Scheme of a dry cobblestone

It is worthwhile to state that dry paving cobblestone are inappropriate for use in driveways, especially for those characterized by heavy and intense traffic.

Following the tradition, the subbase of the cobblestones is accomplished by compacting the natural terrain by calendering, after appropriately humidified in order to maximize the density. This operation was earlier performed using cast iron or stone rollers or mashers (heavy wooden shod pestles).

We spread then a layer of 8 cm -10 cm of coarse and not processed sand, within which is placed a pebble, in such a way that the thinnest part is down and the major axis is vertical. This operation is to dig a small hole with the pen of a hammer (his share thinned), then used to beat the element. In a similar manner they are placed below the other pebbles (in a closed mode), making sure that the heads protrude equally. The smaller elements usually are laid in the side bands of the road or of the surface to be paved, at the center the larger ones are laid.

With the availability of elements of regular conformations and dimensions, placement geometries with design trends can be used.

Completed the laying of cobblestones, we compact the pavement through some typing phases, using the pole-ax (a small wooden pestle) and wooden mashers to not damage or break the elements.

After the first keystroke, the surface layer is sprinkled with moistened sand and, continuing compaction, wet cobblestones with water so that the lubricated inert penetrate into the gaps between the elements. Additional keystrokes guarantee their side contact and a trim or regular attitude of the surface.

In certain situations, especially in the pedestrian areas, the foreseeable conditions are such as to afford the coast or flat disposal of the pebbles. Especially in the first case, we can also achieve decorative results of considerable value by making use of singular pose geometries.

It is also possible to resort to different color elements, usually in black and white, which give radiance to the decorative motifs.

In cobblestone pavements unique accommodations of the elements usually are used, both to achieve adornments and to consider their permeability. In fact, the laying of the pebbles takes place by tilting their major axis in accordance with the slope of the floor line, so that the rain or washing water converge in the drains of the drainage system.

The bumps and the watershed lines, being destined to the scrolling waters, are the most vulnerable parts of the pavement because they involve interruption of the mantle; for this reason, they can be built differently, for example using materials such as properly processed bricks or stones. In the design stage, the resulting appearance should be carefully examined, referring also to the solutions of this type.

Before the nineteenth century, the streets of the city were characterized by a concave road section and an axial sewer, leading to an easy and fast draining of waters.

During the 1800, for various reasons, this model was gradually abandoned for the benefit of the convex section one, suitable for water conveyance in lateral routes disposal generally equipped with sewer sewage systems.

Furthermore, the convex road section makes the pavement much more resistant to the stresses caused by vehicular traffic.

4.2.2. Floor decoration technique

Fig. 4.4. Mosaic

Perhaps the first mosaic works were performed by placing pebbles or lapilluses, very tight among them, in a layer of compacted soil, later replaced by the more durable concrete. The above technique, using different sized and shaped multicolored pebbles, already was suitable to embellish external and internal pavement surfaces. Now this technology is sometimes used and in its simplest representation is the reserved parking spaces for pedestrians and public gardens; however until the early twentieth century was also widely used in pavement.

The remarkable irregularities in the trampling surface and the consequent use of the same inconvenience brought, even in ancient times, in an effective ameliorative change by grinding the surfaces in view of pebbles and following the split of the same and their positioning, with tears flat in the open, in the cement mortar.

Elements in the card, regular geometric shaped, were then produced in a subsequent stage.

The pavement in tessellated mosaic, or in small square tiles of stone and usually 1cm - 2 cm of side, nowadays is a few chosen, both for the high cost of construction and for that of maintenance and this especially in the presence of rigid climates. Furthermore, the gear of such a pavement surface, using compact limestones and marbles, tends to polish with the use, thus becoming slippery, especially when it rains and even worse if it is cold. Usually, the mosaic surface is to be smoothed enough finely, in any case it is necessary that the tiles are first smoothed and placed according to a certain slightly inclined plane, without giving rise to depressions, elevation irregularities and joints.

4.2.3. Combination of cobblestone with stone slabs

Fig. 4.5. Combination of cobblestone with stone slabs

Usually, this type of pavement determines the way in different stripes performed in cobblestones and slabs of stone. The crosswalks made by cobblestone pavement with bands are a typical example, suitable to develop figurative motifs of great value while giving pedestrians the possibility of easy workability. Rarely, the cobbled streets were not broken. They were divided by parallel strips slabs of granite, compact limestone, siliceous sandstone etc. The stone planks were absolutely necessary both to weaken the noise of the cobblestones to the passage of vehicles with wheels and to reduce the wear and tear of the surface; the elements with the passage of time had to be replaced or refurbished to their original position.

Thus surfaces were created with different coatings, intended for different uses of the same journey. Indeed, the uniform and resistant slabs of stone offered to vehicles with a rolling surface which in a good polishing surface (minimum tensile strength) united tiny slipperiness (maximum grip) and the central cobblestone that, with its roughness, allowed a secure shod hooves grip of draft animals.

According to the importance of the road, the guides were placed in the roadway in a single or double lane, in other words depending on whether it was provided for a single or two-way traffic.

This type of pavement is spread abundantly in Europe, especially since the beginning of the nineteenth century.

Today, these pavements, although the characteristics required of them a long time ago fell short, with regard to the practicability of the carriages and their draft animals, retain all their attraction in urban figurative art, belonging to this point at the memory of the historical society.

At the local level, where these pavements still exist, in recent years something has been done for their recovery and restoration of the damaged or bituminous ones and it is hoped their use, in a modern way, especially in the pedestrian areas of new settlements.

The trotting tracks, having no longer to perform the past functions, can also be placed according to the needs of other kinds, such as environment-related aspect.

This is true, even if the traditional pattern of stone guides is still valid, by still allowing modern means to transit, sometimes and when expected, on pedestrian paths, thereby renouncing to use the cobblestones that eventually may deteriorate.

4.2.3.1. Realization of cobblestone and stone pavements

This kind of pavement generally consists of cobbles interrupted in the middle of the street by two 50 cm - 60 cm flag stone wide strips and placed at a one meter distance from the inner edge.

The surfaces in view of these slabs of stone, should be processed according to the scheduled finishing: medium-fine bush-hammered or end blunt.

We finish the pavement and its adaptation to specific characteristics of the street due to existing manhole covers, drains, manholes etc. They must be made with accuracy of particular sizes and shape elements (pieces of keystone). For this reason, during the design phase, the construction of certain stone elements must be planned, such as: manhole covers, drains or specific solutions regarding the creases of the sidewalks. The stone slabs firstly are layed in opera and only later on the cobblestone elements are put in place. The subgrade is prepared and properly shaped according to the predetermined transverse and longitudinal profiles. we continue with the laying, in correspondence of the laying of the stone guides, of a layer of sand having the 8 cm - 10 cm thickness.

These elements shall be placed in well-arranged work, close to each other and compressed with a gear made from a wooden plate provided with the long handle having the weight of not less than 15 Kg (mashers), because they will be subject to high dynamic stresses.

Then we continue with the installation of the cobblestone according to earlier exposed procedures.

4.2.4. The cobbled lime

As seen above, the cobblestones are marked by dry arrangement of the elements and for that reason in antiquity were called dry pavement; but there was also a different and more economical method, the cobbled lime, which used less valuable material and cheaper labor. For its construction fragments of rock, rounded and smoothed by water (pebbles) or derived from processing waste, of different sizes and shapes were used. In Rome they are called " bastardoni ", that is, the wastes of the working of bricks obtained from basaltic magma of the Alban hills.

This type of pavement was much used, especially in steep path, and supported on a subgrade, identical to the one prepared for the dry cobblestone. Subgrade that was leveled with gravel and on which is realized a layer of stone fragments (shavings) and lean lime mortar.

While the superficial stone elements were placed in the bed of laying mortar, 10 cm - 20 cm thick.

Often the execution of the cobbled lime, especially for smaller elements, was made simpler by subdividing the area of the pavement through guides, so as to distribute it in regular portions with the purpose of simplifying the making. There was and there is the opportunity to emphasize the sharing achieving grooves in order to achieve decorative effects.

The shutter unit was chosen on the basis of aesthetic requirements or, more frequently, those also functional in relation to the rock used, the specific nature of the route, the employed type of drainage and the nature and extent of the assumed stress.

Once finished, the cobbled lime could not be used immediately because the lime mortar was consolidating after a suitable time, for which the pavement had to be temporarily covered with sand and soil.

The current execution modes are based on subgrades made with adequate ballast, or even concrete.

The latter case must be carefully examined, and then take the right decisions regarding the expansion joints which serve to prevent damage to the surface layer due to thermal expansion, the withdrawal and the consequent bending loads which we apply to the subgrade.

Finally, nowadays the modern cobbled lime is performed with an appropriate concrete subfloor, sometimes reinforced with electro-welded networks, or in the ballast and concrete bed.

By reconsidering the dry cobblestones, we have to face the final stage of processing, that is, the application of the mash of cement or lime and cement, which creeps into the open areas between the stone elements and causes in the sand bed a strengthening total pavement. Afterwards this operation proceeds to wash the surface of the pebbles march. The pavement, having to withstand considerable stress, may suffer depressions, irregularities and failures if the previous application is not done perfectly. We conclude noting that, with respect to a strict application of the mash, is preferable to resort to a conventional achievement, because the set of pebbles, tight between them and joined to the support of sand, is able to neutralize so easier possible alterations.

4.3. The tile stone

Fig. 4.6. Tile stone

The stone elements used in the tile stones are of cubic or parallelepiped shape and generally have square driving surfaces; these pavements are nothing more than a simple evolution of the cobblestones.

In fact, it is considered an intermediate group between the cobblestones and the flag stones, although it sometimes is classified with the latter name. In general, there is a trend for the first definition because the size of the exposed surfaces are rather small compared to the heights of the elements. In the present age, these elements are obtained from slabs of rock due to a machine called hammer (blade); however a long time ago that production was based on the use, by the stonemasons, of the bribe and wide chisel. Their driving surfaces coincide with the main quarry plans (or verse) of stone blocks and are left rough, however the side walls, obtained by splitting, are pending to the laying surface; these elements take the form of a truncated pyramid whose dimensions usually are standardized.

In the second half of the nineteenth century, the first road pavements in small and medium-sized stone elements, were used in Europe, suitably prepared for this purpose.

For example, in the late nineteenth century, in the city of Hannover (Germany), granite cubes of standardized size (about 10 cm x 10 cm) and in significant quantity were used for the first time.

In Europe, the extensive use of the tile stone, however, came only after the end of World War II.

The small size of the in-sight cube surfaces with regular shapes and roughness of the joints, offered and still offer good tack to the horses' hooves.

The use of granite cubes, frequently of 8/10 cm type, is now widespread in countries such as France, Germany and Sweden.

The use of two-color elements (whites and blacks), obtained from the limestone and from the basalt, falls within the Brazilian and Portuguese tradition; the goal is to create a design motif in the streets and sidewalks pavement.

In Rome, the most remote use probably dates back to the eighteenth century and concerns the sampietrino, or quadruccio (square surface side view of 9.5 cm and height 18 cm), made from basalt rock of the Alban Hills.

For several tile stones of Naples, elements were extracted from the solidified lava of Vesuvius. The Vesuvite, or Pietrarsa, is an effusive rock recently formed (1631 eruption), which is also used for its remarkable resistance to the saltiness of the sea.

In many urban centers in eastern Sicily, however, they have been used for pavement elements derived from the Etna effusive rock.

The Trachite of the Euganean Hills, the Diorite and Syenite of Como Lake, Granite Rosa of Baveno (VB) and Granite of the Giglio island are other types of rocks used to obtain the tile stones cubes.

Since the end of the nineteenth century penultimate decade, however, porphyry was the mostly used stone in pavement. The first few batches were produced in the quarries of the municipalities of Ora and Bronzolo (BZ), in two large size formats; but their widespread use came only after the end of the First World War. The origin of modern and relevant processing of porphyry from Trentino goes back to that period with the start of the first quarries in the municipality of Albiano (TN).

In 1930, it was made, in Via Nazionale in Rome, one of the major interventions in the field of porphyry pavement cubes.

Actually, the tile stones in cubes are made almost exclusively in urban centers and, for quite short distances, in rural roads; they are used a lot to pave the curves in limited range and the mountain roads, as these increase the coefficient of adhesion (cross) and consequently the stability of the vehicles.

4.3.1. Pattern

Overlapping arcs, peacock tailed, in regular courses and redans equipment are usually used; each of them must be chosen with consideration due to the functional and aesthetic appearance, especially for driveways; in fact, it offers the advantage of employing different sized cubes and excludes that the direction of vehicular motion coincides with that of the joints. Such equipment is undoubtedly the most suitable to support some of the complex stresses transmitted from the vehicles to the pavement, namely those deriving from inertial variations and uniform motion.

We note that each arc is in conflict with its outbuildings and with the sides of the paved area in general or of the street. The use of the arc is also motivated by the fact that, in addition to ensure a more satisfactory and efficient realization, are used cubes of different sizes: the greater will be placed at the center and smaller at intersections, according to the succession and the criterion below exposed.

With such apparatus, the cubes of each row are arranged according to a succession of circle contiguous arcs, of predetermined and equal radius, and so that each opposed pair have in common the tax element.

This is achievable only if the central angle is 90°: in this case the key element edge is equal to the cube diagonal tax and consequently the edges of the elements range from tax by increasing the keystone.

Being the surface of the cubes square, the joints of the elements of an arc will assume a trapezoidal shape, with the major base faced towards the outside; since this divergence is not known, we should be limited to a maximum of twenty cubes per bow.

The linear and parallel arrangement to the axis of the road means that that information is easily come off, due to the repeated stresses caused by the transit of vehicles.

To overcome this critical issue, redans is used as equipment, arcs usually are interrupted either before or after the sets of the same, thus allowing the insertion of the adjacent and truncated bows in the same way.

With such a configuration the alignment of the smaller cubes is lost, put it in a herringbone pattern in a fixed width strip, thus offering a higher resistance to dynamic stresses.

There are also other types of equipment, such as the one on the peacock's tail: remarkable aesthetic value, achievable by arranging the elements in such a way as to obtain the contiguous arcs of circumference and by arranging the subsequent sectors on the centerline of those already accommodated.

Such equipment is usually chosen for pedestrian routes and use the cubes type 4/6 or 6/8, that provide a sufficient resistance to such stresses.

Each curvilinear course, consisting of a series of cubes, is monochrome, but for each of them a different color may be provided except for the maximum radius one, in which are present elements of Bianco di Carrara marble or Lasa (BZ) one.

Usage of stones like Botticino (BS), the Pietra di Trani (BA) or other similar technical characteristics, is inappropriate because it does not offer resistance comparable to those of the adjacent elements (porphyry, granite, lava etc.).

The implementation involves the use of steel shapes, at the external wires of which the larger arcs are placed. The figures which were outlined are so filled with other cubes.

In implementing the fan cubes or herringbone ones, we must take care of the selection of elements because each course must be as uniform as possible to avoid too different joints between them without meeting aesthetic criteria. The measures may vary per type of items.

The arrangement of the elements in straight courses, with an inclination of texture at 45° to the axis of the road is widely used in Rome. This provision fails to react in part to the complex stresses due to traffic, downloading them in the direction of the edge of the street.

The contrasting arcs behave optimally, especially when the traffic flow is directed towards the arc-keystone of the center; while in the reverse gear, they are effective during the braking phase (traffic lights, stop, pedestrian crossings etc.).

Even today for irregular areas of reduced extensions to the uncertain work equipment, even if fallen into desuetude, it is used to achieve unique accomplishments expressed with figures, also through the introduction of different elements for chromatism, shape and size.

The various tile stone equipment combined with those of flag one offer several possible solutions.

The tile stone is also used to make elements of urban three-dimensional ornament, such as benches and fittings for planters.

We can realize decorative elements or markings using unequal equipment and/or different color cubes.

From the solutions previously reported, although using the same materials and the same techniques, have the aim to reach figurative and symbolic purposes. In fact, many are the executions dating back to past epochs in which it was used the tile stone and, more generally, pavements in elements of small dimensions, such as some types of tile stones and cobblestones.

For example, in the Italian and European cities, there are many historical tile stones presenting symbols of coats of noble arms, wind roses, urban maps etc.

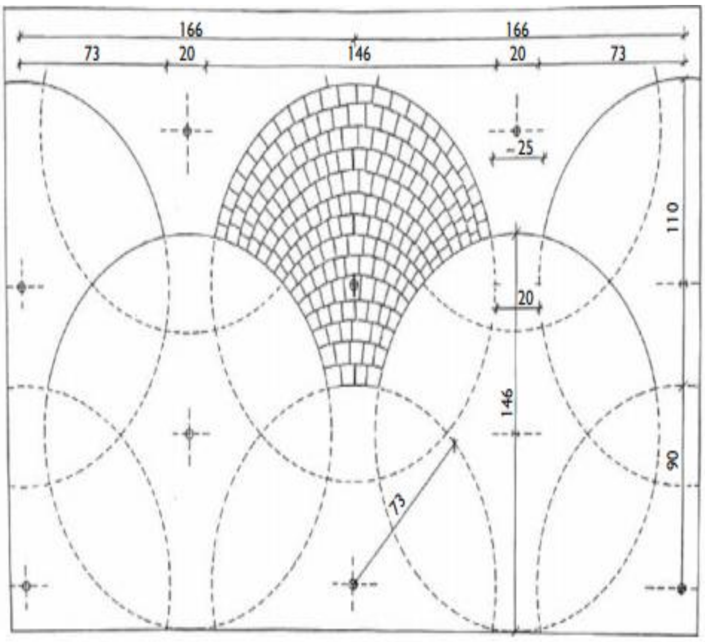


Fig. 4.7. Arrangement pattern

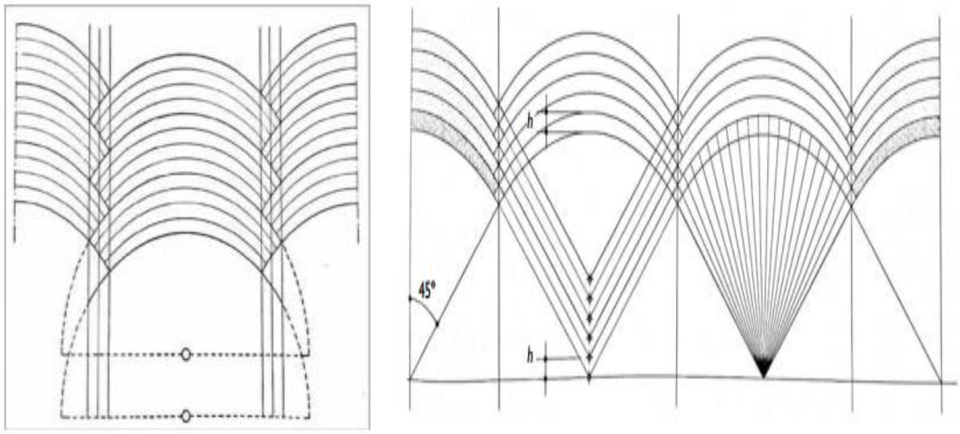


Fig 4.8. Arrangement pattern

4.3.2. Pavement thickness

After verifying the correspondence of the subgrade to the predetermined values of shares and resistance, we carry out the implementation of the pavement: laying and arrangement of the cubes on a layer of sand according to the desired equipment.

At the end of work the sand layer must have approximately a 4 cm - 6 cm thickness. Having the completed pavement to respect predetermined elevations, the upper part of the subgrade should have a right elevation, lower with respect to the rolling surface one, according to the type of cubes that are used.

Surface dimension (cm)	Thicknesses (cm)
5/6cm	5/8 cm
7/8 cm	9/12 cm
9/10 cm	13/15 cm

4.3.3. Construction procedure

For a correct use of overlapping arcs we must consider, besides the usual rules and specified boundaries for the sizes of the same, discharges, gradients, thresholds, required points and especially the more general artistic requirements.

The roads to be paved may have different amplitudes, which usually remain unchanged. In relation to the width of the street and to the type of cubes to be used, we perform the distribution of the arches and the job tracking.

We note that the lengths of the strings are not immutable: they can be changed of a few centimeters, thus allowing strict division in relation to the width of the street. Basic principle is that the roadside should always dispose two half-arcs.

Moreover, in the case of paths with a convex cross section, the arches must always be equal in number so that the one located in the center is symmetrical with respect to the axis of the road. If they were rather an odd number, the aforementioned elements would be put on the axis common of the adjacent arches. This would therefore be a poor situation from the aesthetic, of the strength and, the major problematic, of the installer point of view.

It can sometimes happen that the width of the street does not allow for division into equal number of arcs; in this case we can remedy this unfavorable circumstance placing on the edge of the pavement one or two rows of cubes, called guides, arranged parallel to the road axis and having dimensions roughly equal or superior to those of the elements of the pavement. Keep in mind that in Rome guides present geometric configurations of double size with respect to those of bricks.

Such foresight can be also used in the case in which a route has not always constant width, or is bump-on-the-edge-free, that we can, however, achieve with the guide or, as in the case, with a series of two tiles.

The solution that is adopted in principle involves the establishment of guides to the pavement edges, maybe performed with a single course of cubes.

Usually, roads in urban elements have transverse gable shapes to ease the outflow of rainwater or washing water from the centerline to the gutters, where appropriate drains are placed.

Generally we find gradients ranging from 1% to 2%; with the introduction of accessibility regulations, however, new buildings may not exceed the 1% of slope.

A breakdown of the arches is counted as two half-roads: we place center line in one or more guides located at the same distance, having the same width of the trap doors, which will then be supported for semi-arches.

The central guides of these paths are made by placing two parallel rows of tiles having a 20 cm side or cubes having a 40 cm width.

After establishing the amplitude and the number of arcs, we proceed with the trace of their position on the surface of the concrete subgrade or an existing roadbed, digging into it of metal tips and straining between each other these ropes. Since the sand and the ice cubes, after the beating, undergo a lowering of about 2 cm, the ropes must be positioned at an equal height with respect to the finished tile stone.

Immediately after this work, we proceed with the laying of sand bed, constituting on average of an about 6/7 cm depth. Humidification and beating reduce the layer thickness of about 2 cm, thus achieving the established quota. The sand used must be free of impurities (clay, silt, organic matter etc.) and have a large enough particle size. Sands that don't meet the requirements should be excluded in any way, because the soil contained in it will remove any water infiltration, after dissolving it. In the layer of sand, small irregularities and cavities with consequent lowering of the pavement would thus be created; on the other hand the presence of soil between the joints make the growth of grass much simpler.

The use of sand containing gravel should be excluded in any way, because the size of the granules are such as to prevent adequate union between the cubes.

Even the sand of the sea is to be excluded, because it contains high amounts of salt which would tend to melt once came in contact with the water used during the beating or with the rainwater.

4.3.4. Opera commissioning

In order to create a pavement according to the standards, the following basic rules must be observed:

a) as already highlighted, larger wedges must be placed at the center of the arches (key), rather smaller ones will be placed at the intersection of the same (tax) . Transport of elements of decreasing size, from the tax key, is a necessity because it allows us to achieve arcs with constant bending radii (see equipment). In so doing, however, we meet a drawback: being variable the height of the cubes, the thickness of the layer of sand, below the key elements, is considerably reduced (about 2 cm) . As it is known, the stone materials are extracted from quarries and are worked at open: to the blocks, obtained by shining the mines, a summary work is given in the site because it is made easier by water in them present. Where subsequent operations are performed in the factory, where each element is also checked and selected. However, it can always happen that inadvertently some cubes are with defects or that, in the action of loading and unloading, some of them may have been broken. Therefore it follows that the layer must have the ability to express an assessment on the processing and on the characteristics of the elements that will be used. Ultimately final testing and then the possible decision to remove the not suitable cubes belong to the worker, in charge of the installation, , because on him falls the responsibility of a possible little value realization;

b) the joinings (or joints) of the elements must be parallel and of small thickness. The installer must place each tilted cube toward himself, then force it with the hammer in his exact position, because they must touch near the layer of sand;

c) the joints (or splices) of longitudinally adjacent strings must never be aligned;

d) the poser must use the hammer to make a hole in the sand bed where to place the cube and press it against the adjacent ones, but also to give it the first settling strokes so that the same is immediately locked to the adjacent elements and to the layer of sand . With the beating of pose, the different heights of the various elements are lead as well to the same level (not balanced), thereby the surface of the tile stone presents a regular configuration and the predetermined slopes;

e) specialized workforce must start the implementation of the cubes at the lowest point of the street and the concavity of the arches should be pointed downwards. This way will make our work easier and excludes that the water of the subsequent beating wets the area where the laying is performed;

f) the finished pavement portion should be left perfectly clean by posers.

4.3.5. Beating

After the arrangement of the elements we proceed with the action of general beating and for the same pavement is a task of considerable relevance. Until a few decades ago, the beating was carried out only by hand with the small-head-mashers, in order to hit an element by an element, and with whom it performed three keystrokes for each cube, creating an equal number of steps up to a complete leveling of the surface of the pavement. However masher is still sought to repairs of modest entity, or for specific sections of the pavement, because it is easy to be used. This keystroke is mechanically performed with vibrator plates, put into action by alternative internal combustion engines, whose weight can vary from 60 Kg to 150 Kg. Firstly the tile stone is sanded abundantly, then it is subsequently cleaned with the brooms and by ensuring that the gaps between the cubes remain entirely filled. Instead a layer puts into operation the tool, directing the movement to straight lines. There is a second, or a laborer, that washes the pavement with water before the machine in widespread and abundant way, and causing the fluid jet face, penetrates the grains of sand into the joints and remove other hand those excesses. In the course of beating, it can happen that we must redo some cube put in wrong place rows, replace any damaged or destroyed items and correct the hollows where they become visible to the presence of stagnant water. Sharp metal tools will be used to lift the cubes, belonging to the depressions, a few millimeters, and then with new additions of sand and water, the layer that lies beneath of everyone will be increased, so as to raise them and to align them to pavement floor. A pavement is well performed when the sand occupying the joints reached the maximum density.

4.3.6. Seals

Until a few decades ago, these pavements were completed by sealing the joints with cement grout or, more frequently, with hot asphalt mastic or cold bitumen emulsion.

The sealing of the joints in the paving elements has the purpose to preserve the edges of the cubes by smoothing, but overall to make them impermeable to water infiltration: thus avoiding the devastating drawbacks due to frost and the erosive action of the same on the sand, with the consequent destruction of the mantle.

4.3.6.1. Sealing with hot bitumen

Occurred the settling of the tile stone and, if necessary, after being washed with water jet or air pressure, the joints are sealed by pouring into them the bituminous mastic, previously heated to about 160° C in small portable boilers. For such process, we use a specially prepared funnel, or a special spout cup. Then we continue to the coating of a very thin sand layer on the surface.

This type of bonding is no more used for the following reasons:

1) high cost of implementation;

2) high cost of bitumen (amount necessary about 3 Kg/m^2 - 4 Kg/m^2);

3) bitumen traces on the surface, only deletable thanks to wear over time in the event that the route is subject to an intense traffic.

4.3.6.2. Sealing with cold bitumen emulsion

This type of sealing, despite it is less expensive than the previous and its implementation is less complicated, is now little used. With respect to the hot bitumen, the bitumen emulsion has the disadvantage of being easily absorbed by the underlying sand. Lying cold on the cubes pavement, not impregnated with moisture, it is introduced into the joints until completely saturated, using large brushes. The sand firstly and then the sawdust are used for the cleaning of the surface.

We recall that the bitumen of the mixture (about 55% by weight) and the water (about 40%), having to remain stable, before laying, require the addition of emulsifiers in small amounts (about 5%). The emulsion break occurs at the moment when it is introduced in the joint, and the water evaporates; we have to use not very hard bitumen. The cold bitumen emulsions have the advantage of being achievable in a simple way and also in adverse atmospheric conditions.

4.3.6.3. Sealing with asphalt mastic

Sometimes the joints were sealed by pouring in them mastic asphalt, that is, composed of a mixture of bitumen (about 50% by weight), sand and filler (about 50%). Its composition varied from place to place; for example in the mountains it had to be more fluid and therefore contains a greater amount of bitumen. Outside Italy was also used a putty consisting of bitumen and sawdust (or cotton). It was prepared in small portable boilers, inside which the bitumen previously heated to 160° C, the sand and the filler are poured; the whole was subsequently stirred and heated to 160° C / 180° C.

4.3.6.4. Sealing with cement grout

It is a very pasty mixture with equal weight dosages of sand (to fine and uniform grain), water and cement.

For sealing joints, this mixture is spread on the pavement, using the brushes, up to fill the joints. Depending on the climate of the area, the season and the weather, the grout, so as to begin the grip, must be left to rest for 60/120 minutes, then with a jet of rainwater and with the help of brushes, the surface of the pavement is cleaned. For thorough cleaning, we must sprinkle the water impregnated with sawdust on the surface, then we must wipe it with stiff brushes; procedure which is then taken up with dry sawdust, up to obtain a good cleaning of the pavement.

A thorough cleaning must then be reserved to the drains, to the wells and to all discharges in general, in order to avoid that the grout present in them solidifies.

Today tile stone cubes are made very rarely in roads subject to fast and/or heavy traffic, with the exception of the existing ones that need a set of operations to keep them in efficiency and in good condition (maintenance). For this practice it is almost habitual, both for small jobs and large pedestrian areas, to use the method shown below.

4.3.6.5. Pose in a bed of sand and cement and sealing with cement grout

For the success of the pavement, the following implementing rules must be observed:

1) the laying bed of the cubes must be made dry, with sand and cement equal to 200 Kg/m^2 of a mixture. This mixture should be homogeneous in order to avoid that the pavement, with the passage of time, have lack of uniformity as regards the strength and the waterproofing;

2) Items must be stored dry on that layer;

3) finished laying the pavement, we use the vibrating plates to make a small beating;

4) the cement grout, prepared in the already seen previously manner, after being poured onto the pavement, must then be spread by the aid of rigid brooms; the latter operation must be executed in a workmanlike manner, in order to fill each joint. At the same time, in such way, the mash goes to wet the underlying layer of cement and sand;

5) after 30/60 minutes after wetting pavement, the concluding vibration should be performed;

6) finally, the cleaning of the pavement must be performed: firstly by using wet sawdust and then dry one or somewhat less effective with the water spray.

This method, compared to the previous one, has the advantage of combining the cubes, the sealing and the layer of underlying pose. For the success of the outlet, it is essential that the whole process of installation, beating and wetting (deposit and circulation of the grout) is completed, whenever possible, on the same day and in optimal climatic conditions (high temperatures excluded) also in two or three days.

The above operations must be carried out in a rather limited time, thus avoiding possible discontinuity of cementation between the layer of laying and sealing. And it is an effective expedient because it tends to reduce the degradation of the sealing and to increase the stiffness of the pavement. The permissible extent with the intervals between the various operative phases is obviously closely related to weather conditions (temperature, humidity etc.), which decisively affect the gripping of the cement conglomerate rates.

We note that, in a stretch of roads with considerable slope, only after having completed the entire pavement is realized the sealing of the gaps, in order to avoid that the grout and the water used for its washing go filling the mantle placed more downstream.

4.3.7. Stone pavement between rails

Tramways are communication lines by tram in urban and suburban areas and rails are in stone pavements so that they can be crossed by road vehicles. Even in a tile stone pavement, we can insert these lines provided that the pavement adopted is rigid or flexible and made with unique characteristics. The most used one is certainly the elastic armament whose sleepers are arranged on the ballast.

Unfortunately the elastic armament used may give rise to the following two drawbacks:

1) undulations of the pavement between the rails, determined by certain differentiated defection and gravel sleepers interposed between them;

2) a general failure of the tramway track (ballast and rigging), with depressions of the transverse profile of the pavement and the resulting stagnation of water even for large spaces.

The first construction defect can be avoided by adding sand to crushed rock of the ballast; the so obtained mixture is compacted between the sleepers, using mechanical mallets, in order to increase the density and consequently its resistance to be cut. A layer of lean concrete is then spread over the roadbed and the sleepers, containing cement in an amount equal to 150 Kg/m^2 of concrete, in order to adapt the floor on which the cubes will rest and also to make impossible the dispersion of the sand layer.

To avoid the second constructive defect, the ballast gravel must instead consist of compact (not affected by atmospheric agents or corrosive substances, non-fractured, with low porosity, not freezing and that is that not tend to crumble for the disintegrating action of freezing etc.), tough elements (resistant to breakage by shock), suitable to maintain the original angularity, not lose powder etc., a good coefficient of internal friction and a certain density. Moreover, the special grooved rails, used in tramways, must be kept at a height slightly greater than that of the pavement in cubes.

To obtain a satisfactory distribution of stresses to the pavement, thus avoiding ruinous equipment transformations, at the two sides of each rail are placed courses of binders or other stone elements of further measures than those of the cubes.

Nevertheless, as a result of the significant stresses transferred to the pavement due to the ponderous tramcars that must transit, we should resort to the tile stone, at least in the area of the tracks, with elements of appropriate and relevant thickness and stone with distinctive features.

4.3.8. The pavè

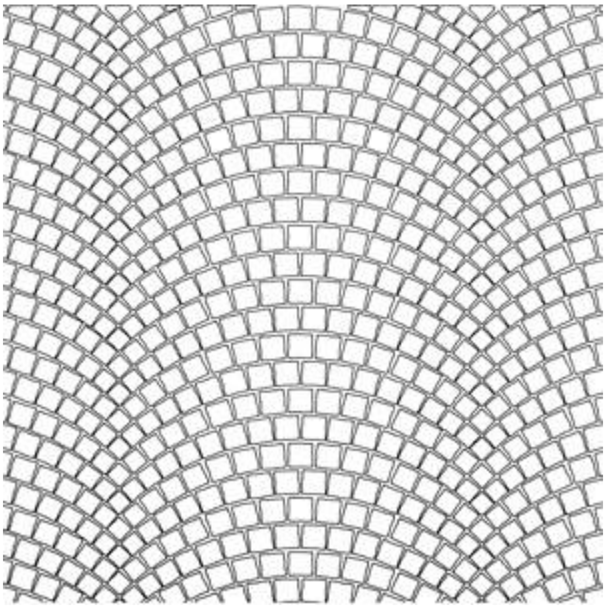


Fig. 4.9. Pavè

It is a tile stone, with tiles of larger dimensions, typical of northern France, Belgium, Members of Northern Europe in general and some places of Liguria.

The dimensional characteristics of the elements are the most various, but the ones used at most are the driving surface with roughly square of side 14 cm and height of 20 cm. The elements with the face in the rectangular view are also quite used and as regards the equipment, we prefer the arrangement in parallel and staggered courses.

Usually, as a material, we employ the granite, sandstone siliceous (sedimentary rock composed of sand cemented) and quartzite (hard and compact metamorphic rock, consisting primarily of quartz); the upper part of each element coincides with the plane of pioda.

The elements are placed on a layer of sand, or in the ways already explained about the other pavements.

The pavè, being provided with a very rough surface, is very used in road paths of considerable slope and located in areas with humid climate and frequent presence of intense cold with consequent formation of ice.

For the already previously highlighted special features, the running surfaces of the furnaces car steep roads performed in such a way do not need to be machined in the tip or chisel.

4.3.9. Pavements with smollers

Fig. 4.10. Pavement with smollers

The pavements, performed with porphyry smollers, have a significant roughness. If these elements are used for coast, the pavements in a remarkable way increase the number of joints and, consequently, the adherence of their road surfaces: thus making them suitable for any route, especially those which have steep slopes and which are in mountains, where frost and snow are present for many months a year.

The size of coarse tiles are: random length, 8 cm - 13 cm width and 3 cm - 10 cm thickness; thus they have a much more elongated and thin shape of the elements used in the cobblestones.

While not used items of uniform dimension, such pavements can be included in the grouping of the pavements.

4.3.10. Tiles arranged in modules for pavements

We often use forms in cubes, suitably compounds in the plant, in order to expedite the work of the installers in the construction of the tile stone, with the consequent decrease of costs.

Such models are produced in series with the aid of the prepared molds in an appropriate manner, on their bottom a layer of concrete is coated and then the cubes are placed, following predetermined patterns,.

Fully set, the modules are released from the armors (unarmed) and transferred to the place of destination to be put in place.

Using different pose geometries we can get several decorative elements (grounds); therefore, there are various shapes used to produce the modules, being closely linked to the distribution of cubes.

These modules, products in different shapes and sizes, are also provided with patent. Several of the above mentioned elements are executed in two different versions in order to satisfy each request; the most used cubes have the measures (cm) 5/7, 6/8 or 7/7 of the squares of travel or, less frequently, the values (cm) 8/10 or 10/10.

Colors and technical quality of the cubes obviously depend on the type of rock used. They are widely used granites (pink, white, red, yellow, and black), the porphyry (purple, gray and mixed) and the Bianco di Carrara.

The shape of the module dictates the choice of type of rock; cubes are also inserted in it, obtained from different nature stones, arranged in an ornamental pattern. Other times to make it more beautiful and more attractive, pavements of different color and forms are prepared, using cubes made from different types of rocks.

4.3.10.1. Construction of the pavement using tiles arranged in modules

In relation to expected traffic, the climatic conditions of the place and the nature of the ground, the implementation of these elements, from the plant, is carried on a layer of concrete or on a ballast (gravel and sand compressed). This procedure is similar to that already described for the pavements:

1) the top surface of the subgrade is kept at a lower rate of 6 cm/10- 12 cm above street level; it is also envisaged that the laying surfaces for water drainage have an adequate slope;

2) a further layer of dry sand and cement, mixed together in maximum ratio of 100 Kg of binder for 1 m^3 of inert, is arranged below the modules. To level this layer, a lower proportion of 3 cm - 8 cm to the viable plane (in

relation to the thickness of the module to be placed) makes use of a straight edge, that is, of a rod of wood or aluminum;

3) at the end of the installation of prefabricated elements, water is splashed on the pavement and the beating is carried out, using a suitable vibrating compactors. With this vibrator, provided with a plate that vibrates in the vertical direction, the road surface is compressed by subjecting it to repeated compressions up to a complete smoothing. This work must be carried out with the utmost precision in order to mask the joints between the modules, in order to make it look like a normal pavement. In covered walkways should be placed above elements with mortar and cement;

4) according to the information given to the pavements, the seams are sealed with a very soft grout, fine-grained sand, cement and water mixed in equal parts. We should also have extreme care to ensure that we achieve the global saturation of joinings. This process can be improved by adding appropriate chemicals (acrylic) to the above mixture.

Sometimes joints are also sealed spreading very thin sand on pavement, which is then sprayed with water in a large quantity in order to make more easy the introduction of the same in the interstices. In doing so, however, they create the unevenness with the joints sealed with cement grout;

5) at the appropriate time, the cleaning of the surface layer is accomplished carefully, through splashing water suitably oriented, or by the aid of a machine equipped with revolving sponge. Eventually the tile stone is rub firstly with water and then soaked dry sawdust. A meticulous

cleaning is well reserved for trap doors, cockpits, discharges etc., thus avoiding the grout in them, this is consolidated by closing them;

6) in relation to the weather conditions of the place, the pavement can be used after 5-15 days of its completion.

4.4. The flag stone

Fig. 4.11. Flag stone

The ancient Romans used the flag stone in the construction of military roads, but their massive use in the streets of urban centers came only in the Middle Ages and where, now, are still popular. This is due to the fact that these pavements have a remarkable strength and durability (even 7-8 decades), reduced maintenance costs and high artistic value, also obtainable by combining stone elements of different nature. However, they have two drawbacks: high noise and remarkable resistance to the motion of vehicles.

Pavements express a comparison parameter to analyze the level of cultural and material, social and spiritual progress achieved by the people. The cobbled certainly reflects the most progressive development with respect to that of the built viewpoint.

According to tradition the slabs are classified, according also to their sizes, as follows:

	Thickness	Lenght	Width
Thin	1-2.5 cm	60-70 cm	60 cm
Normal	2.5-5 cm	70-80 cm	60 cm
Gigantic	3-7 cm	80-90 cm	60 cm

As we can see, we use slabs of not exaggerated dimensions, in such a way as to best exploit the stone blocks that are extracted from quarries and in the meantime to try as well to avoid the phenomenon of rocking, which may occur when a mobile load is going to reach the edge of the element. The used material must not, of course, easily deteriorate due to the work of micro-organisms and to adverse conditions that are expressed by chemical actions, physical and mechanical (Chap. 3).

In this regard, the igneous rocks (porphyry, basalt and granite) are designed to last longer, then the limestone and sandstone follow for last.

At the end of the wear resistance, the behavior of rocks is represented by a classification similar to the previous one. The stone materials that have the best conditions are those which tend to retain the rough surface, while being subject to prolonged use; that is particularly so if the pavement is reserved for vehicles.

A careful selection of the rocks to be employed, of course, is closely linked to environmental requirements, beauty, resistance and consequently design ones. If feasible, the use of stone materials of the place is therefore cost-effective, because easily available and at lower prices (Chap. 5).

The square and rectangular sheets, of different sizes, are at present the most commonly used elements in flag stone; this according to the needs, the use and the type of used stone.

The major sides of the rectangular elements can also be major than 1 m and usually are equal to 1.5-2 times the lower. In the nature and the origin of the hypothesized traffic flow, the workability and the resistance of the used stone, the thicknesses of the slabs may vary from a few centimeters to 20 cm and more. Also we keep in mind that, for reasons of resistance to the stresses, the considerable extension plates are endeavored almost exclusively in pedestrian pavements. In fact, stone materials used in pavement have a high resistance to compressive stresses and a low resistance to those of flexion, traction and cutting.

Frequently the upper parts of the exposed surfaces are trimmed to chisel to a width of about 2 cm. These marginal or perimeter strips (bands), fine -

grain worked and denominated cords, are performed in order to ease proper installation of blocks, otherwise very complex for the roughness of these surfaces. Of course, such processing also regards the upper edges of the side surfaces. The sides of the elements, blanks using a large pyramid-pointed chisel, can be tilted inward, starting from mid-thick down, and overhanging of 2.5 cm; otherwise we can smooth the lower edges. For the installation surface we do not perform any roughing.

According to the stresses foreseen for the pavement, we will choose the type of working of the surface. So that in walking routes the surfaces are machined with a chisel or a bush-hammer (big hammer with mouth provided with pyramidal spikes) in order to obtain thin grooves suitable to ensure a valid water flow and at the same time to not make the movement impossible or uncomfortable.

In fact, for the accessibility, the running surfaces of the elements forming the pavement, must not have a height exceeding 2 mm, joints having thickness greater than or equal to 5 mm (D.M. 14 June 1989 n. 236). Even in road sections with very little motorized traffic is used to describe the type of working, to come gradually to the stage where grooves with a triangular section, even with depths greater than 10 mm, were on plates reserved for ramps. Usually the grooves are made obliquely, with respect to the direction of motion, in order to increase the condition of adherence limit.

Generally the marching of paved surfaces are machined in the following ways:

1) fine-tipped, 2 mm - 5 mm depth of the cuts;

2) mizzen pointed, groove depth 5.8 mm;

3) coarse tip, depth of the grooves 8 mm - 12 mm; carried out with the chisel and divided evenly.

The ordinary operations to maintain a appropriate flag stone thickness in efficiency and in a good condition, must be repeated over time whenever the machining of in-sight-surfaces are worn. Obviously, the roughness is left in pristine state also making possible the adjustment of the plates, following the general reduction of the height of the entire surface coat, which is often mizzen-tipped implemented, or in any way as the type of traffic demands. If the blocks have suitable thickness, routine maintenance can be performed several times without jeopardizing the overall strength of the pavement.

4.4.1. Implementation of flag stone technique

The subgrade usually is performed in a well-paved gravel and compacted by appropriate means.

Where the stresses are expected out of the ordinary, it is however required the use of concrete, sometimes also reinforced. Therefore suitable expansion joints must be provided from prevent cracks due to shrinkage, thermal expansion and flexing consequent to the loads. In order to exclude that the pavement may suffer considerable damages with the passage of time, as a result of the aforementioned stresses, such joints must be also provided in the stone surface, especially if of great extent. The stone elements are arranged on a layer of sand or mortar of suitable thickness. Obviously, the surface of the subgrade should be done in such a way to be perfectly parallel to that of gear, so that the thickness of the pose bed is constant.

Generally the thickness of the sand bed varies between 8 cm and 10 cm of dirt or gravel subgrade and 6 cm of concrete one, while its grain size should be well-matched and quite large. The plates are placed so that the joints are not larger than 1 cm, even with the aid of the chisel to adapt the hips and the grip edges.

Afterwards the pavement is washed thoroughly with a water jet, thus promoting the arena below fluidization and therefore the penetration of the same into the interstices and into any cavity. This process is eased by a proper beating of blocks, achieved with mashers or mechanical vibratory plate, with the utmost care not to damage the elements.

At the end of this operation, in order to equalize the exposed surfaces of the slabs, the very skilled workers in this area involved with the chisel.

In Veneto, Tuscany and many regions of southern Italy is very used the method of the mortar bed (or air or hydraulic binder) laying. This procedure is often used in the event that the pavement is affected by silty, clayey or in any case little compressible sand, ie whenever it is unavoidable to match the installation surface to the specificity of the soil.

4.4.2. The apparatus

Time ago, in the pavements of rolling stock routes, the oblique placement of the courses was privileged with respect to the axis of the road, thereby reducing the consequences of rocking and gasps. Moreover, the arrangement with inclined joints avoided that the metal wheels of vehicles transit along the joints, which are the areas in which they develop the highest stresses. In addition to direct actions on the edges, which are the most exposed and weakest parts of the pavements, the already mentioned stresses could originate as well the displacement of the slabs, with the consequent formation of tensions in their side surfaces.

The provisions of the inclined elements courses compared to the normal In the first situation the edges of the blocks, in correspondence of the joinings, is under less deterioration to passage of vehicles. Moreover, the number of end- axis of the road, most suitable and most used, are at 27° (1/2) or 45° (1/1). Jointed one, orthogonal to the straight line of the courses, is minor and the typical elements of sets (pentagonal pieces) with the same "width" cover less, so the stone is less wasted.

In modern times instead the arrangement of the sheets in the rows perpendicular to the axis of the street is preferred and that's because the wheels of vehicles are now equipped with elastic tires (hard rubber casings, reinforced with canvas, wire, or other). It follows the opportunity to select the best design solution as regards the visual needs.

These provisions of the elements enable fast and less expensive implementations, even for the lack of pentagonal pieces bias cuts.

Traditionally, the arrangement of the slabs, according to longitudinal courses, is generally used in walkways and sidewalks; instead the fishbone one is used specifically for large areas such as pedestrian squares or car furnaces, or may arise in the places where two roads are intersected with inclined equipment.

Each time when there is a project need, it can happen that we use other equipment with respect to the above one, for example in concentric squares and as well with blocks obtained by dissimilar rocks for quality and color.

Many other decorative reasons may be developed when the use of two or more slabs of uneven form, dimensions and colors is expected. In this case one person can resort to forms according to which a complex structure from the ornamental point of view is molded.

In addition to provisions, in part complicated, of the elements with repeated geometric patterns, with flag stone, we can make decisions that assume even complex decorative figures.

Flag stone can be used in blocks of various sizes; pavements made use small and medium elements; however, they offer superior resistance and the laying of the same is eased for their lower weight. We note therefore that, usually, the tile stone has a higher resistance and a pose in work faster than flag stone, made up of elements of remarkable measures.

As already seen for tile stones, even in flag stone quite complicated installation geometries and with appealing appearance can be chosen, if the sizes of the elements to be used are rather low. Whenever possible, the use of the flag stone is preferred as this type of pavement, because it has a considerable aesthetic value, excellent durability and reduced maintenance.

4.4.3. Implementation of the pavements in regular flag

A good solution, for the reasons listed above, may be to realize the flag stone with elements of small and medium size; a good example is the square or rectangular porphyry tiles, worked in various sizes (Chap. 5), mainly used for the pavement of the historical centers.

Based on the amount of stress required for the flag stone and relation to the extension of the exposed surface of the individual element, the above tile can be varied in length from 60 cm to 90 cm and thicknesses from 1 cm to 7 cm. The width is 60 cm.

The laying of the tiles is performed on a cement mortar layer of at least 4-5 cm, placed on a 15-20 cm minimum thickness concrete subgrade.

4.4.3.1. Procedure for the installation of the tiles

1) Indication (tracking) of the movement plans for an advance vision of convexity. To ensure the flow of water, the gradients of the flag stones, although they can be smaller than those of the tile ones, can never fall below 1%;

2) formation of the mortar, for which we resort to a mixture of sand, water and cement, equal to 250 kg / m^3 of conglomerate;

3) spread the mortar onto the subgrade;

4) hand-placing of the tiles on the mortar, with minimum distance between them of 1 cm, and with the benefit of a small rubber mallet (wad), or of a mason hammer, are secured in the same. To ensure that the laying surfaces are fully adherent to the mortar, it must flow back into the joints

between the elements. With the aid of a straight edge, we then seek to obtain, as far as is feasible, the perfect leveling of each tile of the pavement;

5) in the joints a fluid mortar rich cement (grout) is then poured in order to complete its filling them;

6) after a few hours, the mortar of the joints reaches a solidity such that we can clean the grout with the trowel and use iron and stripe to highlight the joints. To avoid damages to the pavement, the workers have to be very careful in doing this procedure. Indeed, the rough surfaces of dirty tiles dried cement, perfectly adherent to them and therefore immovable, become no longer fulfilling to aesthetic criteria.

We note that the tiles are separated slightly from each other because their edges, originated by mortar quarried stone, often have irregularities; this situation is therefore concealed by grouting into the grooves, thus improving the exterior appearance of the pavement. The pavement not always is made of tiles: they sometimes are used together with other variety of elements such as cubes, also suitable for carrying out frequently the gutters at the edge of the road, that is, in the contiguity of the platform cords.

The installation procedure is identical to that previously described.

We must not forget that the gutters, on the roadside, must have sufficient longitudinal slope towards the storm collectors, to make possible the waters drains. Tiled gutters, presenting very lower surface roughness than in cubes ones, in addition to encouraging the rapid flow of water, also form an elegant frame of the pavement. In the event that the same pavement is subject to vehicular traffic, especially heavy, the tiles must have a greater thickness for bearing any resulting increase. Sometimes, in the most demanding situations, they have put a row or two of binders (greater height) instead of tiles.

4.4.4. Trams entries

Through the presence of tram tracks in the roadway, the pavement is subject to considerable stress whenever the mammoth tramcars pass. In such situations the optimal mantle is formed from pavement with elements of appropriate and relevant thickness; in Milan, for example, we use a lot of granite blocks.

In addition to the flag stone pavement we can also choose the mixed mode one.

The latter is as follows: flag stone inside the tracks and along the outer edges to them for a 40 cm width, tile stone or other types in the remainder. The diversity of the side profiles of the rails and blocks forces the experts to place, among themselves, special hollow bricks and to use, in the meantime, cement mortar to make them consistent with the above elements.

The rails should protrude approximately 0.5 cm from the surface of flag stone, because they tend to fall for the settling of the subgrade subsequent to the frequent passage of the tramcars.

The equipments in 27 ° tilted courses, compared to the normal to the axis of the street, require, for each of them, the use between the tracks of two pentagonal elements and a rectangular closing. While outside of the rails, a row of pentagonal pieces per rail is put, adapted to generate the oblique courses.

If the route is in slope, the oblique courses are placed backwards, starting from the center line to the increases that border the sidewalks, for make it easier for the draining of the water.

Elements of limited size often are also used in flag stone, but with considerable thickness such as binders or sizes of the same type. This is a compromise between the tile and flag stone at the relevant elements dimensions that serves to ease the technical processing and the equipment running in certain special situations such as intersections, curves, etc.

4.4.5. Flag stone in uncertain work

The flag stone, implemented in irregular stone slabs, that is uncertain work, is characterized by an uncommon aesthetic. Such pavement is particularly suitable for the execution of pedestrian paths, such as walking surfaces in the green spaces, or sidewalks and is also advantageous from the economic point of view.

This pavement is however unsuitable for high vehicular flow paths, particularly if heavy, and likewise for actuations in cold and humid climates. It is altered because of the mortar sealing, with consequent deterioration of the support underlying layers. As repercussion, a certain fragility of the flag stone is originated in all its extension. Evidently the flag stone in uncertain work is also inadequate for accessibility. The types of rock, employable to realize this kind of pavement, can be the most vary because they depend on local customs and on availability.

Local stones always are widely used in the construction of these pavements, even taking into account their different characteristics of workability. In this regard it is worth mentioning flag stone in bulk with asymmetrical elements of sandstone, adopted in Florence until the mid-nineteenth century.

Even in this type of pavement, it is quite used porphyry and also spread to places far from those of extraction. Keep in mind that it is a very hard stone, very resistant to pressure and wear, no alteration.

The exposed surfaces of the porphyry elements are split slates and their implementation is done with the same method of the tiles and with the identical puttying and unthreading of the joints.

If the elements of the flag stone to uncertain work are of considerable size, up to a diameter of about 60 cm, they also take the name of palladian giant.

In this case the joints can be made through a cement grout drafting on the walking surface and a subsequent thorough cleaning with water-soaked rags. With this procedure is excluded the execution of the lining of the joints, to work concluded, they appear to hollow section, ie slightly open (or slaughtered). At the end, careful cleaning of the rough surfaces of the elements is performed to eliminate the presence of cement, in addition to the thin haze that worst the pavement and that with a low probability in the future will be eliminated from the elements and from wear and tear.

4.4.6. The pavement at "botanical stabilization"

In the spaces occupied by the urban parks and gardens (green spaces), the installation of the elements of flag stone in uncertain work, regarding the paths and the trails, can be at " botanical stabilization ". With this method, the various stone elements are placed on a small sand layer coated in turn on the surface of the ground, so assigning their cementation action of grass union.

In fact, the surface layer of the soil, interposed between the clearances separating the elements, is mainly made up of clumps of grass and roots; it gives solidity. Obviously in these types of pavement, both regular and irregular slabs can be used.

The walkways, the paths to uncertain work and in " botanical stabilization" have materialized in the way described below.

Along the path, a cut should be performed in order to eliminate the grassy rind to a changing thickness in relation to the elements one. Since the surface of the pavement slabs must be kept at a slightly lower level, 1.5-2 cm, in relation to that of the ground surface, and the layer of sand occupies a height of 2.5-3 cm, the excavation must be appropriately detailed.

The lowering of the slabs with respect to grassy terrain makes sure mowing grass with the mower, thus avoiding unpleasant mower breaks.

On the bottom of the excavation, subject to compaction, a layer of coarse sand is coated, subsequently leveled by a screed.

Higher extension stone elements must be placed on the lateral bands, while the others out of them; in so doing a higher resistance to the edge of the pavement is provided.

Interposing a piece of wood between the slabs and the pile, or by using a wooden mallet, settle of shots must be inflicted on their relatively delicate surfaces in order to collapse in the sand.

Such a procedure is interrupted at the moment in which solidity and the predetermined level are achieved. The standing surface is leveled by using the straightedge and possibly by acting, time after time, removing or bringing sand to the bottom.

The possible and considerable vacant forms between the slabs are filled by introducing other smaller elements through keystroke.

Then, using the broom, we progress with the spreading a sand aggregate and land of cultivation on the flag stone in order to make full the joinings. Then comes the seed of the herbaceous varieties reputed most appropriate, ie corresponding to the removed grassy rind in the internal part of the joints; we thicken and coat everything with a final layer of minute farmwand. Sowings are essential to the ultimate goal to making quicker the “ botanical stabilization " on the elements of the pavement.

We apply a similar procedure when the paths in the meadows are made with stone slabs placed at a " to pass " (" wading ") distance, also known as resolution of " lost steps ".

We observe that the operation should be implemented for each slab providing a vertical slit in the sward, along its contour line, through the use of shovel.

4.5. Sidewalks

Fig. 4.12. Sidewalk

Sidewalks belong to the broader set of areas reserved for pedestrians for the movement, the break and their meetings, the crossing of prams, strollers, wheel chairs for disabled persons and small transport vehicles towed or pushed by man.

We remember that squares and streets exclusively reserved for this purpose, sidewalks, paths and walkways are pedestrian areas.

For sidewalk, we mean that part of the street, closed within precise limits and mail the shelter or raised, that is outside of the road and is reserved for pedestrians.

Mostly the sidewalks are placed along the contour lines defining the architectural buildings of a certain size designated for residence or other public or private uses, so as to separate them from the driveway surfaces and thus to allow a convenient movement of pedestrians.

The pavement is achieved mainly through the execution of an eyelash not surmountable (or a curb) of not more than 15 cm height, which keeps the vehicular or cycle floor at a lower level than the pedestrian.

This will help persuade drivers of vehicles to not occupy the pedestrian paths. The sidewalk was put into use by the Etruscans and then taken by the Romans, but with the passage of time, it lost importance.

Although in Veneto, already in the sixteenth century, they were regularly used to perform the paving streets and related sidewalks, the actual reappearance of the same began only in the nineteenth century, coinciding with the replacement of the concave section of the street (" cradle ") with the convex ("humpback"), much more suited to the new, intense traffic flow, and with a most effective draining structure.

Today's sidewalks basically reflect the following two typical examples:

1) urban sidewalk of tradition, if it is located in proximity to the road;

2) the " American " sidewalk, if it is separated from the street through a strip of land, variable or constant transverse width.

We note in this case a clear separation between the driveway and the pedestrian path, although the union between the two is generally feasible in case of necessity. Such connection is achieved through the processing of the restricted central zone arranged to green, or with inconvenient pavements but in any case trafficable (special gratings, surfaces to pebbles, or similar deterrent effect measures). Despite the difference in level between street and sidewalk, many unruly motorists park their cars soaring over pedestrian shelf.

Also the pedestrian traffic sometimes is delimited, in particular in situations where an uncontrolled crossing could jeopardize a smooth flow of heterogeneous road users.

In this difficult situation it is possible to remedy through the reduction of the conflict area between those who drive motor vehicles, cyclists and passers-by, thus establishing better supervision of the crossing gates.

The above is achieved by using weaponry and artifacts of deterrence as small walls, balustrades, wayside, etc. Through an appropriate division of arboreal species, the "American" sidewalk certainly allows a better organization of the conflict surfaces. Nevertheless, sometimes, such a solution cannot be given for reasons linked to aesthetic and principles of interpretation of the project, but especially for the frequent lack of adequate spaces, especially in very developed urban centers.

Surfaces on a temporary heterogeneous use (crossings) and car parks, as well as those vehicular, bicycle and pedestrian ones are visually diversified.

The exposed surfaces of the stone elements, constituting the sidewalks pavements, must be non-slip, therefore, sanded items should be excluded and so those were obtained with the use of stones that become slippery (Chap. 3 and par. 5.3.).

The stone cladding of the pavement must have characteristics that allow easy cleaning and a viability made not difficult by sharp roughness, protruding elements, large voids etc. .

The sidewalks have mostly variable widths from 1.50 to 2.00 m and in any case never values below 1.00-1.20 m, to meet the requirements from disables. Nevertheless this size has to be more than doubled to coincide with delimited surface parts, where possible concentrations of people are hypotized , such as in case of very busy crossroads, in areas where it is necessary to separate in time the different pedestrians and vehicular current and spaces characterized by a large presence of street lights, signages, benches, tree-covered etc.

Sidewalks traverse inclinations, essential to the flow of water into the way, cannot exceed the limit of 1%; instead some time ago these slopes could vary from 1% to 5% and this must be remembered when we have to rearrange everything according to accessibility purposes.

The convexity of the roadways transverse profiles generally does not reduce much the comfort of vehicle users, while inclinations of 4% -5% of the sidewalks, or more generally the pedestrian areas, create in any way a nuisance factor for people moving on foot.

In the conception and execution of sidewalks, a particular care should be paid to the rules relevant to the accessibility, that is, with the removal of everything that impedes or physically and psychologically prevents the individual freedom of movement, but so particularly those people with disabilities.

For this goal, the sidewalks play a vital role. In fact, whether a specific category of disadvantaged users is able or not to make use of urban areas, depends from the degree of usage that they can provide. However, in general, any pedestrian is interested to which regards the containment of the danger causes and more comfortable use of city spaces.

Whenever, in the execution of sidewalks, we are in compliance with level differences (driveways or connections to the road surface), appropriate fittings must be provided in order to ease the crossing of pedestrians, in particular wheelchairs.

In the most basic situations, the above connections can be translated into reality through specific adjustments of the elevation profiles of viable pavements. But in more complex cases, prefabricated concrete elements or even better ones implemented in stone are used, because of their great artistic value, strength and durability.

We repeat that properly marked spaces and spaces in which pedestrian limits don't want to cross a busy street, ie walkways, closely concern the shape of the sidewalks, especially near the areas of conflict.

Always respecting rules accessibility, in case of significant arteries road affected by significant pedestrian steps, we can take extraordinary solutions such as subways, or overpasses. Usually, however, in the event of significant pedestrian crossings on routes in urban areas with normal traffic, appropriate measures are sufficient to highlight a condition of danger and, at the same time, to originate deceleration lanes. For this goal, the walkways have materialized relief to the level of the sidewalks and united to the road surface through tilted floors. This provision is intended to induce vehicle drivers to slow down the run and to increase the visibility of people crossing the street on foot. These bumps can be highlighted so good with the help of road markings, signages and luminous marks.

The presence of such deceleration devices (speed bumps), so as well typically that of the crossings, may be highlighted using a different pavement with respect to that of the carriageway; indeed, whenever feasible, it could be a continuation of the sidewalk. Obviously the visual differences need to be adjusted in order to generate, in the conductors of vehicles and in the passers-by, a more intense application of mind and some senses, because of the lack of continuity of space allocated by them. To further raise the level of attention of the urban road users, a rough pavement band is to be placed before each crosswalk, whose purpose is to warn drivers of vehicles to behave in an appropriate manner to the circumstances of a possible danger. A classic example can be provided by a pavement of the sidewalk resulted in porphyry cubes, or in granite ones, which followed in the zone destined to pedestrian crossing, with adeguate markings prepared with small white cubic elements, obtained by other types of stone as a compact limestone, Bianco di Carrara etc.

During the technical preparation of a sidewalk project and in the course of its execution, we should pay attention also to the existence of functional and decorative three-dimensional components (urban street furniture or decorative elements). These urban decor elements must be carefully examined, especially whenever their existence directly affects the pavement, both according to a perspective iconic and artistic optics, and according to the technical and functional one.

For example, plantations of trees along the sidewalks are certainly the more binding, for damages that may do when we don’t respect their necessities; damages caused by bad pavements, but first of all conceived and/or carelessly transformed into reality.

This concerns in particular the scarcity of soil permeability in the space surrounding the trees and therefore the consequent outcrops in search of the roots of damp sources (hydromorphysmus); the described phenomenon consequently causes the disconnection of the pavement stone elements.

The perfect choice on city streets, thus consists in placing the trees in permeable surfaces of suitable width, such as those adjacent to the "American" sidewalks.

However, this solution is often not feasible, because the leafy ones usually partially occupy the sidewalks of reduced width, thus making essentially impossible to increase the permeable origin areas of the individual trees. In such situations the permeable area should however be assured, avoiding to surround the bases of the trunks with waterproof pavements. The origin of the shafts surfaces are then protected by the movement of pedestrians through appropriate structural intervention, but at the same time able to allow them also a comfortable practicability.

For this purpose, is used especially to turnstile cover constructed in grilled metal, cast iron, elements prefabricated in concrete or with permeable pavement; these are typically performed by placing directly into the soil the stone elements used in the pavement sidewalk.

For this goal, the amplitude of the sidewalk is such to allow the protection of the soil that is around each trunk through the implementation of simple stone barriers, metal bollards etc. We often must protect the trunks with defensive structures (wood protection cages or metal baskets); appropriate solutions make possible the introduction of their posts in pavement or turnstile cover.

Sometimes the use of appropriate bollards barriers is inevitable for the purpose of prevent that the trunks are injured as a result of collisions of vehicles and damage to root systems, and for any recurring compressions often due to improper parking circumstances in areas adjacent to the trees.

Generally, specific parts of the technological services networks, necessary to the community, are placed in the soil located under the sidewalks.

Many times these structures (aqueduct, rain and waste water, gas, electricity, telephone etc.) are only dig out, so that every time we must take action to make a maintenance or a repair, we must make the removal of the pavement and a dig.

This last operation is very delicate and in whatever manner it has done, causes inexorably damage to the root system, sometimes the death of the same plant.

In turn, the roots may cause considerable harms to the aforementioned structures, due to the pressure arising from their envelope around them. If feasible, we remedied this problem by moving the layout of the excavation, a sufficient distance away from the trees. When this is impossible and, in particular, before a large number of technological installations, we make use of the gallery services.

We are dealing with an underground passage, which can be visited in order of inspection, with the technological systems in order to ease the speedy of repairers or of maintenance intervention.

At fixed points of the pavement the hatches (openings armed of closing shutters) are placed in order to place in communication the external environment with the underlying tunnel. We avoid in this way the excavations, very ruinous to the trees, and the removal of the sidewalk pavements every time we must intervene on the underground parts of the services networks; thus often yards openings on pedestrian and road beds are also deleted, bearing serious problems of their respective trades.

Obviously a major benefit regards the economic side of management, instead the invested amount for underground work implementation is abundantly cushioned with time.

The service tunnels were built in major foreign cities as far back as the nineteenth century; they should be seriously taken, during the urbanization, whenever we plan a high or medium density of technological systems: unfortunately in Italy this doesn't happen.

During the planning activity should be considered a series of elements, in order to determine the perimeter shape of the sidewalk.

The most important factors are certainly those that relate the arrangement of parking lots, when programmed. According to their positions (parking stalls in single or comb rows, 30 °, 45 °, 60 ° etc.), there are adequate cuts and appropriate provisions of the stone elements in the pavement (equipment) and specific decisions.

The parking stalls can be combined with the arrangement of the tree-lined streets, respecting the permeability of the soil space surrounding the trunks.

In public parking areas of large or average use, it is convenient to make use of impermeable stone pavements, with smooth surface and in any way with simple in-good-keeping and clean condition. In such cases some waterproof pavement and permeable ballast type, a gravel surface, etc. must not be taken into account.

They are instead recommended in limited use conditions, such as in the private parking or in the emergency, used at certain times of the year such as fairs, festivities, sporting events and so on.

In order to identify the areas reserved for parking stalls from the other, we use different surfaces by color, material and texture.

In designing the car parks, of course, we must respect the rules governing the accessibility, both as regards the number of reserved stalls, having peculiar qualities, and as regards a range of attentions and solutions.

The explication of the municipal service that takes care of the waste collection and street cleaning is an additional factor that affects the perimeter shape of the sidewalks and the management of the entire urban network in general.

Now the biggest obstacles encountered in the exercise of such waste services, are related to parking policies of motor vehicles. In fact, in general, considerable portions of the margins of the streets and sidewalks, where frequently debris and garbage are deposited, are difficultly accessible because of parked vehicles.

Thus the cleaning work is hampered to be implemented by hand, or through suitable equipped vehicles. Then there is also the inconvenience, often due to parking of vehicles in front of the large areas of solid waste containers (bins), placed in suitable recesses in the sidewalks.

Although actual technological evolution leads to rapid transformations of mechanized equipment for waste collection, it is indispensable for this purpose prepare a program defining the protected paths.

In Paris and other centers of great importance, unusual solutions are taken for cleaning the sidewalks and streets. In fact, this is done for washing with streams of water coming from the mouths of a pipe, laid on the steps of the sidewalks, thus allowing the flow in the manner of a time stream in the gutters placed along roadsides.

This ingenious device in addition to allowing the washing both of the edges road and the sidewalks, where the largest quantities of debris are accumulated, also allows that those involved in the trash can easily pile up the waste in the gutters, from the points where they are dragged into drains, or in any event gathered and collected.

In particular in the journeys of great importance both for the number of vehicles and pedestrians passing through in the period of a day, both for the historic and artistic interest, the car parks at the roadside should be eliminated, instead must be favored those on floor, underground or elevated. Where this is not possible, the opportunity to use the bollards or other facilities of deterrence must be considered, in order to induce the drivers of motor vehicles to park accurately.

The niches to be placed in the sidewalks, for stabling of bins, should be adequately protected with bollards barriers. Their arrangement on the edge of the roads should be done with great diligence, so as to promote their cheapest breakdown even in relation to the chain of the protected speculated waste collection routes using automated machines.

From the above discussion, it is clear that the designer is conditioned in the technical elaboration of sidewalks and related specific decisions to be taken, thus engendering the general urban improvement representation and the pavement efficiency of use and operation.

4.5.1. Sidewalks implementation

What is written earlier about the stone pavements undoubtedly also affects the performance of the sidewalks, despite we note that in the pedestrian paths can also be used variety of elements that offer a lower resistance than those subject to vehicular traffic. This concerns precisely the flag stone in uncertain work or especially that using large thin slabs.

Always respecting the local customs, the steps of sidewalks are obtained, usually, from rocks of considerable resistance such as porphyries, granites and travertino. We note that such elements, particularly their edges, are subject to various stresses and shocks resulting from the movement of vehicles.

Usually, the cords (or curbs) of the sidewalks have 15 cm basic rectangular cross section, 20-30 cm height and variable length, also molded according to a predetermined shape. The connections between two neighboring elements can be made through a pad of semi-cylindrical shape and the relative hollow seat.

The visible parts of the leads must be rough; in the event that the material used is the porphyry, the upper surface (or head) will have to be quarry splitted and the side in natural quarry floor.

In case of unfavorable weather conditions, the upper surfaces of the curbs will also be hammered, chiselled or flare-ups.

Into the curbs, we can also get the light well drains, through processing to the cutter or to the tip.

In the execution of the steps there is also the possibility of using binders, whose 10-12 cm thickness is less than that of the curbs, and the height from the road cannot exceed 15 cm, as provided by the rules.

The curbs and the binders must be laid on site using the following procedure:

1) topographic survey and tracking;

2) where it is needed, we run the excavation and then lay the concrete subbases for the installation of the elements;

3) these elements should be made to penetrate a little into the concrete, so as to remain slightly wedged;

4) the joints are strengthened by increasing the amount of concrete in their correspondence;

5) the joints are filled and drawn up with cement mortar.

The just mentioned elements can also be used to achieve frames of different types of pavement: vehicular, bicycle and pedestrian. For this purpose, binders or elements are usually handled, having a reduced cross section in relation to that of the curbs, and are positioned on the floor. The laying in work procedure is in any event that previously exposed.

The protection of pedestrians from vehicular traffic, as there is no step, can take place using other types of bollards, such as curbstones.

Type of pavement	Sizes(cm)	Thickness (cm)	Use	Advantages	Disadvantages
Cobblestone	6,5-15,5 (diameter)	5-15	Pedestrian	Low maintenance Good appeal	Irregular surface High costs (55/80 euros per m^2)
Tile Stone	5-10 in length 5-10 in width	5-15	Pedestrian	No maintenance	Irregular surface High costs (35/70 euros per m^2)
Flag Stone	60-90 in length 60 in width	1-7	Pedestrian Carriageway	Quite reasonable costs	Medium maintenance Must be properly drained

5. USE OF STONE IN ROAD PAVEMENTS

Fig. 5.1. Alpine environment

Nowadays the use of stone in the pavements has always held to an artistic relief function. In addition, recently, there has been a gradual increase in the belief that the stones and the traditional laying techniques need to be used again. This is visible in many urban centers, where in the second half of the twentieth century there was an indiscriminate use of bitumen, both in walking routes and in those ancient and modern driveways.

The current market also offers us innovative processes and new types of installation of the stone elements. The rock types are used of various kind, according to the area of origin of the quarry pebbles, river or sea, are still used to create mosaic pavements.

In principle, the most used materials are porphyry, basalt, granite and the allied rock types, compact limestones, marbles, sandstones, stones and pavers for interlocking concrete pavements.

It is important to remember that the stone pavement have the advantage, in some cases, to reduce or eliminate the local waterproofing, city especially. Therefore their use brings benefits to urban vegetation and the microclimate.

5.1. Porphyrys

Fig. 5.2. Porphyry

The porphyries are effusive igneous rocks (or volcanic) which can have a various mineralogical composition. Their structure is porphyritic, characterized by large crystals immersed in a fund mass of the glassy microcrystalline type, generated by a solidification of the magma at different times. In general, these rocks are poor in magnesium, calcium and iron, but rich in silica (over 70%) and therefore have a high resistance to external agents, in particular at high temperatures. Porphyry comes from acidic lava flows that solidify on the surface. The change of state determines the contraction of the material, which is slit according to a square mesh netting. Beating the porphyry outcrop, it often breaks into cubes following the plot of fractures: these are used to construct the items pavement.

Among the most important we include the paleovolcanic quartz porphyry, ie of ancient formation; it has a composition similar to that of granite and variable color, often reddish brown or brown or greenish liver, light mottled. It is a very hard rock, very resistant to wear, compression (about 2000 N/cm^2), and little or nothing alterable; as already said, for the ease of being split second orthogonal planes, it is easily reduced into cubes.

The exposed face of porphyry remains rough, no-slip even when it rains. The pavement when subjected to friction, wears out the various elements in a different way because they are identified by a different hardness.

Typically the colors range from green to gray, red liver (approximately clear); but always with gray, pink or white pat.

In Italy there are large porphyry quarries: large quantities are produced especially in the Trentino-Alto Adige (95% of the total) and in the province of Brescia; it is the stone material most used in pavement.

Since the nineteenth century, the porphyry represent an element of urban setting. For several decades we have worked with large components and standardized forms.

5.2. Granites

Fig. 5.3.Granite

Granites are igneous rocks but intrusive (or depth massive) and emerge on a large part of the earth's crust. Their granitoid structure, that is characterized by large crystals of a different nature, is originated by a slow solidification of the magma. Quartz, mica and orthoclase are the main components of these acidic rocks.

Quartz is a mineral consisting of silicon dioxide, very widespread in rocks; it comes in large transparent crystals, colorless if pure, or variously colored.

Mica is the general name of a group of minerals, elements essential of many igneous, metamorphic and sedimentary rocks, consisting of aluminum silicates and alkali metals (strongly metallic and very electropositive character), often magnesium and iron, characterized by easy flaking in thin flexible sheets.

The orthoclase is a white or pink silicate of aluminum and potassium, elements being main point of many rocks; it flakes in two orthogonal floors.

It is in granite: the massif of Monte Rosa, Mont Blanc, the Grand Paradise, a vast area of northern Sardinia and the Gennargentu, the Aspromonte and the Sila. As we see, the granite rocks are very common, especially in the Alps; they are present in the province of Novara and of Aosta, while in Tuscany are located in the province of Grosseto and in its archipelago (Elba and Giglio).

The typical colors of granite rocks range from pink, to purple, to red, to grizzled gray (light or dark).

Granites, if healthy, are tough, compact, resistant to wear and to meteorological agents and have a breaking strength of about 2000 N/cm^2; they are very used as materials for the squared platform edges and flocks, are excellent for pavement. Therefore, similarly as the porphyries, granites are also characterized by a rough surface and a high quartz content, which gives them a high resistance to atmospheric agents.

In France and Germany the granites are quite used in paving jobs in cubes (up to a maximum side of 20 cm) with a rough surface (bush-hammered or flamed).

While we, in Italy, often use them in pavements tiles, where these elements are placed in parallel courses and their surface of gear machined in various ways (hammered, saw-floor, etc).

5.3. Marbles

Fig. 5.4. Marble

From the commercial point of view we define "marble" crystalline, compact, polishable, building and decoration rocks, mostly formed by mineral with Mohs hardness from 3 to 4, such as dolomite (mineral consisting of calcium carbonate and magnesium-white crystals), serpentine (made instead of magnesium silicate, color mostly green, with lamellar or fibrous structure) and calcite (UNI 8458).

This class includes:

1) properly so called marbles (metamorphic recrystallized limestone), the cipolline marbles (grayish-white marble with gray or green mica veins) and the calciferous;

2) the limestone alabaster (stalactites);

3) the dolomites, polishable limestone breccias (both are sedimentary rocks: the first consisting of calcium carbonate and magnesium, the latter formed by fragments of different stones conglomerates put together) and the limestones;

4) coils (are metamorphic rocks, usually in compact design and green, consisting mainly of serpentine);

5) the hophicalcites (serpentine).

The specific qualities of resistance to external agents differ greatly from one rock to another.

The Bianco di Carrara is common used in pavement because of its compressive strength values even higher than 1300 N/cm^2.

We note that among the main factors affecting the resistance, there is the percentage of moisture. In fact, laboratory tests are done on samples of the same material, dry and soaked with water (R.D. 2232/1939, art. 10).

However, we must keep in mind that the surfaces in view of the continuous marble pavements tend to wear evenly, even if properly processed (micro roughness), due to the passage of pedestrians or vehicles. In addition to cosmetic damages, the functional ones also appear, because the paths become more dangerous. The slipperiness of the pavement may cause, for example, a fall of persons or the loss of vehicle stability, especially during braking.

It follows that we should avoid flag stone, especially if the elements are large in size. Instead the small marble cubes, if they are inserted in pavements built in porphyry, granite etc., contribute to enhance the aesthetic as well as functional effect in the sector of road markings.

There are also several compact limestones that are particularly resistant to external agents, especially of a mechanical nature. For example, the Rosso di Verona sometimes has a compressive strength greater than 1600 N/cm^2.

The squares and streets of Verona are paved with this rock; the irregularities of the elements and the macro roughness provide the necessary grip to the transit of pedestrians, vehicles and animals.

Keep in mind that the aesthetic value of many Italian cities has historically based on the diversity of local stones and their respective operations. In this sense the pavements still retain, in many cases, these considerable value differences, in which the compact limestone and marble have expressed a specific role. Accurate searches, including laboratory tests, must be made in the eventual use of the mostly limestone structures marbles, particularly when they are used for large extensions, to test their modifications to all the atmospheric conditions (temperature, humidity, pressure) of the place and to the actions of chemical degradation due to air pollution.

5.4. Travertino

Fig. 5.5. Travertino

It is a sedimentary rock formed by evaporation of strongly calcareous water (rich in calcium carbonate) current to the soil surface that very often incorporates travertino leaves, fragments of branches or roots, mosses etc., with porous, hard, lightweight structure, weather resistant and it easily is cut into slabs. Limestone from the classic light yellow color (straw), white and gray. Today there is as well the production of dark color travertinos, such as the walnut (brown) which, used in combination with other travertino elements of different quality, or in different types of stone, give aesthetically appreciable compositions.

The travertino is less suitable to be used in construction of pedestrian pavements and driveways, especially if of large traffic, because it offers very little resistance to wear, thus tending to uniformly unfold and become shiny. However, it is much used to make beanpoles for flower beds, curbs for sidewalks, tiles and slabs for pedestrian pavements.

For an increase in grip and better look at outdoor buildings aimed for the circulation of pedestrians, animals and vehicles, the various elements must turn the vacuolar surface to the users.

Travertino has been and is used in pavement, especially in combination with other stones such as chert (sedimentary rock formed by microcrystals of silicon dioxide, generally very hard).

5.5. Interlocking concrete pavements

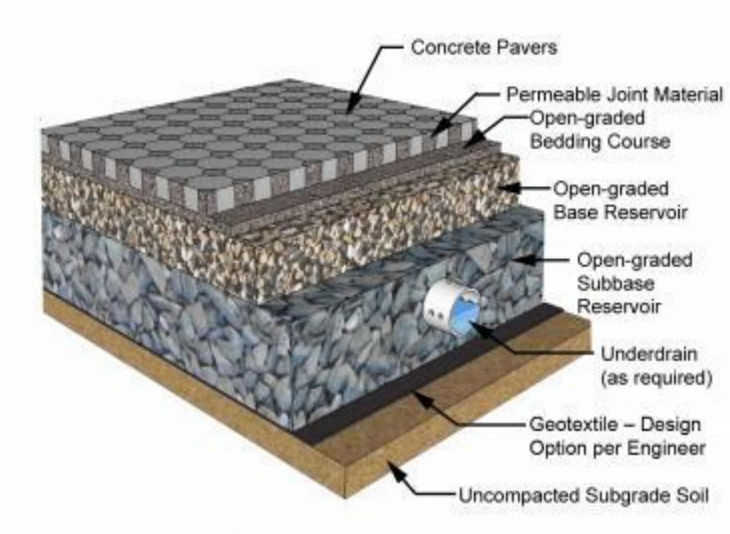


Fig. 5.6. Scheme of an interlocking concrete pavement

The pavement consisting of small prefabricated elements of concrete cement is defined interlocking because it achieves a system able to develop an effective distribution of surface loads through the support surface and the shear stresses developed between contiguous elements. The concrete pavement stones, for which the prefabrication process allows to specialize the geometric and mechanical characteristics but also coloring paste and weaving, have ordinary thicknesses comprised between 50 mm and 60 mm for contexts of pedestrian areas and greater thicknesses (80 mm to 100 mm) for roads with heavy traffic; they are often provided on the side surface with spacer profiles that ease posing by juxtaposition, while maintain constant and not excessive opening of the joints. The definition of optimal road packages thicknesses considered is generally obtained by a structural verification process of realization of assumptions that include a state of stress and strain of the pavement compatible with the resistance of the materials used and the bearing capacity of the subgrades. Often, the solid layer is reduced to the system of individual elements, which have an overall linear elastic behavior, connected by joints in the sand with certain flexural and frictional shear-induced stiffness, essential phenomena for the cooperation of the blocks.

The interlocking concrete pavements are suitable for all areas, from pedestrian to vehicular traffic, regardless of their intended use, including therefore extremely heavy load situations such as forecourts handling, storage containers, parking areas and taxiways at airports .

In the context of the streets, they find application in the areas for which the design speed is less than or equal to 60 Km/h.

The self-locking block of concrete pavement, through the modularity, the color, the variation of the surface texture, also plays a fundamental rule of the hazard traffic moderation function and the traveling speed reduction (traffic calming).

Material	Mass density	Compressive strength	Hardness
Granite	2500-2850 Kg/m^3	150-230 Mpa	6-7 Mohs
Marble	2500-2800 Kg/m^3	100-140 Mpa	3-4 Mohs
Porphyry	2600 Kg/m^3	100-250 Mpa	4.5 Mohs
Travertino	2400 Kg/m^3	45-90 Mpa	3 Mohs
Concrete	2400 Kg/m^3	10 Mpa	-

6. THE DRAINAGES

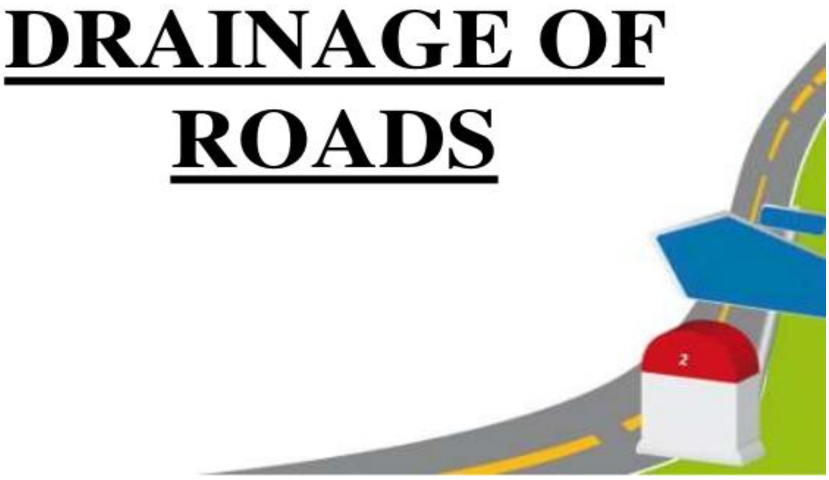


Fig. 6.1. Scheme of road drainage

Drainage is a rational way to get the rainwater flow through a system of ducts, pipes, wells etc.

Surfaces subjected to atmospheric precipitation (rain, snow and storm) are divided into natural and artificial. Drainage of natural surfaces regards the green areas such as grassy driveway surfaces and embankment, paths, walkways, as well as agricultural lands etc.

What it is of interest for us is the drainage of surface (artificial) pavements. Any work of engineering nature in the territory implies changes in the relative flow rates of ground and surface water.

Drainage of groundwater such as filtering (groundwater or vein), percolating and capillarity is something which must be considered as well. Therefore, as mentioned above, every time that we work in a certain area, the cyclic global water balance is subjected to a change.

The levels of the most significant impacts relate to significant changes in groundwater, the reduced potential recharging of reservoirs located under the ground, the floods and the destructive actions of surface slopes. So far, in the design phase, this aspect is often ignored and this has generated the unpleasant events above mentioned, especially in areas densely urbanized and whose territory is very waterproof.

Appropriate compensation works are therefore introduced in the current design and implementation, in order to improve the damaging changes caused thereby to the hydrological system of the territory.

For example, we must pay attention in the choice both of the water collection method and of disposal. In particular, we must have in mind the overall picture of the situation, also in correlation with the vastness of the area and a long period. All the considerations reported above must be implemented not only for big works, but also for those which are less relevant; studies and research, it is therefore essential to implement an accurate planning.

We note that the waters bring different consequences depending on the morphological (form and structure) and geological specificities of the soil, as well as the type of vegetation covering the area and the general situation of the respective catchment area.

With this terminology is meant a plot that, for its particular conformation, collects rainwater by conveying it in a stream.

In the past pavements and the respective sewers network were built based on experience; based on the type of pavements some adaptation to the quantity of water to be conveyed into the ducts have been implemented.

Moreover, in the handed down ancient custom, well the entire premises completing the top of a building to protect from rain, snow, sun etc. were implemented in different ways (pitched roofs, vaulted and flat) and with various types of material in relation to the entity and the essence of the most abundant atmospheric precipitation.

At present (as in the past) the pavement and the relevant sewerage system are planned and built with special qualities and attentions, so as to ensure good drainage in relation to the location and all of the weather conditions prevailing therein.

6.1. Hydrological budget and coefficient of performance

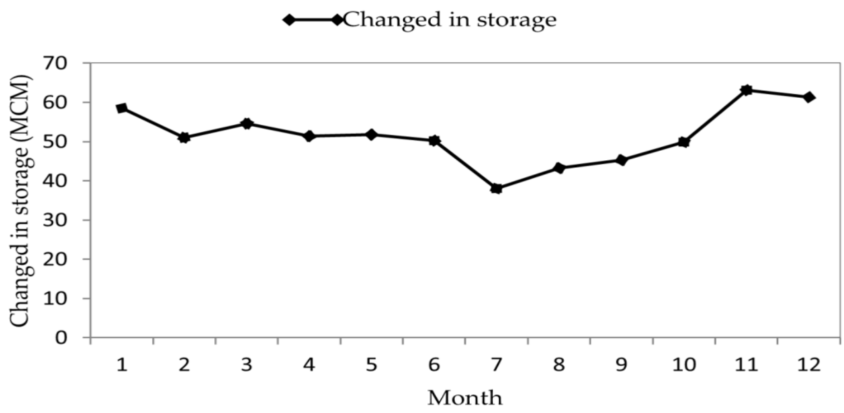


Fig. 6.2. Hydrological budget

Any human intervention in the urban environment should therefore not change the global water budget, or it rather must keep unchanged the characteristics and the quantity both of the surface water that reaches the canals, streams, rivers, lakes etc., and of that underground . To this end, we seek a theoretical almost nil runoff coefficient (ratio of the volume of water drained into the sewer and the influx of meteoric one).

Unfortunately any intervention increases a such coefficient with consequential reduction in percolation water absorbed by the soil.

In addition to scouring and erosion, this can cause flooding and therefore flooding due to the excessive competition of surface water. Exceptional weather conditions, intensity of rainfall, are certainly among the main contributing factors of the above phenomena.

Indeed, the presence of excessive quantities of water does not have the ability to attract inwardly more water than can receive according to its morphological characteristics, as well as the type of flora.

In this unfavorable situation, we try to remedy by resorting to pavements as possible permeable and green areas (parks and gardens), as well as adequate preparation of a spatial plan.

In case of a wide pavement, we still need to facilitate the percolation of water into the ground; in this way, the imposing complex system of pipes that convey surface water to lakes, sea or rivers and canals is avoided. This leads to a major reduction and alteration of the the natural water cycle.

The size of drainage pipes can be estimated via different calculation methods which considers the absorption capacity of the area hit by the rain. For example we can make use of the runoff coefficient (or absorption, or performance), defined as ratio between the volume of water drained to the sewer and the volume of liquid fell by precipitation.

It depends on the environmental conditions of the area and changes with the percentage of humidity, the average intensity of precipitation (increases with duration), with the seasons, with the state of the ground (if wet by earlier rains or dry) and with the nature of the draining area. The sections of the drainage ducts are dimensioned in function of maximum flow expected on average every 10-20 years and of a number of parameters, which given our purposes; we will not pause to consider.

We conclude by recalling that it has been highlighted the effects and links for consistency and quality, between the pavement and overall the hydrogeological system.

6.2. Section types and drainage systems

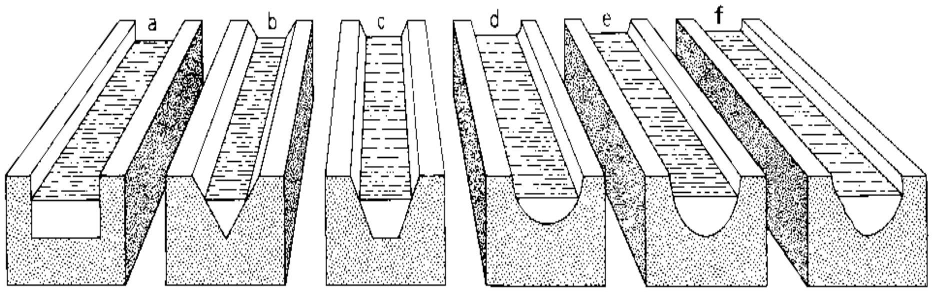


Fig. 6.3. Section types

The slopes of a pavement affect their compliance with the water and the system of drain functions programmed for their collection and canalization. The hydraulic system used to convey the water from the mantle of a road, a square etc. was earlier strictly tied to the size and shape of the elements, the type of stone and available equipment (such as in the realization of the dry cobblestones).

The discharge of water stemmed by a suitable profile of the cross section of the street. Urban roads had a "cradle" (or concave) cross shape; they collect the surface water along their center line, where the sewer equipped with trap doors or a channel of open-air gathering was placed. Instead the rural roads were equipped with a "humpback" (or convex) section, essential for draining off the water in their lateral ditches.

In the case of urban roads having concave cross section, with sewer conduit in the middle, frequently in the past they were expected of connections in the trap doors, performed through small transverse ducts.

In the time in which dry pavements were performed, the stone elements, or clay, which formed the already mentioned transverse ducts, operates the purpose of ensuring a greater extent of the water flow.

In the past there have been times when the sidewalk was not expected, then pedestrian paths placed along the edges of the streets were preserved by curbstones and equipped with a different pavement, often dirt.

With the reappearance of the raised sidewalks, the concave cross section of the cable has been replaced with the convex part, because it has greater resistance to vehicular stresses and because it eases the implementation of more efficient drainage. In fact, during the nineteenth century, due to the considerable urban and industrial development, it became essential to the separation between pedestrian traffic, more and more intense, and that vehicular, continuously expanding.

In the new " humpback " sections, the sewer retains the original central position. However, the collected water is through " falling mouths " trap doors, open on the raised side walls of the roadway, for pedestrians, and connecting the bumps placed under the edges of the sidewalks. The sewer arms (or transverse ducts) in turn led to the central underground sewage bumps.

An urban road can also be achieved by maintaining the sidewalks in internal slope, at the level of the convex transverse profile of the roadway. In this case the ducts in the view (or bumps), placed in coincidence of the watershed lines and provided with grilled manholes, are suitably fastened to the central duct with arms of the culvert.

6.2.1. Surface drainage

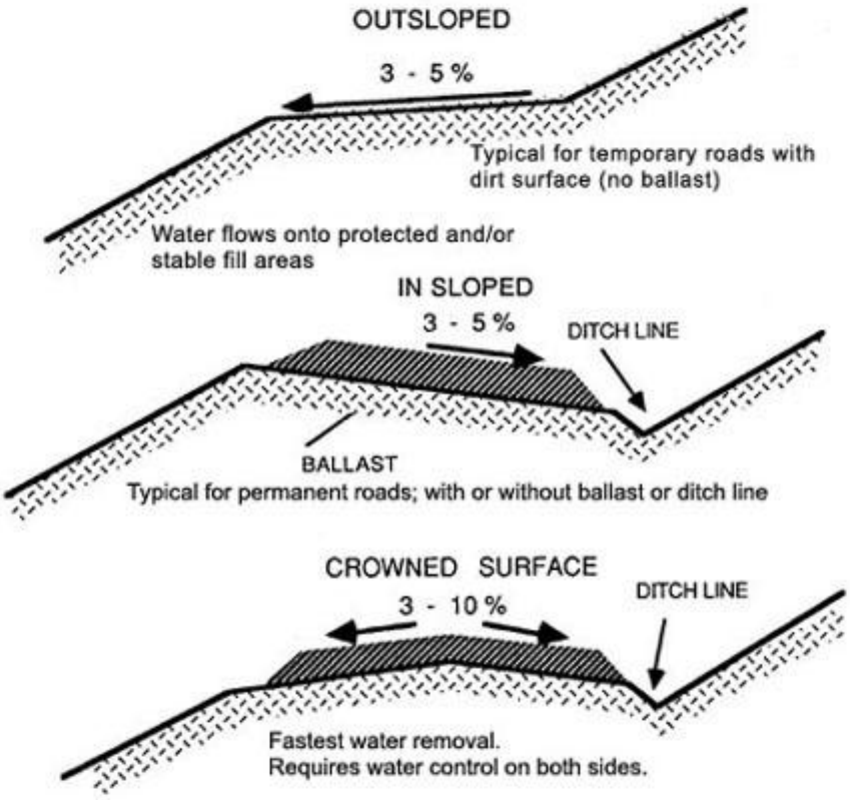


Fig. 6.4. Scheme of surface drainage

Pavements are equipped with surface drainage in order to collect through covered or open-air downspouts rain and washing water. Pavements are designed and built up with appropriate slopes, so that water disposal can occur in predetermined collection points and in such a way to avoid any stagnation zone; they vary with the type of use foreseen for the specific area, the quality of the material and the specificity of the device to be used.

For example, the pedestrian paths to be executed with pavement with stone elements (flag stone, tile stone etc.) should have approximately a minimum slope of 1.5% -2% and a maximum of 10% (8% for accessibility).

6.2.2. Surface waters downspouts

Pits, bumps and ducts with various form and size are major works, ingeniously devised, engaged in collecting and entering surface waters in preset positions.

Coating them with rough material (cobbles etc.) has an effect of water speed reduction during the crossing.

In case of glabrous surfaces, with spaced and less noticeable joinings, the speed of the water flow decreases instead of increasing. The ducts covered with continuous grid, commonly known as surface pits, in addition to be suitable to discharge the waters, allow at the same time the viability of the pavement. For the accessibility of the grills, the D.M. 236/1989 point 8.2.2, provides that the mesh cannot be bypassed by a spherical body having a diameter of 2 cm.

On road sections on slope, or down, pits, sleepers, as well as collector and disposer of the water sometimes are placed in the surface. Foresight to be used in all situations where a significant flow of rainwater is foreshadowed. If it were to drag along a large amount of rock fragments or other, the grilled would be blocked.

About the robustness of the street floor for vehicular and pedestrian movement, we briefly illustrate the DIN standards for drainage systems.

In order to simplify the task of the designer in selecting the most appropriate type of drainage, DIN 19580 provides a group of load classes (A-F: for traffic surfaces).

This provision deals with the drainage ducts (linear drainage), instead DIN 1213 and 19599 relate to pinpoint attacks (drains and roofs). DIN standards regard: standardization, manufacturing, characteristics and quality control. Such reviews will take the utmost account of the extreme variety of loads.

The different productions of the structural elements depend in an essential way by the intensity of the traffic, the speed and the load. Section 9.2 of the standard DIN 19580 requires that the elements of the ducts, in a position of use, are subject to a load test, as previously defined. The grids corresponding to predetermined rules must include the association's acronym DIN, the class and the trade mark.

Finally, the installation must be done in full compliance with the requirements issued by the manufacturer and required by DIN 19580, in order to avoid damages to the structural elements. Now let's see in detail the already announced load classes (DIN 19580).

Class A: traffic areas that can only be used by cyclists and pedestrians and comparable surfaces (eg grassy areas).

Class B: belong to it the covers for parking for cars, parking areas for cars, paths, pedestrian areas and comparable areas.

Class C: regards parking areas, pedestrian paths and rill ducts of roads.

Class D: refer to pedestrian paths and roadways.

Class E: affect traffic surfaces, passable by vehicles with heavy weights on the wheels and excluded to pedestrians.

Class F: refer to airport surfaces.

Linear drainages, produced in compliance with DIN 19580, are marked by a strong design and implementation zeal. The ideal material for the manufacture of the gutter body is the concrete of polyester because it is very durable, extremely lightweight and suitable for performing with extreme accuracy the essential projections to the connections for the different varieties of vertical drains and joints.

The drainage system consists of siphons, sleeves, drains, wells of various collection kinds etc.. Elements of fundamental importance, both from an aesthetic point of view and functional, are the covering gratings; a wide range of them is therefore produced in order to satisfy both the exterior figurative appearance and the respective load class. The materials generally used in their realization are the polyester concrete, fiberglass, cast iron, galvanized and stainless steel etc. Moreover, the grid can be in holes, cracks and to bridge; while its fixing can take place through integrated fingers or frames for the protection of the edges. The methods of laying, prescribed by the manufacturer, are also to be taken into consideration for outward appearances that serve to give shape; they depend on the variety of multiple ducts connected to the load class and type of pavement. In order to meet the needs that concern the design, subjective solutions are also allowed, for example as in the case of curvilinear raceways.

6.2.3. Water underground downspouts

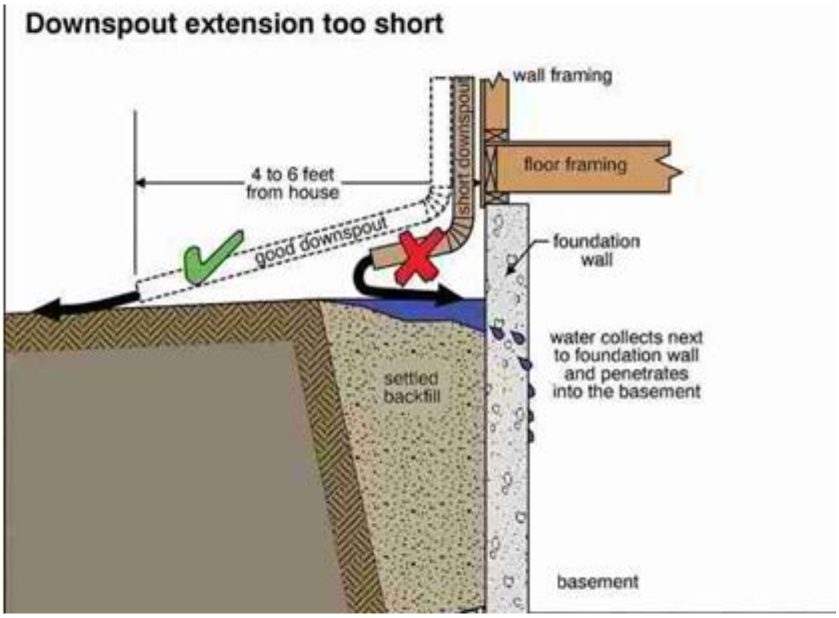


Fig. 6.5. Scheme of water underground downspout

Underground adequate slopes usually are used for pipelines discharging, into a stream, river, lake, etc., the waters flowing over the surfaces of roads. Harvesting structures, called storm collector or falling mouths, are built to connect through openings in the sidewalk curbs, gutters etc.

On the ducts some manholes are located equipped with a hydraulic siphon stopping fumes; in tree-lined or very dry streets, it should be flushed frequently. They are generally constructed in a less reinforced concrete cement. If feasible, we therefore recommend wells approximately 1 m deep and a horizontal square section 40 cm x 40 cm, such as to ensure settling in normal situations. In fact, in too deep manholes make the work of purge difficult and expensive.

Not only that, with the summer heat decomposition some organic matter settled can be generated, with fetid gas production. Both in terms of operation and of technical composition, the pavements are very influenced by surface ducts as well as those underground (Par. 6.2.). In confirmation of what has been said, we note that declivity, number, location and type of run-offs are items entered in an essential way in the realization of the historic paving stone and having to even seriously consider in the ongoing and future construction. This, in particular, in the event that a new intervention is foreseen in an original core of a city, which is typically the part of historical-artistic interest.

6.2.4. Storm collectors or falling mouths

Fig. 6.6. Falling mouth

The hydraulic system to be used to drain the stone pavement must be designed in such a way to adjust the number of drains to expected outflow flow in the ducts.

The falling mouths, of various types, are intended to collect the surface water: are built in concrete, brick masonry, or placed in prefabricated constructions. They frequently are called with the misnomer manhole.

They are accomplished through the openings, in the surface layer of the pavement, to be put in communication with the underground pipelines of the network and providing them with grids, variously implemented, such as to give continuity to the practicability.

On the other hand the accumulation of debris dragged frequently by the water occludes them, thus making essential a prompt intervention of clarity. Bearing in mind the climatic conditions of the place and the consequent cleaning cycles, the number of trap doors in the grid must be suitably increased compared to the real outflow capacity of the network.

In the streets equipped with flush sidewalks or in those with the "cradle", this type of drains is irreplaceable, despite presenting the above-mentioned drawback.

Urban pavements from past eras or made recently are also characterized by the features of grill trap doors.

The grids can have various shapes: round, square, rectangular, triangular, or other special shapes to be inserted in the best way in the different types of pavement, both aesthetically and functionally.

A unique situation is presented every time we use, in pavements with fan apparatus (Par. 6.2), embrasures in triangular grid, with a convex side and two concave, for their adequate accommodation between the elements.

The materials used to achieve the trapdoors in the grid are selected according to aesthetic criteria and requirements for resistance. Those most commonly used are stone, steel, cast iron, ceramics and cement-concrete (prefabricated elements).

In gardens and pavements reserved for pedestrians, traditional materials such as cast iron or stone usually are used to, for their aesthetic appearance.

Frequently also cast iron trapdoors in floors road are used, because endowed with a good resistance to stress, unlike those in stone and in particular so if subject to a intense heavy vehicles traffic.

Both the stone and cast iron gratings were attained with a variety of designs: parallel or concentric circular rectilinear slots, circular or square holes, star, daisy chain and in many other ways in accordance with the project requirements and tradition.

In the most common jobs, precast concrete grid will also be used, despite not having the strength of the cast iron and the value of the stone.

In meeting places, at open air, between sellers and buyers of goods (markets) and in all those situations where we require a fast flow of water and, with a continuous clarity as a result of a significant presence of debris, the drains are made. They are falling mouths with cylindrical configuration, with a protruding metal grid from the pavement and therefore unusable in ordinary vehicular and pedestrian areas, they will, however, lend themselves to easy cleaning and simple maintenance.

When, on the edge of the pavement, there are walls for counter or raised sidewalks, we can also build light well drains because they offer the advantage of not obstruct pedestrian and vehicular traffic. The vents are formed in their side surfaces in sight, at the base and at appropriate distances. In this case, the only drawback which may occur is the breaking of the curb at the openings, resulting, for example, from the stresses caused by the wheels of vehicles parked illegally on the sidewalk. In fact, they are not subject to the stresses affecting the road surface, do not have the breakage and deformation characteristics of drain grids. From this brief analysis we show that, as far as possible, light wells are preferable because we occlude less frequently than using gratings and, of these, have a greater potential disposal, so the result is a reduction in their number.

Nevertheless, in order to ensure a regular flow of water into the collection network, light wells must be expurgated frequently, especially in autumn with the fall of dead leaves or just after a violent storm. Undoubtedly the water running in the stream way, drags along, right into wells, materials of all kinds and flooding the viable venue that result can cause huge lasting years to the circulation, etc. The purge service is performed by suitable teams having a furnished vehicle for removing metal or stone covers, which close the mouth of the wells (manhole covers), the extracted substances and their transport. Very easier is instead the cleaning of drains grid, being sufficient the removal of the debris accumulated on them.

6.2.5. Manhole covers

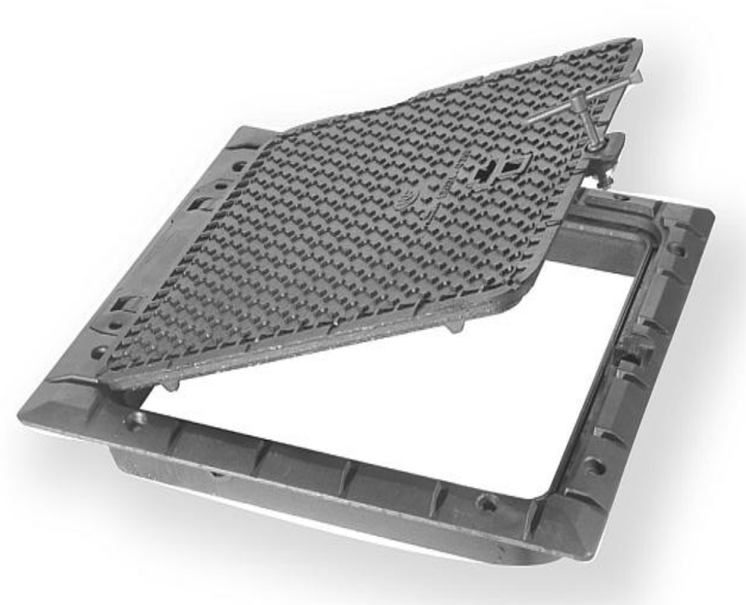


Fig. 6.7. Manhole cover

The manholes are put on the ducts at a distance of 50m - 80m in the practicable sewers, of 25m - 30m in the minor ones and wherever there are junctions or curves; they are covered by a manhole cover in cast iron or in stone.

The stone covers are certainly of much higher artistic value than the cast iron ones; however, they are generally excluded whenever relating wells subject to repeated checks, such as those relating to the light wells. Indeed their continuous removals can cause quite obvious breakage and chipping of the edges. Moreover, with their weight and their fragility, workers responsible for bleeding the system, or simple inspection, are found to play a full difficult job.

As a result, manholes, subject frequently to systematic checks, should be provided with cast iron manhole covers, because they are easily removable even by a single worker through a grapple to handle, to be introduced into the hole located in the center.

In facts, at present, they are cast iron manhole covers: products with rectangular shapes, 50 cm x 60 cm, and circular with diameter of 55 cm: their weight can vary between 40-50 kg, they are therefore easy to be handled.

The lifting of the stone manhole covers is much more complicated because it requires the intervention of some workers, of a little tackle help and of the levers.

We note that a square stone cover, 60 cm x 60 cm, and 20 cm thickness can weigh approximately 2 tons.

Nevertheless, they are employed because of tradition and their high aesthetic value every time when the wells are owned by large section ducts and therefore do not require repetitive checks.

Granite, porphyry, basalt and other rocks are not easily damaged by the freeze, hard, very resistant to compression and to abrasion and therefore suitable to be used for deriving the manhole. The same cannot be said for the limestones because they are a few resistant to wear and then to vehicular traffic, but still suitable for pedestrians.

Also manhole covers are implemented of different types in order to make them look virtually imperceptible to the human eye, in the pavement.

It builds a metallic container in which to place the pavement elements: frame and bottom made by using respectly steel profiles and metal sheets, welded together in a suitable manner.

Another possible solution consists in placing a thin slab of reinforced concrete directly on the predicted frame, in which to place the elements of the pavement in a predetermined order.

In the presence of pavement consisting of stone slabs, ie of flag stone, a single element or a portion can be inserted directly into the frame.

These types of covers, in addition to be generally very heavy, offer a reduced strength to the stress caused by the transit of vehicles. In fact, the frame of manhole tends to expand up to join the fixed one of the well; further adhesion which is then enhanced by the formation of rust on steel sections surfaces. Therefore, whenever there is the need to shake up the manhole cover, we encounter major difficulties and their use in driveways, therefore, is inappropriate. Instead these lids usually are used almost exclusively in pedestrian zones, particularly if paved with small and thus low weight elements.

7. MECHANICAL AND PHYSICAL CHARACTERISTICS OF STONE

Fig. 7.1. Generic stone road pavement

7.1. Physical Properties of Interest

Below we summarize the physical interest properties for road materials.

7.1.1. Mechanical properties

Describe the behavior of the material when it is subject to static and dynamic forces:

- stress-strain behavior (elastic, plastic, viscoelastic) and static strength (typically quantified by the yield stress and rupture);
- stress-strain behavior and high temperature static strength;
- resistance to indentation, scratches and abrasion resistance (hardness);
- impact resistance (resilience);
- resistance to fracture (fracture toughness);
- fatigue resistance.

7.1.2. Thermal properties

Describe the behavior of the material subject to temperature variations:

- Thermal expansion;
- Thermal capacity;
- Thermal conductivity;
- Thermal shock resistance.

7.1.3. Density

The density ϱ is defined as the ratio between the mass of the material and the occupied volume, typically expressed in g / cm^3. In cases where the weight of a component has relevance, one can speak of the specific resistance of the material, meaning the ratio of the magnitude that identifies the resistance and the density (for example, the specific breaking strength is the ratio between the voltage of rupture and density).

7.2. Technological properties

Technological properties describe the ability of a material to be worked to produce manufactured articles and/or to acquire certain properties.

7.2.1. Ductility / malleability

These properties relate to the attitude of a material to be worked by plastic deformation. The ductility and malleability are respectively refer to the attitude on the part of a material to be reduced into wires by means of traction and in compression by means of laminas.

7.2.2. Hardenability

It is the ability of a material to acquire greater hardness and mechanical strength through the process of tempering, consisting of a high temperature heating, but lower than the melting point, and a subsequent rapid cooling.

7.3. Features of stone materials

- Refractory character;
- High hardness;
- High electrical resistivity;
- Very low thermal conductivity;
- Good chemical resistance;
- Ability to manipulate the appearance through surface treatments;
- Fragility;
- High modulus of elasticity;
- Medium-high density.

7.3.1. Chemical-physical and mechanical characteristics of stone materials

Material is qualified by its physical-chemical and mechanical characteristics.

Chemical characteristics: the material must first be chemically stable, ie it must not be adversely affected by aggressive action of the environment. Typically the organic materials do not present a high resistance to chemical attack, while they behave better, from this point of view, those of inorganic nature. It constitutes element determining the porosity of the material, allowing an easier penetration of aggressive agents in depth and therefore a larger contact surface.

Physical characteristics: salient ones are the specific or apparent weight, the porosity, the soaking ratio, the hardness on the Mohs scale, the wear resistance, durability, thermal properties (linear expansion coefficient, flame resistance and thermal conductivity).

Mechanical characteristics: the modulus of elasticity, compressive strength, tensile, bending and impact.

In detail:

• The specific gravity can influence the choices of the pavement surface in the presence of statically precarious situations or when we do not want to load beyond a certain limit the attic.

• The rigidity is sometimes linked to the previous one aspect, since in general the material for heavy duty pavements are rigid, while lighter ones are elastic and flexible. Of elastic structures and read (eg. Wood), it is the appropriate the choice of a pavement with the same characteristics.

• The imbibition coefficient plays an essential role if the pavement is in contact with water. The organic and very porous materials generally have an absorption capacity which under certain conditions causes harmful effects. It is a decisive factor even if the pavement is exposed to thermal excursions, in fact, the water contained in the material, icing, increases of volume causing the surface disruption.

• The hardness (on the Mohs scale), the wear and abrasion resistance are essential in case of heavy traffic or associated with the use of mechanical means (ex. trolleys); it is the case of the public use premises (ex. municipal offices, post offices etc.). In this case a compact material structure, such as a porcelain stoneware tile (granite stoneware), it can offer considerable resistance guarantees.

• Durability is an aspect related to the previous since it implies that the characteristics of the pavement remain constant over time. The materials that provide firm guarantees are those able to defend themselves from attacks by the surrounding environment and the task address them. For example, a present granite under normal conditions of use increased durability sandstone. Such durability difference increases with increasing aggressiveness of the environment.

• The thermal properties are very important because, if there is no compatibility between the deformations of the structure and those of the pavement, to vary the thermal conditions of the surroundings, tensions are created which can lead to breakage of the surface coat.

• The fire resistance, for pavement materials, is generally required according to the safety regulations if not the total incombustibility (class 0), at least the non-active participation to the fire (class 1).

• The mechanical characteristics: using materials with excellent mechanical strength characteristics such as porphyries or the ceramic products in compact structure. If loads are too high and is deemed not compatible with the use of a coating layer, we resort to the concrete pavement with eventual additives and to distribute the loads, homogenize the layer and increase the flexural strength.

7.4. Cost

The cost of any stone depends on its intrinsic valuation in the quarry, the cost of quarrying and manufacturing, and the cost of transportation from the quarry to the worksite . The cost of transportation is often the most important, and this consideration frequently decides not only the choice of stone but even the type of construction - whether stone or concrete masonry. To give a rough idea of the cost of quarrying stone, a
few values are quoted from Gillette's "Handbook of Cost data." In one instance the cost of quarrying granite, exclusive of rental of plant, rental of quarry, and cost of stripping off the uppersoil, averaged about 4.24 euros per cubic meter. In another instance the cost of
quarrying rubble amounted to 1.69 euros per cubic meter. The cost of explosives was not included in this estimate, but it should not have increased the cost to over 1.88 euros per cubic meter. In another instance the cost of quarrying gneiss amounted to 3.35 euros, not including explosives and teaming. Even these items should not have made the total cost more than 4.00 euros per cubic meter.

In Italy, the granite usually reaches a price that varies from 40 to 500 euros per cubic meter, and this depends on the type choice: usually, Bianco di Sardegna is among the most economic types, the Azul Macaubas, among the most expensive ones. The porphyry, however, varies from 10 to 20 euros per cubic meter, depending on the thickness of the slabs, for the cubes, however, ranging from 15 to 50 euros per cubic meter, for the tiles from 35 to 200 euros per cubic meter. The sandstone from 30 to 50 euros per cubic meter; slate, based on the processing, has a price ranging from 30 to 60 euros per cubic meter.

7.5. Durability

Under many conditions the most important qualification is durability. Rocks have to maintain their hardness and roughness for many years under different weather and traffic conditions.

For example, a very porous stone will absorb water, which may freeze and cause crystals near the surface to flake off. Even though such action during a single winter may be hardly perceptible, the continued exposure of freezy surfaces to such action may sooner or later cause a serious loss and disintegration. Even rain water which has absorbed carbonic acid from the atmosphere will soak into the stone, and the acid will have a greater or less effect on many types of stones. Quartz is the only constituent which is absolutely unaffected by acid. The sulphuric acid gas produced by coal will also affect stone very seriously.

7.6. Fire

Natural stone is far less able to withstand a conflagration, more than the artificial compositions such as brick, concrete and terracotta. Granite, so popularly considered the main type of durability, is especially affected. Limestone and marble will be utterly spoiled, at least in appearance if not structurally, by the fire. Sandstone is the least affected among the natural stones.

7.7. Compressive strength

General rock failure criterion can be reduced to a few parameters dependent on lithology and the uniaxial compressive strength. Lithology is commonly derived during log analysis. What is needed still is an initial measure of rock strength provided by compressive strength. It can be estimated from porosity or sonic velocities, but many factors such as grain size, clay content, or saturation have significant influences.

7.8. Appearance

The presence of iron oxide in a stone sometimes could cause a deterioration in appearance by the formation of a reddish stain on the outer surface. It usually happens, however, that a stone whose strength and durability are satisfactory, will have a sufficiently good appearance, unless in high-grade architectural work, where it is considered essential that a certain color or appearance shall be obtained.

7.9. Hardness

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Some materials are harder than others. Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex; therefore, there are different measurements of hardness: scratch hardness, indentation hardness, and rebound hardness. Hardness is dependent on ductility, elastic stiffness, plasticity, strain, strength, toughness, viscoelasticity, and viscosity.

Common examples of hard matter are ceramics, concrete etc.

A scale for the hardness of minerals is first published in 1822 by Frederick Mohs, an Austrian mineralogist who formulated a scale by using a scratch-test that was used in mines. Scratch hardness is the measure of how resistant a sample is to fracture or permanent plastic deformation due to friction from a sharp object. The principle is that an object made of a harder material will scratch an object made of a softer material. When testing coatings, scratch hardness refers to the force necessary to cut through the film to the subgrade.

8. DESIGN METHODS

8.1. Design methods

The design of the pavement has originated a multiplicity of methods that can be grouped in:

• empirical-experimental methods: they derive from surveys on experimental sites and correlations between deformation or distances measured on the wheel track under imposed load conditions (number and weight of axles), the thicknesses of the layers, the characteristics of materials and subgrades. Results are presented as schedules, tables and equations interpolating the experimental data and can be used in the design phase. The most common empirical method is the one proposed from AASHTO (American Association of State Highway and Transportation Officials).

• Semi - empirical methods: derived from simplified theoretical analysis within which are introduced parameters and corrective coefficients to obtain the maximum correspondence between the theoretical model and the measured data. Among these, there is the method of CBR (California Bearing Ratio).

• Rational methods: the above methods have the advantage to be derived from experimental investigations, but they do not allow to take into account the real condition of the site. The rational methods are based on the elastic multi-layer theory or the finite element method FEM. The first, uses a series of simplifying assumptions, to deduce some simple equations solvable in an iterative manner. In FEM it surrenders to the absolute accuracy of the results outside of the finished element but at least there are no limitations in analyzing any load configuration, materials, constraints, etc. They require the determination of stress and strain in the critical positions of the pavement. The pavement fails because of fatigue or excessive rutting. The number of pauses, that cause the failure, depends on the tensile stresses at the base the bounded layer. Such tensions are bound by laws exponential experimental law to the number of repetitions to fatigue eligible. The verification of the pavement is carried out with the law of Miner checking that the sum of the ratios between the number of actual load repetitions and those eligible for each load level is less than 1. The permanent deformation control is usually carried out by limiting the tensions or the vertical compression deformation on the subgrade surface. These are cumulated according to the law of Miner.

The catalogues of pavement turn out to be very useful in a preliminary design, offering a series of prearranged solutions depending on the extent of traffic, type of subgrade, the type of pavement and road. In Italy it was drawn up by the BU 168/95 of CNR "Italian Catalogue of Road Pavement". All design methods take into account, as input data, the following parameters:

- Characteristics of the materials
- Design life
- Subgrade bearing capacity
- Traffic volume and loads
- Environmental conditions (rain, wind, etc.)

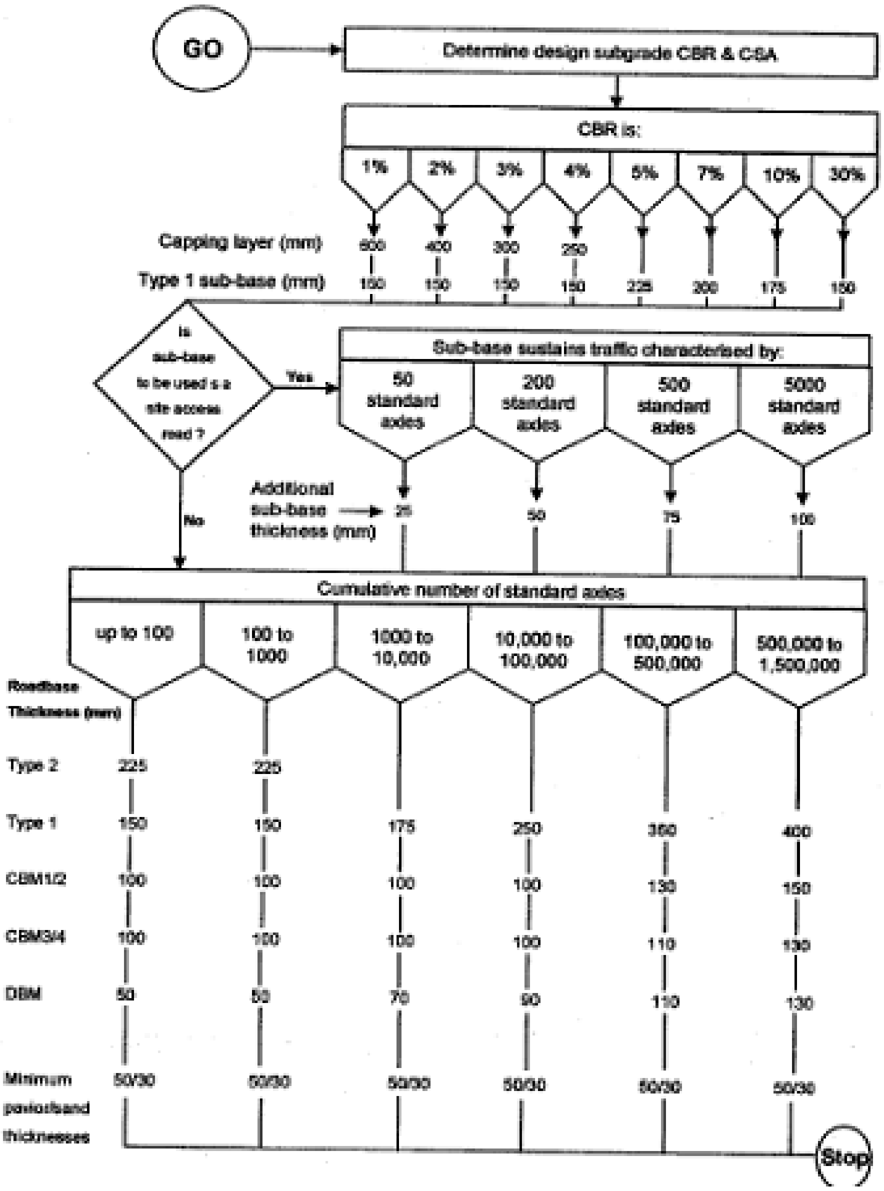
In this thesis, two empirical-experimental methods have been studied:

- The design method from I.D. Cook and J. Knapton
- The AASHTO method

With the aim to compare the results coming from the two methods, a design example has been performed.

8.2. Design guidance for lightly trafficked roads from I.D. Cook and J. Knapton

There are two distinct categories of lightly trafficked pavement. The first category comprises those pavements trafficked by relatively few heavy vehicles and the second pavements trafficked by vehicles no heavier than cars. We consider that these two cases should be treated separately and a design chart is therefore presented for each case:


GO
Determine design subgrade CBR & CSA
CBR is:
1%
2%
3%
4%
5%
7%
10%
30%
Capping layer (mm)
600
400
300
250
Type 1 sub-base (mm)
150
150
150
150
225
200
175
150
Is sub-base to be used s a site access road ?
Yes
No
Sub-base sustains traffic characterised by:
50 standard axles
200 standard axles
500 standard axles
5000 standard axles
Additional sub-base thickness (mm)
25
50
75
100
Cumulative number of standard axles
up to 100
100 to 1000
1000 to 10,000
10,000 to 100,000
100,000 to 500,000
500,000 to 1,500,000
Roadbase Thickness (mm)
Type 2
225
225
Type 1
150
150
175
250
350
400
CBM1/2
100
100
100
100
130
150
CBM3/4
100
100
100
100
110
130
DBM
50
50
70
90
110
130
Minimum paviors/sand thicknesses
50/30
50/30
50/30
50/30
50/30
50/30
Stop

Consider the design of pavements trafficked by cars and similar light vehicles. This allows the thickness of granular subbase material to be proportioned according to local ground conditions. In many such pavement it would be impractical to require that engineering tests are undertaken in order to characterize the ground conditions. Therefore a simple ad hoc test is proposed whereby the impression made in the subgrade by someone walking or pressing their heel into the ground can be used as a basis for design. Whilst there are obviously opportunities for error in this approach, it is preferable either to ignore the ground conditions or to specify detailed engineering tests which would rarely be undertaken. Some U.K researchers have developed similar guidance but have failed to take into consideration subgrade strength at all. It is important that a detailed "ad hoc" test in figure is undertaken when the soil is in similar condition to that which will persist during the design life of the pavement.

Perhaps the most difficult category of pavements to be designed are those that receiving a significant number of commercial vehicles with less than 1.5 m.s.a during the projected design life. The design chart shown in Figure has been developed for such pavements. It is similar in structure to design chart for heavily trafficked roads and indeed there is some overlap between the levels of loading considered in BS7533 (pavements constructed with clay, natural stone or concrete pavers. Code of practice for laying precast concrete paving blocks and clay pavers for flexible pavements) and those detailed in figure. However whereas the least trafficked category in BS7533 is 'up to 0.5 m.s.a., the design method in this chapter includes the following categories:

Category	Cumulative Number of Standard Axles (c.s.a)
A	Upto 100
B	100 - 1000
C	1000 - 10,000
D	10,000 - 100,000
E	100,000 - 500,000
F	500,000 - 1,000,000

As an example of the use of figure, consider a pedestrian area to be trafficked by three heavy refuse disposal vehicles per week. Assume that the pavement will be constructed over a soil with a CBR of 7% and that a design life of 15 years is required.

As a consequence, the number of heavy traffic vehicles on the pavements is:

$$T = 3 \times 52 \times 15 = 2340$$

Assuming that each passage of the vehicles applies 2 No. 8000 Kg standard axles, then the pavement receives a total loading of 4680 standard axles. A feature of the design method is that in cases where the pavement is trafficked by axle loads in excess of 7000 Kg: the calculated number of standard axles must be increased by a factor of 3. If, even with this factor applied, the cumulative number of standard axles is less than 100000, then 100000 standard axles should be used as the basis for the design. The purpose of two changes detailed above is to ensure that when relatively thin pavements are designed there will be no instances where a single passage of a heavy vehicle causes premature pavement failure.

Based upon the above and in this example the calculated number of standard axles is adjusted to 100000 giving a design section based on figure as follows:

Wearing Surface:	(200 x 100 x 65)mm chamfered clay paviors
Bedding Course:	50mm thickness of bedding course sand [3]
Road Base:	250mm Type 1 granular material
Sub-Base:	200mm Type 1 granular material

The pavement section determined above could be used as it stands or modified further. Recent research and development in pavement construction materials has indicated, for example, that the incorporation of some categories of "geogrid" material into the pavement section permits the subbase thickness to be reduced by 30%. This would give rise to the following section:

Wearing Surface:	(200 x 100 x 65)mm chamfered clay paviors
Bedding Course:	50mm of bedding course sand [3]
Merged Road Base and Sub-Base:	390mm Type 1 granular material
Geogrid:	Incorporated immediately beneath the sub-base

CATEGORY OF MATERIAL	MATERIAL CONVERSION FACTOR
Cement bound material 1 (CBM1)	2
Cement bound material 2 (CBM2)	2
Cement bound material 3 (CBM3)	3
Cement bound material 4 (CBM4)	3
Pavement quality concrete	4
Dense bitumen macadam	3
Hot rolled asphalt	3.5
Type 2 granular sub-base material	0.7
Subgrade improvement material	0.5

The use of this table allows materials included in the design process to be exchanged for alternative materials on a weighted basis assuming type 1 granular material has a value of 1.

For example cement bound material 2 (CBM2) has a material conversion factor of 2 which means that the 450 mm of Type 1 material selected in the previous example could be replaced by 450/2= 225mm of CBM2. Alternatively 300mm of granular subbase material could be replaced with 150mm CBM2 and the remanding 150mm reduced to 105mm (say100mm) if a geogrid material is used immediately below the subbase. This would produce the following section:

Wearing Surface:	(200 x 100 x 65)mm chamfered clay paviors
Bedding Course:	30mm of bedding course sand [3]
Road Base:	150mm of CBM2
Sub-Base:	100mm of Type 1 granular material
Geogrid:	Incorporated immediately below the sub-base.

In order to assess which of the alternative designs is preferred, a costing exercise would normally be undertaken based on the unit costs of materials and their associated laying costs.

Additionally the reduction in excavation depth consequent upon a thinner pavement could prove a significant factor in the cost analysis. The existence of statutory undertakers services close to ground level might also be a factor in the selection of a thinner pavement.

Whereas design procedures for heavy duty pavement have been used successfully for many years, designers have frequently been using inappropriate design procedures for lightly trafficked pavements. There are essentially two categories of lightly trafficked pavements: pavements trafficked by motor cars and vehicles of similar weight and pavements trafficked infrequently by heavy commercial vehicles. These two categories of pavement require an entirely different design approach and this chapter as developed and demonstrated two appropriate design methods. In the former case, design is simplified such that the only testing required can be undertaken by a layman. For the more heavily trafficked pavements it is necessary to make an assessment of the CBR value of the subgrade and the cumulative number of standard axles likely to be imposed on the pavement during the design life.

In the case of the lightly trafficked design method to accommodate heavy commercial vehicles, material conversion factors permit a wide range of design solutions to be compared and evaluated so that a "least cost" pavement can be specified.

It is concluded that the design methods presented in this chapter fulfill an important function in dealing with an area of design which hitherto could only be addressed by the application of inappropriate design methods.

8.3. The AASHTO method

In this paragraph an example of stone pavement design is performed. We are dealing with a local road:

Road type	Speed range (Km/h)	Heavy vehicle traffic (veh/week)	Type of subgrade	Design life (years)	CBR
Local road	40-70	3	Clayey gravel	15	7%

The design is performed with the AASHTO empirical method. For minor trafficked pavements, we take into account the CBR and traffic level estimated in number of standard axes.

The structural number SN is a parameter taking into account the structural pavement strength. It is related to layer thicknesses s_i, the material strength, represented by the "structural layer coefficients" a_i, and their sensitiveness to water, represented by the "drainage coefficients" m_i.

The analytical expression of the structural number is:

$$SN = \Sigma\, a_i\, s_i\, m_i$$

Where:

- i is the number of the layer in the road pavement;
- a_i is a coefficient that expresses the relative capacity of the materials used in the various pavement layers to contribute as structural components to the pavement functionality. These coefficients are related to the type and the property of the material.

Since the effect of water on bound materials is virtually null, m is set 1.

The AASHTO method doesn't provide any information about the equivalent coefficients that could be assigned to the stone wearing course.

Since we have 5000 standard axes passages during the design life, we compute such coefficient through this relation:

$$a_{B/S}=0.26+0.09\times\frac{t_p}{t_f}$$

Where:

- $a_{B/S}$ is the equivalent layer coefficient
- t_p is the design life
- t_f is the time in which there are 100000 standard axes passages

In this case:

$$a_{B/S}=0.26+0.09\times\frac{15}{30}=0.305$$

	Thicknesses cm (inch)	a_i	m_i	sn_i cm (inch)		
Stone	6.5 (3.27)	0.305	1	2.9 (1)		
Sand	3 (1.18)			0.9 (0.3)		
Base CBM	15 (5.90)	0.28	1	4.2 (1,6)		
Subbase granular material	10 (3.94)	0.12	1	1.2 (0,4)		
					9.2	SN (cm)
					3.3	SN (inch)

We are going to set a procedure defining the 8000 Kg standard axes number (W_{18}) that are foreseen to pass during the design life (15 years) related to availability requested (expressed through $Z_r \cdot S_0$) , the structural strength of the same (expressed through SN [cm]), the allowed decrease of the Serviceability Index (expressed through the ΔPSI) and the subgrade bearing (expressed through M_r [N/cm²]).

The equation making a comparison between the maximum standard axes number and parameters just listed is:

$$\log W_{18} = Z_R \cdot S_0 + 9.36 \cdot log\left(\left(\frac{SN}{2.54}\right) + 1\right) - 0{,}20 + \frac{log\left(\frac{\Delta PSI}{4.2 - 1.5}\right)}{0.40 + \frac{1094}{\left(\left(\frac{SN}{2.54}\right) + 1\right)^{5.19}}} + 2.32 \cdot log(M_r \cdot 14.19) - 8.07$$

Where:

- Z_r is the value of the standardized variable. For a low traffic road, we have an reliability of 80%.Therefore, in this case, Z_r = -0.841
- S_0 is the standard deviation taking into account the mistake that we commit in the computation of traffic volumes and in pavement performances. Since the stone pavements composed of discontinuous elements has a behavior similar to flexible pavements, S_0 is equal to the value defined for flexible pavements. It assumes a value between 0.4 and 0.5 and in this case we choose 0.45. Since Zr = -0.841, so the product $Z_r \cdot S_0$ = -0.378

- SN is the structural number.
- M_r is the effective subgrade resilient module. When there are not available measures of the resilient modulus, it can be calculated with the following formulas:

$$M_r = 1500 \cdot CBR \text{ (psi)}$$

Or

$$M_r = 10 \cdot CBR \text{ (MPa)}$$

In this case:

$$M_r = 105 \text{ psi}$$

$$M_r = 0.7 \text{ MPa}$$

- ΔPSI is the loss of present serviceability index. It is assumed PSI_{in} equal to 4.2 and PSI_{fin} equal to 2.5.

The conversion of the real vehicles in 8000 Kg standard axes is performed by transforming the axes of each vehicle in 8000 Kg standard axes. The coefficients of equivalence are obtained from the following expressions:

$$\frac{W_{18}}{W_x} = 10^{-A_i}$$

$$A_i = 6.125 - 4.79 \cdot \log(0.225 \cdot P_i + T_i) + 4.33 \cdot \log(T_i) + \frac{G}{B_i} - \frac{G}{B^*}$$

Where:

$$G = \log\left(\frac{PSI_{in} - PSI_{fin}}{2.7}\right) \qquad B_i = 0.40 + \frac{0.081(0.225 * P_i + T_i)^{3.23}}{\left(\frac{SN}{2.54}+1\right)^{5.19} \cdot T_i^{3.23}}$$

- B* is the value that B_i assumes for the 8000 Kg standard axes
- T_i is the axis typology and assumes the 1 value for single axes, the 2 value for tandem axes and the 3 value for tridem axes
- P_i is the axis weight [KN]

We are going to compute the standard axes number, by substituting the values described above in the equations:

$$G = \log\frac{4.2-2.5}{2.7} = -0.463 \qquad T_i = 1 \qquad P_i = 80$$

$$B_i = 0.40 + \frac{0.081(0.225 * 80 + 1)^{3.23}}{\left(\frac{3.3}{2.54}+1\right)^{5.19} \cdot 1^{3.23}} = 0,986$$

$$A_i = 6.125 - 4.79 \cdot \log(0.225 \cdot 80 + 1) - \frac{0.463}{0.986} + \frac{0.463}{0.986} = -7.979$$

Therefore:

$$\frac{W_{18}}{W_x} = 10^{-A_i} = 9.528 \cdot 10^7$$

$$\log W_{18} = -0.378 + 9.36 \cdot log\left(\frac{8.3}{2.54}+1\right) - 0.20 + \frac{log\left(\frac{4.2-2.5}{2.7}\right)}{0{,}40+\frac{1094}{\left(\frac{8.3}{2.54}+1\right)^{5.19}}} + 2.32 \cdot \log(0.7 \cdot 14.19) - 8.07 = 16.443$$

$W_{18} = 17872.2$

And

$W_x = \frac{17872.2}{9.528 \cdot 10^7} = 0.000188$

The pavement considered above bears a total load of 4680 standard axles that is minor than the maximum standard axes number that the pavement can withstand. In fact:

$4680 < W_{18} = 17872.2$

The pavement is verified.

Both methods verify the pavement. In fact with the first method, by knowing the load, we computed the layer thickness needed to withstand such stress; with the second one, by knowing the thickness, we confirmed that a so designed pavement could withstand even a major load than the one previously assigned.

Conclusions

My thesis took care to describe the road surfaces, with special attention to those in stone, by analyzing all the details that make up them and by highlighting the importance and frequency of use.

We discovered that there are three main stone pavement typologies: the cobblestone, the tile stone and the flag stone. For each one we highlighted characteristics, analysis and achievement methods, costs, advantages and disadvantages. The first two types are mainly used in pedestrian roads due to their irregular surface, while the flag stone is used both for pedestrian and vehicular use. Moreover the last one is cheaper than the others.

Afterwards, we examined the types of stone used in road pavements, by analyzing the compressive strength, the mass density and the Mohs hardness. For example, if we need to build an high compressive resistence stone road pavement, we will choose granite or porphyry.

Finally, we dealt with stone pavement design methods, particularly the empirical-experimental one, because, as we already said in the thesis, it is the most suitable for stone pavements. Through two methods belonging to this category, we designed an example of a light traffic local road.

The goal of this thesis is to give some important information about stones and stone pavements to an hypothetical designer, in order to plan an hypothetical project.

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