Concrete Tests for Rigid Pavements Design

Course No: C02-087
Credit: 2 PDH

Najib Gerges, Ph.D., P.E.

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.com

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Section 1 — Background

Overview

Pavement design is one of the most important parts of transportation engineering. To carry traffic from one place to another place comfortably, economically, and safely, an engineering design of pavements is essential. In this handout, the required background knowledge about the structural design of pavements is discussed. The pavement structure should be able to provide an acceptable riding quality, satisfactory skid resistance, favorable light-reflecting characteristics, and low noise. The aim is to ensure that the transmitted wheel loads are sufficiently reduced, so that they do not exceed the capacity of all the layers of pavement including the subgrade.

A highway pavement is a structure consisting of layers of natural and processed materials above the natural ground (often called subgrade). A pavement's primary function is to distribute the vehicle loads from the top of the pavement to a larger area of the subgrade without causing any damage to the subgrade. The pavement structure should be able to provide an acceptable riding quality, satisfactory skid resistance, favorable light-reflecting characteristics, and low noise. The aim is to ensure that the transmitted wheel loads are sufficiently reduced, so that they do not exceed the capacity of all the layers of pavement including the subgrade

A pavement is expected to meet the following requirements:

- Sufficient thickness to distribute the wheel-induced stresses to a reduced value on the subgrade soil.
- Structurally adequate to keep the cracking and deformation within tolerable limits.
- Structurally strong to withstand all types of stresses imposed upon it.
- Adequate coefficient of friction to prevent skidding of vehicles.
- Smooth surface to provide comfort to road users even at the expected speed.
- Produces least noise from moving vehicles.
- Dust and waterproof surface for avoiding reduced visibility.
- Drains water laterally or vertically without washing layer particles.

• Long service life with a desirable level of comfort considering the economy.

Two types of pavements are generally recognized: Flexible Pavements and Rigid Pavements, as shown in Figure 1.

A combination of these two pavements is also possible, and is termed Composite Pavement as shown in Figure 2.

Flexible pavement   Rigid pavement

Figure 1 Flexible and Rigid Pavements

Figure 2 Composite Pavement Black Topping (top) and White Topping (bottom)

Section 2 — Pavement Types

Flexible Pavements

- Flexible pavements are usually surfaced with Asphalt Materials. These pavements are called flexible because the pavement structures can flex or bend under a traffic loading.

- A flexible pavement structure requires several layers of materials because these layers are not stiff enough to distribute the wheel load to a large area (Figure 3).

- Beneath the asphalt layer, a crushed aggregate base layer is commonly seen. Below the base layer, a subbase layer is also used based on the subgrade strength.

- The natural subgrade soil can be improved by compaction or mixing of some improved soil, asphalt millings, low-quality aggregate based on the availability of these materials, and degree of improvement required.

- Superpave, which is an acronym for Superior Performing Asphalt Pavements, is a performance-based specification for asphalt binder and volumetric mixture design. The idea was to allow asphalt pavement designs that could handle the unique weather and traffic conditions of a given site in any geographic area of the U.S. The system consisted of three components:

    - Asphalt binder specification: a system of classifying asphalt binder based on its performance response to temperatures and aging characteristics.

    - A design system grounded in traffic loading and environmental conditions.

    - Mix design system and analysis tests for performance prediction models.

- Superpave leverages modern asphalt paving technology to develop mixtures more resistant to cracking from low temperature and fatigue factors and reduce permanent deformation. Superpave means mix designs can be tailored for better performance and longer life based on a geographical area's temperature extremes, traffic loads, and utilization of the road or highway.

Rigid Pavements

- Rigid pavements are composed of reinforced or non-reinforced Portland cement concrete (PCC) surface course.
- Such pavements are stiffer than flexible pavements due to the high modulus of elasticity [typically 3000–4000 Ksi (21–28 GPa) for PCC and 500–1000 Ksi (3.4–6.9 GPa) for asphalt layer] of the PCC material.

- These pavements can have reinforcing steel to reduce thermal cracking or eliminate joints. Each of these pavement types distributes load over the subgrade in a different fashion.

- Rigid pavements, because of PCC's high elastic modulus, tend to distribute the load over a relatively wide area of a subgrade (Figure 3).

- The concrete slab itself supplies most of a rigid pavement's structural capacity. On the other hand, a flexible pavement having a low modulus distributes loads over a smaller area. It requires a thicker pavement, which is achieved through a combination of thin layers due to field compaction difficulty of constructing a thicker layer.

- Compared to flexible pavements, rigid pavements are placed either directly over the prepared subgrade or over a single layer of granular or stabilized material called base course.

- In rigid pavements, the load is distributed by the slab action, in which the pavement behaves like an elastic plate resting on an elastic medium.

- Rigid pavements should be analyzed by the "plate theory" instead of the "layer theory", assuming an elastic plate resting on an elastic foundation.

- The "plate theory" assumes the concrete slab as a medium thick plate that is plane before loading and remains plane after loading.

- Bending of the slab due to wheel load and temperature variation causes tensile and flexural stresses within the pavement layers.

- Layered elastic models assume that each pavement structural layer is homogeneous, isotropic, and linearly elastic. In other words, it is the same everywhere and will rebound to its original form once the load is removed.

- The plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading. Bending of the slab due to wheel load and temperature variation and the resulting tensile and flexural stress.

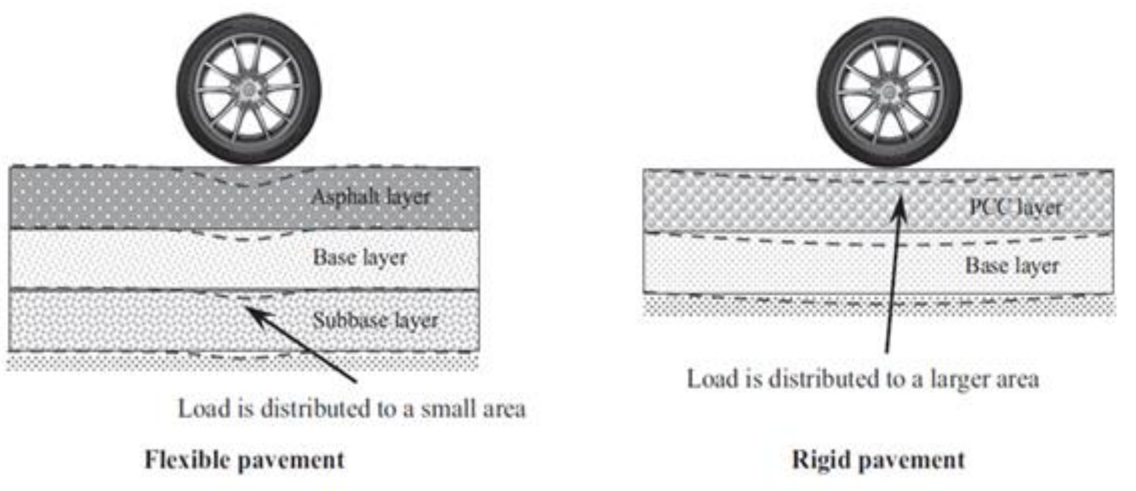

Figure 3 Deformation Behaviour of Flexible and Rigid Pavements

Three levels are available for determining the input values for most of the materials and traffic parameters: Level 1 from site specific and actual tests, resulting in higher accuracy, Level 2 from less than optimal testing or by correlations, and Level 3 from the agency database, user selected default values.

Section 3 — Portland Cement Concrete (Rigid Pavements)

Portland Cement is the most common type of cement in general use around the world as a basic ingredient of concrete, mortar, stucco, and non-specialty grout. It was developed from other types of hydraulic lime in England in the early 19^{th} century by Joseph Aspdin, and is usually made from limestone. It is a fine powder, produced by heating limestone and clay minerals in a kiln to form clinker, grinding the clinker, and adding 2 to 3 percent of gypsum. Several types of Portland Cement are available. The most common, called Ordinary Portland Cement (OPC), is grey, but white Portland Cement is also available. Its name is derived from its resemblance to Portland stone which was quarried on the Isle of Portland in Dorset, England. It was named by Joseph Aspdin who obtained a patent for it in 1824. However, his son William Aspdin is regarded as the inventor of "modern" Portland Cement due to his developments in the 1840's.

Portland cement concrete (PCC), shown in Figure 4 and produced using Portland cement, is one of the most versatile construction materials available in the world. The low cost and widespread availability of Portland cement and aggregates make PCC the lowest-cost material widely used over the last century. In rigid pavements, the surface layer is constructed with PCC, reinforced or unreinforced. The reinforcement is provided by structural steel rebar. PCC is also used for some high structures such as curbs, footpaths, roadside rigid barriers, and retaining walls. This section discusses the knowledge of PCC required for rigid pavement design.

Figure 4 Pouring Portland Cement Concrete on a Highway

PCC Characterizations (Tests)

PCC Characterizations consist of performing the following tests:

Elastic Modulus, Compressive Strength, Poisson's Ratio

The modulus of elasticity is the slope of the stress-strain curve at the initial phase or until the linear elastic region (proportional limit). The ratio of lateral to longitudinal strain within linear elastic region is known as Poisson's ratio. The modulus of elasticity and Poisson's ratio are used in sizing of reinforced and unreinforced structural members, establishing the quantity of reinforcement, and computing developed stress-strain. The elastic modulus (modulus of elasticity) and Poisson's ratio of PCC are determined using the ASTM C 469 standard using cylindrical specimens, as shown in Figure 5. This test method provides the stress-strain curve until failure. The stress-strain curves of concretes of different strengths show that the curve becomes nonlinear after about 30% to 40% of the ultimate stress.

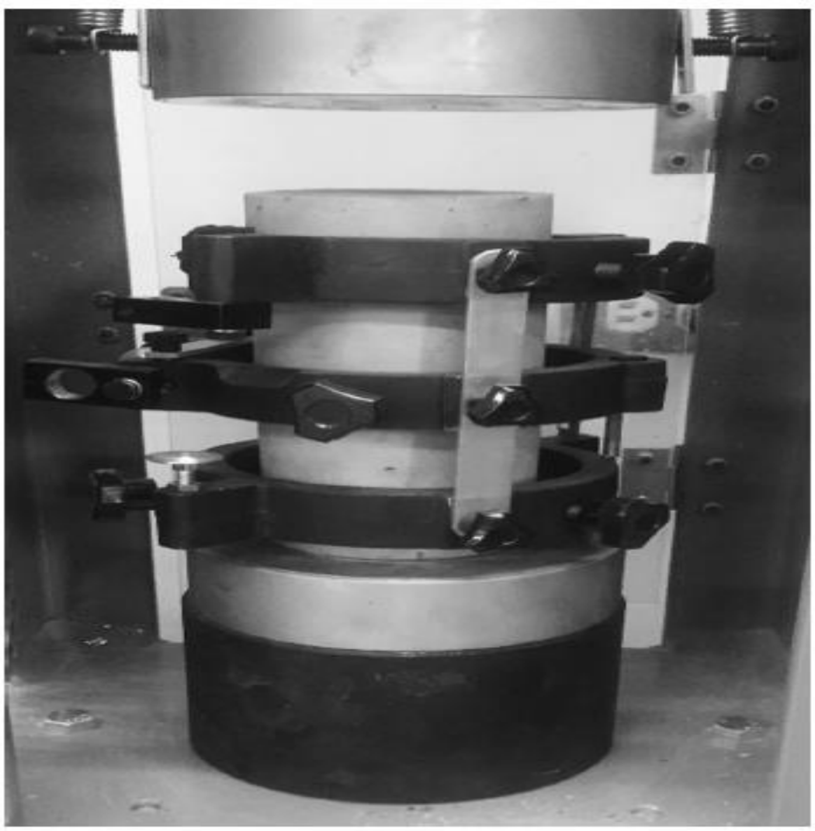

Figure 5 Modulus of Elasticity and Poisson's Ratio of Concrete Testing

Poisson's ratio (μ) can be defined as the ratio of lateral strain (ε_t) and axial strain (ε_a).

$$\mu = -\frac{\text{Lateral strain}}{\text{Axial strain}} = -\frac{\varepsilon_t}{\varepsilon_a}$$

$$\text{where Lateral strain, } \varepsilon_t = \frac{\Delta D}{D_o} = \frac{\Delta r}{r_o} = \frac{\Delta w}{w_o} = \frac{\Delta t}{t_o}$$

$$\text{Axial strain, } \varepsilon_a = \frac{\Delta L}{L_o}$$

L_o = Original length of member
ΔL = Change in length (final length minus the original length)
r_o = Original radius
Δr = Change in radius (final radius minus the original radius)
w_o = Original width
Δw = Change in width (final width minus the original width)
t_o = Original thickness
Δt = Change in thickness (final thickness minus the original thickness)

The elastic modulus values of existing intact and fractured PCC are illustrated in Table 1 and default Poisson's ratios of PCC materials are illustrated in Table 2.

Pavement type	Elastic modulus (ksi)	
Existing intact PCC	Adequate	3,000–4,000
	Marginal	1,000–3,000
	Inadequate	300–1,000
Existing fractured PCC	Crack and seat or break and seat	150–1,000
	Rubblized	50–150

Table 1 Elastic Modulus Values of Existing Intact and Fractured PCC

PCC materials	Poisson's ratio
PCC slabs (new or existing)	0.20
Fractured slab–crack/seat	0.20
Fractured slab–break/seat	0.20
Fractured slab–rubblized	0.30

Table 2 Default Poisson's Ratios of PCC Materials

Example 1: Modulus of Elasticity and Poisson's Ratio

A compressive force of 15 kips is applied on a 6-in.-diameter and 12-in.-high long cylindrical concrete specimen. After applying the load, the diameter of the rod increases to 6.0002 in. and the length decreases to 11.9998 in. Assuming no permanent deformation occurs in that material, calculate the modulus of elasticity and Poisson's ratio.

Solution

$$\text{Axial stress, } \sigma = \frac{\text{Load}}{\text{Area}} = \frac{15{,}000 \text{ lb}}{\frac{\pi}{4}(6 \text{ in.})^2} = 530.5 \text{ psi}$$

$$\text{Axial strain, } \varepsilon_a = \frac{\Delta L}{L_o} = \frac{11.998 - 12}{12} = -0.000167 \text{ (negative sign is commonly omitted)}$$

$$\text{Lateral/transverse strain, } \varepsilon_t = \frac{\Delta D}{D_o} = \frac{6.0002 - 6}{6} = 0.000033$$

$$\text{Elasticity, } E = \frac{\sigma}{\varepsilon_a} = \frac{530.5 \text{ psi}}{0.000167} = 3{,}176{,}600 \text{ psi}$$

$$\text{Poisson's ratio, } \mu = \frac{\varepsilon_t}{\varepsilon_a} = \frac{0.000033}{0.000167} = 0.198$$

Answers *The modulus of elasticity is 3,176,600 psi and Poisson's ratio is 0.198.*

Flexural Strength (Modulus of Rupture)

Concrete Modulus of Rupture Testing applying a Center-Point Loading

Modulus of rupture (R) or the flexural strength of concrete is the bending strength capacity of a PCC slab. When a PCC slab is loaded by traffic, the slab bends and bending stress develops similar to a beam/slab. This is why the flexural strength is an important input for rigid pavement design especially for predicting the amount of transverse cracking in a pavement PCC slab. The flexural strength is determined by applying a third-point loading on a beam specimen following the AASHTO 97 test protocol. The specimen is placed on its side in the machine in such a manner that a minimum of 1 in. (25 mm) of the beam extends outside the support rollers as shown in Figure 6 and the types of cracks in concrete beams and their causes are shown in Figures 7 and 8. A load of between 3% and 6% of the expected ultimate load is applied. The beam specimen is subjected to an increasing load until failure, with the extreme fiber stress between 125 psi/min (860 kPa/min) and 175 psi/min (1,200 kPa/min).

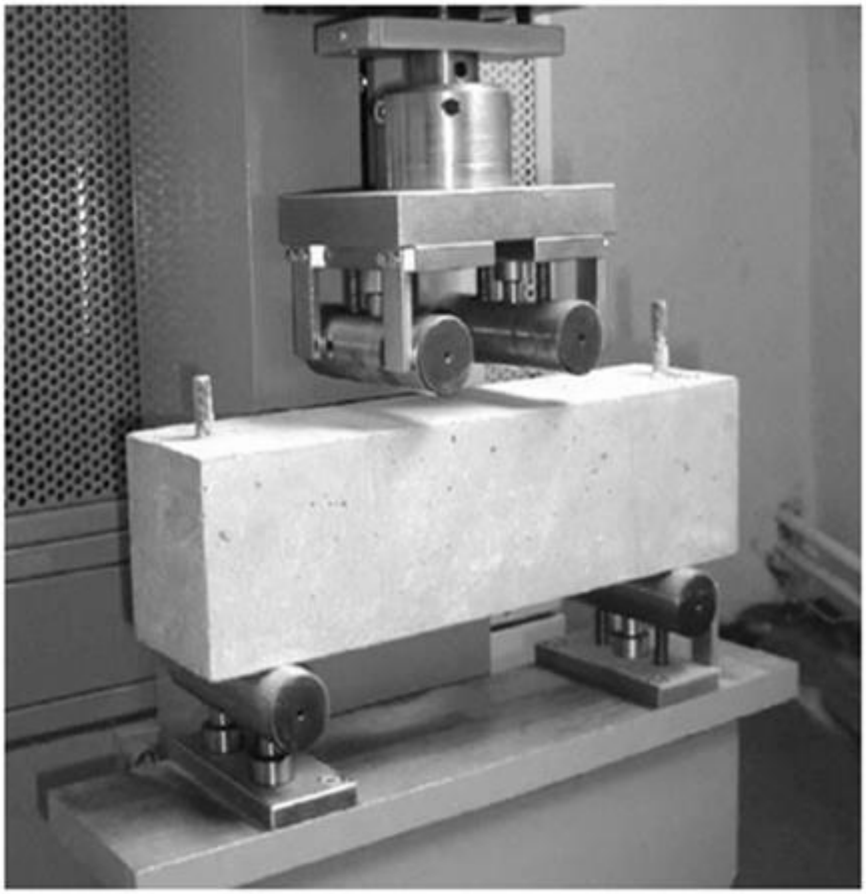

Figure 6 Concrete Modulus of Rupture Testing applying a Third-Point Loading

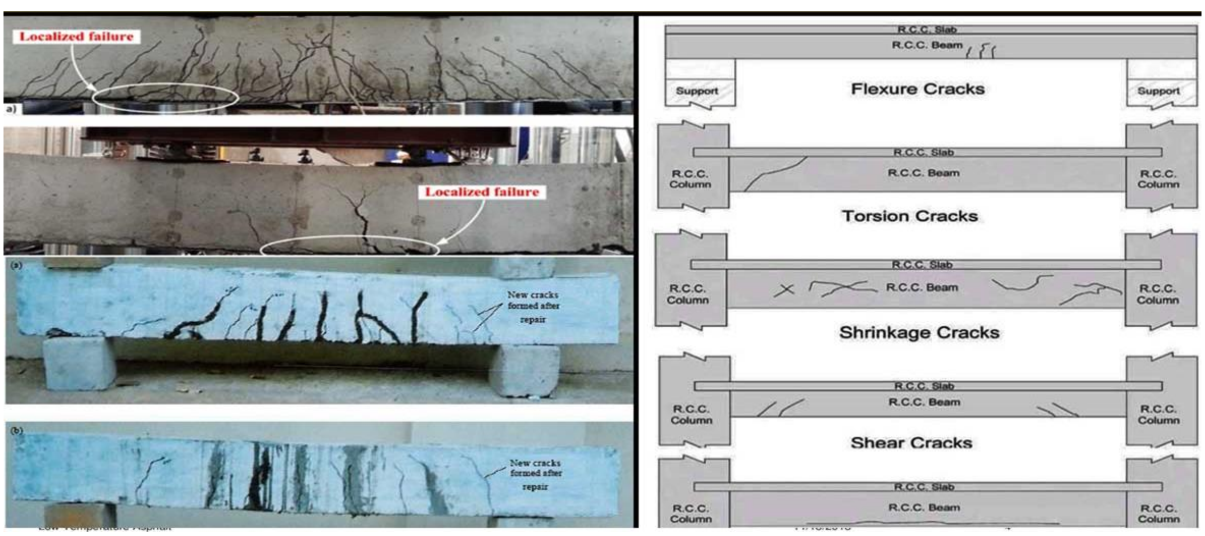

Figure 7 Types of Cracks in Concrete Beams and their Causes

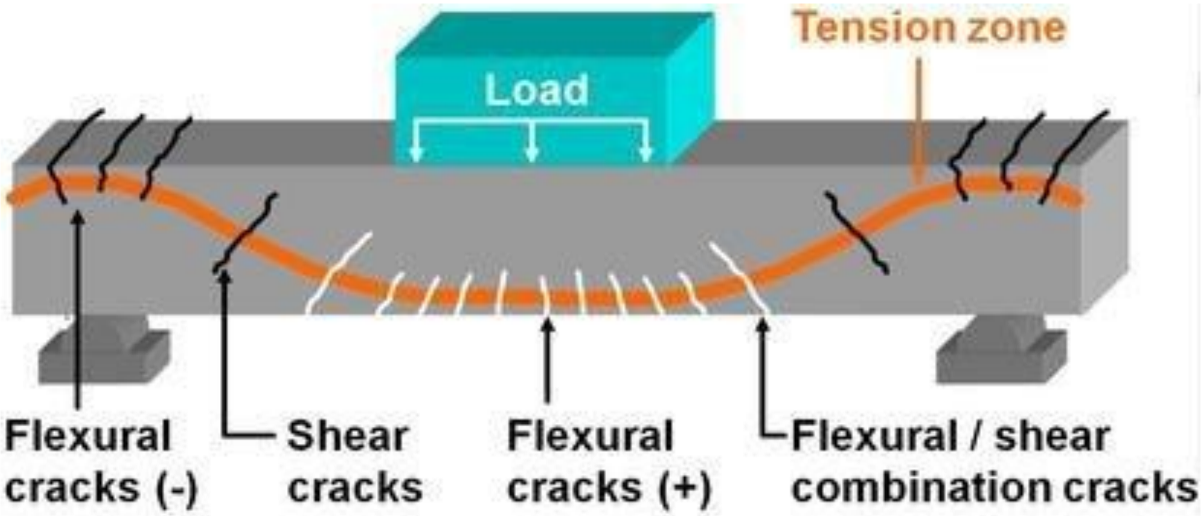

Figure 8 Cracks in Concrete Beams

- If the fracture initiates in the tension surface within the middle-third of the span length, the modulus of rupture is calculated as follows:

$$R = \frac{Mc}{I} = \frac{\left(\frac{PL}{6}\right)\frac{d}{2}}{\frac{bd^3}{12}} = \frac{PL}{bd^2}$$

where R = Modulus of rupture, psi or MPa

P = Maximum applied load indicated by the testing machine, lb or N

L = Span length, in. or mm

b = Average width of specimen at the fracture, in. or mm

d = Average depth of specimen at the fracture, in. or mm

- If the fracture occurs in the tension surface outside of the middle-third of the span length by not more than 5% of the span length, the modulus of rupture is calculated as follows:

$$R = \frac{3Pa}{bd^2}$$

where a = average distance between line of fracture and the nearest support measured on the tension surface of the beam, in. or mm.

- If the fracture occurs in the tension surface outside of the middle-third of the span length by more than 5% of the span length, the result of the test is discarded.

Example 2: Flexural Strength Computations

A 6 × 6 × 18-in. concrete beam is being tested applying the third-point loading for flexure as shown in Figure 9. The beam fails when the load value reaches 6.0 kips. The failure is within the middle-third of the beam. Calculate the flexural strength of the beam.

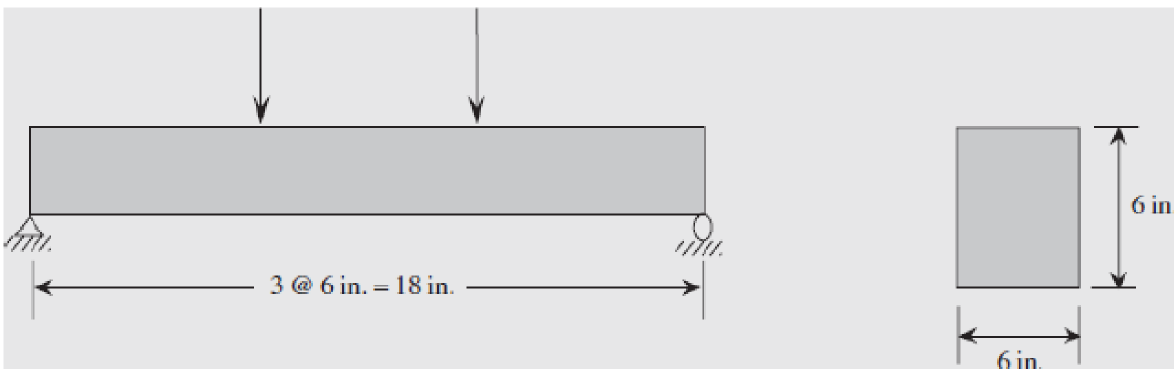

Figure 9 Modulus of Rupture Testing applying a Third-Point Loading

Solution

Given: Width, b = 6 in. Depth, d = 6 in. Peak load, P = 6,000 lb,

$$\text{Modulus of rupture, } R = \frac{PL}{bd^2} = \frac{(6{,}000\,\text{lb})\,(18\text{ in.})}{(6\text{ in.})\,(6\text{ in.})^2} = 500\,\text{psi}$$

Answer The flexural strength of the beam is 500 psi.

Concrete Modulus of Rupture Testing applying a Center-Point Loading

The flexural strength can also be determined using the center-point concentrated loading as shown in Figure 10 following the ASTM C 293 test protocol. If a center-point loading is applied on the concrete beam, the flexural strength of the concrete beam is determined using the following equation:

$$R = \frac{3}{2}\frac{PL}{bd^2}$$

where R = Modulus of rupture, psi or MPa

P = Maximum applied load indicated by the testing machine, lb or N

L = Span length, in. or mm

b = Average width of specimen at the fracture, in. or mm

d = Average depth of specimen at the fracture, in. or mm

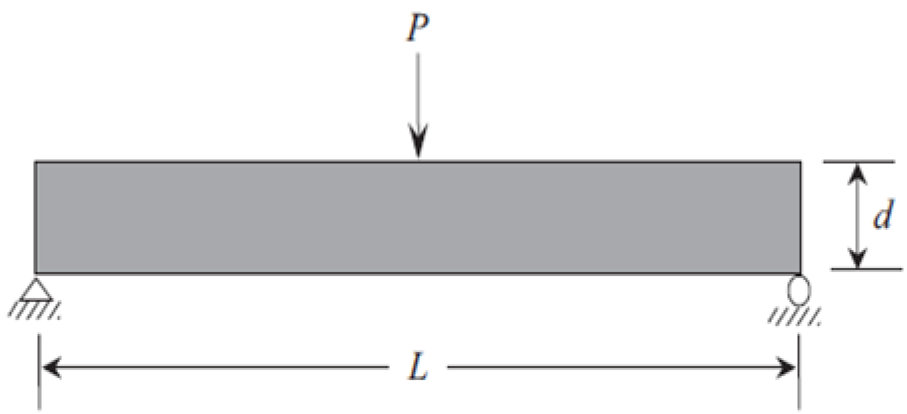

Figure 10 Concrete Modulus of Rupture Testing applying a Center-Point Loading

Indirect or Concrete Splitting Tensile Strength of PCC

It is about impossible to test a concrete specimen in direct tension. An indirect method of determining tensile strength is used where a diametric compressive load is then applied along the length of the cylindrical specimen as shown in Figure 11. Tensile strength is typically used as a PCC performance measure for pavements because it best simulates tensile stresses at the bottom of the PCC surface course as it is subjected to loading. These stresses are typically the controlling structural design stresses. PCC tensile strength is important in pavement applications, although PCC is not nearly as strong in tension as it is in compression. The indirect tensile strength test (also known as splitting tension test) is conducted using the AASHTO T 198 and ASTM C 496 test standards. A splitting tension test uses a standard 6-in. (150-mm) diameter, 12 in. (300 mm) long test cylinder laid on its side. A diametric compressive load is then applied along the length of the cylinder until it fails. The cylinder typically fails due to horizontal tension and not vertical compression because PCC is much weaker in tension than compression.

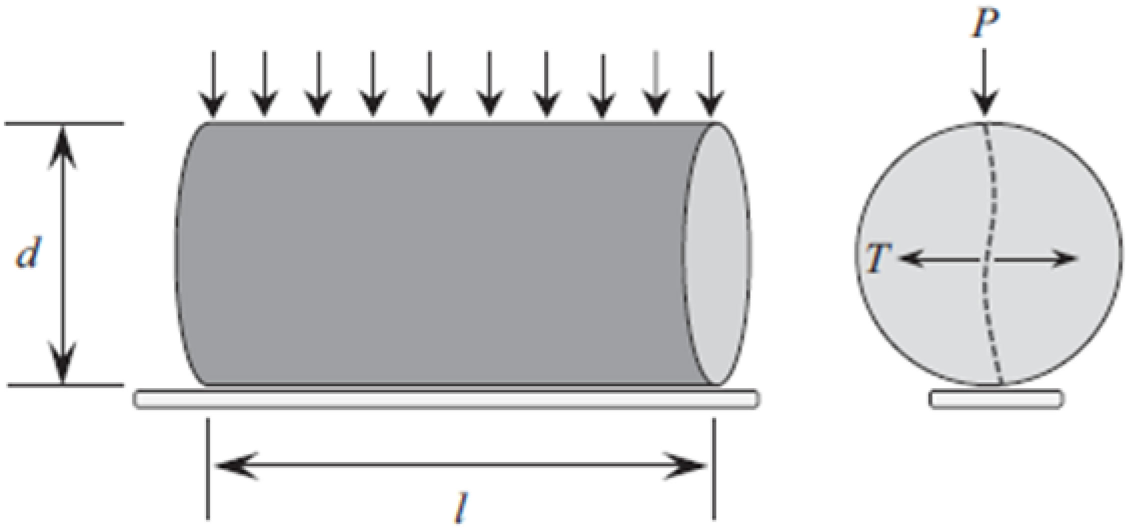

Figure 11 Concrete Splitting Tension Testing

The indirect tensile strength or splitting tensile strength or fracture strength T is calculated as:

$$T = \frac{2P}{\pi l D}$$

where T = Indirect or splitting or fracture tensile strength, psi or MPa

P = Peak force needed to crack the specimen diagonally, lb or N

D = Diameter of the specimen, in. or mm

l = Length of the specimen, in. or mm

Example 3: Tensile Strength Computations

In a splitting tensile strength test, the peak load required to fail a specimen of 6.0-in. diameter and 12-in. length is 90,000 lb. Calculate the indirect or splitting tensile strength of the specimen.

Solution

Given: Peak load, P = 90,000 lb Diameter, D = 6 in. Length, l = 12 in.

$$\text{Indirect tensile strength, } T = \frac{2P}{\pi l D} = \frac{2(90{,}000 \text{ lb})}{\pi(6.0 \text{ in.})(12.0 \text{ in.})} = 796 \text{ psi}$$

Answer The indirect tensile strength is 796 psi.

Unit Weight

Unit weight means the weight of a concrete slab for a unit volume. The unit weight of concrete is determined using the AASHTO T 121 test standard. A cylindrical mold, shown in Figure 12, is filled up with freshly mixed concrete in three equal layers. Each layer is compacted 25 times using a standard tamping rod. The surface of the fill is leveled using a cutting plate. The weight of the material filled is divided by the interior volume of the mold to calculate the unit weight. Agency historical data or typical range for normal weight concrete of 140 to 160 lb/ft (22–25 kN/m) can be used.

Figure 12 Unit Weight Testing of Concrete

Air Content

Air space (voids) inside a concrete slab is required if there is a probability that concrete may be exposed to freeze-thaw (Figure 13). The air content of concrete can be determined using the AASHTO T 152, which determines the air content of freshly mixed concrete from observation of the change in volume of concrete with a change in pressure.

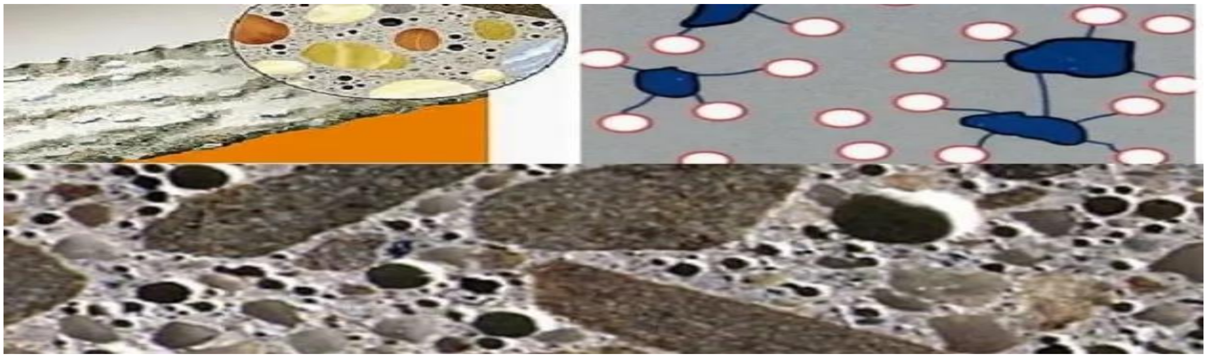

Figure 13 Air Content in Concrete

Coefficient of Thermal Expansion

The coefficient of thermal expansion is defined as the change in unit length per degree of temperature change. In a concrete element, it is therefore a measure of the free strain produced in concrete subject to a unit change in temperature and is usually expressed in microstrain per degree centigrade (με/°C). The coefficient of Thermal Expansion can be determined using the AASHTO TP 60 test protocol. Some common values are listed in Table 3.

Surface Shortwave Radiation Absorptivity

The short-wave radiation absorptivity indicates the fraction of the total solar radiation incident on the pavement surface which is absorbed. This value is used to calculate the surface layer temperature variation within a day. The AASHTOWare pavement ME design default value of 0.85 is to be used unless the test standard is available. This value was used in the global calibration process. The dimensionless surface short wave absorptivity defines the fraction of available solar energy that is absorbed by the pavement surface. It depends on the composition, color, and texture of the surface layer. Generally speaking, lighter and more reflective surfaces tend to have lower short wave absorptivity. Refer to Figure 14. There are no current AASHTO certified standards for paving materials.

Aggregate type	Coefficient of thermal expansion (10^{-6} per °F)
Andesite	5.3
Basalt	5.2
Diabase	4.6
Gabbro	5.3
Granite	5.8
Schist	5.6
Chert	6.6
Dolomite	5.8
Limestone	5.4
Quartzite	6.2
Sandstone	6.1
Expanded shale	5.7

Table 3 Coefficients of Thermal Expansions of PCC Materials

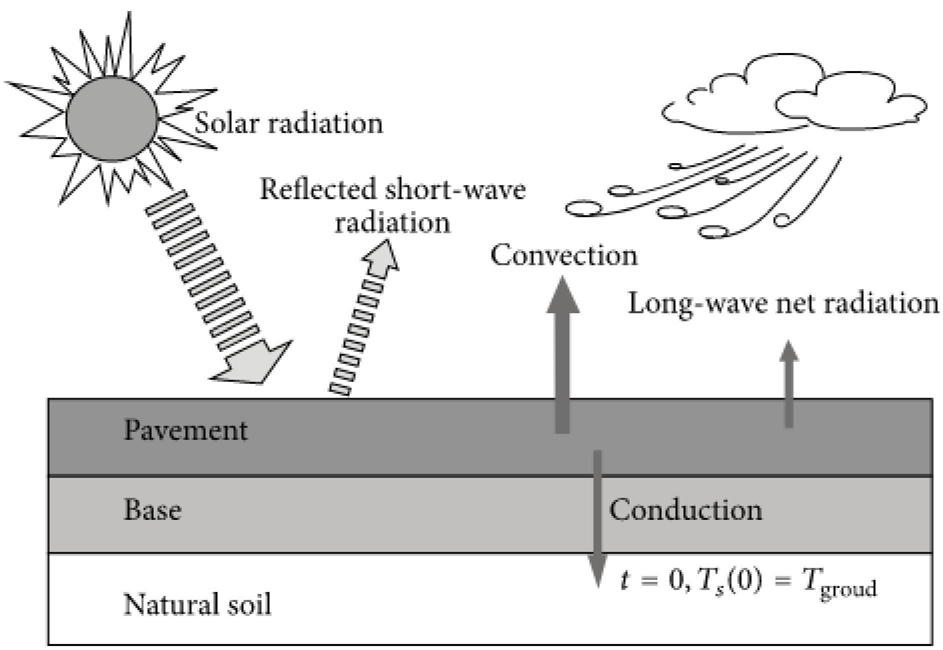

Figure 14 Illustration of Surface Shortwave Absorptivity

Thermal Conductivity

The thermal conductivity can be defined as the rate at which heat is transferred by conduction through a unit cross-section area of a material, when a temperature gradient exits perpendicular to the area. ASTM E 1952 test standard can be used to determine the thermal conductivity. However, this value is not measured very often. Rather, typical values of the thermal conductivity for PCC are used which range from 0.2 to 2.0 BTU/(ft)(h)(°F). The default value set in the AASHTOWare pavement ME design software is 1.25 BTU/(ft)(h)(°F).

Heat Capacity

The heat capacity is the ratio of heat absorbed by a material to the temperature change. It is usually expressed as calories per degree in terms of the actual amount of material being considered, most commonly a mole (the molecular weight in grams). ASTM D 2766 test standard can be used to determine the heat capacity. Typical heat capacity values for PCC range from 0.10 to 0.50 BTU/(lb)(°F). The default value set in the AASHTOWare pavement ME design software is 0.28 BTU/(lb)(°F).

Zero-Stress Temperature

The zero-stress temperature (ZST), defined as an inelastic indicator for the behavior of concrete elements in early-age, is one of the critical factors affecting the behavior and performance of concrete pavements. The zero-stress temperature (also called PCC set temperature) is considered the temperature at which concrete has no residual stress; below that temperature concrete shrinks and above that temperature concrete expands. Refer to Figures 15 and 16. There is no national test protocol available to determine the PCC zero-stress temperature. zero-stress temperature, T_z, can be input directly or can be estimated from monthly ambient temperature and cement content using the equations:

$$Tz = (\mathrm{CC} \times 0.59328 \times H \times 0.5 \times 1{,}000 \times 1.8/(1.1 \times 2{,}400) + \mathrm{MMT})\ or$$

$$Tz = (0.20225 \times \mathrm{CC} \times H + \mathrm{MMT})$$

where T_z = Zero-stress temperature (allowable range: 70 to 212°F)

CC = Cementitious content, lb/yd^3

H = $-0.0787 + 0.007 \times \mathrm{MMT} - 0.00003 \times \mathrm{MMT}^2$

MMT = Mean monthly temperature for month of construction, °F

The zero-stress temperatures for different mean monthly temperatures and different cement contents in the PCC mix design are presented in Table 4.

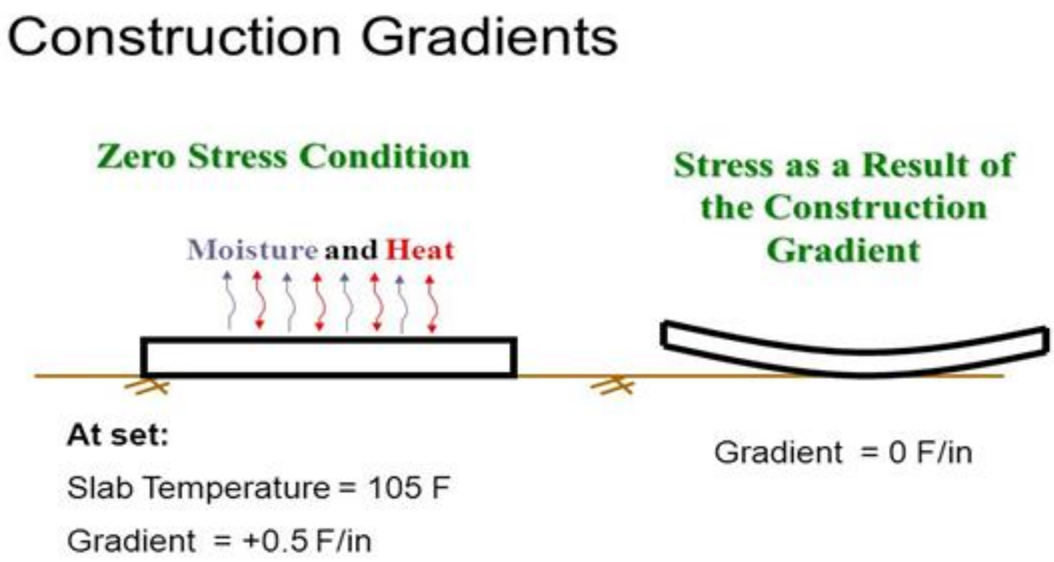

Figure 15 Illustration of Zero-Stress Temperature

Mean monthly temperature (°F)	Cement content (lb/yd³)			
	400	500	600	700
40	52	56	59	62
50	66	70	74	78
60	79	84	88	93
70	91	97	102	107
80	103	109	115	121
90	115	121	127	134
100	126	132	139	145

Table 4 Zero-Stress Temperatures (°F) for Different Mean Monthly Temperatures

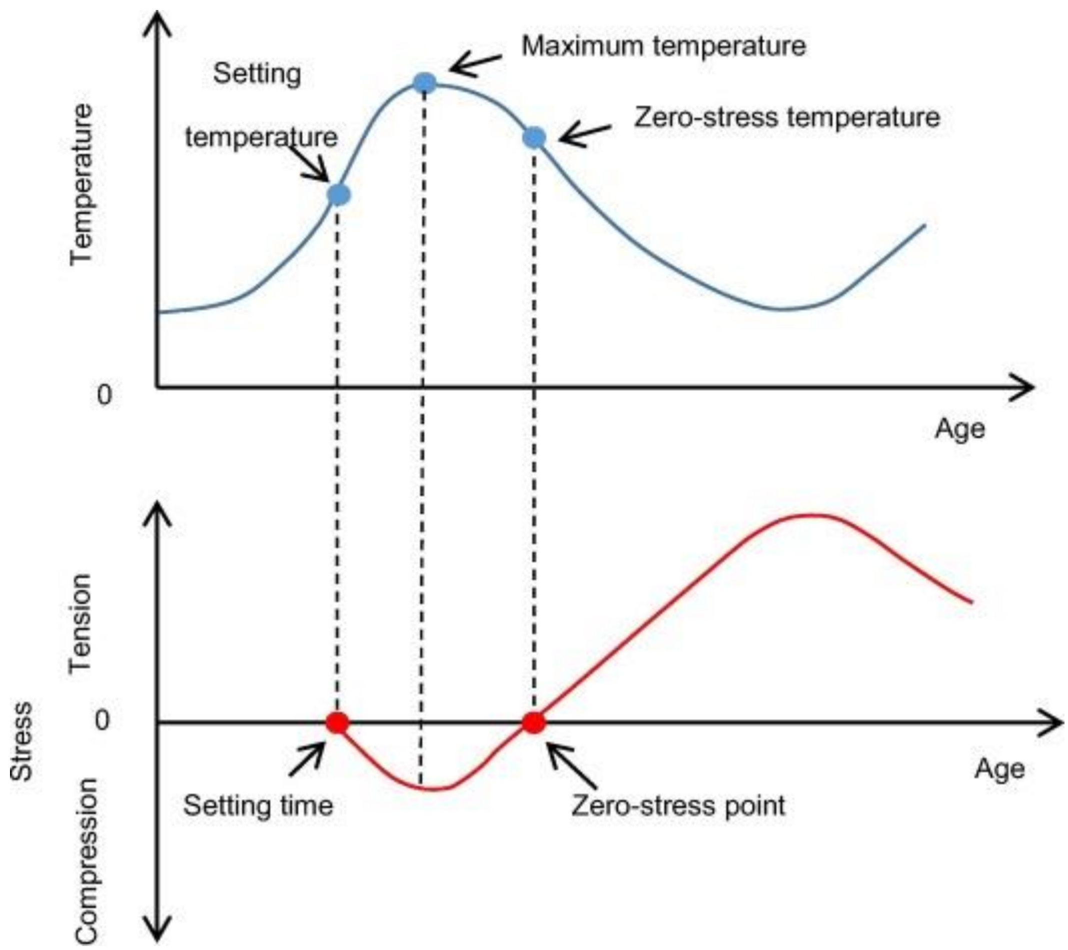

Figure 16 Variation of Temperature and Stress with Time

Example 4: Zero-Stress Temperature

A concrete pavement is to be constructed in April which mean monthly temperature is 60°F. The concrete slab uses the cement with a proportion of 500 lb/yd^3. Calculate the zero-stress temperature of the produced concrete slab in the pavement.

Solution

Equation to be used: $T_z = (0.20225 \times CC \times H + MMT)$

CC = Cementitious content = 500 lb/yd^3

$H = -0.0787 + 0.007 \times MMT - 0.00003 * MMT^2$

$= -0.0787 + 0.007 \times 60 - 0.00003 \times 60^2 = 0.2333$

Then $T_z = (0.20225 \times CC \times H + MMT) = 0.20225 \times 500 \times 0.23333 + 60 = 83.6$

Answer The zero-stress temperature is 84°F.

Cement Types

Cement type is an input while designing rigid pavement, as cement type plays a role in strength, hydration rate, heat generation, setting, etc. It is selected based on actual or expected cement source.

Generally, there are two types of Cement:

Hydraulic Cement: As the name indicates, Hydraulic Cement is the type which hardens by hydration in the presence of water. Limestone, clay, and gypsum are the main raw material to produce non-hydraulic cement. This raw material is burned at a very high temperature to manufacture Hydraulic Cement. Hydraulic Cement (cement that not only hardens by reacting with water but also forms a water-resistant product) produced by pulverizing clinkers which consist essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an inter ground addition.

Non-Hydraulic Cement: The Non-Hydraulic Cement does not require water to get harden. It gets with the help of carbon dioxide (CO_2) from the air. This type of cement needs dry conditions to harden. Lime, gypsum plasters, and oxychloride are the required raw material to produce non-hydraulic cement. Example: slaked lime is a non-hydraulic cement.

The various types of cement are:

Ordinary Portland Cement, Portland Pozzolana Cement, Rapid Hardening Cement, Quick Setting Cement, Low Heat Cement, Sulphate Resisting Cement, Blast Furnace Cement, High Alumina Cement, White Cement, Coloured Cement, Air Entraining Cement, Expansive Cement, and Hydrophobic Cement.

Ordinary Portland Cement (OPC)

In usual construction work, Ordinary Portland Cement is widely used.

The composition of Ordinary Portland Cement: Argillaceous or silicates of alumina (clay and shale), Calcareous or calcium carbonate (limestone, chalk, and marl).

Uses of Ordinary Portland Cement: it is used for general construction purposes; It is also used in most of the masonry works.

Portland Pozzolana Cement (PPC)

Pozzolans are natural or synthetic materials that contain silica in reactive forms.

Uses of Portland Pozzolana Cement: PPC is usually used in hydraulic structures, marine structures, construction near the seashore, dam construction, etc. It is also used in pre-stressed and post-tensioned concrete members. As it gives a better surface finish, it is used in decorative and art structures. It is also used in the manufacture of precast sewage pipes.

Rapid Hardening Cement

This type of cement gains strength more quickly than OPC. This type of OPC is called Rapid Hardening Cement. It's initial Setting Time 30 minutes and Final Setting Time 600 minutes.

Uses of Rapid Hardening Cement: Rapid Hardening Cement is mostly used where rapid construction is needed like the construction of pavement. It also gives high strength.

Quick Setting Cement

Quick Setting Cement is the cement which sets in a very short time. The initial setting time is 5 minutes and the final setting time is 30 minutes.

Uses of Quick Setting Cement: it is used in underwater construction. It is also used in rainy & cold weather conditions. It is used at higher temperatures where water evaporates easily and for anchoring or rock bolt mining, and tunneling.

Low Heat Cement

Low Heat Cement is a spatial type of cement which produces low heat of hydration during the setting.

Uses of Low Heat Cement: it is used for the construction of dam's large footing, large raft slabs, and wind turbine plinths. It is also used for the construction of chemical plants.

Sulphate Resisting Cement

Sulphate Resisting Cement is used to resist sulphate attacks in concrete.

Uses of Sulphate Resisting Cement: Construction in contact with soils or groundwater having more than 0.2% or 0.3 % g/l sulphate salts respectively. Concrete surfaces subjected to alternate wetting and drying such as bridge piers, concrete surface in the tidal zone, apron, buildings near the seacoast, effluent treatment plans, chimneys, chemical industries, water storage, sumps, drainage works, cooling towers, coastal protective works such as sea walls, breakwaters, tetrapods, etc.

Blast Furnace Cement

Portland Cement clinker and granulated blast furnace slag are intergraded to make Blast Furnace Cement. A maximum of 65 percent of the mixture could be comprised of blast furnace slag.

Uses of Blast Furnace Cement: It is highly sulphate resistant. Frequently used in seawater construction.

High Alumina Cement

High Alumina Cement is obtained by mixing calcining bauxite (it's an aluminum ore) and ordinary lime with clinker during the manufacture of OPC. In which the total amount of alumina content should not be lesser than 32% and it should maintain the ratio by weight of alumina to the lime between 0.85 to 1.30.

Uses of High Alumina Cement: It is used where concrete structures are subjected to high temperatures like workshops, refractory, foundries, etc. It also used where the concrete is subjected to frost and acidic action.

White Cement

White Cement is quite similar to Ordinary Portland Cement except for color. Amounts of iron oxide and manganese oxide are low in White Cement. It is more expensive then OPC so not economical for ordinary work.

Uses of White Cement: It is usually used in decorative work. It can also use for traffic barriers, tile grouts, swimming pools, roof tiles patching materials, and terrazzo surfaces.

Coloured Cement

To make 5 to 10 percent of suitable pigments are ground with OPC. Types of pigments are selected according to the desired color.

Uses of Coloured Cement: Coloured Cement is used for different decorative work.

Air Entraining Cement

It is seen that entrainment of air or formation of gas bubbles while applying cement increases resistance to frost action, fire, scaling, and other similar defects. Air-Entraining Cement is a special type of cement which entrains tinny air bubbles in concrete. It is produced by grinding minute air entertaining materials with clinker by adding some resinous materials e.g. vinsol resin to Ordinary Portland Cement. When the water in concrete gets frizzed due to low temperature, it expands. When Air-Entraining Cement, the air voids in concrete provides space for water to expand without cracking concrete. It should be noted that this type of cement does not provide high strength in concrete.

Uses of Air-Entraining Cement: Especially it is used in areas where the temperature is very low. It also resists the Sulphate attack. It is used where the de-icing chemical is used.

Expansive Cement

In the hydration process, the Expansive Cement expands its volume. It can be possible to overcome shrinkage loss by using Expansive Cement. There are three types of Expansive Cement: K Type Expansive Cement, M Type Expansive Cement, and S Type Expansive Cement.

Uses of Expansive Cement: it is used in the construction of the prestressed concrete component. It is also used for sealing joints and grouting anchor bolt. In the construction of different hydraulic structures, this type of cement is also used.

Hydrophobic Cement

To resist the hydration process in the transportation or storage stage, clinkers are ground with water repellent film substance such as Oleic Acid or Stearic Acid. These chemicals form a layer on the cement particle and do not allow water to mix and start the hydration process. When cement and aggregates are thoroughly mixed in the mixer, protective layers break and start normal hydration with some air-entrainment which increases workability.

Uses of Hydrophobic Cement: usually, it is used in the construction of water structures such as dams, spillways, or other submerged structures. It is also used in the construction of underground structures like tunnels, etc.

Cementitious Material Content

Cement material content is an input while designing rigid pavement and is selected based on actual or expected cement source. The cement content of concrete is normally in the range from 10-15% by volume.

Water-to-Cement Ratio

Water to cement ratio is an input while designing rigid pavement and is selected based on actual or expected cement source. A properly designed mixture possesses the desired workability for the fresh concrete and the required durability and strength for the hardened concrete. Typically, a mix is about 10 to 15 percent cement, 60 to 75 percent aggregate and 15 to 20 percent water.

Aggregates Type

Cement content is an input while designing rigid pavement and is selected based on actual or expected cement source. The four primary aggregates are sand, gravel, crushed stone, and recycled concrete or fill. These different materials work to hold the ingredients together to harden into various landscaping projects such as sidewalks, driveways, roads, and parking lots.

Curing Method

Curing method is an input while designing rigid pavement and is selected based on actual or expected cement source. Water curing, if properly carried out, can be the most efficient - and the most appropriate for some types of work, e.g. floors, and include ponding, sprinkling, and wet coverings. On flat surfaces such as pavements, footpaths, and floors, concrete can be cured by ponding.

Shrinkage of Concrete

Shrinkage is the change in volume over time in a way it decreases the dimensions of the concrete. The volume of concrete changes during the hardening process due to the effect of hydration of cement and concrete drying process with the loss of water in the paste. The time at which shrinkage cracks occur depends on the rate of drying but is usually several months to three or four years after casting. The loss of moisture from fresh concrete results in a reduction in volume. If the shrinkage movement is opposed by some external or internal restraint, stresses will develop.

Ultimate Shrinkage

The probable ultimate shrinkage is an input while designing rigid pavement. Testing the ultimate shrinkage is not practical and thus the prediction equation used in AASHTOWare pavement ME design can be used.

Reversible Shrinkage

The amount of Reversible Shrinkage is considered 50% of the Ultimate Shrinkage as the default value in the AASHTOWare pavement ME design software.

Time to Develop 50% of Ultimate Shrinkage

The AASHTOWare pavement ME design software uses the default value of 35 days for the time to develop 50% of ultimate shrinkage.

The summary of different properties of PCC and the test protocols for new overlays and existing PCC when subject to a bonded PCC overlay are listed in Tables 5 and 6.

Measured property	Test	Estimate	Recommended test protocol and/or data source
Elastic modulus	x		ASTM C 469
Poisson's ratio	x		ASTM C 469
Flexural strength	x		AASHTO T 97
Indirect tensile strength	x		AASHTO T 198
Unit weight	x		AASHTO T 121 M/T 121
Air content	x		AASHTO T 152 or T 196 M/T 196
Coefficient of thermal expansion	x		AASHTO TP 60
Surface shortwave absorptivity		x	Use AASHTOWare pavement ME design default value
Thermal conductivity	x		ASTM E 1952
Heat capacity	x		ASTM D 2766
Zero-stress temperature		x	Use AASHTOWare pavement ME design default value
Cement type		x	Select based on actual or expected cement source
Cementitious material content		x	Select based on expected concrete mix design
Water-to-cement ratio		x	Select based on expected concrete mix design
Aggregate type		x	Select based on expected aggregate source
Curing method		x	Select based on agency recommendations and practices
Ultimate shrinkage		x	Estimate using prediction equation in the AASHTOWare pavement ME design
Reversible shrinkage		x	Estimate using agency historical data or select AASHTOWare pavement ME design defaults
Time to develop 50% of ultimate shrinkage		x	Estimate using agency historical data or select AASHTOWare pavement ME design defaults

Table 5 Summary of Different Properties of PCC and Test Protocols for New Overlays and Existing PCC When Subject to a Bonded PCC Overlay

Measured property	Test	Estimate	Recommended test protocol and/or data source
Elastic modulus	x		ASTM C 469 (extracted cores) AASHTO T 256 (non-destructive deflection testing)
Poisson's ratio	x		ASTM C 469 (extracted cores)
Flexural strength	x		AASHTO T 97 (extracted cores)
Unit weight	x		AASHTO T 121 M/T 121
Surface shortwave absorptivity		x	Use AASHTOWare pavement ME design default value
Thermal conductivity	x		ASTM E 1952 (extracted cores)
Heat capacity	x		ASTM D 2766 (extracted cores)

Table 6 Summary of Different Properties of PCC and the Test Protocols for Existing Intact and Fractured PCC

Chemically Stabilized PCC Materials

Several types of chemically stabilized materials are used under pavements as base courses, subbase courses, or treated subgrade. These include lean concrete, cement stabilized or treated aggregate, soil cement, lime-cement fly ash, and lime-stabilized materials. The summary of different chemically stabilized PCC and the test protocols are listed in Tables 7 and 8. The recommended input parameters of different chemically stabilized PCC and the test protocols are summarized in Tables 9 and 10.

Example 5: Modulus of Elasticity for Chemically Stabilized PCC

A chemically stabilized lean concrete specimen failed at a compressive force of 50 kip is applied on a 6-in.-diameter and 12-in.-high long cylinder. Assuming no permanent deformation occurs in that material, calculate the modulus of elasticity.

Solution

$$\text{Failure stress, } f_c' = \frac{\text{Load}}{\text{Area}} = \frac{50{,}000\text{ lb}}{\frac{\pi}{4}(6\text{ in.})^2} = 1{,}768\text{ psi}$$

$$\text{Elasticity, } E = 57{,}000\sqrt{f_c'} = 57{,}000\sqrt{1{,}768\,\text{psi}} = 2{,}396{,}700\text{ psi}$$

Answer The modulus of elasticity is 2,396,700 psi.

	Measured property	Test	Estimate	Recommended test protocol and/or data source
Lean concrete cement-treated aggregate	Elastic modulus	x		ASTM C 469
	Flexural strength	x		AASHTO T 97
Lime cement-fly ash	Elastic modulus		x	No test protocols available. Estimate using Levels 2 and 3
	Flexural strength	x		AASHTO T 97
Soil cement	Elastic modulus		x	No test protocols available. Estimate using Levels 2 and 3
	Flexural strength	x		ASTM D 1635
Limestabilized soil	Resilient modulus	x		AASHTO T 307
	Flexural strength		x	No test protocols available. Estimate using Levels 2 and 3
All	Unit weight		x	No testing required. Estimate using Levels 2 and 3
	Poisson's ratio		x	No testing required. Estimate using Levels 2 and 3
	Thermal conductivity	x		ASTM E 1952
	Heat capacity	x		ASTM D 2766
	Surface short-wave absorptivity		x	No test protocols available. Estimate using Levels 2 and 3

Table 7 Chemically Stabilized Materials Input Requirements and Test Protocols for New Chemically Stabilized Materials

Measured property	Test	Estimate	Recommended test protocol and/or data source
Calculated modulus from FWD deflection basins	x		AASHTO T 256 & ASTM D 5858
Flexural strength		x	Estimate using Levels 2 and 3
Unit weight		x	Estimate using Levels 2 and 3
Poisson's ratio		x	Estimate using Levels 2 and 3
Thermal conductivity	x		ASTM E 1952 (cores)
Heat capacity	x		ASTM D 2766 (cores)
Surface shortwave absorptivity		x	Estimate using Levels 2 and 3

Table 8 Chemically Stabilized Materials Input Requirements and Test Protocols for All Existing Chemically Stabilized Materials

Material	Relationship for modulus	Test method	Common values (psi)
Lean concrete	$E = 57{,}000(f_C')^{0.5}$	AASHTO T 22	2,000,000
Cement-treated aggregate	$E = 57{,}000(f_C')^{0.5}$	AASHTO T 22	1,000,000
Open-graded cement-stabilized aggregate	Use input Level 3	None	750,000
Lime-cement-fly ash	$E = 500 + q_u$	ASTM C 593	1,500,000
Soil cement	$E = 1{,}200q_u$	ASTM D 1633	500,000
Lime-stabilized soil	$M_R = 124(q_u) + 9{,}980$	ASTM D 5102	45,000

E = Elastic modulus; psi; M_R = Resilient modulus, psi; q_u or f_C' = unconfined compressive strength (psi).

Table 9 Recommended Elastic (E)/Resilient Modulus (M_R) Values for Chemically Stabilized Material

Property	Materials	Common values
Flexural strength	Use 20% of the compressive strength of lab specimens or extracted cores as an estimate of the flexural strength for all chemically stabilized materials. OR	
	Chemically stabilized material placed under flexible pavement (base)	750 psi
	Chemically stabilized material used as subbase, select material, or subgrade under flexible pavement	250 psi
Poisson's ratio	Lean concrete and cement-stabilized aggregate	0.1 o 0.2
	Soil cement	0.15 to 0.35
	Lime-fly ash materials	0.1 to 0.15
	Lime-stabilized soil	0.15 to 0.2
Unit weight	Use default AASHTOWare pavement ME design values of 150 pcf	
Thermal conductivity	Use default AASHTOWare pavement ME design values of 1.25 BTU/h·ft·°F	
Heat capacity	Use default AASHTOWare pavement ME design values of 0.28 BTU/lb·°F	

Table 10 Recommended Properties for Chemically Stabilized Material

Section 4 — References

- AASHTO 2015 Mechanistic-Empirical Pavement Design Guide: A Manual of Practice. Washington, DC: American Association of State and Highway Officials.