- pavement composition
- drainage
- ground water condition
- traffic volume

As described in 2.5.1 Asphalt Pavement of this guide line, the design of pavement thickness shall be based on that for new construction.

2.4 Rehabilitation of Cement Concrete Pavement

2.4.1 Evaluation of Pavement Condition

Evaluation of pavement condition can be classified into two types, namely; evaluation by M.C.I. method and evaluation by damage type criteria for rehabilitation.

(1) Evaluation of pavement condition by M.C.I. method

In order to secure good condition of pavement, it is necessary to rehabilitate the damage of pavement at appropriate timing. It is desirable to use the M.C.I. rating method for evaluation to determine the necessity and extent of the rehabilitation for the pavement. The following formula is employed to evaluate the cement concrete pavement condition in the study.

The details of this formula is shown in Chapter 1, Pavement Rehabilitation of this report.

$$M.C.I. = 10 - 0.83C^{0.3} - 2.65\sigma^{0.2} \quad \dots\dots\dots\dots\dots\dots\dots (6)$$

where: C : Cracking index (cm/m^2)

σ : Standard deviation of longitudinal roughness (mm)

M.C.I. formula have been developed in order to evaluate the pavement condition of the roads quantitatively and, to determine the needs for rehabilitation. In practice, it is used in the following procedure for cement concrete pavement;

- To decide whether damaged pavement should be rehabilitated or not.
- To decide the necessity and extent of rehabilitation.
- To indicate the priority of rehabilitation.

Table 2.4.1 describes the degree of rehabilitation required to the pavement condition evaluated by M.C.I. values.

Table 2.4.1 Evaluation of Pavement Condition by M.C.I. Values

M.C.I	Required Extent of Rehabilitation
MCI ≧ 5.0	Unnecessary to repair
4.0 ≦ MCI < 5.0	Maintenance
3.0 ≦ MCI < 4.0	Partial repair
MCI < 3.0	Full scale repair

(2) Evaluation of pavement condition by damage type criteria for rehabilitation

In order to secure the good condition of pavement, it is necessary to rehabilitate the independent type of pavement damages, such as damage of joints and bumps regardless of M.C.I. value, if they are severe.

Hence, it is also necessary to evaluate the degree of damages taking into account damage type criteria for rehabilitation. Table 2.4.2 shows damage type criteria for rehabilitation for cement concrete pavement.

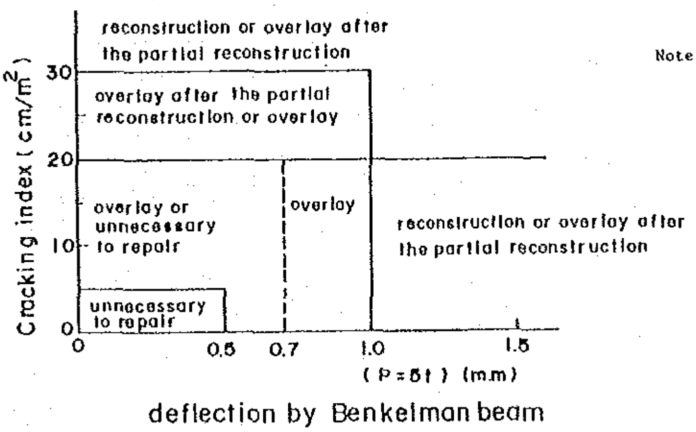
Table 2.4.2 Damage Type Criteria for Rehabilitation
(Cement Concrete Pavement)

Item / Road Classification	Rutting depth (mm)	Bump (mm)	Skid Resistance Coefficient	Longitudinal Roughness (mm)	Cracking index (cm/m²) (develops the bottom of the slab)	Joint damage
Highways with heavy traffic	30-40	15	0.25	5.0 (σ) (3 m profile)	30	If the damage can be found
Other highways	40-50	-	-	-	50	

2.4.2 Selection of Rehabilitation Method

In order to select the suitable rehabilitation method for damaged pavement, the comprehensive consideration of the following items are necessary.

- M.C.I. value (Table 2.4.1)
- Damage type criteria for rehabilitation (Table 2.4.2)
- Rehabilitation methods by type of damages (Table 2.4.3)
- Rehabilitation method which can be determined by relationship between cracking index and deflection (Figure 2.4.1).



Note 1) If the pavement condition (on certain road section) is considered as "unnecessary to repair", routine pavement maintenance should be carried out carefully together with the regular observation of condition of cracking and deflection.

2) If the pavement condition is considered as between two levels, higher ranking method should be adopted unless under the special circumstances.

3) Even though the pavement condition is considered as "Overlay" it is desirable to carry out sub-sealing work before overlay work or partial reconstruction work on certain spots, if the pavement of the certain road sections is under the following condition:

- There is any void under the concrete slab;
- Average deflection at road section with cracking is more than 0.7 mm or
- Cracking index is big.

Figure 2.4.1 Selection of Rehabilitation Method by Cracking Index-Deflection

Table 2.4.3 Rehabilitation Methods for Cement Concrete Pavement by Type of Damages

Type of Damage	Rehabilitation method
Cracking which undevelop to the bottom of concrete slab	. Seal by paraffin, Synthetic rubber, Resin, Asphalt emulsion
Roughness near to a structure and Bump between slabs	. Injection method, . Patching, . Overlay, . Reconstruction
Longitudinal roughness	. Injection method, . Patching, . Overlay, . Reconstruction
Ravelling	. Patching, . Surface treatment, . Overlay
Polishing	. Resinous seal coat, . Overlay, . Grooving
Scaling	. Patching, . Surface treatment, . Overlay
Damage of joint-sealer	. Excision of joint sealing, . Injection of joint sealer
Damage on edge of joint	. Patching by cement mortar, . Resinous mortar or cement concrete
Perforation	- ditto -
Cracking which develop to the bottom of concrete slab	. Injection method, . Partial reconstruction, . Overlay, . Patching
Blow-up	. Reconstruction
Crashing	. Patching, . Reconstruction

2.4.3 Rehabilitation Method

In general, life span of cement concrete pavement is longer than that of asphalt pavement, if the suitable maintenance work would be carried out. However, if cement concrete pavement are damaged such as joint failure, cracking and bump, the life span of cement concrete pavement is rapidly shortened.

It is very important to detect damaged pavements in early stage and to repair them properly in order to extend their life span.

The rehabilitation methods are classified into two types i.e. the maintenance method and repair method. The typical maintenance methods are shown below.

- Injection of joint sealer into the joint and cracking sites
- Patching
- Surface treatment
- Partial reconstruction
- Injection

The types of repair methods are shown below.

- Overlay
- Reconstruction

(1) Maintenance method

Maintenance methods are to be carried out to secure the pavement performance.

1) Injection of joint sealer into the joint and cracking spots

a) Damage of joint

There are three types of joint, i.e., expansion joint, construction joint and warping joint. The joint would be damaged by changing of joint widths caused by the change of the surface temperature of pavement. Usually, cracking and breakdown of the cement concrete slab (spalling) occurs at the edge of slab and these damages are mainly caused by joint failure or pumping by seepage of water through the joint. Other causes of the damages are segregation of concrete materials, bump of the slab, bend of joint, poor arrangement of bar, and etc.

b) Injection of joint sealer into the joint and cracking spots

This method is to inject the joint sealer into the joint or cracking spots.

In order to secure the pavement life span and to prevent the progress of pavement damage, this method should be carried out periodically. If this method is to be used for cracking which occurs around underground structure like box culvert, grooving shall be carried out at cracking spots before the injection of joint sealer (see Figure 2.4.2.).

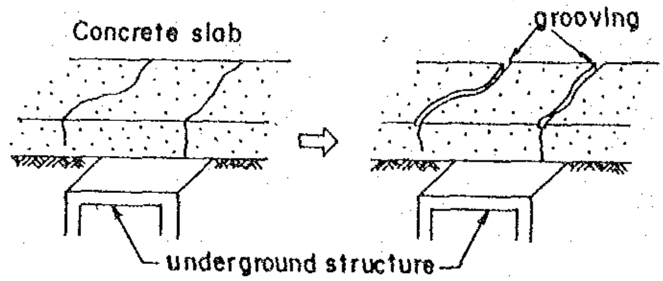


Figure 2.4.2 Repair of Cracking Around the Underground Structure

2) Patching

In order to cover the longitudinal roughness, ravelling, scaling, alligator cracking and bump, etc., this method should be carried out. The materials of this method are classified into three types; asphalt, cement concrete and resin.

a) Patching by cement concrete

Cement concrete is desirable to patch the damaged sites, because workability is high and suitable strength of concrete can be made.

However, this method needs curing period for concrete. The cement can be selected from portland cement, high-early-strength portland cement, super-high-early-strength portland cement, very rapid setting cement and alumina cement.

In case that patching thickness is thin, cement mortar can be used, while in case that patching is thick, concrete can be used and the maximum size of coarse aggregate should be selected to be within one-third of the patching thickness. The concrete used in the work shall be of stiff consistency.

The implementation procedure of this method are shown below.

- The damaged concrete is taken off and chipping of the existing slab shall be done before patching.
- The surface of existing concrete is made to saturated surface-dry condition.
- The surface is covered with cement mortar or cement paste.
- Before the cement mortar or cement paste hardens, concrete or cement mortar shall be spread on the surface and its compaction and curing shall be carried out fully.

b) Patching by asphalt

First, the damaged concrete is taken off and the surface is cleaned, and then patching is carried out after tack-coating is done. Asphalt mortar or dence graded asphalt concrete is used for repair of bump.

c) Patching by resin

Resin material is suitable for patching because of short curing time. However, this method is expensive. There are many resins such as epoxy, polyester and polyurethane used in this method, but epoxy resin is prevailing.

Epoxy mortar consists of the binder which are mixed with main ingredient of epoxy resin and setting agent, and aggregate (ex. silica sand and other hard aggregates). In general, the mixture ratio of the binder and aggregate ranges 1:4 - 1:10.

Implementation Procedure:

- Damaged concrete, joint sealer, oil, asphalt, paint for marking and the dust are taken off from the damaged spot.
- The surface of damaged spot is dried up.
- The primer is spread on the dry surface of damaged spot.
- The epoxy mortar is spread and compacted fully.

3) Surface treatment

Where the local alligator cracking, ravelling, polishing and scaling occur on the concrete slab, thin surfacing should be carried out on the damaged surface of slab.

In general, implementation of procedure is similar to patching method. For anti-skid pavement, surface treatment with resin material is used.

4) Partial reconstruction

When the crackings which develop to the bottom of concrete slab occurs on the edge or transverse of the concrete slab, and the load transmission worsen on the damaged slab, the damaged slab should be reconstructed. It is important that the cause of damage should be eliminated before the reconstruction.

Where the cracking occurs on the edge of both side of joint, the reconstruction of the slab should be carried out one side by one side.

Where the transverse cracking occurs on the slab within 3m from joint, the portion of the slab between the joint and the cracked zone are reconstructed. On the other hand if the transverse cracking occures on the slab more than 3m from the joint, partical reconstruction of the pavement should be done only in the zone including the cracking. (see Figure 2.4.3)

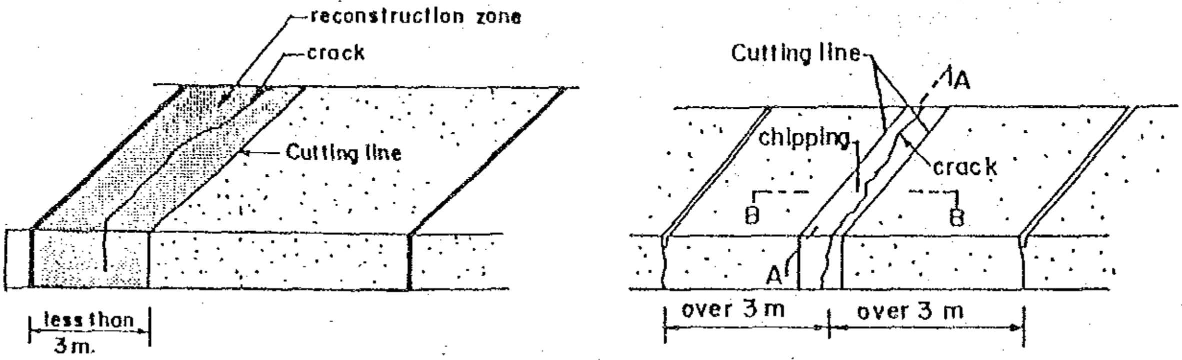


Figure 2.4.3 Example of Reconstruction for Transverse Cracking

5) Injection method

This method is used to fill up the void which occurs between the concrete slab and base course, or to push up the sinking concrete slab in order to level the concrete slab.

In order to extend the pavement life span, injection method is effective. Injection method is classified into two types, i.e. injections by asphalt and cement.

a) Injection method by asphalt

The road which use this method can be reopened quickly, after asphalt is injected into void between the concrete slab and base course. The blown asphalt (penetration index is 10 to 40) is normally used in this method.

The implemention procedure of this method is described below.

- A hole is made by jack hammer on the concrete slab in order to inject the asphalt into void between the concrete slab and base course. The hole size depends on the size of the nozzle for injection (usually, 50mm to 60mm).

  As the arrangement of the hole for injection control the quality of injection, hole arrangement should be carefully determined considering such factors as the concrete slab thickness, condition of cracking, injection machine, injection pressure and bituminous material for injection. The examples of the arrangement of the hole for injection are shown in Figure 2.4.4.

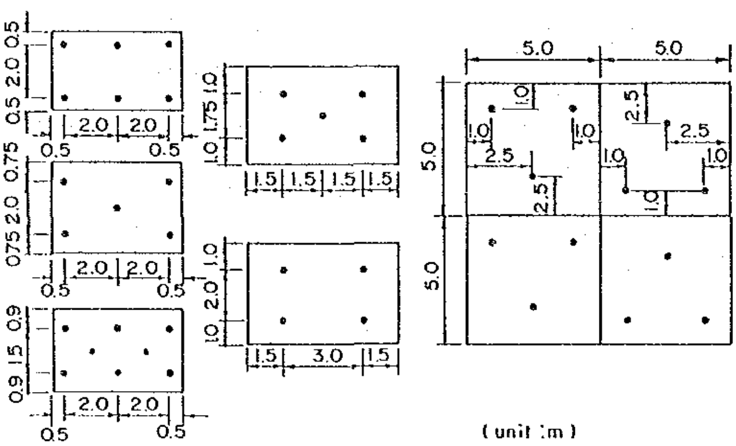


Figure 2.4.4 Example of Arrangement of Holes for Injection

- The holes are cleaned and the void under the slab is blown off by compressed air. This is done in order to let the injected asphalt go into the void smoothly.
- The asphalt is dissolved by heating(over 210°C) and dissolved asphalt is injected by asphalt-distributor which uses the nozzle for injection as shown in Figure 2.4.5 (Pressure of injection is 2 - 4 kg/cm^2, volume of asphalt to be injected is 2 - 6 kg/cm^2 in general).
- During the injection, it is necessary to pay attention not to let out the asphalt from hole, joint and cracking site.
- The nozzle for injection should remain inserted in the hole 30 seconds after the injection then, the nozzle is taken off, and the wooden stopper is pushed into the hole at once.
- When the asphalt becomes hard and its temperature decreases, the hole shall be covered by cement mortar or asphalt mortar.

In general, the road which use this method can be reopened to traffic within 30 minutes to one hour after implementation.

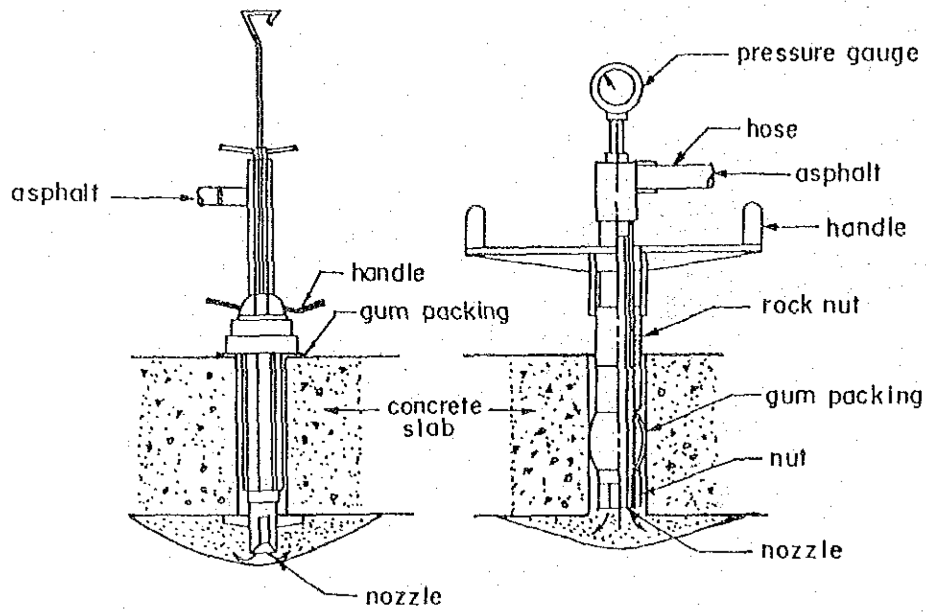


Figure 2.4.5. Examples of Injection Nozzle for Asphalt

b) Injection by cement

There are two cases to use this method, i.e. to fill up the void which occurs between the bottom of the slab and base course, and to level the sunk concrete slab. The curing period of injection by cement is longer than that of asphalt.

It is desirable to extend the curing period more than 3 days in order to avoid the pumping. The materials of injection mainly consist of cement and water. However, there are many cases to put in the additives such as, fine-grained soil, fly ash, diatom-earth or lime, together with aluminum powder. The implementation procedure is almost same as asphalt injection.

In case of pushing up the sunk concrete slab, the holes for injection shall be drilled on the slab as shown in Figure 2.4.6. Injection pressure is 3 - 5 kg/cm^2.

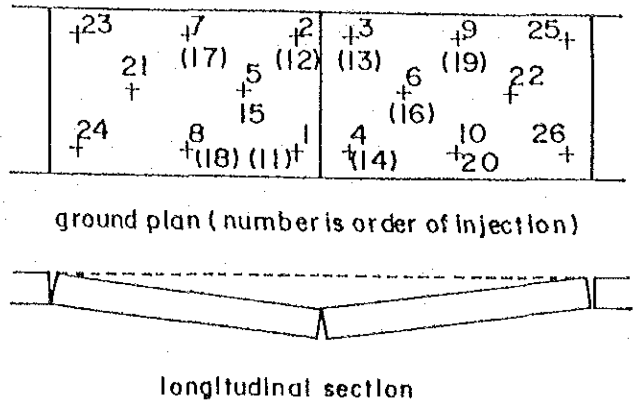


Figure 2.4.6 Example of Pushing Up the Concrete Slab

6) Grooving

Grooving is used to cut the surface either in parallel to the direction of the road or perpendicular to it in order to increase the frictional coefficient when the surface is wet. It is also effective as the counter-measure for hydroplaning.

Nowadays, tine grooving method is also used as simple and economical grooving, which is to scratch fresh cement concrete pavement surface with steel wire.

(2) Repair method

1) Overlay

Overlay works are usually carried out where there are many damages, such as crackings, wearing of surface and stripping of surface on pavements.

When the overlay works are carried out for the repair of cracking, it is necessary to pay attention to prevent the reflection crack. In general, asphalt mix is used for the overlay works.

a) Design of overlay thickness

Design of overlay thickness of cement concrete pavement is similar to that of asphalt pavement. However, it is desirable that the minimum overlay thickness is 8 cm, while maximum thickness is 15 cm.

b) Method to prevent the reflection crack

If overlay thickness is insufficient, an reflection crack often occurs on the surface of pavement. Therefore, it is important to prevent the reflection crack. There are two methods to check this reflection crack. One of the methods is to utilize the sheet which is cotton or polypropylene cloth covered with blown asphalt between the surface of cement concrete slab and the bottom of overlay layer, and the other is to utilize the opengraded asphalt concrete as the binder course.

2) Reconstruction

This method should be carried out when the concrete slab damage is remarkable and it cannot be repaired by any other methods such as overlay.

There are two types of reconstruction, i.e. reconstruction by asphalt pavement and cement concrete. In selecting pavement type, it is necessary to consider the reconstruction area, subgrade condition, base course condition, and traffic condition.

The design method of pavement thickness is based on that of pavement for new construction which will be described in 2.5.2 of this guideline, or it is as same as neighboring pavement composition.

2.5 Pavement Design for New Construction

2.5.1 Asphalt Pavement

This method is based on the CBR method. The principal factors of this design method are described below.

- Bearing capacity of subgrade is obtained by the CBR method.
- Layer equivalency obtained by the AASHO road tests is used.
- The traffic volume is classified according to the distribution of vehicle weights.

Details of design are described below.

(1) Pavement design classification of roads by traffic volume

As the first step, the one-way daily traffic volume of heavy vehicle in 5 years is estimated to determine pavement design classification of roads by traffic volume as shown in Table 2.5.1.

Table 2.5.1 Pavement Design Classification by Traffic Volume

Classification	One Way Daily Traffic of Heavy Vehicles
L	Less than 100
A	100 to 250
B	250 to 1,000
C	1,000 to 3,000
D	More than 3,000

"Heavy vehicles" refers to buses, mini buses, truck with over 6 wheels, trailers and tractors.

For roads with 3 or more traffic lanes, the design traffic load may be taken at about 80% of the estimated traffic when designing its pavement.

For the design of pavements catering for particularly large volume of heavy vehicle or heavy wheel loads, the application shall be referred to Appendix 2.5.1.

(2) Design CBR

For the design of pavement thickness, subgrade[2/] soils are sampled to determine the design CBR. In determining the design CBR, preliminary studies (including soil tests) and CBR tests shall be performed.

1) Determination of CBR value for individual spots

For any given locations, where multiple strata of different soil types or conditions exist within 1.0 m depth from the subgrade level, the average CBR value of the soil within this depth should be taken as the CBR value for that location. In calculating the average value, the filter course should be ignored.

Where replacement or stabilization of the subgrade soil is done, the total depth of soil undergone such treatment minus 20 cm is taken as the effective depth of subgrade soil improvement. For the bottom 20 cm of the improved soil, the CBR value is taken at the same value as that of the original soil in the case of soil replacement, and the average of the CBR values before and after the treatment in the case of soil stabilization. The maximum CBR value of an improved subgrade soil is limited to 20. For the calculation of the average CBR value, the following equation shall be applied.

$$CBRm = \left(\frac{h_1 \cdot CBR_1 + h_2 \cdot CBR_2 + \ldots + hn \cdot CBRn}{100}\right) \qquad \ldots\ldots\ldots(7)$$

where CBRm : Average CBR of the location
CBR_1, CBR_2, ..., CBRn : CBR value of each layer
h_1, h_2, ..., hn : Thickness of each layer
$h_1+h_2+\ldots+hn = 100$ (cm)

2) Determination of design CBR

The road section to be constructed with a uniform pavement thickness shall be determined based on the results of preliminary studies and the CBR test. The design CBR is determined based on CBR values of individual locations within the road section, with extreme values discarded, by the following formula.

$$\text{Design CBR} = \text{Average value of CBR of individual} - \frac{(\text{Max.CBR} - \text{Min.CBR})}{C} \qquad \ldots\ldots\ldots(8)$$

2/ The subgrade depth is defined approximately 1 m below the subbase bottom.

where C is a coefficient given in Table 2.5.2.

Table 2.5.2 Values of C for Calculating Design CBR.

No. of Values Avaliable (n)	2	3	4	5	6	7	8	9	10 or more
C	1.41	1.91	2.24	2.48	2.67	2.83	2.96	3.08	3.18

Where design CBR of the subgrade is below 2, the subgrade should be improved to obtain a design CBR greater than 3.

(3) Design of pavement thickness

Pavement thickness shall be designed based on the design CBR and the pavement design classification of road by traffic volume given in Table 2.5.1, so that each individual course does not fall below the target value of T_A shown in Table 2.5.3 and that the total pavement thickness does not become smaller than the target total thickness in Table 2.5.3 by 1/5 or more.

Table 2.5.3 T_A Target Values and for the Total Pavement Thickness, H, cm

Design CBR equal to larger than	Road Classification (cm.)									
	L		A		B		C		D	
	T_A	H	T_A	H	T_A	H	T_A	H	T_A	H
2	17	52	21	61	29	74	39	90	51	105
3	15	41	19	48	26	58	35	70	45	83
4	14	35	18	41	24	49	32	59	41	70
6	12	27	16	32	21	38	28	47	37	55
8	11	23	14	27	19	32	26	39	34	46
12	-	-	13	21	17	26	23	31	30	36
20 or more	-	-	-	-	-	-	20	23	26	27

Where the design CBR of the subgrade soil is 2 to 3, a filter course of 15 to 30 cm in thickness should be laid as part of the subgrade. Pavement thickness in this case is determined based on the design CBR of the subgrade soil, without taking the CBR of the filter course into account. Where the soil varies in the subgrade depending on the depth, construction of a filter course is not required even if the design CBR falls below 3, provided that the CBR of the uppermost layer, 30 cm or more in thickness, is 3 or more.

T_A represents the pavement thickness which would be required if the entire depth of the pavement is to be constructed of hot asphalt mixes used for binder and surface courses.

(4) Pavement structure

In determining the pavement structure, a tentative design is first made using a minimum combined thickness of the binder and surface courses as taken from Table 2.5.4 and the process exemplified in the next section "5) Design Example" shall be followed to obtain the values of T_A and the total pavement thickness. These values are then compared with the target values given in Table 2.5.3. When the value of T_A falls below the target, or when the total pavement thickness, H is found to fall below the target by 1/5 or more, the above process is repeated with an alternative design, until the final design which meets the targets is obtained.

Table 2.5.4 Minimum Combined Thickness of Binder and Surface Courses

Road Classification	Minimum Combined Thickness of Binder and surface Courses (cm.)
L, A	5
B	10 (5)
C	15 (10)
D	20 (15)

For the calculation of T_A, the following formula is applied.

$$T_A = a_1T_1 + a_2T_2 + \ldots + a_nT_n \qquad (9)$$

where $a_1, a_2, \ldots, an$: Coefficients of relatives strength given in Table 2.5.5

$T_1, T_2, \ldots, Tn$: Thickness of individual layers of pavement, cm.

Table 2.5.5 Coefficients of Relative Strength for Calculating T_A

Pavement	Method and Material of Construction Used	Conditions	Coefficient
Binder and Surface Course	Hot asphalt mix for binder and surface courses		1.0
Base	Bituminous stabilization	- Hot-mixed Marshall stability:350 kg or more	0.80
		- Cold-mixed, Marshall stability:250 kg or more	0.55
	Cement Stabilization	- Unconfined compressive strength (7 days):30 kg/m^2	0.55
	Mechanically Stabilized Gravel	- Modified CBR:80 or more	0.35
Subbase	Crusher-run,	- Modified CBR:30 or more	0.25
	Sand, etc.	- Modified CBR:20 or more, less than 30	0.20
	Cement Stabilization	- Unconfined compressive Strength (7 days):10 kg/m^2	0.25

Note : Layer coefficient for any construction method or material other than those listed in Table 2.5.5 should only be adopted when based on established engineering experience

Coefficient of relative strength in Table 2.5.5 indicates in cm the thickness of hot asphalt mix used in constructing binder and surface courses, having a strength equivalent to 1 cm layer of pavement of other materials and methods of construction. For example, the coefficient being 0.35 for a mechanically stabilized material indicates that the strength of a 1 cm layer of such material is equivalent to that of a 0.35 cm layer of hot asphalt mixes used in binder and surface courses.

(5) Design examples

1) Design conditions

- Pavement Design classification of road by traffic volume : C
- Design CBR of subgrade : 3
- Strength of available materials
  . crusher-run : modified CBR = 30
  . crusher-run mechanically stabilized by adding pit sand : modified CBR=80
  . crusher-run with bituminus stabilization : marshall stability = 250 kg
  . crusher-run with cement stabilization : unconfined compression strength = 30 kg/cm^2

2) Design examples

From Table 2.5.3 the target values are: T_A=35cm, and H=70cm. Therefore, the minimum required total pavement thickness is: 70 x (1-1/5) = 56 cm. The minimum combined thickness of the binder and surface courses according to Table 2.5.4 is 10 cm in case of the base being treated by bituminous stabilization and 15 cm otherwise.

a) For alternative design (a) in Figure 2.5.1 T_A and H are:

T_A = 1.0x10 + 0.8x12 + 0.35x25 + 0.25x30 = 35.9cm

H = 10 + 12 + 25 + 30 = 77 cm

which satisfy the target values in Table 2.5.3.

b) In case where the base is treated by cement, the required combined thickness of the binder and surface courses is 15 cm according to Table 2.5.4 and since the minimum required depth of cement stabilization is 20 cm. the value of T_A for these courses is:

1.0x15 + 0.55x20 = 26 cm

and the required value of T_A for the layer of mechanically stabilized gravel or crusher-run is:

35-26 = 9 cm

Assuming the layer of crusher-run to be 40 cm thick, the pavement composition would be as illustrated in Figure 2.5.1(b) and the value of T_A and the pavement thickness H would be:

T_A=1.0x15 + 0.55x20 + 0.25x40 = 36 cm

H = 15 + 20 + 40 = 75 cm

c) In case where both bituminous and cement stabilization are uneconomic for construction of the base, and the use of mechanically stabilized gravel is accordingly preferable, the value of T_A for binder and surface courses combined is:

$1.0x15 = 15$ cm

and the value of T_A to be contributed by mechanically stabilized gravel and crusher-run becomes:

$35-15 = 20$ cm

With a 40 cm layer of mechanically stabilized gravel and a 25 cm layer of crusher-run, the required value of T_A is satisfied as:

$0.35x40 + 0.25x25 = 20.3$ cm

The cross section becomes as shown in Figure 2.5.1(c). The value of T_A and the thickness H of this pavement become as follows:

$T_A = 1.0x15 + 0.35x40 + 0.25x25 = 35.3$ cm

$H = 15 + 40 + 25 = 80$ cm

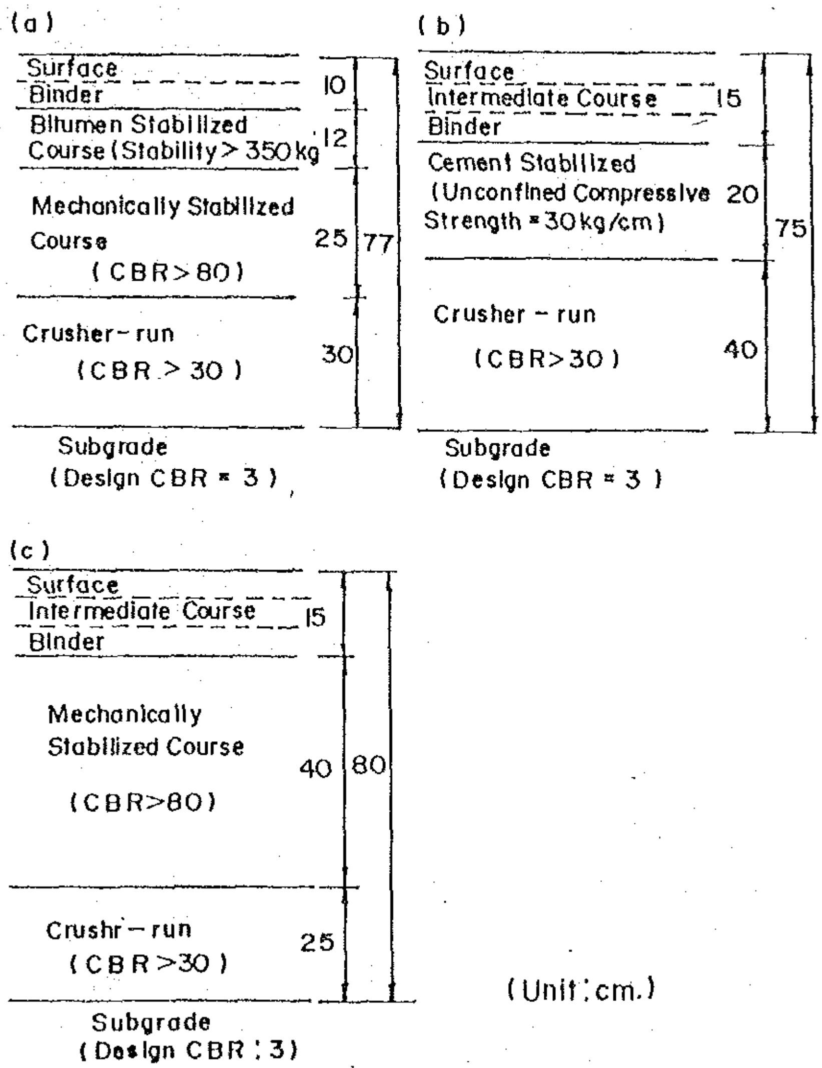


Figure 2.5.1 Pavement Design Examples

2.5.2 Cement Concrete Pavement

The principal features of this design method are described below.

- There are two kind of design methods for base course.
- The pavement design classification of road by traffic volume is same as the design method of asphalt pavement.

Details of design are described below.

(1) Pavement design classification of roads by traffic volume

Pavement design classification of roads by traffic volume is shown in Table 2.5.1.

(2) Strength of subgrade

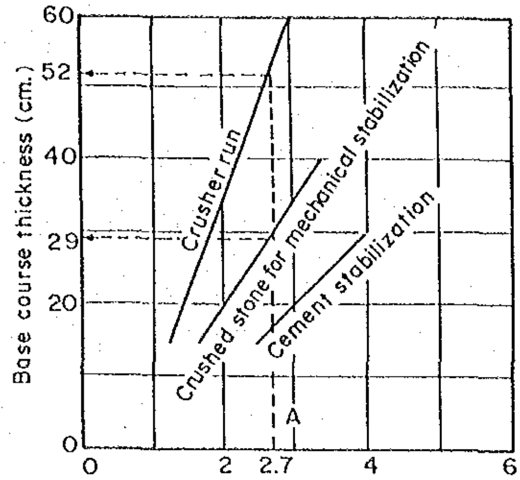
Strength of subgrade is evaluated by the design CBR. Design CBR is determined by CBR value which is obtained from CBR test. Where, the CBR value of the subgrade is less than 2, the subgrade should be improved to obtain the CBR value greater than 3.

(3) Design of base course

There are two kinds of design methods for base course. One is the design method which is based on the coefficient of bearing capacity of subgrade and the other is the method which is in accordance with the design CBR of subgrade.

1) Design of base course by coefficient of bearing capacity of subgrade

To obtain base course thickness from coefficient of bearing capacity, it shall be so designed that; coefficient of bearing capacity of base course in B, C, and D road types shall be K_1=20kg/cm^3 and over; and in L, A road types K_1=15kg/cm^3 and over respectively. Design method includes: design curve as illustrated in Figure 2.5.2. For measurement of coefficient of bearing capacity, a loading plate 30cm in diameter shall be used.



$$\frac{\text{Coefficient of bearing capacity of base course}}{\text{Design coefficient of bearing of subgrade}} = \frac{K_1}{K_2}$$

[Example]

Traffic classification : C :
and coefficient of bearing capacity of subgrade : 7.4

$$\frac{K_1}{K_2} = \frac{20}{7.4} = 2.7$$

(In the illustrated marked (A))

Therefore in the case of crusher-run, 52 cm, while in the case of crushed stone for mechanical stabilization, 29 cm.

Figure 2.5.2 Design Curve of Base Course
(Using 30 cm Loading Plate)

2) Design of base course by design CBR of subgrade

For design of base course thickness from design CBR of subgrade, the value in Table 2.5.6 shall be used as the base course thickness in accordance with pavement design classification of road by traffic volume and design CBR.

Table 2.5.6 Relationship between Design CBR and Base Course Thickness

(Unit : cm)

Traffic Classification \ Design CBR of subgrade	2	3	4	6	8	12 and over
L and A traffic	50	35	25	20	15	15
B, C and D traffic	60	45	35	25	20	15

(4) Design of cement concrete slab

1) Design bending strength of concrete

Design bending strength of concrete for design of concrete pavement shall be 45kg/cm^2 (age 28 days), but roads classified in L and A are allowed to be designed with 40kg/cm^2, if large amounts of cement content are needed to obtain the design bending strength of concrete to be 45kg/cm^2.

2) Standard thickness of concrete slab

Standard thickness of concrete slab in accordance with pavement design classification of road by traffic volume is shown in Table 2.5.7.

Table 2.5.7 Standard Thickness of Concrete Slab

Traffic Classification	Thickness of Concrete Slab (cm)
L traffic	15 (20)
A traffic	20 (25)
B traffic	25
C traffic	28
D traffic	30

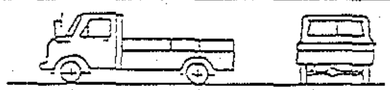
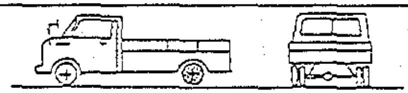
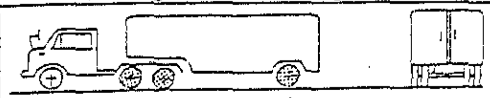
Note : Figures in parentheses are under bending strength of 40 kg/cm^2 in L and A traffic.

2.5.3 Continuous Reinforced Concrete Pavement

The details of this pavement is described in Appendix 2.5.2.

APPENDICES

Standard Axle Load in Thailand

No.	Distribution of axle load ○ Single tire ◍ Double tire	1st axle number of axle	1st axle Type of Tire	1st axle axle load (Kg)	2nd axle and 3rd axle or trailer number of axle	2nd axle and 3rd axle or trailer Type of Tire	2nd axle and 3rd axle or trailer axle load (Kg)	number of total tire	gross weight (Kg)
1	 1,700 kg. 6,800 kg.	1	Single	1,700	1	Single	6,800	4	8,500
2	 2,900 kg. 9,100 kg.	1	Single	2,900	1	Double	9,100	6	12,000
3	 4,600 kg. 8,200kg 8,200 kg.	1	Single	4,600	2	Double	8,200 8,200	10	21,000
4	 4,600 kg. 8,200kg 8,200kg. 8,200kg. 8,200 kg.	1	Single	4,600	2	Double	8,200 8,200 8,200 8,200	18	37,400
5	 4,600kg. 8,200kg. 8,200kg. 9,100kg.	1	Single	4,600	2	Double	8,200 8,200 8,200	14	30,100

TEST FOR DEFLECTION OF ASPHALT PAVEMENT

STUDY ON ROAD IMPROVEMENT REHABILITATION AND TRAFFIC SAFETY IN BANGKOK

District : BANGKOK YAI

Surface temperature : 41.7 c°

Route Name : ITSARAPHAP

Weather : (clear), cludy, after rain

Date 27th, JUNE, 1986

Pavement condition : (dry), wet

	D_1 (LEFT)		D_2 (RIGHT)		AV. (mm.)	Surface temperature : c°	Remark
1	0.6		—		0.6	39	
2	—		—		—	43	
3	0.7		—		0.7	42	
4	1.0		0.5		0.75	41	
5	0.6		—		0.6	40	
6	1.2		0.35		0.775	42	
7	0.85		1.0		0.925	42	
8	0.95		0.5		0.725	42	
9	0.7		—		0.7	44	
10	1.1		0.8		0.95	42	
(i) Total						417	
α : Average ((i)/ number of deflection value)					0.78	41.7	

$\sqrt{V} = 0.252$

* Remark : measuring point ; joint or cracking site
(J) (C)

TEST FOR DEFLECTION OF CONCRETE PAVEMENT

STUDY ON ROAD IMPROVEMENT REHABILITATION AND TRAFFIC SAFETY IN BANGKOK

District : YANNAWA

Surface temperature : ______ C°

Route Name : NANG LINCHI

Weather : clear, cludy, after rain

Date 20 , 9 , 1985

Pavement condition : (dry), wet

	D1	L	D2	R	AV. (mm.)	Remark
1	0	00	0	20	0.10	C
2	0	00	0	20	0.10	C
3	0	10	0	30	0.20	J
4	0	00	0	55	0.275	C
5	0	00	0	70	0.35	J
6	0	10	0	15	0.125	C
7	0	00	0	65	0.325	J
8						
9						
10						
(i) Total						
d : Average					0.211	(i)/ number of deflection value

* Remark : measuring point ; joint or cracking site
(J) (C)

TEST FOR DEFLECTION OF CONCRETE PAVEMENT

STUDY ON ROAD IMPROVEMENT REHABILITATION AND TRAFFIC SAFETY IN BANGKOK

District : PHAYA THAI　　Surface temperature : ______ C°

Route Name : PHETCHABURI　　Weather : clear, cludy, after rain

Date 21 , 9 , 1985　　Pavement condition : (dry), wet

	D_1 L		D_2 R		AV. (mm.)	Remark
1	0	20	0	40	0.30	C
2	0	20	0	30	0.25	J
3	0	20	0	50	0.35	C
4	0	10	0	50	0.30	C
5	0	20	0	10	0.15	J
6	0	10	0	25	0.175	C
7	0	30	0	45	0.375	C
8						
9						
10						
(I) Total						
α : Average					0.271	(I)/ number of deflection value

* Remark : measuring point ; joint or cracking site
(J) (C)

TEST FOR DEFLECTION OF ASPHALT PAVEMENT

STUDY ON ROAD IMPROVEMENT REHABILITATION AND TRAFFIC SAFETY IN BANGKOK

District : PHAYA THAI

Route Name : SUTHISARN RD.

Date 29 th, JUNE, 1986

Surface temperature : 31.1 C°

Weather (clear), (cludy), after rain

Pavement condition : (dry) wet

	D_1 (LEFT)		D_2 (RIGHT)		AV. (mm.)	Surface temperature : C°	Remark
1	0.3		0.1			31	
2	0.35		—			31	
3	0.5		0.2			31	
4	0.4		0.6			31	
5	0.6		0.45			31	
6	0.8		0.8			31	
7	0.9		0.6			31	
8	0.65		0.5			31	
9	0.4		0.45			31	
10	0.5		0.75			31	
(1) Total						311	
α : Average ((1)/ number of deflection value)					0.52	31.1	

$\sqrt{V} = 0.209$

* Remark : measuring point ; joint or cracking site
(J) (C)

TEST FOR DEFLECTION OF ASPHALT PAVEMENT

STUDY ON ROAD IMPROVEMENT REHABILITATION AND TRAFFIC SAFETY IN BANGKOK

District : YANNAWA Surface temperature : 33.4 C°

Route Name : CHAROEN KRUNG Weather : clear, (cludy) after rain

Date 29 th JUNE , 1986 Pavement condition : (dry), wet

	D_1 (LEFT)		D_2 (RIGHT)		AV. (mm.)	Surface temperature : C°	Remark
1	0.6		0.5			33	
2	0.45		0.15			33	
3	0.8		1.05			33	
4	—		0.8			33	
5	0.5		0.6			33	
6	—		0.8			33	
7	0.45		0.9			34	
8	0.55		0.8			34	
9	0.55		0.75			34	
10	0.25		0.6			34	
① Total						334	
α : Average (①/ number of deflection value)					0.62	33.4	

$\sqrt{V} = 0.226$

* Remark : measuring point ; joint or cracking site (J) (C)

Appendix Survey Procedure and Compilation of Survey Results

(1) Survey procedure

1) Survey area

Basically, each area for detailed pavement survey measures 100 m for the longitudinal and one lane width for the cross section.

2) Preparation works for surveys

In order to carry out pavement surveys on a road, it is necessary to pay attention to minimize traffic disturbance and to ensure safety of surveyors as well as road users.

Main preparation works are traffic control, marking of survey lots and preparation of survey equipment.

The arrangement for traffic control is shown in Figure 1.

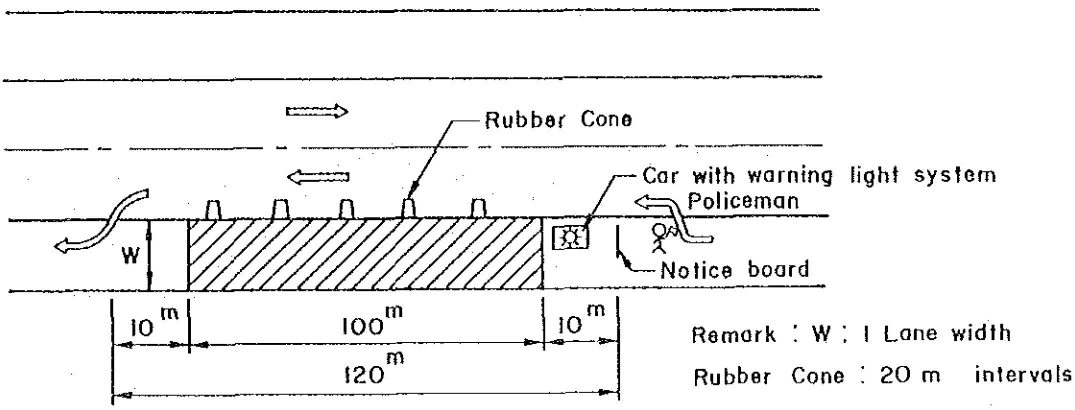


Figure 1 Traffic Control Arrangement

The start point and end point at each survey site are marked with white paint on the road surface, and the pavement surface in the survey lot is marked traversely by white lines at intervals of 5 meters to help cracking surveys.

3) Cracking survey

Cracking survey is carried out by sketching and each length of crack and extent of cracking and patching area are measured at the same time. Figure 2 shows samples of crack sketches.

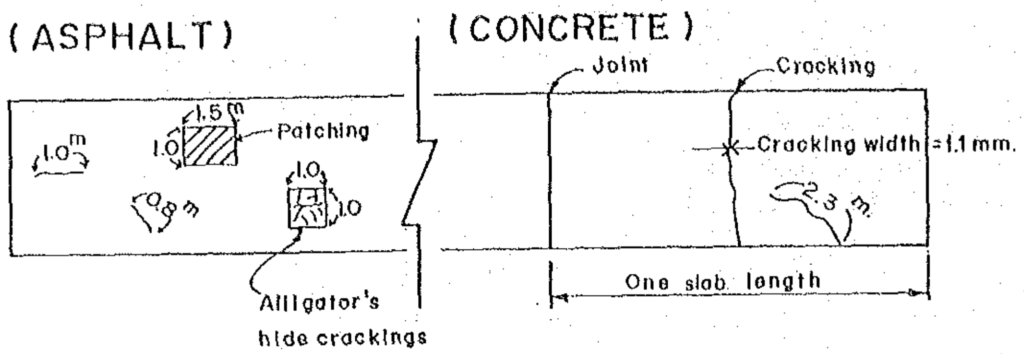


Figure 2 Samples of Crack Sketches

4) Longitudinal roughness survey

A profilemeter (3m type) is employed to measure longitudinal roughness along the dotted line in Figure 3.

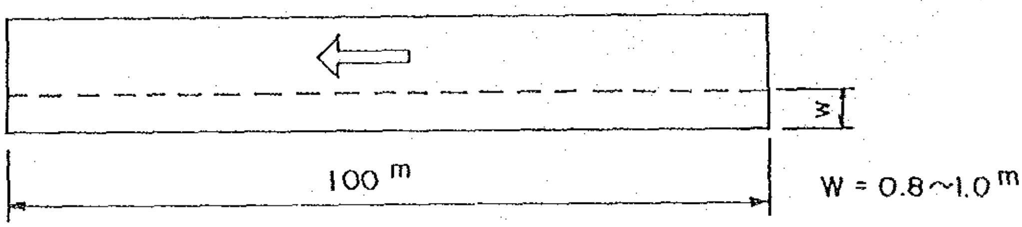


Figure 3 Longitudinal Roughness Survey Line

During the measurements irregular points such as manholes, joints are marked on graph paper of profilemeter for the consideration in the course of data analyses.

5) Rutting depth survey

A profilemeter for cross section measuring type is used to measure rutting depth along the transverse lines at intervals of 20m as shown in Figure 4.

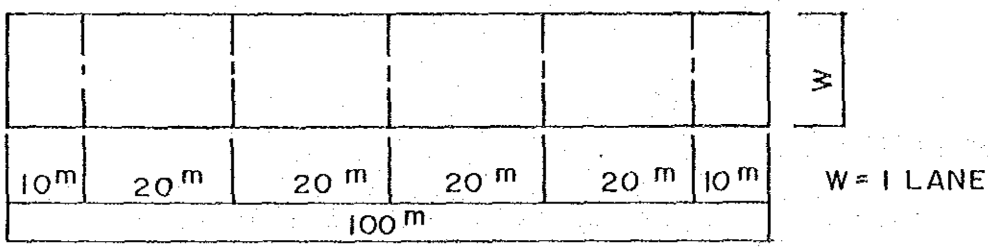


Figure 4 Rutting Depth Survey Line

6) Bump survey at approaching sites of bridge

This survey should be carried out, when road engineer find unusual bumps during routine observation.

There are two method of measuring the bump at approaching sites of the bridge. One method is measuring the bump by using the level, and the other method is measuring it by using the string. Measurement procedure by using the string is summarized below.

Bump at approaching sites of the bridge is measured by the string and the rule as shown in Figure 5.

Longitudinal length of measurement is 10m from the expansion joint of the abutment. Lateral position of measurement might be outer wheel path.

Depth of the pavement surface from the base line string is measured at 0.5m intervals for up to 5m and at 1m intervals from 5 to 10m.

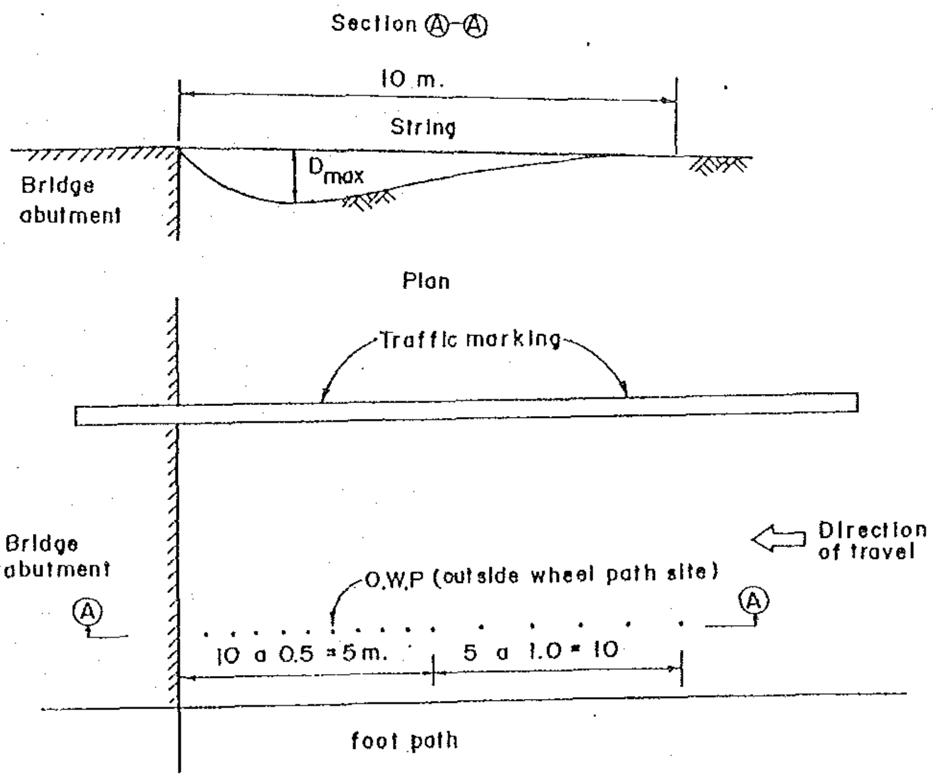


Figure 5 Measuring Points of Bump Survey

The profile of approaching site of bridge is drawn and the maximum depth, Dmax, is read off from the profile.

7) Deflection survey

Deflection of pavement is regarded as an index to show the structual pavement condition. The result of this survey is utilized to evaluate the pavement condition and to design of overlay thickness for pavement.

A Benkelman beam for the measurement of the deflection is employed. Main preparation for the measurement are shown below.

- Adjustment of wheel load
- Adjustment of tire pressure and tire size

For example : Japanese standard
Wheel load : 5 ton
Tire pressure : 6.5 Kg/cm^2
Tire size : 10.00 x 20 - 14PR

The measurement of asphalt pavement deflection is carried out basically at spots indicated in the Figure 6 at each site, while the cement concrete pavement deflection is carried out basically at spots indicated in the Figure 7 at each site.

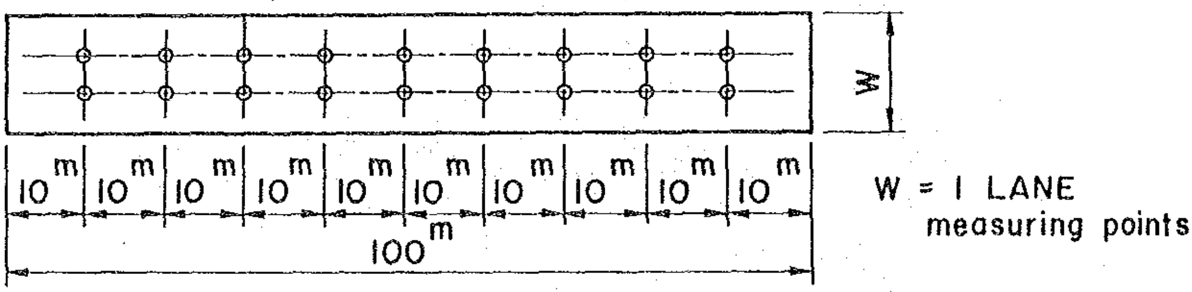


Figure 6 Measuring Points of Deflection Survey on Asphalt Pavement

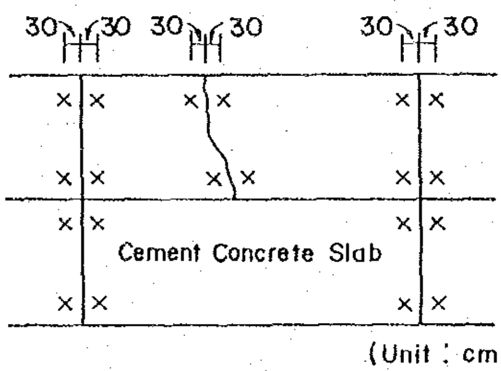


Figure 7 Measuring Points of Deflection Survey on Cement Concrete Pavement

(2) Compilation of survey results

1) Cracking survey

Degree of cracking damage is described by cracking ratio for asphalt pavement and cracking index for cement concrete pavement.

Cracking ratio (%) and Cracking index(cm/m^2) are calculated based on the results of field survey by the following formulas.

Cracking ratio (%)

$$= \frac{\text{Patching area } (m^2) + \text{Cracking area } (m^2)}{\text{Area of survey site } (m^2)} \times 100$$

Cracking index (cm/m^2)

$$= \frac{\text{Cracking length (cm)}}{\text{Area of survey site } (m^2)}$$

2) Longitudinal roughness

A longitudinal roughness of pavement surface is defined by the value of the standard deviation of all recorded roughness measurements over the entire stretch of a survey site.

The procedure of calculation of standard deviation is shown below.

- All of the measurements shall be classified into 6 to 10 groups.
- The differences (Rn) between maximum and minimum values on each group shall be calculated and then the average of the differences (R) shall be computed.
- The standard deviation shall be calculated by the following equation.

$$\sigma = \frac{\bar{R}}{C}$$

σ : Standard deviation (mm)
R : The average value of the difference
(R = Rn/n)
C : A coefficient fixed in accordance with determined number of measurements involved in the group, as shown in Table 1.

Table 1 Values of C for Computation of Standard Deviations

Number of Measurements Involved in a group	C
6	2.53
7	2.70
8	2.85
9	2.97
10	3.08

3) Rutting depth

The rutting depth at each cross section is defined by a bigger value between D1 and D2 (see Figure 8). The rutting depth at a survey site can be represented by an average value of all the data of rutting depth at a survey site.

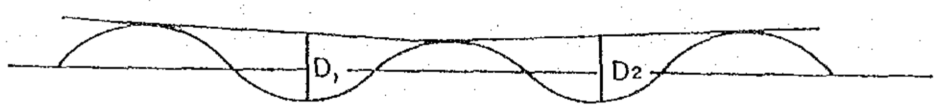


Figure 8 Rutting Depth

Appendix Design Principles for Asphalt Pavement

The required thickness for the asphalt pavement is derived from the following equations:

$$H = \frac{28.0\,N^{0.1}}{CBR^{0.6}} \quad .....(1)$$

$$T_A = \frac{3.84\,N^{0.16}}{CBR^{0.3}} \quad .....(2)$$

where H : The pavement thickness (cm)
T_A : The design thickness, (i.e., the required thickness of a full depth hot mix asphalt pavement having an equivalent strength).
N : The number of equivalent 5ton wheel-loads in one direction to be expected during the 10-year period following construction.

The number of equivalent 5-ton wheel-loads (N) shall be computed based on the result of wheel load survey using the following formula.

$$\alpha_i = \left(\frac{Pi}{5}\right)^4 \quad .....(3)$$

The ten year total of equivalent 5-ton wheel-loads shall be obtained as follows:

$$N = N_5 \times a \times 365 \times 10 \quad .....(4)$$

where αi : The rate of structural damage caused to road pavementby wheel load Pi tons, where αi, for a 5-ton wheel-load equals 1. The values of αi for wheel loads of various magnitude are as shown in Table 1.
Pi : Wheel-loads surveyed at the site.
N_5 : Daily volume of one-way traffic load in equivalent 5-ton wheel-loads.
a : The 5-year traffic volume growth rate.

Table 1 Structural Damage Factor : αi

Equivalent wheel-load Pi(t)	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5
Rate of Structural Damage αi	0.0001	0.008	0.06	0.25	0.65	1.5	2.8	5.0	8.5	13.0	20.0

Figure 1 is a graphic illustration of the required pavement thickness (H) and design thickness (T_A) calculated by the use of Formulas (1) and (2) above for equivalent 5-ton wheel-loads of $3x10^4$, $15x10^4$, $1x10^6$, $7x10^6$ and $35x10^6$ which correspond respectively to traffic classifications L, A, B, C and D.

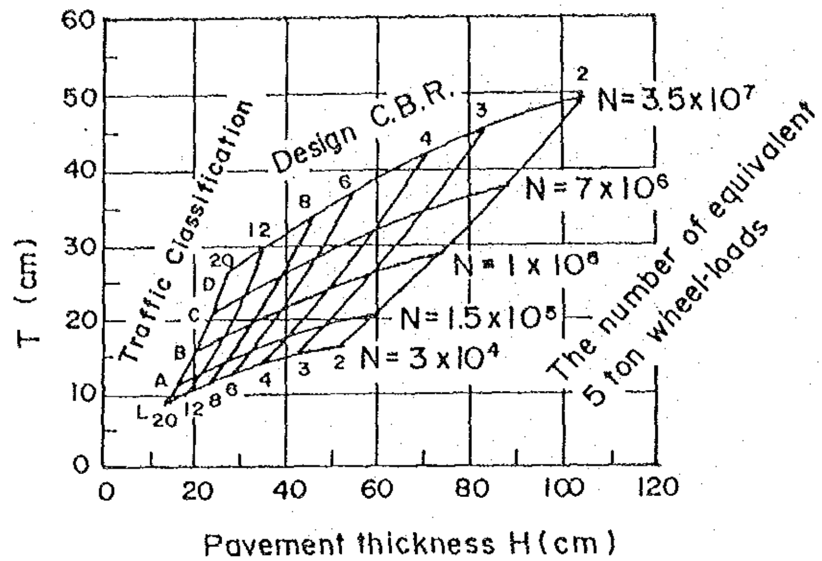


Figure 1 Design Curves

Appendix Continuous Reinforced Concrete Pavement

(1) Thickness of concrete pavement slab

Table 1 Thickness of Concrete Pavement Slab

Classification of Traffic	Thickness of Concrete Pavement Slab (cm)
L, A, B traffic	20
C, D traffic	25

L : heavy vehicle volume are less than 100 Vehicle/day/one direction
A : 100 - 250,
B : 250 - 2000,
C : 1000- 3000,
D : more than 3000

The thickness of slab of the continuous reinforced pavement is decided about 80 - 90 % of ordinary cement concrete pavement slab based on experiences and also the amount of longitudinal reinforcement is about 0.6 - 0.7%.

(2) Diameter and pitch of reinforcement for continuous reinforced concrete slab

Table 2 Diameter and Pitch of Reinforcement for Continuous Reinforced Concrete Slab

Thickness of Concrete Slab (cm)	Longitudinal Reinforcement		Transverse Reinforcement	
	Diameter (mm)	Space (cm)	Diameter (mm)	Space (cm)
20	D 16	15	D 13	60
	D 13	10	D 10	30
25	D 16	12.5	D 13	60
	D 13	8	D 10	30

(3) Quality standards for cement concrete pavement

Table 3 Quality Standards for Cement Concrete Pavement
(Same for the Continuous Reinforced Concrete)

Kinds of Cement Concrete	Case of Usage	Bending Strength on 28 Days Age	Max size of Coarse Agregate (mm)	Consistency		Air Content (%)
				Slump (cm)	Settle-ment (sec)	
H_{1-1}	Ordinary	45	40	1.5±1	30 over	4±1
H_{2-1}	Small Scale by Man Power	45	40	6.5±1.5		4±1

Note: 1. Consistency and air content are shown at the time of placing of concrete
2. When cement for pavement is used, bending strength at 91 days age is used.

(4) Standard cross section of the continuous reinforced concrete pavement

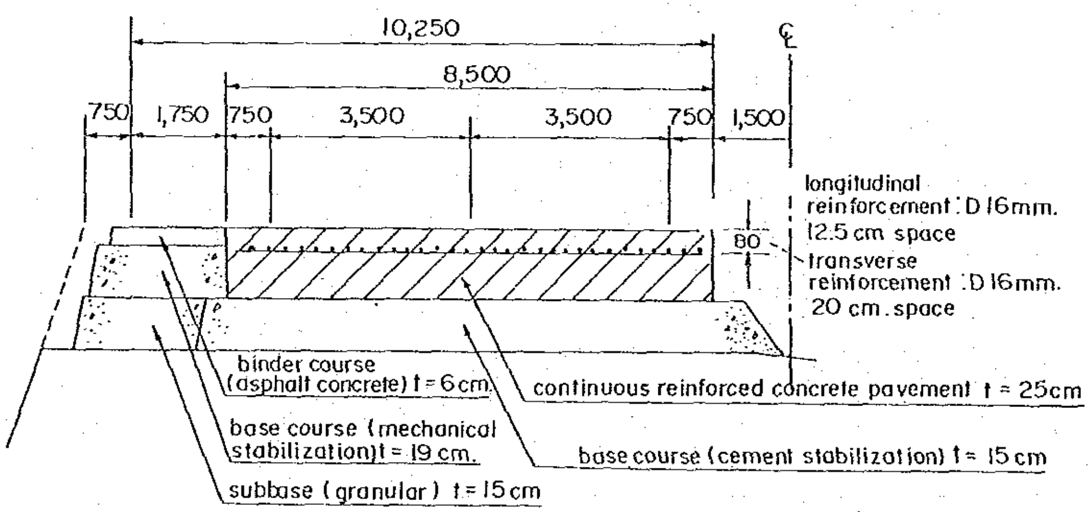


Figure 1 Standard Cross Section of the Continuous Reinforced Concrete Pavement

(5) Treatment of slab end
(Expansion joint for smoothing)

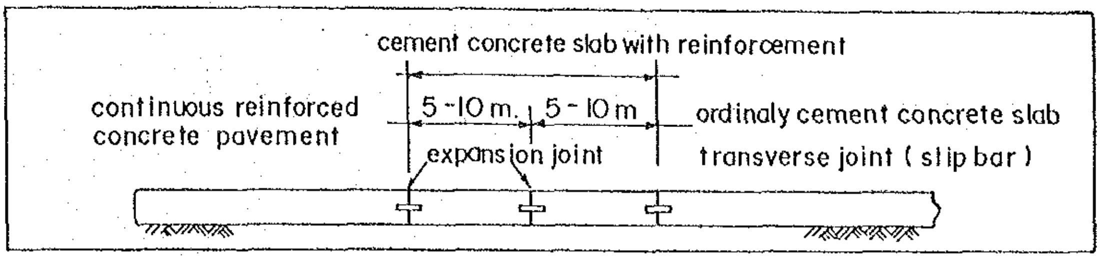


Figure 2 Treatment of Slab End (Expansion Joint for Smoothing)

Table 4 Examples of Implementation (In Japan) (1)

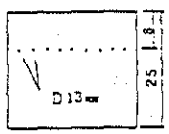
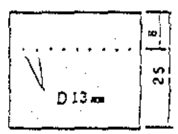
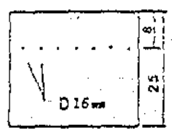
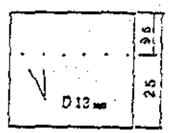
Item	Example of imprementation	National Highway (Route 302)	National Highway (Route 113)	National Highway (Route 7)	National Highway (Route 292)		
Concrete Slab	Thickness (cm)	25cm	25cm	25cm	25cm		
	Width (m)	4m, 3m, 5m 3.5m (total 11m)	3.5m x 2	5-6m x 2	5-7m		
	Length of Imprementation	240m	500m	328m	100-150m 5 sections (L=2040m)		
Reinforcing Steel Bar	Reinforcement Ratio (%)	0.61%	0.61%	0.63%	0.64%		
	Longitudinal	SD-30, D13mm intervals of 8.2cm	SD-30, D13mm intervals of 8.3cm	SD-30, D16mm intervals of 12.5cm	SD-30, D16mm intervals of 10cm or 15cm		
	Transverse	SD-30, D10mm intervals of 30cm	SD-30, D10mm intervals of 30cm	SD-30, D13mm intervals of 30cm	SD-30, D13mm intervals of 30cm		
	Depth of Setting	8cm	8cm	8cm	9.6cm		
	Overlap of Bar (cm)	40cm	40cm	40cm	-		
Mix Proportion of Concrete	Max. Size of Aggregate	40mm	40mm	40mm	40mm		
	Slump (cm)	5.0cm	2.5cm	2.5cm	5±1cm		
	Air Content (%)	4.0%	4.0%	4.5%	4±1%		
	Water Cement Ratio (%)	43.0%	41.5%	39.0%	-		
	Sand Ratio (%)	35.5%	30.0%	37.0%	-		
Joint		expansion joint	expansion joint	expansion joint	expansion joint		
Arrangement of Longitudinal Bar							

Table 4 Examples of Implementation (In Japan) (2)

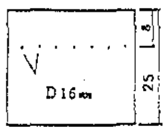
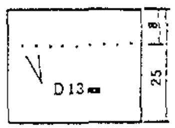
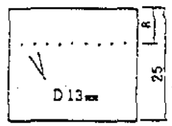
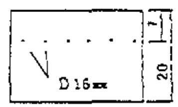
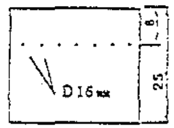
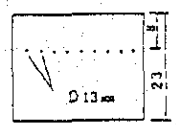
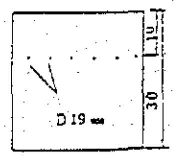
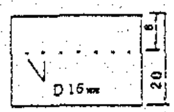
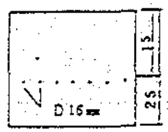
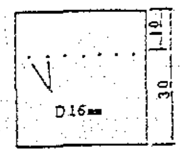
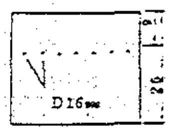
Item	Example of implementation	National Highway (Route 4)	National Highway (Route 4)	National Highway (Route 4)	National Highway (Route 4)	Prefectual Road (Numazu)	National Highway (Route 1)
Concrete Slab	Thickness (cm)	25cm	25cm	25cm	25cm	20cm	25cm
	Width (m)	7.5cm	7.5cm	7.5cm	7.5cm	3.32m ~ 6.07mx2	7.5cm
	Length of Imprementation	80m	630m	473.5m	436m	151.2m	117.3m, 130m, 521m
Reinforcing Steel Bar	Reinforcement Ratio (%)	0.64%	0.61%	0.61%	0.61%	0.66%	0.63%
	Longitudinal	SD-30, D16mm intervals of 12.5cm	SD-30, D13mm intervals of 8.3cm	SD-30, D13mm intervals of 8.3cm	SD-30, D13mm intervals of 8.3cm	SD-30, D16mm intervals of 15cm	SD-30, D16mm intervals of 12.5cm
	Transverse	SD-30, D13mm intervals of 30cm	SD-30, D10mm intervals of 30 cm	SD-30, D10mm intervals of 30cm	SD-30, D10mm intervals of 30cm	SD-30, D13mm intervals of 30cm	SD-30, D13mm intervals of 30cm
	Depth of Setting	8cm	8cm	8cm	8cm	7cm	8cm
	Overlap of Bar (cm)	40cm	40cm	40cm	40cm	40cm	-
Mix Proportion of Concrete	Max. Size of Agregate	40mm	40mm	40mm	40mm	25mm	40mm
	Slump (cm)	2.5cm	3.5cm	2.5±1cm	2.5±1cm	5.0cm	2.5cm
	Air Content (%)	4.0%	4.0%	4±1%	4±1%	-	-
	Water Cement Ratio (%)	37.8%	39.0%	40.0%	37.8%	42.0%	-
	Sand Ratio (%)	35.7%	35.2%	31.5%	33.3%	40.4%	-
Joint		expansion joint	expansion joint		expansion joint	expansion joint for smoothing	expansion joint
Arrangement of Longitudinal Bar							

Table 4 Examples of Implementation (In Japan) (3)

Item	Example of imprementation	National Highway (Route 4)	Apron of air port	National Highway (Route 5)	Expressway (Touhoku)	National Highway (Route 254)	Test Course (Tsukuba)
Concrete Slab	Thickness (cm)	23 cm	30 cm	20 cm	25 cm	30 cm	25 cm
	Width (m)	45m x 2	mainrenance apron 7.0m x 17	3.3 m	8.5m x 2	7.43 m	8.5m + 4.25m
	Length of Imprementation	500m	500m (Average)	1000m	1055.54m	270m	2068m
Reinforcing Steel Bar	Reinforcement Ratio (%)	0.60%	0.60%	0.80%	0.63%	0.52%	0.60%
	Longitudinal	SD-30, D13mm intervals of 9cm	SD-40, D19mm intervals of 15cm	SD-30, D16mm intervals of 12.5cm	SD-30, D16mm intervals of 12.5cm	SD-30, D16mm intervals of 12.5cm	SD-30, D16mm intervals of 12.5cm
	Transverse	SD-30, D9mm intervals of 28.4cm	SD-40, D13mm intervals of 50cm	SD-30, D13mm intervals of 40cm	SD-30, D13mm intervals of 30cm	SD-30, D13mm intervals of 30cm	SD-30, D13mm intervals of 30cm and 60cm
	Depth of Setting	under the surface 8cm	10cm	8cm	15cm	10cm	9cm
	Overlap of Bar (cm)	35cm	60cm (zigzag alignment)	50cm	48cm		40cm
Mix Proportion of Concrete	Max. Size of Aggregate	50mm	40mm	25mm	40mm	40mm	40mm
	Slump (cm)	2.5cm	2.5cm	2.5cm	less than 2.5cm	2.5cm	2.5cm
	Air Content (%)	4±1%	3-4%	5±1%	3-6%	3.5%	4.0%
	Water Cement Ratio (%)	40.5%	41.0%	45%	36%	40%	37.4%
	Sand Ratio (%)	32.1%	35.3%	39%	33.5%	-	33.8%
Joint		expansion joint	expansion joint	expansion joint		expansion joint	expansion joint
Arrangement of Longitudinal Bar							

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