1. Introduction and Description of Pavements

Pavements are an essential part of our life. We use them as roads, runways, parking lots, and driveways. Surface transportation is the most widely used mode of transportation in the world, and a country's development is often measured in terms of its total paved road mileage. Like any other engineered structure, pavements are expected to be adequately strong and durable for their design life. They are expected to function properly by providing a smooth traveling surface for the traffic under various conditions of the environment. In order to ensure this, pavements must be designed, constructed, maintained, and managed properly.

Pavements can be broadly classified into asphalt (or flexible) and concrete (or rigid) pavements (Figure 1). Pavements consist of different layers, more so in the case of asphalt pavements than concrete ones. From the bottom up, these layers are known as the subgrade, subbase, base, and binder and/or surface. There are certain pavements with asphalt surface layers on top of concrete layers.

The most important function of the pavement is to withstand the load applied from a vehicle such as a truck or an aircraft, without deforming excessively. The layered structure of the pavement is meant for ensuring that the load is spread out below the tire, such that the resultant stress at the bottom layer of the pavement, the subgrade, is low enough not to cause damage. The most significant load applied to a pavement surface comes from a truck or an aircraft tire. The approach in a flexible pavement is to spread the load in such a way that the stress at the subgrade soil level is small enough so that it can sustain the stress without any major deformation. When the existing soil is not stiff enough to support the relatively small stress, then there is a need to improve the soil.

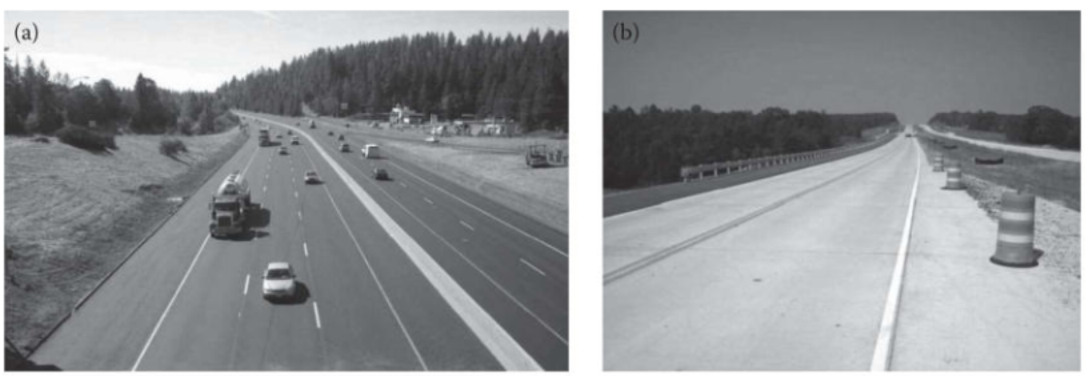


Figure 1: (a)Example of asphalt pavement, (b)Example of concrete pavement

2. Important Issues

Traffic keeps on increasing, while the costs of materials and methods keep on climbing, as budgets dwindle everywhere. At the same time, we are becoming increasingly aware of the detrimental impacts of many of the unavoidable factors involved in the road construction processes (such as emissions). The only way to keep up and still have good roads is through learning and applying good principles, implementing proven new concepts and technologies that would make roads more durable and sustainable, and continually researching for better materials and methods. Therefore, **the important issues can be summarized as follows:**

1. Drainage is needed to drain water quickly and effectively away from the pavement.
2. The materials must be evaluated and selected properly so that they can withstand the effects of the traffic and the environment.

3. The mix must be designed properly such that it can withstand traffic and environmental factors.
4. The structure should be designed properly such that it has adequate thickness to resist excessive deformation under traffic and under different environmental conditions.
5. The pavement must be constructed properly such that it has desirable qualities.
6. The pavement must be maintained/managed properly through periodic work, regular testing, and timely rehabilitation.
7. Sustainable technologies must be continuously incorporated in road construction process.
8. Generation of knowledge through research is critical for ensuring good pavements in the future.

3. Functional Requirements

A pavement's primary purpose is to provide a functional surface for a specific transportation need. The basic function is to withstand load, under different seasonal environmental conditions, without deforming or cracking, since either of these distress conditions would reduce the functionality of the pavement. The function of the different layers in the pavement is to spread out the load on the surface and reduce its intensity with depth, such that the pressure on the subgrade is much less than the pressure on the surface and can be tolerated by the subgrade without undergoing excessive deformation.

A pavement consisting of asphalt mixtures only is referred to as a flexible pavement, since the pavement layers deflect under a traffic load. The typical applied concept of a flexible pavement is that a layered structure with better materials near the top would distribute the load in such a way that the resulting stress in the bottommost layer will be small enough to cause no significant deformation of the layer. The bottommost layer is the existing layer, or the existing layer modified with some materials. The materials and the thicknesses of the different layers will be such as to be able to withstand the different effects of temperature and moisture due to changes in season in a specific location. The subbase, in addition to providing structural support, may also serve as a platform for constructing the base and prevent the fine materials from the subgrade from contaminating the base layer. If the subgrade is of frost-susceptible material, then the subbase could be made up of non-frost-susceptible materials to prevent frost related damage.

Rigid (or concrete) pavements, which deflect very little under traffic loads, behave differently than flexible pavements under loads. The slab, due to its higher stiffness as characterized by elastic modulus, usually distributes the loading across a large pavement area. This in turn reduces the stresses experienced by the underlying base and subgrade layers. Rigid pavements may or may not have a base or subbase layer and could be placed directly over the subgrade. However, in high-performance pavements, a base or subbase is typically included. Besides providing a wearing course and a contact surface with traffic, the slab provides friction, drainage, smoothness, noise control, and waterproofing for the underlying layers.

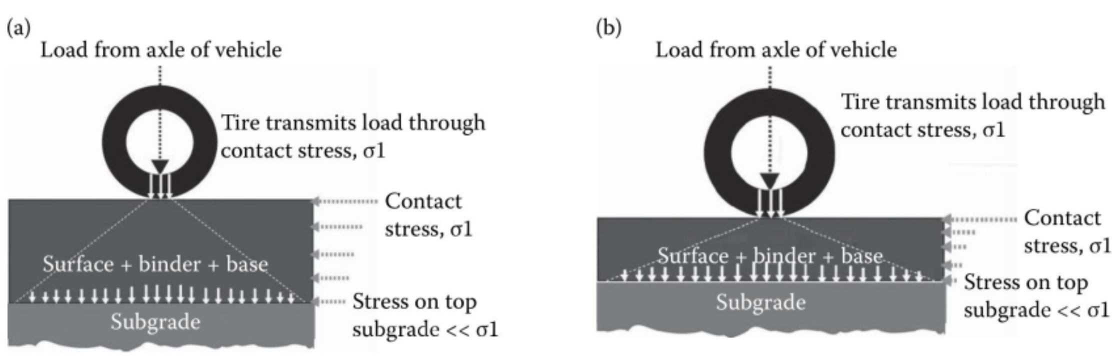


Figure 2: Function of the pavement is to decrease the tire contact stress on the subgrade to a tolerable level; flexible pavement (a), rigid pavement (b).

4. Types and Uses of Pavements

Under the broad definition, there exist several different types of pavements with specific functions. Let us review the more important types.

1. ***Pavement for roads:*** There are different types of roads ranging from high-traffic-volume interstate highways to low-traffic-volume local roads. These roads have different types and volumes of traffic. Accordingly, they are designed and constructed in different ways. Thicker pavements are constructed for both heavier and high-volume traffic, of which trucks are the major load applicators.
2. ***Pavement for airports***: Pavements are required in airports in aircraft holding/terminal areas, taxiways, and runways.
3. ***Pavement for parking lots***: Parking lots are essential features in cities and towns and are commonly found adjacent to business/office buildings, including those near hospitals, schools, and airports.
4. ***Loading and unloading areas in ports and other areas:*** Heavy-duty pavements are constructed to support equipment and materials unloaded from ships, rail, and trucks. These areas may also require special protections such as those from fuel droppings/spillage.

Notes:

1. The bottom layer on which the pavement is built is called the ***subgrade***. The other layers, upward in order, are the ***subbase, base, binder, and surface layers***. In many cases, the pavement can be a full depth asphalt pavement, in which case all the layers above the subgrade are composed of HMA constructed in several layers. In other cases, the subbase and base may be combined to form one single layer, as far as materials are concerned, but constructed in multiple layers.
2. A ***binder layer*** is provided because it would be difficult to compact the surface and the binder layers in one step, and also the binder layer part can be made up of larger aggregates and with lower asphalt content, thus costing less.
3. The ***base layer*** could be designed as a permeable base layer to let any water inside the pavement flow down to the sides for drainage. This water can be coming from the top rain and snow through open voids or cracks in the surface or from groundwater.
4. The ***surface layer*** should be compacted to a high density, and cracks should be filled as soon as possible to prevent the flow of rain and snow water inside.
5. On the other hand, ***groundwater level*** should be reduced before construction of the pavements by providing interceptor drains. However, there could still be some water coming inside the pavement which needs to be drained out.
6. The selection of the appropriate type of pavement should be made on the basis of primary factors that include ***traffic, soil type, construction considerations, climate, recycling options, and cost*** and secondary factors, consisting of ***energy and material conservation and availability, performance history, and adjacent pavements.***
7. ***Subgrade soils*** under the pavement must be stiff and durable enough to resist both construction and traffic loading without excessive distress. For subgrade soils, the key factors are geographical and seasonal variability.
8. Periodic rainfall and freeze thaw can have significant seasonal effects on the stiffness of subgrade.

9. Furthermore, the temperature of the project region also needs ***to be considered for the proper selection of materials for the pavements.***

الأعمال الترابية

وتشمل جميع أصناف التعديل والتسوية وحفر السواقي وجميع أنواع الحفريات والإملاءات الترابية

- سطح الأعمال الترابية Formation level ويقصد به منسوب سطح أسفل طبقة تحت الأساس في حالة الإملاءات والقطوعات، وهي طبقة مهمة جدا، حيث أنها ستكون الحاملة لكل الأثقال، وتسمى أيضا بطبقة Subgrade ، وقد حُددت مواصفات خاصة لهذه الطبقة، وخاصة قيمة الـ CBR (كان الحد الأدنى لها 4%، ثم عدلت لتكون إلى 6%) ، والأفضل ألا تقل عن 8%، كما أن سمك الطبقة لا يقل عن 30 سم، وتكون نسبة الحدل فيها لا تقل عن 95% من البروكتور المعدل، ويُعتنى بمنسوبها، وتُطبق عليها شروط استوائية السطح، كونها الأساس لكل الطبقات اللاحقة.
- **المواد الصالحة**: وتشمل جميع أنواع الترب القابلة للحدل لتكون إملاءات ثابتة وذات ميول جانبية مقبولة
- **المواد غير الصالحة** (Unsuitable materials) وتشمل: (التربة الحاوية على أكثر من 12% من المواد العضوية وزناً، الأغصان والجذور وجميع المواد النباتية القابلة للتحلل، والمواد سريعة الاشتعال، والتربة الملحية أو الجبسية الحاوية على أكثر من 10% وزناً من الأملاح القابلة للذوبان بالماء عند استعمالها في الطبقة الترابية الأخيرة التي بعمق 30 سم، و20% عند استعمالها في بقية التعلية الترابية، وكذلك الترب الطينية التي يتجاوز فيها حد السيولة Liquid limit عن 70% أو يتجاوز فيها دليل اللدونة Plastic limit عن 45.
- **أما فيما يتعلق بتهيئة سطح الأرض قبل التعلية الترابية، فيجب أن تؤخذ النقاط التالية بنظر الاعتبار:**

أ- قبل المباشرة بالتعلية الترابية والاملاءات يجب قشط وتنظيف سطح الأرض ورفع المواد غير الصالحة .
ب- حدل سطح الأرض لتصبح الكثافة الجافة للأرض الطبيعية (88٪)كحد أدنى وذلك لعمق 25 سم .
ت- أذا تضمن سطح الأرض حفر وســـواقي ومجاري وجب مليء تلك المنخفضات وحدلها .
ث- أذا كانت الاملاءات فـــوق تبليط سابق وجب تخديشها الى عمق لا يقل عـن 15سم وتفتيتها لكي يتم ربط وتداخل مواد الإملاء مع السطح القديم .

أما إذا كان عمق التعلية الترابية الجديدة أقل من متر واحد وجب رفع التبليط السابق كلياً وأبعاده عن الطريق .

- **وعند حدل الأعمال الترابية، فيجب أن تؤخذ النقاط التالية بنظر الاعتبار:**

أ- لا يتم حدل مواد التعلية الترابية إلا عندما تكون نسبة الرطوبة فيها ضمن الحدود المقررة .
ب- تقاس درجة الحدل لكل طبقة نقطتين على الأقل لكل (2000) متر مربع أو بتردد أكبر بموجب طلب المهندس المقيم .
ت- يجب أن لا تقل درجة الحدل عن 95٪ من الكثافة العظمى الجافة للاملاءات الترابية للحفريات الإنشائية وحفريات سواقي تصريف المياه .
ث- لا تقل درجة الحدل عن 95٪ من الكثافة العظمى الجافــة للطبقة الترابيـة الأخيرة والأكتاف التي بعمق 30سم عن السطح النهائي ولا تقل نسبة(CBR)عن 4٪ ويجب أن يجب ان يكون حد السيولة اقل من 55٪ ودليل اللدونة اقل من 30 ٪. وتعتبر التربة التي تكون كثافتها اقل مــن 1,7 غم\سم^3 غير مقبولة للاسـتعمال في الطبقةالعليا النهائية بسمك 30 سم ويجب استبداله بمواد صالحة .
ج- تحدل التعلية الترابية ذات الارتفاع أقل مــن 2 متر(عدا الطبقة النهائية) الى نسبة 94٪ مــن الكثافة الجافة العظمى كحد أدنى .
ح- يحدل جزء التعلية الترابية ذات الارتفاع الذي يزيد على2 متر الى نسبة 93٪ من الكثافة الجافة العظمى كحد أدنى .

سادساً : الانحرافات في منسوب السطوح النهائية

تقاس الانحرافات للسطوح الترابية باستخدام مسطرة بطول 3 م ويجب أن لا يتجاوز قياس أعمق نقاط الانحراف عن المسطرة ما يأتي :
3 سم للسطح النهائي
10 سم للميول الجانبية
3 سم للأكتاف

ملاحظات مهمة تتعلق بطبقة ما تحت الأساس Subbase course

- يكون سمك هذه الطبقة 40 سم للطرق السريعة والرئيسية، و30 سم للطرق الثانوية، وبما لا يقل عن 20 سم للطرق الأخرى، ويفضل خلط المواد في معمل مركزي، ثم فرشها بواسطة الفارشة لضمان الاستوائية، ومحتوى الرطوبة المثالي.
- يجب التأكد من مطابقة المواد المستخدمة للمواصفات، من خلال إجراء الفحوصات المطلوبة
- يجب ألا تتجاوز نسبة التآكل في المواد الخشنة عن 45%، أما فيما يتعلق بالمواد الناعمة، فيجب ألا تزيد نسبة المواد العضوية عن 2%، ولا تزيد نسبة الكتل الطينية عن 0.25%، إضافة لذلك فإن حد السيولة لا يزيد عن 25%، ودليل اللدونة لا يزيد عن 6%، ويجب ألا تزيد نسبة الأملاح القابلة للذوبان عن 10%، ولا تزيد نسبة الكبريتات عن 5% وزناً.
- يجب ألا تقل قيمة CBR عن 35% للنوع B، و 30% للنوع C، و 20% للنوع D، عند كثافة قدرها 95% من الكثافة الجافة.
- يجب ألا يتجاوز سمك الطبقة 20 سم ، ويفضل أن يكون 15 سم، لتحقيق نسبة حدل 95-98% ويجب أن يكون السطح صقيلا ومنتظما وموازيا للسطح النهائي للطريق، ولا يزيد الانحراف عن 2 سم عند الفحص بمسطرة طول 4 م.

جدول (1) : تدرج مواد طبقة تحت الأساس

مقاس المنخل الأمريكي مم	مقاس المنخل الأمريكي إنج	النسبة المئوية للمواد العابرة (وزناً) النوع A	النوع B	النوع C	النوع D
75	3	100	-	-	-
50	2	100-95	100	-	-
25	1		95 – 75	100	100
9,5	8\3	65 -30	75 – 40	85 – 50	100 – 60
4,75	رقم 4	55 -25	60 – 30	65 – 35	85 – 50
2,36	رقم 8	42- 16	47 – 21	52 – 26	72 – 42
0,30	رقم 50	18 - 7	28 – 14	28 – 14	42 – 23
0,075	رقم 200	8 – 2	15 - 5	15 -5	20 - 5

تدرج الركام المستخدم في العمل يجب إن لا يتراوح بين الحد الأدنى لمنخل والحد الأعلى للمنخل المجاور بل يجب إن يكون بتدرج متناسق

ملاحظات مهمة تتعلق بطبقة الأساس Base course

تتكون طبقة الأساس عادة من الحصى المكسر (Crushed gravel) أو الحجر المكسر (Crushed stone) وقد يكون من الكونكريت (Concrete base) وهو الافضل على الاطلاق، وفي السبعينات تم اعتماد طبقة اساس من الكونكريت الاسفلتي سميت طبقة الاستبلايزر (Stabilizer course) ، وهي المعتمدة في معظم طرق العراق والشائع أن سمكها بحدود 10 سم، ويوصى باعتماد السمك الاتي للطبقات: 20 سم للمرور السريع والطرق الرئيسية، 12-14سم للطرق المجمعة او الشريانية، 8-10سم للطرق المحلية وشوارع المحلات.

5. Classification of soils for highway use

Soil classification is a method by which soils are categorized according to their engineering characteristics. It therefore serves as a means of identifying suitable subbase materials and predicting the probable behaviour of a soil when used as subgrade material.

- The classification of a given soil is determined by conducting relatively simple tests on disturbed samples of the soil; the results are then correlated with field experience.
- Classifying the soil should be considered as a means of obtaining a general idea of how the soil will behave if used as a subgrade or subbase material.
- The most commonly used classification system for highway purposes is the American Association of State Highway and Transportation Officials (AASHTO) Classification System.

AASHTO Soil Classification System

The AASHTO Classification System is based on the Public Roads Classification System that was developed from the results of extensive research conducted by the Bureau of Public Roads, now known as the Federal Highway Administration. Several revisions have been made to the system since it was first published. The system has been described by AASHTO as a means for determining the relative quality of soils for use in embankments, subgrades, subbases, and bases. **Usually, soils are classified into seven groups, A-1 through A-7, with several subgroups**. **The classification of a given soil is based on its particle size distribution, liquid limit (LL), and plasticity index (PI)**. Soils are evaluated within each group by using an empirical formula to determine the group index (GI) of the soils, given as:

$$GI = (F - 35)[0.2 + 0.005(LL - 40)] + 0.01(F - 15)(PI - 10)$$

where

GI = group index
F = percent of soil particles passing 0.075 mm (No. 200) sieve in whole number based on material passing 75 mm (3 in.) sieve
LL = liquid limit expressed in whole number
PI = plasticity index expressed in whole number

- The GI is determined to the nearest whole number. **A value of zero should be recorded when a negative value is obtained for the GI**.
- Furthermore, in determining the GI for A-2-6 and A-2-7 subgroups, the LL part of Eq. above is not used—that is, only the second term of the equation is used.
- Under the AASHTO system, granular soils fall into classes A-1 to A-3. A-1 soils consist of well-graded granular materials, A-2 soils contain significant amounts of silts and clays, and A-3 soils are clean but poorly graded sands.

- Classifying soils under the AASHTO system will consist of first determining the particle size distribution and Atterberg limits of the soil and then reading Table from left to right to find the correct group.
- The correct group is the first one from the left that fits the particle size distribution and Atterberg limits and should be expressed in terms of group designation and the GI.
- In general, the suitability of a soil deposit for use in highway construction can be summarized as follows.
  1. Soils classified as A-1-a, A-1-b, A-2-4, A-2-5, and A-3 can be used satisfactorily as subgrade or subbase material if properly drained. In addition, such soils must be properly compacted and covered with an adequate thickness of pavement (base and/or surface cover) for the surface load to be carried.
  2. Materials classified as A-2-6, A-2-7, A-4, A-5, A-6, A-7-5, and A-7-6 will require a layer of subbase material if used as subgrade. If these are to be used as embankment materials, special attention must be given to the design of the embankment.
  3. A soil with a GI of zero (an indication of a good subgrade material) will be better as a subgrade material than one with a GI of 20 (an indication of a poor subgrade material).

Group Index (GI)	Subgrade Rating
0	Excellent
0–1	Good
2–4	Fair
5–9	Poor
10–20	Very poor

Table AASHTO Classification of Soils and Soil Aggregate Mixtures

General Classification	*Granular Materials (35% or Less Passing No. 200)*							*Silt-Clay Materials (More than 35% Passing No. 200)*			
	A-1			*A-2*							*A-7*
Group Classification	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*	*A-4*	*A-5*	*A-6*	*A-7-5, A-7-6*
Sieve analysis											
Percent passing											
No. 10	−50 max.	–	–	–	–	–	–	–	–	–	
No. 40	30 max.	50 max.	51 min.	–	–	–	–	–	–	–	–
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit	–		–	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

*Plasticity index of A-7-5 subgroup ≤ LL − 30. Plasticity index of A-7-6 subgroup > LL − 30.
SOURCE: Adapted from *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 27th ed., Washington, D.C., The American Association of State Highway and Transportation Officials, copyright 2007. Used with permission.

Example Classifying a Soil Sample Using the AASHTO Method

The following data were obtained for a soil sample.

Mechanical Analysis

Sieve No.	*Percent Finer*	*Plasticity Tests:*
4	97	LL = 48%
10	93	PL = 26%
40	88	
100	78	
200	70	

Using the AASHTO method for classifying soils, determine the classification of the soil and state whether this material is suitable in its natural state for use as a subbase material.

Solution:

- Since more than 35% of the material passes the No. 200 sieve, the soil is either A-4, A-5, A-6, or A-7.
- LL > 40%, and therefore the soil cannot be in group A-4 or A-6. Thus, it is either A-5 or A-7.
- The PI is 22% (48 – 26), which is greater than 10%, thus eliminating group A-5. The soil is A-7-5 or A-7-6.
- (LL − 30) = 18 < PI (22%). Therefore the soil is A-7-6, since the plasticity index of A-7-5 soil subgroup is less than (LL − 30). The GI is given as:

$$(70 - 35)[0.2 + 0.005(48 - 40)] + 0.01(70 - 15)(22 - 10) = 8.4 + 6.6 = 15$$

The soil is A-7-6 (15) and is therefore unsuitable as a subbase material in its natural state.

الردميات للطرق (Embankment)

أنواع التربة المستخدمة في الردميات: جميع أنواع التربة يصلح للردم ما عدا الترب A-6 & A-7 وذلك لأنها تربة طينينة بمجرد وصول الماء إليها فإنها تتمدد بسرعة ، وبمجرد تبخر الماء فإنها تنكمش ويحدث أنهيار للسطح.

أفضل أنواع التربة المستخدمة في أعمال الردميات (A1-a, A1-b, A-4)، ويمكن أستخدام التربة A3 بأعمال الردميات ، وذلك بعد عمل Plating لها.

■ تعريف Plating

هو حصر جوانب التربة الرملية A3 بتربة (A1-a, A1-b, A2-4)، وذلك لحمايتها من التأكل والأنهيار، ويمكن أستخدام الصخور أيضا في أعمال الردميات وذلك إذا زاد عمق الردم عن 20 م.ط كمثال حتي لا يحدث هبوط.

ويراعي الآتي عند استخدام الصخور في الردميات

* يجب ألا يزيد سمك الطبقة الواحدة عن واحد متر.
* يتم تحديد سمك الطبقة بناءا علي أوزان المعدات ، وعدد الأهتزازات التي تعملها.

سمك الطبقة عدد الاهتزازات

40	سم	2900 :2300
60	سم	3600 :2900
80	سم	4300 :3600
100	سم	5000 :4300

- ألا يزيد حجم القطع الصخرية المستخدمة في الردميات عن 3/2 سمك الطبقة.
- يتم رص الصخور الكبيرة ، ومعها الصخور الصغيرة بأستخدام الهراسات ، ويتم الرش بالماء ، وعمل الدمك لها
- يجب أن يستمر الهراسات في الدمك حتي يكون الهبوط الناتج عن الدمك أقل من 1% من سمك الطبقة.
- أقل عدد مشاوير للهراسات (5) مشاوير.

سمك طبقات الردم : يعتمد سمك طبقات الردميات علي نوع التربة المستخدم للردميات إذا كانت التربة(A2-4 ،A1-a، A1-b)أقصي سمك لطبقة الردم الواحدة 30 سم أما الطبقة A3 أقصي سمك لطبقة الردم الواحدة 50 سم.

نسبة الدمك في طبقات الردم: لا تقل عن 90% لطبقات الردم ما عدا 60 سم العليا فإن نسبة الدمك لا تقل عن 95% ، وذلك للطرق السريعة ،أما الطرق الزراعية فنسبة الدمك لاتقل عن 90% لكل طبقات الردم.

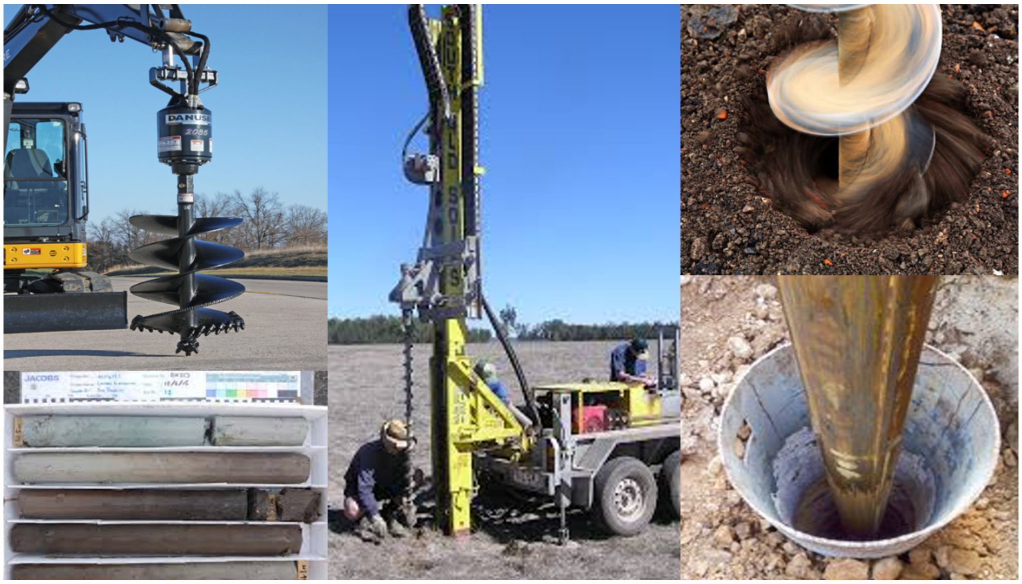
أنواع التربة بعد الدمك

تربة نوع : A نسبة الدمك > 90 %
تربة نوع : AA نسبة الدمك > 95 %
تربة نوع : AAA نسبة الدمك > 98%

6. Soil Surveys for Highway Construction

The first step in any soil survey is in the collection of existing information on the soil characteristics of the area in which the highway is to be located. Such information can be obtained from geological and agricultural soil maps, existing aerial photographs, and an examination of excavations and existing roadway cuts. It is also usually helpful to review the design and construction of other roads in the area. The information obtained from these sources can be used to develop a general understanding of the soil conditions in the area and to identify any unique problems that may exist.

The next step is to obtain and investigate enough soil samples along the highway route to identify the boundaries of the different types of soils so that a soil profile can be drawn. Samples of each type of soil along the route location are obtained by auger boring or from test pits for laboratory testing. The engineering properties of the samples are then determined and used to classify the soils. It is important that the characteristics of the soils in each hole be systematically recorded, including the depth, location, thickness, texture, and so forth. It is also important that the location of the water level be noted. These data are then used to plot a detailed soil profile along the highway.



Geophysical Methods of Soil Exploration

Soil profiles can also be obtained from one of two geophysical methods of soil exploration known as the resistivity and seismic methods.

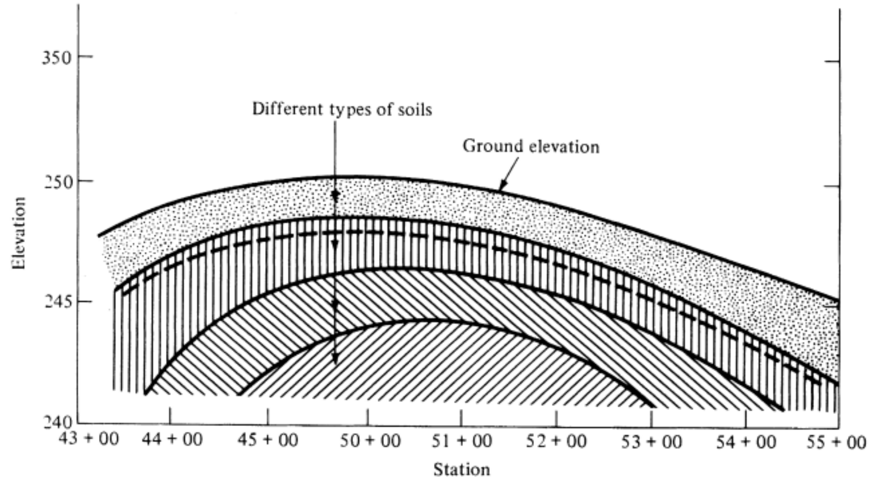
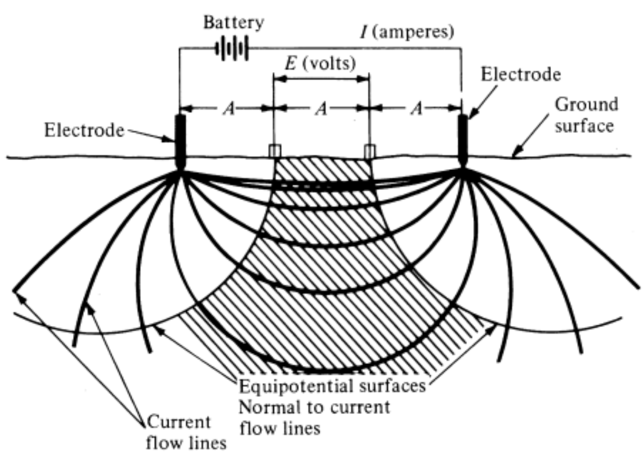


Figure Soil Profile Along a Section of Highway

Resistivity Method

The resistivity method is based on the difference in electrical conductivity or resistivity of different types of soils. An electrical field is produced in the ground by means of two current electrodes, as shown in the Figure below, and the potential drop between the two intermediate or potential electrodes is then recorded. The apparent resistivity of the soil to a depth approximately equal to the spacing "A" is then computed. The resistivity equipment used usually is designed such that the apparent resistivity can be read directly on the potentiometer. Data for the soil profile are obtained by moving the electrode along the center line of the proposed highway without changing the spacing. The apparent resistivity is then determined along the highway within a depth equal to the spacing "A".



Apparent resistivity, $\rho = \frac{2\pi A E}{I}$

Figure Electrical Resistivity Method of Soil Exploration

Seismic Method

The seismic method is used to identify the location of rock profiles or dense strata underlying softer materials (Figure below shows the layout for the seismic method). It is conducted by inducing impact or shockwaves into the soil by either striking a plate located on the surface with a hammer or exploding small charges in the soil. Listening devices known as geophones then pick up the shockwaves. The time lapse of the wave traveling to the geophone then is used to calculate the velocity of the wave in the sur-face soil. Some of the shockwaves can be made to pass from the surface stratum into underlying layers and then back into the surface stratum by moving the shock point away from the geophone. This permits the computation of the wave velocity in the underlying material.

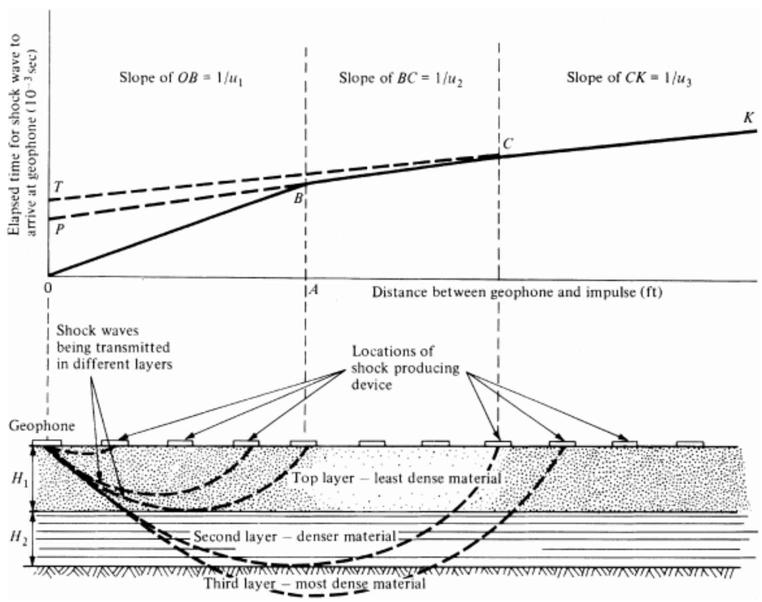
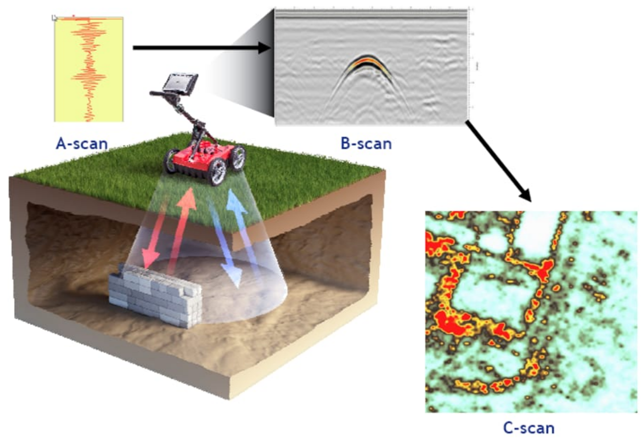


Figure Soil Exploration by the Seismic Method

Ground Penetrating Radar (GPR): It is a geophysical method used to non-destructively investigate the subsurface layers of the ground. It uses electromagnetic waves to detect and image objects, voids, and structures buried beneath the surface. GPR is widely employed in various fields, including engineering, archaeology, environmental studies, and utility detection.



Principle: GPR works on the principle of sending high-frequency electromagnetic pulses into the ground. When these pulses encounter different materials or interfaces with contrasting electrical properties, such as soil layers, rocks, voids, or buried objects, they reflect back to the surface.

Advantages of GPR:

1. Non-destructive: GPR does not require drilling or excavation, making it a non-intrusive method for subsurface investigations.
2. High Resolution: GPR can provide high-resolution images, allowing for precise identification of buried objects or structures.
3. Quick and Versatile: GPR data collection is relatively quick, and it can be used in various settings, including concrete inspection, utility detection, and archaeological surveys.
4. Real-time Data: GPR provides real-time data, enabling immediate on-site analysis and decision-making.

7. Soil Compaction

When soil is to be used as embankment or subbase material in highway construction, it is essential that the material be placed in uniform layers and compacted to a high density. **Proper compaction of the soil will reduce subsequent settlement and volume change to a minimum, thereby enhancing the strength of the embankment or subbase** Compaction is achieved in the field by using hand-operated tampers, Sheep's foot rollers, rubber-tired rollers, or other types of rollers.

- The strength of the compacted soil is directly related to the maximum dry density achieved through compaction. The relationship between dry density and moisture content for practically all soils takes the form shown in Figure below. It can be seen from this relationship that for a given compactive effort, the dry density attained is low at low moisture contents.

The dry density increases with increase in moisture content to a maximum value when an optimum moisture content is reached. Further increase in moisture content results in a decrease in the dry density attained. This phenomenon is due to the effect of moisture on the soil particles. At low moisture content, the soil particles are not lubricated, and friction between adjacent particles prevents the densification of the particles. As the moisture content is increased, larger films of water develop on the particles, making the soil more plastic and easier for the particles to be moved and densified. When the optimum moisture content is reached, how-ever, the maximum practical degree of saturation (where S 100%) is attained. The degree of saturation at the optimum moisture content cannot be increased by further compaction because of the presence of entrapped air in the void spaces and around the particles. Further addition of moisture therefore results in the voids being over filled with water, with no accompanying reduction in the air. The soil particles are separated, resulting in a reduction in the dry density. The zero-air void curve (shown in the Figure below) is the theoretical moisture-density curve for a saturated soil and zero-air voids, where the degree of saturation is 100%. This curve usually is not attained in the field, since the zero-air void cannot be attained.

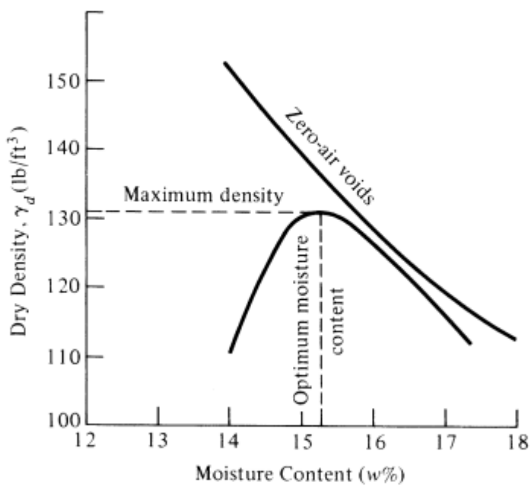


Figure Typical Moisture-Density Relationship for Soils

Optimum Moisture Content

- The determination of the optimum moisture content of any soil to be used as embankment or subgrade material is necessary before any field work is commenced. Most highway agencies now use dynamic or impact tests to determine the optimum moisture content and maximum dry density. In each of these tests, samples of the soil to be tested are compacted in layers to fill a specified size mould.
- **Compacting effort**: it is a measure of the mechanical energy imposed on the soil mass during compaction.
- It is obtained by dropping a hammer of known weight and dimensions from a specified height a specified number of times for each layer. The moisture content of the compacted material is then obtained, and the dry density determined from the measured weight of the compacted soil and the known volume of the mould. The soil is then broken down or another sample of the same soil is obtained. The moisture content is then increased and the test repeated. The process is repeated until a reduction in the density is observed. Usually, a minimum of four or five individual compaction tests are required. A plot of dry density versus moisture content is then drawn from which the optimum moisture content is obtained. The two types of tests commonly used are the standard AASHTO or the modified AASHTO.

Table Details of the Standard AASHTO and Modified AASHTO Tests

Test Details	*Standard AASHTO (T99)*	*Modified AASHTO (T180)*
Diameter of mold (in.)	4 or 6	4 or 6
Height of sample (in.)	5 cut to 4.58	5 cut to 4.58
Number of lifts	3	5
Blows per lift	25 or 56	25 or 56
Weight of hammer (lb)	5.5	10
Diameter of compacting surface (in.)	2	2
Free-fall distance (in.)	12	18
Net volume (ft^3)	1/30 or 1/13.33	1/30 or 1/13.33

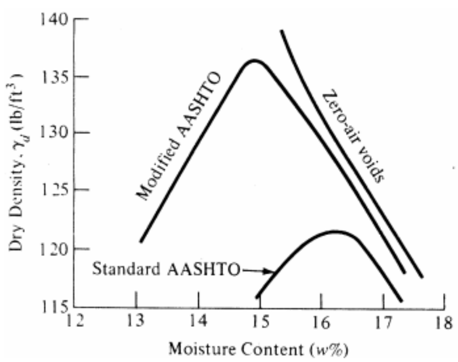


Figure Effect of Compactive Effort in Dry Density

Field Compaction Procedures

- The first step in the construction of a highway embankment is the identification and selection of a suitable material. This is done by obtaining samples from economically feasible borrow pits or borrow areas and testing them in the laboratory to determine the group of each.
- It has been shown earlier that, based on the AASHTO system of classification, materials classified as A-1, A-2-4, A-2-5, and A-3 are usually suitable embankment materials.
- In cases where it is necessary to use materials in other groups, special consideration should be given to the design and construction. For example, soils in groups A-4 and A-6 can be used for embankment construction if the embankment height is low, the field compaction process is carefully controlled, and the embankment is located where the moisture content is not expected to exceed that at which the construction was undertaken.
- A factor that also significantly influences the selection of any material is whether that material can be economically transported to the construction site. Having identified suitable materials, their optimum moisture contents and maximum dry densities are determined.

Embankment Formation. Highway embankments are formed by spreading thin layers of uniform thickness of the material and compacting each layer at or near the optimum moisture content. End dumping of the material from trucks is not recommended. The process of constructing one layer at a time facilitates obtaining uniform strength and moisture content in the embankment. End dumping or compaction of thick layers on the other hand may result in variable strengths within the embankment, which could lead to differential settlement between adjacent areas. All transportation agencies have their own requirements for the minimum density in the field. Some of these are based on the AASHTO specifications for transportation materials. Table below gives commonly used relative density values for different embankment heights. The relative density is given as a percentage of the maximum dry density obtained from the standard AASHTO (T99) test.

Table 17.7 Commonly Used Minimum Requirements for Compaction of Embankments and Subgrades

	Minimum Relative Density		
	Embankments		
AASHTO Class of Soil	*Height Less Than 50 ft*	*Height Greater Than 50 ft*	*Subgrade*
A-1, A-3	≥ 95	≥ 95	100
A-2-4, A-2-5	≥ 95	≥ 95	100
A-2-6, A-2-7	> 95	—[a]	≥ 95[b]
A-4, A-5, A-6, A-7	> 95	—[a]	≥ 95[b]

[a]Use of these materials requires special attention to design and construction.
[b]Compaction at 95 percent of T99 moisture content.

<u>Field compaction equipment</u>

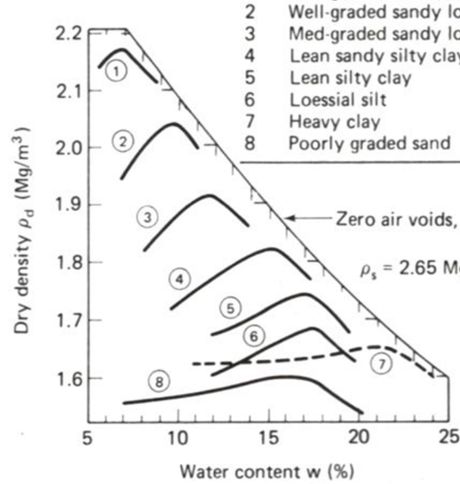
Compaction equipment used in the field can be divided into two main categories: **Equipment used for spreading the material to the desired layer or lift thickness, and the second category includes the equipment used to compact each layer of material**.

Effect of soil types on compaction

- The soil type-that is, grain-size distribution, shape of the soil grains, specific gravity of soil solids, and amount and type of clay minerals present.

Soil texture and plasticity data

No.	Description	Sand	Silt	Clay	LL	PI
1	Well-graded loamy sand	88	10	2	16	N.P.
2	Well-graded sandy loam	72	15	13	16	N.P.
3	Med-graded sandy loam	73	9	18	22	4
4	Lean sandy silty clay	32	33	35	28	9
5	Lean silty clay	5	64	31	36	15
6	Loessial silt	5	85	10	26	2
7	Heavy clay	6	22	72	67	40
8	Poorly graded sand	94	– 6 –		N.P.	–



Special Soil Tests for Pavement Design

There are a few special soil tests that are some-times undertaken to determine the strength or supporting value of a given soil if used as a subgrade or subbase material. The results obtained from these tests are used individually in the design of some pavements,

California Bearing Ratio (CBR) Test

- It involves the determination of the load-deformation curve of the soil in the laboratory using the standard CBR testing equipment, according to ASTM **D1883** and AASHTO **T 193**.
- It was originally developed by the California Division of Highways prior to World War II and was used in the design of some highway pavements.
- CBR is the ratio expressed in percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. The ratio is usually determined for penetration of 2.5 and 5 mm. When the ratio at 5 mm is consistently higher than that at 2.5 mm, the ratio at 5 mm is used.
- The test is conducted on samples of soil compacted to required standards and immersed in water for four days, during which time the samples are loaded with a surcharge that simulate the estimated weight of pavement material the soil will support.
- **The objective of the test is to determine the relative strength of a soil (subgrade, subbase and base) with respect to crushed rock, which is considered an excellent coarse base material**. This is obtained by conducting a penetration test on the samples still carrying the simulated load and using a standard CBR equipment. The CBR is defined as:

$$\text{CBR} = \frac{(\text{unit load for 0.1 piston penetration in test specimen})\ (\text{lb/in}^2.)}{(\text{unit load for 0.1 piston penetration in standard crushed rock})\ (\text{lb/in}^2.)}$$

The unit load for 0.1 piston in standard crushed rock is usually taken as 1000 lb/in.2, which gives the CBR as

$$\text{CBR} = \frac{(\text{unit load for 0.1 piston penetration in test sample})}{1000} \times 100$$

Loads and Stresses Corresponding to 0.1 and 0.2 inches Penetration for the Standard Rocks

Penetration	0.1” (2.5 mm)	0.2” (5.0 mm)
Load of Standard Rocks (Ib)	3000	4500
Load of Standard Rocks (kN)	13.24	19.96
Stress of Standard Rocks (KPa)	6895	10342
Stress of Standard Rocks (psi)	1000	1500

Calculate CBR at 0.1 in (25 mm) and 0.2 in (50 mm) deformation then use the Maximum value as the design CBR.

The main criticism of the CBR test is that it does not correctly simulate the shearing forces imposed on subbase and subgrade materials as they support highway pavements. For example, it is possible to obtain a relatively high CBR value for a soil containing rough or angular coarse material and some amount of troublesome clay if the coarse material resists penetration of the piston by keeping together in the mould.

CBR Laboratory Test Preparation

Preparation takes place using the same or similar steps found in method C of ASTM **D698** or **D1557** (AASHTO T 99 and T 180) moisture/density relationship (Proctor) tests. The specifier of the CBR test may request changes to the dry density of the specimens. Changing the required number of blow counts will adjust the dry density. Spacer discs, surcharge weights, and other apparatus to measure expansion are also necessary.

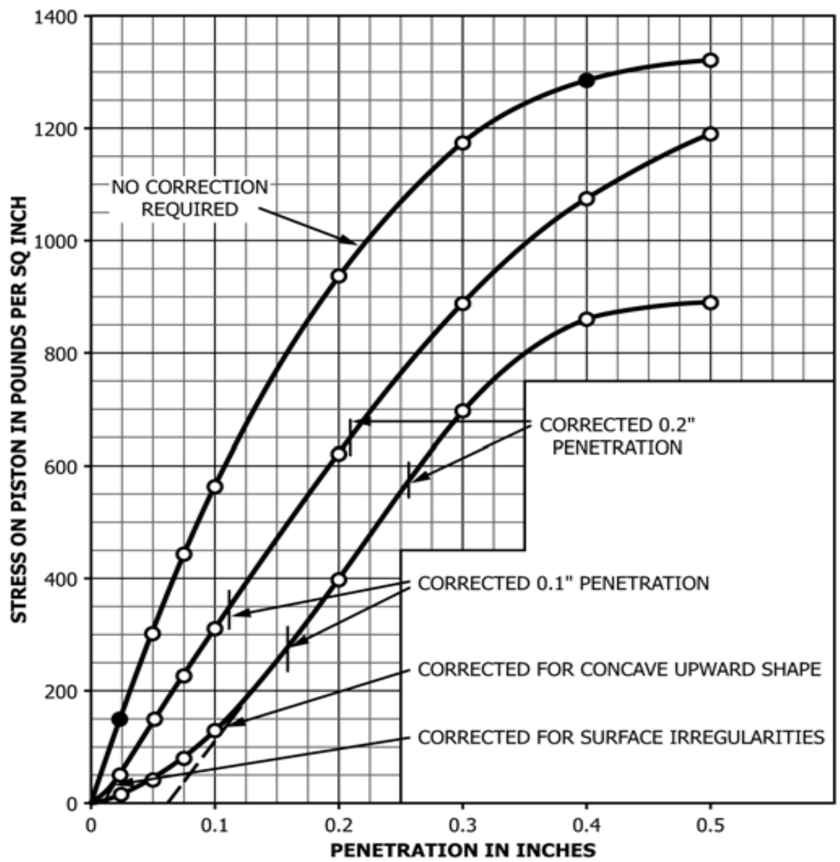
Sample: If all material passes a ¾-in. (19-mm) sieve, the entire gradation shall be used for preparing specimens for compaction without modification. If material is retained on the ¾-in. (19-mm) sieve, the material retained on the ¾-in. (19-mm) sieve shall be removed and replaced by an equal mass of material passing the ¾-in. (19-mm) sieve and retained on the No. 4 (4.75 mm) sieve obtained by separation from portions of the sample not used for testing. For most methods, three to five samples are prepared and soaked for a period before the penetration test.

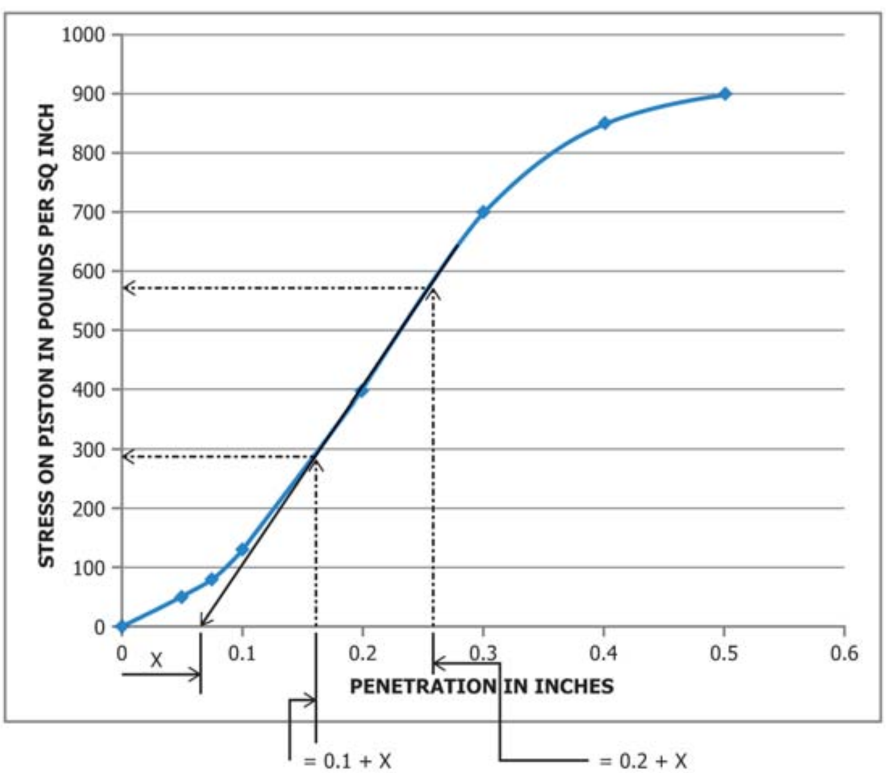
Soaked CBR Test Specimens

- ✓ Soaking accounts for adverse moisture conditions from potential rainfall or flooding, and most CBR tests use this procedure. In addition to the compaction process, preparation usually involves soaking each specimen in water for 96 hours before the penetration test.
- ✓ During the soaking period, a surcharge load of 4.54 kg or more must be placed on the sample using **surcharge weights** to simulate the weight of the pavement and other loads specified. The soil swell resulting from soaking must be measured using **expansion measuring apparatus** and **swell plates** placed on the sample before penetration testing. It takes a significant amount of time to prepare multiple compacted specimens for a single test. **Complete CBR testing sets** containing multiple CBR molds and components are available to maximize testing productivity and efficiency.

Note: *Unsoaked tests are not unusual in areas where rainfall amounts and the local water table are both low.*

- ✓ The prepared test specimens are positioned in a load frame and subjected to regulated penetration loads from a piston with a surface area of $3in^2$ ($1{,}935mm^2$).
- ✓ Penetrations vs. load values are plotted on a graph and corrected following the procedure specified in the test standard. Corrected stress values from penetration depths of 0.100 and 0.200in (2.54 and 5.08mm) are divided by standard stresses of 1,000psi (6.9mPa) and 1,500psi (10.3mPa), then multiplied by 100. In most cases, CBR values decrease as penetration increases. The CBR value is the stress at the 0.100in (2.54mm) penetration depth. Occasionally, the ratio at the 0.200in (5.08mm) penetration depth is higher than the 0.100in depth, and the test must be rerun. If the check test shows similar results, the stress from the 0.200in penetration depth is the reported CBR.

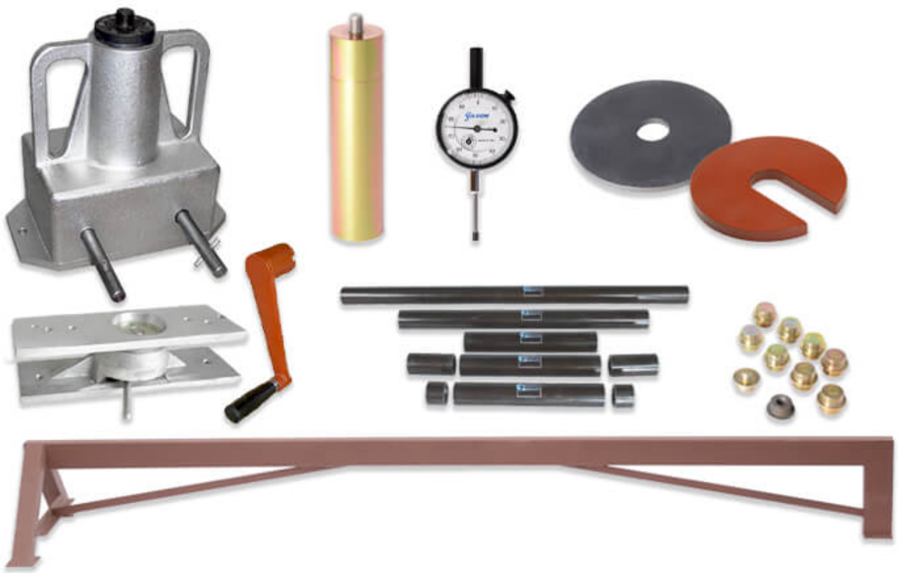

1400
1200
1000
800
600
400
200
0
0
0.1
0.2
0.3
0.4
0.5
STRESS ON PISTON IN POUNDS PER SQ INCH
PENETRATION IN INCHES
NO CORRECTION REQUIRED
CORRECTED 0.2" PENETRATION
CORRECTED 0.1" PENETRATION
CORRECTED FOR CONCAVE UPWARD SHAPE
CORRECTED FOR SURFACE IRREGULARITIES


1000
900
800
700
600
500
400
300
200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
X
STRESS ON PISTON IN POUNDS PER SQ INCH
PENETRATION IN INCHES
= 0.1 + X
= 0.2 + X

Field CBR Test

Field CBR testing is performed in-place on soil subgrades to determine in-place conditions of soils and bases or to confirm laboratory test results. The ASTM D4429 test method requires special **CBR field equipment** for loading. Soil saturation can be controlled in the laboratory but not in the field, so it is difficult to make a direct correlation between the two types of tests.

Note: *This is a withdrawn ASTM standard that will be reinstated soon as a new or revised test method.*



CBR Values

California bearing ratios of field tests represent in-situ strengths of the material under existing field conditions and will not typically correlate with laboratory CBR values of the same material. Saturation levels are near 100% for soaked laboratory samples. Field materials are often less than 80% saturated and, therefore, more resistant to penetration. The significance and use sections in the standard test methods give detailed guidance for interpretation. The chart below provides a rough idea of what to expect for laboratory and field CBR values of different soil types.

CBR (%)	Level	Objective
0-3	*Very poor*	*Subgrade*
3-7	*Poor to fair*	*Subgrade*
7-20	*Fair*	*Subbase*
20-50	*Good*	*Base or Subbase*
>50	*Excellent*	*Base*

(Source: Bowles, 1992)

8. Soil stabilization

Soil stabilization is the treatment of natural soil to improve its engineering properties. It can be divided into two categories, namely, mechanical and chemical. ***Mechanical stabilization*** is the blending of different grades of soils to obtain a required grade, while ***Chemical stabilization*** is the blending of the natural soil with chemical agents. The most commonly used agents are **Portland cement, asphalt binders, and lime.**

Cement Stabilization

The procedure for stabilizing soils with cement involves:

a) Pulverizing the soil
b) Mixing the required quantity of cement with the pulverized soil
c) Compacting the soil cement mixture
d) Curing the compacted layer

Pulverizing the Soil

The soil to be stabilized first should be pulverized thoroughly to facilitate the mixing of the cement and soil. When the material to be stabilized is imported to the site, the soil is evenly spread to the required depth above the subgrade and then pulverized by using rotary mixers. Sieve analysis is conducted on the soil during pulverization, and pulverization is continued (except for gravel) until all material can pass through a 1 in. sieve and not more than 20 percent is retained on the No. 4 sieve. A suitable moisture content must be maintained during pulverization which may require air drying of wet soils or the addition of water to dry soils.

Mixing of Soil and Cement

It involves the addition of 5 to 14% Portland cement by volume of the compacted mixture to the soil being stabilized. This type of stabilization is used mainly to obtain the required engineering properties of soils that are to be used as base course materials.

- The first step in the mixing process is to determine the amount of cement to be added to the soil by conducting laboratory experiments to determine the minimum quantity of cement required.
- The mixing can be carried out either on the field (***road mixing***) or in a central plant (***plant mixing***). Plant mixing is used primarily when the material to be stabilized is borrowed from another site. With road mixing, the cement usually is delivered in bulk in dump or hopper trucks and spread by a spreader box or some other type of equipment that will provide a uniform amount over the pulverized soil. Enough water is then added to achieve a moisture content that is 1 or 2 % higher than the optimum required for compaction, and the soil, cement, and water are properly blended to obtain a uniform moisture of soil cement. Blending at a moisture content slightly higher than the compaction optimum moisture content allows for loss of water by evaporation during the mixing process.
- In plant mixing, the borrowed soil is properly pulverized and mixed with the cement and water in either a continuous or batch mixer. It is not necessary to add more than the quantity of water that will bring the moisture content to the optimum for compaction, since moisture loss in plant mixing is relatively small. The soil–cement mixture is then delivered to the site in trucks and uniformly spread. The main advantage of plant mixing over road mixing is that the proportioning of cement, water, and soil can be controlled easily.

Compacting the Soil–Cement Mixture

- It is essential that compaction of the mixture be carried out before the mixture begins to set. However, the length of time between the addition of water and the compaction of the mix at the site should not be greater than two hours for plant mixing and not more than one hour for road mixing.
- The soil–cement mixture is initially compacted with sheepsfoot rollers, or pneumatic-tired rollers when the soil (for example, very sandy soil) cannot be effectively compacted with a sheepsfoot roller. The uppermost layer of 1-to-2-inch depth is usually compacted with a pneumatic-tired roller, and the final surface compaction is carried out with a smooth-wheeled roller.

Curing the Compacted Layer

Moisture loss in the compacted layer must be prevented before setting is completed because the moisture is required for the hydration process. This is achieved by applying a thin layer of bituminous material such as RC-250 or MC-250. Tars and emulsions also can be used.

بعض الشروط الخاصة بتثبيت التربة النهائية، وطبقات تحت الأساس والأساس بالسمنت:

1. يكون مزج المكونات في الموقع عند توفر الرمل والحصى او مزيج الحصى والرمل في نفس الموقع
2. في حالة التربة الغرينية والطينية فإن أعلى حد للسيولة مسموح به هو 45% ، أما الحد الأعلى لدليل اللدونة فهو 20%، كما أن قيمة الـ PH للتربة يجب ألا تقل عن 12.1 (وإلا فإنه بتوجب تحسين التربة بإضافة كلوريد الكالسيوم الى حد 2% من الوزن الجاف للتربة)، أم الحد الأعلى للأملاح القابلة للذوبان هو 4% للكبريتات، و 8% للكلوريدات، ويشترط أن تكون نسبة المواد الطينية الأقل نعومة من 0.002 مم أقل من 35%.
3. نسبة الانحراف المسموح بها في معادلة المزج تكون كالتالي: (نسبة السمنت: -1 إلى 2 % من معادلة المزج) ، (نسبة الماء: 0 إلى 2 % من معادلة المزج)
4. يجب ألا تزيد نسبة الانتفاخ الحجمي عن 2%، ولا تزيد نسبة فقدان الوزن عن 8%.
5. يجب ألا يقل سمك الطبقة المثبتة عن 8 سم ولا يزيد عن 20 سم بعد الحدل، وإذا زاد عن 20 سم فإنه يتوجب العمل بطبقتين أو أكثر، ويجري المزج عند درجة حرارة أكثر من 4 ، شرط ألا يكون الجو ممطراً

Asphalt Stabilization

Asphalt stabilization is carried out to achieve one or both of the following:

1. Waterproofing of natural materials: By reducing the effect of any surface water that may enter the soil when it is used as a base course.
2. Binding of natural materials: Improves the durability characteristics of the natural soil by providing an adhesive characteristic, whereby the soil particles adhere to each other, increasing cohesion.

Some notes to be considered:

- It is usually used Cutback asphalt (RC 70, RC250, RC800, MC70, MC250, MC800) or Emulsion (Cationic SS) based on the type of soil and weathering condition.
- Several types of soil can be stabilized with asphalt, although it is generally required that less than 30 percent of the material passes the No. 200 sieve. This is necessary because the smaller soil particles tend to have extremely large surface areas per unit volume and require a large quantity of bituminous materials.

- It is also necessary to use soils that have a plasticity index (PI) of less than 15 (Preferred less than 10 in some specifications), because difficulty may be encountered in mixing soils with a high PI, which may result in the plastic fines swelling on contact with water and thereby losing strength.
- The mixing of the soil and bituminous materials also can be done in a central or movable plant (plant mixing) or at the roadside (road mixing).
- In plant mixing, the desired amounts of water and bituminous material are automatically fed into the mixing hoppers, whereas in road mixing, the water and bituminous material are measured and applied separately using a pressure distributor. The materials then are mixed thoroughly in the plant when plant mixing is used or by rotary speed mixers or suitable alternative equipment when road mixing is used.
- The material then is spread evenly in layers of uniform thickness, usually not greater than 6 in. and not less than 2 in. Each layer is properly compacted until the required density is obtained using a pneumatic-tired roller.
- **The mixture must be aerated completely before compaction to ensure the removal of all volatile materials.**

Lime Stabilization

Lime stabilization is one of the oldest processes of improving the engineering properties of soils and can be used for stabilizing both base and subbase materials. In general, the oxides and hydroxides of calcium and magnesium are considered as lime but **the materials most commonly used for lime stabilization are calcium hydroxide $Ca(OH)_2$ and Dolomite $Ca\ (OH)_2\ MgO$**. The dolomite, however, should not have more than 36 % by weight of magnesium oxide (MgO) to be acceptable as a stabilizing agent.

Clayey materials are most suitable for lime stabilization, but these materials prefer to have PI values less than 10 for the lime stabilization to be most effective. When lime is added to fine-grained soil, cation exchange takes place, with the calcium and magnesium in the lime replacing the sodium and potassium in the soil. The tendency to swell as a result of an increase in moisture content is therefore immediately reduced. The PI value of the soil is also reduced. Pozzolanic reaction may also occur in some clays, resulting in the formation of cementing agents that increase the strength of the soil. When silica or alumina is present in the soil, a significant increase in strength may be observed over a long period of time. An additional effect is that lime causes flocculation of the fine particles, thereby increasing the effective grain size of the soil.

The percentage of lime used for any project depends on the type of soil being stabilized. The determination of the quantity of lime is usually based on an analysis of the effect that different lime percentages have on the reduction of plasticity and the increase in strength on the soil. The PI is most commonly used for testing the effect on plasticity, whereas the unconfined compression test, the Hveem Stabilometer test, or the California bearing-ratio (CBR) test can be used to test for the effect on strength. However, most fine-grained soil can be effectively stabilized with 3 to 8% lime (can be up to 10% in some specifications) based on the dry weight of the soil.

Fly Ash and Slag Stabilization: Industrial by-products like fly ash and slag have been investigated for their potential to stabilize expansive soils and provide sustainable alternatives to traditional stabilizers like lime and cement.

Polymer-Based Stabilization (Polymer-based water solutions): Polymer additives, such as polyacrylamides, have shown promise in enhancing the stability and erosion resistance of soil. Polymer-based water solutions are made up of water and water-soluble polymers, such as polyacrylamides, that have the ability to improve soil properties when mixed together. These polymers are long-chain molecules that, when dissolved in water, can form a stable solution. When applied to soils, the polymer molecules interact with soil particles, leading to the following benefits:

1. *Erosion Control*: Polymer-based water solutions can help in reducing soil erosion by binding soil particles together and increasing surface stability. They are often used in erosion control applications on slopes, construction sites, and areas prone to erosion.
2. *Water Infiltration Management:* These solutions can help manage water infiltration in soil, reducing water seepage and enhancing the soil's ability to retain moisture, particularly in sandy or gravelly soils.
3. *Dust Control*: Polymer water solutions are used to control dust on construction sites, unpaved roads, and mining areas by preventing fine particles from becoming airborne.
4. *Soil Stabilization*: By increasing soil cohesion and reducing its plasticity, polymer-based water solutions can improve the strength and stability of certain types of soils.
5. *Road Construction and Maintenance*: Polymer water solutions are used in road construction and maintenance to stabilize road surfaces.

ملاحظات تتعلق بانحرافات السمك والإنهاء لطبقات التربة المثبتة

1. السطوح الترابية: يجب ألا يتجاوز قياس أعمق نقاط الانحراف عن المسطرة عن 3 سم للسطح النهائي، و 10 سم للميول الجانبية، و 3 سم للأكتاف
2. الانحراف عن المنسوب المقرر لطبقة ما تحت الأساس يكون (1 سم إلى – 2 سم)
3. لا يزيد انحراف استوائية السطح النهائي عن 2 سم باستعمال مسطرة طولها 4 م
4. لا يزيد أعلى انحراف للميل الجانبي Cross Fall عن ±0.5 %

9. Synthetic Materials

- In recent years, there has been a growing trend in the use of synthetic materials, commonly known as ***geosynthetics***, to significantly improve soil behaviour properties. Geosynthetics are versatile and can effectively fulfil a wide range of functions essential for a landfill unit's barrier system, including lining, material separation, drainage, filtration, and reinforcement.
- **Common types of geosynthetic materials include** geotextiles, geogrids, geomembranes, geocells, and geocomposites. They are widely used in civil engineering, environmental protection, and geotechnical applications to improve the performance and durability of construction projects, reduce maintenance costs, and enhance the overall safety and sustainability of various structures and infrastructure.

Geogrids are grid-like structures used for soil reinforcement and stabilization.
Geomembranes are impermeable or low-permeability sheets used as barriers to control fluid migration.

Geotextiles are permeable fabrics that serve various functions like separation, filtration, reinforcement, and drainage in civil engineering projects.

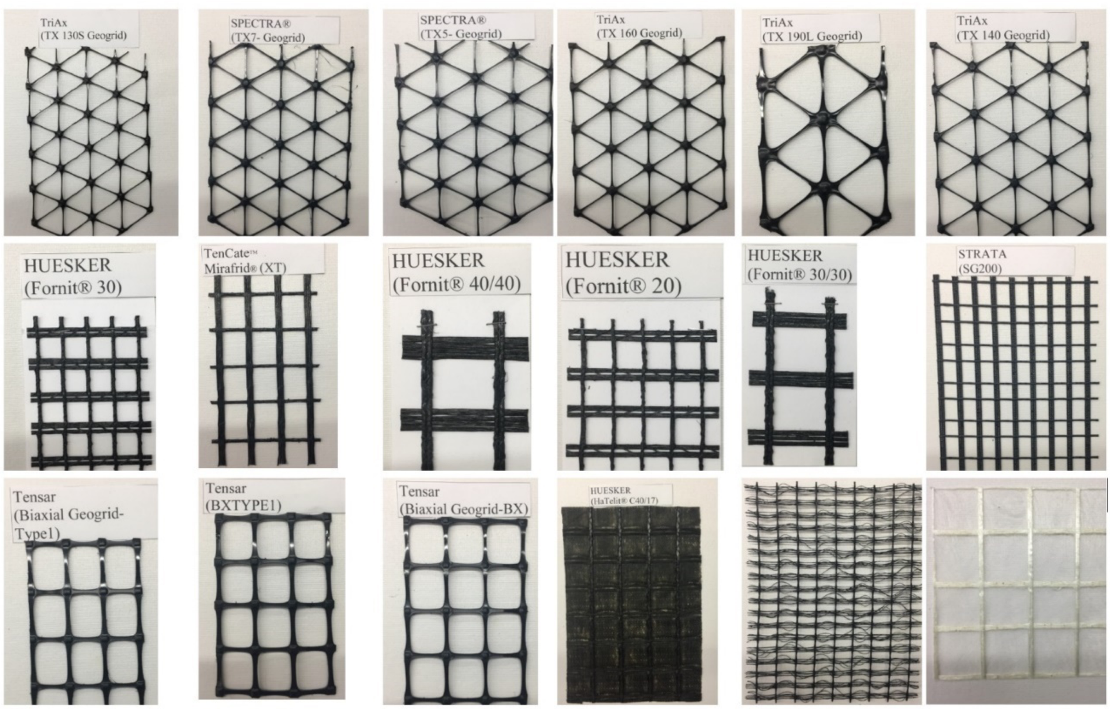
Geogrid is a type of geosynthetic material made of high-strength polymer or composite materials. They are typically manufactured in the form of a grid with regularly spaced apertures. **Geogrids are specifically designed to improve the mechanical properties of soils, enhance their stability, increase their load-bearing capacity, and prevent excessive deformation.**

Types of Geogrids:

1. ***Uniaxial Geogrid***: These geogrids have apertures that are elongated in one direction, offering strength and reinforcement primarily in one direction. They are commonly used for applications like road base reinforcement.
2. ***Biaxial Geogrid***: These geogrids have apertures that are evenly spaced in both directions, providing balanced reinforcement in two dimensions. They are suitable for applications like retaining walls and slopes.
3. ***Triaxial Geogrid***: These geogrids have a unique design that provides reinforcement in all three dimensions. They are suitable for challenging soil stabilization projects that require multidirectional strength.

Key Considerations for Geogrid Selection and Installation:

1. **<u>Soil Type and Properties</u>**: Before selecting a geogrid, it is essential to assess the soil type and its properties, such as cohesion, angle of internal friction, and shear strength.
2. **<u>Design Requirements</u>**: The specific project requirements, including the expected loads and traffic conditions, will influence the choice of geogrid type and its strength.
3. **<u>Geogrid Material</u>**: Geogrids are available in various materials, including high-density polyethylene (HDPE), polyester, and polypropylene. The selection of the geogrid material should take into account factors such as chemical resistance, environmental conditions, and durability.
4. **<u>Aperture Size and Shape</u>**: The aperture size and shape of the geogrid can impact its performance. Smaller apertures may provide better confinement of soil particles, while larger apertures might facilitate better interlocking with the soil matrix.
5. **<u>Junction Strength</u>**: Geogrids have junctions where the intersecting ribs are connected. The strength of these junctions plays a crucial role in determining the overall performance of the geogrid.
6. **<u>Installation Techniques</u>**: Proper installation is vital for the successful performance of geogrids. The installation method may vary based on the application and site conditions. Adequate anchoring and overlap of geogrid sheets are essential to ensure efficient load transfer to the soil.
7. **<u>Long-Term Durability</u>**: Geogrids are designed to have long-term durability, but factors such as UV exposure and chemical exposure may affect their lifespan.

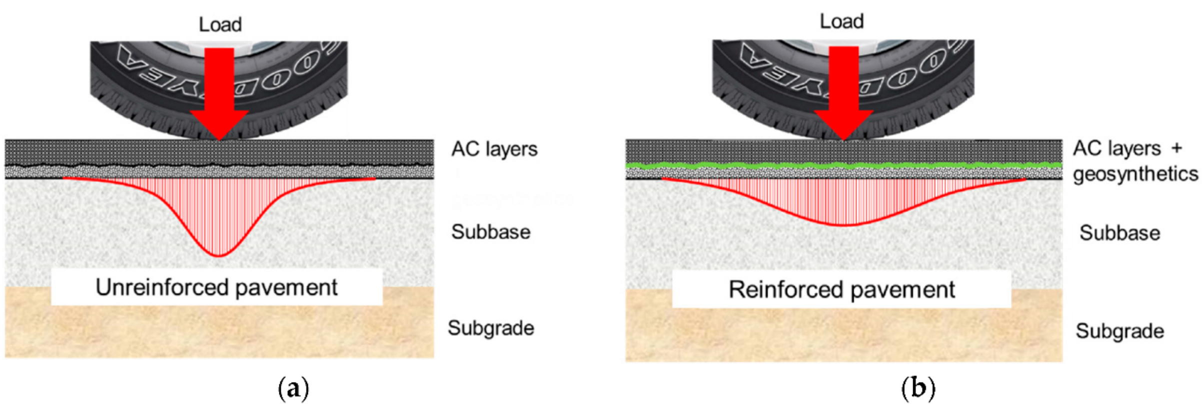


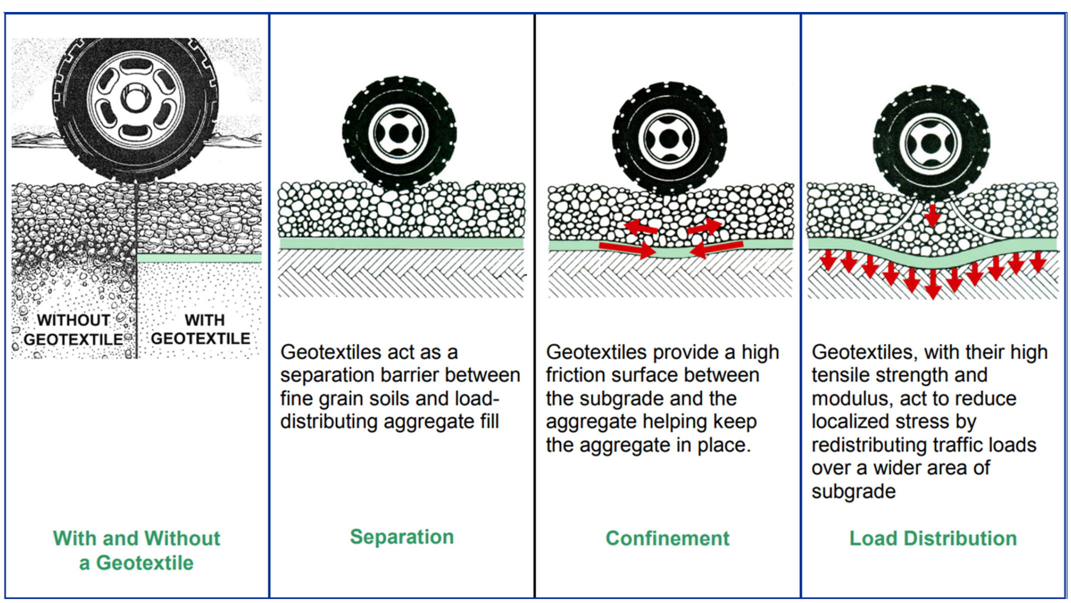
The use of geogrid in asphalt layers offers several benefits, including:

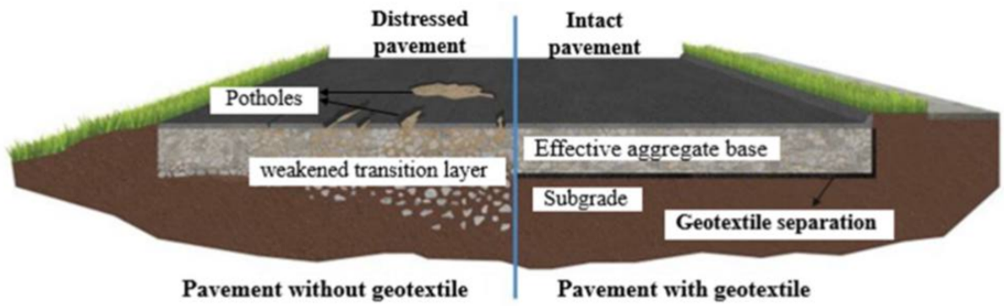
1. <u>Improved Structural Integrity:</u> Geogrids enhance the tensile strength of the asphalt layer, making it more resilient to cracking and rutting. This results in a longer-lasting pavement structure.
2. <u>Reduced Maintenance Costs:</u> By reducing the occurrence of cracks and deformation, geogrids help prolong the life of the asphalt pavement. This, in turn, reduces maintenance and repair expenses.

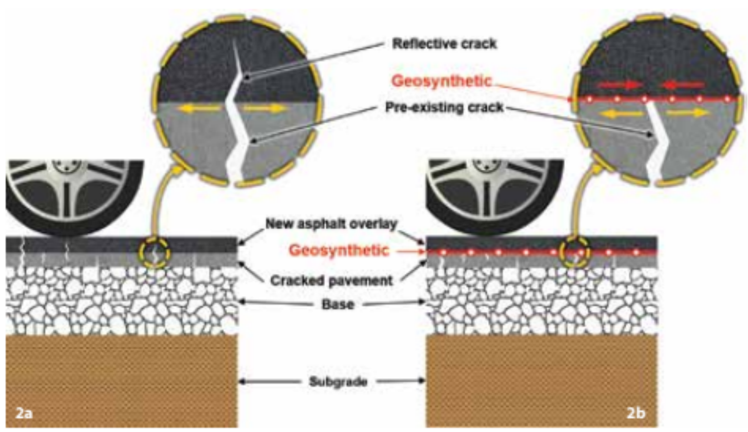
3. Increased Load-Bearing Capacity: Geogrids distribute the load more evenly across the pavement, allowing it to withstand heavier traffic loads without significant damage.
4. Enhanced Fatigue Resistance: The use of geogrid can improve the fatigue resistance of the asphalt, which is particularly important in high-traffic areas where repeated loading occurs.
5. Prevention of Reflective Cracking: Geogrids can help mitigate the development of reflective cracks, which occur when cracks in the underlying pavement surface propagate through the new asphalt layer.
6. Thinner Asphalt Layers: Geogrid reinforcement can allow for the construction of thinner asphalt layers while maintaining the required structural performance.
7. Improved Geotechnical Performance: Geogrids stabilize the base and subgrade soils, preventing soil movement and maintaining a stable foundation for the asphalt pavement.
8. Environmental Benefits: Thinner asphalt layers and reduced maintenance translate to lower resource consumption and less waste, making geogrid-reinforced asphalt a more sustainable option.

The effects of geosynthetic materials are shown in the following Figures:

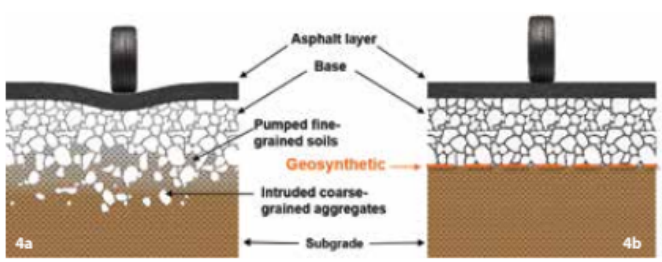








Use of geosynthetics in mitigation of reflective cracking in asphalt overlays:(a) roadway designed without geosynthetics, (b) roadway designed with geosynthetics.



Use of geosynthetics in separation: (a) roadway designed without geosynthetics, (b) roadway designed with geosynthetics.

10. Frost Action in Soils

- When the ambient temperature falls below freezing for several days, it is quite likely that the water in soil pores will freeze. Since the volume of water increases by about 10 percent when it freezes, the first problem is the increase in volume of the soil. The second problem is that the freezing can cause ice crystals and lenses that are several centimetres thick to form in the soil. These two problems can result in heaving of the subgrade (***frost heave***), which may result in significant structural damage to the pavement.

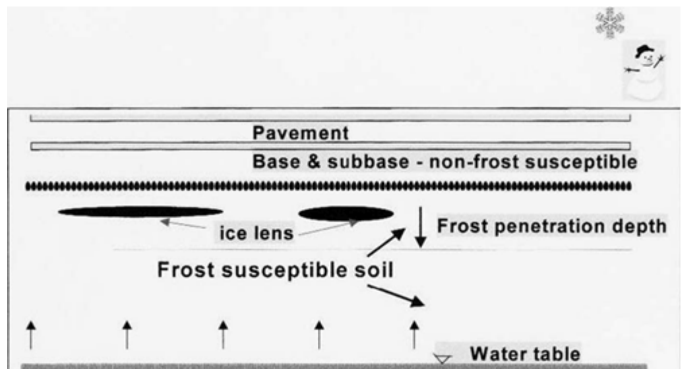
- In addition, the ice lenses melt during the spring (***spring thaw***), resulting in a considerable increase in the water content of the soil. This increase in water significantly reduces the strength of the soil, causing structural damage of the highway pavement known as "***spring break-up***."

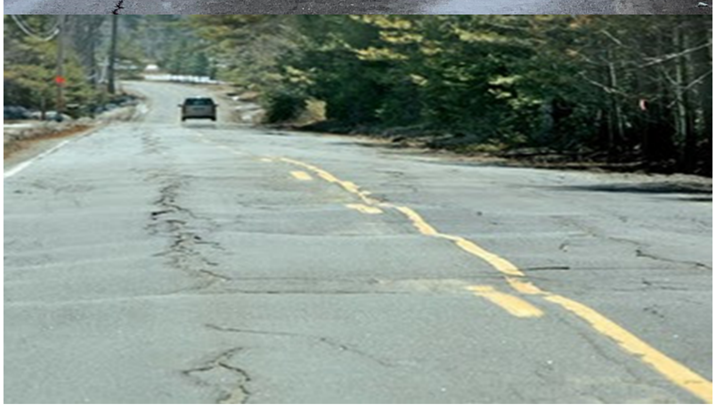
In general, three conditions must exist for severe frost action to occur:

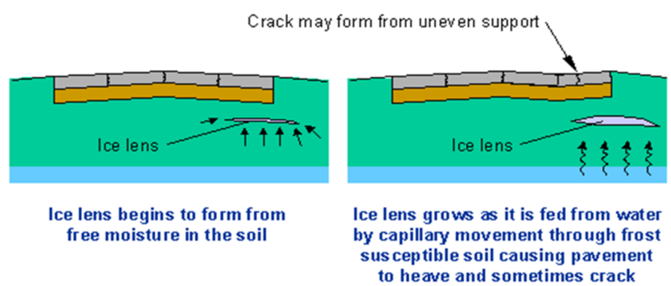
1. Ambient temperature must be lower than freezing for several days.
2. The shallow water table that provides capillary water to the frost line must be available.
3. The soil must be susceptible to frost action.

Current measures taken to prevent frost action, include:

1. Removing frost-susceptible soils to the depth of the frost line and replacing them with gravel material
2. Lowering the water table by installing adequate drainage facilities, using membranes or chemical additives,
3. Restricting truck traffic on some roads during the spring thaw.







- Granular soils are not susceptible to frost action (they have a relatively high coefficient of permeability).
- Clay soils also are not highly susceptible to frost action (they have very low permeability, so not enough water can flow during a freezing period to allow the formulation of ice lenses).
- Sandy or silty clays or cracked clay soils near the surface, however, may be susceptible to frost action.
- Silty soils are most susceptible to frost action.
- It has been determined that 0.02 mm is the critical grain size for frost susceptibility.
- Soils with less than 1 % of their material finer than the critical size are rarely affected by frost action.

11. Asphalt materials

<u>Bitumen</u>: Mixtures of hydrocarbons of natural or pyrogenous origin or combinations of both (liquid, semisolid or solid and which are completely soluble in carbon disulfide.

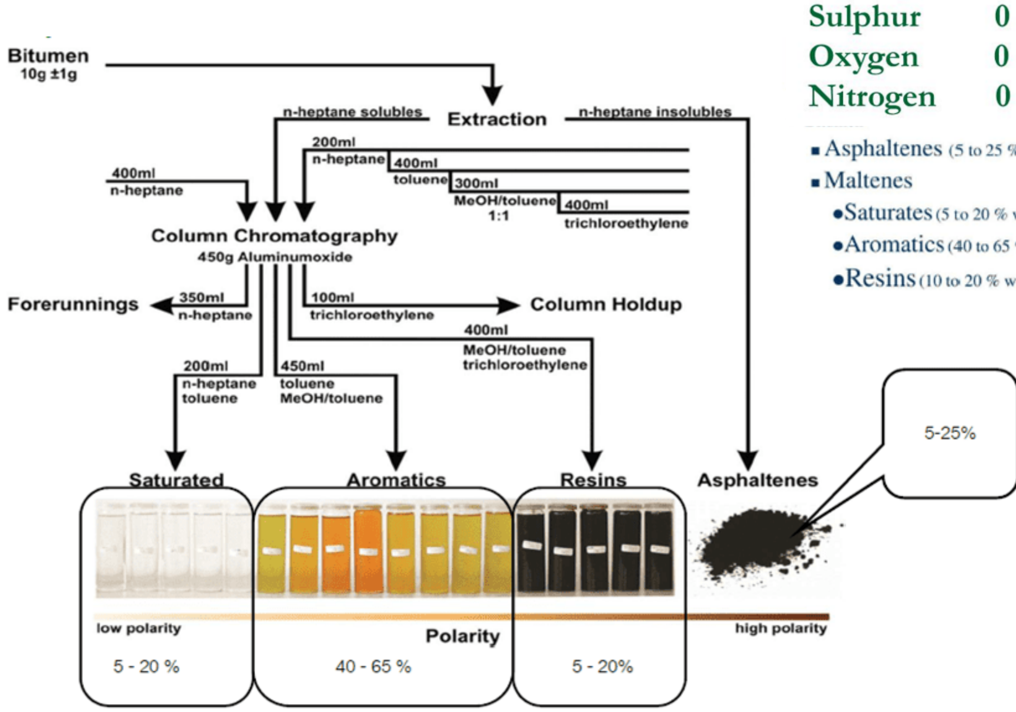
<u>Asphalt</u>: Sticky materials a dark brown to black cementations material, solid or semisolid in consistency based on temperature. The asphalt binder is a co-product of the petroleum-refining system that produces gasoline, diesel fuel, lubricating oil, as well as several other petroleum products. The production of asphalt binder involves adjusting its properties to meet specific performance requirements, such as temperature susceptibility, aging resistance, and durability.

<u>Asphalt binder Composition:</u>

1. The solid part, Asphaltenes, looks like black powder.
2. The liquid parts (Maltenes) are resins, aromatics, and saturates.

Carbon	82 - 88%
Hydrogen	8 - 11%
Sulphur	0 - 6%
Oxygen	0 - 1.5%
Nitrogen	0 - 1%

- Asphaltenes (5 to 25 % wt.)
- Maltenes
  - Saturates (5 to 20 % wt.)
  - Aromatics (40 to 65 % wt.)
  - Resins (10 to 20 % wt.)



Fractions	Saturates	Aromatics	Resins	Asphaltenes
wt.% of asphalt	5–20	40–65	± 20	5–25
Polarity	Non-polar	Non-polar	Highly polar	Highly polar
Color	-	Yellow to red	Dark brown	Black
Behavior	Viscous oil	Viscous liquid	Solid/semi-solid	Solid
Avg. MW (g/mole)	600	800	1100	800–3500
Solvent	*n*-Heptane	Toluene and toluene/methanol 50/50	Trichloroethylene	*n*-Heptane insoluble
Solubility parameter ($MPa^{0.5}$)	15–17	17–18.5	18.5–20	17.6–21.7
Density at 20 °C (g/cm^3)	0.9	1	1.07	1.15
Glass transition temperature (°C)	−70	−20	-	-
H/C	1.9	1.5	1.4	1.1
C (%)	78–84	80–86	67–88	78–88
H (%)	12–14	9–13	9–12	7–9
O (%)	<0.1	0.2	0.3–2	0.3–5
N (%)	<0.1	0.4	0.2–1	0.6–4
S (%)	<0.1	0–4	0.4–5	0.3–11

Classification or Source of Asphalt:

Asphalt is found in widely parts of the world in one or another of the following forms:

1. **Natural Asphalts:** laid down in geologic strata (layers) and occurring both as soft or hard bitumen material and as friable, black bitumen in veins of rock. Natural deposits of asphalt occur as either native asphalt or rock asphalt. The largest deposit of native asphalt is known to have existed in Iraq several thousand years ago.

- **Native asphalt** (after being softened with petroleum fluxes) was at one time used extensively as binders in highway construction. The properties of native asphalt vary from one deposit to another, particularly with respect to the amount of insoluble material the asphalt contains.
- **Rock asphalt** is a natural deposit of sandstone or limestone rocks filled with asphalt. The amount of asphalt varies from one deposit to another and can be as low as 4.5 % and as high as 18 %. Rock asphalt is not used widely because of its high transportation costs.

2. **Artificial Asphalts: have been classified:**
   a. **Petroleum Asphalts**: The soft to hard asphalts of high solubility in carbon disulfide (>99%), derived from vacuum and or steam distribution of crude oils (high asphalt content).
   b. **Cracked Asphalt:** - These materials are petroleum derivatives but are formed as by-products in oil cracking processes. This material contained variable percentage of "free carbon" under high temperature and pressure.
   c. **Coal Tar**: It is derived from tars; they are classified as bitumen.

Refining Processes

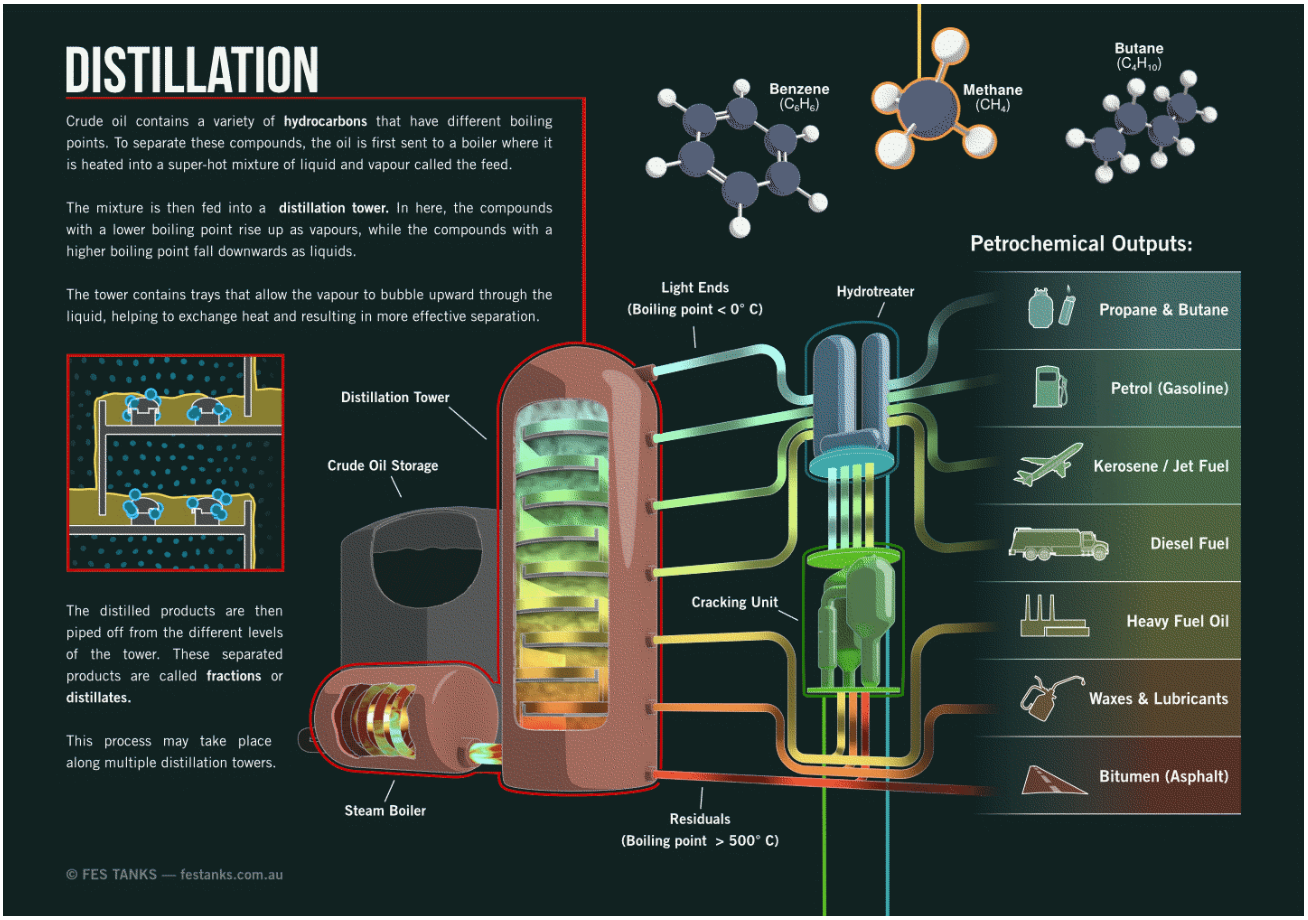
The refining processes used to obtain petroleum asphalts can be divided into two main groups: *fractional distillation* and *destructive distillation* (cracking). The fractional distillation processes involve the separation of the different materials in the crude petroleum without significant changes in the chemical composition of each material. The destructive distillation processes involve the application of high temperature and pressure, resulting in chemical changes.

Fractional Distillation: The fractional distillation process removes the different volatile materials in the crude oil at successively higher temperatures until the petroleum asphalt is obtained as residue. Steam or a vacuum is used to gradually increase the temperature.

Steam distillation is a continuous flow process in which the crude petroleum is pumped through tube stills or stored in batches, and the temperature is increased gradually to facilitate the evaporation of different materials at different temperatures. Tube stills are more efficient than batches and are therefore preferred in modern refineries. Immediately after increasing the temperature of the crude in the tube still, it is injected into a bubble tower which consists of a vertical cylinder into which are built several trays or platforms stacked one above the other. The first separation of materials occurs in this tower. The lighter fractions of the evaporated materials collect on the top tray, and the heavier fractions collect in successive trays, with the heaviest residue containing asphalt remaining at the bottom of the distillation tower. The products obtained during this first phase of separation are gasoline, kerosene distillate, diesel fuel, lubricating oils, and the heavy residual material that contains the asphalt. The various fractions collected are stored and refined further into specific grades of petroleum products. Note that a desired consistency of residue can be obtained by continuing the distillation process.

Destructive Distillation:

Cracking processes are used when larger amounts of light fractions of materials (such as motor fuels) are required. Intense heat and high pressures are applied to produce chemical changes in the material. Although several specific methods of cracking exist, the process generally involves the application of temperatures as high as 600°C and pressure higher than 5000 kPa to obtain the desired effect. The asphalt obtained from cracking is not used widely in paving, because it is more susceptible to weather changes than that produced from fractional distillation.



Tar

<u>Tars are obtained from the destructive distillation of such organic materials as coal</u>. Their properties are significantly different from petroleum asphalts. In general, they are more susceptible to weather conditions than similar grades of asphalts, and they set more quickly when exposed to the atmosphere. ASTM has classified road tars into three general categories based on the method of production.

1. Gashouse coal tars are produced as a by-product in gashouse retorts in the manufacture of illuminating gas from bituminous coals.
2. Coke-oven tars are produced as a by-product in coke ovens in the manufacture of coke from bituminous coal.
3. Water-gas tars are produced by cracking oil vapours at high temperatures in the manufacture of carburetted water gas.

Road tars also have been classified by AASHTO into 14 grades: RT-1 through RT-12, RTCB-5, and RTCB-6. RT-1 has the lightest consistency and can be used effectively at normal temperatures for prime or tack coat (described later in this chapter). The viscosity of each grade increases as the number designation increases to RT-12, which is the most viscous. RTCB-5 and RTCB 6 are suitable for application during cold weather, since they are produced by cutting back the specific grade of tar with easily evaporating solvent.

Blown Asphalts:

Blown asphalt is obtained by blowing air through the semisolid residue obtained during the latter stages of the distillation process. The process involves stopping the regular distillation while the residue is in the liquid form and then transferring it into a tank known as a *converter.* The material is maintained at a high temperature while air is blown through it. This is continued until the required properties are achieved.

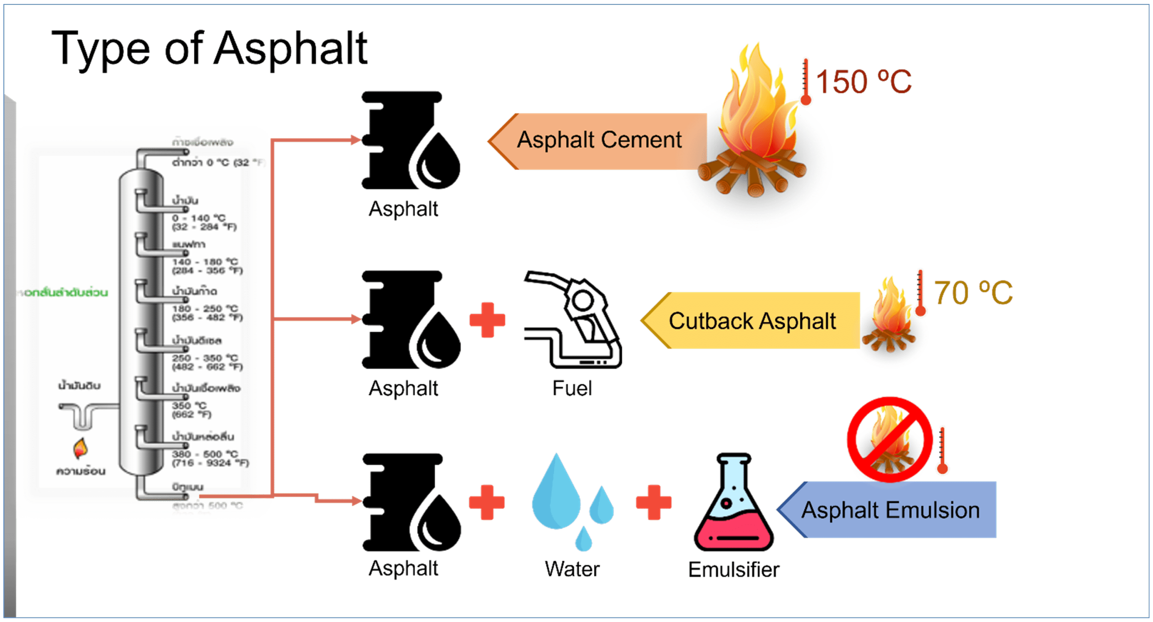
Common Types of Asphalt:

Asphalt can be divided into several types:

1. **Asphalt Binder** is a product derived from the refining of crude oil. It is a strong and versatile binding material with weather and chemical resistant characteristics that can be used ideally for road, bridge, highway and runway construction and maintenance works.
2. **Cutback Asphalt** is liquid asphalt produced by blending asphalt cement with petroleum solvent. (Slow Curing (SC), Medium Curing (MC), Rapid Curing (RC)). Cutback asphalt is used to reduce asphalt viscosity for road applications. After cutback asphalt is applied the petroleum solvent evaporates leaving behind asphalt cement on the surface to which it was applied.
3. **Emulsion** is a liquid asphalt with combination of three main ingredients of asphalt, water, and emulsifier (Rapid Setting (RS), Medium Setting (MS), Slow Setting (SS)). Key properties of the asphalt in asphalt emulsion are cohesion and waterproofing which can be used in cold processes for road construction and maintenance by applying on the road surface with or without mixing with the aggregate.

Other Types of Asphalt, such as:

- Modified Asphalt Emulsion is a premium grade of asphalt emulsion produced by mixing the asphalt emulsion with polymer or other appropriate materials to yield greater quality advantages over normal asphalt emulsion.
- Polymer Modified Asphalt (PMA) is an improved asphalt cement produced by blending either natural polymer (such as natural rubber) or synthetic polymer (such as SBS or EVA). PMA will provide better strength and durability to road surfaces than conventional asphalt used in hot mix asphalt (High resistance to wear, High resistance to rutting, High elastic recovery at lower/higher temperature, High cohesion or less revelling, High resistance to stripping)



Cutback Asphalt

Slow-Curing Asphalts (SC): It can be obtained directly as slow-curing straight run asphalts through the distillation of crude oil by cutting back asphalt cement with a heavy distillate such as oil (lower viscosity than asphalt and very slow to harden).

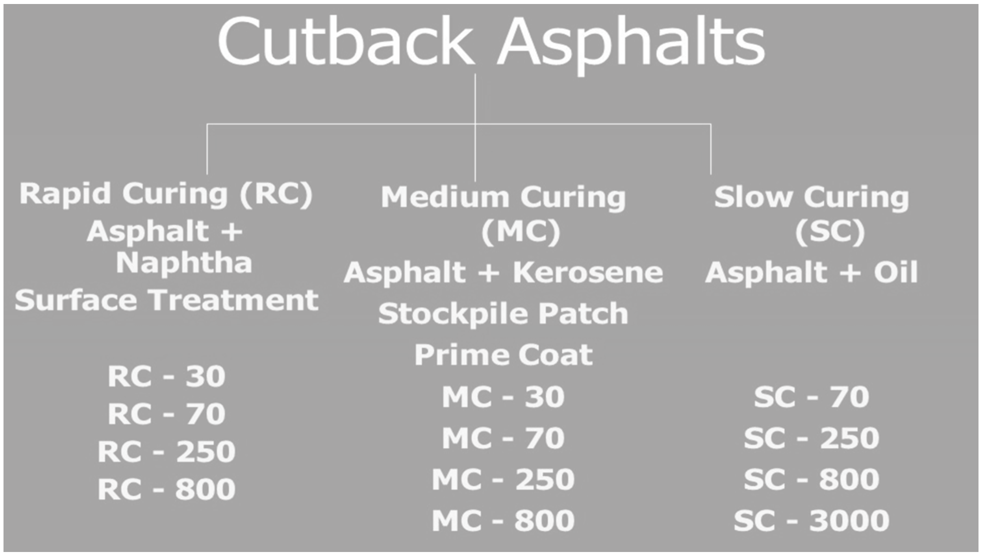
- Sc +(number), this number represent to approximate kinematics viscosity (70, 250, 800 and 3000) centistokes at 60 °C.

Medium-Curing Asphalt (MC): It is produced by fluxing or cutting the residual asphalt (120-150 penetration) with light fuel oil or kerosene (harden faster than Sc and similar in consistencies). The fluidity of Mc depends on the amount of solvent in material.

- MC-3000 (20% solvent) and Mc-70 (45% solvent). MC can used for the construction of pavement bases and surfaces.

Rapid-Curing Asphalt (RC): It is produced by blending asphalt cement with an oil distillate that will easily evaporate, thereby facilitating a quick change from the liquid form at time of application to the consistency of original asphalt. – Gasoline or naphtha is used as the solvent.

- ✓ **CSS-1** is the slow-setting asphalt emulsion, used for Prime Coat application. Key properties of the asphalt in asphalt emulsion are cohesion and waterproofing which can be used in cold processes for road construction and maintenance by applying on the road surface with or without mixing with the aggregate.
- ✓ **CRS-2** is a rapid-setting asphalt emulsion, used as a binder between pavement layers (Tack Coat), key property is cohesion and waterproofing.

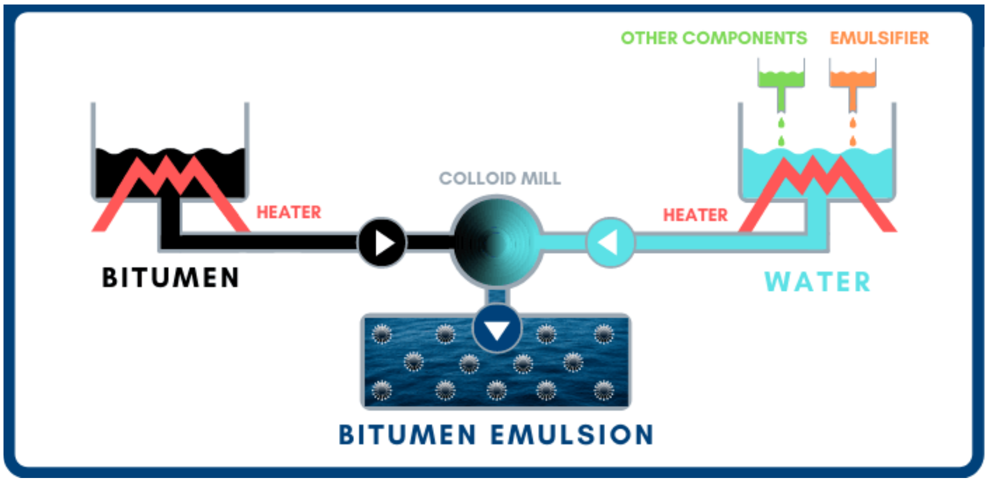


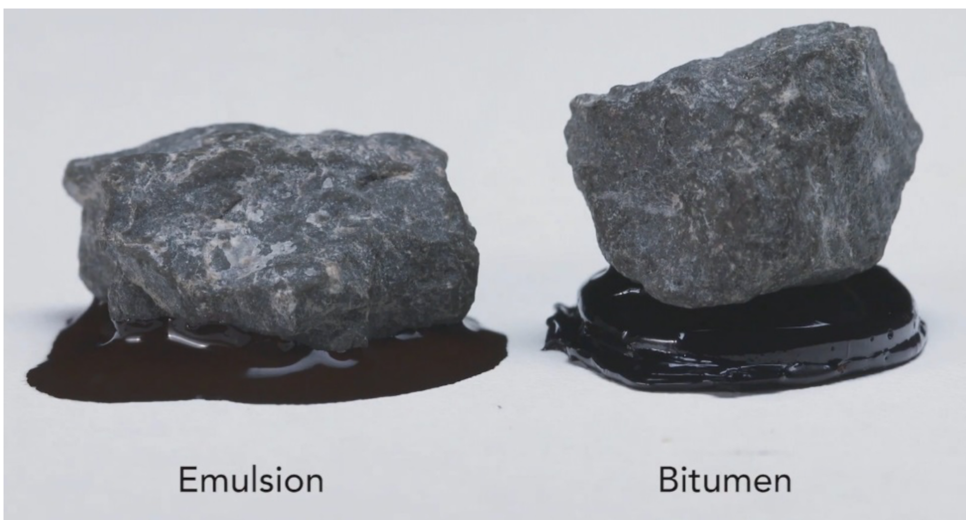
Emulsion:

Emulsified asphalts are produced by breaking asphalt binder, usually of 100 to 250 penetration range, into minute particles and dispersing them in water with an emulsifier. These minute particles have like-electrical charges and therefore do not coalesce. They remain in suspension in the liquid phase as long as the water does not evaporate, or the emulsifier does not break.

- Asphalt emulsions therefore consist of asphalt, which makes up about 55 to 70 % by weight, water, and an emulsifying agent, which in some cases also may contain a stabilizer.
- Asphalt emulsions generally are classified as anionic, cationic, or nonionic. The first two types have electrical charges surrounding the particles, whereas the third type is neutral.
- Classification as anionic or cationic is based on the electrical charges that surround the asphalt particles. Emulsions containing negatively charged particles of asphalt are classified as anionic, and those having positively charged particles of asphalt are classified as cationic.
- The anionic and cationic asphalts generally are used in highway maintenance and construction, although it is likely that the non-ionic may be used more frequently in the future as emulsion technology advances.
- Each of these categories is further divided into three subgroups based on how rapidly the asphalt emulsion returns to the state of the original asphalt cement. These subgroups are rapid-setting (RS), medium setting (MS), and slow-setting (SS). A cationic emulsion is identified by placing the letter "C" in front of the emulsion type; no letter is placed in front of anionic and non-ionic emulsions. For example, CRS-2 denotes a cationic emulsion, and RS-2 denotes either an anionic or non-ionic emulsion.
- Emulsified asphalts are used in cold-laid plant mixes and road mixes (mixed in-place) for several purposes, including the construction of highway pavement surfaces and bases and in surface treatments.
- Note, however, that since anionic emulsions contain negative charges, they are more effective in treating aggregates containing electropositive charges (such as limestone), whereas cationic emulsions

are more effective with electronegative aggregates (such as those containing a high percentage of siliceous material). Also note that ordinary emulsions must be protected during very cold spells because they will break down if frozen.





Prime Coat

It refers to the application of a low-viscosity bituminous material, such as asphalt emulsion or cutback asphalt, to the prepared surface of a road or pavement base before laying the final asphalt layer. The primary purpose of a prime coat is to bond and seal the surface, providing a stable foundation for the subsequent layers. Here are some benefits and warnings associated with prime coats:

Benefits of Prime Coat:

Bonding: A prime coat enhances the bonding between the underlying base and the asphalt layer, ensuring a stronger, more durable pavement structure.

Dust Control: It helps to control dust and reduce the erosion of the base materials.

Waterproofing: The prime coat acts as a waterproofing layer, preventing moisture from infiltrating the base material, which can lead to structural damage.

1. **المواد الرابطة: وتتكون من** MC 250 MC 30, MC 70، ويتم انتاج هذه المواد بمزج قير من صنف اختراق 85\100 مع نفط كورا (GORA Kerosene)
2. **الفحوصات:** تجري فحوص النمذجة، ومحتوى الماء، واللزوجة، والتقطير، ونقطة الوميض التالية بموجب مواصفات AASHTO القياسية ، كما تجرى فحوصات على المادة المتبقية بعد التقطير وهي النفاذية والسحب والذوبان واللزوجة الكينماتية والتبقع
3. **مزج المواد**: يُمزج جزء واحد من النفط الابيض الى واحد ونصف من الاسفلت، كما يمكن ان تكون المواد الرابطة القيرية من المستحلب القيري موجب الشحنة Cationic Bituminous Emulsion بموجب المواصفة AASHTO M208 ومن صنف CSS-I او CSS-1h.
4. **الكميات المستعملة**: يجب أن ترش المواد بمعدل لا يقل عن 0.5 لتر\م^2 ولايزيد عن 1.2 لتر\م^2 لطبقة الاساس ,حيث تتغير الكميات حسب حالات الموقع ويجري اقرار ذلك من قبل ممثل المهندس المقيم. وفي حالة المستحلب القيري موجب الشحنة فيجب أن يستعمل بحيث يؤمن وجود قير فوق سطح طبقة الاساس بما لا تقل عن 0.6 لتر\م^2 ولايزيد عن 1.2 لتر\م^2.
5. **محددات الطقس:** عند فرش طبقة Prime coat فيجب أن يكون السطح جافاً أو يحتوي على رطوبة قليلة بحيث يضمن توزيع منتظم واختراق (تغلغل) داخل الطبقة. ويجب عدم فرش الطبقة إذا كانت درجة حرارة الجو أقل من 15 درجة سيليزية.
6. **تهيئة السطح** : يجب ازالة كافة الاوساخ والمواد العالقة والغبار من على السطح قبل فرش طبقة Prime coat باستخدام الهواء المضغوط والمكانس التي تعمل بطاقة المكائن واليدوية ايضا، وفي حالة كون السطح جافا بشكل كبير أو يحمل غباراً، فيجب رش كمية قليلة من الماء على السطح ثم يمكن بعد ذلك فرش طبقة Prime coat ، ولكن ليس قبل اختفاء (تبخر) الماء من على السطح .
7. **وضع المواد الرابطة القيرية:** يُترك السطح بعد الفرش بدون تاثيرات خارجية لغرض الانضاج لمدة لا تقل عن 24 ساعة. وفي حالة وضع مواد رابطة قيرية فائضة عن الحاجة، فيتم عندئذ فرش رمل نظيف على تلك البقع لغرض تنشيف السطح .
8. **صيانة السطح المفروش:** يتم صيانة السطح الذي عليه وضع طبقة البريم قبل وضع طبقة الخرسانة الاسفلتية الاتية فوقه .

Tack Coat

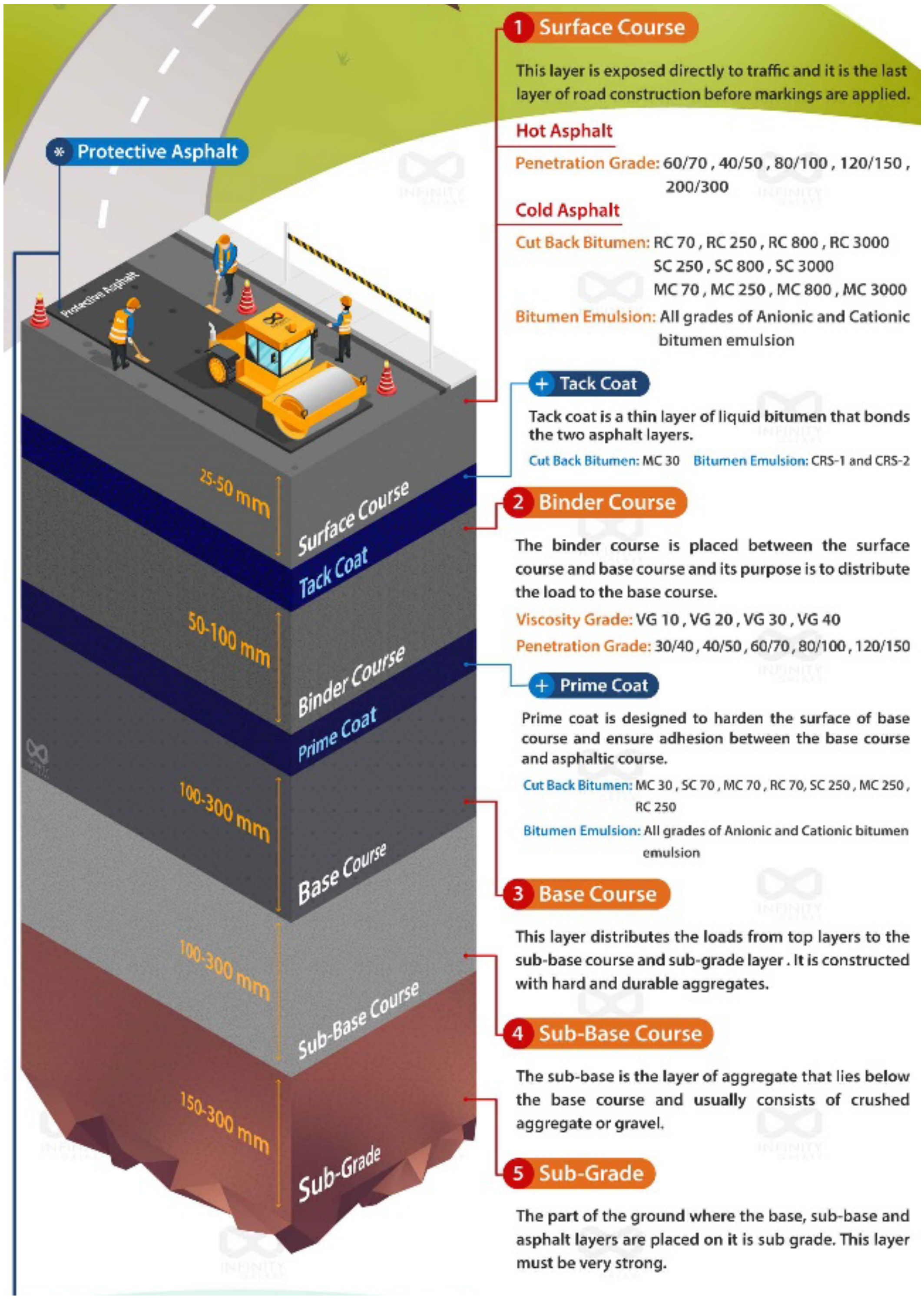
A tack coat, similar to a prime coat, is a bituminous material application in road construction but is applied on an existing surface before overlaying it with a new layer of asphalt or pavement. The tack coat acts as an adhesive layer between the existing and new surfaces.

Benefits of Tack Coat:

Adhesion: It enhances the bond between the existing and new asphalt layers.
Prevents Slippage: It reduces the risk of slippage or delamination between layers, ensuring the pavement remains intact and safe.
Waterproofing: It serves as a waterproofing layer to protect the pavement structure from moisture infiltration.
Improved Longevity: Properly applied tack coats contribute to the longevity and performance of the road surface.

1. **المواد الرابطة: وتتكون من** RC 70 , RC 250، ويتم انتاج المواد انفا بمزج قير من صنف اختراق 85\100 مع البنزين Cora Standard Motor Spirit
2. **الفحوصات:** تجري فحوص النمذجة، ومحتوى الماء، واللزوجة، والتقطير، ونقطة الوميض التالية بموجب مواصفات AASHTO القياسية ، كما تجرى فحوصات على المادة المتبقية بعد التقطير وهي النفاذية والسحب والذوبان واللزوجة الكينماتية والتبقع

3. **مزج المواد**: يُمزج جزء واحد من البنزين الى جزئين من الاسفلت، كما يمكن ان تكون المواد الرابطة القيرية من المستحلب القيري موجب الشحنة Cationic Bituminous Emulsion بموجب المواصفة AASHTO M208-2013 ومن صنف CSS-I او CSS-1h.
4. **الكميات المستعملة**: يجب أن ترش المواد بمعدل لا يقل عن 0.15 لتر\م^2 ولايزيد عن 0.5 لتر\م^2 لطبقة الاساس ,حيث تتغير الكميات حسب حالات الموقع ويجري اقرار ذلك من قبل ممثل المهندس المقيم. وفي حالة المستحلب القيري موجب الشحنة فيجب أن يستعمل بحيث يؤمن وجود قير فوق سطح طبقة الاساس بما لا تقل عن 0.1 لتر\م^2 ولايزيد عن 0.35 لتر\م^2.
5. **محددات الطقس:** عند فرش طبقة Tack coat فيجب أن يكون السطح جافاً أو يحتوي على رطوبة قليلة بحيث يضمن توزيع منتظم واختراق (تغلغل) داخل الطبقة. ويجب عدم فرش الطبقة إذا كانت درجة حرارة الجو أقل من 15 درجة سيليزية.
6. **تهيئة السطح :** يجب ازالة كافة الاوساخ والمواد العالقة والغبار من على السطح قبل فرش طبقة Tack coat باستخدام الهواء المضغوط والمكانس التي تعمل بطاقة المكائن واليدوية ايضا.
7. **وضع المواد الرابطة القيرية:** يجب وضع طبقة التاك مسافات صغيرة على الطبقة الرابطة أو السطحية بفترة لا تزيد عن ساعتين قبل فرش الخرسانة الإسفلتية. ويجب التأكد من تبخر المادة المذيبة قبل فرش طبقة الخرسانة الإسفلتية فوق المادة اللاصقة، كما تجب المحافظة على السطح المعامل بطبقة التاك في حالة جيدة لحين وضع طبقة الخرسانة الإسفلتية وعدم السماح بحركة مرور وسائط النقل عليه قبل فرش طبقة الخرسانة الإسفلتية.



Protective Asphalt
Protective Asphalt
1 Surface Course
This layer is exposed directly to traffic and it is the last layer of road construction before markings are applied.
Hot Asphalt
Penetration Grade: 60/70 , 40/50 , 80/100 , 120/150 , 200/300
Cold Asphalt
Cut Back Bitumen: RC 70 , RC 250 , RC 800 , RC 3000
SC 250 , SC 800 , SC 3000
MC 70 , MC 250 , MC 800 , MC 3000
Bitumen Emulsion: All grades of Anionic and Cationic bitumen emulsion
+ Tack Coat
Tack coat is a thin layer of liquid bitumen that bonds the two asphalt layers.
Cut Back Bitumen: MC 30 Bitumen Emulsion: CRS-1 and CRS-2
2 Binder Course
The binder course is placed between the surface course and base course and its purpose is to distribute the load to the base course.
Viscosity Grade: VG 10 , VG 20 , VG 30 , VG 40
Penetration Grade: 30/40 , 40/50 , 60/70 , 80/100 , 120/150
+ Prime Coat
Prime coat is designed to harden the surface of base course and ensure adhesion between the base course and asphaltic course.
Cut Back Bitumen: MC 30 , SC 70 , MC 70 , RC 70, SC 250 , MC 250 , RC 250
Bitumen Emulsion: All grades of Anionic and Cationic bitumen emulsion
3 Base Course
This layer distributes the loads from top layers to the sub-base course and sub-grade layer . It is constructed with hard and durable aggregates.
4 Sub-Base Course
The sub-base is the layer of aggregate that lies below the base course and usually consists of crushed aggregate or gravel.
5 Sub-Grade
The part of the ground where the base, sub-base and asphalt layers are placed on it is sub grade. This layer must be very strong.
25-50 mm
Surface Course
Tack Coat
50-100 mm
Binder Course
Prime Coat
100-300 mm
Base Course
100-300 mm
Sub-Base Course
150-300 mm
Sub-Grade

12. Properties of Asphalt Materials

The properties of asphalt materials pertinent to pavement construction can be classified into four main categories: <u>Consistency, Aging & temperature susceptibility, Rate of curing and Resistance to water action.</u>

<u>Consistency</u>

The consistency properties of an asphalt material usually are considered under two conditions: <u>variation of consistency with temperature and consistency at a specified temperature</u>.

Variation of Consistency with Temperature*:** the consistency of any asphalt material changes as the temperature varies. The change in consistency of different asphalt materials may differ considerably even for the same amount of temperature change. For example, if a sample of blown semisolid asphalt and a sample of semisolid regular paving-grade asphalt with the same consistency at a given temperature are heated to a high enough temperature, the consistencies of the two materials will be different at the high temperatures with the regular paving-grade asphalt being much softer than the blown asphalt. Further increase in temperature eventually will result in the liquefaction of the paving asphalt at a temperature much lower than that at which the blown asphalt liquefies. If these two asphalts then are cooled down gradually to about the freezing temperature of water, the blown asphalt will be much softer than the paving-grade asphalt. Thus, the consistency of the blown asphalt is affected less by temperature changes than the consistency of regular paving-grade asphalt. This property of asphalt materials is known as ***temperature susceptibility. The temperature susceptibility of a given asphalt depends on the crude oil from which the asphalt is obtained, although variation in temperature susceptibility of paving-grade asphalts from different crudes is not as high as that between regular paving-grade asphalt and blown asphalt.

***Consistency at a Specified Temperature*:** as stated earlier, the consistency of an asphalt material will vary from solid to liquid depending on the temperature of the material. It is therefore essential that when the consistency of an asphalt material is given, the associated temperature also should be given.

Aging and Temperature *Susceptibility*

When asphaltic materials are exposed to environmental elements, natural deterioration gradually takes place, and the materials eventually lose their plasticity and become brittle. This change is caused primarily by chemical and physical reactions that take place in the material. This natural deterioration of the asphalt material is known as ***weathering***. For paving asphalt to act successfully as a binder, the weathering must be minimized as much as possible. The ability of an asphalt material to resist weathering is described as the ***durability*** of the material. Some of the factors that influence weathering are oxidation, volatilization, temperature, and exposed surface area.

- ***Oxidation***: it is the chemical reaction that takes place when the asphalt material is attacked by oxygen in the air. This chemical reaction causes gradual hardening (eventually permanent hardening) and considerable loss of the plastic characteristics of the material.
- ***Volatilization***: is the evaporation of the lighter hydrocarbons from the asphalt material. The loss of these lighter hydrocarbons also causes the loss of the plastic characteristics of the asphalt material.
- ***Temperature***: it has been shown that temperature has a significant effect on the rate of oxidation and volatilization. The higher the temperature, the higher the rates of oxidation and volatilization. The percentage increase in rate of oxidation and volatilization is usually much greater than the percentage increase in temperature that causes the increase in oxidation and volatilization. It has been postulated that the rate of organic and physical reactions in the asphalt material approximately doubles for each 10 °C increase in temperature.
- ***Surface Area***: the exposed surface of the material also influences its rate of oxidation and volatilization. There is a direct relationship between surface area and rate of oxygen absorption and loss due to evaporation in grams/cm^3/minute. An inverse relationship, however, exists between volume and rate of

oxidation and volatilization. This means that the rate of hardening is directly proportional to the ratio of the surface area to the volume.

Rate of Curing

Curing is defined as the process through which an asphalt material increases its consistency as it loses solvent by evaporation.

Rate of Curing of Cutbacks: the rate of curing of any cutback asphalt material depends on the distillate used in the cutting-back process. This is an important characteristic of cutback materials, since the rate of curing indicates the time that should elapse before a cutback will attain a consistency that is thick enough for the binder to perform satisfactorily. The rate of curing is affected by both inherent and external factors.

The important inherent factors are:

1. Volatility of the solvent
2. Quantity of solvent in the cutback
3. Consistency of the base material

The more volatile the solvent is, the faster it can evaporate from the asphalt material, and therefore, the higher the curing rate of the material. This is why gasoline and naphtha are used for rapid-curing cutbacks, whereas light fuel oil and kerosene are used for medium-curing cutbacks. For any given type of solvent, the smaller the quantity used, the less time is required for it to evaporate, and therefore, the faster the asphalt material will cure. Also, the higher the penetration of the base asphalt, the longer it takes for the asphalt cutback to cure.

The important external factors that affect curing rate are

1. Temperature
2. Ratio of surface area to volume
3. Wind velocity across exposed surface.

Rate of Curing for Emulsified Asphalts: the curing and adhesion characteristics of emulsions (anionic and cationic) used for pavement construction depend on the rate at which the water evaporates from the mixture. When weather conditions are favourable, the water is displaced relatively rapidly, and so curing progresses rapidly. When weather conditions include high humidity, low temperature, or rainfall immediately following the application of the emulsion, its ability to properly cure is affected adversely. Although the effect of surface and weather conditions on proper curing is more critical for anionic emulsions, favourable weather conditions also are required to obtain optimum results for cationic emulsions. A major advantage of cationic emulsions is that they release their water more readily.

Resistance to Water Action

When asphalt materials are used in pavement construction, it is important that the asphalt continues to adhere to the aggregates even with the presence of water. If this bond between the asphalt and the aggregates is lost, the asphalt will strip from the aggregates, resulting in the deterioration of the pavement.

Temperature Effect on Volume of Asphaltic Materials

The volume increases with an increase in temperature and decreases with a decrease in temperature. The rate of change in volume is given as the coefficient of expansion, which is the volume change in a unit volume of the material for a unit change in temperature. Because of this variation of volume with temperature, the volumes of asphalt materials usually are given for a temperature of 15.6°C.

Asphalt Mixtures

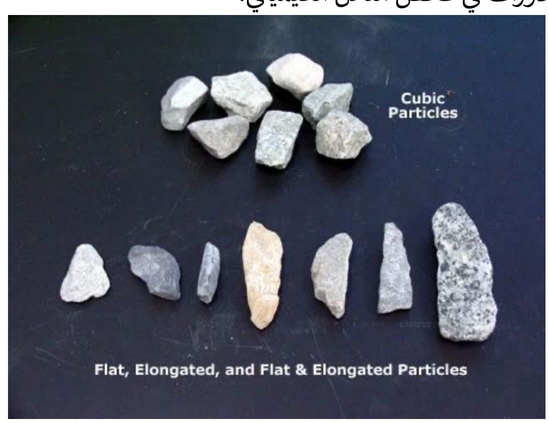
Asphalt mixtures are a uniformly mixed combination of asphalt binder, coarse aggregate, fine aggregate, filler and additives, depending on the type of asphalt mixture. The different types of asphalt mixtures commonly used in pavement construction are hot mix asphalt (HMA), warm mix asphalt (WMA) and cold mix asphalt.

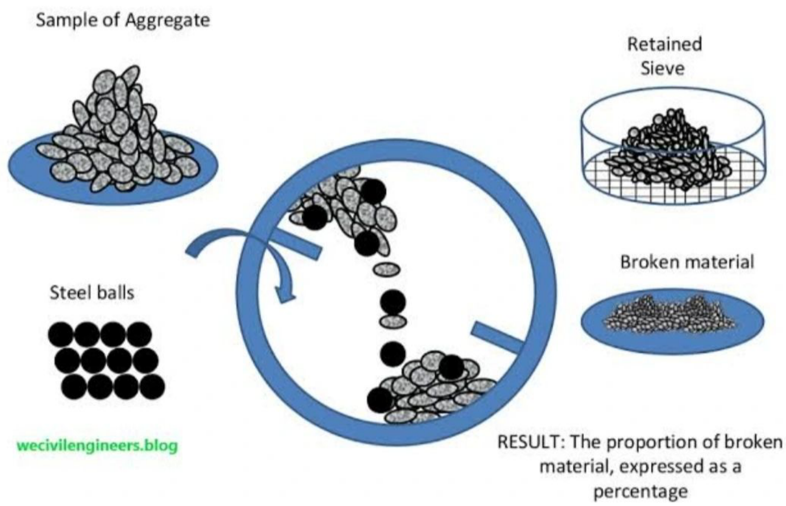
الركام (Aggregate):

- يجب أن يكون الركام من نوعية متجانسة مكسر إلى الحجم المطلوب، وتكون مواده سليمة، صلدة، ذات ديمومة، ونظيفة، وخالية من المواد الطينية وكرات الطين، ومواد الركام المغلف بالطين والجبس
- يجب ألا تزيد نسبة التآكل الميكانيكي للركام ذو المقاس الأكبر من 2.36 مم عن 30% للطبقة السطحية، و35 % للطبقة الرابطة، و40% لطبقة الأساس.
- يجب ألا يزيد معامل اللدونة للمادة المالئة عن 4
- يجب ألا تزيد نسبة المواد الضارة عن 3% وزناً

الركام الخشن Coarse aggregate: هو الركام المتبقي على منخل رقم 4.75 مم ويتكون من الحجر أو الحصى المكسر ويستخدم للطبقة السطحية أو الرابطة، أما في حالة طبقة الأساس، فمن الممكن أن يكون من الحجر المكسر أو غير المكسر، أو من كليهما وحسب التدرج المطلوب، ووفقاً للمواصفات العامة للطرق والجسور العراقية (SORB/R9)

- يجب أن يكون 90% على الأقل من الركام الخشن من النوع المكسر، بحيث أن كل قطعة ركام تحتوي على وجه واحد مكسر على الأقل للطبقة الرابطة والسطحية
- يجب ألا تزيد نسبة المواد المسطحة والمستطالة عن 10% بنسبة 5 (طول) إلى 1 (السمك)
- يجب ألا يفقد الركام أكثر من 12% من وزنه (عند استخدام كبريتات الصوديوم)، أو 18% (عند استخدام كبريتات المعنيسيوم) عندما يخضع لـ 5 دورات في فحص التآكل الكيميائي.





<u>الركام الناعم Fine aggregate:</u> هو الجزء العابر من منخل 4.75 مم، ويجب أن يكون نظيفاً، خشن الملمس، ذات أركان حادة، وذا ديمومة، وأن يكون صلباً، خالياً من المواد العضوية أو الضارة، ويجب أن يكون مكافئ الرمل لا يقل عن 45% عند الفحص بموجب المواصفة AASHTO T176 ، ويجب الانتباه إلى أن نسبة الرمل الطبيعي المستخدم ≥ 25% من الأجزاء المارة من منخل 2.36 مم

<u>المادة المالئة Filler:</u> وتعتبر مكون رئيسي في الخلطة الاسفلتية، ولها دور كبير جداً في الحصول على كثافة عالية للخلطة الإسفلتية ، والتي بدورها تزيد من مقاومة الطريق للحمل المرروي، ويجب أن تتكون من المواد الآتية: الحجر الجيري، أو سمنت بورتلاندي، أو النورة المطفأة، أو أي مادة خاملة، وذلك بموجب المواصفات العامة للطرق والجسور العراقية (SORB/R9). ويجب أن يكون نظيفاً، خالياً من تكتل المواد الناعمة ، وجافاً وخاضعاً لمتطلبات التدرج.

- يجب فحص معامل اللدونة Plasticity index (PI) للفلر المستخدم في كل خطلة اسفلتية والتأكد من أن الرقم لا يتجاوز 4
- يجب عدم استخدام ما يسمى بـ back-house كفلر Filler في الطبقة الرابطة أو السطحية، ويمكن استخدامه بشكل جزئي بطبقة الأساس (الستبلايزر) شرط أن يحقق حدود المواصفات المطلوبة.

جدول : متطلبات المادة المالئة

معامل اللدونة	4 %حد أعلى ، الفحص حسب المواصفة AASHTO T90-2008	
التدرج	مقاس المنخل مم	النسبة المئوية العابرة وزناً
	0,600 (رقم 30)	100
	0,300 (رقم 50)	100 – 95
	0,075 (رقم 200)	100 - 70

<u>الأسفلت (Asphalt binder):</u> يجب أن يكون متجانساً، خالياً من الماء، لا يرغو عند التسخين بدرجة حرارة 180 م، ومتطابقاً مع المواصفات المذكورة في الجدول المرفقة:

جدول : متطلبات الإسفلت السمنتي المصنف حسب اللزوجة

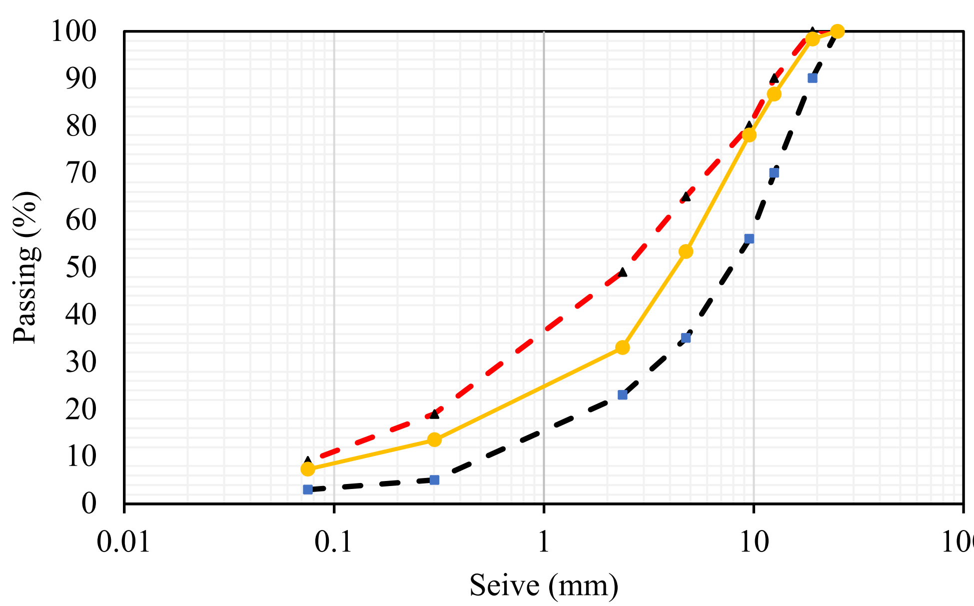
الخاصية	صنف اللزوجة		
	AC-40	AC-30	AC-20
اللزوجة في 60س (بويز)	800±4000	600±3000	400±2000
(حد أدنى) -- اللزوجة في 135س ،سنتي ستوك (حد أدنى) - الاختراق (1\10) مم عند 25س، 100غم ،5ثا درجة الاتقاد ، COC ، س (حد أدنى) - الذوبان في محلول تراي كلورو أثليين ٪ (حد أدنى)	400 40 232 99	350 50 232 99	300 60 232 99
الفحص علي المتبقي من فحص الصفيحة الرقيقة (بالفرن) دقيقة (حد أدنى)- اللزوجة في 60 س ، بويز (حد أعلى) - الاستطالة (سم) عند 25س، 5سم \	20000 25	15000 40	10000 50

جدول : متطلبات الإسفلت السمنتي المصنف حسب الاختراق

الخاصية	50-40	60-50	70-60
	صنف الاختراق		
	50-40	**60-50**	**70-60**
1- الاختراق (1\10)مم عند 25س، 100غم، 5ثا	50-40	60-50	70-60
2- الاستطالة في درجة 25س، 5سم \دقيقة(سم)	100<	100<	100<
3- درجة الاتقاد ، س	232<	232<	232<
4- الذوبان في محلول ترايكلوروواثيلين(٪)	99<	99<	99<
5- المتبقي من فحص الصفيحة الرقيقة في الفرن - الاختراق المتبقي (٪ من الأصل) - الاستطالة في درجة 25س، 5سم\دقيقة(سم)	 55< 25<	 53< 40<	 52< 50<

متطلبات تدرج مزيج الركام

صنف الخرسانة الإسفلتية		I	II	IIIA	IIIB
استعمال الخلطة		طبقة الأساس	الطبقة الرابطة	الطبقة السطحية	
مقاس المنخل مم	إنج	٪ نسبة العابر بالنسبة للوزن الكلي للركام + المادة المالئة			
37,5	1,5	100			
25	1	100-90	100		
19	4\3	90-76	100-90	100	
12,5	2\1	80-56	90-70	100-90	100
9,5	8\3	74-48	80-56	90-76	100-90
4,75	رقم 4	59-29	65-35	74-44	85-55
2,36	رقم 8	45-19	49-23	58-28	67-32
0,3	رقم 50	17-5	19-5	21-5	23-7
0,075	رقم 200	8-2	9-3	10-4	10-4
الاسمنت الإسفلتي ٪ (من الوزن الكلي)		5,5-3	6-4	6-4	6-4



Mix Design Methods: Marshall Method**,** Hveem Method **and** Superpave Method

Marshall Mix Design:

It is a method used to determine the optimum asphalt binder content for a specific asphalt mixture. The amount of binder content in a hot mix asphalt (HMA) mixture should be high enough to make the pavement durable, but not too high that it makes the mixture unstable. Finding the optimal binder content depends on these factors:

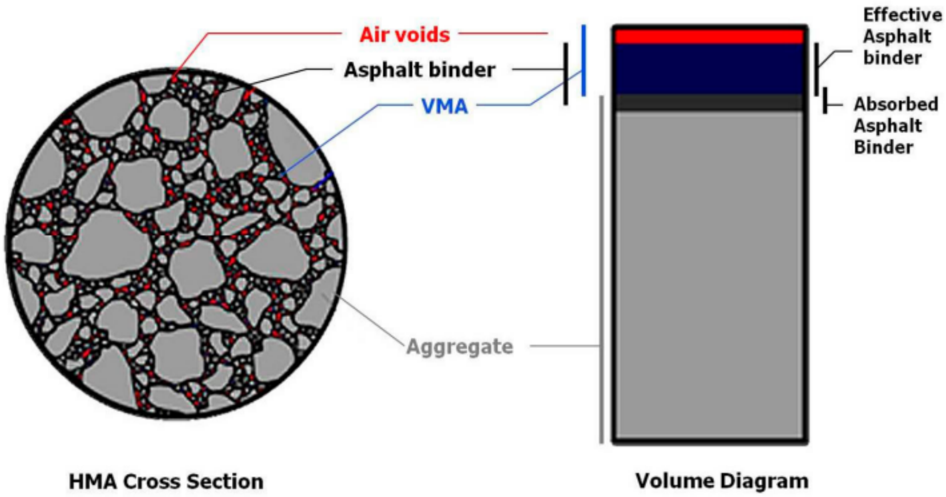
1. Type of aggregate used.
2. Size distribution of the aggregate particles
3. How well the mixture is compacted.
4. The desired air void content.
5. Type of binder and its specifications

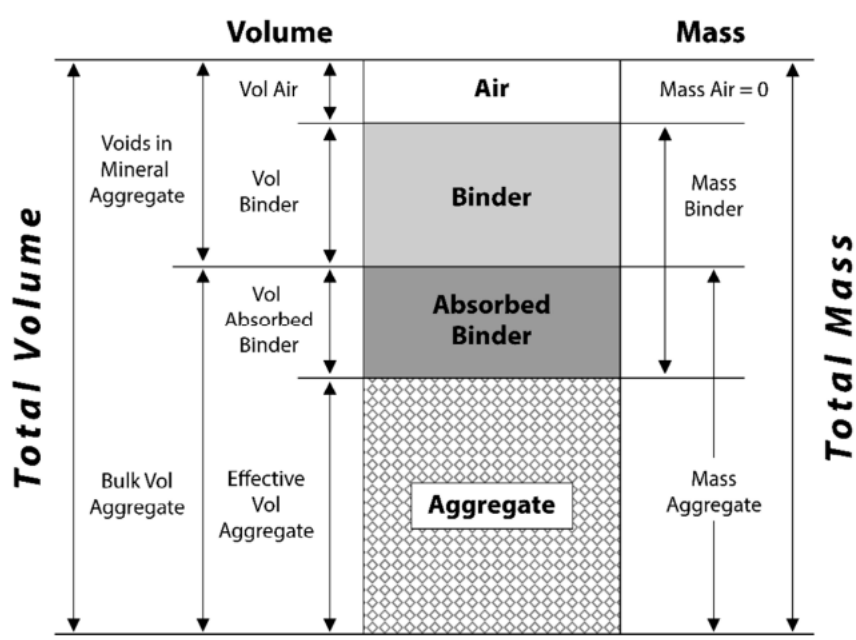
- ❖ Performance of pavement is not only affected by materials, but also the environment, loading and construction as well as structural design.

Definition of Terms

- G_{mm} = theoretical maximum specific gravity (Gravity $_{mix\ max}$)
- G_{mb} = measured bulk specific gravity (Gravity $_{mix\ bulk}$)
- G_{sb} = oven-dry bulk specific gravity of aggregate (Gravity $_{stone\ bulk}$)
- G_{sa} = apparent specific gravity of aggregate (Gravity $_{stone\ apparent}$)
- G_{se} = effective specific gravity of aggregate (Gravity $_{stone\ effective}$)
- G_b = specific gravity of the binder (Gravity $_{binder}$)
- V_a = air Voids (Voids $_{air}$)
- VMA = Voids in Mineral Aggregate
- VFA = Voids Filled with Asphalt (binder)
- V_{ba} = absorbed binder volume (Voids $_{binder\ absorbed}$)
- V_{be} = effective binder volume (Voids $_{binder\ effective}$)
- P_b = percent binder content (Percent $_{binder}$)
- P_{ba} = percent absorbed binder (Percent $_{binder\ absorbed}$)
- P_{be} = percent effective binder content (Percent $_{binder\ effective}$)
- P_s = percent of aggregate (Percent $_{stone}$)
- DP = Dust proportion to effective binder ratio ($P_{\#200}/P_{be}$)

Volumetric Relationship of Asphalt Mixture Constituents



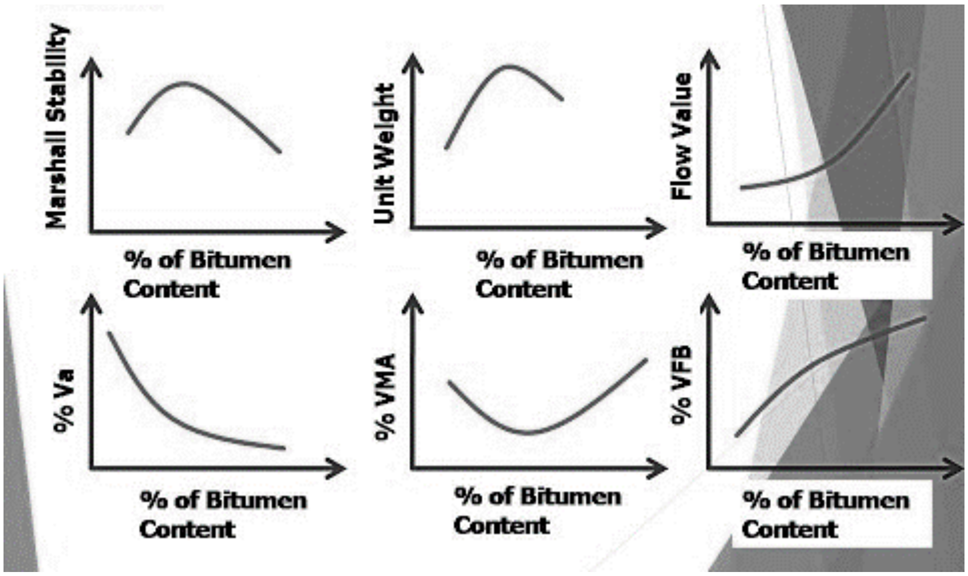


- Bulk Density **vs** Asphalt binder Content
- Stability **vs** Asphalt binder Content
- Marshall Flow **vs** Asphalt binder Content
- Air voids **vs** Asphalt binder Content
- VMA **vs** Asphalt binder content
- VFB **vs** Asphalt binder content.

% BIT SPEC. NO.	Weight (gm)			BULK VOL. cc.	SG		Volume-% total			Voids - %			Stability- kg			Flow mm
	SSD	In Air	In Water		SG Bulk	Max Theor.	Bit	Agg	Voids	Agg.	Filled (Bit)	Total Mix	Corr. Factor	Meas	Corr.	
b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r
% Bit by wt of Mix				c-e	d/f		(bxg)/ Sgbit	(100-b)x g/SG agg	100-i-j	100-j	100(i/l)	100-(100g/h)			P x O	
4.00	1255.3	1244.7	720.8	534.5	2.329								0.89	1496	1331	2.55
	1255.5	1244.9	721.0	534.5	2.329								0.89	1489	1325	2.71
	1250.0	1238.2	718.0	532.0	2.327								0.89	1651	1470	2.58
AVG					**2.328**	**2.502**	**9.0**	**84.0**	**7.0**	**16.0**	**56.5**	**7.0**			**1397**	**2.61**
4.50	1249.3	1245.9	720.8	528.5	2.357								0.89	1675	1491	2.72
	1244.0	1239.2	714.8	529.2	2.342								0.93	1605	1493	3.00
	1252.0	1244.9	720	532.0	2.340								0.89	1640	1459	2.84
AVG					**2.346**	**2.484**	**10.3**	**84.2**	**5.5**	**15.8**	**65.0**	**5.5**			**1481**	**2.85**
5.00	1258.0	1253.6	728.1	529.9	2.366								0.93	1489	1384	2.95
	1252.9	1248.7	728.5	524.4	2.381								0.93	1535	1428	3.10
	1242.0	1238.0	719.8	522.2	2.371								0.93	1524	1417	3.20
AVG					**2.376**	**2.466**	**11.5**	**84.8**	**3.6**	**15.2**	**76.0**	**3.6**			**1422**	**3.08**
5.50	1255.2	1254.1	732.1	523.1	2.397								0.93	1407	1309	3.54
	1256.6	1255.2	729.1	527.5	2.380								0.93	1128	1049	3.44
	1248.7	1247.7	725.7	523.0	2.386								0.93	1198	1114	3.62
AVG					**2.388**	**2.448**	**12.7**	**84.8**	**2.5**	**15.2**	**83.9**	**2.5**			**1157**	**3.53**
6.00	1245.0	1243.2	723.1	521.9	2.382								0.89	1128	1004	4.58

THEORETICAL MAXIMUM DENSITY	Sample 1	Sample 2		
Weight of bowl in Air (gm) , A	4150	4150.5		
Weight of bowl in Water (gm) , B	668.8	668.8		
Weight of bowl and Sample in Air (gm) , C	5711.4	5712.7		
Weight of Sample (gm), D = C-A	1561.4	1562.2		
Weight of bowl and Sample in Water (gm), E	1597.3	1597		
Asphalt Content of Mix (%) , G	5	5		
SG of Asphalt, H	1.03	1.03		
Max SG of Mix, Gmm = D / (D+B-E)	2.467	2.464		**2.466**
Effective SG of Aggregate, Gse = (100-G)/{(100/Gmm) – (G/H)}	2.663	2.659		**2.661**

Maximum Theoretical Specific Gravity at different Bitumen content, Gmm = 100 / {((100-G)/Gse) + (G/H)}



<u>What is the difference between VMA, VFA and VA in Marshall mix design?</u>

- VMA (Voids in Mineral Aggregate): It is the percentage of the total volume of a compacted asphalt mixture that is not occupied by mineral aggregate. VMA includes the volume of air voids and the volume of effective asphalt binder.
- VFA (Voids Filled with Asphalt): It is the percentage of the VMA that is occupied by effective asphalt binder.
- Va (Air Voids): It is the percentage of the VMA that is occupied by air.

<u>The relationship between VMA, VFA, and Va can be expressed by the following equation:</u>

- VMA = Va + VFA
- VMA is important for ensuring that there is enough asphalt binder to coat the aggregate particles and provide adequate durability.
- VFA is important for ensuring that there is enough asphalt binder to fill the voids in the aggregate and provide adequate stability.
- Va is important for ensuring that there are enough air voids to allow for compaction and drainage.

These relationships are critical in optimizing the asphalt mix design to ensure the road's durability, strength, and performance under various conditions.

Requirements for Asphalt Mixture

The overall objective of the mix design is to determine an optimum blend of different components that will satisfy the requirements of the given specifications. The mixture should have:

1. **<u>Stability</u>**: Resistance to: Permanent deformation due to shear strength, cracking deformation due to tensile strength and densification deformation due to compression strength
    - Good stability can be achieved using coarse aggregate with high crushing strength and angular shape.

- Stability is function of: (i) Inter particle based on the roughness of the surface particles and inter angular contact pressure, (ii) Binder frictions: high enough viscosity to give as great a liquid friction.

2. **Flexibility**: Ability to resistance fatigue cracking due to repeated traffic load and temperature (higher binder contact are used)
3. **Durability**: Ability to resistance to changes due to weather or rapid ageing. (oxidation of binder). Good durability is achieved using dense mixes containing well-graded aggregate and high binder content.
4. **Workability**: The mixes must be able to spread easily and compacted to its max. density. Good workability at reasonable temp. can be obtained by less viscous binder and higher binder content.
5. **Safety**: The mix should be providing a surface with good skid resistance, and resistant fretting which creates loose particles on the road surface.
6. **Sufficient voids**: The mixes should be content a min. voids ratio in order to avoid bleeding.
   - According to SORB: % voids 3-5% in binder surface layer, % voids 3-6% in base layer
   - According to SHRP: min. 4% should be provided if not the binder would be squeezed to surface by the action of traffic load which will then become smooth and skid.
7. **Stiffness**: The compacted mix should have a high stiffness (modulus of elasticity), which is the ratio between stress to strain ($E = \sigma/\varepsilon$).

خصائص الخلطة الإسفلتية

الطبقة السطحية	الطبقة الرابطة	طبقة الأساس	الخاصية
8 4-2	7 4-2	5 4-2	المقاومة ضـــد الزحف اللدن (ASTM D6926-2010 & D6927-2015) 75 ضربة لكل وجه - قوة ثبات مارشال (KN) (حد أدنى) - زحف مارشال (مم)
5-3	5-3	6-3	نسبة الفراغات في نماذج مارشال٪
14	13	12	نسبة الفراغات في الركام المعدنى ٪ (حد ادنى)
70	70	70	الضغط في حالة الغمر في الماء بموجب2005\ ASTM D 1075) - دليل القوة المتبقية٪ (حد أدنى)

التغايرات المسموحة في معادلة المزج

التغايرات٪	مقاس الركام أو مكونات الخليط
± 6٪	الركام العابر من منخل 4,75 مم أو أكبر
± 4٪	الركام العابر من منخل 2,36مم-0,3 مم
± 2٪	المادة المالئة العابرة من منخل 0,075 مم (رقم 200)
± 0,3٪	نسبة الإسفلت
± 15س	درجة حرارة المزج

<u>Marshall mix design for asphalt involves several key pillars or components to select the asphalt mixture for a specific project</u>. These pillars typically include:

1. **<u>Aggregate Selection:</u>** Choosing the right combination of aggregates (coarse and fine) based on their properties, such as gradation, shape, and durability.

2. **Asphalt Binder Selection:** Selecting the appropriate type and grade of asphalt binder, considering factors like climate, traffic, and project requirements.
3. **Mixing and Compaction:** Mixing different combinations of aggregates and asphalt binder at various temperatures within the specified range (135 to 163°C) and determining the compaction method to achieve the desired pavement performance and durability.
4. **Prepare compacted samples** at different trial asphalt binder contents (4-6%)
5. **Stability and Flow (ASTM D6927):** Evaluating the mixture's stability and flow characteristics through Marshall stability and flow tests. The stability test measures the resistance to deformation under load, while the flow test assesses the deformation of the mix at a specified temperature.
6. **Air Voids and VMA:** Monitoring the air void content and Voids in Mineral Aggregate (VMA) to ensure adequate space for asphalt binder and proper durability.
7. **Density:** Evaluating the mixture's density for every mixture to achieve the desired properties.
8. **Optimal Asphalt Content:** Determining the optimum asphalt binder content that provides the desired mix properties while minimizing potential rutting or cracking issues, based on the results of the maximum stability, 4% air voids and maximum density.
9. **Moisture Sensitivity:** Assessing the mixture's susceptibility to moisture damage by conducting tests like Tensile Strength Ratio (TSR) test.
10. **Aging and Durability:** Evaluating the mixture's long-term performance and resistance to aging and environmental factors.
11. **Quality Control and Quality Assurance:** Establishing procedures for quality control during production and quality assurance during and after construction to maintain the desired mixture properties.

These pillars collectively form the basis of the Marshall mix design method, which aims to create asphalt mixes that meet specific project requirements and ensure the longevity and performance of the pavement.

(تشكل هذه الركائز مجتمعة الأساس لطريقة تصميم خلطة مارشال، والتي تهدف إلى إنشاء خلطات أسفلتية تلبي متطلبات المشروع المحددة وتضمن ديمومة وأداء التبليط)

Evaluation and Adjustment of Mix Design

When the mix design for the optimum asphalt content does not satisfy all of the requirements, it is necessary to adjust the original blend of aggregates. Trial mixes can be adjusted by using the following general guidelines:

Low Voids and Low Stability: In this situation, the voids in the mineral aggregates can be increased by adding more coarse aggregates. Alternatively, the asphalt content can be reduced, but only if the asphalt content is higher than that normally used and if the excess is not required as a replacement for the amount absorbed by the aggregates. Care should be taken when the asphalt content is reduced because this can lead to both a decrease in durability and an increase in permeability of the pavement.

Low Voids and Satisfactory Stability: This mix can cause reorientation of particles and additional compaction of the pavement with time as continued traffic load is imposed on the pavement. This in turn may lead to instability or flushing of the pavement. Mixes with low voids should be altered by adding more aggregates.

High Voids and Satisfactory Stability: When voids are high, it is likely that the permeability of the pavement also will be high, which will allow water and air to circulate through the pavement and result in premature hardening of the asphalt. High voids should be reduced to acceptable limits, even though the stability is satisfactory. This can be achieved by increasing the amount of mineral dust filler in the mix.

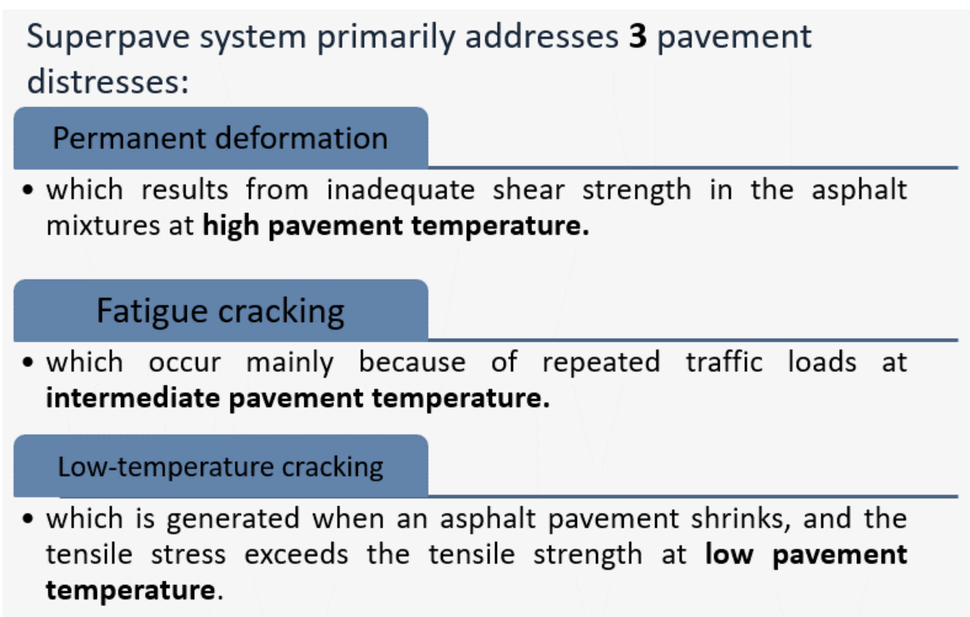
Satisfactory Voids and Low Stability: This condition suggests low quality aggregates; the quality should be improved.

High Voids and Low Stability: It may be necessary to carry out two steps in this case. The first step is to adjust the voids as discussed earlier. If this adjustment does not simultaneously improve the stability, the second step is to consider the improvement of the aggregate quality.

Superpave Mix Design

- **Su**perior **Per**forming Asphalt **Pave**ment
- Strategic Highway Research Program (SHRP)
- 1987 - 1992 (150 million dollars)
- 50 million dollars (Development of PG)
- Development of Simulation Between the Laboratory Analysis & Field Performance.

A grading system is employed to evaluate the performance and select the appropriate asphalt binder. There are three main grading systems currently in worldwide use: penetration grading system, viscosity grading system, and Superpave performance grading (PG) system.

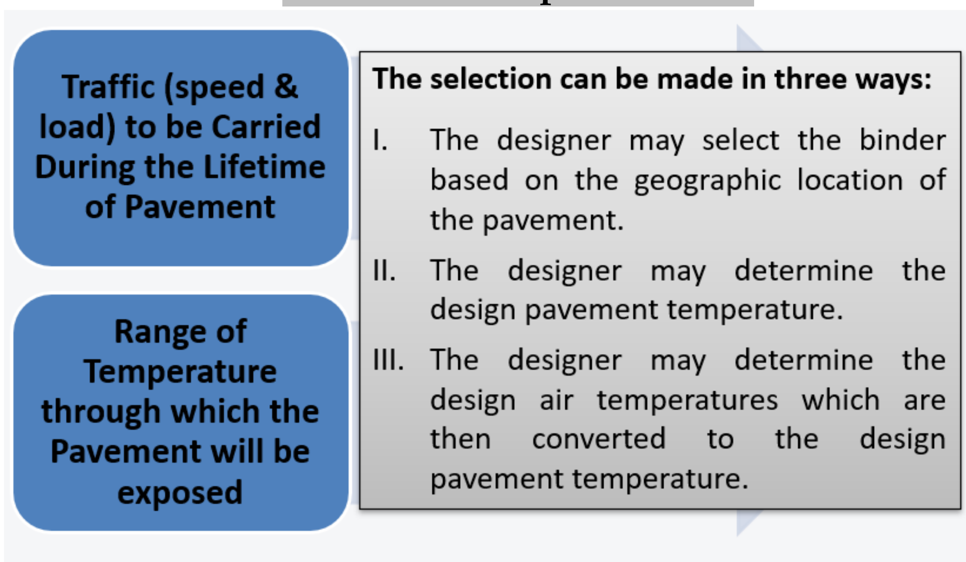


Major Steps in Superpave

1. Selection of Materials
2. Design Aggregate Structure
3. Design Binder Content

4. Moisture Sensitivity

Selection of Asphalt Binder



- Superpave system makes use a temperature database consisting of data from 6092 reporting weather stations in US and Canada that has been in operation for 20 years or more.
- According to AASHTO M 320, Superpave PG is reported using two numbers: the first number is the average 7-day maximum pavement temperature (in °C) and the second number is the minimum pavement design temperature likely to be experienced (in °C)
- A standard deviation is determined to facilitate the use of the reliability measurement in the selecting the design pavement temperatures.

For example: PG 76-10

76 = High pavement design temperature at a depth of 20mm below the pavement surface
-10 = Low pavement design temperature at the surface of the pavement

- The Superpave system also considers the fact that the pavement temperature and not the air temperature should be used as the design temperature. The system therefore uses the expression given in the following equation to convert the maximum air temperature to the maximum design pavement temperature (Asphalt Institute SP-1 2003):

$$T_{20\text{mm}} = (T_{\text{air}} - 0.00618 \times \text{Lat}^2 + 0.2289 \times \text{Lat} + 42.2) \times 0.9545 - 17.78,$$

- where $T_{20\text{mm}}$ is the high pavement design temperature at a depth of 20 mm, Tair is the 7-day average high air temperature (°C) and Lat is the geographical latitude of the project (°).

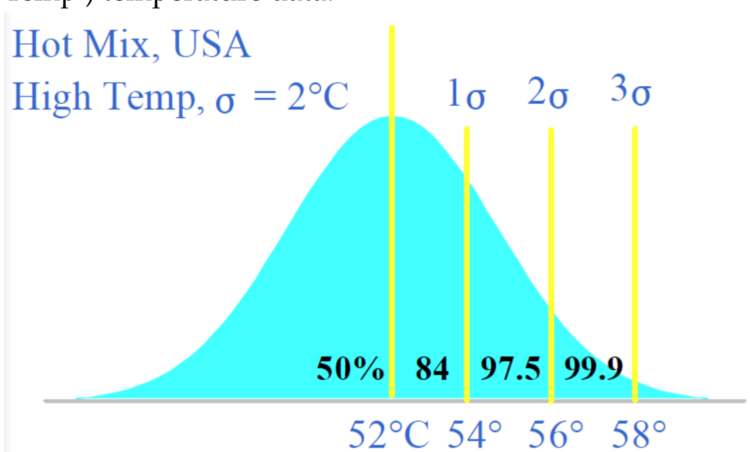
- The low-pavement design temperature can be selected as either the low air temperature, which is rather conservative or can be determined from the following equation:

$$T_{pav} = -1.56 + 0.72 \times T_{air} - 0.004 \times \text{Lat}^2 + 6.26 \log_{10} \times (H + 25) - Z \times (4.4 + 0.52 \times \sigma_{air})^{1/2}$$

جدول (10) رفع درجة الرابط الإسفلتي عالي الأداء اعتمادًا على حجم المرور وسرعته

حجم المرور التصميمي بالمحاور القياسية المكافئة (مليون) ESALs	رفع درجة الاداء "وفقا" لسرعة المرور		
	اقل من 20 كيلومتر/ساعة	20-70 كيلومتر/ساعة	اكثر من 70 كيلومتر/ساعة
اقل من 0.3	لا يحتاج لرفع درجة الاداء		
0.3-اقل من 10	درجتين	درجة واحدة	لايحتاج لرفع درجة الاداء
10-اقل من 30			درجة واحدة (اختياريا)
اكبر من او يساوي 30			درجة واحدة

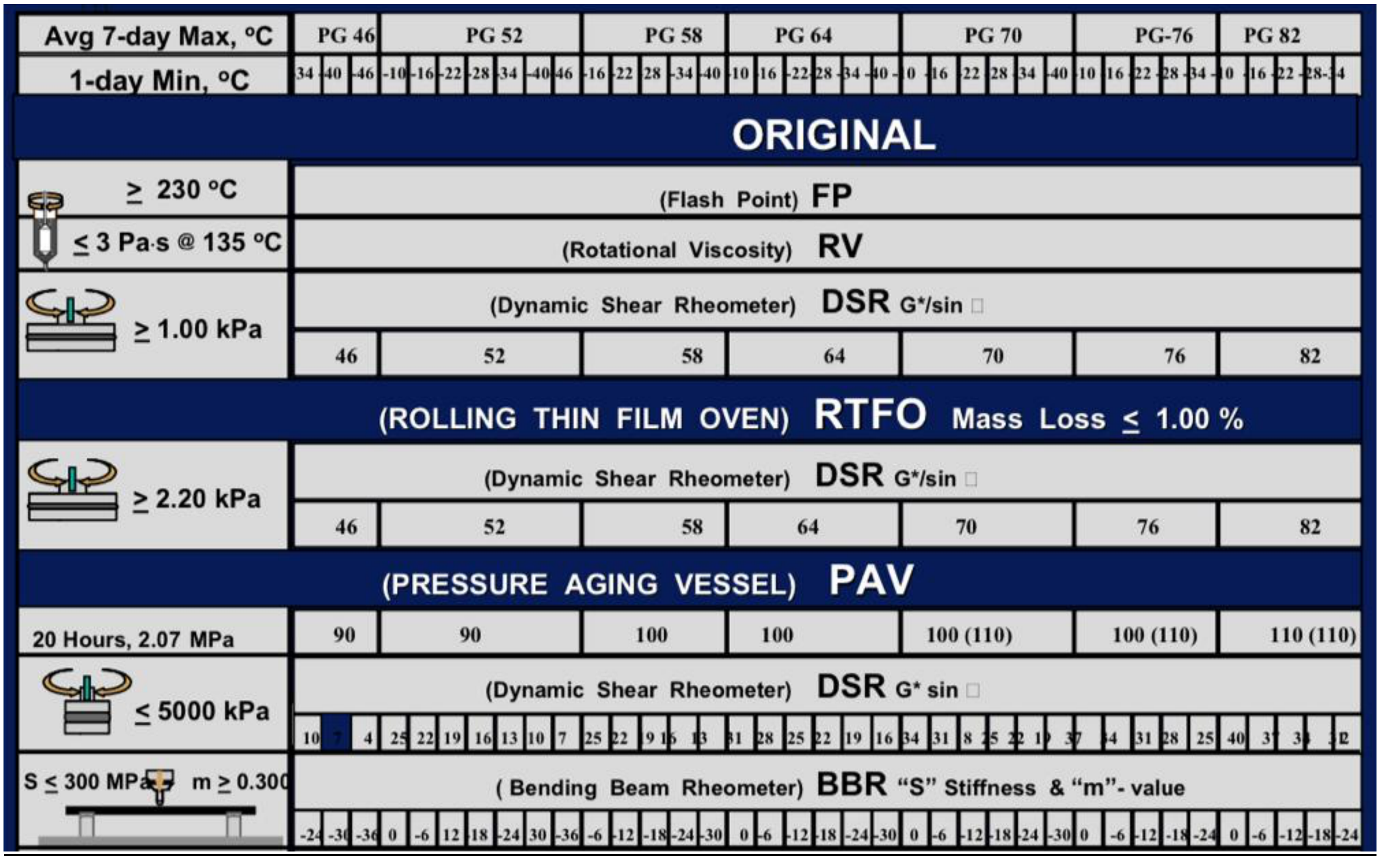
- A factor of safety can be incorporated into the performance grading system based on temperature reliability. The 50 % reliability temperatures represent the straight average of the weather data. The 98 % reliability temperatures are determined based on the standard deviations of the low (σ Low Temp) and high (σ High Temp) temperature data.

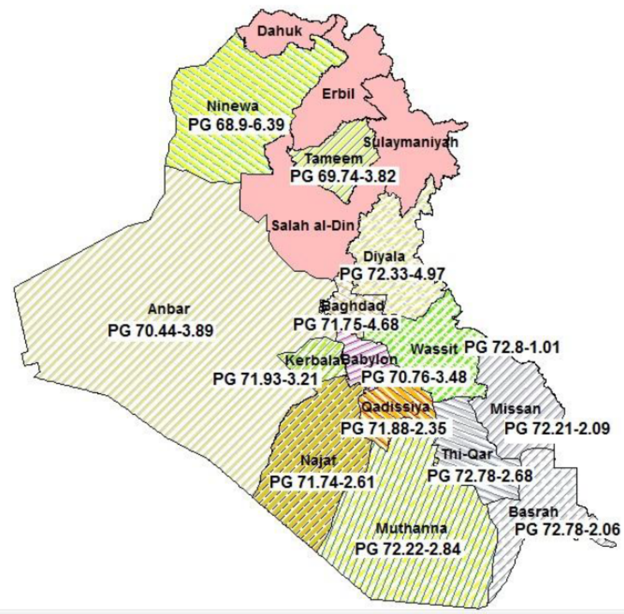


- $T_{\text{max at 98\%}} = T_{\text{max at 50\%}} + 2 * \sigma_{\text{High Temp}}$
- $T_{\text{min at 98\%}} = T_{\text{min at 50\%}} - 2 * \sigma_{\text{Low Temp}}$

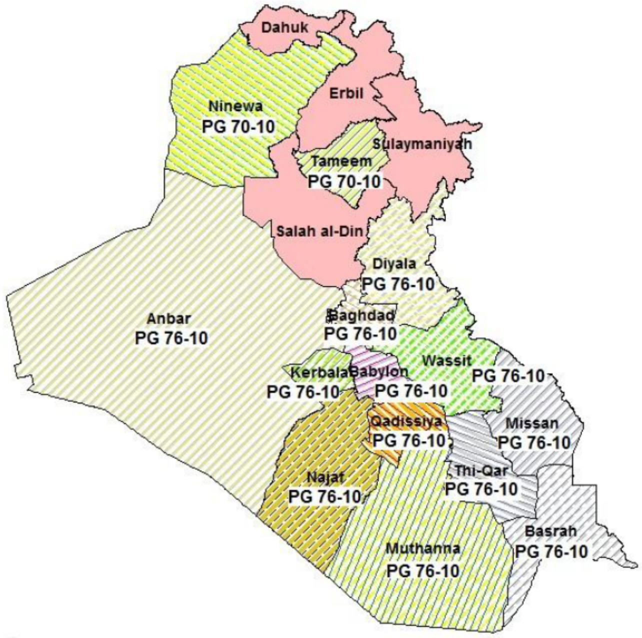
Performance Grade (Superpave) Tests		
Rotational Viscometer test	**ASTM 4402-15**	**Flow**

Dynamic Shear Rheometer (DSR)	ASTM 7175-08	Permanent deformation-Fatigue cracking
Bending Beam Rheometer (BBR)	ASTM 6648-16	Low temperature Cracking
Rolling Thin Film Oven (RTFO)	ASTM 2872-21	Aging Susceptibility (STA)
Pressure Aging Vessel (PAV)	ASTM 6521-19a	Aging Susceptibility (LTA)

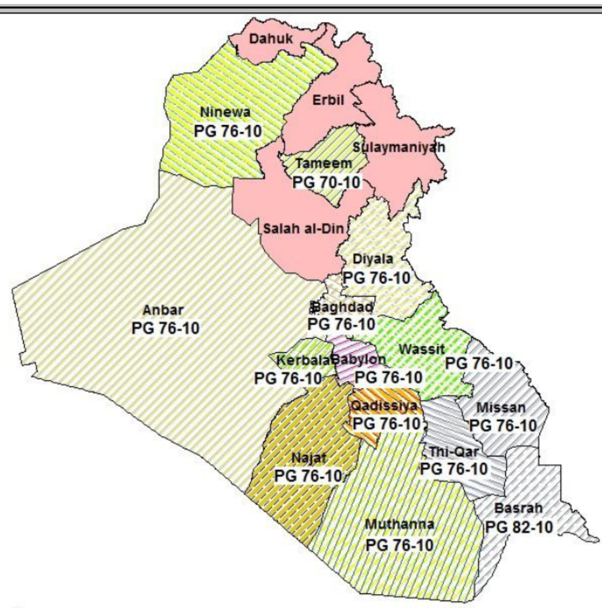




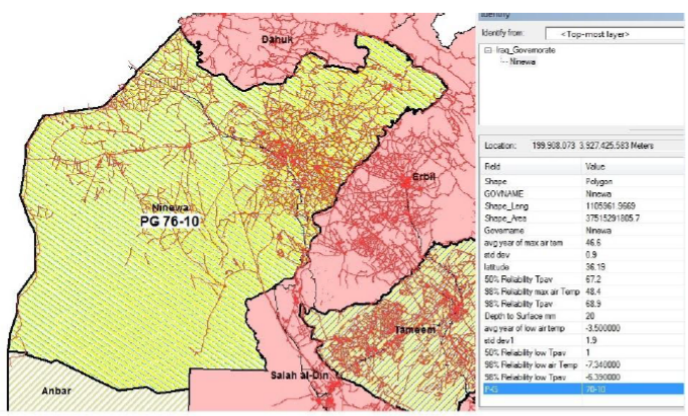
الشكل (41) درجة أداء الاسفلت الفعلية المطلوبة استنادا الى درجات الحرارة بموثوقية 98%



الشكل (42) درجة أداء الاسفلت المطلوبة استنادا الى درجات الحرارة وتبعاً لنظام Superpave



الشكل (43) يبين درجة الأداء المطلوبة وفقا لنظام Superpave بعد الاخذ بنظر الاعتبار الاحمال المحورية والسرعة



الشكل (54) درجة الاداء المطلوبة للاسفلت عالي الأداء لمحافظة نينوى وفقاً لمتطلبات درجات الحرارة

Aggregate Selection

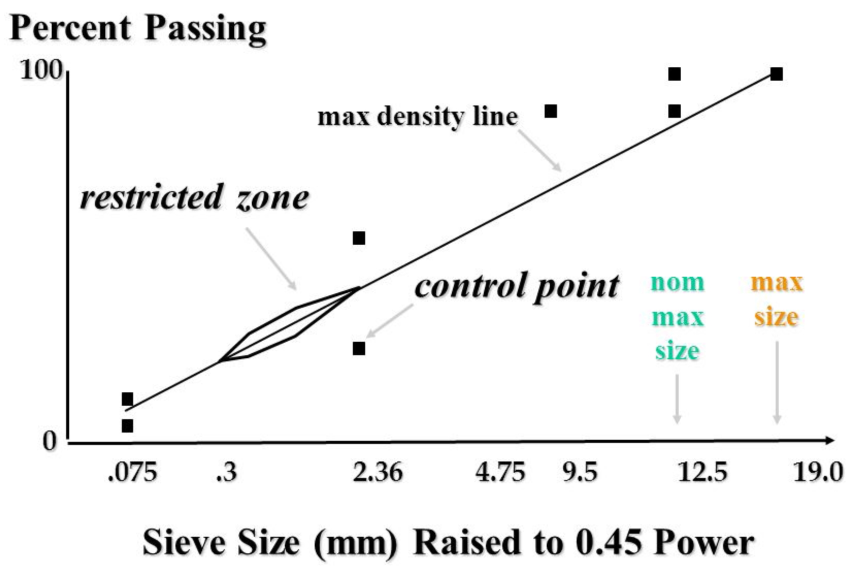
- Aggregates are characterized by their gradation, shape, and durability. Superpave uses the Aggregate Gradation Control Points to specify the desired aggregate structure.

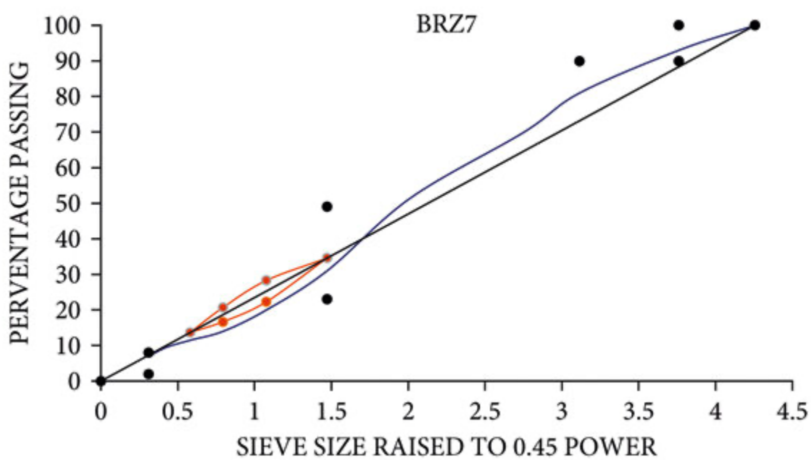
- Two categories of aggregate properties were identified by the developers of Superpave for use in the system. These are referred to as consensus standards and source (agency) standards.
- Consensus Properties: Coarse & fine aggregate angularity, flat & elongated particles and clay content). These characteristics were accepted by the experts as critical for good performance of the HMA,
- Source (agency) standards: Toughness, soundness, and deleterious materials.

Gradation

- The distribution of aggregate particle sizes for a given blend of aggregate mixture is known as the *design aggregate structure*.
- The gradation system used for Superpave is based on the 0.45 gradation plot. This is a plot of the percent passing a given sieve against the sieve size in mm raised to the 0.45 power.
- Aggregate gradation influences such key asphalt mix parameters as stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage.
- The Superpave mix design also specifies aggregate gradation control points, through which aggregate gradations must pass and the control points are a starting point for a mix formula.
- In order to understand the gradation system used, it is first necessary to define certain gradation terms that the Superpave system uses.
  - ✓ ***Maximum size***: It is defined as one sieve larger than the nominal maximum size.
  - ✓ ***Nominal maximum size***: It represents one sieve larger than the first sieve that retains more than 10 percent of the aggregate.
  - ✓ ***Maximum density gradation***: It is obtained when the aggregate particles fit together in their densest form.

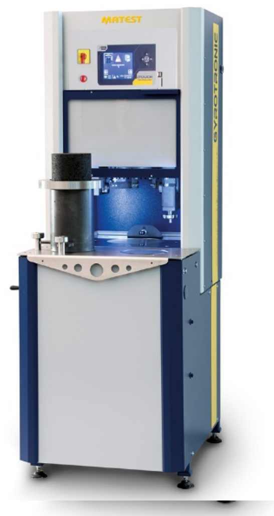
Superpave Designation	*Nominal Maximum Size, mm*	*Maximum Size, mm*
37.5 mm	37.5	50.0
25.0 mm	25.0	37.5
19.0 mm	19.0	25.0
12.5 mm	12.5	19.0
9.5 mm	9.5	12.5



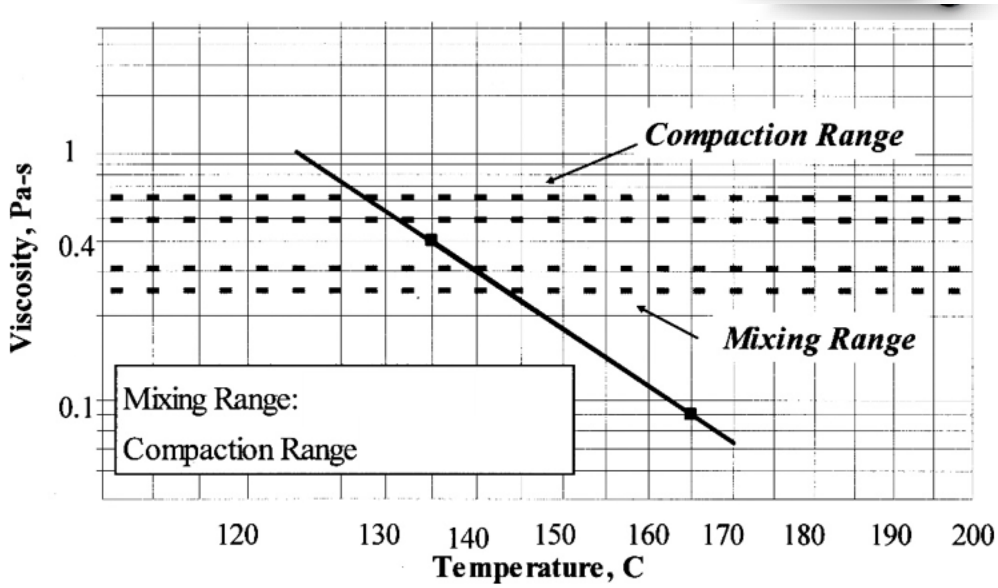


- **Superpave Mixtures:**

- Two specimens of each of the trial asphalt mixes (using the computed trial asphalt contents) then will be prepared and compacted using the Superpave Gyratory Compactor (SGC)



- Superpave Gyratory Compactor (SGC)
- Sample Diameter = 6 inch = 150mm, Nominal Height = 250mm
- Max. Size = 50mm, Nominal Size = 37.5mm
- Compaction Angle = 1.25^0
- Rotation Speed = 30 rpm (30 gyrations / min)
- Compaction Pressure = 600kPa
- Mixing Temperature = (155 – 160) ^{0} C
- Compaction Temperature ≈ 150 ^{0} C



- The mixture is conditioned for 2 hours at the specified compaction temperature. During short term aging, loose mix specimens are required to be spread into a thickness resulting in 21 to 22 kg per square meter and stirred every hour to ensure uniform aging.
- The compaction molds and base plates should also be placed in an oven at 135°C for at least 30 to 45 minutes prior to use.

Three gyration levels are of interest:

1. Design number of gyrations (N_{design} or N_{des}).
2. Initial number of gyrations ($N_{initial}$, or N_{ini}), and
3. Maximum number of gyrations ($N_{maximum}$ or N_{max}).

✓ Test specimens are compacted using N_{des} gyrations.

✓ The relationship between N_{des}, N_{max}, and N_{ini} are:

$\text{Log}_{10} N_{max} = 1.10 \times \text{Log}_{10} N_{des}$

$\text{Log}_{10} N_{ini} = 0.45 \times \text{Log}_{10} N_{des}$

- ✓ When N_{des} has been reached, the compactor automatically stops.
- ✓ After the angle and pressure are released, the mold containing the compacted specimen is then removed. After a suitable cooling period, the specimen is extruded from the mold.
- ✓ The bulk specific gravity and the maximum theoretical specific gravity of the specimens should be measured,
- ✓ Compute V_a, VMA, VFA for asphalt mixture.
- ✓ Compute % dust (passing sieve No. 200) as ratio from effective binder content of mixture
- ✓ Range of accepted dust is (0.6 – 1.2)

Table 5.8 Gyratory compaction effort for superpave hot mix design

	Compaction parameters		
Design ESALs[a] (×10⁶)	N_{ini}	N_{des}	N_{max}
<0.3	6	50	75
0.3 to <3	7	75	115
3 to <30	8	100	160
≥30	9	125	205

Table 5.7 Superpave volumetric mixture design requirements

	Required density (% of theoretical maximum specify gravity)			*Voids in mineral aggregate (VMA) (%), minimum*						
				Nominal maximum aggregate size (mm)						
Design ESALs[a] (×10⁶)	N_{ini}[d]	N_{des}[e]	N_{max}[f]	*37.5*	*25.0*	*19.0*	*12.5*	*9.5*	*VFA[b,g]*	*D/B[c]*
<0.3	≤91.5								70–80	0.6–1.2[h]
0.3 to <3	≤90.5	96.0	≤98.0	11.0	12.0	13.0	14.0	15.0	65–78	
3 to <10	≤89.0								65–75	
10 to <30										
≥30										

Source: Asphalt Institute, *Superpave mix design*, Superpave Series No. 2 (SP-2), 3rd Edition, Lexington, USA: Asphalt Institute, 2001. With permission.

Asphalt Road Construction Process

This process includes transportation of asphalt mixture, laying (paving) and rolling (compaction)

Preparation of Asphalt Binder (without polymer): The asphalt binder shall be maintained at a temperature at which it can be properly handled through the pumping system and uniformly distributed throughout the mixture. At no time during the processing, from storage to mixing, will temperature of the asphalt binder be allowed to exceed 176.6 ℃. (ASTM D3515)

***Preparation and Handling of Mineral Aggregates*:** Each size aggregate shall be separately fed by feeders to the cold elevator or elevators in proper proportion and at a rate to permit correct and uniform temperature control of the heating and drying operation. The aggregate shall be dried and delivered to the mixer at a temperature such that the mixture will be produced at a temperature within the range suited to the asphalt binder used, as follows (121.1 – 162.7 °C). The temperature between those limits shall be regulated according to the grade and viscosity characteristics of the asphalt binder, ambient temperature, and workability of the mixture. Aggregates in the hot bins shall not contain moisture to such an extent as to cause the mixture to foam, slump, or segregate during hauling and placing operations.

The mixing shall be accomplished in the shortest time that will produce a satisfactory mixture. Mixing time shall be specified within the following limits, except that the minimum may be determined based on the percentage of coated particles as determined by ASTM D 2489. The minimum values for percentage of coated particles used to establish the minimum mixing time shall be set by the engineer. These values will vary with aggregate gradation, particle shape, and surface texture, and with the asphalt binder content and use for which the mix is intended.

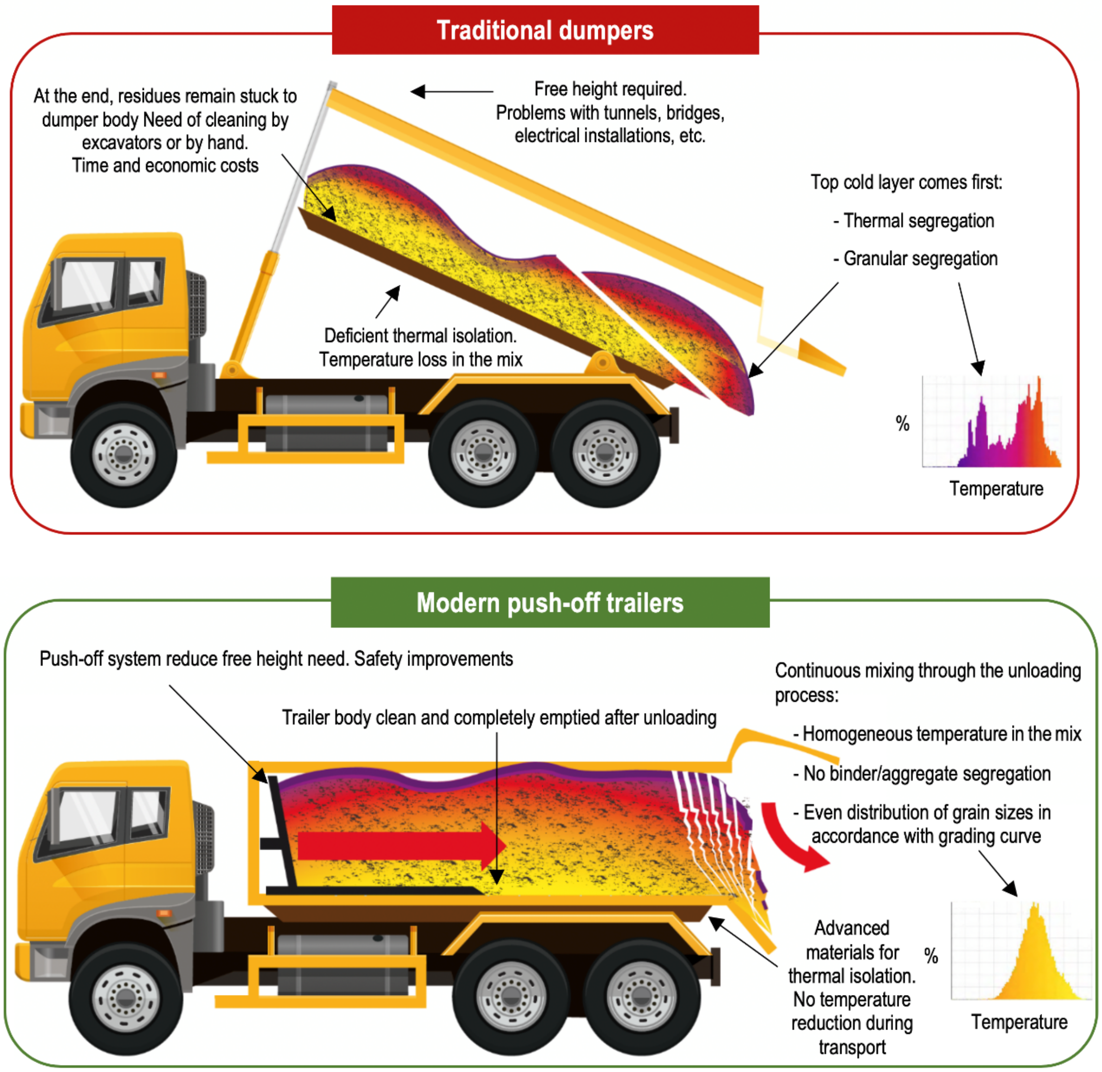
Batch Plants *(the most common type)*: 0 to 10-s dry mixing followed by 25 to 50-s additional mixing after the addition of the asphalt binder. (based on the type of plant)

Continuous Mix Plants: 25 to 60 s based on the following equation:

$$Mixing\ time = \frac{Pugmill\ capacity\ (kg)}{Pugmill\ output\ (kg/s)}$$

5. Transportation of asphalt mixture (loading, transportation to site and tipping into the hopper)

- The truck should be covered and isolated especially during the cold weather.
- Floor and walls should be clean and free of foreign materials.
- Risk of asphalt segregation should be minimized.
- Decrease the asphalt temperature should be minimized (by quickest possible and uninterrupted loading)
- Ensure regular feeding.
- Prevent asphalt segregation.
- The truck may be coated with approved release agent.



6. Laying (paving) using Pavers

Advantages of Asphalt Pavers

Asphalt pavers are used for several important reasons in the construction and maintenance of roads and other paved surfaces:

1. Precise Asphalt Placement: Asphalt paver machines provide precise control over the thickness and width of the asphalt layer being laid. This ensures that roads are built to the required specifications, which is crucial for safety and durability.
2. Efficient Construction: These machines can lay asphalt quickly and consistently, making construction projects more efficient. This helps reduce traffic disruptions and construction time.
3. Smooth Surface: Asphalt pavers have screeds that help create a smooth and even surface. This is vital for driving comfort and safety, as well as for proper water drainage.

4. Improved Durability: Properly paved asphalt surfaces are more durable and less prone to damage, such as potholes and cracks. Asphalt paver machines contribute to the longevity of roads.
5. Adaptable to Different Projects: Asphalt pavers come in various sizes and configurations, making them suitable for different types of projects, from highways to parking lots.

Different Types of Asphalt Pavers:

Tracked (Crawler): Long and stable tracks, assure very good grip, maximum traction under difficult conditions, and can pave mats up to 14m-16m based on the size of the paver. (Standard in Iraq 12 m)

Wheeled: Provide excellent maneuverability, driven easily for short distance, require less purchase and operation cost, and can pave mats up to 9m wide. (Standard in Iraq 5 m)

Mini Asphalt Pavers: used for smaller-scale paving projects and are equipped with features catering to these unique needs. Their compact size allows them to navigate tight spaces with ease, making them an excellent choice for applications such as patchwork, driveway construction, sidewalk paving, and minor road repairs.

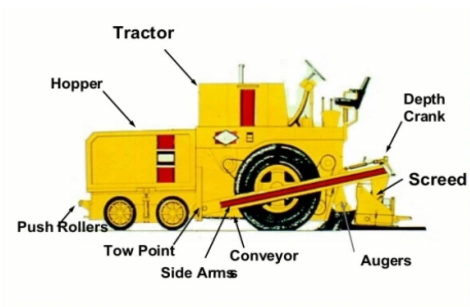

Pavers consist of two basic parts:

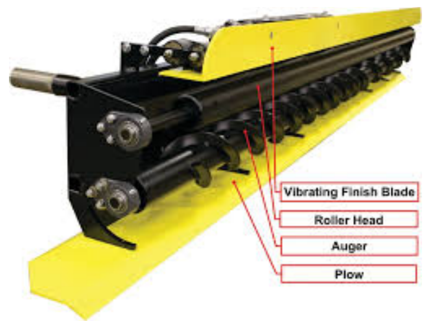
(a)Tractor Unit:

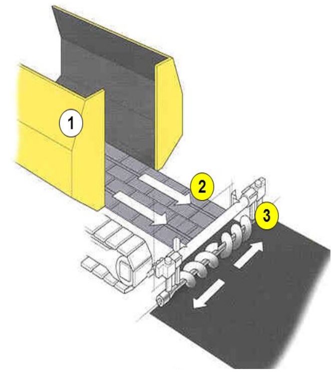
- To pull the screed
- To receive the mixture from truck and transfer it to paver.
- To provide mechanical, electronic and hydraulic energy for function of all systems of device

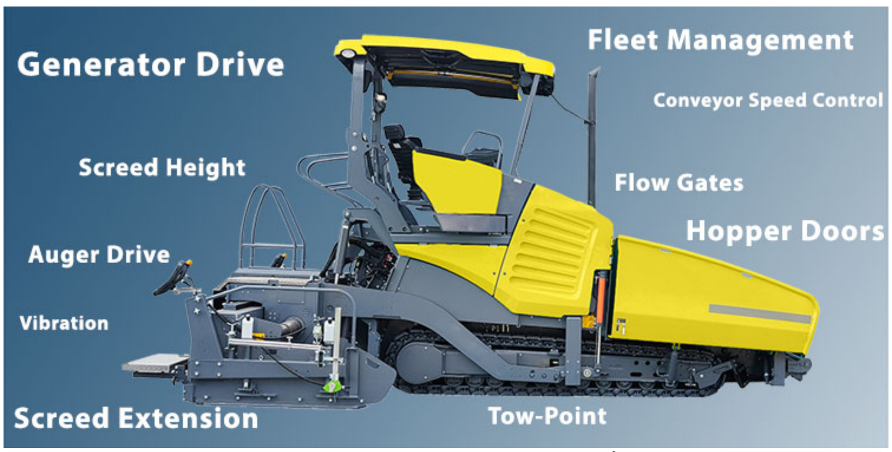
(b) Screed

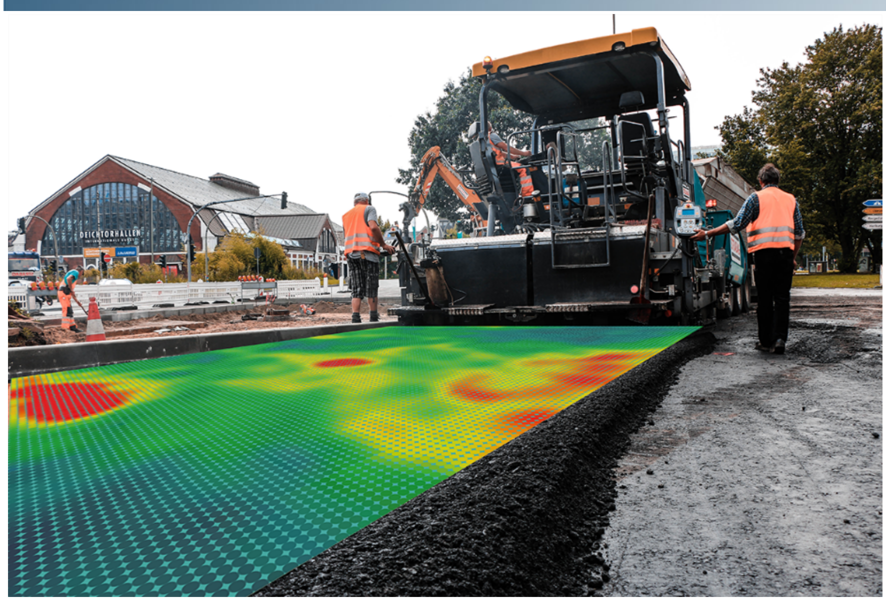
- A wide flat piece of heated steel that levels and pre-compacts the asphalt placed in front of it by augers to a specific width, grade and cross slope.











❖ Paving is a crucial process that demands careful attention to detail to ensure a smooth, durable, and high-quality result. *Therefore, the following critical points during paving should be considered to achieve a successful outcome:*

Asphalt Temperature Control: Ensure that the asphalt arrives on-site at the appropriate temperature. This is vital for achieving optimal compaction and adhesion.

Material Supply: Maintain a consistent rate of material supply to prevent interruptions in the paving process. This ensures a uniform and continuous pavement surface.

Screed Head Volume: Correct and maintain a constant volume or quantity of asphalt in front of the screed throughout the paving operation. This consistency is essential for achieving even and level surfaces.

Paver Operation: Operate the paver at a constant speed. Minimize stoppages to prevent inconsistencies in the pavement surface.

Staff Training: Provide appropriate training for your staff to ensure the proper use of automation systems related to level and slope control. This training is essential for precision in paving.

Screed Maintenance: Always preheat the screed to a temperature between 100 to 150 degrees Celsius before commencing paving. Additionally, ensure the screed is clean by performing daily inspections before each operation.

Screed Frequency and Amplitude: Use the appropriate screed frequency and amplitude settings to achieve the desired compaction and finish. Proper adjustment is crucial for high-quality pavement.

Auger Position and Speed: Position the augers at the appropriate height and control their turning speed to ensure uniform material distribution and proper screed engagement.

Layer Thickness Control: Continuously monitor the layer thickness using a specifically modified metal ruler. This will help you maintain the desired thickness throughout the paving process.

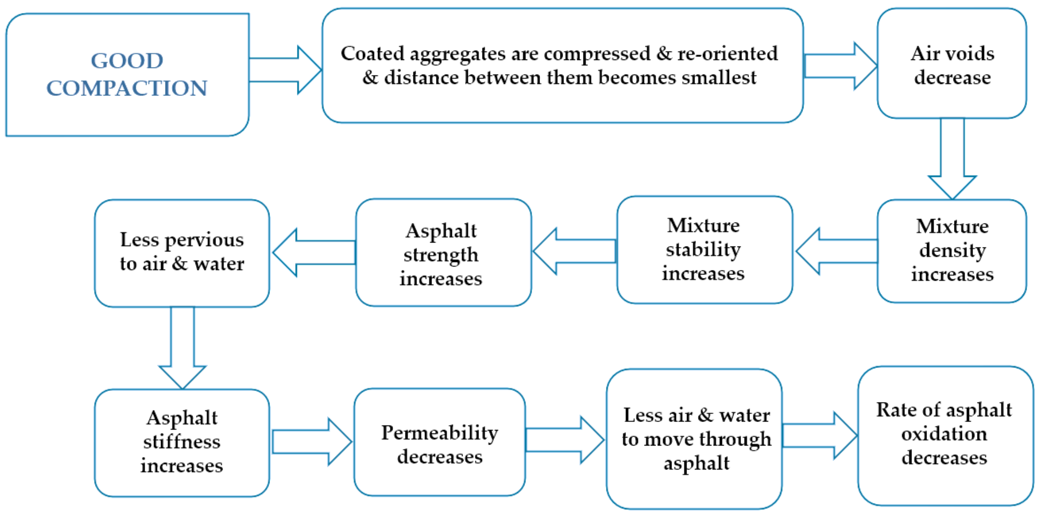
Surface Inspection: Before commencing paving, thoroughly inspect the surface to be paved for any irregularities. Correct any surface imperfections to ensure a smooth and uniform finished product.

7. Rolling (compaction)

The compaction of asphalt mixtures is a critical step in the construction of durable and high-quality pavements. Several factors can significantly impact the compaction process. Understanding and addressing these factors is essential for achieving the desired density and performance of the asphalt pavement. Here are the key factors affecting the compaction of asphalt mixtures:

1. **Asphalt Mix Design**: The properties of the asphalt mixture, including the gradation of aggregates, asphalt binder content, and type of aggregate, can influence compaction. A well-designed mix that balances these factors is crucial for successful compaction.
2. **Temperature**: Asphalt mixtures must be at the correct temperature for compaction. If the mix is too cool, it may not compact properly, resulting in inadequate density. Conversely, if it is too hot, it can lead to rutting and other issues. **Asphalt can't be compacted when the mixture temperature be less than 85℃ - 90℃.**
3. **Compaction Equipment**: The type and condition of compaction equipment play a significant role. Rollers, compactors, and their settings (vibration, frequency, and amplitude) should be selected and adjusted according to the mix and project requirements.
4. **Layer Thickness**: The thickness of the asphalt layer being compacted is important. Thicker layer may require more passes for adequate compaction, while thinner layer can be compacted more easily. **Layers with thickness of 25mm – 40mm should not be laid during cold winter.**
    - **Optimum layer thickness:** 4 * Nominal maximum aggregate size
    - **Acceptable layer thickness:** 3-5 * Nominal maximum aggregate size
    - **Problem compacting:** 2 * Nominal maximum aggregate size or less,
      6 * Nominal maximum aggregate size or more

5. **Speed of Compaction**: The speed at which compaction equipment moves over the asphalt surface affects the compaction process. Proper speed ensures uniform compaction without causing over-compaction or surface damage.
6. **Number of Passes**: The number of rollers passes required depends on the mixture type and layer thickness, weathering condition and roller type. Over-compaction can lead to mix degradation, while under-compaction results in reduced density.
7. **Compaction Effort**: The level of force applied by the compaction equipment, typically measured in terms of compactive effort (measured as impact or static load), should be appropriate for the mix type and layer thickness.
8. **Air Voids**: Proper control of air voids within the compacted asphalt mixture is critical. Excessive air voids can lead to permeability and reduced durability, while low air voids can result in rutting.
9. **Aggregate Segregation**: Uneven distribution of aggregate particles in the mix can lead to localized areas of inadequate compaction. Ensuring proper mix uniformity is vital.
10. **Surface Preparation**: The surface onto which the asphalt mixture is placed should be clean, free of debris, and properly compacted. Irregularities in the base or subgrade can affect compaction.
11. **Temperature Differential**: Sudden temperature changes, such as rapid cooling, can impact the compaction process. Proper scheduling and temperature monitoring are essential.
12. **Traffic Control**: Preventing traffic from passing over freshly laid asphalt before completing the compaction is crucial to achieving uniform density.
13. **Time**: The time available for compaction is limited, as asphalt mixtures cool and become less workable over time. Efficient coordination is essential.

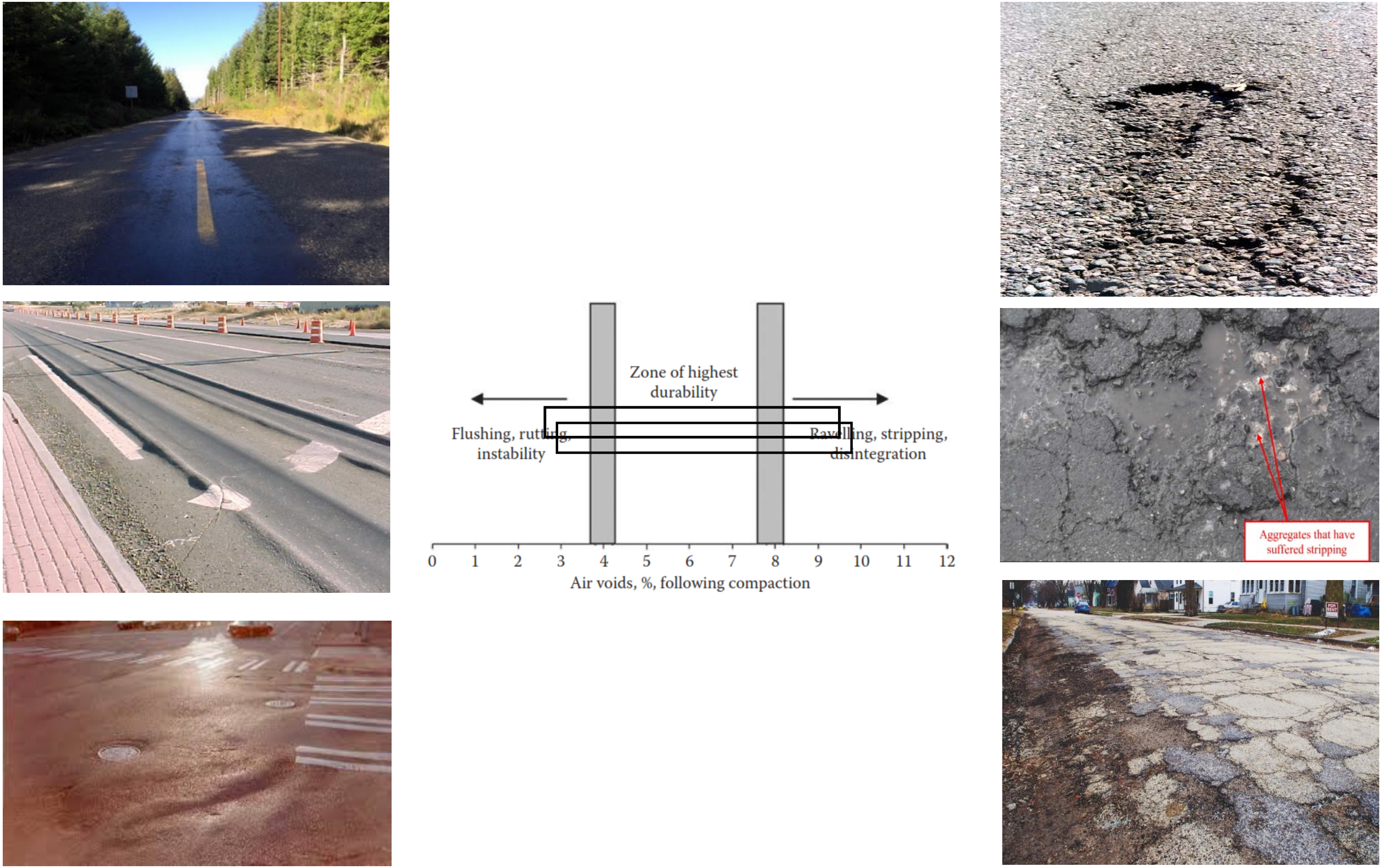


Phases of asphalt mixture compaction typically include the following steps: Initial rolling, intermediate rolling and final rolling.

تقسم عادة اعمال الحدل (الصحيحة) إلى ثلاث مراحل بعد الانتهاء من عملية الفرش:

1. الحدل الابتدائي مع الهزاز (وبدرجة حرارة بحدود 140-160 °C)، يتم استخدام الحادلة المزدوجة وزن ١٢-١٤ طن ، ويكون تكرار المرور على الطريق بحدود ٤-٦ مرات، وتختلف العملية من ناحية الزيادة أو النقصان في الصيف عن الشتاء اعتماداً على درجات الحرارة.
2. الحدل الرئيسي. أو المتوسط (وبدرجة حرارة بحدود 90-115 °C)، ، ويتم باستخدام حادلة تاير ٢٤ طن، ويكون المرور على الطريق ١٠-١٢ مرة.
3. الحدل النهائي (بدون هزاز) باستخدام حادلة وزن ١٢-١٤ طن، ويكون مرورها على الشارع حسب الحاجة، على ألّا يزيد ذلك عن ١٠ مرات. كما تستخدم أحياناً الحادلات المزدوجة بوزن ٢.٥طن في المرحلة الأخيرة بهدف إزالة آثار الحدل، ويكون مرور الحادلة فوق التبليط متغير وحسب توجيهات المهندس المشرف.

Environmental Factors	Mix Property Factors	Construction Factors
Temperature	Aggregate	Rollers
*Ground temperature	*Gradation	*Type
*Air temperature	*Size	*Number
*Wind speed	*Shape	*Speed and timing
*Solar flux	*Fractured faces	*Number of passes
	*Volume	*Lift thickness
	Asphalt Binder	Other
	*Chemical properties	*HMA production temperature
	*Physical properties	*Haul distance
	*Amount	*Haul time
		Foundation support


Zone of highest durability
Flushing, rutting, instability
Ravelling, stripping, disintegration
0 1 2 3 4 5 6 7 8 9 10 11 12
Air voids, %, following compaction
Aggregates that have suffered stripping

Joint and Edge Compaction:

Special attention should be given to the compaction of joints, edges, and other critical areas where the main roller cannot easily reach. This process can be achieved using smaller rollers or handheld compactors.

Common Types of rollers

There are several types of rollers commonly used for the compaction of flexible pavement. The choice of roller type and the compaction process depends on the specific requirements of the pavement project, including the asphalt mix type, thickness, temperature, and the desired compaction density. Contractors and engineers typically select the appropriate roller type and use a combination of these rollers to achieve the best results during flexible pavement construction. Here are some common types of rollers used for flexible pavement compaction:

1. **Smooth Steel Wheeled Rollers**: They are used for static or vibratory compaction and are often Used in all rolling phases (initial, intermediate & finishing)
   - Typical static weight of compacting asphalt layers having thickness of 4cm – 6cm is 8 tons – 12 tons.
   - Vibration can provide better compaction or compact thicker layers more effectively.

2. **Pneumatic Rollers**:
   - Contact pressure can be easily changed by changing the tire pressure.
   - Same roller can be used for all types of asphalt ranging from very flexible to very stiff, as well as for very thick to very thin layers.
   - Typical mass 6 – 27 tons.
   - Usually used at intermediate and final phase of compaction.
   - Using pneumatic roller at final compaction obtains better surface texture & eliminating hair cracks, which may be created when compacted with steel wheel roller.

3. **Combination Rollers**: Combination rollers have both a smooth drum and a set of pneumatic tires. They can be used for initial and intermediate compaction, as well as for achieving a smooth surface finish.
   - Vibrating drum (quicker compaction)
   - Rubber wheel (denser and smoother surface)
   - Maximum mass 2.5 tons - 11 tons
   - Equipped with vibrating drum at the front and pneumatic tires at the rear (usually four).

7-1- نوع الحادلة : يتم حدل كل من الطبقة الرابطة والسطحية باستخدام حادلات من النوع الموجود في الجدول لاحقاً :

الوزن	نوع الحادلة	عرض الاسطوانة
8000-10000 كغم	حادلات فولاذية Smooth Steel Wheeled Roller	لا يقل عن 45سم
8000-10000 كغم	Multi- Wheeled Pneumatic-Tyred Roller	-
على أن يتم حدل الوجه النهائي للتبليط بواسطة حادلات فولاذية ملساء Smooth Steel Wheeled Roller		

Intelligent compaction systems (ICS)

Powerful tools, which provide the operator with valuable data in real time to increase the quality and efficiency of compaction works. These tools provide much more accountability in quality control and greater road service life. In addition, they increase the construction efficiency, as they indicate the operator when the compaction work is complete, moving to the next one in the optimum moment.

These systems integrate:

1. Monitoring systems to measure work site conditions in real time (number of passes, pavement stiffness, temperature, humidity, etc.)
2. Global navigation satellite systems, which allow operators, supervisors and engineers to record and visualise the quality and uniformity of the work over the entire site.
3. Analysis software able to automatically identify and document hidden efficiencies.

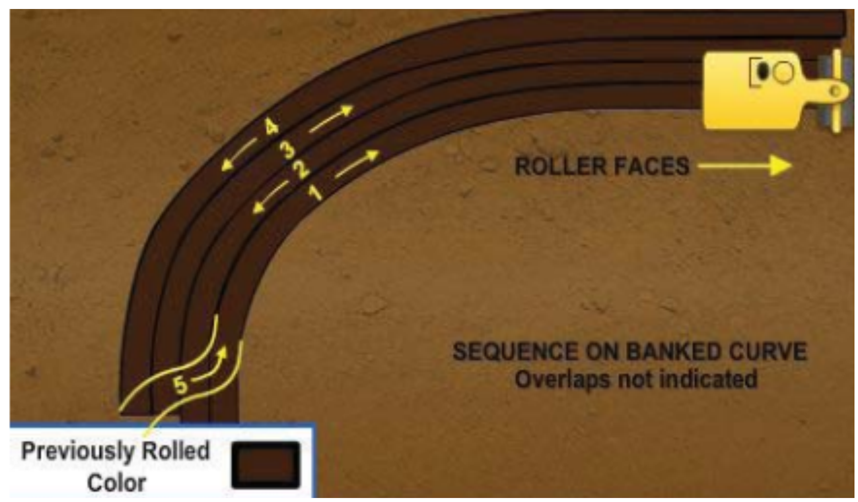
Instead of traditional methods, which analyse the compaction level of the material based on its density, modern ICS use accelerometers to measure the stiffness, or the ability of the material to resist deformation. This mechanical property is more related to the actual bearing capacity of the layer, rather than the density. With this value being continuously monitored, the operator simply needs to execute compaction passes until the required stiffness has been reached. At this point, the testing crew check the section and the compactor is moved to the next area.

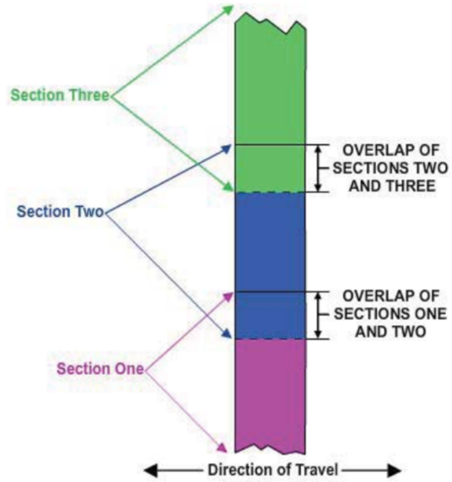
Key points to consider during the compacting process of pavement.

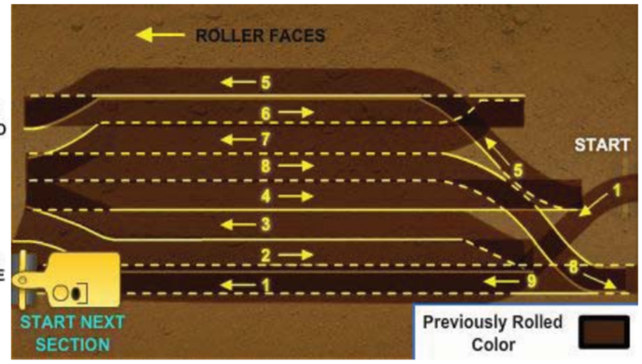
1. Rolling should commence as quickly as possible after the asphalt has been laid, provided that the mix's temperature is not excessively high, and it has developed sufficient stability to withstand the roller's weight.
2. Rolling comprises three consecutive phases: initial or breakdown rolling, intermediate rolling, and finish rolling. The majority of compaction occurs during the breakdown rolling phase. Intermediate rolling further enhances the mix's density and minimizes all surface pores. Finish rolling is essential for eliminating roller traces and other surface imperfections. There should be no time delay between these three phases.
3. The number of rollers required is determined by the width of the paving lane. The roller's width is typically chosen to be approximately one-third of the paving lane's width.
4. Rolling always begins from the lowest point of the mat in the case of a transverse slope.
5. The roller traverses the same path twice, moving forwards and then backwards.
6. When a longitudinal joint is formed, rolling initiates from the joint. The roller moves over the hot mat with approximately 200 mm of its drum overlapping the previously compacted mat. This is known as hot side rolling. Cold side rolling, where the roller is placed on the cold mat and gradually moved

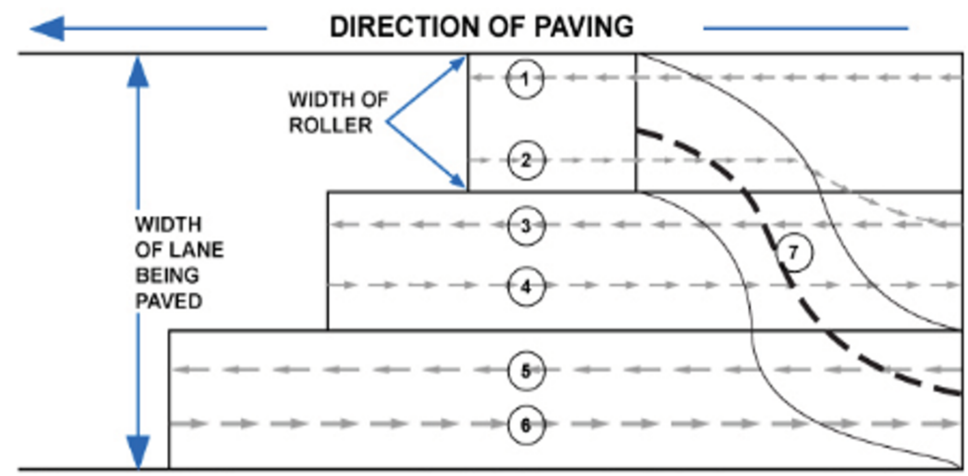
toward the hot mat, should be avoided because the hot mat cools while the roller operates on the cold mat.

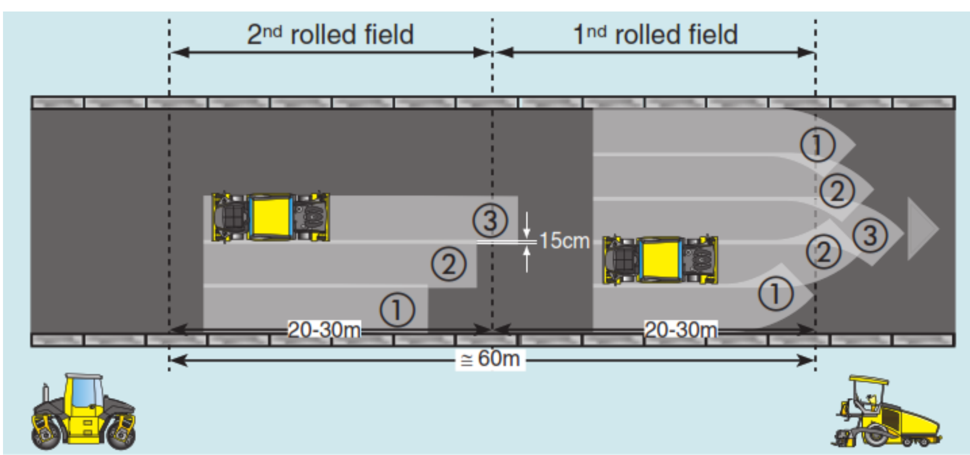
7. The length of the first and second rolling passes, as well as all subsequent passes, primarily depends on the mat's thickness. Longer rolling lengths can be used on thick mats (over 60mm in thickness) compared to thin mats. Typically, an ideal length is between 30 and 40 m for a 100 mm thick asphalt concrete mat.
8. If paving starts from a transverse cold joint, with or without the formation of a longitudinal joint, various techniques can be employed. In all cases, cross rolling of the transverse joint is the initial step.
9. The cylinder's or tires' surface should be lightly sprayed with water during the rolling to prevent the mixture from adhering to them.
10. Rollers should operate at low speeds, not exceeding 5 km/h for static or vibrating rollers and not exceeding 8 km/h for rubber ones. The selected speed should remain constant throughout the rolling process.
11. Changing rolling lanes (paths) should be done outside the freshly laid material to avoid damaging it. Additionally, the roller should not stop or stand on a freshly laid mat.
12. For breakdown rolling, it is recommended to use static or vibratory steel drum rollers, and for finish rolling, pneumatic rollers or static steel drum rollers are preferred. For leveling courses or thin layers (less than 40 mm), breakdown rolling is best carried out using pneumatic rollers.

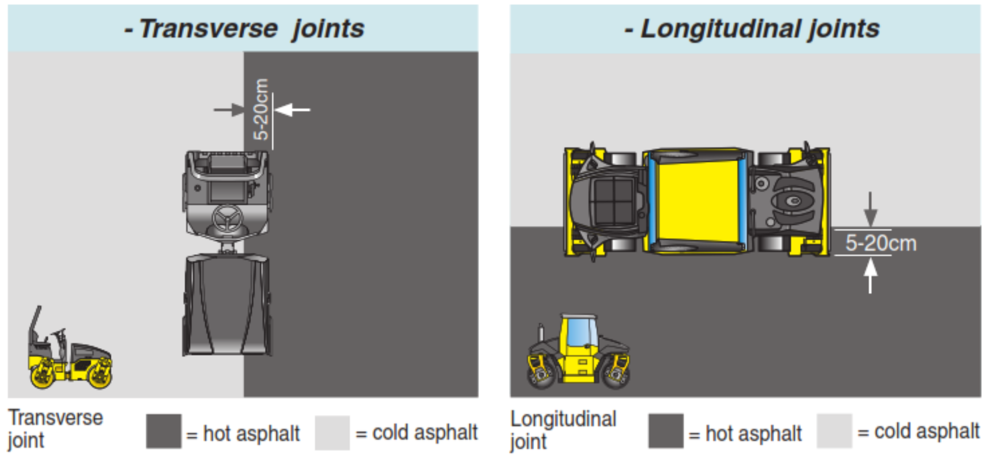


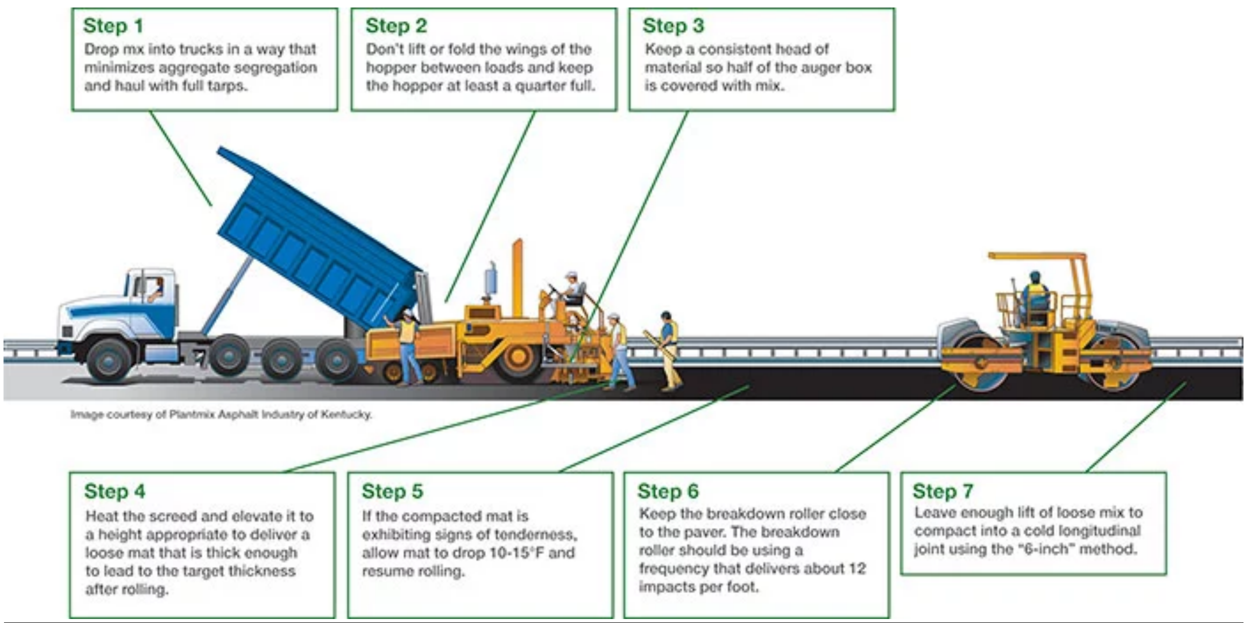

Section Three
Section Two
Section One
OVERLAP OF SECTIONS TWO AND THREE
OVERLAP OF SECTIONS ONE AND TWO
Direction of Travel


ROLLER FACES
START
START NEXT SECTION
Previously Rolled Color
1
2
3
4
5
6
7
8
9


DIRECTION OF PAVING
WIDTH OF ROLLER
WIDTH OF LANE BEING PAVED
1
2
3
4
5
6
7


2nd rolled field
1nd rolled field
15cm
20-30m
20-30m
≅ 60m
1
2
3


- Transverse joints
5-20cm
- Longitudinal joints
5-20cm
Transverse joint
= hot asphalt
= cold asphalt
Longitudinal joint
= hot asphalt
= cold asphalt


Step 1
Drop mx into trucks in a way that minimizes aggregate segregation and haul with full tarps.
Step 2
Don't lift or fold the wings of the hopper between loads and keep the hopper at least a quarter full.
Step 3
Keep a consistent head of material so half of the auger box is covered with mix.
Image courtesy of Plantmix Asphalt Industry of Kentucky.
Step 4
Heat the screed and elevate it to a height appropriate to deliver a loose mat that is thick enough to lead to the target thickness after rolling.
Step 5
If the compacted mat is exhibiting signs of tenderness, allow mat to drop 10-15°F and resume rolling.
Step 6
Keep the breakdown roller close to the paver. The breakdown roller should be using a frequency that delivers about 12 impacts per foot.
Step 7
Leave enough lift of loose mix to compact into a cold longitudinal joint using the "6-inch" method.

General notes about refusing the H.M.A on site:

- Color of H.M.A. is non-homogeneous → Mixing of H.M.A. is incomplete → Low asphalt content in the mix

- Appearance of H.M.A. with a flat surface on truck (not as pyramid shape) → High asphalt content in the mix

- Mounting of blue smoke from H.M.A → Mixture is burned
  Temperature of H.M.A. must be measured → If it is greater than flash point → Mixture is refused

- Glossiness of aggregates disappear → Low asphalt content in mix
  Tendency of mixture color to brown → Low asphalt content in mix

ملاحظات مهمة جداً

1. **تهيئة سطح التبليط**: يجب فحص استوائية السطح المراد تبليطه بمسطرة طول 4 م بحيث أن أعلى فرق في الاستواء بالطبقة السطحية هو 6 مم، و 10 مم في الطبقة الرابطة، وفي حالة وجود وجود مناطق موضعية غير منتظمة (مستوية) بفرق استواء أكثر من 20 مم، فيتم وضع مزيج من الخرسانة الاسفلتية في تلك المناطق، وبعد الحدل يتم فحص السطح مرة ثانية.
2. **درجة حرارة الفرش والانهاء**: يجب ألا تقل درجة حرارة المزيج عند وضعه بالفارشة عن 130 °C كحد أدنى عند تبليط الطبقة السطحية، ولا تقل عن 120 °C للطبقة الرابطة والأساس. ولا يسمح للحادلة بالتوقف أو المرور على سطح التبليط الذي درجة حرارته ما زالت أكثر من 70 °C.
3. **نسبة الحدل**: يجب قياس كثافة التبليط الإسفلتي بعد التبليط حسب المواصفة AASHTO T166 بواسطة قياس كثافة اللباب، أو عبر الطريقة النووية حسب المواصفة ASTM D2950، ويتم مقارنة الكثافة الموقعية مع المختبرية (< 97% للطرق الاعتيادية، و < 98% لطرق المرور السريع والجسور ومقترباتهم على مسافة 200 م من كل جهة، والتقاطعات.
4. **محددات الجو Weathering condition** : يتم توقف فرش طبقات التبليط بالخرسانة الإسفلتية في الحالات الآتية: وجود مياه متجمعة فوق السطح، السطح متجمد، السطح مغطى بالجليد أو البرد، درجة الحرارة 5 °C وتميل للانخفاض، وعندما يكون الجو رطباً ويهدد بالاستمرار لفترة طويلة. ويمكن الاستمرار بفرش طبقة الاسفلت عندما تكون درجة الحرارة 5 °C وتميل للصعود، وعند هبوط درجة الحرارة عن 15 °C فيجب

اتخاذ الاجراءات المناسبة للحفاظ على درجة حرارة المزيج ابتداءً من نقله من المعمل ولحين فرشه باستخدام الفارشة، بحيث درجة حرارة المزيج الاسفلتي تلائم عملية الحدل.

5. **نعومة سطح التبليط**: يجب أن يكون سطح التبليط ناعماً بعد الانتهاء من أعمال الحدل، وأن أي تغييرات في السطح تزيد عن الحد المسموح، وتؤدي إلى تجمع المياه يجب أن تزال، ويتم فرش طبقة جديدة
6. **سمك طبقات التبليط:** يجب اتخاذ الاجراءات التالية في حالة وجود نقص في سمك التبليط: أقل من 3 مم (مقبول) ، أكثر من 3 مم (غير مقبول بشكل عام)، 3-10 مم (يمكن قبوله مع خصم بالسعر)، وحالة الفرق أكثر من 10 مم (يتم استبدال الطبقة).
7. **حالة سطح التبليط:** يجب أن يتصف سطح التبليط بما يلي: متجانس وخشن الملمس، غير نافذ للماء، المفاصل محدولة بشكل جيد، واتصالها بالتبليط القديم بشكل جيد، لا يحوي التبليط على نزف اسفلتي Bleeding، ويجب أن يكون السطح مستقراً وخالياً من الأخاديد والفطور والتفتت.
8. **استوائية سطح التبليط:** العمق العمودي للتبليط بين أي سطحين للتبليط يجب أن يخضع للجدول التالي:

الطبقة	التفاوت المسموح به
السطحية	± 4 مم
الرابطة	± 6 مم
الأساس	+ 8-20 مم
تحت الأساس	+ 10-20 مم

9. **انتظام سطح التبليط:** ان انتظام سطح التبليط بالاتجاه الطولي للطبقة السطحية والرابطة يجب أن يخضع للجدول التالي وبمسافة 300 م.

- المقصود بعدم الانتظامية هو التغاير في مستوى سطح التبليط مقاساً بواسطة مسطرة مستقيمة الحافة والمتدحرجة على عجلات على طول أي خط موازٍ الخط الوسطي للطريق لأن عدم الانتظامية التي تزيد عن 10 مم غير مسموح بها.

الحد الاعلى المسموح به لانتظامية سطح التبليط

الطبقة \ الانتظامية*	4-5,9 مم	6-10 مم
الطبقة السطحية	20	2
الطبقة الرابطة والأساس	40	3

- أما في حالة الاتجاه العرضي، فيتم أيضاً قياس انتظام السطح بواسطة مسطرة بطول 4 م بشكل عمودي على الخط الوسطي للطريق، ويجب ألا يزيد أعلى تغاير لسطح التبليط تحت حافة المسطرة عن 3 مم.

What are quality control procedures done after placing asphalt according to ASTM?

1. **Density and Thickness Verification:** Perform random spot checks of the in-place density and thickness to confirm they meet project specifications. This often involves coring samples from the pavement and conducting additional testing to verify compliance.
2. **Surface Smoothness Testing:** Evaluate the smoothness of the asphalt surface using methods like the International Roughness Index (IRI) measurement, ensuring that the pavement meets rideability standards. Visual Inspection: Inspect the surface for any defects, such as cracks, ravelling, or irregularities, and document their locations and severity.
3. **Density and Core Sampling:** Conduct additional density and core sampling to verify that the pavement has the desired density and that it complies with the design specifications.
4. **Gradation Analysis:** Analysing the gradation of the mixture to ensure it meets project specifications and provides adequate strength and durability.

5. **Asphalt Binder Testing:** Verify that the asphalt binder content and properties, such as penetration, softening point, and viscosity, are in compliance with project specifications.
6. **Void Content Testing**: Assess the air void content and compactness of the asphalt pavement, ensuring that it falls within the specified range for durability and moisture resistance.
7. **Field Testing of Mix Properties:** Perform field tests to verify properties like the Marshall Stability and Flow, ensuring that the asphalt mix has maintained its required characteristics after placement and compaction.
8. **Adhesion Testing:** Assess the bond between the asphalt layers (such as the bond between the surface course and the underlying layers) to check for adequate adhesion, often using methods like pull-off adhesion tests.
9. **Friction Testing:** Measure the skid resistance and friction of the asphalt surface to ensure it meets safety standards.
10. **Moisture Testing**: Check for the presence of moisture beneath the asphalt, as excess moisture can lead to premature pavement distress.
11. **Deflection Testing:** Conduct non-destructive deflection tests to assess the structural integrity of the pavement and ensure it can support the intended traffic loads.
12. **Joint and Crack Sealing:** Inspect joints and cracks in the pavement and perform necessary sealing or repair to prevent moisture infiltration and further damage.
13. **Documentation:** Maintain thorough records of all quality control tests, observations, and results, including photographs, to ensure accountability and compliance.

Core sampling for hardened asphalt serves several purposes:

1. **Quality Control**: It helps assess the quality of the asphalt pavement by examining the core sample for factors like density, air voids, and compaction, which can affect the pavement's durability and performance.
2. **Thickness Measurement**: Core samples provide information about the thickness of the asphalt layer, which is crucial for determining if it meets design specifications.
3. **Material Composition**: Core samples can be analyzed to determine the composition of the asphalt mixture, including the types and proportions of aggregates and binders used. This information is important for quality control and maintenance.
4. **Structural Integrity**: It helps assess the structural integrity of the pavement, including the presence of cracks, voids, or other defects that may impact its performance.
5. **Aging and Wear:** Core samples can be used to assess the aging and wear characteristics of the asphalt over time, helping with maintenance and rehabilitation decisions.
6. **Forensic Analysis**: In the case of pavement failures or accidents, core samples can be analyzed to understand the root causes and to aid in forensic investigations.

Dynamic Cone Penetrometer (DCP):

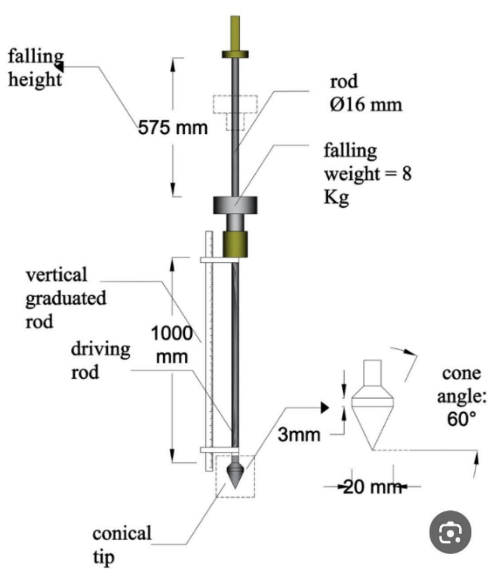
DCP Test

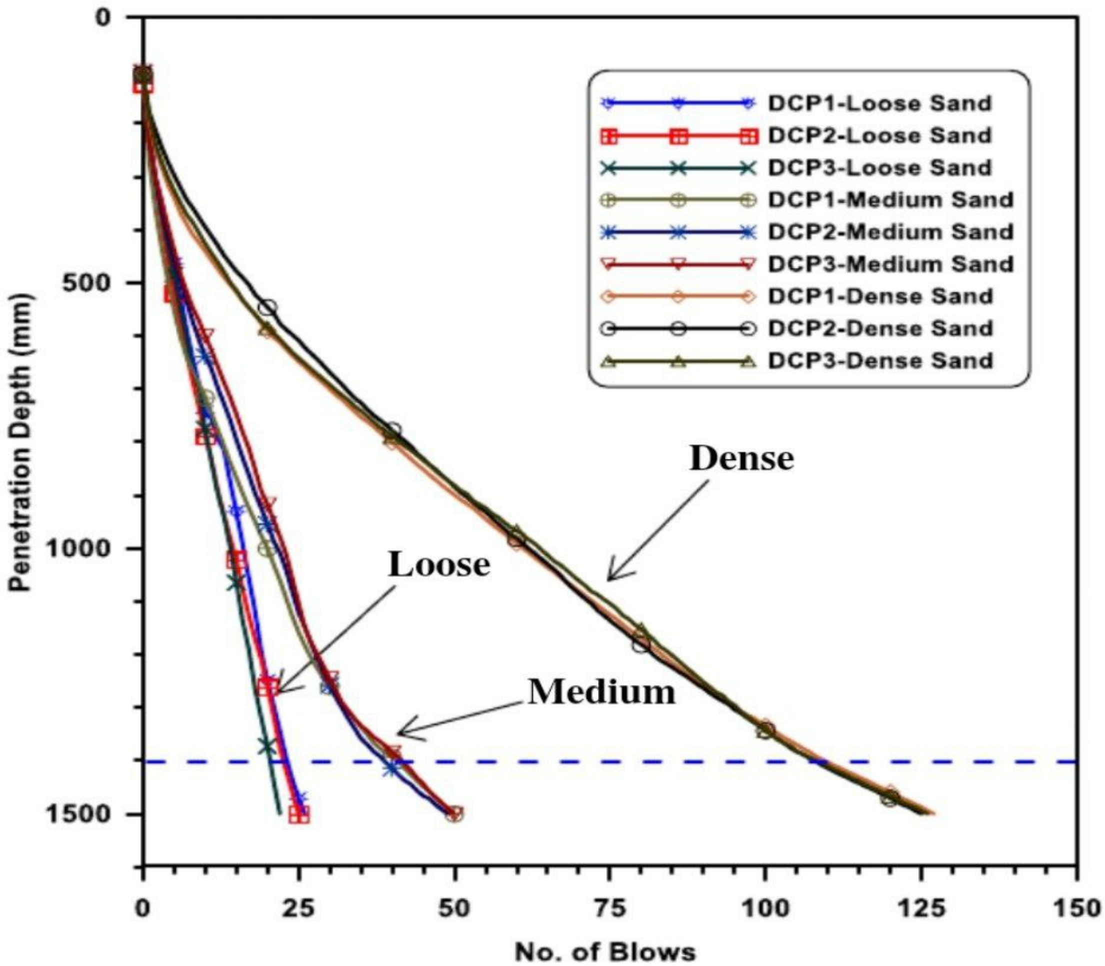
The **Dynamic Cone Penetrometer** (DCP) is another field test and often used to estimate in-place CBR values. ASTM **D6951** outlines the requirements to use this test method for pavement design applications, and the measured values are widely accepted.

DCP test equipment is more portable and generally easier to set up in remote locations than the apparatus for field CBR. With this method, a cone-shaped point is driven with a sliding hammer down through soil layers, measuring penetration resistance. The DCP can also be used to characterize soil strata and relative strengths to a depth of 39in (1M) or more.

Primary Use: The DCP is primarily used to assess the in-situ (in-place) strength and compaction characteristics of soil and unbound materials. It measures the resistance of the soil to penetration by a steel cone driven into the ground using a series of hammer blows.
Application: DCP is typically used in construction and geotechnical engineering to evaluate the quality of soil compaction during projects like road construction and building foundations.
Measurement: DCP measures soil density and compaction by analyzing the resistance to penetration of a steel cone driven into the ground.

- هو اداة تستخدم لتقييم وقوة وكثافة طبقات التربة وقد صمم هذا الجهاز ليخترق التربة لعمق متر واحد ويتطلب هذا الاختبار شخصين فقط احدهما يقوم باسقاط المطرقة والاخر يقوم بتسجيل عدد الضربات وعمق الاختراق ويبين الشكل التالي مواصفات هذا الجهاز.





- يتم احياناً تقييم قوة التربة من عدد الضربات والعمق مباشرة دون الرجوع الى الشكل، فإذا كان عدد الضربات لاختراق التربة بمقدار 100 ملم كانت بين (5-10) هذا يعني ان مقاومة التربة قليلة وكذلك كثافتها ونسبة حدلها، أما إذا كانت عدد الضربات لاختراق 100 ملم اكثر من 10 ضربات يعني ان كثافة ومقاومة التربة مقبولة

Deflectometer:

Primary Use: A deflectometer is used to evaluate the structural capacity and load-bearing behaviour of pavements and road surfaces. It assesses the deflection or deformation of a pavement surface under a simulated load, providing insights into the pavement's structural integrity.

Application: Deflectometers are commonly used for assessing the condition of roads, runways, and other pavement structures. They help determine the load-carrying capacity and identify areas of structural distress.

Measurement: Deflectometers measure the deflection or deformation of a pavement surface when subjected to a load, which is used to calculate parameters related to the pavement's stiffness, layer thickness, and structural performance.

In summary, the primary difference lies in their intended use: DCP is for assessing soil compaction, while a deflectometer is for evaluating the structural capacity and performance of pavement surfaces. Both instruments involve measurements of deflection, but they serve distinct purposes in geotechnical and civil engineering applications.

Addressing Bleeding in a Flexible Pavement

Addressing bleeding in an existing asphalt pavement requires a targeted approach to alleviate the immediate problem and prevent further deterioration. Here are steps you can take to address bleeding in the current layer:

Surface Milling: If the bleeding is localized and not widespread, consider milling the affected areas to remove the excess asphalt binder. Milling involves the removal of a specified depth of the pavement surface, and it can help eliminate the bleeding layer.

Application of Absorbent Materials: Apply absorbent materials, such as blotting sand or aggregate, to the bleeding areas. These materials can help absorb excess asphalt binder and improve surface friction. However, keep in mind that this is a temporary solution.

Hot-Mix Asphalt (HMA) Overlay: Consider applying a hot-mix asphalt overlay to the affected areas. This involves placing a new layer of asphalt over the existing pavement. Ensure that the overlay has an appropriate mix design and adequate compaction to prevent future bleeding.

Evaluate Drainage: Assess the drainage conditions in the affected areas. Ensure that any drainage issues contributing to the bleeding are addressed. Improving the drainage can help prevent water accumulation and reduce the risk of further bleeding.

Quality Control Inspection: Conduct a thorough quality control inspection of the affected areas to identify any underlying issues with the pavement structure. This may involve coring and laboratory testing to assess the condition of the asphalt binder and aggregates.

Consider Microsurfacing or Slurry Seal: In cases of minor bleeding, microsurfacing or slurry seal treatments may be considered. These thin surface treatments can help correct minor surface irregularities and provide a new wearing surface.

Intelligent Pavement Assessment Vehicle

ARRB Systems has developed the first fully integrated road surface and sub-surface condition assessment system, providing functional and structural data at highway speeds.

Road agencies across the globe have similar issues in relation to managing their networks with the major question being: How long will our pavements last and what is the optimal maintenance and rehabilitation strategy? Determining a reliable remaining life of a pavement requires assessment of both the structural and functional condition.

Methods of measuring pavement deterioration have primarily focused on surface condition. For many decades structural condition assessment was based on stationary or slow-moving devices which could cause hazardous situations in normal traffic. Structural condition surveys using these devices, therefore, became less common, eliminating vital information about pavement structural life. Combining the two assessment techniques have, until today, been impossible. ARRB Systems iPAVe technology changes this forever.

Having a complete dataset, incorporating information of the pavement above and below the surface, enables the road asset manager to better understand its condition. This dramatically improves decision making in managing the road network. Road agencies in North America, Europe, South Africa, China, Australia and New Zealand are now using iPAVe to collect millions of deflection basin results yearly, along with associated synchronized and simultaneous collected surface condition data.

The iPAVe collects all of the following information:

Pavement surface condition, including:
– Cracking
– Roughness (IRI)
– Texture (MPD and SMTD)
– Rutting
Continuous pavement deflection (Traffic Speed Deflectometer)
Geometry (slope, crossfall, gradients)
Spatial location (GNSS)
Asset inventory imaging


ACTS
ADVANCED CONSTRUCTION
TECHNOLOGY SERVICES
Bu on our credentials
www.acts-int.com
BOXER

What is the international roughness index for asphalt according to ASTM?!

🔅The International Roughness Index (IRI) for asphalt is a measure of the roughness or smoothness of a road surface after it's hardened.

🔅It is commonly determined according to the ASTM (American Society for Testing and Materials) standard ASTM E1926. This standard specifies the procedures for collecting and analyzing data to calculate the IRI, which is important for assessing road quality and ride comfort.

🔅The IRI is usually expressed in units of inches per mile or meters per kilometer and provides valuable information for road maintenance and construction. Please note that standards may evolve, so it's a good practice to check the latest ASTM documentation for the most current information.

The International Roughness Index (IRI) is a widely used method for measuring and quantifying the roughness or unevenness of road surfaces. It provides a numerical value that represents the quality of a road's ride comfort, primarily focusing on the perception of roughness by vehicle occupants.

The IRI is calculated by measuring the vertical deviations of a road profile from a straight and smooth reference line over a specific distance. This profile data is collected using specialized equipment, such as a laser, accelerometer, or profilograph, which records the bumps and dips in the road surface.

The IRI value is typically reported in units of meters per kilometer (m/km) or inches per mile (in/mi). It represents the average roughness experienced by a vehicle traveling along the road section. Higher IRI values indicate rougher road conditions, resulting in a bumpier ride, increased vehicle wear and tear, and potentially decreased safety.

The IRI is widely used by transportation agencies, engineers, and researchers to assess road conditions, prioritize maintenance and rehabilitation efforts, and evaluate the effectiveness of road improvement projects. It provides a standardized and objective measure for comparing road roughness across different locations, facilitating data-driven decision-making in road infrastructure management.

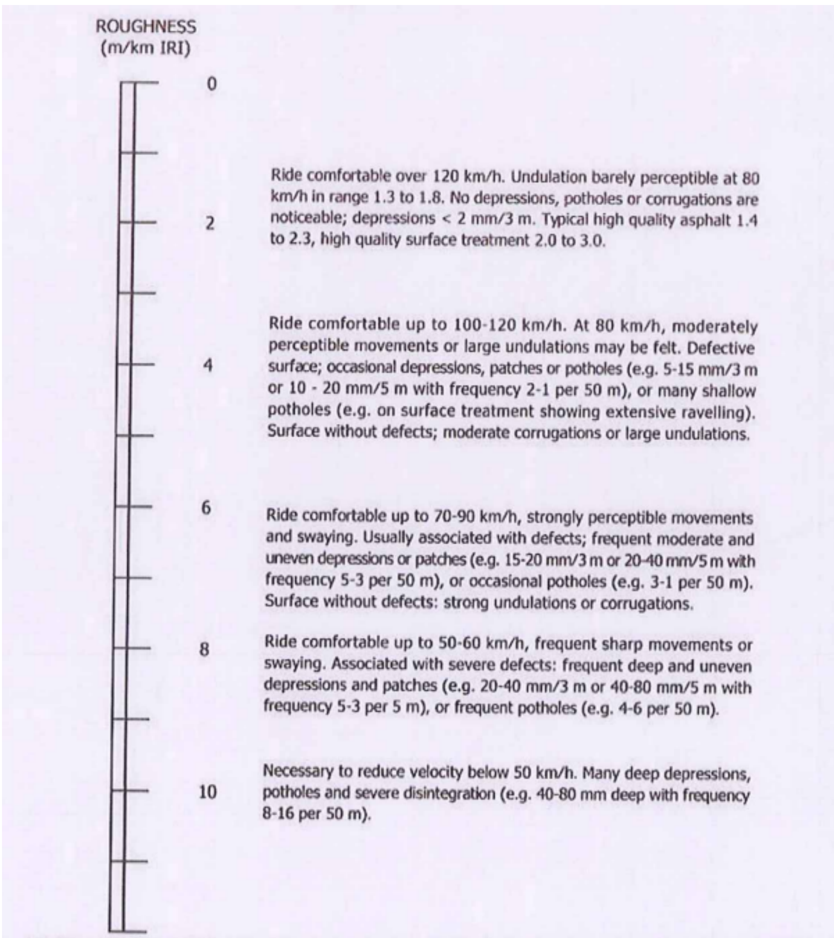


FIG. 1 Road Roughness Estimation Scale for Paved Roads With Asphaltic Concrete or Surface Treatment (Chipseal)

Pavement Structural Design

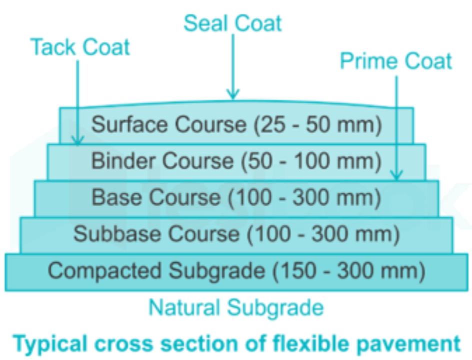
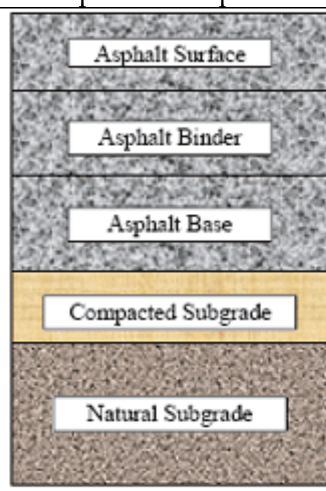
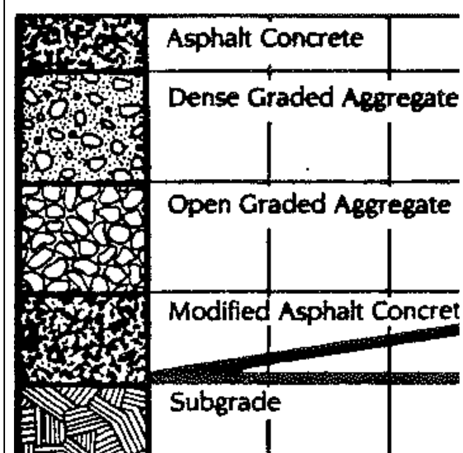
It involves a study of soils and paving materials their behaviour under load and the design of pavement to carry that load under all climatic conditions. The purpose of the pavement system is to provide a smooth surface over which vehicles may safely pass under all climatic conditions for the specific performance period of the pavement.

Pavement Structure = Subbase + Base + Surfacing

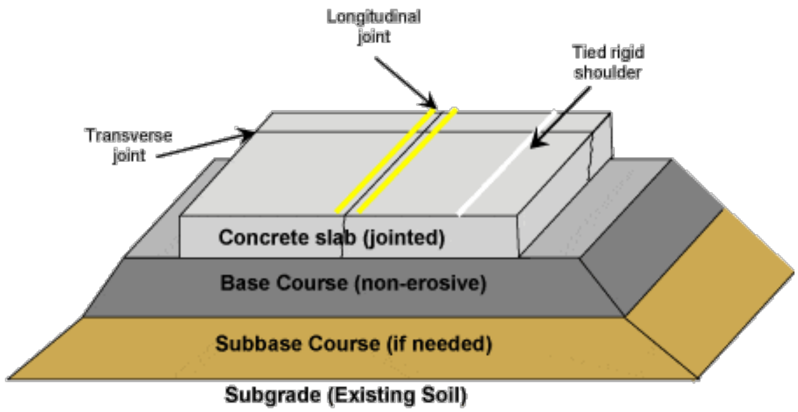
يتضمن التصميم الإنشائي للطريق إيجاد سمك كل طبقة بحيث تكون قادرة على تحمل الأحمال المحورية للمركبات التي تسير على هذه الطرق.

Types of Pavements:

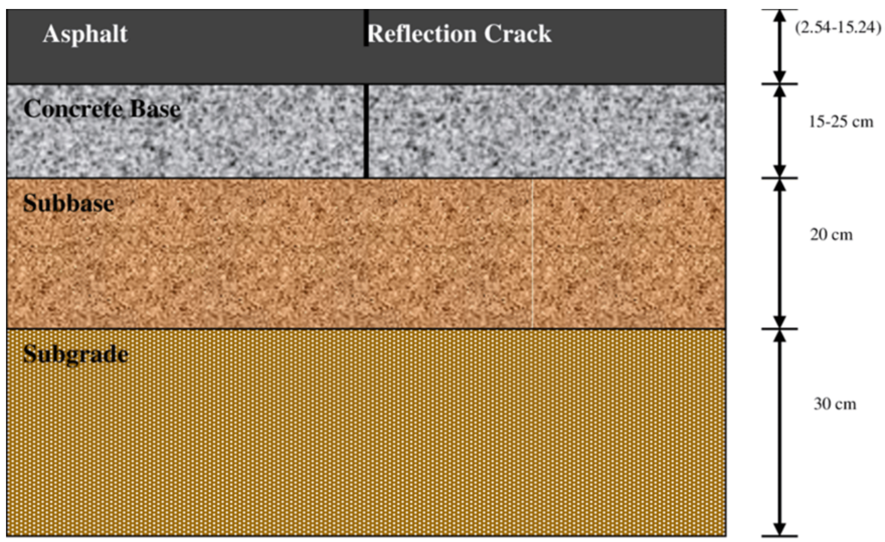
1. Flexible pavement

Conventional flexible pavement	Full depth flexible pavement	Contained rock asphalt mats (CRAM)
		
1. Subgrade 2. Subbase Coarse 3. Base Coarse 4. Asphalt mixtures (Stabilizer, Binder, Surface)	1. Subgrade 2. Asphalt Base Coarse 3. Asphalt Intermediate Coarse 4. Asphalt Surface Coarse	1. Subgrade 2. Modified Dense-Graded HMA 3. Open-Graded Aggregates 4. Dense-Graded Aggregates 5. Dense-Graded HMA

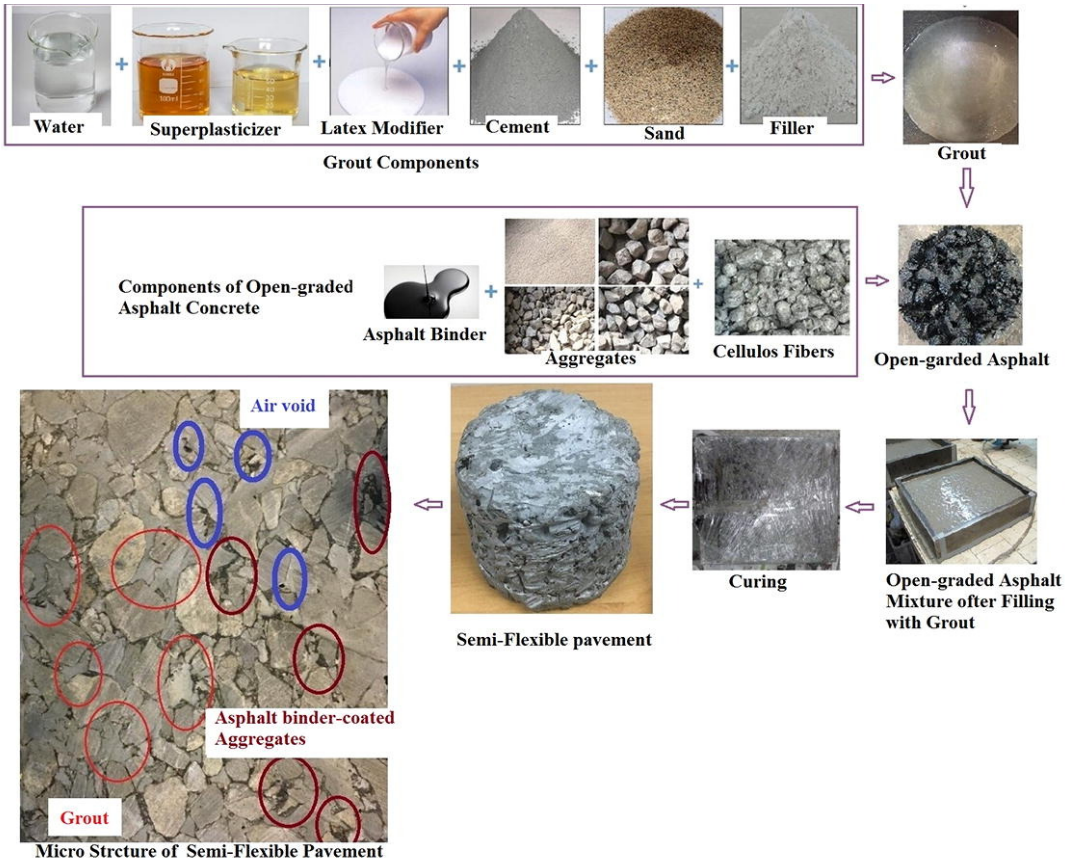
2. Rigid pavement



3. Composite pavement



4. Semi-Rigid Type of Flexible Pavements

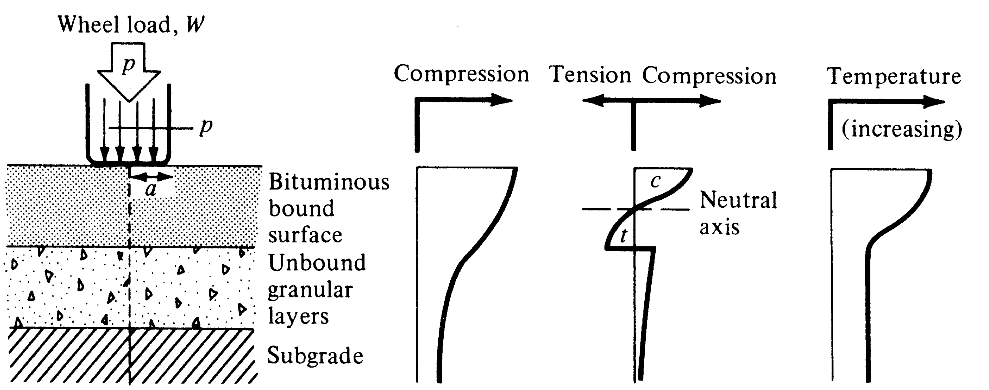


طرق تصميم الطرق المرنة:

1. طريقة مؤشر المجموعة (Group Index GI)
2. طريقة معهد الأسفلت (Asphalt Institute method)
3. طريقة شل
4. طريقة الآشتو(AASHTO Method)
5. طريقة (Multi Layers Elastic Theory)
6. الطريقة البريطانية (Road Note 29)
7. طريقة سلاح المهندسين الأمريكي (Crops of Engineers)
8. **طريقة التحمل الكاليفورني (CBR)** : وهي طريقة تجريبية ومعتمدة في العراق ومعظم الدول العربية، ويتم فيها إيجاد التحمل الكاليفورني لطبقة التعلية الترابية الأخيرة، ولطبقات الطريقة غير المثبتة، ثم يتم تحديد سمك كل طبقة من طبقات التبليط، ويتم فيها تصنيف المرور إلى ثقيل ومتوسط وخفيف، وتمتاز هذه الطريقة بالبساطة، خاصة أنها تشتمل على إجراء تجارب لتحديد قيمة CBR لطبقة التربة الطبيعية الحاملة Subgrade. وأساس التصميم هو أن كل طبقة رصف تحتاج إلى طبقة تعلوها، سمكها يتوقف على قيمة الـ CBR للطبقة السفلية. وقد تم وضع مرتسمات توضح العلاقة بين مقدار الـ CBR وسمك التبليط اعتماداً على عدد السيارات التجارية التي تمر على الطريق في اليوم الواحد. علماً بأن الطريقة المتبعة في تصميم الطرق في العراق تفترض مرور 300 شاحنة على كل من الطرق الرئيسية في الساعة (7200 شاحنة في اليوم) على كل مسار. ويوصى أن إلا تقل قيمة الـ CBR لطبقة التربة الطبيعية الحاملة Subgrade عن 6% ، وبسمك لا يقل عن 30 سم للطرق السريعة والرئيسية التي يتم تبليطها بالاسفلت.

General Principles of Flexible Pavement Design According to AASHTO Method

- In the design of flexible pavements, the pavement structure usually is considered as a multilayered elastic system, with the material in each layer characterized by certain physical properties that may include the modulus of elasticity, the resilient modulus, and the Poisson ratio.
- **Assumptions**:
  - The subgrade layer is infinite in both horizontal & vertical directions.
  - Subbase layer is finite in vertical direction & infinite in horizontal direction.
  - Base layer is finite in vertical direction & infinite in horizontal direction.
  - Surface layer is finite in vertical direction & infinite in horizontal direction.
- The application of a wheel load causes a stress distribution. The maximum vertical stresses are compressive and occur directly under the wheel load. These decrease with an increase in depth from the surface. The maximum horizontal stresses also occur directly under the wheel load but can be either tensile or compressive.
- When the load and pavement thickness are within certain ranges, horizontal compressive stresses will occur above the neutral axis whereas horizontal tensile stresses will occur below the neutral axis.
- The temperature distribution within the pavement structure will also have an effect on the magnitude of the stresses.
- The design of the pavement therefore generally is based on strain criteria that limit both the horizontal and vertical strains below those that will cause excessive cracking and excessive permanent deformation. These criteria are considered in terms of repeated load applications because the accumulated repetitions of traffic loads are of significant importance to the development of cracks and permanent deformation of the pavement.

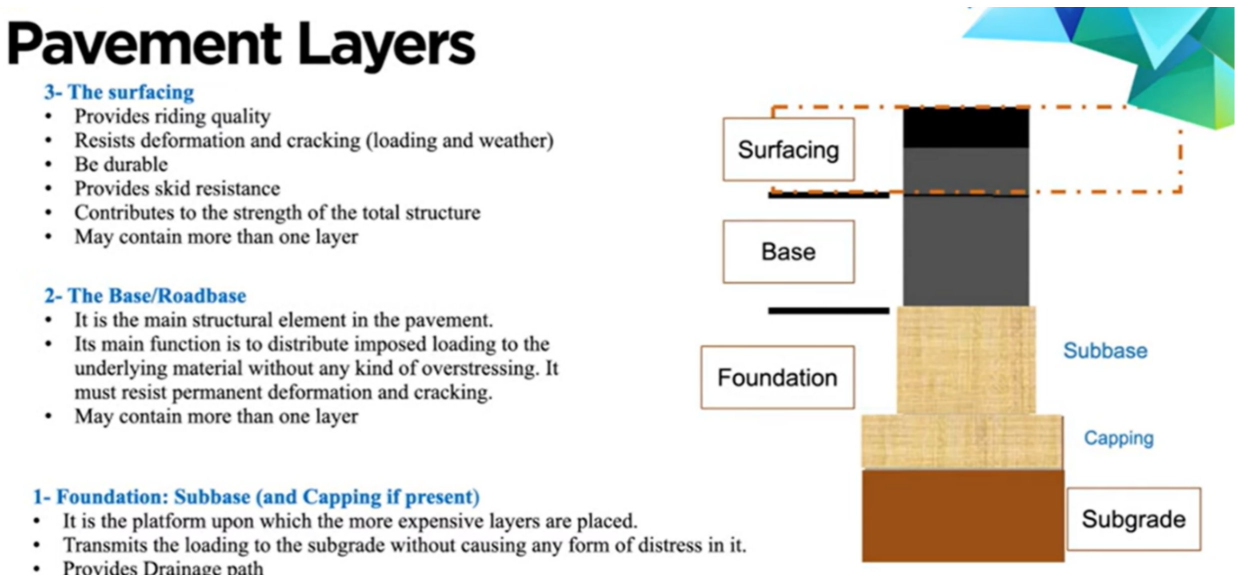


(a) Pavement layers (b) Distribution of vertical stress under centerline of wheel load (c) Distribution of horizontal stress under centerline of wheel load (d) Temperature distribution

p = wheel pressure applied on pavement surface
a = radius of circular area over which wheel load is spread
c = compressive horizontal stress
t = tensile horizontal stress

ملاحظة:

- كلما يزداد العمق تقل الاجهادات (اكبر اجهاد يكون عند السطح) لذلك يجب ان تكون مواد الطبقة السطحية قوية وعادة تكون مكلفة وكلما زاد العمق نستخدم مواد ضعيفة ورخيصة
- كلما يزداد العمق، يزداد عرض الطبقات لغرض توزيع الاحمال على مساحة .كبر و تعمل كأسناد للطبقات العليا في حالة الفشل.



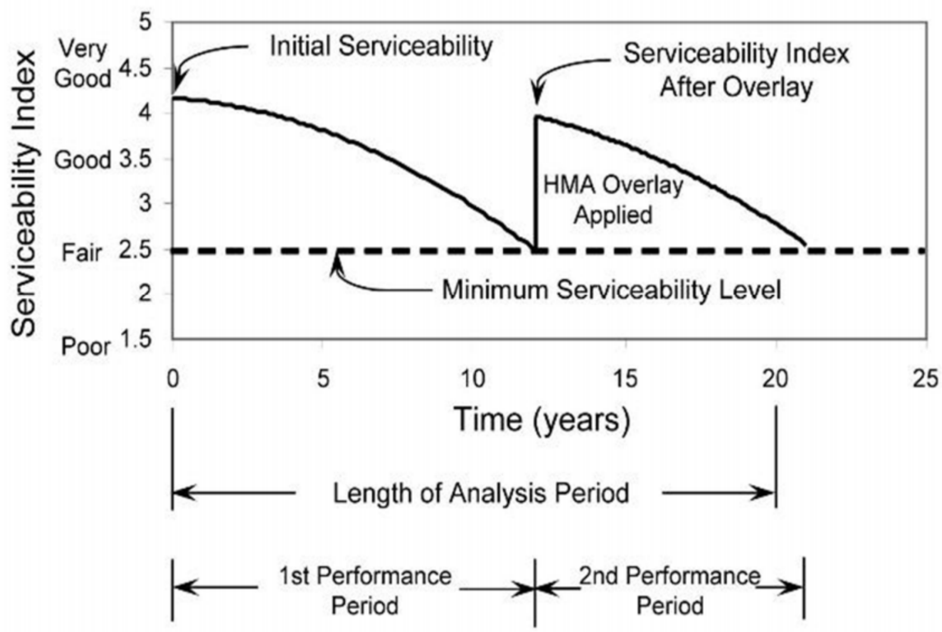
Design Considerations

The factors considered in the AASHTO procedure for the design of flexible pavement are:

1. **Pavement performance:** The primary factors considered under pavement performance are *the structural and functional* performance of the pavement. **Structural performance** is related to the physical condition of the pavement with respect to factors that have a negative impact on the capability of the pavement to carry the traffic load. These factors include cracking, faulting and ravelling. **Functional performance** is an indication of how effectively the pavement serves the user. The main factor considered under functional performance is riding comfort.

   To quantify pavement performance, a concept known as the *serviceability performance* was developed. Under this concept, a procedure was developed to determine the **present serviceability index (PSI)** of the pavement, based on its roughness and distress, which were measured in terms of extent of cracking, patching, and rut depth for flexible pavements. **The scale ranges from 0 to 5, where 0 is the lowest PSI and 5 is the highest.**

   Two serviceability indices are used in the design procedure: the initial serviceability index (*pi*), which is the serviceability index immediately after the construction of the pavement; and the terminal serviceability index (*pt*), which is the minimum acceptable value before resurfacing or reconstruction is necessary. In the AASHTO road test, a value of 4.2 was used for *pi* for flexible pavements. AASHTO, however, recommends that each agency determine more reliable levels for *pi* based on existing conditions. Recommended values for the terminal serviceability index are 2.5 or 3.0 for major highways and 2.0 for highways with a lower classification. In cases where economic constraints restrict capital expenditures for construction, the *pt* can be taken as 1.5, or the performance period may be reduced. However, this low value should be used only in special cases on selected classes of highways.



2. **<u>Traffic</u>:** (Axle loads, Number of load repetitions, Tire-contact area and Vehicle speeds)
The traffic load is determined in terms of the number of repetitions of an 18,000-lb (80 kN, 18 kip) single-axle load applied to the pavement on two sets of dual tires. This is usually referred to as the <u>equivalent single-axle load (ESAL)</u>.

تتمثل هذه الطريقة بدلالة عدد مرات تكرار الثقل المحوري المكافئ المسلط على الطريق عبر مجموعة ثنائية من الإطارات، يتم تمثيل مجاميع الإطارات بشكل دائرة ثنائية، قطر كل منها 4.5 انج والمسافة بين الإطارات 13.57 انج، حيث يولد هذا التميل ضغط تلامس قدره 70 باوند/انج.

يجب أن تحول كل المحاور المسجل مرورها على الطريق إلى ما يكافؤها من المحاور القياسية.

The effect of any load on the performance of a pavement can be represented in terms of the number of single applications of an 18,000-lb single axle (ESALs). The equivalence factors used in this case are based on the terminal serviceability index to be used in the design and the structural number (SN). To determine the ESAL, the number of different types of vehicles such as cars, buses, single-unit trucks, and multiple unit trucks expected to use the facility during its lifetime must be known.

The distribution of the different types of vehicles expected to use the proposed highway can be obtained from results of classification counts that are taken by state highway agencies at regular intervals. These can then be converted to equivalent 18,000-lb loads using the equivalency factors.

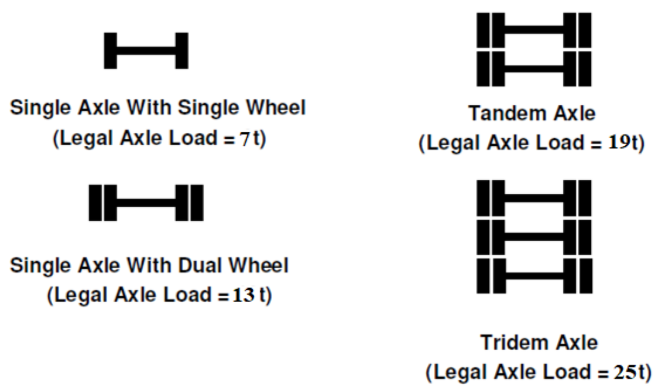
The design period is the number of years the pavement will effectively continue to carry the traffic load without requiring an overlay. Flexible highway pavements are usually designed for a 20-year period. Since traffic volume does not remain constant over the design period of the pavement, it is essential that the rate of growth be determined and applied when calculating the total ESAL. The overall growth rate in the United States is between 3 and 5 % per year, although growth rates of up to 10 percent per year have been suggested for some interstate highways.

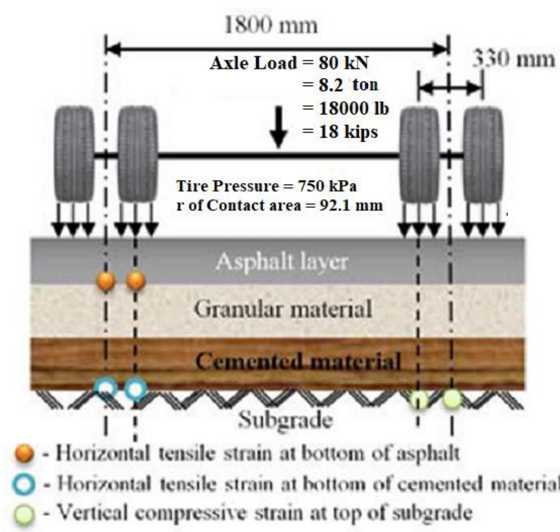
$Grn = [(1+r)^n - 1]/r$

$R = i/100$

i = growth rate

n = design life, years

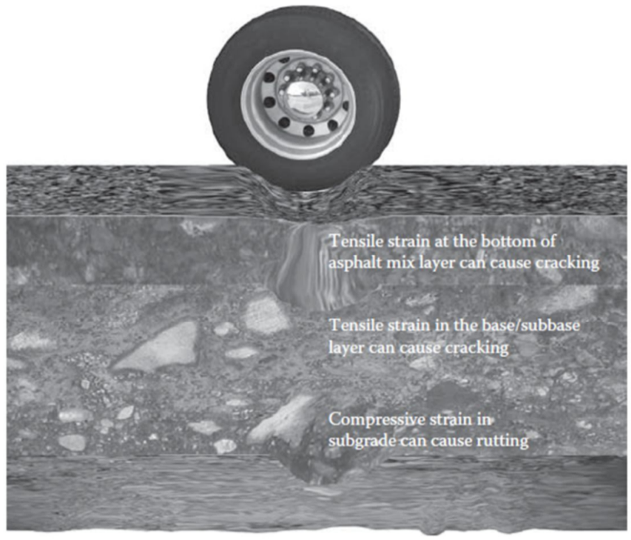




ملاحظة:

- الحد الأقصى لوزن الحمل المحوري للمركبة المسموح بسيرها على الطرق المبلطة، وفقاً لقانون الطرق العامة رقم 35 لسنة 2002 المعدل، وقرار مجلس الوزراء رقم 302 لسنة 2019، كما يلي:
  أ. المحور المفرد ذو العجلات قابلة للتوجيه (7) أطنان
  ب. المحور المزدوج ذو العجلات قابلة للتوجيه (12) طن
  ت. المحور المفرد ذو العجلات غير القابلة للتوجيه (13) طن
  ث. المحور المزدوج ذو العجلات غير القابلة للتوجيه (20) طن
  ج. المحور الثلاثي ذو العجلات غير القابلة للتوجيه (27) طن
  ح. المحور الرباعي ذو العجلات غير القابلة للتوجيه (32) طن.
- زيادة الحمل المروري بنسبة ١٠٠٪ عن الحد الطبيعي، تؤدي إلى زيادة كلفة الصيانة للمتر المربع الواحد بنسبة ٢٥٠٪ (أي بمعدل ضعفين ونصف)
- يعتمد الأثر التخريبي لتجاوز الأثقال المحورية على المعادلة التي تمثل حاصل قسمة الثقل المحوري الفعلي على الثقل المحوري القياسي (٨ طن) مرفوعاً للأس (٤)، بمعنى أنه عند مضاعفة الحمل المحوري، فإن الأثر التخريبي الناتج سيكون ١٦ مرة بقدر مرور المحور القياسي!

Relative damage factor = (Load/18000 Ib)^4

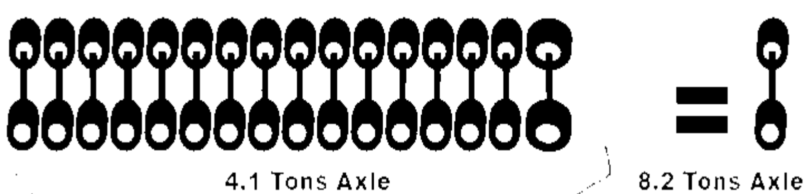


A flexible pavement "flexes" under a load; repeated loadings cause repeated compressive strains as well as tensile strains

Consider two single axles A and B where:

B-Axle = 4.1 tons

- **Damage caused per pass by B-Axle = $(4.1/8.2)^4$ = 0.0625**
- **This means that B-Axle causes only 0.0625 times damage per pass as caused by 1 pass of standard 8.2 tons axle.**
- **In other words, 16 passes (1/0.625) of B-Axle cause same amount of damage as caused by 1 pass of standard 8.2 tons axle i.e.,**



3. **Roadbed soils (subgrade material):** AASHTO guide also uses the resilient modulus (*Mr*) of the soil to define its property. However, the method allows for the conversion of the CBR or *R* value of the soil to an equivalent *Mr* value using the following conversion factors:

   Mr (lb/in^2) = 1500 CBR (for fine-grain soils with soaked CBR of 10 or less)
   Mr (lb/in^2) = 1000 555 *R* value (for $R \leq 20$)

4. **<u>Materials of construction</u>:** The materials used for construction can be classified under three general groups: those used for subbase construction, those used for base construction, and those used for surface construction.
5. **<u>Environment</u>:** *Temperature and rainfall* are the two main environmental factors used in evaluating pavement performance in the AASHTO method. The effects of temperature on asphalt pavements include stresses induced by thermal action, changes in the creep properties, and the effect of freezing and thawing of the subgrade soil. The effect of rainfall is due mainly to the penetration of the surface water into the underlying material. If penetration occurs, the properties of the underlying materials may be altered significantly.
6. **<u>Drainage</u>:** The effect of drainage on the performance of flexible pavements is considered in the AASHTO guide with respect to the effect water has on the strength of the base material and roadbed soil.
7. **<u>Reliability</u>:** AASHTO guide proposes the use of a reliability factor that considers the possible uncertainties in traffic prediction and performance prediction.

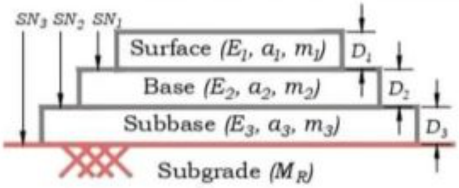
Mechanistic-Empirical Pavement Design (MEPD) Method

It uses empirical relationships between cumulative damage and pavement distress to determine the adequacy of a pavement structure to carry the expected traffic load on the pavement. The procedure is iterative in that the designer first selects a trial design and evaluates it for adequacy with respect to certain input performance criteria and reliability values based on predicted distresses and smoothness of the pavement. In selecting the trial pavement structure, the designer considers site conditions that include traffic, climate, and subgrade. If the predicted performance criteria do not satisfy the input performance criteria at the specified reliability, the trial design is revised, and the evaluation repeated.

SUMMARY

The design of flexible pavements basically involves determining the strength characteristics of the materials of the pavement surface and underlying materials, and then determining the respective thicknesses of the subbase (if any), base course, and pavement surface that should be placed over the native soil. The pavement is therefore usually considered as a multilayered elastic system. The thicknesses provided should be adequate to prevent excessive cracking and permanent deformation beyond certain limits. These limits are considered in terms of required load characteristics which can be determined as the number of repetitions of 18,000 lb single axle loads the pavement is expected to carry during its design life as in the AASHTO design method or in terms of the number of repetitions for a full axle-load spectrum data for each axle type as in the MEPDG design guide.

Flexible Pavement Design (AASHTO Method)

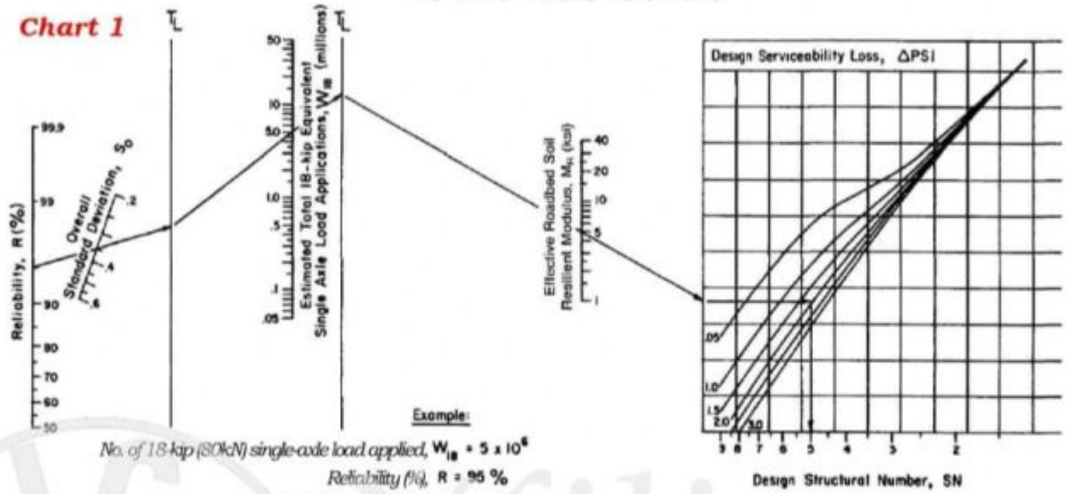


Design Output

1. SN_1, SN_2, SN_3 - Structure number for surface, base and subbase. Obtained from nomograph in Chart 1.
2. D_1, D_2, D_3 - Layer thickness for surface, base and subbase (in.). Obtained from the following equation:

$$D_1 \geq SN_1 / a_1$$
$$D_2 \geq (SN_2 - a_1 D_1) / a_2 m_2$$
$$D_3 \geq (SN_3 - a_2 m_2 D_2 - a_1 D_1) / a_3 m_3$$

Chart 1



Example:

No. of 18-kip (80kN) single-axle load applied, $W_{18} = 5 \times 10^6$

Reliability (%), R = 95 %

Standard deviation, $S_0 = 0.35$

Resilient modulus of underlying layer (psi), M_R = 5000 psi

Design serviceability loss, ΔPSI = 1.9

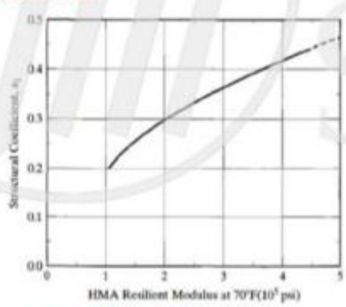
Solution: SN = 5.0

Note on using nomograph (chart 1) for design

1. When designing surface course layer, use E_2 as M_R.
2. When designing base course layer, use E_3 as M_R.
3. When designing subbase course layer, use M_R.

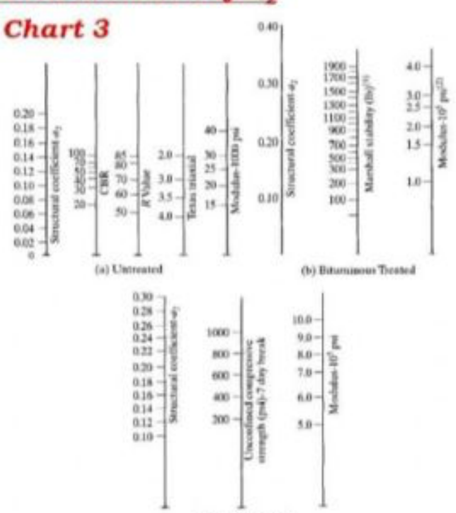
Determination of a_1

Chart 2



Determination of a_2

Chart 3



Determination of a_3

Chart 4

Determination of m_2 and m_3

Table 1

Rating	Water removed within	% of time pavement is approaching saturated condition			
		<1%	1-5%	5-25%	>25%
Excellent	2 hours	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1 day	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1 week	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1 month	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very poor	Never drain	1.05-0.95	0.95-0.75	0.75-0.40	0.40

Remark

a_1 = 0.44 for dense-graded HMA as per AASHO road test (resilient modulus of 450,000psi)

a_2 = 0.14 for granular base material as per AASHO road test (base resilient modulus of 30,000psi)

a_3 = 0.11 for granular subbase material as per AASHO road test (base resilient modulus of 15,000psi)

m_2 = 1 and m_3 = 1 as per AASHO road test site

Reference

Yang, H.H. (2004). *Pavement analysis and design (2nd ed.)* Pearson Education Inc. New Jersey.

Rigid Pavement

Rigid highway pavements are normally constructed of Portland cement concrete and may or may not have a base course between the subgrade and the concrete surface. When a base course is used in rigid pavement construction, it is usually referred to as a subbase course. Rigid pavements have some flexural strength that permits them to sustain a beamlike action across minor irregularities in the underlying material. Thus, the minor irregularities may not be reflected in the concrete pavement. Properly designed and constructed rigid pavements have long service lives and usually are less expensive to maintain than flexible pavements.

- Thickness of highway concrete pavements normally ranges from 150-300 mm.
- The Portland cement concrete commonly used for rigid pavements consists of Portland cement, coarse aggregate, fine aggregate, and water.
- Steel reinforcing rods may or may not be used, depending on the type of pavement being constructed.

Reinforcing Steel

Steel reinforcing may be used in concrete pavements to reduce the amount of cracking that occurs, as a load transfer mechanism at joints, or as a means of tying two slabs together. Steel reinforcement used to control cracking is usually referred to as ***temperature steel***, whereas steel rods used as load transfer mechanisms are known as ***dowel bars***, and those used to connect two slabs together are known as ***tie bars***.

Temperature Steel

Temperature steel is provided in the form of a bar mat or wire mesh consisting of longitudinal and transverse steel wires welded at regular intervals. The mesh usually is placed about 7.5 cm. below the slab surface. The cross-sectional area of the steel provided per meter width of the slab depends on the size and spacing of the steel wires forming the mesh. **The amount of steel required depends on** the length of the pavement between expansion joints, the maximum stress desired in the concrete pavement, the thickness of the pavement, and the moduli of elasticity of the concrete and steel.

General guidelines for the minimum cross-sectional area of the temperature steel.

1. Cross-sectional area of longitudinal steel should be at least equal to 0.1 percent of the cross-sectional area of the slab.
2. Longitudinal wires should not be less than No. 2 gauge, spaced at a maximum distance of 15 cm.
3. Transverse wires should not be less than No. 4 gauge, spaced at a maximum distance of 30 cm.

Temperature steel does not prevent cracking of the slab, but it does control the crack widths because the steel acts as a tie holding the edges of the cracks together. This helps to maintain the shearing resistance of the pavement, thereby maintaining its capacity to carry traffic load, even though the flexural strength is not improved.

Dowel Bar

Dowel bars are used mainly as load-transfer mechanisms across joints. They provide flexural, shearing, and bearing resistance. The dowel bars must be of a much larger diameter than the wires used in temperature steel.

Size selection is based mainly on experience. Diameters of 25 to 37.5 mm and lengths of 60 to 90 cm have been used, with the bars usually spaced at 0.3 m centers across the width of the slab. At least one end of the bar should be smooth and lubricated to facilitate free expansion.

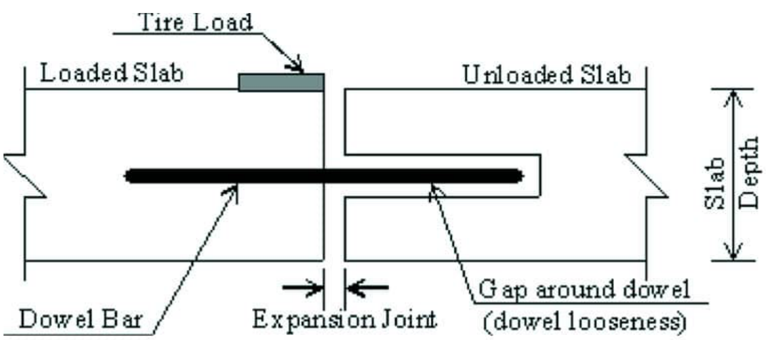
<u>The objective of Dowel Bar</u>

- To deliver the load from one slab to its adjoining slab with the purpose of moving two successive slabs simultaneously and minimizing the impact loading produced by the slabs with their independent movement.
- To minimize joint faulting and corner cracking.
- To improve the functioning of pavement joints.

<u>Benefits of Dowel Bars</u>

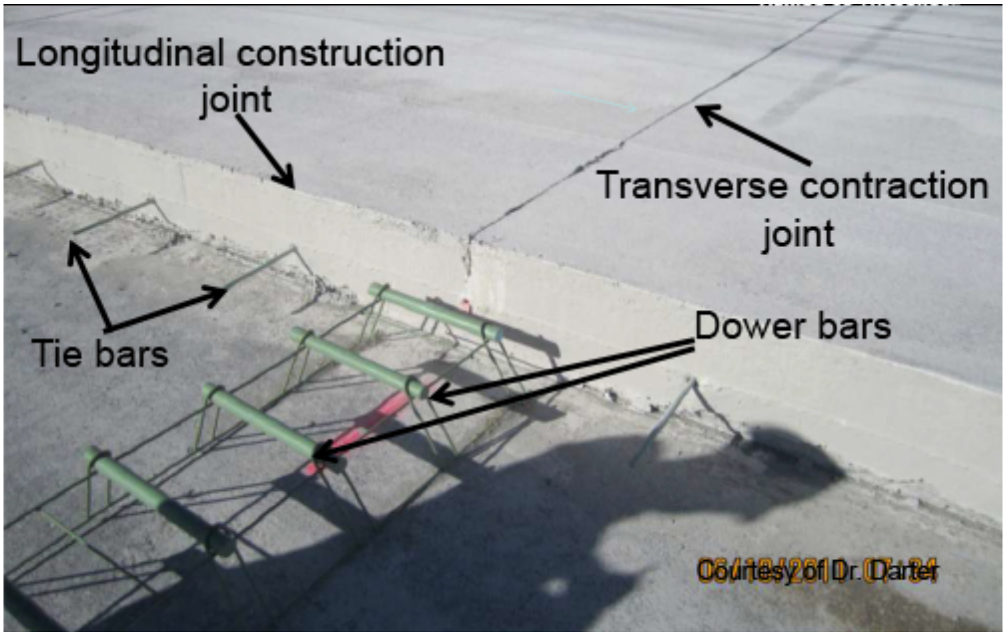
- Minimizes deflection and stresses.
- It raised the load-bearing strength of slabs.
- It improves the initial pavement life.

The effective depth is calculated from the face of the member to the centre of area of main reinforcement. Therefore, Effective cover = Clear cover + (Dia of Stirrups/links) + (Dia of main reinforcement bars) + 0.5*(distance among bars).



Tie bars

Tie bars are used to tie two sections of the pavement together, and therefore they should be either deformed bars or should contain hooks to facilitate the bonding of the two sections of the concrete pavement with the bar. These bars are usually much smaller in diameter than the dowel bars and are spaced at larger centers. Typical diameter and spacing for these bars are 19 mm and 90 cm, respectively.

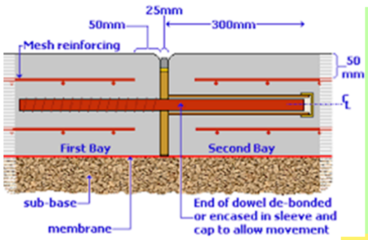


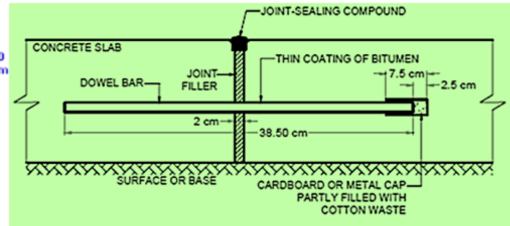
Joints in Concrete Pavements

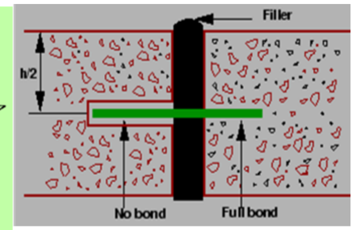
Different types of joints are placed in concrete pavements to limit the stresses induced by temperature changes and to facilitate proper bonding of two adjacent sections of pavement when there is a time lapse between their construction (for example, between the end of one day's work and the beginning of the next). These joints can be divided into four basic categories:

1. **Expansion joints**: When concrete pavement is subjected to an increase in temperature, it will expand, resulting in an increase in length of the slab. When the temperature is sufficiently high, the slab may buckle or "blow up" if it is sufficiently long and if no provision is made to accommodate the increased length. Therefore, ***expansion joints*** are usually placed transversely, at regular intervals, to provide adequate space for the slab to expand. These joints are placed across the full width of the slab and are 3⁄4 to 1 in. wide in the longitudinal direction. The joint space is filled with a compressible filler material that permits the slab to expand. Filler materials can be cork, rubber, bituminous materials, or bituminous fabrics.

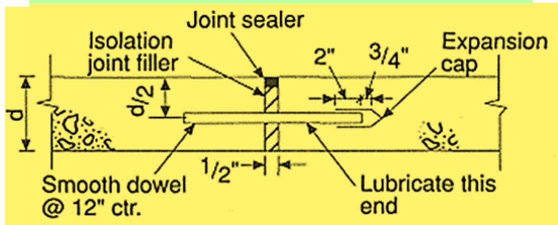
- A means of transferring the load across the joint space must be provided since there are no aggregates that will develop an interlocking mechanism. The load-transfer mechanism is usually a smooth dowel bar that is lubricated on one side. An expansion cap usually also is installed to provide a space for the dowel to occupy during expansion.



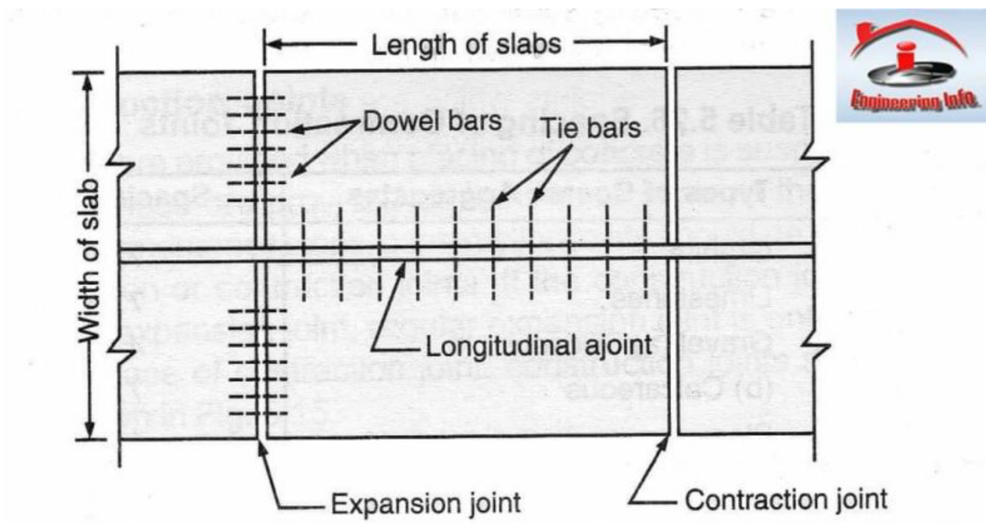




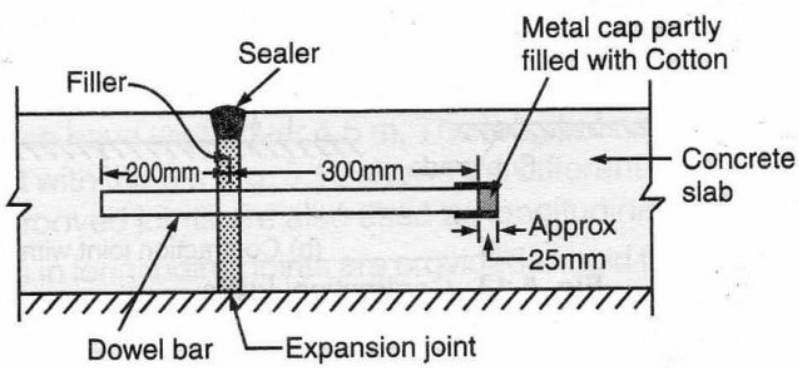
Expansion Joints



Expansion Joints



Location of joints



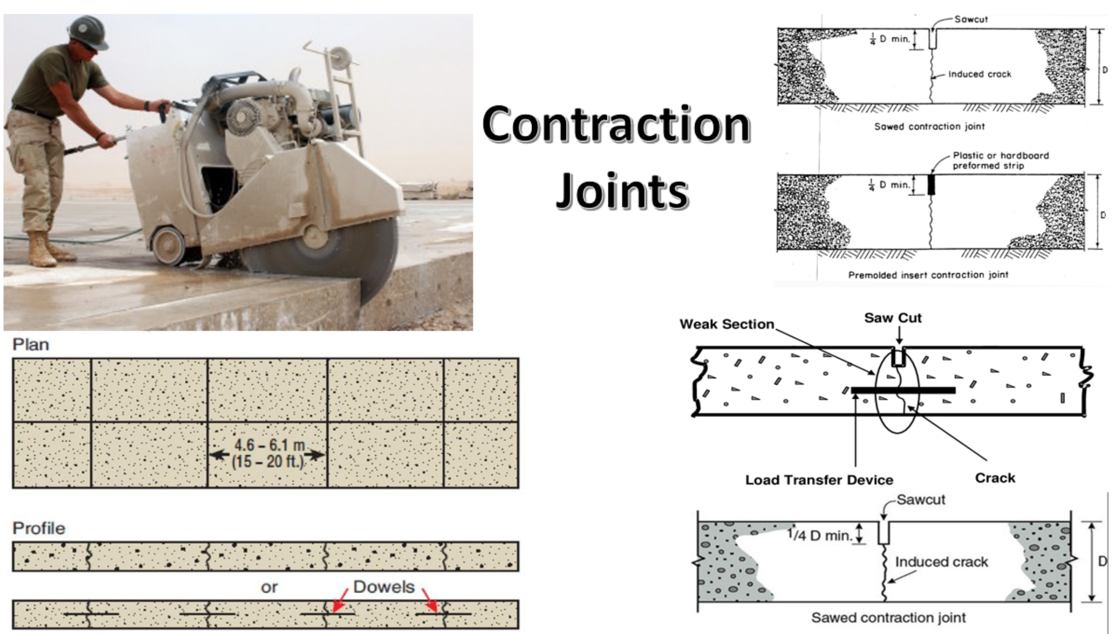
Spacing of Expansion Joints in Plain Cement Concrete Pavement slab

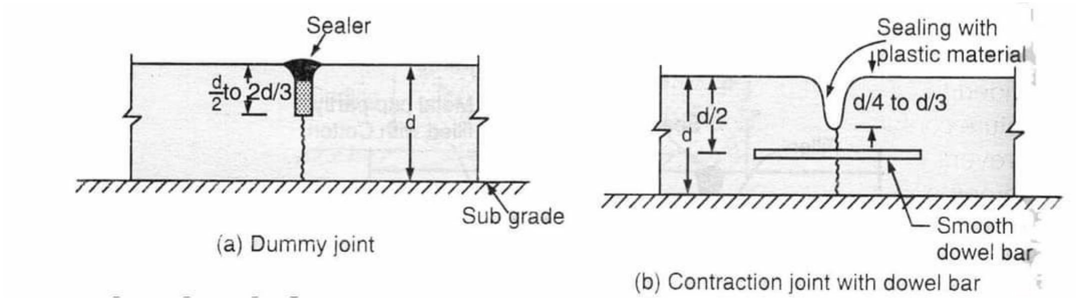
S. No.	Thickness of Slab (mm)	Maximum Spacing of Expansion Joints (m)
1.	100	27
2.	130	27
3.	200	37

Spacing of Expansion Joints in Reinforced Cement Concrete Pavement slab

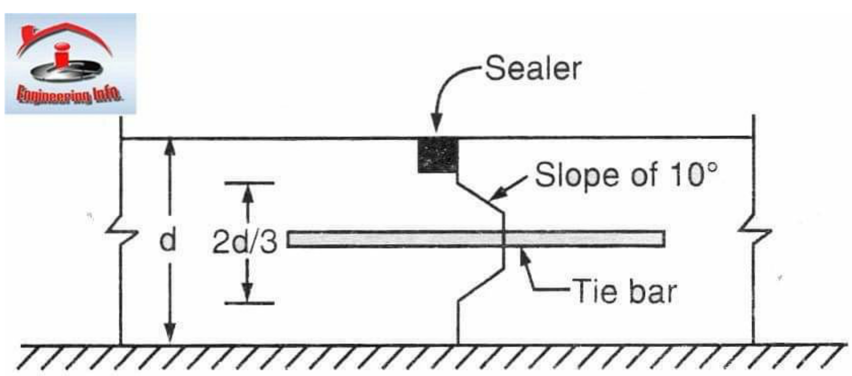
S. No.	Thickness of slab (mm)	Weight of reinforcement (kg/m^2)	Maximum spacing of expansion joints (m)
1.	100	2.7	12.5
2.	150	3.8	25.0
3.	200	5.5	37.0

2. **<u>Contraction joints</u>**: When concrete pavement is subjected to a decrease in temperature, the slab will contract if it is free to move. Prevention of this contraction movement will induce tensile stresses in the concrete pavement. *Contraction joints* therefore are placed transversely at regular intervals across the width of the pavement to release some of the tensile stresses that are so induced.





3. **Hinge joints**: Hinge joints are used mainly to reduce cracking along the center line of highway pavements.



Tongue and groove warping joints

4. **Construction joints**: Construction joints are placed transversely across the pavement width to provide suitable transition between concrete laid at different times. For example, a construction joint is usually placed at the end of a day's pour to provide suitable bonding with the start of the next day's pour.

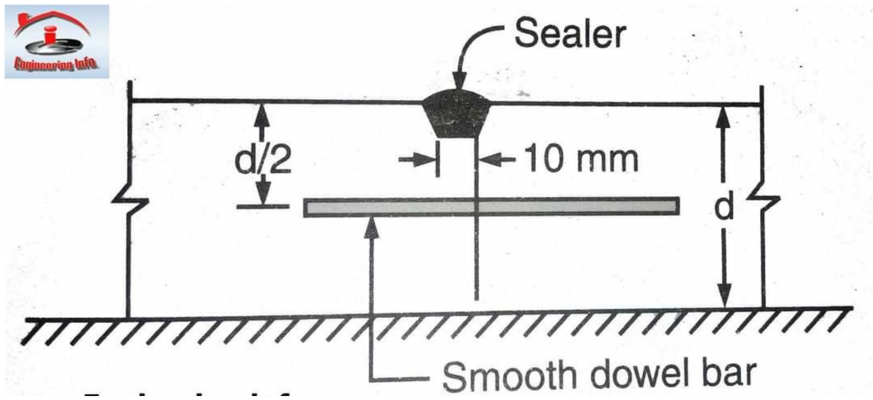
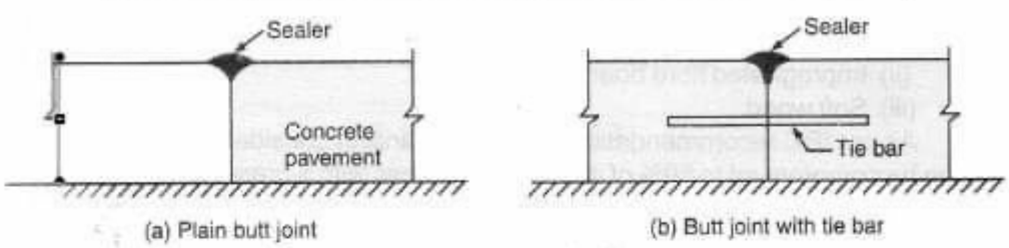


Table Sizes of Tie Bars for Longitudinal Joints

S. No.	Traffic Intensity	Diameter of Tie Bars (mm)
1.	Very heavy	25
2.	Heavy	20
3.	Medium	12



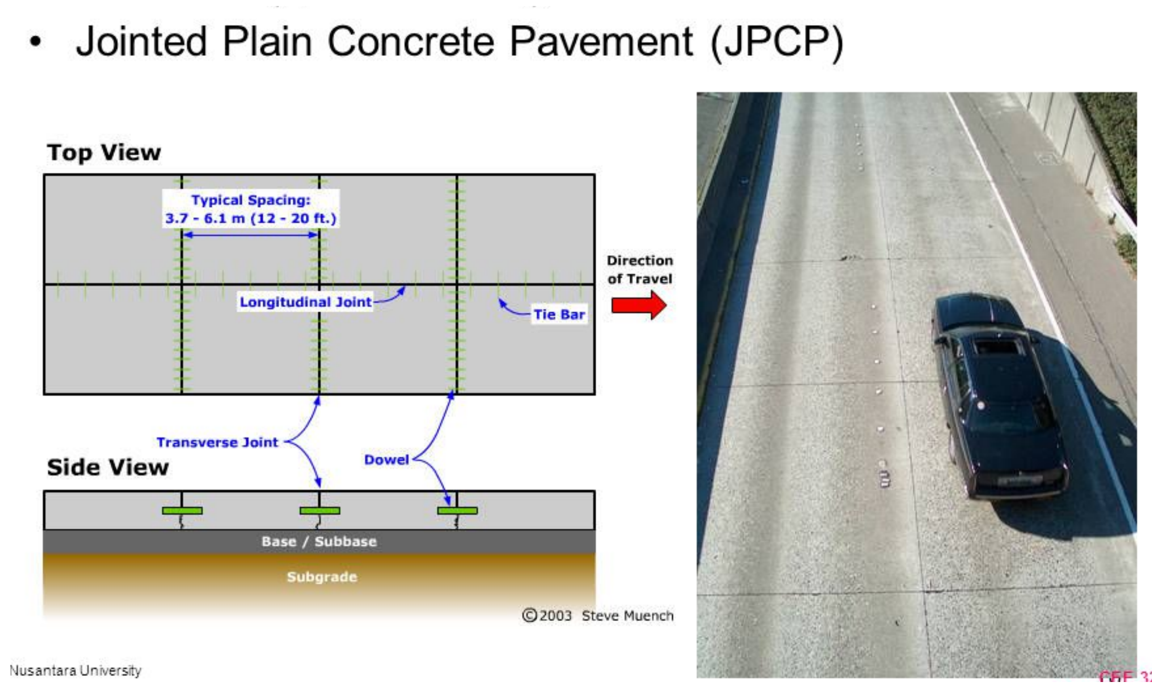
Longitudinal Joints

Types of Rigid Highway Pavements

Rigid highway pavements can be divided into three general types: **plain concrete pavements, simply reinforced concrete pavements, and continuously reinforced concrete pavements.**

1. **Jointed Plain Concrete Pavement (JPCP):** Plain concrete pavement has no temperature steel or dowels for load transfer. However, steel tie bars often are used to provide a hinge effect at longitudinal joints and to

prevent the opening of these joints. It is used mainly on low-volume highways or when cement-stabilized soils are used as subbase. Joints are placed at relatively shorter distances (3 to 6 m) than with other types of concrete pavements to reduce the amount of cracking.



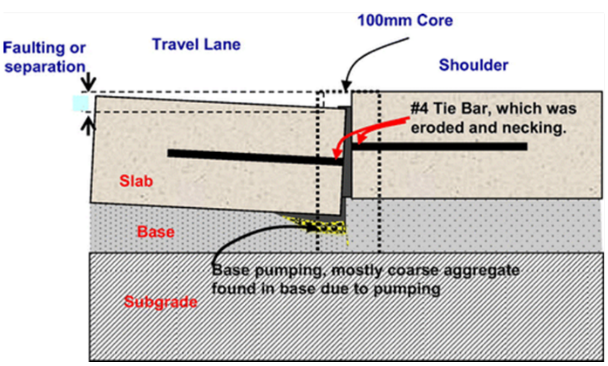
2. **Simply Reinforced Concrete Pavement:** Simply reinforced concrete pavements have dowels for the transfer of traffic loads across joints, with these joints spaced at larger distances, ranging from 9 to 30 m. Temperature steel is used throughout the slab, with the amount dependent on the length of the slab. Tie bars also are used commonly at longitudinal joints.
3. **Continuously Reinforced Concrete Pavement (CRCP):** Continuously reinforced concrete pavements have no transverse joints, except construction joints or expansion joints when they are necessary at specific positions, such as at bridges. These pavements have a relatively high percentage of steel, with the minimum usually at 0.6 percent of the cross section of the slab. They also contain tie bars across the longitudinal joints.

Pumping of Rigid Pavements:

It is the discharge of water and subgrade (or subbase) material through joints, cracks, and along the pavement edges. It primarily is caused by the repeated deflection of the pavement slab in the presence of accumulated water beneath it. The mechanics of pumping can best be explained by considering the sequence of events that lead to it. **The first event is the formation of void space beneath the pavement. This void forms from either the combination of plastic deformation of the soil, due to imposed loads and the elastic rebound of the pavement after it has been deflected by the imposed load, or warping of the pavement, which occurs as a result of temperature gradient within the slab. Water then accumulates in the space after many repetitions of traffic load. The water may be infiltrated from the surface through joints and the pavement edge.** To a lesser extent, groundwater may settle in the void. If the subgrade or base material is granular, the water will freely drain through the soil. If the material is fine-grained, however, the water is not easily discharged, and additional load repetitions will result in the soil going into suspension with the water to form a slurry. Further load repetitions and deflections of the slab will result in the slurry being ejected to the surface (pumping). Pumping action will then continue, with the result that a relatively large void space is formed underneath the concrete slab. This results in faulting of the joints and eventually the formation of transverse cracks or the breaking of the corners of the slab. Joint faulting and cracking are therefore progressive, since formation of a crack facilitates the pumping action. Visual manifestations of pumping include:

1. Discharge of water from cracks and joints
2. Spalling near the centreline of the pavement and a transverse crack or joint
3. Mud boils at the edge of the pavement
4. Pavement surface discoloration (caused by the subgrade soil)
5. Breaking of pavement at the corners





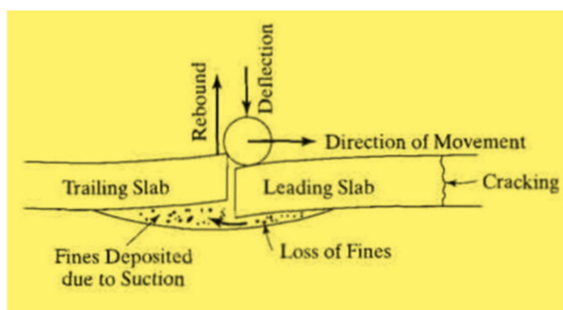


Figure 1.5: Pumping of rigid pavement.

Design Considerations for Preventing Pumping

A major design consideration for preventing pumping is the reduction or elimination of expansion joints, since pumping is usually associated with these joints. This is the main reason why current design practices limit the number of expansion joints to a minimum. Since pumping is also associated with fine-grained soils, another design consideration is either to replace soils that are susceptible to pumping with a nominal thickness of granular or sandy soils, or to improve them by stabilization. Current design practices therefore usually include the use of 3 to 6 in. layers of granular subbase material at areas along the pavement alignment where the subgrade material is susceptible to pumping or stabilizing the susceptible soil with asphalt or Portland cement. The American Concrete Pavement Association method of rigid pavement design indirectly considers this phenomenon in the erosion analysis.

Stresses in Rigid Pavements

Stresses are developed in rigid pavements as a result of several factors, including the action of traffic wheel loads, the expansion and contraction of the concrete due to temperature changes, yielding of the subbase or subgrade supporting the concrete pavement, and volumetric changes. For example, traffic wheel loads will induce flexural stresses that are dependent on the location of the vehicle wheels relative to the edge of the pavement, whereas expansion and contraction may induce tensile and compressive stresses, which are dependent on the range of temperature changes in the concrete pavement. These different factors that can induce stress in concrete pavement have made the theoretical determination of stresses rather complex, requiring the following simplifying assumptions.

- Concrete pavement slabs are considered as unreinforced concrete beams. Any contribution made to the flexural strength by the inclusion of reinforcing steel is neglected.
- The combination of flexural and direct tensile stresses will inevitably result in transverse and longitudinal cracks. The provision of suitable crack control in the form of joints, however, controls the occurrence of these cracks, thereby maintaining the beam action of large sections of the pavement.
- The supporting subbase and/or subgrade layer acts as an elastic material in that it deflects at the application of the traffic load and recovers at the removal of the load.

Stresses Induced by Bending: The ability of rigid pavement to sustain a beamlike action across irregularities in the underlying materials suggests that the theory of bending is fundamental to the analysis of stresses in such pavements. The theory of a beam supported on an elastic foundation therefore can be used to analyze the stresses in the pavement when it is externally loaded.

Stresses Due to Traffic Wheel Loads: The basic equations for determining flexural stresses in concrete pavements due to traffic wheel loads were first developed by Westergaard. Although several theoretical developments have been made since then, the Westergaard equations are still considered a fundamental tool for evaluating stresses on concrete pavements.

Stresses Due to Temperature Effects: The tendency of the slab edges to curl downward during the day and upward during the night as a result of temperature gradients is resisted by the weight of the slab itself. This resistance tends to keep the slab in its original position, resulting in stresses being induced in the pavement. Compressive and tensile stresses therefore are induced at the top and bottom of the slab, respectively, during the day, whereas tensile stresses are induced at the top and compressive stresses at the bottom during the night.

Thickness Design of Rigid Pavements

The main objective in rigid pavement design is to **determine the thickness of the concrete slab that will be adequate to carry the projected traffic load for the design period**. Several design methods have been developed over the years, some of which are based on the results of full-scale road tests, others on theoretical development of stresses on layered systems, and others on the combination of the results of tests and theoretical development.

Design Considerations: The basic factors considered in the AASHTO method are:

1. Pavement performance
2. Subgrade strength
3. Subbase strength
4. Traffic
5. Concrete properties
6. Drainage
7. Reliability

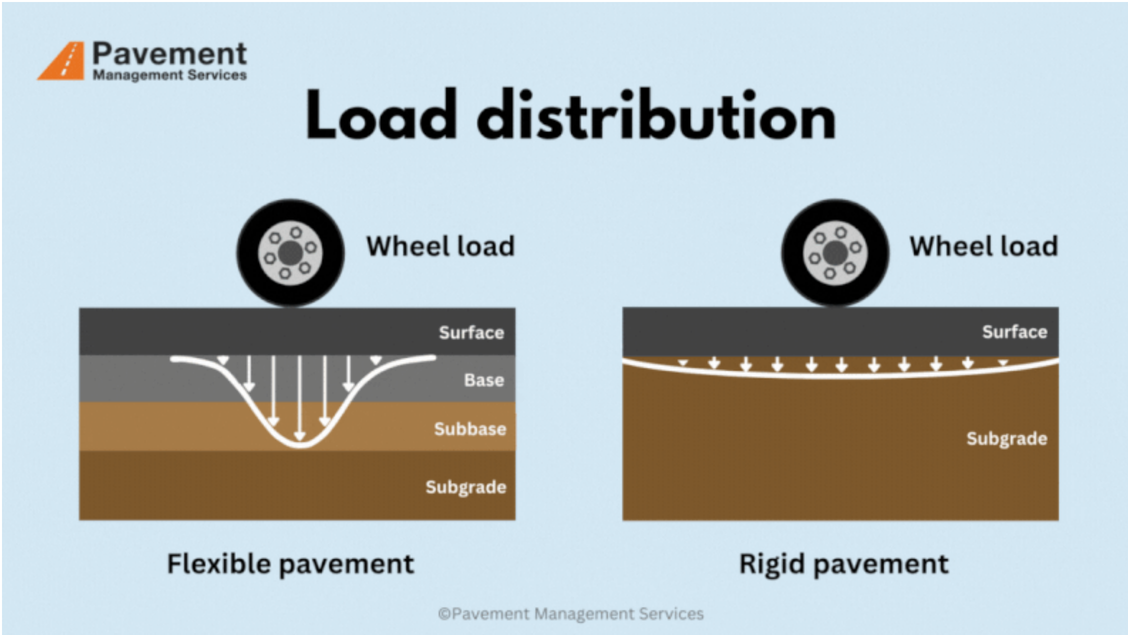
PCA Design Method

The PCA method for concrete pavement design is based on a combination of theoretical studies, results of model and full-scale tests, and experience gained from the performance of concrete pavements normally constructed and carrying normal traffic loads.

Design Considerations: The basic factors considered in the PCA design method are:

1. Flexural strength of the concrete
2. Subgrade and subbase support
3. Traffic load

Differences between Rigid Pavement and Flexible Pavement



Feature	Flexible Pavement	Rigid Pavement
Material Composition	Consists of multiple layers, including asphalt concrete, base course, and subbase.	Comprises a single layer of reinforced or unreinforced concrete.
Flexibility	Exhibits flexibility and distributes loads over a larger area.	Relatively rigid and distributes loads over a smaller area.
Load Distribution	Spreads loads through the entire structure, allowing for some deformation.	Distributes loads primarily through flexural strength without significant deformation.
Cracking	Tends to develop surface cracks and may require periodic maintenance.	Prone to fewer but wider cracks, which may be more challenging to repair.
Repair and Maintenance	Generally easier and less expensive to repair; resurfacing is common.	Repairs are often more complex and costly; full-depth reconstruction may be necessary.
Construction Time	Typically, quicker to construct due to the layered structure.	Construction may take longer due to the curing time of concrete.
Adaptability to Subgrade	Adapts well to varying subgrade conditions.	More sensitive to subgrade quality; may require additional subgrade preparation.
Cost	Often more cost-effective in terms of initial construction.	Initial construction cost may be higher, but long-term maintenance costs can be lower.
Keep in mind that the choice between flexible and rigid pavement depends on various factors, including traffic load, soil conditions, climate, and budget considerations		

Pavement Design as per UK, USA & Australian Standards and their Comparison

UK PAVEMENT DESIGN:

The Design Manual for Roads and Bridges (DMRB) in the UK provides a comprehensive set of guidelines used for the design, assessment, and maintenance of road infrastructures. Developed by National Highways (formerly Highways Agency & Highways England) on behalf of the devolved administrations of Scotland, Wales, and Northern Ireland, the DMRB includes detailed standards for pavement design. The DMRB Standards used for pavement design are:

- CD224 - Traffic Assessment
- CD 225 - Pavement Foundation Design
- CD 226 - New Pavement Construction

Example Pavement Design Process According to DMRB:

Step 1: Foundation Design

The subgrade surface modulus shall be used in the pavement foundation design. CBR is traditionally used as indirect test for sub grade strength. The following equation is used in the estimation of subgrade surface modulus:

E = 17.6 (CBR)0.64 MPa

Design approaches for foundation:

1. Restricted Design Approach – It allows a limited number of designs to be applied for foundation classes 2 and 3 and is particularly intended for use on schemes of limited extent.

2. Performance Based Design Approach – This method is used to enable the efficient use of materials. This method is used for wider sites. The foundation designs shall be subject to performance testing. The foundation classes are given below:

- Foundation Class 1 ≥ 50MPa – Capping Layer only – not used for traffic > 20msa – for non-trunk roads only.
- Foundation Class 2 ≥ 100MPa – Capping Layer plus/or granular subbase material
- Foundation Class 3 ≥ 200MPa – Hydraulically bound material (using cement, furnace slag, fly ash etc.) are used
- Foundation Class 4 ≥ 400MPa – Hydraulically bound material (using cement furnace slag, fly ash etc.) are used

Step 2: Traffic Assessment

Design Traffic = Commercial vehicle loading over the design period (expressed as the number of equivalent standard axle load (80KN or 8.16T)

For new scheme AADF from Traffic Appraisal Manual 12.1.1

For existing road scheme, a classified count shall be carried out over a 12, 16 or 24-hour period. AADF is flow in one direction. AADT is traffic on both directions.

Step 3: Commercial vehicles at opening (F):

Min 3.5 tonnes gross weight

PSV – Public Service Vehicles - Buses and Coaches

OGV1 – 2 & 3 Axle rigid

OGV2 – 4 or more axle articulated

Percentage of commercial vehicles within the AADF (in one direction) For new road schemes, the commercial vehicle flows by class / category shall be determined from traffic transport analysis using the principles described in the Department for Transport's WebTAG Unit

Step 4: Design Period (Y):

A design period of 40 years is used.

Step 5: Growth Factor (G):

A table is used for growth factors.

Step 6: Wear Factor (W):

Structural wear is proportional to 4th power of axle load. Thus a 50% increase in Axle load results in a five-fold increase in calculated structural wear. The wear factors to be used for the Maintenance (Wm) and New Design (Wn) cases are shown in a table.

Step 7: Percentage of Commercial Vehicles in Heaviest Loaded Lane (P):

As all lanes are designed as for the heaviest loaded lane. For new and existing carriageways with 2 or more lanes in one direction, the proportion of vehicles in the most heavily loaded lane shall be estimated using a table provided in DMRB.

Step 8: Design Traffic = 365*F*Y*G*W*P*10-6

Step 9: Pavement Thickness

Nomographs for determining the design thickness of flexible pavement are shown in DMRB CD226.

AASHTO PAVEMENT DESIGN:

The American Association of State Highway and Transportation Officials (AASHTO) pavement design method is a widely used approach for designing both flexible (asphalt) and rigid (concrete) pavements. This method has evolved over time, with significant updates reflected in various editions of the AASHTO Guide for Design of Pavement Structures. The method is grounded in empirical research and practical experience, primarily derived from the AASHO Road Test conducted in the late 1950s. Here's an overview of how AASHTO pavement design works:

Example of Pavement Design Using AASHTO Guidelines:

Step 1: Develop Equivalent Single Axle Load, W18

Traffic is represented in the AASHTO method by the equivalent single axle load (ESAL), or the number of 18-kip (or 18 Tons) equivalent single axle loads that will pass over the pavement during its initial service lifetime.

Step 2: Develop soil resilient modulus, MR

The AASHTO correlation below gives reasonable agreement between the California Bearing Ratio (CBR) and the soil resilient] modulus. Unless site specific investigations determine different resilient modulus-CBR correlation factors, the AASHTO correlation should be used.

Mr = 1500(CBR)

where: Mr = Resilient Modulus (psi)

CBR = California Bearing Ratio

Step 3: Determine the overall standard deviation, So

The overall standard deviation is a dimensionless parameter that accounts for random variation in the traffic projections and normal variation in the pavement parameters. Simply put, it provides a means of accounting for areas of weaker than average pavement receiving higher than expected traffic. A value of 0.45 for So is commonly used for flexible pavement materials.

Step 4: Select the level of reliability, R

The level of reliability describes the degree of certainty that the pavement will last as long as the design service period. The level of reliability is represented in the AASHTO equation by the standard normal deviate, ZR, and in the design nomograph by R.

Step 5: Select design serviceability loss, PSI

The pavement serviceability is a general measure of the pavements ability to service the traffic which must pass over it. Serviceability ranges from 0 (impassable) to 5 (ideal) and represents a quantification of subjective impressions about the roadway quality. The design serviceability loss is obtained by simply subtracting the final value from the initial value, and so describes the amount of degradation of service which is acceptable during the design lifetime.

Step 6: Solve for the structural number, SN

The preceding steps 1-5 were independent. However, a value must be obtained for each one in order to complete step 6, solving for the structural number. The structural number can be solved for using in an equation, using a trial and-error procedure.

Step 7: Determine pavement and base thickness

Once determined from step 6, the structural number is used to determine the thickness of each pavement material layer using the appropriate material coefficients from a prescribed table.

Various combinations of pavement materials of various thickness are possible to meet or exceed a given structural number. Once the structural requirements are met the combination and thickness of the individual pavement material sections is based on such factors as aggregate availability, aggregate size, cost of various pavement materials, minimum recommended thickness, restrictions on overall thickness, number of lifts required.

AUSTRODES PAVEMENT DESIGN:

Austroads is the peak organisation of Australasian road transport and traffic agencies, including those in Australia. It plays a crucial role in researching, publishing guidelines, and setting standards for road design, construction, maintenance, and safety, including pavement design. Austroads' work is highly influential in shaping pavement engineering practices across Australia and New Zealand, aiming to enhance the efficiency and safety of road networks while considering environmental sustainability.

A typical example of pavement design according to the Austroads standard involves several key steps:

1. Determine the Pavement Design Traffic:

This involves calculating the number of Equivalent Standard Axle Loads (ESALs) that the pavement is expected to support over its design life. The calculation considers factors such as traffic growth, distribution of heavy vehicles, and axle configurations.

2. Subgrade Assessment:

The strength and properties of the subgrade material are evaluated using the California Bearing Ratio (CBR) test or other relevant tests. The subgrade performance influences the thickness and materials needed for the pavement layers.

3. Material Selection:

Based on the subgrade assessment and the expected traffic loads, suitable materials for the subbase, base, and surfacing layers are selected. Material selection also considers local availability, cost, and environmental factors.

4. Structural Design:

The structural design process uses the determined traffic loads and material properties to calculate the required thicknesses of the pavement layers. Austroads provides methods for designing both flexible and rigid pavements. For flexible pavements, the design might involve the use of empirical formulas or mechanistic-empirical design principles. For rigid pavements, considerations such as slab thickness, joint spacing, and reinforcement are made.

The specific details, such as layer thicknesses and material types, would depend on the outcomes of the design process steps, including traffic loads, subgrade strength, and environmental conditions.

COMARISON OF UK, USA and AUSTRALIAN PAVEMENT DESIGNS STANDARDS:

- **Design Philosophy**: The UK and Australia both use a mix of performance-based and empirical methods, with a strong emphasis on sustainability and the use of recycled materials. The US, while historically relying on empirical methods from the AASHO Road Test, is moving towards more mechanistic-empirical methods with the adoption of the MEPDG.

- **Methodology**: The UK and Australia utilize the CBR method for subgrade evaluation, while the US has traditionally used the Structural Number concept and is now incorporating more advanced mechanistic-empirical models through MEPDG.
- **Sustainability**: All three countries are increasingly focusing on sustainable pavement design, though the extent and methods of incorporating sustainability into design standards may vary.
- **Adaptation to Local Conditions**: Each country's methodology is adapted to its specific environmental conditions, traffic patterns, and material availability, reflecting the need for local customisation in pavement design.
- E**volution of Design Practices**: There is a global trend towards incorporating more mechanistic-empirical design methods that can more accurately predict pavement performance and consider a broader range of factors, including environmental impacts.

Overall, while there are similarities in the basic principles of pavement design among the UK, USA, and Australia, each country has developed its standards and methodologies to suit its specific needs, resources, and experiences.