

# Road Construction and Technology



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## Chapter- 1

# Introduction to Road Construction

**Road construction** requires the creation of a continuous right-of-way, overcoming geographic obstacles and having grades low enough to permit vehicle or foot travel and may be required to meet standards set by law or official guidelines. The process is often begun with the removal of earth and rock by digging or blasting, construction of embankments, bridges and tunnels, and removal of vegetation (this may involve deforestation) and followed by the laying of pavement material. A variety of road building equipment is employed in road building.

After design, approval, planning, legal and environmental considerations have been addressed alignment of the road is set out by a surveyor. The Radii and gradient are designed and staked out to best suit the natural ground levels and minimize the amount of cut and fill.

Roadways are designed and built for primary use by vehicular and pedestrian traffic. Storm drainage and environmental considerations are a major concern. Erosion and sediment controls are constructed to prevent detrimental effects. Drainage lines are laid with sealed joints in the road easement with runoff coefficients and characteristics adequate for the land zoning and storm water system. Drainage systems must be capable of carrying the ultimate design flow from the upstream catchment with approval for the outfall from the appropriate authority to a watercourse, creek, river or the sea for drainage discharge.



A road being torn up



Surveyor at work with a leveling instrument



Asphalt layer and roller



Sub-base layer composed of cement-based material being applied during construction of the M8 motorway in Ireland.

A borrow pit (source for obtaining fill, gravel, and rock) and a water source should be located near or in reasonable distance to the road construction site. Approval from local authorities may be required to draw water or for working (crushing and screening) of materials for construction needs. The top soil and vegetation is removed from the borrow pit and stockpiled for subsequent rehabilitation of the extraction area. Side slopes in the excavation area not steeper than one vertical to two horizontal for safety reasons.



Road construction on Marquette Avenue in Minneapolis, Minnesota, United States

Old road surfaces, fences, and buildings may need to be removed before construction can begin. Trees in the road construction area may be marked for retention. These protected trees should not have the topsoil within the area of the tree's drip line removed and the area should be kept clear of construction material and equipment. Compensation or replacement may be required if a protected tree is damaged. Much of the vegetation may be mulched and put aside for use during reinstatement. The topsoil is usually stripped and stockpiled nearby for rehabilitation of newly constructed embankments along the road. Stumps and roots are removed and holes filled as required before the earthwork begins. Final rehabilitation after road construction is completed will include seeding, planting, watering and other activities to reinstate the area to be consistent with the untouched surrounding areas.

Processes during earthwork include excavation, removal of material to spoil, filling, compacting, construction and trimming. If rock or other unsuitable material is discovered it is removed, moisture content is managed and replaced with standard fill compacted to 90% relative compaction. Generally blasting of rock is discouraged in the road bed. When a depression must be filled to come up to the road grade the native bed is compacted after the topsoil has been removed. The fill is made by the "compacted layer method" where a layer of fill is spread then compacted to specifications, the process is repeated until the desired grade is reached.



Typical pavement strata for a heavily traveled road

General fill material should be free of organics, meet minimum California bearing ratio (CBR) results and have a low plasticity index. The lower fill generally comprises sand or

a sand-rich mixture with fine gravel, which acts as an inhibitor to the growth of plants or other vegetable matter. The compacted fill also serves as lower-stratum drainage. Select second fill (sieved) should be composed of gravel, decomposed rock or broken rock below a specified Particle size and be free of large lumps of clay. Sand clay fill may also be used. The road bed must be "proof rolled" after each layer of fill is compacted. If a roller passes over an area without creating visible deformation or spring the section is deemed to comply.

The completed road way is finished by paving or left with a gravel or other natural surface. The type of road surface is dependent on economic factors and expected usage. Safety improvements like Traffic signs, Crash barriers, Raised pavement markers, and other forms of Road surface marking are installed.

According to a May 2009 report by the American Association of State Highway and Transportation Officials (AASHTO) and TRIP—a national transportation research organization—driving on rough roads costs the average American motorist approximately \$400 a year in extra vehicle operating costs. Drivers living in urban areas with populations more than 250,000 are paying upwards of \$750 more annually because of accelerated vehicle deterioration, increased maintenance, additional fuel consumption, and tire wear caused by poor road conditions.

When a single carriageway road is converted into dual carriageway by building a second separate carriageway alongside the first, it is usually referred to as *duplication*, *twinning* or *doubling*. The original carriageway is changed from two-way to become one-way, while the new carriageway is one-way in the opposite direction. In the same way as converting railway lines from single track to double track, the new carriageway is not always constructed directly alongside the existing carriageway.

## Maintenance



Like all structures, roads deteriorate over time. Deterioration is primarily due to accumulated damage from vehicles, however environmental effects such as frost heaves, thermal cracking and oxidation often contribute. According to a series of experiments carried out in the late 1950s, called the AASHO Road Test, it was empirically determined that the effective damage done to the road is roughly proportional to the 4th power of axle weight. A typical tractor-trailer weighing 80,000 pounds (36.287 t) with 8,000 pounds (3.6287 t) on the steer axle and 36,000 pounds (16.329 t) on both of the tandem axle groups is expected to do 7,800 times more damage than a passenger vehicle with 2,000 pounds (0.907 t) on each axle. Potholes on roads are caused by rain damage and vehicle braking or related construction works.

Pavements are designed for an expected service life or design life. In some UK countries the standard design life is 40 years for new bitumen and concrete pavement. Maintenance is considered in the whole life cost of the road with service at 10, 20 and 30 year milestones. Roads can be and are designed for a variety of lives (8-, 15-, 30-, and 60-year designs). When pavement lasts longer than its intended life, it may have been overbuilt, and the original costs may have been too high. When a pavement fails before its intended design life, the owner may have excessive repair and rehabilitation costs. Many concrete pavements built since the 1950s have significantly outlived their intended design lives. Some roads like Chicago, Illinois's "Wacker Drive", a major two-level viaduct in downtown area are being rebuilt with a designed service life of 100 years.

Virtually all roads require some form of maintenance before they come to the end of their service life. Pro-active agencies continually monitor road conditions and apply preventive maintenance treatments as needed to prolong the lifespan of their roads. Technically advanced agencies monitor the road network surface condition with sophisticated

equipment such as laser/inertial Profilometers. These measurements include road curvature, cross slope, asperity, roughness, rutting and texture (roads). This data is fed into a pavement management system, which recommends the best maintenance or construction treatment to correct the damage that has occurred.

Maintenance treatments for asphalt concrete generally include crack sealing, surface rejuvenating, fog sealing, micro-milling and surface treatments. Thin surfacing preserves, protects and improves the functional condition of the road while reducing the need for routing maintenance, leading to extended service life without increasing structural capacity.

Failure to maintain roads properly can create significant costs to society, in a 2009 report released by the American Association of State Highway and Transportation Officials (USA) about 50% of the roads in the USA are in bad condition with urban areas worse. The report estimates that urban drivers pay an average of \$746/year on vehicle repairs while the average US motorist pays about \$335/year. In contrast, the average motorist pays about \$171/year in road maintenance taxes (based on 600 gallons/year and \$0.285/gallon tax).

## **Slab Stabilization**

Distress and serviceability loss on concrete roads can be caused by loss of support due to voids beneath the concrete pavement slabs. The voids usually occur near cracks or joints due to surface water infiltration. The most common causes of voids are pumping, consolidation, subgrade failure and bridge approach failure. Slab stabilization is a non-destructive method of solving this problem and is usually employed with other Concrete Pavement Restoration (CPR) methods including patching and diamond grinding. The technique restores support to concrete slabs by filling small voids that develop underneath the concrete slab at joints, cracks or the pavement edge. The process consists of pumping a cementitious grout or polyurethane mixture through holes drilled through the slab. The grout can fill small voids beneath the slab and/or sub-base. The grout also displaces free water and helps keep water from saturating and weakening support under the joints and slab edge after stabilization is complete. The three steps for this method after finding the voids are locating and drilling holes, grout injection and post-testing the stabilized slabs.

Slab stabilization does not correct depressions, increase the design structural capacity, stop erosion or eliminate faulting. It does, however, restore the slab support, therefore, decreasing deflections under the load. Stabilization should only be performed at joints and cracks where loss of support exists. Visual inspection is the simplest manner to find voids. Signs that repair is needed are transverse joint faulting, corner breaks and shoulder drop off and lines at or near joints and cracks. Deflection testing is another common procedure utilized to locate voids. It is recommended to do this testing at night as during cooler temperatures, joints open, aggregate interlock diminishes and load deflections are at their highest.

Another testing method is ground penetrating radar. It pulses electromagnetic wave technology into the pavement and then ceases the transmission during which the transmitter-receiver detects signals that are deflected from the pavement. Yet another method is the epoxy/core test, which confirms void presence by visual and mechanical methods. It consists of drilling a 25 to 50 millimeter hole through the pavement and into the sub-base with a dry-bit roto-hammer. Next, a two-part epoxy is poured into the hole that is dyed for visual clarity. Once the epoxy is hardened, the technicians drill through the hole. If a void is present, the epoxy will stick to the core and provide physical evidence.

Common stabilization materials are pozzolan-cement grout and polyurethane. The requirements for slab stabilization are strength and the ability to flow into or expand to fill small voids. Colloidal mixing equipment is necessary to use the pozzolan-cement grouts. The contractor should place the grout using a positive-displacement injection pump or a non-pulsing progressive cavity pump. A drill is also necessary but it must produce a clean hole with no surface spalling or breakouts. The injection devices must include a grout packer that is capable of sealing a hole. The injection device must also have a return hose or a fast-control reverse switch in case workers detect slab movement on the uplift gauge. The uplift beam helps to monitor the slab deflection and has to have sensitive dial gauges.

## **Joint Sealing**

Also called joint and crack repair, this method's purpose is to minimize infiltration of surface water and incompressible material into the joint system. Joint sealants are also used to reduce dowel bar corrosion in Concrete Pavement Restoration (CPR) techniques. Successful resealing consists of old sealant removal, shaping and cleaning the reservoir, installing the backer rod and installing the sealant. Sawing, manual removal, plowing and cutting are methods used to remove the old sealant. Saws are used to shape the reservoir. When cleaning the reservoir, no dust, dirt or traces of old sealant should remain. Thus, it is recommended to water wash, sand-blast and then air blow to remove any sand, dirt or dust. The backer rod installation requires a double-wheeled, steel roller to insert the rod to the desired depth. After inserting the backer rod, the sealant is placed into the joint. There are various materials to choose for this method including hot pour bituminous liquid, silicone and preformed compression seals.

## Safety considerations



Pedestrian crossing, line markings and street furniture

Careful design and construction of roads can increase Road traffic safety and reduce the harm (deaths, injuries, and property damage) on the highway system from traffic collisions.

On neighborhood roads traffic calming, safety barriers, pedestrian crossings and cycle lanes can all protect pedestrians and cyclists.

Lane markers in some countries and states are marked with Cat's eyes or Botts dots, bright reflectors that do not fade like paint. Botts dots are not used where it is icy in the winter, because frost and snowplows can break the glue that holds them to the road, although they can be embedded in short, shallow trenches carved in the roadway, as is done in the mountainous regions of California.

For major roads risk can be reduced by providing limited access from properties and local roads, grade separated junctions and median dividers between opposite-direction traffic to reduce likelihood of head-on collisions.

The placement of energy attenuation devices (e.g. guardrails, wide grassy areas, sand barrels) is also common. Some road fixtures such as road signs and fire hydrants are designed to collapse on impact. Light poles are designed to break at the base rather than violently stop a car that hits them. Highway authorities may also remove larger trees from the immediate vicinity of the road.

## Environmental performance



Air pollution along Pasadena Highway in Los Angeles, United States

Careful design and construction of a road can reduce any negative environmental impacts.

Water management systems can be used to reduce the effect of pollutants from roads. Rainwater and snowmelt running off of roads tends to pick up gasoline, motor oil, heavy metals, trash and other pollutants and result in Water pollution. Road runoff is a major source of nickel, copper, zinc, cadmium, lead and polycyclic aromatic hydrocarbons (PAHs), which are created as combustion byproducts of gasoline and other fossil fuels. De-icing chemicals and sand can run off into roadsides, contaminate groundwater and pollute surface waters; and road salts can be toxic to sensitive plants and animals. Sand applied to icy roads can be ground up by traffic into fine particulates and contribute to air

pollution. Sand can alter stream bed environments, causing stress for the plants and animals that live there.

Roadways are a chief source of environmental noise generation. In the early 1970s it was recognized that design of roads can be conducted to influence and minimize noise generation. Noise barriers are used to reduce Noise pollution, in particular where roads are located close to built-up areas. Regulations can restrict the use of Engine braking.

Motor vehicle emissions contribute air pollution. Concentrations of air pollutants and adverse respiratory health effects are greater near the road than at some distance away from the road. Road dust kicked up by vehicles may trigger allergic reactions.

## Regulation



## **Right- and left-hand traffic**

Traffic flows on the right or on the left side of the road depending on the country. In countries where traffic flows on the right, traffic signs are mostly on the right side of the road, roundabouts and traffic circles go counter-clockwise/anti-clockwise, and pedestrians crossing a two-way road should watch out for traffic from the left first. In countries where traffic flows on the left, the reverse is true.

About 33% of the world by population drive on the left, and 67% keep right. By roadway distances, about 28% drive on the left, and 72% on the right, even though originally most traffic drove on the left worldwide.

## Economics



A city street in Mumbai, India with left-hand traffic

Transport economics is used to understand both the relationship between the transport system and the wider economy and the complex network effects when there are multiple paths and competing modes for both personal and freight (road/rail/air/ferry) and where Induced demand can result in increased or decreased transport levels when road provision is increased by building new roads or decreased (for example California State Route 480). Roads are generally built and maintained by the public sector using taxation (although implementation may be through private contractors), or occasionally using road tolls.

Economics and society depend heavily on efficient roads. In the European Union (EU) 44% of all goods are moved by trucks over roads and 85% of all persons are transported by cars, buses or coaches on roads. The term was also commonly used to refer to roadsteads, waterways that lent themselves to use by shipping.

### **Construction costs**

According to [www.nysthruway.gov](http://www.nysthruway.gov), some typical costs to construct roads in several USA states include: CONSTRUCTION COST Expressway Section Per-Mile Cost Connecticut Turnpike \$3,449,000 New Jersey Turnpike \$2,200,000 Pennsylvania Turnpike (Delaware Extension) \$1,970,000 Northern Indiana Toll Road \$1,790,000 Garden State Parkway \$1,720,000 Massachusetts Turnpike \$1,600,000 Thruway, New York to Pennsylvania Line \$1,547,000 Ohio Turnpike \$1,352,000 Pennsylvania Turnpike (early construction) \$736,000

### **Statistics**

The United States has the largest network of roadways of any country with 6,430,366 kilometres (3,995,644 mi) (2005). The People's Republic of China is second with 3,583,715 kilometres (2,226,817 mi) of roadway (2007). The Republic of India has the third largest road system in the world with 3,383,344 kilometres (2,102,312 mi) (2002). When looking only at expressways the National Trunk Highway System (NTHS) in People's Republic of China has a total length of 45,000 kilometres (28,000 mi) at the end of 2006, and 60,300 km at the end of 2008, second only to the United States with 90,000 kilometres (56,000 mi) in 2005.

## Chapter- 2

# Asphalt Concrete



Asphalt concrete.



As shown in this cross-section, many older roadways are smoothed by applying a thin layer of **asphalt concrete** to the existing portland cement concrete.



A layer of asphalt concrete. In road construction, a base layer of crushed rock is usually laid down first to increase durability



Machine laying asphalt concrete, fed from a dump truck

**Asphalt concrete** is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. It consists of asphalt (used as a binder) and mineral aggregate mixed together, then laid down in layers and compacted.

The terms "asphalt (or asphaltic) concrete", "bituminous asphalt concrete" and the abbreviation "AC" are typically used only in engineering and construction documents and literature. Asphalt concrete pavements are often called just "asphalt" by laypersons who tend to associate the term concrete with Portland cement concrete only. The engineering definition of concrete is any composite material composed of mineral aggregate glued together with a binder, whether that binder is Portland cement, asphalt or even epoxy. Informally, asphalt concrete is also referred to as "blacktop", particularly in North America.

## Mixture formulations

Mixing of asphalt and aggregate is accomplished in one of several ways:

- **Hot mix asphalt concrete** (commonly abbreviated as HMAC or HMA) is produced by heating the asphalt binder to decrease its viscosity, and drying the aggregate to remove moisture from it prior to mixing. Mixing is generally performed with the aggregate at about 300 °F (roughly 150 °C) for virgin asphalt and 330 °F (166 °C) for polymer modified asphalt, and the asphalt cement at 200 °F (95 °C). Paving and compaction must be performed while the asphalt is

sufficiently hot. In many countries paving is restricted to summer months because in winter the compacted base will cool the asphalt too much before it is packed to the optimal air content. HMAC is the form of asphalt concrete most commonly used on highly trafficked pavements such as those on major highways, racetracks and airfields.

- **Warm mix asphalt concrete** (commonly abbreviated as WMA or WAM) is produced by adding either zeolites, waxes, or asphalt emulsions to the mix. This allows significantly lower mixing and laying temperatures and results in lower consumption of fossil fuels, thus releasing less carbon dioxide, aerosols and vapours. Not only are working conditions improved, but the lower laying-temperature also leads to more rapid availability of the surface for use, which is important for construction sites with critical time schedules. The usage of these additives in hot mixed asphalt (above) may afford easier compaction and allow cold weather paving or longer hauls.
- **Cold mix asphalt concrete** is produced by emulsifying the asphalt in water with (essentially) soap prior to mixing with the aggregate. While in its emulsified state the asphalt is less viscous and the mixture is easy to work and compact. The emulsion will break after enough water evaporates and the cold mix will, ideally, take on the properties of cold HMAC. Cold mix is commonly used as a patching material and on lesser trafficked service roads.
- **Cut-back asphalt concrete** is produced by dissolving the binder in kerosene or another lighter fraction of petroleum prior to mixing with the aggregate. While in its dissolved state the asphalt is less viscous and the mix is easy to work and compact. After the mix is laid down the lighter fraction evaporates.
- **Mastic asphalt concrete** or sheet asphalt is produced by heating hard grade blown bitumen (oxidation) in a green cooker (mixer) until it has become a viscous liquid after which the aggregate mix is then added.

The bitumen aggregate mixture is cooked (matured) for around 6-8 hours and once it is ready the mastic asphalt mixer is transported to the work site where experienced layers empty the mixer and either machine or hand lay the mastic asphalt contents on to the road. Mastic asphalt concrete is generally laid to a thickness of around  $\frac{3}{4}$ – $1\frac{3}{16}$  inches (20-30 mm) for footpath and road applications and around  $\frac{3}{8}$  of an inch (10 mm) for flooring or roof applications.

In addition to the asphalt and aggregate, additives, such as polymers, and antistripping agents may be added to improve the properties of the final product.

- **Natural asphalt concrete** can be produced from bituminous rock, found in some parts of the world, where porous sedimentary rock near the surface has been impregnated with upwelling bitumen.



A landing strip, one of the uses of asphalt concrete

Asphalt concrete is often touted as being *100% recyclable*. Several in-place recycling techniques have been developed to rejuvenate oxidized binders and remove cracking, although the recycled material is generally not very water-tight or smooth and should be overlaid with a new layer of asphalt concrete. Asphalt concrete that is removed from a pavement is usually stockpiled for later use as a base course material. This reclaimed material, commonly known by the acronym 'RAP' for recycled or reclaimed asphalt pavement, is crushed to a consistent gradation and added to the HMA mixing process. Very little asphalt concrete is actually disposed of in landfills. Sometimes waste materials, such as rubber from old tires, are added to asphalt concrete as is the case with rubberized asphalt, but there is a concern that the hybrid material may not be recyclable.



Asphalt damaged by cryoturbation, or freezing of groundwater

Asphalt deterioration can include alligator cracks, potholes, upheaval, raveling, rutting, shoving, stripping, and grade depressions. In cold climates, freezing of the groundwater underneath can crack asphalt even in one winter (by cryoturbation). Filling the cracks with bitumen can temporarily fix the cracks, but only proper construction, i.e. allowing water to drain away from under the road, can slow this process.

Asphalt concrete pavements—especially those at airfields—are sometimes called tarmac for historical reasons, although they do not contain tar and are not constructed using the macadam process.

## **Performance characteristics**

Asphalt concrete has different performance characteristics in terms of surface durability, tire wear, braking efficiency and roadway noise. The appropriate asphalt performance characteristic is obtained by the traffic level amount in categories A,B,C,D,E, and friction coarse (FC-5). Asphalt concrete generates less roadway noise than Portland cement concrete surfacing, and is typically less noisy than chip seal surfaces. Tire noise effects are amplified at higher operating speeds. The sound energy is generated through rolling friction converting kinetic energy to sound waves. The idea that highway design could be

influenced by acoustical engineering considerations including selection of surface paving types arose in the very early 1970s

## Asphalt



A layer of asphalt concrete paving

The primary use of asphalt is in road construction, where it is used as the glue or binder for the aggregate particles.

**Asphalt** (or Bitumen) is a sticky, black and highly viscous liquid or semi-solid that is present in most crude petroleum and in some natural deposits. Until the 20th century, the term **asphaltum** was also used. It is most commonly modelled as a colloid, with *asphaltenes* as the dispersed phase and *maltenes* as the continuous phase (though there is some disagreement amongst chemists regarding its structure). One writer states that although a "considerable amount of work has been done on the composition of asphalt, it is exceedingly difficult to separate individual hydrocarbon in pure form", and "it is

almost impossible to separate and identify all the different molecules of asphalt, because the number of molecules with different chemical structure is extremely large".

In American English, asphalt (or asphalt cement) is the carefully refined residue from the distillation process of selected crude oils. Outside the U.S., the product is often called bitumen. Natural deposits terminology also sometimes uses the word bitumen, such as at the La Brea Tar Pits.

## Etymology

The word *asphalt* is derived from the late Middle English : from French *asphalte*, based on Late Latin *asphalton*, *asphaltum*, which is the romanization of the Greek *ásphalton*, *ásphaltos* (ἄσφαλτος), a word meaning "asphalt/bitumen/pitch" which some derive from α- "without" and σφάλλω, (*sfallō*), "to make fall". Note that in French, the term *asphalte* is used for naturally occurring bitumen-soaked limestone deposits, and for specialised manufactured products with fewer voids or greater bitumen content than the "asphaltic concrete" used to pave roads. Another description has it that the term derives from the Accadian term "asphaltu" or "sphallo," meaning "to split." It was later adopted from the Homeric Greeks as a verb meaning "to make firm or stable," "to secure". It is a significant fact that the first use of asphalt by the ancients was in the nature of a cement for securing or joining together various objects, and it thus seems likely that the name itself was expressive of this application. From the Greek, the word passed into late Latin, and thence into French ("asphalte") and English ("asphaltum" and "asphalt"). The expression "bitumen" originated in the Sanskrit, where we find the words "jatu," meaning "pitch," and "jatu-krit," meaning "pitch creating," "pitch producing" (referring to coniferous or resinous trees). The Latin equivalent is claimed by some to be originally 'gwitu-men' (pertaining to pitch), and by others, "puxtumens" (exuding or bubbling pitch), which was subsequently shortened to "bitumen," thence passing via French into English. From the same root is derived the Anglo Saxon word "cwidu" (Mastix), the German word "Kitt" (cement or mastic) and the old Norse word "kvada".

## Modern usage

In British English, the word 'asphalt' refers to a mixture of mineral aggregate and bitumen (or tarmac in common parlance). The earlier word 'asphaltum' is now archaic and not commonly used. In American English, 'asphalt' is equivalent to the British 'bitumen'. However, 'asphalt' is also commonly used as a shortened form of 'asphalt concrete' (therefore equivalent to the British 'tarmac'). In Australian English, bitumen is sometimes used as the generic term for road surfaces. In Canadian English, the word bitumen is used to refer to the vast Canadian deposits of extremely heavy crude oil, while asphalt is used for the oil refinery product used to pave roads and manufacture roof shingles. Diluted bitumen (diluted with naphtha to make it flow in pipelines) is known as dilbit in the Canadian petroleum industry, while bitumen "upgraded" to synthetic crude oil is known as syncrude and syncrude blended with bitumen as *synbit*.

## Background



Asphalt in use for resurfacing of Francisco Delandes Avenue, in Belo Horizonte, Brazil.



Asphalt being used to pave a street in Poá - SP - Brazil.

Asphalt or bitumen can sometimes be confused with tar, which is a similar black thermoplastic material produced by the destructive distillation of coal. During the early- and mid-20th century when town gas was produced, tar was a readily available product and extensively used as the binder for road aggregates. The addition of tar to macadam roads led to the word tarmac, which is now used in common parlance to refer to road making materials. However, since the 1970s, when natural gas succeeded town gas, asphalt (bitumen) has completely overtaken the use of tar in these applications.

Asphalt can be separated from the other components in crude oil (such as naphtha, gasoline and diesel) by the process of fractional distillation, usually under vacuum conditions. A better separation can be achieved by further processing of the heavier fractions of the crude oil in a de-asphalting unit, which uses either propane or butane in a supercritical phase to dissolve the lighter molecules which are then separated. Further processing is possible by "blowing" the product: namely reacting it with oxygen. This makes the product harder and more viscous.

Natural deposits of asphalt include lake asphalts (primarily from the Pitch Lake in Trinidad and Tobago and Lake Bermudez in Venezuela), Gilsonite, the Dead Sea, and Tar Sands. Asphalt was mined at Ritchie Mines in Macfarlan in Ritchie County, West Virginia in the United States from 1852 to 1873.

Asphalt is typically stored and transported at temperatures around 150 degrees Celsius (300 °F). Sometimes diesel oil or kerosene are mixed in before shipping to retain

liquidity; upon delivery, these lighter materials are separated out of the mixture. This mixture is often called **bitumen feedstock**, or BFS. Some dump trucks route the hot engine exhaust through pipes in the dump body to keep the material warm. The backs of tippers carrying asphalt, as well as some handling equipment, are also commonly sprayed with a releasing agent before filling to aid release. Diesel oil is sometimes used as a release agent, although it can mix with and thereby reduce the quality of the asphalt.

## **Known uses**

### **Ancient times**

In the ancient Middle East, natural asphalt deposits were used for mortar between bricks and stones, to cement parts of carvings, such as eyes, into place, for ship caulking, and for waterproofing. The Persian word for asphalt is *moom*, which is related to the English word mummy. Asphalt was also used by ancient Egyptians to embalm mummies. In the ancient Far East, natural asphalt was slowly boiled to get rid of the higher fractions, leaving a material of higher molecular weight which is thermoplastic and when layered on objects, became quite hard upon cooling. This was used to cover objects that needed waterproofing, such as scabbards and other items. Statuettes of household deities were also cast with this type of material in Japan, and probably also in China.

In North America, archaeological recovery has indicated that asphaltum was sometimes used to apply stone projectile points to a wooden shaft.

## Early use in Europe



Bituminous outcrop of the Puy de la Poix, Clermont-Ferrand, France

An 1838 edition of *Mechanics Magazine* cites an early use of asphalt in France. A pamphlet dated 1621, by "a certain Monsieur d'Eyrinys, states that he had discovered the existence (of asphaltum) in large quantities in the vicinity of Neufchatel", and that he proposed to use it in a variety of ways - "principally in the construction of air-proof granaries, and in protecting, by means of the arches, the water-courses in the city of Paris from the intrusin of dirt and filth", which at that time made the water unusable. "He expatiates also on the excellence of this material for forming level and durable terraces" in palaces, "the notion of forming such terraces in the streets not one likely to cross the brain of a Parisian of that generation". But it was generally neglected in France until the

revolution of 1830. Then, in the 1830s, there was a surge of interest, and asphalt became widely used "for pavements, flat roofs, and the lining of cisterns, and in England, some use of it had been made of it for similar purposes". Its rise in Europe was "a sudden phenomenon", after natural deposits were found "in France at Osbann (BasRhin), the Parc (l'Ain) and the Puy-de-la-Poix (Puy-de-Dome)", although it could also be made artificially. One of the earliest uses in France was the laying of about 24,000 square yards of Seyssel asphalt at the Place de la Concorde in 1835.

## **Early use in the United Kingdom**

Among the earlier uses of asphalt in the United Kingdom, was for etching. William Salmon's *Polygraphice* (1673) provides a recipe for varnish used in etching, consisting of three ounces of virgin wax, two ounces of mastic, and one ounce of asphaltum. By the fifth edition in 1685, he had included more asphaltum recipes from other sources.

The first British patent for the use of asphalt was 'Cassell's patent asphalte or bitumen' in 1834. Then on 25 November 1837, Richard Tappin Claridge patented the use of Seyssel asphalt (patent #7849), for use in asphalte pavement, having seen it employed in France and Belgium when visiting with Frederick Walter Simms, who worked with him on the introduction of asphalt to Britain. Dr T. Lamb Phipson claims that his father, Samuel Ryland Phipson, a friend of Claridge, was also "instrumental in introducing the asphalte pavement (in 1836)". Indeed, mastic pavements had been previously employed at Vauxhall by a competitor of Claridge, but without success.

In 1838, Claridge obtained patents in Scotland on 27 March, and Ireland on 23 April, and in 1851 extensions were sought for all three patents, by the trustees of a company previously formed by Claridge. This was *Claridge's Patent Asphalte Company*, formed in 1838 for the purpose of introducing to Britain "Asphalte in its natural state from the mine at Pyrimont Seysell in France", and "laid one of the first asphalt pavements in Whitehall". Trials were made of the pavement in 1838 on the footway in Whitehall, the stable at Knightsbridge Barracks, "and subsequently on the space at the bottom of the steps leading from Waterloo Place to St. James Park". "The formation in 1838 of Claridge's Patent Asphalte Company (with a distinguished list of aristocratic patrons, and Marc and Isambard Brunel as, respectively, a trustee and consulting engineer), gave an enormous impetus to the development of a British asphalt industry". "By the end of 1838, at least two other companies, Robinson's and the Bastenne company, were in production", with asphalt being laid as paving at Brighton, Herne Bay, Canterbury, Kensington, the Strand, and a large floor area in Bunhill-row, while meantime Claridge's Whitehall paving "continue(d) in good order".

Indeed in 1838, there was a flurry of entrepreneurial activity over asphalt, which had uses beyond paving. For example, asphalt could also be used for flooring, damp proofing in buildings, and for waterproofing of various types of pools and baths, with these latter themselves proliferating in the 19th century. On the London stockmarket, there were various claims as to the exclusivity of asphalt quality from France, Germany and England. And numerous patents were granted in France, with similar numbers of patent

applications being denied in England due to their similarity to each other. In England, "Claridge's was the type most used in the 1840s and 50s"

In 1914, Claridge's Company entered into a joint venture to produce tar-bound macadam, with materials manufactured through a subsidiary company called Clarmac Roads Ltd. Two products resulted, namely *Clarmac*, and *Clarphalte*, with the former being manufactured by Clarmac Roads and the latter by Claridge's Patent Asphalte Co., although *Clarmac* was more widely used. However, the First World War impacted financially on the Clarmac Company, which entered into liquidation in 1915. The failure of Clarmac Roads Ltd had a flow-on effect to Claridge's Company, which was itself compulsorily wound up, ceasing operations in 1917, having invested a substantial amount of funds into the new venture, both at the outset, and in a subsequent attempt to save the Clarmac Company.

### **Early use in the United States**

The first use of asphaltum in the New World was by indigenous tribes. On the west coast, as early as the 13th century, the Tongva and Chumash Nations collected the naturally occurring asphaltum that seeped to the surface above underlying petroleum deposits. Both tribes used the substance as an adhesive. It is found on many different artifacts of tools and ceremonial items. For example, it was used on rattles to adhere gourds or turtle shells to rattle handles. It was also used in decorations. Small round shell beads were often set in asphaltum to provide decorations. It was used as a sealant on baskets to make them water tight for carrying water. Asphaltum was used also to seal the planks on ocean-going canoes.

Roads in the US have been paved with asphalt since at least 1870, when a street in front of Newark, NJ's City Hall was paved. In 1876, asphalt was used to pave Pennsylvania Avenue in Washington, DC, in time for the celebration of the national centennial. Asphalt was also used for flooring, paving and waterproofing of baths and swimming pools during the early 20th century, following similar trends in Europe.

### **Rolled asphalt concrete**

The largest use of asphalt is for making asphalt concrete for road surfaces and accounts for approximately 85% of the asphalt consumed in the United States. Asphalt pavement material is commonly composed of 5 percent asphalt cement and 95 percent aggregates (stone, sand, and gravel). Due to its highly viscous nature, asphalt cement must be heated so that it can be mixed with the aggregates at the asphalt mixing plant. There are about 4,000 asphalt mixing plants in the U.S.

Asphalt road surface is the most widely recycled material in the US, both by gross tonnage and by percentage. According to a report issued by the Federal Highway Administration and the United States Environmental Protection Agency, 80% of the asphalt removed each year from road surfaces during widening and resurfacing projects is reused as part of new roads, roadbeds, shoulders and embankments.

Roofing shingles account for most of the remaining asphalt consumption. Other uses include cattle sprays, fence post treatments, and waterproofing for fabrics.

Asphalt is widely used in airports around the world. Due to the sturdiness, it is widely used for runways dedicated to aircraft landing and taking off.

### **Mastic asphalt**

Mastic asphalt is a type of asphalt which differs from dense graded asphalt (asphalt concrete) in that it has a higher bitumen (binder) content, usually around 7–10% of the whole aggregate mix, as opposed to rolled asphalt, which has only around 5% added bitumen. This thermoplastic substance is widely used in the building industry for waterproofing flat roofs and tanking underground. Mastic asphalt is heated to a temperature of 210 °C (410 °F) and is spread in layers to form an impervious barrier about 20 millimeters (0.8 in) thick.

### **Asphalt emulsion**

A number of technologies allow asphalt to be mixed at much lower temperatures. These involve mixing the asphalt with petroleum solvents to form "cutbacks" with reduced melting point or mixtures with water to turn the asphalt into an emulsion. Asphalt emulsions contain up to 70% asphalt and typically less than 1.5% chemical additives. There are two main types of emulsions with different affinity for aggregates, cationic and anionic. Asphalt emulsions are used in a wide variety of applications. Chipseal involves spraying the road surface with asphalt emulsion followed by a layer of crushed rock, gravel or crushed slag. Slurry Seal involves the creation of a mixture of asphalt emulsion and fine crushed aggregate that is spread on the surface of a road. Cold mixed asphalt can also be made from asphalt emulsion to create pavements similar to hot-mixed asphalt, several inches in depth and asphalt emulsions are also blended into recycled hot-mix asphalt to create low cost pavements.

### **Alternatives and bioasphalt**

Certain activist groups have become increasingly concerned about the global peak oil and climate change problem in recent years due to by-products that are released into the atmosphere. Most of the emissions are derived primarily from burning fossil fuels. This has led to the introduction of petroleum bitumen alternatives that are more environmentally friendly and non-toxic.

## Chapter- 3

# Road Roller



John Deere roller being used to compact the ground before placing concrete



An old diesel road roller

A **road roller** (sometimes called a *roller-compactor*, or just *roller*) is a compactor type engineering vehicle used to compact soil, gravel, concrete, or asphalt in the construction of roads and foundations, similar rollers are used also at landfills or in agriculture.

In some parts of the world, road rollers are still known colloquially as steam rollers, regardless of their method of propulsion. This typically only applies to the largest examples (used for road-making).

# History



Horse-drawn road roller from 1800



Steam-powered roller



Zettelmeyer diesel road roller

The first road rollers were horse-drawn, and were probably just borrowed farm implements.

Since the effectiveness of a roller depends to a large extent on its weight, self-powered vehicles replaced horse-drawn rollers from the mid-19th century. The first such vehicles were steam rollers. Double-cylinder designs were preferred. Single-cylinder steam rollers were uncommon and unpopular, as the power impulses from the steam engine would produce slight waves in the road. Some road companies in the United States used steamrollers through the 1950s, and in the UK, some remained in commercial service until the early 1970s.











As internal combustion engine technology improved during the 20th century, kerosene-, gasoline- (petrol), and diesel-powered rollers gradually replaced their steam-powered counterparts. The first internal-combustion powered road rollers were very similar to the steam rollers they replaced. They used similar mechanisms to transmit power from the engine to the wheels, typically large, exposed spur gears. Some companies did not like them in their infancy, as the engines of the era were typically difficult to start, particularly the kerosene-powered ones.

Virtually all road rollers in commercial use now use diesel power.

## Uses

Road rollers use the weight of the vehicle to compress the surface being rolled. Initial compaction of the substrate is done using a **pneumatic-tyred roller**, with two rows (front and back) of pneumatic tyres. The flexibility of the tyres, with a certain amount of vertical movement of the wheels, enables the roller to operate effectively on uneven ground. The finish is done using metal-drum rollers to ensure a smooth, even result.

Rollers are also used in landfill compaction. Such compactors typically have knobbed ("sheeps-foot") wheels, and do not achieve a smooth surface. The knobs aid in compression due to the smaller area contacting the ground.











## Configurations

The roller can be a simple drum with a handle that is operated by one person, and weighs 100 pounds, or as large as a ride-on road roller weighing 21 short tons (44,000 lb or 20 tonnes) and costing more than US\$150,000. A landfill unit can weigh 59 short tons (54 tonnes). On some machines the drums may be filled with water.

## Roller Types

- Manual walk-behind
- Powered walk-behind (electric or diesel/gas powered)
- Trench roller (manual units or radio-frequency remote control)
- Ride-on
- Ride-on with knock-down bar
- Ride-on articulating-swivel
- Vibratory
- Pneumatic-tyre
- Tandem roller
- Tractor-mounted and -powered



Powered, vibrating walk-behind



Ride-on with articulating-swivel (small machine)



Ride-on with articulating-swivel (large machine)



Vibrating Dynapac CC232



A Caterpillar CS-533E vibratory roller.



Pneumatic roller



A road-roller powered by a tractor mounted on it from rural India



Road roller, museum, Tenterfield, NSW

## Drum types

Drums come in various widths: 24-to-84 inches

- Single-drum sheeps/pad-foot (soil)
- Single-drum smooth (asphalt)
- Double-drum (duplex) sheeps/pad-foot (soil)
- Double-drum (duplex) smooth (asphalt)
- 3-wheel cleat with bulldozing blade (landfills)

## Variations and features

- On some machines, the drums may be filled with water on site to achieve the desired weight. When empty, the lighter machine is easier and cheaper to transport between work sites.
- Additional compaction may be achieved by vibrating the roller drums, making a small, light machine perform as well as a much heavier one. Vibration is typically caused by a free-spinning hydrostatic motor inside the drum to whose shaft eccentric weights have been attached.

- Water lubrication may be provided to the drum surface to prevent (for example) hot asphalt sticking to the drum
- Hydraulic transmissions permit greater design flexibility, while early examples used direct mechanical drives; hydraulics reduce the number of moving parts exposed to contamination.
- Human-propelled rollers may only have a single roller drum.
- Self-propelled rollers may have two drums, mounted one in front of the other (format known as "duplex"), or three rolls, or just one, with the back rollers replaced with treaded pneumatic tyres for increased traction









## Manufacturers

- AGICO
- Aveling-Barford
- BOMAG
- Buffalo-Springfield Roller Company
- Case CE
- Caterpillar
- CORINSA
- CMI-Terex
- Dynapac (= Atlas Copco)
- Galion
- GEMCO
- Hamm
- Huber
- HYPAC
- Hyster
- Ingersoll Rand
- Ingram Compaction
- Kemna, Breslau
- KMEC
- Lebrero
- LeeBoy
- LiuGong
- Mikasa
- Multiquip/Rammax
- Rex
- Sinoway Industrial (Shanghai) Co.,Ltd
- Stone Equipment
- SuperPac
- Vibromax
- Volvo CE

## Chapter- 4

# Steamroller



A steam powered road roller

A **steamroller** (or **steam roller**) is a form of road roller – a type of heavy construction machinery used for levelling surfaces, such as roads or airfields – that is powered by a steam engine. The levelling/flattening action is achieved through a combination of the size and weight of the vehicle and the *rolls*: the smooth wheels and the large cylinder or drum fitted in place of treaded road wheels.

The majority of steam rollers are outwardly similar to traction engines as many traction engine manufacturers later produced rollers based on their existing designs, and the patents owned by certain roller manufacturers tended to influence the general arrangements used by others. The key difference between the two vehicles is that on a roller the main roll replaces the front wheels and axle that would be fitted to a traction engine.

In many parts of the world, the term *steam roller* is still used regardless of the method of propulsion. This typically only applies to the largest examples (used for road-making).

## Configurations

The majority of rollers were of the same basic configuration, with two large smooth wheels at the back and a single wide roll at the front. However, there was also a distinctive variant, the "tandem", which had two wide rolls, one front, one rear. A further steam-powered variant was the tri-tandem, made by Robey, which was a like a tandem but with *two* large rear rolls, one mounted immediately in front of the other.











A variation of the basic configuration was the "convertible": an engine which could be either a steam roller or a traction engine and could be changed from one form to the other in a relatively short time – *i.e.*, less than half a day. Convertible engines were liked by local authorities, since the same machine could be used for haulage in the winter and road-mending in the summer.

## Design features

Although most steam roller designs are derived from traction engines, and were manufactured by the same companies, there are a number of features that set them apart.

### Wheels

The most obvious difference is in the wheels. All traction engines were built with large fabricated spoked steel wheels with wide rims. Those intended for road use would have continuous solid rubber tyres bolted around the rims, to improve traction on tarmac. Engines intended for agricultural use would have a series of strakes bolted diagonally across the rims, like the tread on a modern pneumatic tractor tyre, and the wheels were typically wider to spread the load more evenly.

Steam rollers, on the other hand, had smooth rear wheels and a roller at the front. The roller was a single wide cylinder supported at either end. This replaced the separate wheels and axle of a traction engine.











## Smokebox

In the conventional arrangement, the front roller is mounted centrally, forward of the chimney. In order to allow enough clearance from the boiler (and hence a larger front roll), the smokebox is extended forward substantially at the top to incorporate a support plate on which to mount the bearing for the roller assembly. This gives the distinctive, hooded look to the front of a steam roller. It also necessitates a different design of smokebox door – it has to drop down, rather than opening sideways, due to the limited access available.

## Special equipment

The rear rollers were fitted with **scraper bars**. As the vehicle moved along, these removed any surface material that had become stuck to the roll, to prevent a build-up of material and ensure a flat finish was maintained.

Some steam rollers were fitted with a **scarifier** mounted on the tender box at the rear. They could be swung down to road level and used to rip up the old surface before a road was remade.

Another accessory was a **tar sprayer** – a bar mounted on the back of the roller. This was not a common fixture.

## Manufacturers

Britain was a large exporter of steam rollers to the world over the years, with the firm of Aveling and Porter probably being the most famous and the most prolific.

Many other traction engine manufacturers built steam rollers, but after Aveling and Porter, the most popular were Marshall, Sons & Co., John Fowler & Co., and Wallis & Stevens.

In America, the Buffalo-Springfield Roller Company was a large builder. J. I. Case made a roller variant of their famed farm engines, but had a small market share. Other nations had makers including the Czechs, Swiss, Swedes, Germans and Dutch which produced steam rollers.



United States -built 1924 Buffalo Springfield steam roller: a vertical boiler design with tandem rolls. Note position of firebox door, facing out of frames.



Other side of same roller showing offset driving position: driver faces boiler controls (ie 'backwards') and steers with right hand

## Usage



A former Bedfordshire County Council Aveling & Porter roller in 2004

In the UK, a number of companies owned fleets of steam rollers and contracted them out to local authorities.

Many were still in use into the 1960s, and part of the M1 motorway was made with the help of steam rollers.

A few steam rollers were still being used for road maintenance in the early 1970s, and this may go some way to explaining why diesel-powered rollers are still colloquially known as *steam* rollers to this day.





Bundesarchiv, B 145 Bild-F001870-0004  
Foto: Brodde | Mai 1954



Bundesarchiv, Bild 183-E12033  
Foto: o. Ang. | Oktober 1939



Bundesarchiv, Bild 183-E12034  
Foto: o. Ang. | Oktober 1939



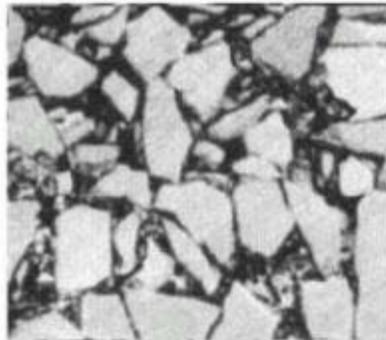
### Preservation

Many steam rollers are preserved in working order, and can be seen in operation during special live steam festivals, where operating scale models may also be displayed. At some of the UK steam fairs and rallies, demonstrations of road building using the old techniques, tools and machines are re-enacted by 'Road Gangs' in authentic dress; steam rollers feature prominently in these demonstrations. The annual Great Dorset Steam Fair has a section dedicated to road-making machinery, including a line-up of working steam rollers.

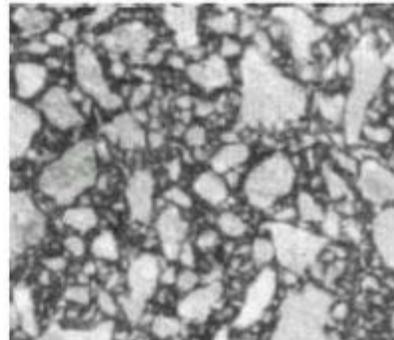
## Chapter- 5

# Stone Mastic Asphalt

**Stone mastic asphalt (SMA)** was developed in Germany in the 1960s. It provides a deformation resistant, durable surfacing material, suitable for heavily trafficked roads. SMA has found use in Europe, Australia, the United States, and Canada as a durable asphalt surfacing option for residential streets and highways. SMA has a high coarse aggregate content that interlocks to form a stone skeleton that resists permanent deformation. The stone skeleton is filled with a mastic of bitumen and filler to which fibres are added to provide adequate stability of bitumen and to prevent drainage of binder during transport and placement. Typical SMA composition consists of 70–80% coarse aggregate, 8–12% filler, 6.0–7.0% binder, and 0.3 per cent fibre.



(a) Stone mastic asphalt



(b) Dense graded asphalt

The deformation resistant capacity of SMA stems from a coarse stone skeleton providing more stone-on-stone contact than with conventional dense graded asphalt (DGA) mixes. Improved binder durability is a result of higher bitumen content, a thicker bitumen film, and lower air voids content. This high bitumen content also improves flexibility. Addition of a small quantity of cellulose or mineral fibre prevents drainage of bitumen during transport and placement. There are no precise design guidelines for SMA mixes. The essential features, which are the coarse aggregate skeleton and mastic composition, and the consequent surface texture and mixture stability, are largely determined by the selection of aggregate grading and the type and proportion of filler and binder.

## **Manufacture**

SMA is mixed and placed in the same plant as that used with conventional hot mix. In batch plants, the fibre additive is added direct to the pugmill using individually wrapped press packs or bulk dispensing equipment. Mixing times may be extended ensure that fibre is homogeneously distributed throughout the mix and temperatures controlled in order to avoid overheating or damage to the fibre. In drum plants, particular care must be taken to ensure that both the additional filler content and fibre additive are incorporated into the mixture without excessive losses through the dust extraction system. Filler systems that add filler directly into the drum rather than aggregate feed are preferred. Pelletised fibres may be added through systems designed for addition of recycled materials, but a more effective means is addition through a special delivery line that is combined with the bitumen delivery, so that the fibre is captured by bitumen at the point of addition to the mixture.

## **Placement**

The primary difference in placing SMA, compared to DGA is in compaction procedures. Multi-tyred rollers are not used due to the possible working of binder-rich material to the surface of the asphalt and consequent flushing and pick-up. Trafficking of the newly placed asphalt while still warm may have the same effect and it is generally preferable for surfaces to cool below about 40°C before opening to traffic. The preferred method of compaction is to use heavy, non-vibrating, steel-wheeled rollers. If these are not available, vibrating rollers may be used but vibration should be kept to a minimum to avoid fracture of coarse aggregate particles, or drawing of binder to the surface of the mix. The use of polymer modified binder may decrease mix workability and necessitate increased compactive effort to achieve high standards of compacted density. Achieving high standards of compacted density and low field air voids has been identified as an important factor in the performance of all SMA work. SMA is normally placed with a minimum layer thickness of 2.5 to 3 times the nominal maximum aggregate particle size. Greater layer thicknesses assist in achieving appropriate standards of compacted density.

## **Materials**

Aggregates used in SMA must be of high quality – well shaped, resistant to crushing and of suitable polish resistance.

Binders used in SMA include:

- Class 320 bitumen - used in many general applications.
- Multigrade binder - used to provide enhanced performance at higher traffic levels.
- Polymer modified binder - increasingly used in heavy traffic conditions to provide additional resistance to flushing and rutting.

Cellulose fibre is most commonly used in SMA work in Australia. Other fibre types, including glass fibre, rockwool, polyester, and even natural wool, have all been found to be suitable but cellulose fibre is generally the most cost-effective. Fibre content is generally 0.3% (by mass) of the total mix.

## **Advantages**

- SMA provides a textured, durable, and rut resistant wearing course.
- The surface texture characteristics of SMA are similar to Open graded asphalt (OGA) so that the noise generated by traffic is lower than that on DGA but equal to or slightly higher than OGA.
- SMA can be produced and compacted with the same plant and equipment available for normal hot mix, using the above procedure modifications.
- SMA may be used at intersections and other high traffic stress situations where OGA is unsuitable.
- SMA surfacings may provide reduced reflection cracking from underlying cracked pavements due

to the flexible mastic.

- The durability of SMA should be equal, or greater than, DGA and significantly greater than OGA.

## **Disadvantages**

- Increased material cost associated with higher binder and filler contents, and fibre additive.
- Increased mixing time and time taken to add extra filler, may result in reduced productivity.
- Possible delays in opening to traffic as the SMA mix should be cooled to 40°C to prevent flushing of the binder to the surface (bleeding).
- Initial skid resistance (lack of Friction) may be low until the thick binder film is worn off the top of the surface by traffic. In critical situations, a small, clean grit, may need to be applied before opening to traffic.

## **Concerns over skid resistance**

Concerns have been raised in both the UK and Australia over the use of Stone mastic as, under certain conditions, it can take up to two years for the material to offer an acceptable level of skid resistance (grip).

## Chapter- 6

# Other Road Construction Equipments and Technology

## Asphalt milling machine



**Asphalt milling machines** have been around for over 30 years. Asphalt milling is the process of grinding up asphalt that can then be recycled. The process came about because many streets were getting higher and higher on curbs, and therefore drainage of the roadway was becoming an increasingly bad problem. The first production milling machines were called Galions after their manufacturer, Galion Iron Works. These machines resembled graders in shape and size. The difference was there was a 30-inch-wide (760 mm) milling head where the scraper blade would normally be. The cutter drum was set into action by a rather large hydraulic pump.

Today's machines are much larger. They also have elaborate conveyor systems to reduce the labor of picking up the material from the roadway. With many new types of asphalt aggregates in use today the asphalt cold milling machines are often used. These new production machines are designed to tackle any mix design they chew into. Some of the larger machines, depending on the depth of the cut, can cut close to 15,000 square yards (13,000 m<sup>2</sup>) a day, at 75 feet per minute.

Operating an asphalt milling machine requires specialized training. Typically newer machines require two or more people to operate safely and efficiently. The operator stands on the deck of the machine and controls most of the machines functions, while another person on the ground controls the depth of the cut and keeps an eye out for obstructions in the roadway such as manholes and/or water valves. Operators typically learn by on-the-job training, making the transition from operating on the ground to running the machine on top.

## **Bioasphalt**

**Bioasphalt** is an asphalt alternative made from non-petroleum based renewable resources.

These sources includes sugar, molasses and rice, corn and potato starches, natural tree and gum resins, natural latex rubber and vegetable oils, lignin, cellulose, palm oil waste, coconut waste, peanut oil waste, canola oil waste, potato starch, dried sewerage effluent and so on. Bitumen can also be made from waste vacuum tower bottoms produced in the process of cleaning used motor oils, which are normally burned or dumped into land fills.

Non-petroleum based bitumen binders can be colored, which can reduce the temperatures of road surfaces and reduce the Urban heat islands.

## **Petroleum, environmental, and heat concerns**

Because of concerns over Peak oil, pollution and climate change, as well the oil price increases since 2003, non-petroleum alternatives have become more popular. This has led to the introduction of biobitumen alternatives that are more environmentally friendly and non toxic.

For millions of people living in and around cities, heat island are of growing concern. This phenomenon describes urban and suburban temperatures that are 1 to 6°C (2 to 10°F) hotter than nearby rural areas. Elevated temperatures can impact communities by increasing peak energy demand, air conditioning costs, air pollution levels, and heat-related illness and mortality. Fortunately, there are common-sense measures that communities can take to reduce the negative effects of heat islands, such as replacing conventional black asphalt road surfaces with the new pigmentable bitumen that gives lighter colors.

## **History and implementation**

Asphalt made with vegetable oil based binders was patented by Colas SA in France in 2004.

A number of homeowners seeking an environmentally-friendly alternative to asphalt for paving have experimented with waste vegetable oil as a binder for driveways and parking areas in single-family applications. The earliest known test occurred in 2002 in Ohio, where the homeowner combined waste vegetable oil with dry aggregate to create a low-cost and less polluting paving material for his 200-foot driveway. After five years, he reports the driveway is performing as well or better than petroleum-based materials.

Shell Oil Company paved two public roads in Norway in 2007 with vegetable-oil-based asphalt. Results of this study are still premature.

On October 6, 2010, a bicycle path in Des Moines, Iowa was paved with bio-oil based asphalt through a partnership between Iowa State University, the City of Des Moines, and Avello Bioenergy Inc. Research is being conducted on the asphalt mixture, derived from plants and trees to replace petroleum-based mixes.

## Cold planer



A machine tearing up one street at Sestri Ponente (Genoa)

A **cold planer** (also known as a pavement planer, pavement recycler, mill or milling machine or rotomill) is an Heavy equipment used to remove bituminous pavement or asphalt concrete from roadways, resulting in a smooth, even surface. This is accomplished by bringing a spinning mandrel or "head" into contact with the pavement at an exact depth or slope. It is normally fed by conveyor into a dump truck, or semi trailer but can be left in place or "wind-rowed" to be removed at a later date or used in reclaiming.

## Pothole



A pothole on New York City's Second Avenue.

A **pothole** (sometimes called **kettle** and known in parts of the Western United States as a **chuckhole**) is a type of disruption in the surface of a roadway where a portion of the road material has broken away, leaving a hole.

## Formation



Small potholes in the road in Banbury, UK

Most potholes are formed due to fatigue of the pavement surface. As fatigue fractures develop they typically interlock in a pattern known as "alligator cracking". The chunks of pavement between fatigue cracks are worked loose and may eventually be picked out of the surface by continued wheel loads, thus forming a pothole.

The formation of potholes is exacerbated by low temperatures, as water expands when it freezes to form ice, and puts greater stress on an already cracked pavement or road. Once a pothole forms, it grows through continued removal of broken chunks of pavement. If a pothole fills with water the growth may be accelerated, as the water "washes away" loose particles of road surface as vehicles pass. In temperate climates, potholes tend to form most often during spring months when the subgrade is weak due to high moisture content. However, potholes are a frequent occurrence anywhere in the world, including in the tropics.

Potholes can grow to feet in width, though they usually only become a few inches deep, at most. If they become large enough, damage to tires and vehicle suspensions occurs.

Serious car accidents can occur as a direct result, especially on motorways where vehicle speeds are greater. They are frequently almost invisible to drivers.

## Pothole gardening

Steve When plants flowers such as cyclamen in potholes in London so that their bright, unusual appearance will warn cyclists. The flowers may only last hours before being crushed by traffic but this guerrilla gardening has attracted numerous fans to his website who suggest good places for further plantings.

## Power trowel



Walk Behind Power Trowel



**13hp Boren Power Trowel**



**6.5hp Boren Power Trowel**

A **power trowel** (also known as a "power float", "helicopter" or "trowel machine") is a piece of light construction equipment used by construction companies and contractors, to apply a smooth finish to concrete slabs.

Power trowels differ in the way they are controlled:

- Ride-on power trowels are used by an operator sitting on a seat upon the machinery, controlling the power trowel with the necessary buttons.
- Walk-behind power trowels are used by an operator walking behind the machine.

## Operation

Both walk-behind and ride-on operate on the same principle. A spinning disc (either a disc or 'pan' or blades. The image of the ride-on Power Float has the disc/pan fitted to both rotors) has pressure applied to one area where the additional friction of the blades against the floor moves the Power Float in the opposite direction of the rotor blades.

The machine is steered by applying the weight of the machine at a certain segment of the rotor arc, which will take the machine in the desired direction. With the 'walk behind' model, the handle is pressed or lifted. This puts weight on the rear or front of the rotor which will move it from side to side, and with judicious positioning of the handle, forward or backward motion is possible using this side-to-side control.

With the 'ride on' model, there is a control for each blade that fulfills the same role. There is either a pole or hydraulic control that fulfills the same principle as the walk-behind but the ride-on differs in that its control of rotor direction is like that of a helicopter.

To operate them: start the engine, adjust throttle control and pull in the clutch lever which spins the rotor. They all have a 'dead man' control for the clutch, that is, the machine stops the rotors when the lever is released.

Then the trowel is glided over the surface at different periods during the concrete 'set', starting with a flat disc or 'pan' that fits over the rotor blades, which brings up the 'fat' of the concrete while filling depressions and removing high spots. Later the blades are used at an increasingly sharp angle until the surface is hard, flat, and starts shine.

Edges to the bay, or areas the Power Float can't access, are finished with a hand trowel. Newer Power Floats have blades with curved ends that are flush with the wire skirt so the edges can be troweled, plus the blades don't hit or snag objects.

## Which type?

The walk-behind is cheaper to buy, lighter to move, and the user can see what the discs do while the disc is at that area. But it is one disc and the big ones can 'give your abs a workout' as you try stop their motion at the end of each pass.

The ride-ons have two rotors so one can theoretically double the area trowelled; they also tend to have more blades per rotor. But you are looking in front at where you are going, not at what surface the machine has left leaving you with the possibility of picking up defects 'next time around'. They are expensive, heavier to move and only pay for themselves on big areas, but they are very comfortable and easy to use.

## Other uses

There is a trend to use walk-behind machines, or versions of the same but designed to be light weight and using pneumatic air via hoses instead of a heavy power plant and fuel, for the use in thin epoxy coatings and/or thin coloured decorative coatings.

## Road metal



Metal pavement road.

The term **road metal** refers to the crushed rock used for road beds, surfaces, 'all-weather' walkways and paths, foundations, and railway embankments, among other things. The use of road metal dates back to antiquity.

## **History**

The word metal comes from the Latin "metallum" and the Greek "metallon" meaning "mine, quarry, ore, metal". The reference to crushed rock thus becomes more apparent. It was more recently pioneered by John Loudon McAdam in the late 18th century.

The term is relatively rarely used today, with "gravel" being more typically used and understood. One of the places where it is still in common usage is New Zealand.

## Rut (roads)



14 cm rut on a main road between Częstochowa and Katowice

A **rut** is a depression or groove worn into a road or path by the travel of wheels or skis or by erosion from flowing water. In cold climate areas, such as Scandinavia, studded tires cause significant road surface wear in terms of rutting. Ruts can be removed by grading a road surface.

A vehicle with wheels or skis, travelling on a rutted road, if its wheels or skis enter an existing rut will have difficulty steering out of the rut. If it proves impossible to steer out

of a rut, though forward and backward progress can be made by the vehicle, it is referred to as being stuck in the rut.

The term *stuck in a rut* can be used figuratively to refer to a situation in which, as time progresses, the situation is unable to be changed or steered in a desired way.

Rutting is measured at highway speeds with a laser/inertial Profilograph. Typically rutting is reported in terms of rut depth.

## Rubberized asphalt

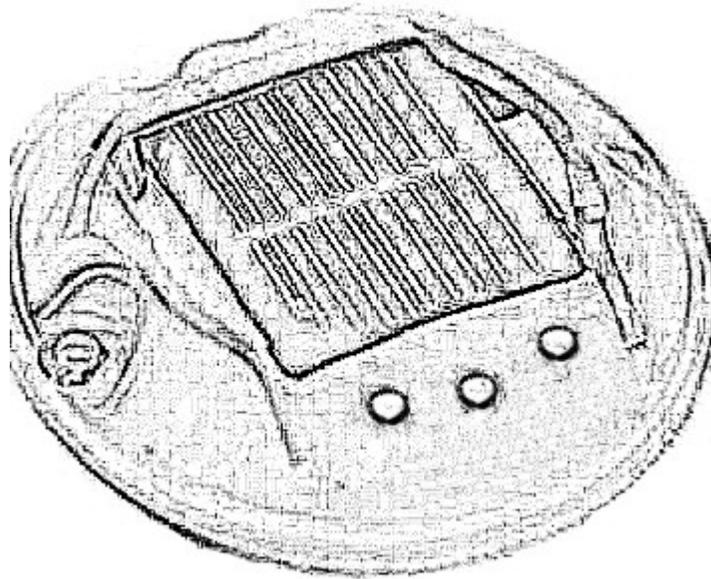
**Rubberized asphalt concrete (RAC)**, also known as **asphalt rubber** or just **rubberized asphalt**, is pavement material that consists of regular asphalt concrete mixed with crumb rubber -- ground, used tires that might otherwise be discarded, taking up space in landfills, if they were not re-directed for use as tire derived fuel in power plants or other recycled rubber products. Asphalt rubber is the largest single market for ground rubber in the United States, consuming an estimated 220 million pounds, or approximately 12 million tires annually.

Use of rubberized asphalt as a pavement material was pioneered by the city of Phoenix, Arizona on several area freeways in the 1960s because of its high durability. Since then it has garnered interest for its ability to reduce road noise.

In 2003 the Arizona Department of Transportation began a three-year, \$34-million Quiet Pavement Pilot Program, in cooperation with the Federal Highway Administration to determine if sound walls can be replaced by rubberized asphalt to reduce noise alongside highways. After about one year, asphalt rubber overlays resulted in up to a 12-decibel reduction in road noise, with a typical reduction of 7 to 9 decibels.

Arizona has been the leader in using rubberized asphalt, but California, Florida, Texas, South Carolina, and New Mexico are also using asphalt rubber. Tests are currently underway in other parts of the United States to determine the durability of rubberized asphalt in northern climates, including a 1.3 mile stretch of Interstate 405 in Bellevue and Kirkland, Washington and a handful of local roads in the city of Colorado Springs, Colorado.

## Solar road stud



**Solar road studs** are flashing solar cell powered LED maintenance-free lighting devices used in road construction to delineate road edges and centrelines. Embedded in the road surface, they are an electronic improvement on the traditional cat's eyes in that they may give drivers more than a thirty-second reaction window compared with about 3 seconds for conventional reflective devices. The intense brightness of the LEDs makes them easily visible at distances of about 900m under favourable conditions.

Averaging about 100mm square or 100mm diameter and about 40mm thick, units are extremely robust to avoid damage by passing vehicles, and are normally constructed of engineering plastics and polycarbonates. Use of solar road studs reduces the necessity of headlight main beams and the accompanying hazard of dazzling oncoming drivers. They are also more visible in rain and fog conditions where the old type retroreflectors and road markings are problematic. The solar cells charge batteries or capacitors during sunlit hours, over which period the flashing LEDs are turned off by a photoswitch.

## Sosrobahu

**Sosrobahu** is a construction technique which allows long stretches of flyovers to be constructed above existing main roads with a minimum of disruption to traffic. The technique was designed by Tjokorda Raka Sukawati and involves the construction of the horizontal supports for the highway beside the existing road, which are then lifted and turned 90 degrees before being placed on top of the vertical supports to form the flyover pylons.

This technique is of considerable value in increasing road mileage in large cities where there is restricted space for new roads and where the closure of existing roads for the length of time to build a flyover using normal construction techniques would impose significant economic costs.

## **Background**

By the 1980s, Jakarta was experiencing increased traffic congestion, and flyovers were seen as one solution to the improving transport infrastructure. One construction company operating at that time was PT Hutama Karya, which was granted a contract to build a highway above bypass A Yani, an extremely important stretch of highway where it was vital that the road would continue to be open to traffic throughout the period of construction.

In addition to this challenge, PT Hutama Karya were also granted a contract to build a flyover between Cawang and Tanjung Priok in 1987. The most difficult issue was the requirement to support the road with a row of concrete pylons (pier shafts) 30 m apart, on top of which would sit the 22 m wide road supports. The vertical pier shafts were to be hexagonal in shape with a diameter of 4 m, and were to sit in the central lane of the existing road. The erection of the pier shafts was not difficult; what caused problems were the poured concrete pier heads. With conventional construction techniques, the pier heads would be moved into place with the help of iron supports beneath the outspread pier heads, but the use of iron supports would necessitate the closure of the road below. Another option was to support the pier heads from above, but this increased the costs of the project.

In response to these problems, Sukawati had the idea of initially erecting the concrete pier shafts and then building the poured concrete pier heads in the centre lane, parallel to the existing roadway, and then raising and turning the pier heads 90 degrees into place. The only problem with this idea was that the pier heads weigh approximately 480 tonnes each.

## **Inspiration from a hydraulic car-jack**

One day Tjokorda was working on his 1974 Mercedes-Benz, which he had jacked up so that the back two wheels were supported on the slippery floor of the garage where some oil had been accidentally spilled. When the car was pushed, it pivoted with the jack as the axis. He noted that it is a principle of physics that when friction is banished it is easy to move even the heaviest of objects.

This event inspired the realization that a hydraulic pump could be used to lift heavy objects and, as long as they were supported by something slippery, the heavy objects could be easily moved. Tjokorda's goal was to lift and move concrete pier heads each weighing 480 tonnes.

Tjokorda conducted trials with cylinders 20 cm in diameter converted into a hydraulic lift and loaded with 80 tonnes of concrete. The weight was successfully lifted and turned slightly, but could not then be lowered as the position of the hydraulic jack had shifted. Tjokorda then made some improvements on the original design, and in subsequent lifts the hydraulic jack stayed stable even with the full weight of the concrete above it.

Other problems to be overcome included establishing the best type of oil to use that wouldn't lose its viscosity. The type of oil was a critical factor because it was the oil which transmitted the force required to lift the heavy concrete pier heads.

After the trials, Tjokorda finalised his design called the LBPH (the Indonesian acronym for Free Moving Platform) which consisted of a two concrete discs with a diameter of 80 cm enclosed in a container. Although only 5 cm thick, the discs are capable of supporting a weight of 625 tonnes each.

Between the two plates is pumped lubricating oil. A rubber seal around the edges of the plates protected against the oil escaping under the high forces experienced during the lift. The oil in the container was connected to a hydraulic pump through a small pipe. This hydraulic system was capable of lifting loads using a pressure of 78 kgf/cm<sup>2</sup> (7.6 MPa, although the reasons for this were a mystery to Tjokorda at that time.

## **Field trials**

The new technique had not yet been trialled because of time constraints, however Tjokorda was certain that it would work and was willing to bear the responsibility should the concrete pier heads not be able to be turned 90 degrees as required for the construction of the flyover.

On the 27 July 1988 at 22:00 Jakarta time, the hydraulic pump was pressurized to 78 kgf/cm<sup>2</sup> (7.6 MPa). The pier head, despite lack of iron supports, was lifted and placed on top of the pier shaft and then with a light push was turned 90 degrees into its final position. The oil was then slowly pumped out and the pier head was lowered onto the shaft. The LPBH system was then shut down as it required heavy machinery to move it. Because he was worried that the single pier shaft and head might shift for a lack of support, he propped them up with eight concrete supports, 3.6 m in diameter. The LPBH was then used to raise the other pier heads over their respective shafts.

## **Naming the technique and the granting of a patent**

In November 1989, President Soeharto of Indonesia gave the name Sosrobahu to the new technology. The name was taken from a character in the Mahabharata, and derives from Old Javanese for thousand (sosro) shoulders (bahu).

Tjokorda's invention was used by US engineers in the construction of a bridge in Seattle. They placed the oil under a pressure of 78 kg/cm<sup>2</sup> (7.6 MPa) as per Tjokorda's original

theories. Tjokorda himself wanted to investigate further the limits of his invention and built himself a laboratory where he successfully tested the LPBH to a limit of 78.05 kgf/cm<sup>2</sup> (7.654 MPa).

Patents have been granted for the invention from Indonesia, Japan, Malaysia, and the Philippines, and has been applied for in South Korea. The Indonesian patent was granted in 1995, while the Japanese patent was granted in 1992. The technology has been exported to the Philippines, Malaysia, Thailand and Singapore. The longest stretch of overpass built using this technique is in Metro Manila, Philippines at the Villamor/Bicutan link located at the southern part of the metropolis. In the Philippines, 298 supports have been erected, while in Kuala Lumpur, the figure is 135. When the technology was introduced to the Philippines, the President of the Philippines, Fidel Ramos commented: "This is an Indonesian invention, but is also an ASEAN invention".

A second version of the technology has been developed. Whereas the first version used a steel anchor inserted in a concrete base, the second version uses a single plate with a hole in the middle which is not only simpler, but also significantly speeds up the time it takes to erect a pylon from 2 days to 45 minutes. It is expected that the lifespan of flyovers constructed using the Sosrobahu method will be approximately 100 years.

According to Dr Drajat Hoedajanto, an expert from the Bandung Institute of Technology, Sosrobahu is a very simple solution to the problem of erecting flyover pylons and is suitable for use in the construction of elevated toll roads which have traffic running underneath them. Sosrobahu is clearly a useful and versatile technology.

## Sources

"Sosrobahu Bertumpu di Atas Piring", Gatra Magazine, 21 August 2004; in Indonesian, requests payment

## Chapter- 7

# Road Surface



A road in the process of being resurfaced

**Road surface** (British English) or **pavement** (American English) is the durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as a road or walkway. In the past cobblestones and granite setts were extensively used, but these surfaces have mostly been replaced by asphalt or concrete. Such surfaces are frequently marked to guide traffic. Today, permeable paving methods are beginning to be used for low-impact roadways and walkways.

## Metalling

The term *road metal* refers to the broken stone or cinders used in the construction or repair of roads or railways, and is derived from the Latin *metallum*, which means both "mine" and "quarry". Metalling is known to have been used extensively in the construction of roads by soldiers of the Roman Empire but a limestone-surfaced road,

thought to date back to the Bronze Age, has been found in Britain. Metalling has had two distinct usages in road surfacing. The term originally referred to the process of creating a gravel roadway. The route of the roadway would first be dug down several feet and, depending on local conditions, French drains may or may not have been added. Next, large stones were placed and compacted, followed by successive layers of smaller stones, until the road surface was composed of small stones compacted into a hard, durable surface. "Road metal" later became the name of stone chippings mixed with tar to form the road surfacing material tarmac. A road of such material is called a "metalled road" in Britain, a "paved road" in the USA, or a "sealed road" in Australia.

## Asphalt



Closeup of asphalt on a driveway

Asphalt (specifically, asphalt concrete) has been widely used since 1920–1930. The viscous nature of the bitumen binder allows asphalt concrete to sustain significant plastic deformation, although fatigue from repeated loading over time is the most common failure mechanism. Most asphalt surfaces are built on a gravel base, which is generally at least as thick as the asphalt layer, although some 'full depth' asphalt surfaces are built directly on the native subgrade. In areas with very soft or expansive subgrades such as clay or peat, thick gravel bases or stabilization of the subgrade with Portland cement or lime may be required. Polypropylene and polyester materials have also been used for this

purpose and in some northern countries, a layer of polystyrene boards have been used to delay and minimize frost penetration into the subgrade.

Depending on the temperature at which it is applied, asphalt is categorized as hot mix asphalt (HMA), warm mix asphalt, or cold mix asphalt. Hot mix asphalt is applied at temperatures over 300 F with a free floating screed. Warm mix asphalt is applied at temperatures of 200 to 250 degrees F, resulting in reduced energy usage and emissions of volatile organic compounds. Cold mix asphalt is often used on lower volume rural roads, where hot mix asphalt would cool too much on the long trip from the asphalt plant to the construction site .

An asphalt concrete surface will generally be constructed for high volume primary highways having an Average Annual Daily Traffic load higher than 1200 vehicles per day. Advantages of asphalt roadways include relatively low noise, relatively low cost compared with other paving methods, and perceived ease of repair. Disadvantages include less durability than other paving methods, less tensile strength than concrete, the tendency to become slick and soft in hot weather and a certain amount of hydrocarbon pollution to soil and groundwater or waterways.

In the 1960s, rubberized asphalt was used for the first time, mixing crumb rubber from used tires with asphalt. In addition to using tires that would otherwise fill landfills and present a fire hazard, rubberized asphalt is more durable and provides a 7–12 decibel noise reduction over conventional asphalt. However, application of rubberized asphalt is more temperature-sensitive, and in many locations can only be applied at certain times of the year.

## Concrete

**Concrete** surfaces (specifically, Portland cement concrete) are created using a concrete mix of Portland cement, gravel, sand and water. The material is applied in a freshly-mixed slurry, and worked mechanically to compact the interior and force some of the thinner cement slurry to the surface to produce a smoother, denser surface free from honeycombing. The water allows the mix to combine molecularly in a chemical action called hydration.

Concrete surfaces have been refined into three common types: jointed plain (JPCP), jointed reinforced (JRCP) and continuously reinforced (CRCP). The one item that distinguishes each type is the jointing system used to control crack development.

Jointed Plain Concrete Pavements (JPCP) contain enough joints to control the location of all the expected natural cracks. The concrete cracks at the joints and not elsewhere in the slabs. Jointed plain pavements do not contain any steel reinforcement. However, there may be smooth steel bars at transverse joints and deformed steel bars at longitudinal joints. The spacing between transverse joints is typically about 15 feet for slabs 7–12 inches thick. Today, a majority of the U.S. state agencies build jointed plain pavements.

Jointed Reinforced Concrete Pavements (JRCP) contain steel mesh reinforcement (sometimes called distributed steel). In jointed reinforced concrete pavements, designers increase the joint spacing purposely, and include reinforcing steel to hold together intermediate cracks in each slab. The spacing between transverse joints is typically 30 feet or more. In the past, some agencies used a spacing as great as 100 feet. During construction of the interstate system, most agencies in the Eastern and Midwestern U.S. built jointed-reinforced pavement. Today only a handful of agencies employ this design, and its use is generally not recommended as JPCP and CRCP offer better performance and are easier to repair.

Continuously Reinforced Concrete Pavements (CRCP) do not require any transverse contraction joints. Transverse cracks are expected in the slab, usually at intervals of 3–5 ft. CRCP pavements are designed with enough steel, 0.6–0.7% by cross-sectional area, so that cracks are held together tightly. Determining an appropriate spacing between the cracks is part of the design process for this type of pavement.

Continuously reinforced designs generally cost more than jointed reinforced or jointed plain designs initially due to increased quantities of steel. However, they can demonstrate superior long-term performance and cost-effectiveness. A number of agencies choose to use CRCP designs in their heavy urban traffic corridors.

One advantage of cement concrete roadways is that they are typically stronger and more durable than asphalt roadways. They also can easily be grooved to provide a durable skid-resistant surface. Disadvantages are that they typically have a higher initial cost and are perceived to be more difficult to repair.

The first street in the United States to be paved with concrete was Court Avenue in Bellefontaine, Ohio, but the record for first mile of concrete pavement to be laid in the United States is claimed by Michigan.

## **Composite surfaces**

Composite surfaces combine Portland cement concrete and asphalt. They are usually used to rehabilitate existing roadways rather than in new construction.

Asphalt overlays are sometimes laid over distressed concrete to restore a smooth wearing surface. A disadvantage of this method is that the joints between the underlying concrete slabs usually cause cracks, called *reflective cracks* in the asphalt.

Whitetopping uses Portland cement concrete to resurface a distressed asphalt road.

## **In-place recycling**

Distressed road materials can be reused when rehabilitating a roadway. The existing pavement is ground or broken up into small pieces, then compacted to form the base or subbase for new pavement. Some methods used include:

- Rubblizing of concrete pavement. Existing concrete pavement is broken into gravel-sized particles, compacted, then overlaid with asphalt pavement.
- Cold in-place recycling. Bituminous pavement is ground or milled into small particles, compacted, and overlaid with asphalt pavement. The asphalt millings are blended with a small amount of asphalt emulsion, paved and compacted, allowed to cure for seven to ten days, then overlaid with asphalt.
- Hot in-place recycling. Bituminous pavement is heated to 250 to 300°F (120 to 150°C), milled, combined with a rejuvenating agent or virgin asphalt binder, and compacted. It may then be overlaid with a new asphalt overlay. This process only recycles the top two inches (50 mm) or less, so it can be used to correct rutting, polishing or other surface defects. It is not a good procedure for roads with structural failures. It also generates high heat and vapor emissions, and may not be a good candidate for built-up areas.
- Full depth reclamation is a process which pulverizes the full thickness of the asphalt pavement and some of the underlying material to provide a uniform blend of material. A binding agent may be mixed in to form a base course for the new pavement, or it may be left unbound to form a subbase course. Common binding agents include asphalt emulsion, fly ash, Portland cement or calcium chloride. It can also be mixed with aggregate, recycled asphalt millings, or crushed Portland cement to improve the gradation of the material.

## Bituminous Surface Treatment (BST)



Concrete pavers

**Bituminous Surface Treatment (BST)** is used mainly on low-traffic roads, but also as a sealing coat to rejuvenate an asphalt concrete pavement. It generally consists of aggregate spread over a sprayed-on asphalt emulsion or cut-back asphalt cement. The aggregate is then embedded into the asphalt by rolling it, typically with a rubber-tired roller. BSTs of this type are described by a wide variety of regional terms including "chip seal", "tar and chip", "oil and stone", "seal coat", "sprayed seal" or "surface dressing".

BST is used on hundreds of miles of the Alaska Highway and other similar roadways in Alaska, the Yukon Territory, and northern British Columbia. The ease of application of BST is one reason for its popularity, but another is its flexibility, which is important when roadways are laid down over unstable terrain that thaws and softens in the spring.

Other types of BSTs include micropaving, slurry seals and Novachip. These are laid down using specialized and proprietary equipment. They are most often used in urban areas where the roughness and loose stone associated with chip seals is considered undesirable.

## **Thin membrane surface**

A thin membrane surface (TMS) is an oil treated aggregate which is laid down upon a gravel road bed producing a dust free road. A TMS road reduces mud problems and provides stone free roads for local residents where loaded truck traffic is negligible. The TMS layer adds no significant structural strength, and so is used on secondary highways with low traffic volume and minimal weight loading. Construction involves minimal subgrade preparation, following by covering with a 50 to 100 millimetres (2.0–3.9 in) cold mix asphalt aggregate. The Operation Division of the Ministry of Highways and Infrastructure in Saskatchewan has the responsibility of maintaining 6,102 kilometers (3,792 mi) of thin membrane surface (TMS) highways.

## **Granular**

A granular surface can be used with a traffic volume where the average annual daily traffic is 1,200 vehicles per day or less. There is some structural strength as the road surface combines a sub base, base and is topped with a double graded seal aggregate with emulsion. Besides the 4,929 kilometers (3,063 mi) of granular pavements maintained in Saskatchewan, over 90% of New Zealand roads are unbound granular pavement structures.

## **Otta seal**

Otta seal is a low-cost road surface using a 16–30-millimetre (0.63–1.2 in) thick mixture of bitumen and crushed rock.



A brick main street in Lebanon, Illinois

## **Other surfaces**

**Pavers** (or **paviours**), generally in the form of pre-cast concrete blocks, are often used for aesthetic purposes, or sometimes at port facilities that see long-duration pavement loading. Pavers are rarely used in areas that see high-speed vehicle traffic.

Brick, cobblestone, sett, and wood plank pavements were once common in urban areas throughout the world, but fell out of fashion in most countries, due to the high cost of labor required to lay and maintain them, and are typically only kept for historical or aesthetic reasons. In some countries, however, they are still common in local streets. Likewise, macadam and tarmac pavements can still sometimes be found buried underneath asphalt concrete or Portland cement concrete pavements, but are rarely constructed today.

## **Acoustical implications**

Roadway surfacing choices are known to affect the intensity and spectrum of sound emanating from the tire/surface interaction. Initial applications of this knowledge occurred in the early 1970s. Roadway surface types contribute differential noise effects of up to four dB, with chip seal type and grooved roads being the loudest and concrete surfaces without spacers being the quietest. Asphaltic surfaces perform intermediately relative to concrete and chip seal. These phenomena are, of course, highly influenced by vehicle speed. Rubberized asphalt has been shown to give a very significant 7–12 decibel reduction in road noise when compared to conventional asphalt applications.

## **Surface deterioration**

As pavement systems primarily fail due to fatigue (in a manner similar to metals), the damage done to pavement increases with the fourth power of the axle load of the vehicles traveling on it. Civil Engineers consider truck axle load, current and projected truck traffic volume, supporting soil properties (can be measured using the CBR) and sub-grade drainage in design. Passenger cars are considered to have no practical effect on a pavement's service life, from a fatigue perspective.

Other failure modes include aging and surface abrasion. As years go by, the binder in a bituminous wearing course gets stiffer and less flexible. When it gets "old" enough, the surface will start losing aggregates, and macrotexture depth increases dramatically. If no maintenance action is done quickly on the wearing course potholing will take place. If the road is still structurally sound, a bituminous surface treatment, such as a chipseal or surface dressing can prolong the life of the road at low cost. In areas with cold climate, studded tires may be allowed on passenger cars. In Sweden and Finland, studded passenger car tires account for a very large share of pavement rutting.

Several design methods have been developed to determine the thickness and composition of road surfaces required to carry predicted traffic loads for a given period of time.

Pavement design methods are continuously evolving. Among these are the Shell Pavement design method, and the American Association of State Highway and Transportation Officials (AASHTO) 1993 "Guide for Design of Pavement Structures". A new mechanistic-empirical design guide has been under development by NCHRP (Called Superpave Technology) since 1998. A new design guide called Mechanistic Empirical Pavement Design Guide (MEPDG) was developed and is about to be adopted by AASHTO.

According to the AASHO Road Test, heavily loaded trucks can do more than 10,000 times the damage done by a normal passenger car. Tax rates for trucks are higher than those for cars in most countries for this reason, though they are not levied in proportion to the damage done.

The physical properties of a stretch of pavement can be tested using a falling weight deflectometer.

Further research by University College London into pavements has led to the development of an indoor, 80-sq-metre artificial pavement at a research centre called Pedestrian Accessibility and Movement Environment Laboratory (PAMELA). It is used to simulate everyday scenarios, from different pavement users to varying pavement conditions. There also exists a research facility near Auburn University, the NCAT Pavement Test Track, that is used to test experimental asphalt pavements for durability.