Faulting of Transverse Joints and Cracks

Description:

Faulting is the difference of elevation across a joint or crack. Faulting i caused in part by a buildup of loose materials under the approach slab near the joint or crack as well as depression of the leave slab. The buildup of eroded or infiltrated materials is caused by pumping from under the leave slab and shoulder (free moisture under pressure) due to heavy loadings. The warp and/or curl upward of the slab near the joint or crack due to moisture and/or temperature gradient contributes to the pumping condition. Lack of laod transfer contributes greatly to faulting.

Severity Levels:

Severity is determined by the average faulting over the joints within the sample unit.

How to Measure:

Faulting is determined by measuring the difference in elevation of slabs at transverse joints for the slabs in the sample unit. Faulting of cracks are measured as a guide to determine the distress level of the crack. Faulting is measured 1 foot in from the inside (left) slab edge on the inner passing lane. If temporary patching prevents measurements, proceed on to the next joint. Sign convention: "+" when approach slab is higher than departure slab, - when the opposite occurs. Faulting never occurs in the opposite direction.

Joint Seal Damage of Transverse Joints

Description:

Joint seal damage exists when incompressible materials and/or water can infiltrate into the joints. This infiltration can result in pumping, spalling, and blow-ups. A joint sealant bonded to the edges of the slabs protects the joints from accumulation of the incompressible materials and also reduces the amount of water seeping into the pavement structure. Typical types of joint seal damage are: (1) stripping of joint sealant, (2) extrusion of joint sealant, (3) weed growth, (4) hardening of the filler (oxidation) (5) loss of bond to the slab edges, and (6) lack or absence of sealant in the joint.

Severity Levels:

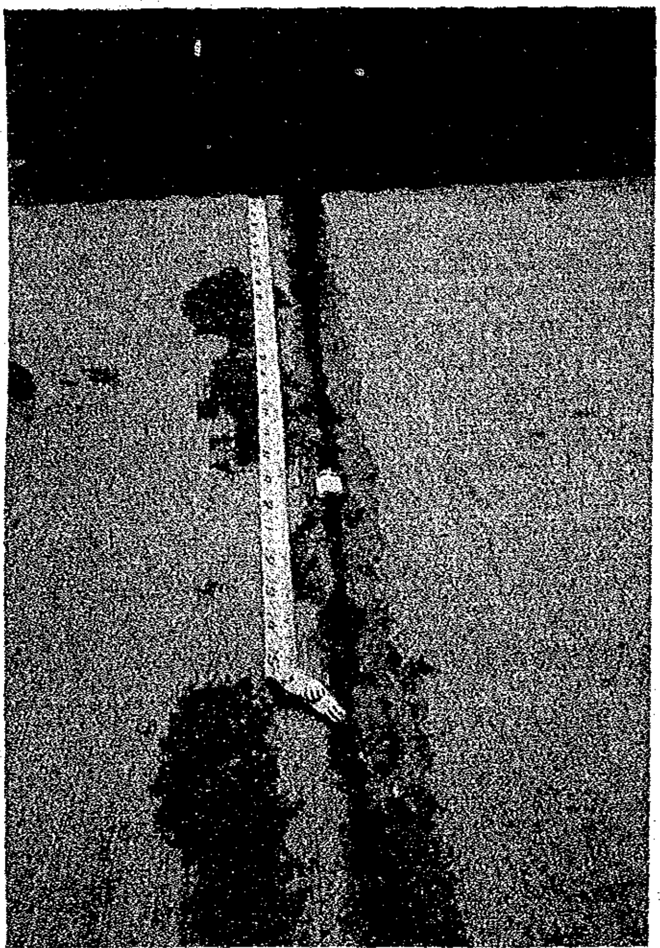
L - Joint sealant is in good condition throughout the section with only a minor amount of any of the above types of damage present. Little water and no incompressibles can infiltrate through the joint.

M - Joint sealant is in fair condition over the entire surveyed section, with one or more of the above types of damaged occuring to a moderate degree. Water can infiltrate the joint fairly easily; some incompressibles can infiltrate the joint. Sealant needs replacement within 1 to 3 years.

H - Joint sealant is in poor condition over most of the sample unit, with one or more of the above types of damage occuring to a severe degree. Water and incompressibles can freely infiltrate the joint. Sealant needs immediate replacement.

How to Measure:

Joint sealant damage of transverse joints is rated based on the overall condition of the sealant over the entire sample unit.



Lane/Shoulder Drop-off Heave

Description:

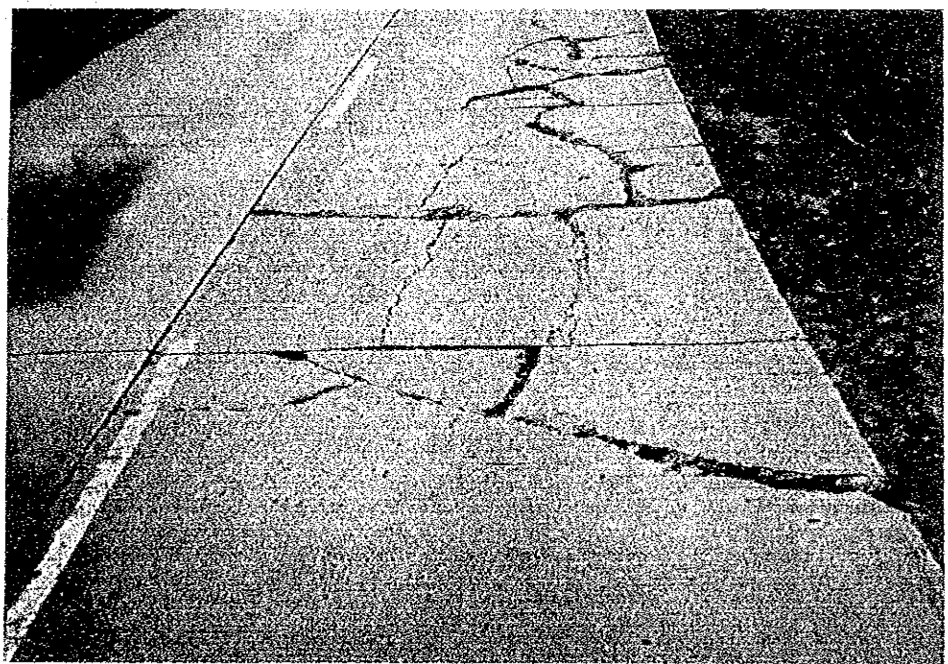
Lane/shoulder drop-off or heave occurs when there is a difference in elevation between the traffic lane and shoulder. Typically, the outside shoulder settles due to consolidation or a settlement of the underlying granular or subgrade material or pumping of the underlying material. Heave of the shoulder may occur due to frost action or swelling soils. Drop-off of granular or soil shoulder is generally caused from blowing away of shoulder material from passing trucks.

Severity Levels:

Severity level is determined by computing the mean difference in elevation between the traffic lane and shoulder.

How to Measure:

Lane/should drop-off or heave is measured in the sample unit all joints when joint spacing is 50 feet (15 m), at every third joint when spacing is 50 feet (15 m). It is also measured at mid-slab in each slab measured at the joint. The mean difference in elevation is computed from the data and used to determine severity level. Measurements at joints are made 1 foot (0.3 m) from the transverse joint on the departure slab only on the outer lane/shoulder.



Longitudinal Cracks

Description:

Longitudinal cracks occur generally parallel to the centerline of the pavement. They are often caused by improper construction of longitudinal joints or by a combination of heavy load repetition, loss of foundation support, and thermal and moisture gradient stresses.

Severity Levels:

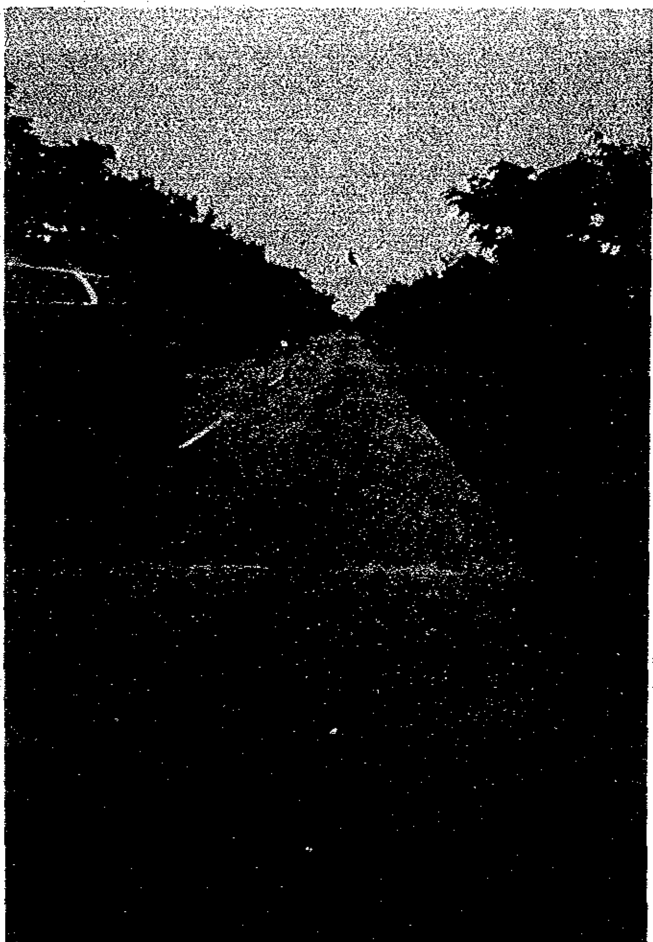
L - Hairline (tight) crack with no spalling or faulting, or a well sealed crack with no visible faulting or spalling.

M - Working crack with a moderate or less severity spalling and/or faulting less than 1/2 inch (12 mm).

H - A crack with width greater than 1 inch (25 mm); a crack with a high-severity level of spalling; or a crack faulted 1/2 inch (13mm) or more.

How to Measure:

Cracks are measured in linear feet (or meters) for each level of distress. The length and average severity of each crack should be identified and recorded.



Longitudinal Joint Faulting

Description:

Longitudinal joint faulting is a difference in elevation of two traffic lanes measured at the longitudinal joint. It is caused primarily by heavy truck traffic and settlement of the foundation.

Severity Levels:

Severity level is determined by measuring the maximum fault.

How to Measure:

Where the longitudinal joint has faulted, the length of the affected area and the maximum joint faulting is recorded.

Popouts

Description:

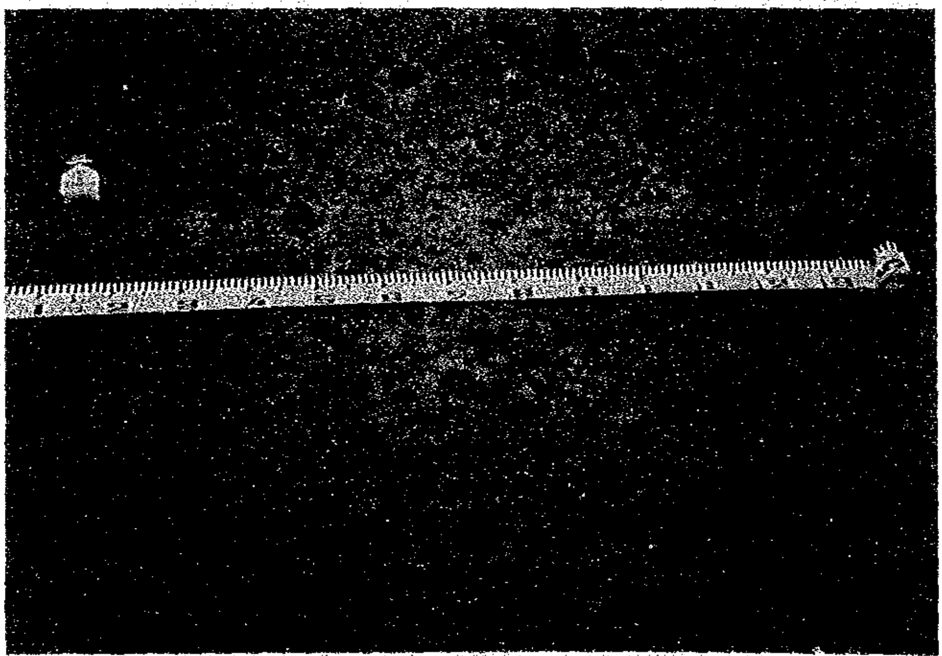
A popout is a small piece of concrete that breaks loose from the surface due to freeze-thaw action, expansive aggregates, and/or nondurable materials popouts may be indicative of unsound aggregates and "D" cracking. Popouts typically range from approximately 1 inch (25 mm) to 4 inches (10 cm) in diameter from 1/2 to 2-inches (13-51 mm) deep.

Severity Levels:

No degrees of severity are defined for popouts. The average popout density must exceed approximately one popout per square yard (square meter) over the entire slab area before they are counted as a distress.

How to Measure:

The density of popouts can be determined by counting the number of popouts per square yard (square meter) of surface in areas having typical amounts.



Pumping and Water Bleeding

Description:

Pumping is the movement of material by water pressure beneath the slab when it is deflected under a heavy moving wheel load. Sometimes the pumped material moves around beneath the slab, but often it is ejected through joints and/or cracks (particularly along the longitudinal lane/shoulder joint with an asphalt shoulder). Beneath the slab there is typically particle movement counter to the direction of traffic across a joint or crack that results in a buildup of loose materials under the approach slab near the joint or crack. Many times some fine materials (silt, clay, sand) are pumped out, leaving a thin layer of relatively loose clean sand and gravel beneath the slab, along with voids causing loss of support. Pumping occurs even in pavement sections containing stabilized subbases.

Water bleeding occurs when water seeps of joints and/or cracks. Many times it drains out over the shoulder in low areas.

Severity Levels:

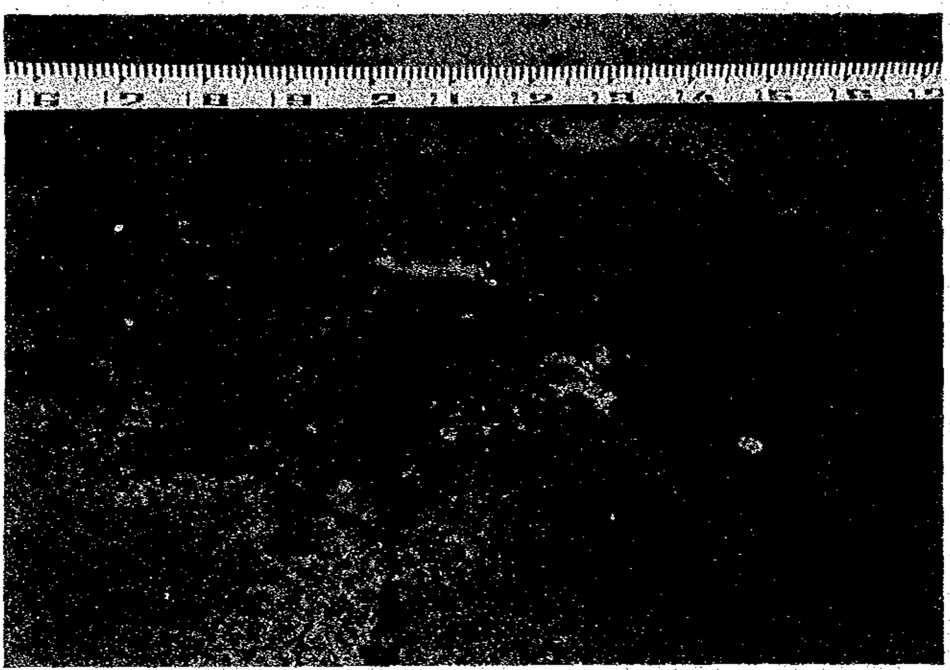
L - Water is forced out of a joint or crack when trucks pass over the joints or cracks; water is forced out of the lane/shoulder longitudinal joint when trucks pass along the joint; or water bleeding exists. No fines can be seen on the surface of the traffic lanes or shoulder.

M - A small amount of pumped material can be observed near some of the joints or cracks on the surface of the traffic lane or shoulder. Blow holes may exist.

H - A significant amount of pumped materials exist on the pavement surface of the traffic lane or shoulder along the joints or cracks.

How to Measure:

If pumping or water bleeding exists anywhere in the sample unit, it is counted as occuring at highest severity level as defined above.



Reactive Aggregate Distresses

Description:

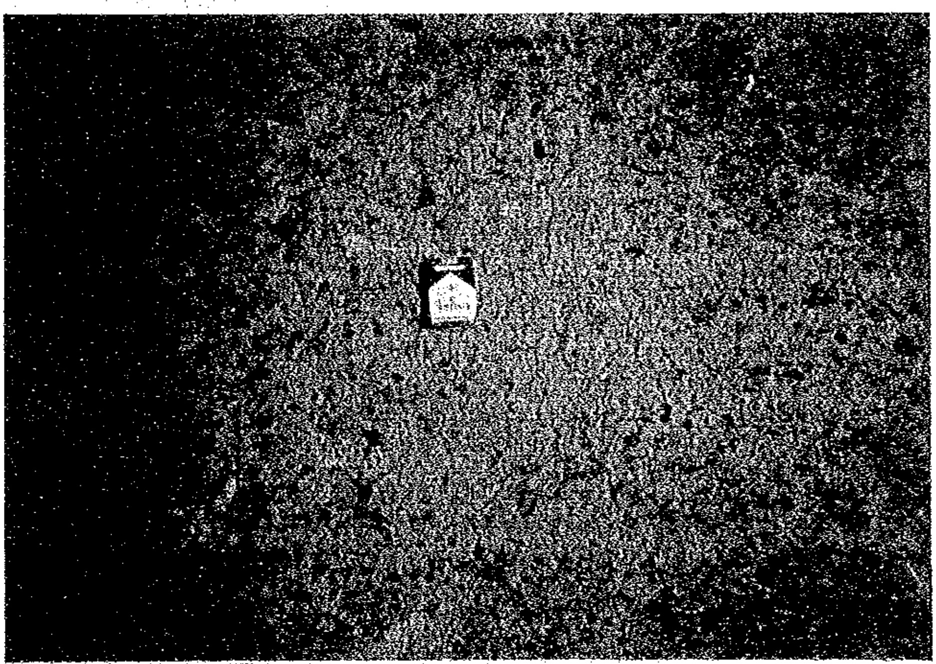
Reactive aggregates either expand in alkaline environments or develop prominent siliceous reaction rims in concrete. It may be an alkali-silica reaction or an alkali-carbonate reaction. As expansion occurs, the cement matrix is disrupted and cracks. It appears as a map-cracked area; however, the cracks may go deeper into the concrete than in normal map cracking. It may affect most of the slab or it may first appear at joints and cracks.

Severity Levels:

Only one level of severity is defined. If alkali-aggregate cracking occurs anywhere in the slab, it is counted. If the reaction has caused spalling or map cracking, these are also counted.

How to Measure:

Reactive-aggrerate distress is measured in square feet or square meters.



Scaling and Map Cracking or Crazing

Description:

Scaling is the deterioration of the upper 1/8 to 1/2 inch (3-13 mm) of the concrete slab surface. Map cracking or crazing is a series of fine cracks that extend only into the upper surface of the slab surface. Map cracking or crazing is usually caused by over-finishing of the slab and may lead to scaling of the surface. Scaling can also be caused by reinforcing steel being too close to the surface.

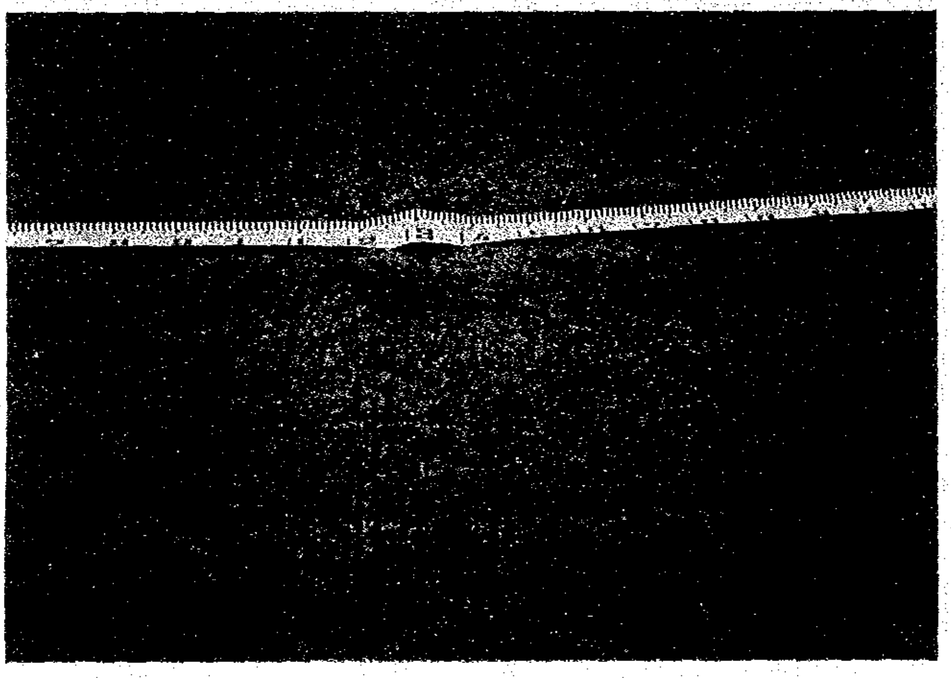
Severity Levels:

L - Crazing or map cracking exists; the surface is in good condition with no scaling.

M/H - Scaling exists.

How to Measure:

Scaling and map cracking or crazing are measured by area of slab in square feet or meters.



Spalling (Transverse and Longitudinal Joint/Crack)

Description:

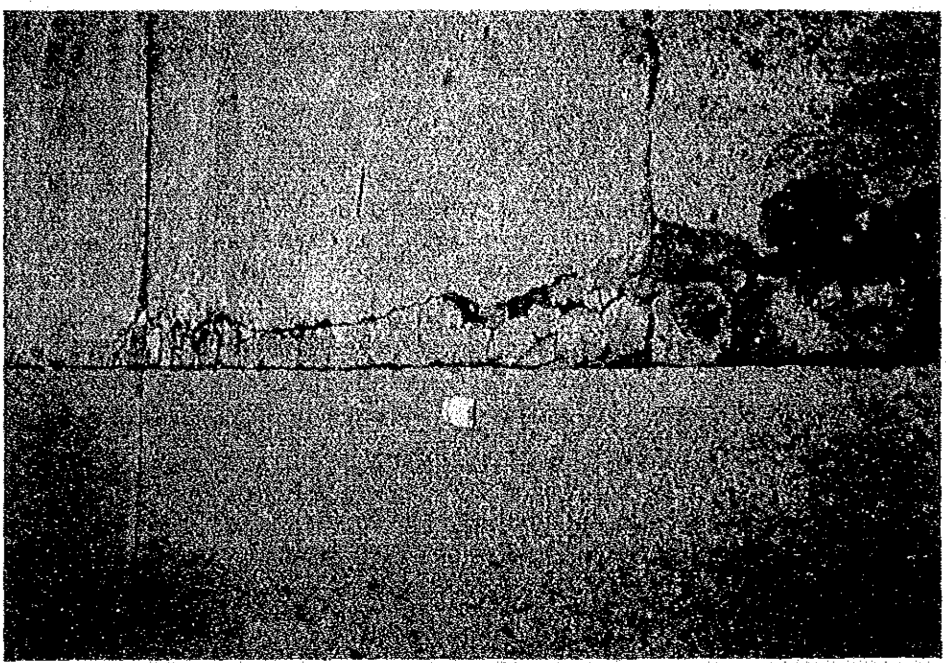
Spalling of cracks and joints is the cracking, breaking, or chipping (or fraying) of the slab edges within 2 feet (0.6 m) of the joint/crack. A spall usually does not extend vertically through the whole slab thickness but extends to intersect the joint at an angle. Spalling usually results from (1) excessive stresses at the joint or crack caused by infiltration of incompressible materials and subsequent expansion, (2) disintegration of the concrete from freeze-thaw action of "D" cracking, (3) weak concrete at the joint (caused by honey-combing), (4) poorly designed or constructedload transfer device (misalignment, corrosion), and/or (5) heavy repeated traffic loads.

Severity Levels:

- L - The spall or fray does not extend more than 3 inches (8 cm) on either side of the joint or crack. No temporary patching has been placed to repair the spall.
- M - The spall or fray extends more than 3 inches (8 cm) on either side of the joint or crack. Some pieces may be loose and/or missing, but the spalled area does not present a tire damage or safety hazard. Temporary patching may have been placed because of spalling.
- H - The jointis severely spalled or frayed to the extent that a tire damage or safety hazard exists.

How to Measure:

Spalling is measured by counting and recording separately the number of joints with each severity level. If more than one level of severity exists along a joint, it will be recorded as containing the highest severity level present. Although the definition and severity levels are the same, spalling of cracks should not be recorded. The spalling of cracks is included in rating severity levels of cracks. Spalling of transverse and longitudinal joints will be recorded separately. Spalling of the slab edge adjacent to a permanent patch will be recorded as patch adjacent slab deterioration. If spalling is caused by "D" cracking, it is counted as both spalling and "D" cracking at appropriate severity levels.



Transverse and Diagonal Cracks

Description:

Linear cracks are caused by one or a combination of the following: heavy load repetition, thermal and moisture gradient stresses, and drying shrinkage stresses. Medium or high-severity cracks are working cracks and are considered major structural distresses. They may sometimes be due to deep-seated differential settlement problems. (Note: hairline cracks that are less than 6 feet (1.8 m) long are not rated.

Severity Levels:

L - Hairline (tight) crack with no spalling or faulting, a well-sealed crack with no visible faulting or spalling.

M - Working crack with low-to medium-severity level of spalling, and/or faulting less than 1/2 inch (13 mm). Temporary patching may be present.

H - A crack with width greater than 1 inch (25 mm); a crack with a high-severity level of spalling; or a crack faulted 1/2 inch (13 mm) or more.

How to Measure:

The number and severity level of each crack should be identified and recorded. If the crack does not have the same severity level along the entire length, the crack is rated at the highest severity level present. Cracks in patches are recorded under patch deterioration.

Block Cracking, Random Crack, Third Stage Crack

Description:

Multiple irregular breaks or separation of the slab.

Possible Causes:

- Inappropriate slab design with regard to existing traffic.
- Inadequate road bed support
- Overloading
- Undermining of subgrade.

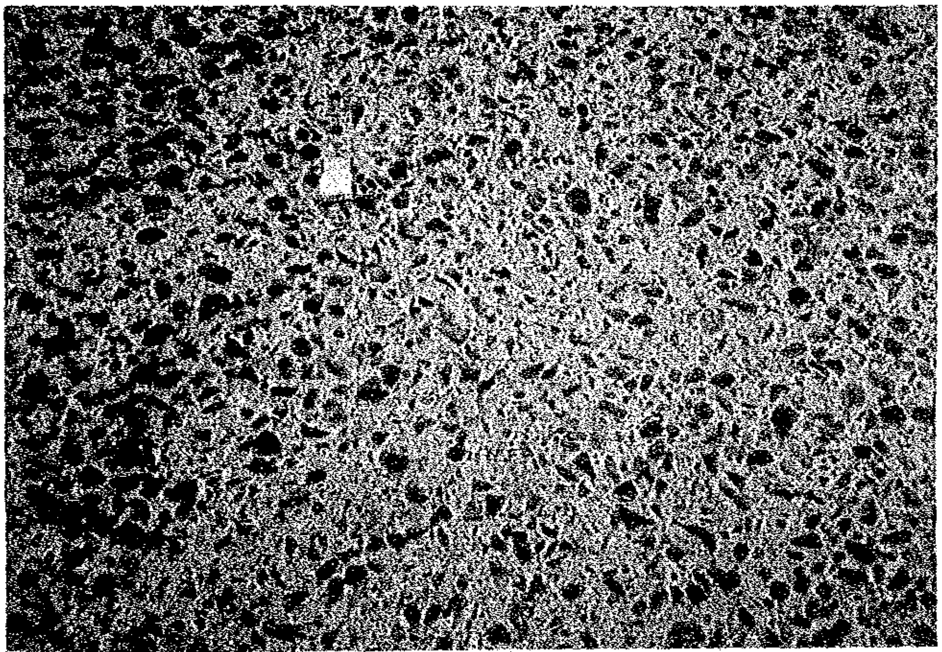
Peeling

Description:

Removal of surface in the form of large places of mortar or fine resurfacing concrete.

Possible Causes:

- Traffic acting on a poorly laid resurfacing coarse (bad bond with underlying concrete, poor composition).
- Insufficient thickness of resurfacing layer.



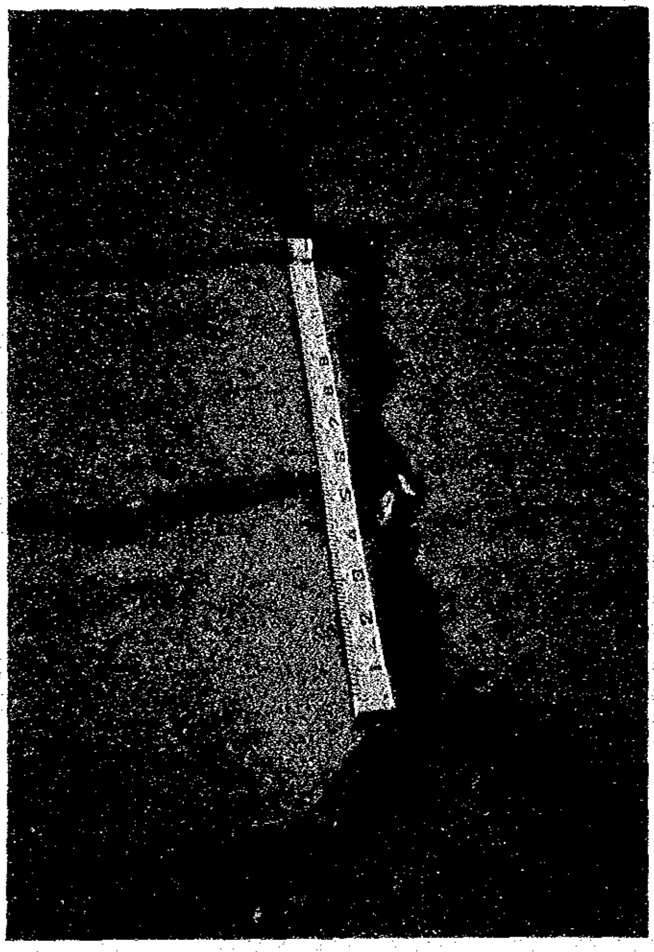
Slab Rocking

Description:

Vertical movement at Joint (or crack) when vehicles pass over.

Possible Causes:

Due to traffic passing over or concrete pavement with undowelled joints structures over subgrade or plastic soil which has been deformed due to pumping effects.



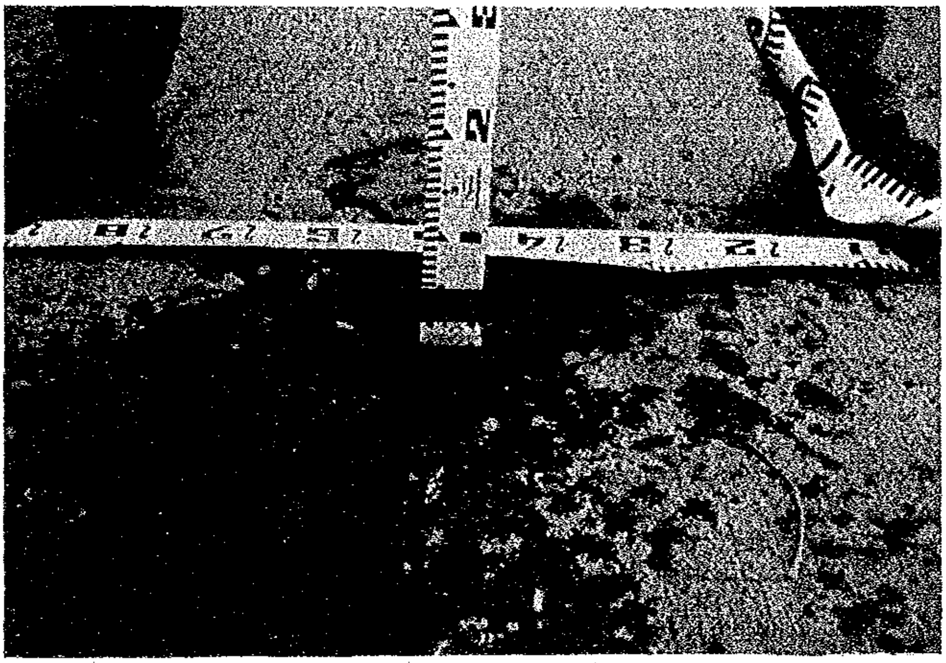
Pothole, Chuck-Hole

Description:

Bowl-shape holes of various sizes in the pavements.

Possible Causes:

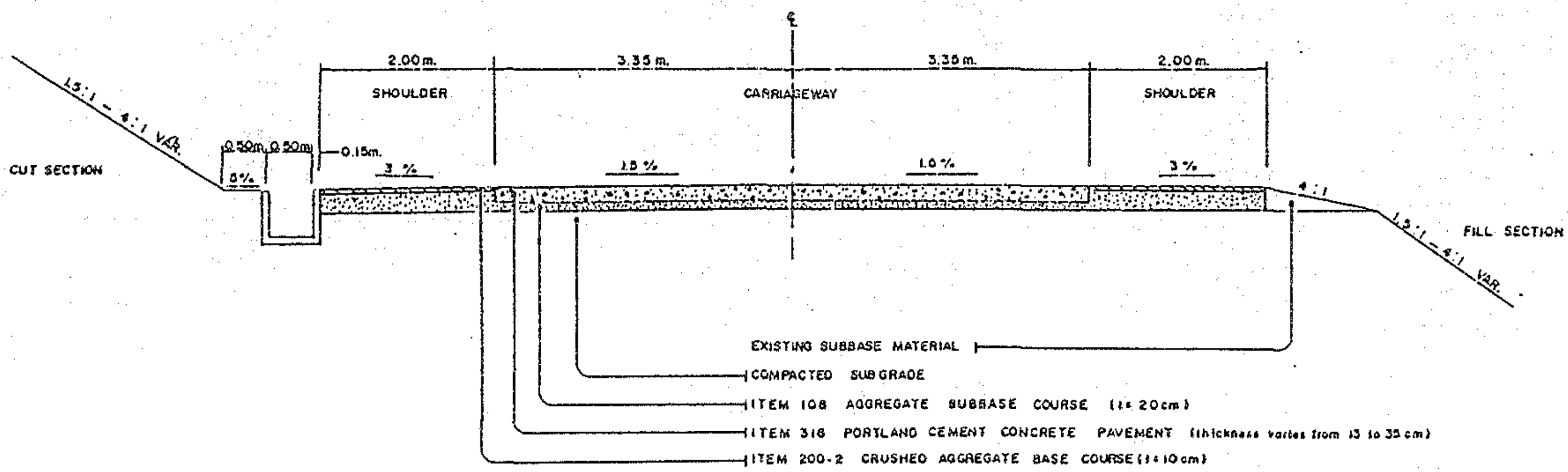
Local inclusion in the concrete (pocket of clay, quick lime or non-homogeneous mortar)



APPENDIX 9-1

TYPICAL CROSS SECTIONS OF PROPOSED REHABILITATION WORKS

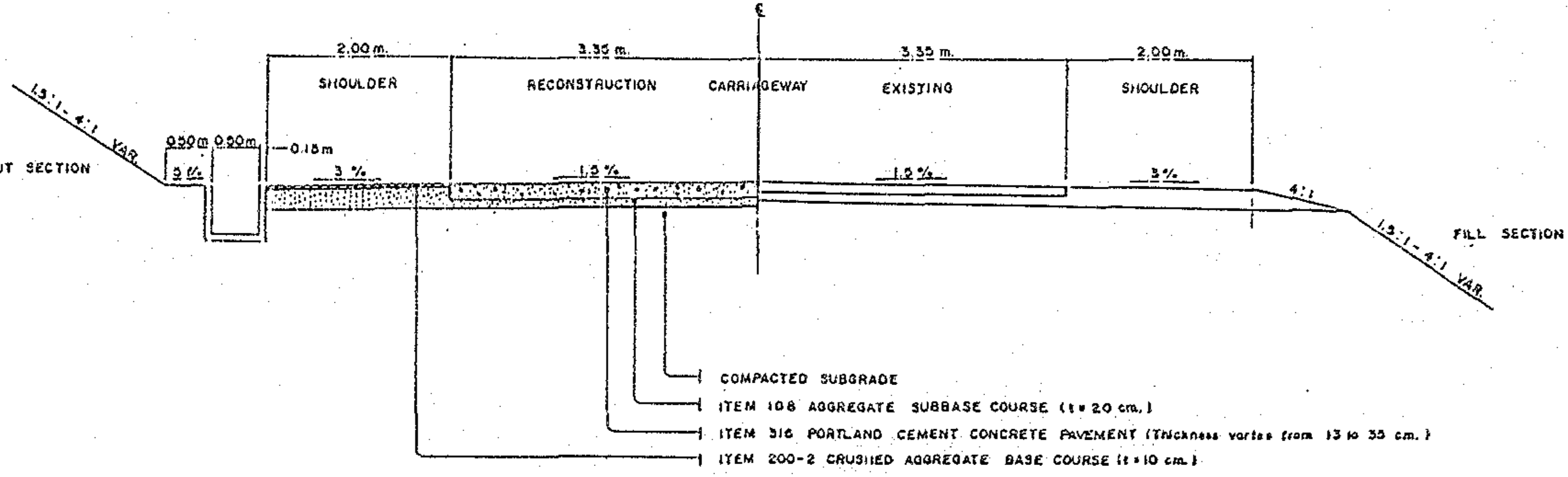
FIGURE 1 TYPICAL CROSS - SECTION
PCC RECONSTRUCTION (2-LANES)



Unit : Peso per meter

Slab Thickness (cm.)	ITEM 104: Removal of Miscellaneous Structures	ITEM 105 Roadway Excavation	ITEM 108 Aggregate Subbase	ITEM 316: Portland Cement Concrete Pavement	ITEM 200-2: Crushed Aggregate Base	Total Cost (P/m)
13	176.01	96.12	471.32	1042.33	110.66	1896.44
15	176.01	106.45	488.01	1202.68	110.66	2083.81
18	176.01	121.96	513.03	1443.22	110.66	2364.88
20	176.01	132.29	529.72	1603.58	110.66	2552.26
23	176.01	147.80	554.74	1844.11	110.66	2833.32
25	176.01	158.13	571.43	2004.47	110.66	3020.70
28	176.01	173.64	596.45	2245.01	110.66	3301.77
30	176.01	183.97	613.14	2405.37	110.66	3489.15
33	176.01	199.48	638.16	2645.90	110.66	3770.21
35	176.01	209.82	654.85	2806.26	110.66	3957.60

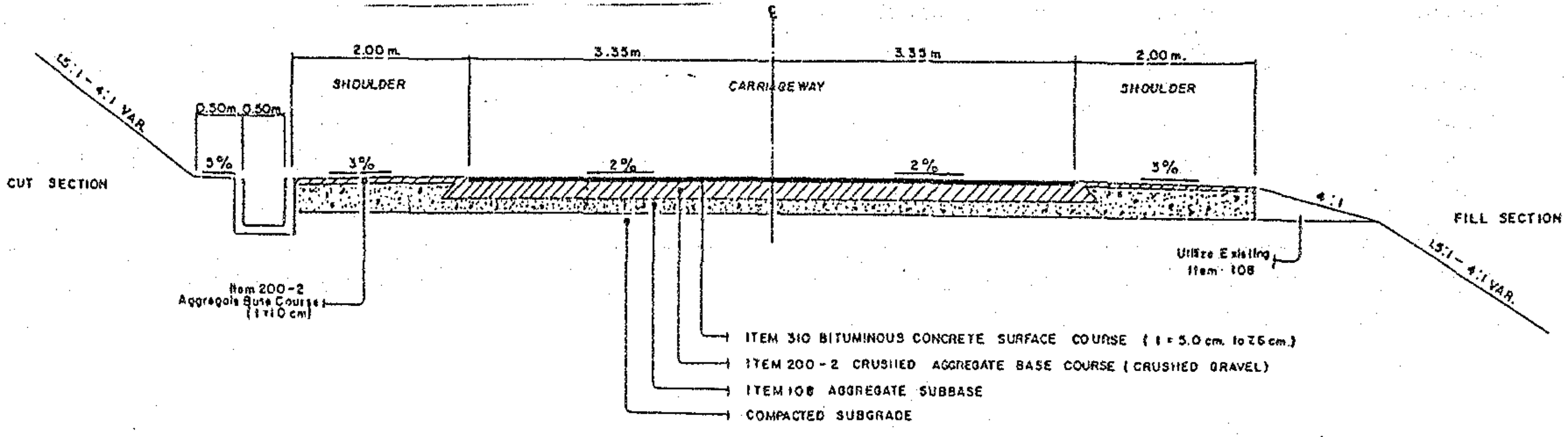
FIGURE 2 TYPICAL CROSS-SECTION
PCC RECONSTRUCTION (1-LANE)



Unit: Peso per meter

Slab Thickness (cm.)	Item 104 Removal of Miscellaneous Structures	Item 105 Roadway Excavation	Item 108 Aggregate Subbase	Item 316 Portland Cement Concrete Pavement	Item 200-2 Crushed Aggregate Base	Total Cost (₱/m)
13	88.01	48.06	235.66	521.16	55.33	948.22
15	88.01	53.23	244.00	601.34	55.33	1041.91
18	88.01	60.98	256.52	721.61	55.33	1162.45
20	88.01	66.15	264.86	801.79	55.33	1276.14
23	88.01	73.90	277.37	922.06	55.33	1416.67
25	88.01	79.07	285.71	1002.24	55.33	1510.36
28	88.01	86.82	298.23	1122.50	55.33	1650.89
30	88.01	91.99	306.57	1202.68	55.33	1744.58
33	88.01	99.74	319.08	1322.95	55.33	1855.11
35	88.01	104.91	327.42	1403.13	55.33	1978.80

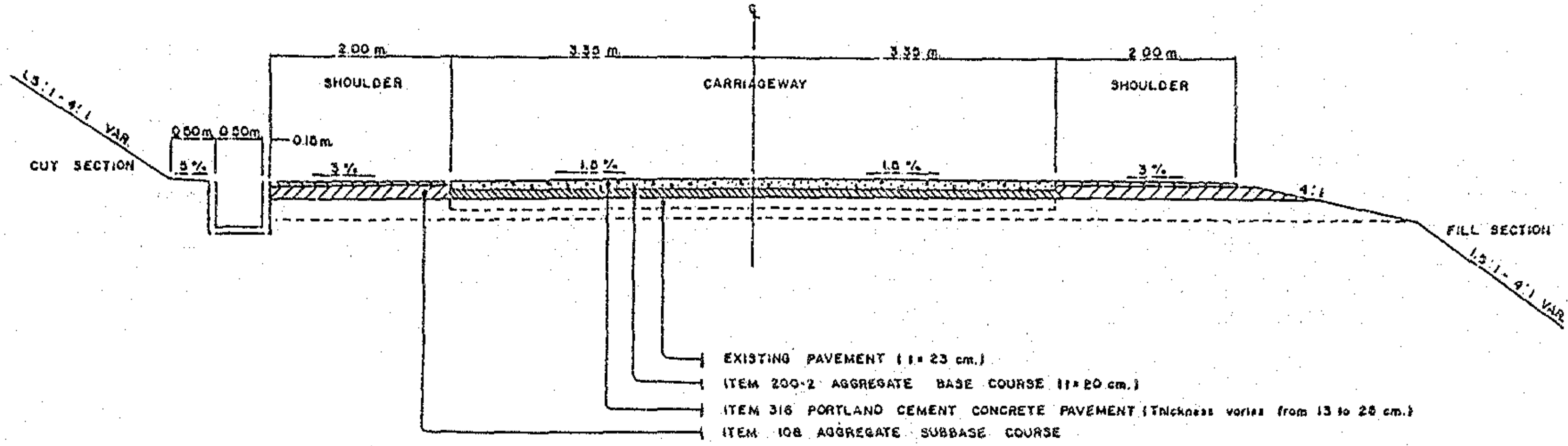
FIGURE 3 TYPICAL CROSS – SECTION
AC RECONSTRUCTION (2-LANES)



SN	Item 104 Removal of Miscellaneous Structure	Item 105 Roadway and Drainage Excavation	Item 108 Aggregate Subbase	Item 200-1 Mechanically Stabilized Aggregate Base Course (Crushed Stone)	Item 202-2 Aggregate Base Course Crushed Gravel	Item 205 Bituminous Plant Mix Base Course	Item 10; Bituminous Concrete Surface Course Including Prime Coat and Tack Coat (Thickness = 10 cm)	Total Cost (₱/m)
1.3	176.01	38.64	70.91	—	405.29	—	840.78	1531.63
1.7	176.01	106.46	405.63	—	405.29	—	840.78	1934.16
2.1	176.01	119.88	423.98	—	409.72	—	1270.05	2399.64
2.5	176.01	171.56	571.01	—	510.70	—	1270.05	2699.33
3.0	176.01	209.82	699.69	—	514.57	—	1645.72	3245.81
3.5	176.01	287.34	882.17	—	716.52	—	1645.72	3707.76
4.0	176.01	339.02	953.07	448.04	547.77	—	1645.72	4109.63
4.5	176.01	416.54	1059ı43	560.05	758.02	—	1645.72	4615.77
5.0	176.01	416.54	1059.43	560.05	572.67	1278.01	1645.72	5708.43
5.5	176.01	494.06	1165.79	672.06	782.92	1278.01	1645.72	6214.57

NOTE: SN 1.7 and 2.0 have no Tack Coat

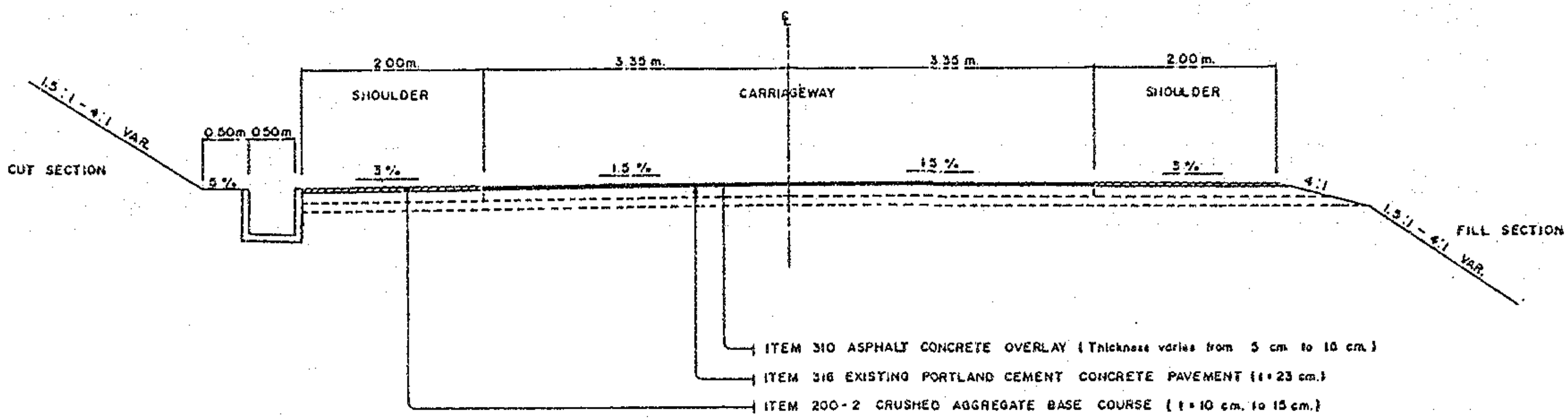
FIGURE 4 TYPICAL CROSS-SECTION
RIGID OVERLAY- RIGID EXISTING (2 - LANES)



Slab Thickness (cm)	Item 118 Repreparation of Previously Constructed Road	Item 108 Aggregate Subbase	Item 200-2 Aggregate Base Course Crushed Gravel	Item 316 Portland Cement Concrete Pavement	Total Cost (P/m)
13	141.67	191.67	481.37	1042.33	1857.24
15	141.67	208.55	481.37	1202.68	2034.27
18	141.67	233.58	481.37	1443.22	2299.84
20	141.67	250.26	481.37	1603.58	2476.88
23	141.67	275.29	481.37	1844.11	2742.44
25	141.67	291.97	481.37	2004.47	2919.48
28	141.67	317.00	481.37	2245.01	3185.05
30	141.67	333.68	481.37	2405.37	3362.09
33	141.67	358.71	481.37	2645.90	3627.65

FIGURE 5 TYPICAL CROSS-SECTION

FLEXIBLE OVERLAY RIGID EXISTING (2-LANES)

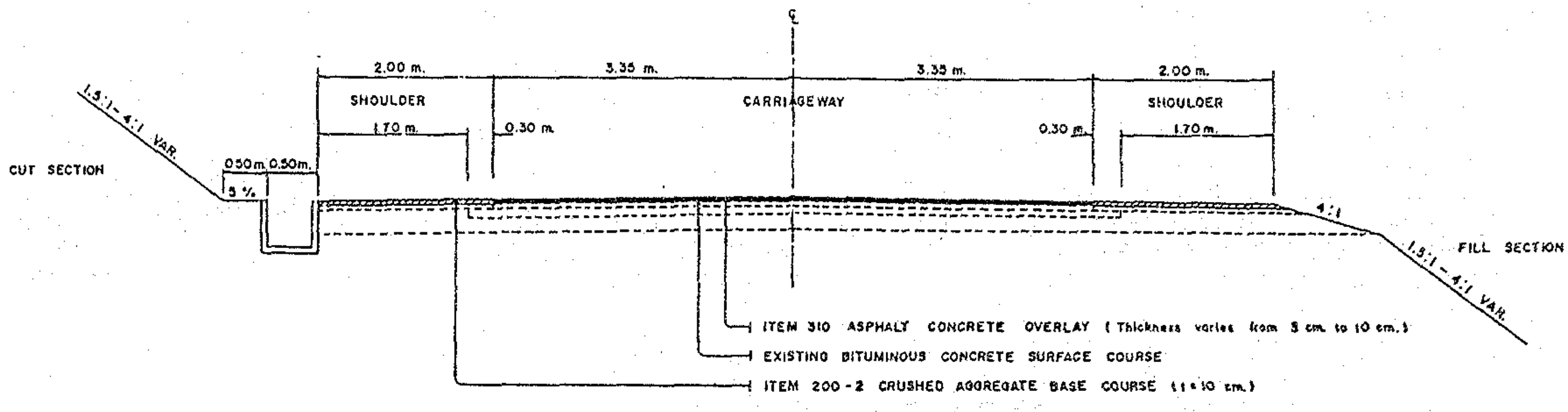


Unit: Peso per meter

AC Thickness (cm)	Item 118-1 Repreparation of Previously Constructed Road	Item 200-2 Crushed Aggregate Base Course	Item 302 Bituminous Prime Coat	Item 303 Bituminous Tack Coat	Item 310 Bituminous Concrete Surface Course	Total Cost (₱/m)
5	141.67	110.66	58.16	—	782.66	1,093.15
8	141.67	110.66	58.16	22.24	1252.25	1 584.98
10	141.67	110.66	58.16	22.24	1565.31	1 898.04
13	141.67	143.86	58.16	22.24	2034.91	2 400.84
15	141.67	165.99	58.16	22.24	2347.97	2736.03

FIGURE 6 TYPICAL CROSS-SECTION

FLEXIBLE OVERLAY - FLEXIBLE EXISTING (2-LANES)



Unit : Peso per meter

AC Thickness (cm.)	ITEM 118-2 Repreparation of Previously Constructed Road	ITEM 200-2 Aggregate Base Course	ITEM 302 Bituminous Prime Course	ITEM 303 Bituminous Tack Coat	ITEM 310 Bituminous Concrete Surface Course	Total Cost (₱/m.)
3	96.71	110.66	58.16	—	469.59	735.12
5	96.71	110.66	58.16	—	782.66	1048.19
8	96.71	110.66	58.16	22.24	1252.25	1540.02
10	96.71	110.66	58.16	22.24	1565.31	1853.08

APPENDIX 9-2
BASIC STRUCTURAL DESIGN OF PAVEMENT REHABILITATION METHODS

TABLE 1

Basic Design

Rehabilitation Method	Traffic Loading Class	CBR / k / Mr	2 / 80 / 2500	3 / 130 / 4000	4 / 170 / 5000	6 / 210 / 6000	8 / 230 / 7000	10 / 250 / 8000	15 / 280 / 12000	20 / 300 / 15000	Design Performance Period
	L-1	D	15.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
		x	26.5	19.2	21.7	24.2	25.4	26.5	28.2	29.3	
		C1	2734	1896	1896	1896	1896	1896	1896	1896	
		C2	2952	2179	2148	2121	2118	2115	2111	2109	
	L-2	D	18.0	15.0	15.0	15.0	15.0	15.0	15.0	13.0	
		x	32.6	20.1	22.3	24.3	25.2	26.2	27.6	19.1	20 Years
		C1	3015	2084	2084	2084	2084	2084	2084	1896	
		C2	3213	2357	2328	2309	2306	2304	2300	2165	
	L-3	D	20.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	
		x	25.2	19.0	20.7	22.2	23.0	23.7	24.7	25.3	
		C1	3202	2365	2365	2365	2365	2365	2365	2365	
		C2	3424	2660	2634	2609	2605	2596	2588	2587	
	A	D	23.0	23.0	23.0	23.0	23.0	23.0	20.0	20.0	
		x	18.7	20.7	22.0	23.1	23.7	24.2	14.6	15.0	
		C1	3979	3329	3329	3329	3329	3329	3048	3048	
		C2	4393	3633	3589	3569	3566	3554	3495	3456	
	B	D	25.0	25.0	25.0	23.0	23.0	23.0	23.0	23.0	
		x	16.8	18.5	19.6	14.4	14.8	15.2	15.7	16.1	15 Years
		C1	4167	3517	3517	3329	3329	3329	3329	3329	
		C2	4692	3886	3841	3809	3796	3752	3739	3705	
	C	D	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	
		x	17.4	18.9	19.9	20.8	21.2	21.5	22.1	22.4	
		C1	4448	3798	3798	3798	3798	3798	3798	3798	
		C2	4961	4174	4125	4094	4072	4068	4049	4047	
	D	D	30.0	30.0	30.0	30.0	28.0	28.0	28.0	28.0	
PCC Reconstruction		x	16.1	17.5	18.4	19.2	14.3	14.6	15.1	15.3	
		C1	4635	3985	3985	3985	3798	3798	3798	3798	
		C2	5221	4415	4352	4312	4280	4269	4215	4209	
	E	D	33.0	33.0	33.0	30.0	30.0	30.0	30.0	30.0	
		x	19.6	21.0	21.9	14.9	15.2	15.5	15.9	16.2	
		C1	4916	4266	4266	3985	3985	3985	3985	3985	
		C2	5350	4576	4551	4483	4431	4419	4400	4364	15 Years
	F	D	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	
		x	14.7	15.9	16.7	17.3	17.6	17.9	18.3	18.6	
		C1	4916	4266	4266	4266	4266	4266	4266	4266	
		C2	5663	4792	4710	4656	4642	4632	4594	4590	
	G	D	35.0	35.0	35.0	35.0	33.0	33.0	33.0	33.0	
		x	16.0	17.1	17.9	18.5	14.3	14.6	15.0	15.2	
		C1	5104	4454	4454	4454	4266	4266	4266	4266	
		C2	5771	4908	4861	4815	4760	4746	4722	4680	
	H	D	35.0	35.0	35.0	35.0	33.0	33.0	33.0	33.0	
		x	13.5	14.6	15.3	15.8	12.1	12.3	12.6	12.9	
		C1	5104	4454	4454	4454	4266	4266	4266	4266	
		C2	5993	5066	4960	4925	4877	4852	4819	4810	
	I	D	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	
		x	11.8	12.7	13.3	13.9	14.1	14.3	14.7	14.9	12 Years
		C1	5104	4454	4454	4454	4454	4454	4454	4454	
		C2	6216	5216	5084	5030	4955	4940	4913	4905	
	J	D	(35.0)	(35.0)	35.0	35.0	35.0	35.0	35.0	35.0	
		x	(10.4)	(11.3)	11.8	12.3	12.6	12.8	13.1	13.3	
		C1	(5104)	(4454)	4454	4454	4454	4454	4454	4454	
		C2	(6426)	(5349)	5237	5109	5073	5041	4961	4951	

Analysis Period : 25 years
D : Thickness of Slab (cm)
x : Initial Performance Period (years)
C1 : Initial Construction Cost (pesos/meter)
C2 : Total Discounted Cost including Maintenance Cost (pesos/meter)
() : Initial Performance Period less than Design

TABLE 2

Basic Design

Rehabilitation Method	Traffic Loading Class	CBR / k / Mr	2 / 80 / 2500	3 / 130 / 4000	4 / 170 / 5000	6 / 210 / 6000	8 / 230 / 7000	10 / 250 / 8000	15 / 280 / 12000	20 / 300 / 15000	Design Performance Period
	L-1	SN	2.5	2.5	2.5	2.1	2.1	2.1	1.7	1.7	
		x	18.2	18.2	25.4	16.4	20.9	25.4	20.7	28.4	
		C1	3799	2699	2699	2400	2400	2400	1934	1934	
		C2	4193	3093	2972	2831	2731	2674	2258	2201	
	L-2	SN	3.0	3.0	2.5	2.5	2.5	2.1	2.1	1.7	15 Years
		x	25.0	25.0	16.1	21.5	26.8	16.1	29.3	18.4	
		C1	4346	3246	2699	2699	2699	2400	2400	1934	
		C2	4621	3521	3152	3025	2968	2832	2663	2293	
	L-3	SN	3.5	3.5	3.0	3.0	3.0	2.5	2.1	2.1	
		x	23.9	23.9	17.1	22.7	28.1	16.0	14.3	20.6	
		C1	4808	3708	3246	3246	3246	2699	2400	2400	
		C2	5103	4003	3691	3559	3508	3152	2898	2734	
	A	SN	4.0	4.0	3.5	3.5	3.5	3.0	2.5	2.5	
		x	15.2	15.2	12.0	16.4	20.9	13.5	12.0	17.5	
		C1	5705	4605	4204	4204	4204	3742	3195	3195	
		C2	6159	5059	4868	4640	4535	4298	3857	3602	
	B	SN	4.5	4.5	4.0	4.0	3.5	3.5	3.0	3.0	12 Years
		x	16.0	16.0	13.3	18.1	12.8	16.1	16.2	22.9	
		C1	6212	5112	4605	4605	4204	4204	3742	3742	
		C2	6648	5548	5135	4976	4808	4642	4182	4044	
	C	SN	5.0	5.0	4.5	4.5	4.0	4.0	3.5	3.0	
		x	16.3	16.3	14.0	19.0	14.2	17.7	19.1	14.2	
		C1	7304	6204	5112	5112	4605	4605	4204	3742	
		C2	7713	6613	5597	5468	5095	4990	4557	4253	
AC Reconstruction	D	SN	5.0	5.0	4.5	4.5	4.0	4.0	3.5	3.0	
		x	10.6	10.6	9.0	12.7	9.2	11.7	12.8	9.2	
		C1	7304	6204	5112	5112	4605	4605	4204	3742	
		C2	7987	6887	5915	5678	5451	5238	4809	4656	
	E	SN	5.0	5.0	5.0	4.5	4.5	4.0	3.5	3.5	
		x	7.9	7.9	12.1	9.5	12.7	8.8	9.6	14.4	
		C1	7304	6204	6204	5112	5112	4605	4204	4204	
		C2	8289	7189	6772	5902	5678	5512	5068	4711	8 Years
	F	SN	5.5	5.5	5.0	5.0	4.5	4.5	4.0	3.5	
		x	10.0	10.0	8.7	12.3	9.2	11.8	13.5	10.6	
		C1	7810	6710	6204	6204	5112	5112	4605	4204	
		C2	8563	7463	7077	6770	5914	5728	5133	4972	
	G	SN	5.5	5.5	5.5	5.0	4.5	4.5	4.0	3.5	
		x	7.9	7.9	12.0	9.8	7.2	9.3	10.8	8.3	
		C1	7810	6710	6710	6204	5112	5112	4605	4204	
		C2	8782	7682	7307	6959	6155	5913	5322	5196	
	H	SN	5.5	5.5	5.5	5.0	4.5	4.5	4.0	3.5	
		x	6.5	6.5	10.0	8.1	5.9	7.8	9.0	6.9	
		C1	7810	6710	6710	6204	5112	5112	4605	4204	
		C2	8977	7877	7423	7094	6464	6102	5497	5460	
	I	SN	5.5	5.5	5.5	5.0	4.5	4.5	4.0	3.5	5 Years
		x	5.5	5.5	8.6	6.9	5.0	6.6	7.7	5.9	
		C1	7810	6710	6710	6204	5112	5112	4605	4204	
		C2	9164	8064	7584	7306	6601	6287	5656	5663	
	J	SN	(5.5)	(5.5)	5.5	5.0	5.0	4.5	4.0	3.5	
		x	(4.8)	(4.8)	7.6	6.1	8.3	5.8	6.8	5.1	
		C1	(7810)	(6710)	6710	6204	6204	5112	4605	4204	
		C2	(9378)	(8278)	7698	7401	7092	6465	5812	5794	

Analysis Period : 25 years
SN : Structural Number
x : Initial Performance Period (years)
C1 : Initial Construction Cost (pesos/meter)
C2 : Total Discounted Cost including Maintenance Cost (pesos/meter)
() : Initial Performance Period less than Design

TABLE 3

Basic Design

Rehabilitation Method	Traffic Loading Class	CBR k Mr	2 80 2500	3 130 4000	4 170 5000	6 210 6000	8 230 7000	10 250 8000	15 280 12000	20 300 15000	Design Performance Period
	L-1	h	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
		x	45.0	49.1	51.7	53.9	55.0	56.0	57.4	58.3	
		C1	1857	1857	1857	1857	1857	1857	1857	1857	
		C2	2051	2048	2047	2045	2045	2044	2043	2043	
	L-2	h	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
		x	32.2	35.8	38.1	40.2	41.2	42.1	43.4	44.3	20 Years
		C1	1857	1857	1857	1857	1857	1857	1857	1857	
		C2	2065	2060	2058	2055	2055	2054	2052	2052	
	L-3	h	15.0	15.0	13.0	13.0	13.0	13.0	13.0	13.0	
		x	22.5	25.3	20.4	21.9	22.6	23.3	24.1	25.0	
		C1	2034	2034	1857	1857	1857	1857	1857	1857	
		C2	2291	2256	2149	2127	2111	2097	2083	2080	
	A	h	20.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	
		x	19.4	15.5	16.6	17.7	18.2	18.5	19.1	19.6	
		C1	2973	2796	2796	2796	2796	2796	2796	2796	
		C2	3312	3273	3229	3191	3160	3158	3130	3127	
	B	h	23.0	23.0	23.0	20.0	20.0	20.0	20.0	20.0	
		x	19.3	21.1	22.1	14.7	15.1	15.5	16.1	16.4	15 Years
		C1	3238	3238	3238	2973	2973	2973	2973	2973	
		C2	3588	3531	3507	3520	3471	3468	3425	3422	
	C	h	25.0	25.0	25.0	23.0	23.0	23.0	23.0	23.0	
		x	16.2	17.6	18.6	14.4	14.8	15.1	15.6	15.9	
		C1	3415	3415	3415	3238	3238	3238	3238	3238	
		C2	3901	3851	3809	3819	3817	3763	3760	3757	
	D	h	28.0	28.0	28.0	28.0	28.0	28.0	28.0	25.0	
Rigid OI -Rigid Ex		x	17.0	18.3	19.2	20.0	20.4	20.7	21.2	14.3	
		C1	3681	3681	3681	3681	3681	3681	3681	3415	
		C2	4139	4092	4051	4017	4015	4012	3984	4020	
	E	h	30.0	30.0	28.0	28.0	28.0	28.0	28.0	28.0	
		x	17.5	18.8	15.0	15.6	15.9	16.2	16.7	16.9	
		C1	3858	3858	3681	3681	3681	3681	3681	3681	
		C2	4325	4275	4311	4247	4244	4191	4187	4185	15 Years
	F	h	33.0	33.0	30.0	30.0	30.0	30.0	30.0	30.0	
		x	19.5	20.8	14.8	15.4	15.7	16.0	16.4	16.6	
		C1	4124	4124	3858	3858	3858	3858	3858	3858	
		C2	4511	4470	4512	4444	4442	4439	4382	4380	
	G	h	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	
		x	16.0	17.1	17.8	18.5	18.8	19.1	19.5	19.7	
		C1	4124	4124	4124	4124	4124	4124	4124	4124	
		C2	4731	4614	4607	4558	4556	4515	4512	4510	
	H	h	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	
		x	13.6	14.5	15.2	15.8	16.1	16.3	16.7	16.9	
		C1	4124	4124	4124	4124	4124	4124	4124	4124	
		C2	4899	4813	4739	4734	4673	4671	4668	4666	
	I	h	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	
		x	11.8	12.7	13.3	13.8	14.1	14.3	14.6	14.9	12 Years
		C1	4124	4124	4124	4124	4124	4124	4124	4124	
		C2	5112	5000	4903	4898	4818	4816	4812	4810	
	J	h	(33.0)	(33.0)	33.0	33.0	33.9	33.0	33.0	33.0	
		x	(10.4)	(11.2)	11.8	12.3	12.5	12.7	13.0	13.2	
		C1	(4124)	(4124)	4124	4124	4124	4124	4124	4124	
		C2	(5249)	(5121)	5112	5004	5002	4999	4907	4905	

Analysis Period : 25 years
h : Thickness of PCC Overlay (cm)
x : Initial Performance Period (years)
C1 : Initial Construction Cost (pesos/meter)
C2 : Total Discounted Cost including Maintenance Cost (pesos/meter)
() : Initial Performance Period less than Design

TABLE 4

Basic Design

Rehabilitation Method	Traffic Loading Class	CBR / k / Mr	2 / 80 / 2500	3 / 130 / 4000	4 / 170 / 5000	6 / 210 / 6000	8 / 230 / 7000	10 / 250 / 8000	15 / 280 / 12000	20 / 300 / 15000	Design Performance Period
	L-1	h	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
		x	40.7	62.8	74.0	83.3	91.2	98.2	119.3	131.1	
		C1	1093	1093	1093	1093	1093	1093	1093	1093	
		C2	1353	1345	1343	1341	1340	1340	1338	1337	
	L-2	h	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
		x	28.5	48.4	59.1	68.1	75.9	82.7	103.7	115.4	15 Years
		C1	1093	1093	1093	1093	1093	1093	1093	1093	
		C2	1363	1350	1346	1344	1342	1341	1339	1338	
	L-3	h	8.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	
		x	24.2	28.3	37.3	45.3	52.5	58.9	79.2	90.7	
		C1	1585	1093	1093	1093	1093	1093	1093	1093	
		C2	1863	1364	1355	1351	1348	1346	1342	1340	
	A	h	13.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	
		x	12.6	16.8	23.7	30.4	36.6	42.4	61.6	72.7	
		C1	2897	2394	2394	2394	2394	2394	2394	2394	
		C2	3423	2777	2679	2654	2642	2635	2619	2614	
	B	h	(15.0)	13.0	10.0	10.0	10.0	10.0	10.0	10.0	
		x	(10.8)	16.9	14.8	19.9	25.0	29.9	47.3	57.9	12 Years
		C1	(3232)	2897	2394	2394	2394	2394	2394	2394	
		C2	(3873)	3285	2824	2724	2669	2655	2630	2622	
	C	h	(15.0)	15.0	13.0	10.0	10.0	10.0	10.0	10.0	
		x	(6.0)	14.6	14.9	12.1	15.8	19.6	34.2	43.8	
		C1	(3232)	3232	2897	2394	2394	2394	2394	2394	
		C2	(4362)	3683	3338	2907	2799	2725	2647	2633	
	D	h		15.0	13.0	10.0	10.0	10.0	10.0	10.0	
Flexible OI -Rigid Ex		x	n.a.	9.5	9.6	7.7	10.3	13.1	25.0	33.5	
		C1		3232	2897	2394	2394	2394	2394	2394	
		C2		3961	3599	3246	3014	2867	2669	2648	
	E	h		(15.0)	15.0	13.0	10.0	10.0	10.0	10.0	
		x	n.a.	(7.0)	10.8	10.2	7.7	9.9	19.9	27.5	
		C1		(3232)	3232	2897	2394	2394	2394	2394	
		C2		(4215)	3873	3555	3246	3070	2724	2661	8 Years
	F	h		(15.0)	(15.0)	15.0	13.0	13.0	10.0	10.0	
		x	n.a.	(4.9)	(7.7)	10.9	9.8	12.5	15.0	21.4	
		C1		(3232)	(3232)	3232	2897	2897	2394	2394	
		C2		(4665)	(4168)	3872	3598	3423	2823	2700	
	G	h			(15.0)	15.0	13.0	13.0	10.0	10.0	
		x	n.a.	n.a.	(6.0)	8.6	7.7	10.0	12.1	17.7	
		C1			(3232)	3232	2897	2897	2394	2394	
		C2			(4362)	4041	3795	3597	2916	2758	
	H	h			15.0	15.0	13.0	13.0	10.0	10.0	
		x	n.a.	n.a.	4.9	7.2	6.4	8.3	10.1	15.1	
		C1			3232	3232	2897	2897	2394	2394	
		C2			4665	4183	3956	3706	3015	2802	
	I	h				15.0	13.0	13.0	10.0	10.0	
		x	n.a.	n.a.	n.a.	6.1	5.4	7.1	8.7	13.2	5 Years
		C1				3232	2897	2897	2394	2394	
		C2				4346	4143	3845	3159	2867	
	J	h				15.0	15.0	13.0	10.0	10.0	
		x	n.a.	n.a.	n.a.	5.3	7.3	6.2	7.7	11.7	
		C1				3232	3232	2897	2394	2394	
		C2				4505	4182	4007	3246	2949	

Analysis Period : 25 years
h : Thickness of AC Overlay (cm)
x : Initial Performance Period (years)
C1 : Initial Construction Cost (pesos/meter)
C2 : Total Discounted Cost including Maintenance Cost (pesos/meter)
() : Initial Performance Period less than Design

TABLE 5

Basic Design

Rehabilitation Method	Traffic Loading Class	CBR k Mr	2 80 2500	3 130 4000	4 170 5000	6 210 6000	8 230 7000	10 250 8000	15 280 12000	20 300 15000	Design Performance Period
	L-1	h	8.0	5.0	5.0	3.0	3.0	3.0	3.0	3.0	
		x	11.7	10.8	16.0	11.1	14.6	18.2	32.4	41.8	
		C1	1540	1048	1048	735	735	735	735	735	
		C2	2080	1580	1416	1175	1107	1055	1004	1000	
	L-2	h	10.0	8.0	8.0	5.0	5.0	3.0	3.0	3.0	
		x	11.8	15.8	22.5	13.1	17.1	10.9	21.5	29.4	10 Years
		C1	1853	1540	1540	1048	1048	735	735	735	
		C2	2426	1938	1834	1483	1399	1199	1029	1006	
	L-3	h		10.0	8.0	8.0	8.0	8.0	3.0	3.0	
		x	n.a.	11.7	10.1	14.1	18.2	22.3	9.6	14.4	
		C1		1853	1540	1540	1540	1540	735	735	
		C2		2427	2143	1965	1884	1834	1247	1107	
	A	h			10.0	10.0	8.0	8.0	5.0	5.0	
		x	n.a.	n.a.	5.1	7.4	5.7	7.5	6.5	10.1	
		C1			2349	2349	2036	2036	1544	1544	
		C2			3656	3272	3162	2894	2372	2087	
	B	h					10.0	10.0	8.0	5.0	
		x	n.a.	n.a.	n.a.	n.a.	5.5	7.2	9.2	5.6	5 Years
		C1					2349	2349	2036	1544	
		C2					3581	3303	2715	2484	
	C	h							8.0	8.0	
		x	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5.1	8.0	
		C1							2036	2036	
		C2							3236	2862	
	D	h							10.0	8.0	
Flexible OI -Flexible Ex		x	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5.5	4.9	
		C1							2349	2036	
		C2							3581	3317	
	E	h								10.0	
		x	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	6.3	
		C1								2349	
		C2								3429	5 Years
	F	h									
		x	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
		C1									
		C2									
	G	h									
		x	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
		C1									
		C2									
	H	h									
		x	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
		C1									
		C2									
	I	h									
		x	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5 Years
		C1									
		C2									
	J	h									
		x	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
		C1									
		C2									

Analysis Period : 25 years
h : Thickness of AC Overlay (cm)
x : Initial Performance Period (years)
C1 : Initial Construction Cost (pesos/meter)
C2 : Total Discounted Cost including Maintenance Cost (pesos/meter)
() : Initial Performance Period less than Design

APPENDIX 9-3
PAVEMENT DESIGN METHOD

1. PCA METHOD

Source; Thickness Design for Concrete Highway and Street Pavements, 1984, Portland Cement Association

1.1 Basis and Applications

The thickness design methods presented in this Bulletin are based on knowledge of pavement theory, performance, and research experience from the following sources:

- Theoretical studies of pavement slab behavior by Westergaard, Pickett and Ray and finite-element computer analysis.
- Model and full scale tests such as Arlington Test and several research projects conducted by PCA and other agencies
- Experimental pavements subjected to controlled test traffic such as the Bates Test Road, the AASHO Road Test and others.

In this Bulletin, two design criteria, such as fatigue and erosion were defined as follows:

- Fatigue, to keep pavement stress due to repeated loads within safe limits and thus prevent fatigue cracking
- Erosion, to limit the effects of pavement deflections at slab edges, joint, and corners and thus control the erosion of foundation and shoulder materials. This criterion is vital since some modes of pavement distress such as pumping, faulting, and shoulder distress are unrelated to fatigue.

Types of concrete pavement, subbase and shoulder discussed in the Bulletin are;

- Plain pavement with or without dowels
- Reinforced jointed pavement with dowels
- Continously reinforced pavement
- Type of subbase (untreated subbase and cement-treated subbase)
- Type of shoulder (with or without concrete shoulders, curb and gutter or integral curb

1.2 Design Requirement

Four design factors (strength of concrete, strength of subgrade and subbase, traffic and design period) are applied in this method.

Flexural Strength of the Concrete (Modulus of Rupture, MR)

Flexural strength is determined by modulus of rupture tests (ASTM C78, third point method) and 28 days strength was used in this thickness design. The effects of variation in concrete strength from point to point in the pavement and gains in concrete strength with age are incorporated in the design.

Strength of the Subgrade, or Subgrade and Subbase Combination (K)

Subgrade and subbase support is defined in terms of the Westergaard modulus of subgrade reaction (k), which is equal to value obtained by 30 inches diameter plate-loading test. The K value can be estimated by correlation to CBR or R-value, where a subbase is used, effect of subbase (an increase in K value) should be considered. Effect of an untreated granulin materials as subbase can be taken from the table below.

TABLE 1.1 EFFECT OF UNTREATED SUBBASE ON K VALUES (UNTREATED GRANULAR MATERIALS)

Subgrade k Value pci	Subbase k value, pci			
	4 in.	6 in.	9 in.	12 in
50	65	75	85	110
100	130	140	160	190
200	220	230	270	320
300	320	330	370	430

Traffic Characteristics

Average daily truck traffic (ADTT) is used in the design procedure. The AADT value includes only trucks with six tires or more and does not include panel and pick-up trucks and other four-tire vehicles. Axle load distribution is needed to compute the numbers of single and tandem axles of various weight.

Load Safety Factors

In the design procedure, the axle loads are multiplied only by a load safety factor (LSF). These load safety factors are recommended as follows:

- For multilane projects where there will be uninterrupted traffic flow and high volume of truck traffic, LSF = 1.2
- For highways and arterial streets where there will be moderate volume of truck traffic, LSF = 1.1
- For roads, residential streets and others that will carry small volumes of truck traffic, LSF = 1.0

These LSF also provides a degree of conservatism such as unpredicted truck overloads and normal construction variations in material properties and layer thickness.

Design Period

Selection of the design period for a specific project is based on engineering judgement and economic analysis of pavements. Design period is usually taken at 20 years, but may be more or less.

1.3 Design Procedure

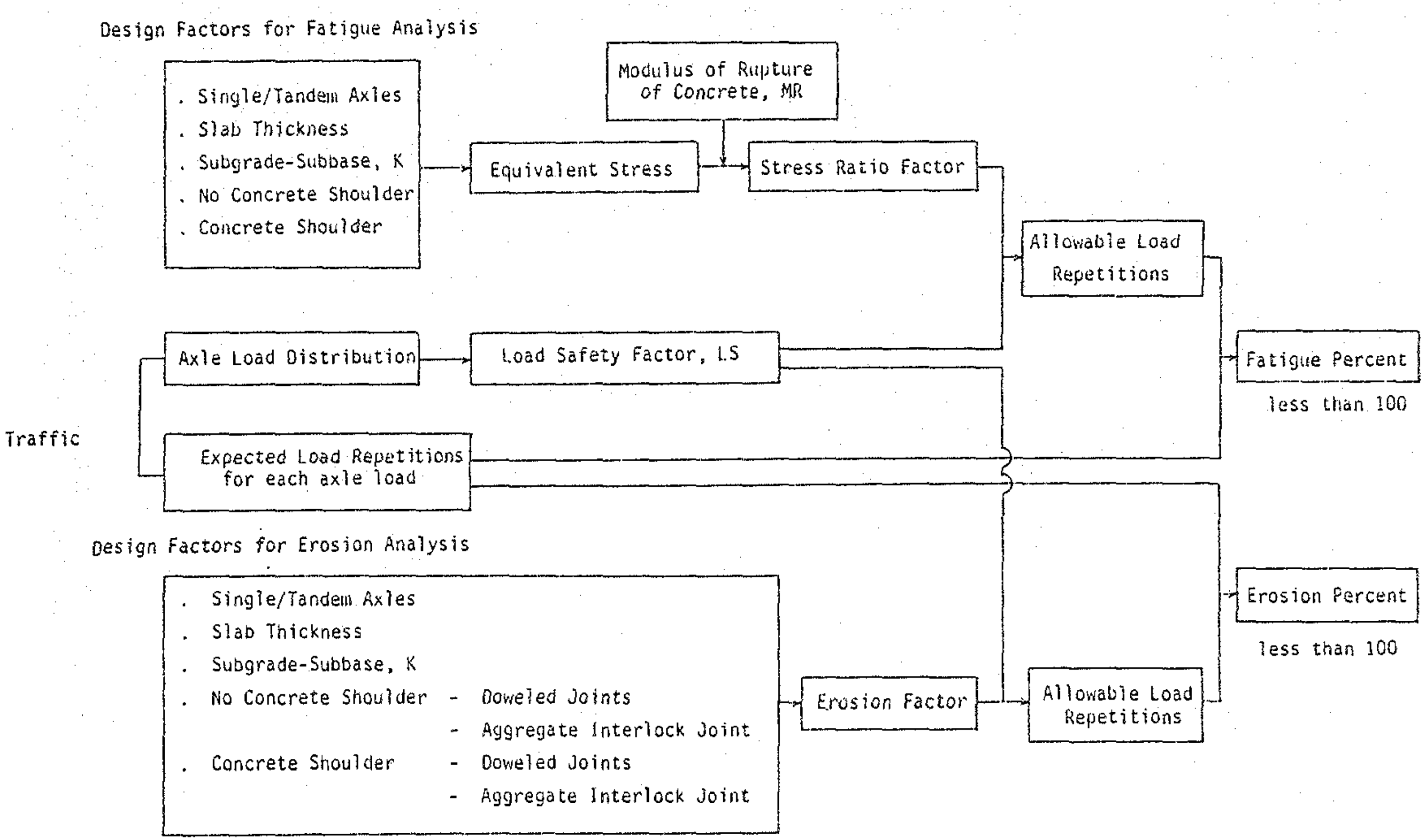
The fatigue analysis will usually control the design of light-traffic pavements (residential streets and secondary roads regardless of whether the joints are doweled or not) and medium traffic pavements with doweled joints.

The erosion analysis will usually control the design of medium- and heavy-traffic pavements with undoweled (aggregate-interlock) joints and heavy-traffic pavements with doweled joints.

For pavements carrying a normal mix of axle weights, single-axle loads are usually more severe in the fatigue analysis, and tandem-axle loads are more severe in the erosion analysis.

The conceptional flow of design procedure is illustrated in Figure 1.1.

FIGURE 1-1 FATIGUE AND EROSION ANALYSIS



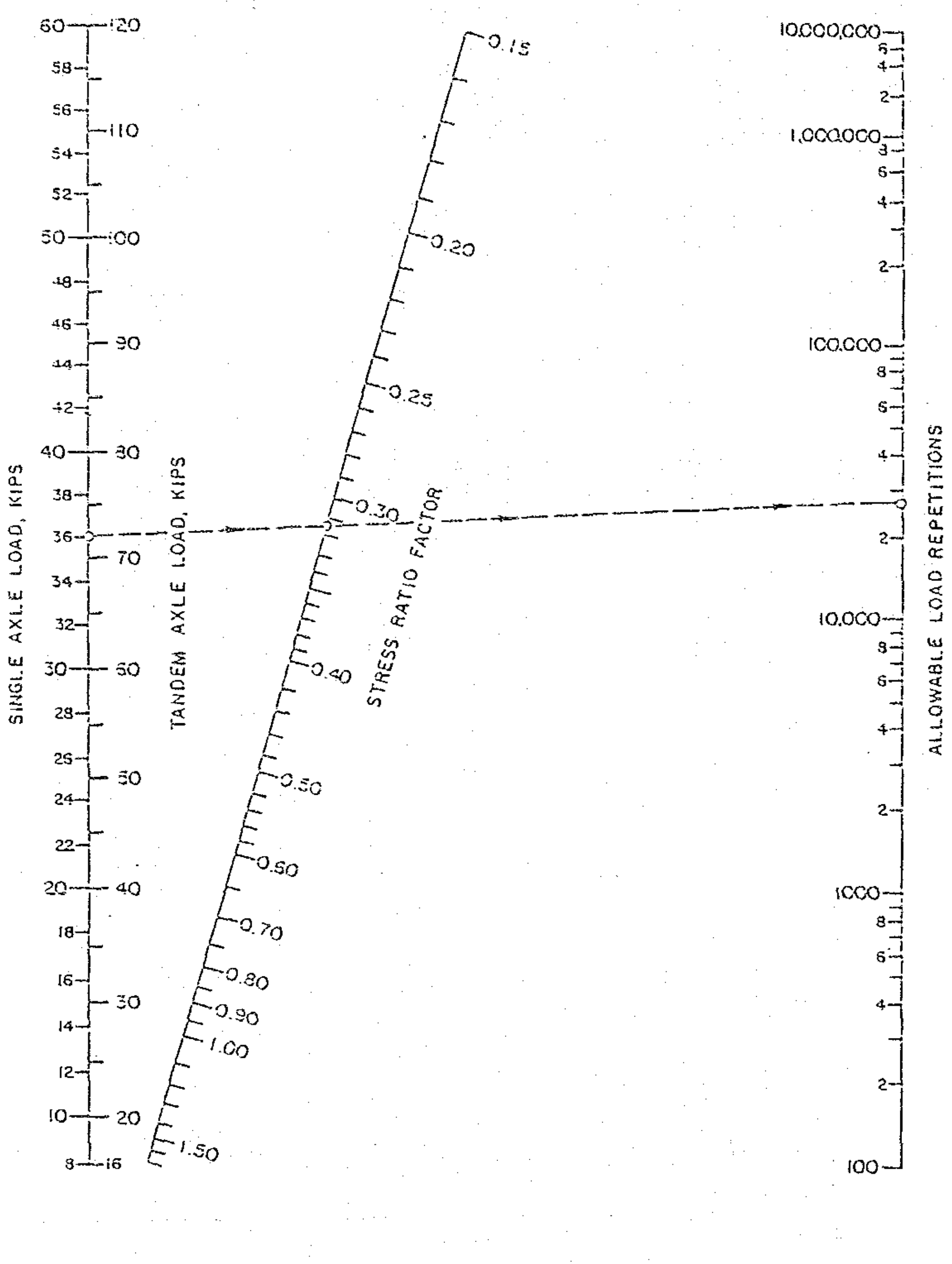


FIGURE 1.2 FATIGUE ANALYSIS-ALLOWABLE LOAD REPETITIONS BASE ON STRESS RATIO FACTOR (WITH AND WITHOUT CONCRETE SHOULDER)

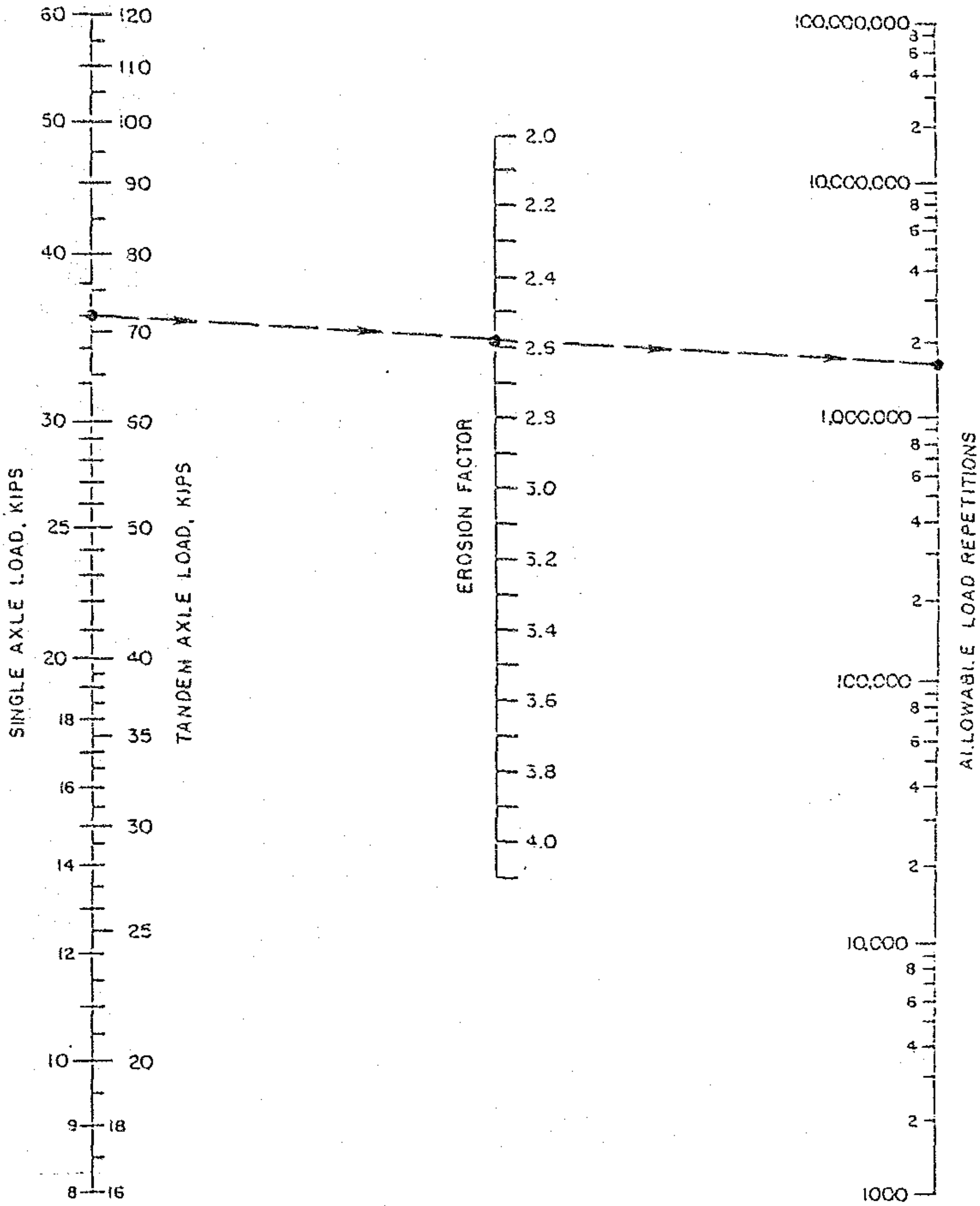


FIGURE 1.3 EROSION ANALYSIS-ALLOWABLE LOAD REPETITIONS BASED ON EROSION FACTOR (WITHOUT CONCRETE SHOULDER)

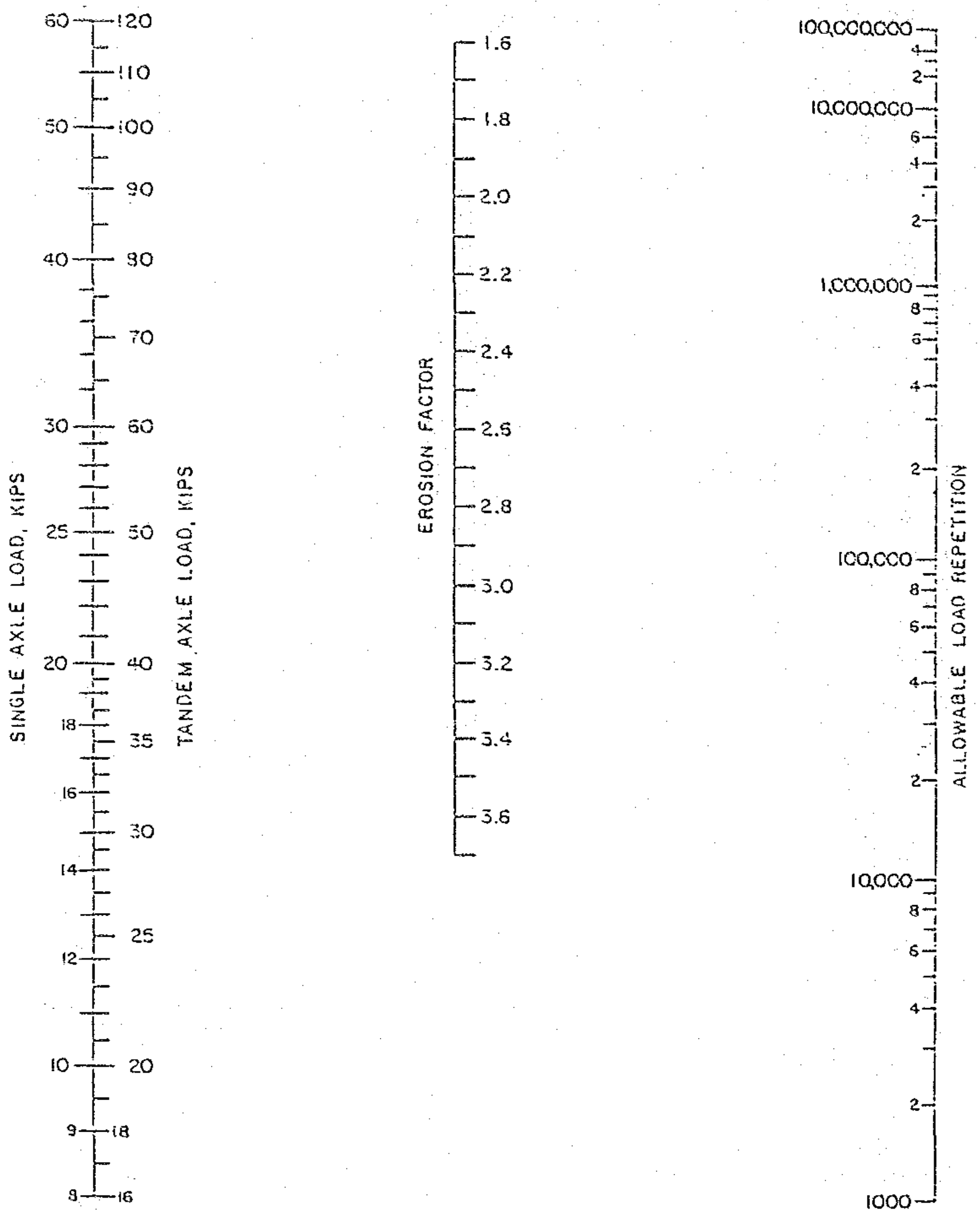


FIGURE 1.4 EROSION ANALYSIS-ALLOWABLE LOAD REPETITIONS BASED ON EROSION FACTOR (WITH CONCRETE SHOULDER)

TABLE 1.2 (a) EQUIVALENT STRESS - NO CONCRETE SHOULDER
(SINGLE AXLE/TANDEM AXLE)

Slab Thickness in.	k of Subgrade-Subbase, pci						
	50	100	150	200	300	500	700
4	825/679	726/585	671/542	634/516	584/486	523/457	484/443
4.5	699/586	616/500	571/460	540/435	498/406	448/378	417/363
5	602/516	531/463	493/399	467/376	432/349	390/321	363/307
5.5	526/461	464/387	431/353	409/331	379/305	343/278	320/264
6	465/416	411/348	382/316	362/296	336/271	304/246	285/232
6.5	417/380	367/317	341/286	324/267	300/244	273/220	256/207
7	375/349	331/290	307/262	292/244	271/222	246/199	231/186
7.5	340/323	300/268	279/241	265/224	246/203	224/181	210/169
8	311/300	274/249	255/223	242/208	225/188	205/167	192/155
8.5	285/281	252/232	234/208	222/193	206/174	188/154	177/143
9	264/264	232/218	216/195	205/181	190/163	174/144	163/133
9.5	245/248	215/205	200/183	190/170	176/153	161/134	151/124
10	228/235	200/193	186/173	177/160	164/144	150/126	141/117
10.5	213/222	187/183	174/164	165/151	153/136	140/119	132/110
11	200/211	175/174	163/155	154/143	144/129	131/113	123/104
11.5	188/201	165/165	153/148	145/136	135/122	123/107	116/ 98
12	177/192	155/158	144/141	137/130	127/116	116/102	109/ 93
12.5	168/183	147/151	136/135	129/124	120/111	109/ 97	103/ 89
13	159/176	139/144	129/129	122/119	113/106	103/ 93	97/ 85
13.5	152/168	132/138	122/123	116/114	107/102	98/ 89	92/ 81
14	144/162	125/133	116/118	110/109	102/ 98	93/ 85	88/ 78

TABLE 1.2 (b) EQUIVALENT STRESS - CONCRETE SHOULDER
(SINGLE AXLE/TANDEM AXLE)

Slab Thickness in.	k of Subgrade-Subbase, pci						
	50	100	150	200	300	500	700
4	640/534	559/468	517/439	489/422	452/403	409/388	383/384
4.5	547/461	479/400	444/372	421/356	390/338	355/322	333/316
5	475/404	417/349	387/323	367/308	341/290	311/274	294/267
5.5	418/360	368/309	342/285	324/271	302/254	276/238	261/231
6	372/325	327/277	304/255	289/241	270/225	247/210	234/203
6.5	334/295	294/251	274/230	260/218	243/203	223/188	212/180
7	302/270	266/230	248/210	236/198	220/184	203/170	192/162
7.5	275/250	243/211	226/193	215/182	201/168	185/155	176/148
8	252/232	222/196	207/179	197/168	185/155	170/142	162/135
8.5	232/216	205/182	191/166	182/156	170/144	157/131	150/125
9	215/202	190/171	177/155	169/146	158/134	146/122	139/116
9.5	200/190	176/160	164/146	157/137	147/126	136/114	129/108
10	186/179	164/151	153/137	146/129	137/118	127/107	121/101
10.5	174/170	154/143	144/130	137/121	128/111	119/101	113/ 95
11	164/161	144/135	135/123	129/115	120/105	112/ 95	106/ 90
11.5	154/153	136/128	127/117	121/109	113/100	105/ 90	100/ 85
12	145/146	128/122	120/111	114/104	107/ 95	99/ 86	95/ 81
12.5	137/139	121/117	113/106	108/ 99	101/ 91	94/ 82	90/ 77
13	130/133	115/112	107/101	102/ 95	96/ 86	89/ 78	85/ 73
13.5	124/127	109/107	102/ 97	97/ 91	91/ 83	85/ 74	81/ 70
14	118/122	104/103	97/ 93	93/ 87	87/ 79	81/ 71	77/ 67

TABLE 1.3 (a) EROSION FACTORS — DOWELED JOINTS, NO CONCRETE SHOULDER (SINGLE AXLE/TANDEM AXLE)

Slab Thickness in.	k of Subgrade-Subbase, pci					
	50	100	200	300	500	700
4	3.74/3.83	3.73/3.79	3.72/3.75	3.71/3.73	3.70/3.70	3.68/3.67
4.5	3.59/3.70	3.57/3.65	3.56/3.61	3.55/3.58	3.54/3.55	3.52/3.53
5	3.45/3.58	3.43/3.52	3.42/3.48	3.41/3.45	3.40/3.42	3.38/3.40
5.5	3.33/3.47	3.31/3.41	3.29/3.36	3.28/3.33	3.27/3.30	3.26/3.28
6	3.22/3.38	3.19/3.31	3.18/3.26	3.17/3.23	3.15/3.20	3.14/3.17
6.5	3.11/3.29	3.09/3.22	3.07/3.16	3.06/3.13	3.05/3.10	3.03/3.07
7	3.02/3.21	2.99/3.14	2.97/3.08	2.96/3.05	2.95/3.01	2.94/2.98
7.5	2.93/3.14	2.91/3.06	2.88/3.00	2.87/2.97	2.86/2.93	2.84/2.90
8	2.85/3.07	2.82/2.99	2.80/2.93	2.79/2.89	2.77/2.85	2.76/2.82
8.5	2.77/3.01	2.74/2.93	2.72/2.86	2.71/2.82	2.69/2.78	2.68/2.75
9	2.70/2.96	2.67/2.87	2.65/2.80	2.63/2.76	2.62/2.71	2.61/2.68
9.5	2.63/2.90	2.60/2.81	2.58/2.74	2.56/2.70	2.55/2.65	2.54/2.62
10	2.56/2.85	2.54/2.76	2.51/2.68	2.50/2.64	2.48/2.59	2.47/2.56
10.5	2.50/2.81	2.47/2.71	2.45/2.63	2.44/2.59	2.42/2.54	2.41/2.51
11	2.44/2.76	2.42/2.67	2.39/2.58	2.38/2.54	2.36/2.49	2.35/2.45
11.5	2.38/2.72	2.36/2.62	2.33/2.54	2.32/2.49	2.30/2.44	2.29/2.40
12	2.33/2.68	2.30/2.58	2.28/2.49	2.26/2.44	2.25/2.39	2.23/2.36
12.5	2.28/2.64	2.25/2.54	2.23/2.45	2.21/2.40	2.19/2.35	2.18/2.31
13	2.23/2.61	2.20/2.50	2.18/2.41	2.16/2.36	2.14/2.30	2.13/2.27
13.5	2.18/2.57	2.15/2.47	2.13/2.37	2.11/2.32	2.09/2.26	2.08/2.23
14	2.13/2.54	2.11/2.43	2.08/2.34	2.07/2.29	2.05/2.23	2.03/2.19

TABLE 1.3 (b) EROSION FACTORS — AGGREGATE - INTERLOCK JOINTS NO CONCRETE SHOULDER (SINGLE XLE/TANDEM AXLE)

Slab Thickness in.	k of Subgrade-Subbase, pci					
	50	100	200	300	500	700
4	3.94/4.03	3.91/3.95	3.88/3.89	3.86/3.86	3.82/3.83	3.77/3.80
4.5	3.79/3.91	3.76/3.82	3.73/3.75	3.71/3.72	3.68/3.68	3.64/3.65
5	3.66/3.81	3.63/3.72	3.60/3.64	3.58/3.60	3.55/3.55	3.52/3.52
5.5	3.54/3.72	3.51/3.62	3.48/3.53	3.46/3.49	3.43/3.44	3.41/3.40
6	3.44/3.64	3.40/3.53	3.37/3.44	3.35/3.40	3.32/3.34	3.30/3.30
6.5	3.34/3.56	3.30/3.46	3.26/3.36	3.25/3.31	3.22/3.25	3.20/3.21
7	3.26/3.49	3.21/3.39	3.17/3.29	3.15/3.24	3.13/3.17	3.11/3.13
7.5	3.18/3.43	3.13/3.32	3.09/3.22	3.07/3.17	3.04/3.10	3.02/3.06
8	3.11/3.37	3.05/3.26	3.01/3.16	2.99/3.10	2.96/3.03	2.94/2.99
8.5	3.04/3.32	2.98/3.21	2.93/3.10	2.91/3.04	2.88/2.97	2.87/2.93
9	2.98/3.27	2.91/3.16	2.86/3.05	2.84/2.99	2.81/2.92	2.79/2.87
9.5	2.92/3.22	2.85/3.11	2.80/3.00	2.77/2.94	2.75/2.86	2.73/2.81
10	2.86/3.18	2.79/3.06	2.74/2.95	2.71/2.89	2.68/2.81	2.66/2.76
10.5	2.81/3.14	2.74/3.02	2.68/2.91	2.65/2.84	2.62/2.76	2.60/2.72
11	2.77/3.10	2.69/2.98	2.63/2.86	2.60/2.80	2.57/2.72	2.54/2.67
11.5	2.72/3.06	2.64/2.94	2.58/2.82	2.55/2.76	2.51/2.68	2.49/2.63
12	2.68/3.03	2.60/2.90	2.53/2.78	2.50/2.72	2.46/2.64	2.44/2.59
12.5	2.64/2.99	2.55/2.87	2.48/2.75	2.45/2.68	2.41/2.60	2.39/2.55
13	2.60/2.96	2.51/2.83	2.44/2.71	2.40/2.65	2.36/2.56	2.34/2.51
13.5	2.56/2.93	2.47/2.80	2.40/2.68	2.36/2.61	2.32/2.53	2.30/2.48
14	2.53/2.90	2.44/2.77	2.36/2.65	2.32/2.58	2.28/2.50	2.25/2.44

TABLE 1.4 (a) EROSION FACTORS-DOWELED JOINTS, CONCRETE SHOULDER
(SINGLE AXLE/TANDEM AXLE)

Slab Thickness in.	k of Subgrade-Subbase, pci					
	50	100	200	300	500	700
4	3.28/3.30	3.24/3.20	3.21/3.13	3.19/3.10	3.15/3.09	3.12/3.08
4.5	3.13/3.19	3.09/3.08	3.06/3.00	3.04/2.96	3.01/2.93	2.98/2.91
5	3.01/3.09	2.97/2.98	2.93/2.89	2.90/2.84	2.87/2.79	2.85/2.77
5.5	2.90/3.01	2.85/2.89	2.81/2.79	2.79/2.74	2.76/2.68	2.73/2.65
6	2.79/2.93	2.75/2.82	2.70/2.71	2.68/2.65	2.65/2.58	2.62/2.54
6.5	2.70/2.86	2.65/2.75	2.61/2.63	2.58/2.57	2.55/2.50	2.52/2.45
7	2.61/2.79	2.56/2.68	2.52/2.56	2.49/2.50	2.46/2.42	2.43/2.38
7.5	2.53/2.73	2.48/2.62	2.44/2.50	2.41/2.44	2.38/2.36	2.35/2.31
8	2.46/2.68	2.41/2.56	2.36/2.44	2.33/2.38	2.30/2.30	2.27/2.24
8.5	2.39/2.62	2.34/2.51	2.29/2.39	2.26/2.32	2.22/2.24	2.20/2.18
9	2.32/2.57	2.27/2.46	2.22/2.34	2.19/2.27	2.16/2.19	2.13/2.13
9.5	2.26/2.52	2.21/2.41	2.16/2.29	2.13/2.22	2.09/2.14	2.07/2.08
10	2.20/2.47	2.15/2.36	2.10/2.25	2.07/2.18	2.03/2.09	2.01/2.03
10.5	2.15/2.43	2.09/2.32	2.04/2.20	2.01/2.14	1.97/2.05	1.95/1.99
11	2.10/2.39	2.04/2.28	1.99/2.16	1.95/2.09	1.92/2.01	1.89/1.95
11.5	2.05/2.35	1.99/2.24	1.93/2.12	1.90/2.05	1.87/1.97	1.84/1.91
12	2.00/2.31	1.94/2.20	1.88/2.09	1.85/2.02	1.82/1.93	1.79/1.87
12.5	1.95/2.27	1.89/2.16	1.84/2.05	1.81/1.98	1.77/1.89	1.74/1.84
13	1.91/2.23	1.85/2.13	1.79/2.01	1.76/1.95	1.72/1.86	1.70/1.80
13.5	1.86/2.20	1.81/2.09	1.75/1.98	1.72/1.91	1.68/1.83	1.65/1.77
14	1.82/2.17	1.76/2.06	1.71/1.95	1.67/1.88	1.64/1.80	1.61/1.74

TABLE 1.4 (b) EROSION FACTORS - AGGREGATE-INTERLOCK JOINTS,
CONCRETE SHOULDER (SINGLE AXLE/TANDEM AXLE)

Slab Thickness in.	k of Subgrade-Subbase, pci					
	50	100	200	300	500	700
4	3.46/3.49	3.42/3.39	3.38/3.32	3.36/3.29	3.32/3.26	3.28/3.24
4.5	3.32/3.39	3.28/3.28	3.24/3.19	3.22/3.16	3.19/3.12	3.15/3.09
5	3.20/3.30	3.16/3.18	3.12/3.09	3.10/3.05	3.07/3.00	3.04/2.97
5.5	3.10/3.22	3.05/3.10	3.01/3.00	2.99/2.95	2.96/2.90	2.93/2.86
6	3.00/3.15	2.95/3.02	2.90/2.92	2.88/2.87	2.86/2.81	2.83/2.77
6.5	2.91/3.08	2.86/2.96	2.81/2.85	2.79/2.79	2.76/2.73	2.74/2.68
7	2.83/3.02	2.77/2.90	2.73/2.78	2.70/2.72	2.68/2.66	2.65/2.61
7.5	2.76/2.97	2.70/2.84	2.65/2.72	2.62/2.66	2.60/2.59	2.57/2.54
8	2.69/2.92	2.63/2.79	2.57/2.67	2.55/2.61	2.52/2.53	2.50/2.48
8.5	2.63/2.88	2.56/2.74	2.51/2.62	2.48/2.55	2.45/2.48	2.43/2.43
9	2.57/2.83	2.50/2.70	2.44/2.57	2.42/2.51	2.39/2.43	2.36/2.38
9.5	2.51/2.79	2.44/2.65	2.38/2.53	2.36/2.46	2.33/2.38	2.30/2.33
10	2.46/2.75	2.39/2.61	2.33/2.49	2.30/2.42	2.27/2.34	2.24/2.28
10.5	2.41/2.72	2.33/2.58	2.27/2.45	2.24/2.38	2.21/2.30	2.19/2.24
11	2.36/2.68	2.28/2.54	2.22/2.41	2.19/2.34	2.16/2.26	2.14/2.20
11.5	2.32/2.65	2.24/2.51	2.17/2.38	2.14/2.31	2.11/2.22	2.09/2.16
12	2.28/2.62	2.19/2.48	2.13/2.34	2.10/2.27	2.06/2.19	2.04/2.13
12.5	2.24/2.59	2.15/2.45	2.09/2.31	2.05/2.24	2.02/2.15	1.99/2.10
13	2.20/2.56	2.11/2.42	2.04/2.28	2.01/2.21	1.98/2.12	1.95/2.06
13.5	2.16/2.53	2.08/2.39	2.00/2.25	1.97/2.18	1.93/2.09	1.91/2.03
14	2.13/2.51	2.04/2.36	1.97/2.23	1.93/2.15	1.89/2.06	1.87/2.00

2. TRRL Method

Source: Road Note 29, A guide to the structural design pavements for new roads, Third Edition, 1970, Department of the Environment, Road Research Laboratory

The recommendations given in this document have been based largely on experience gained from the full-side experimented roads carried out by the Transport and Road Research Laboratory.

(1) Design Factors

Strength of Subgrade

The strength of the subgrade is assessed on CBR as shown in Table 2-1.

Table 2-1 Estimated labortary CBR values for soils compacted at the natural moisture content

Type of soil	Plasticity index (per cent)	CBR (per cent)	
		Depth of water-table below formation level	
		More than 600 mm	600 mm or less
Heavy clay	70 60 50 40	2 2 2.5 3	1 1.5 2 2
Silty clay	30	5	3
Sandy clay	20 10	6 7	4 5
Silt	-	2	1*
Sand (poorly graded)	non-plastic	20	10
Sand (well graded)	non-plastic	40	15
Well-graded sandy gravel	non-plastic	60	20

Subbase

The minimum thickness of subbase recommended for the three types of subgrade is given in Table 2-2.

Table 2-2 Classification of subgrades for concrete roads and minimum thickness of sub-base required

Type of subgrade	Definition	Minimum thickness of sub-base required
Weak	All subgrades of CBR value 2 per cent or less as defined in Table 3	150 mm
Normal	Subgrades other than those defined by the other categories	80 mm
Very stable	All subgrades of CBR value 15 per cent or more as defined in Table 3. This category includes undisturbed foundations of old roads	0

However, to cater for heavy traffic, the subbase thicknesses shown in Table 2-3 are recommended.

TABLE 2-3 SUBBASE THICKNESS FOR HEAVY TRAFFIC

CBR of Subgrade	:	Subbase Thickness (mm)
Less than 2	:	280
2 - 4	:	180
4 - 6	:	130
6 -15	:	80
Over 15	:	0

Drainage and Weather Protection

Wherever practicale, the water table should be prevented from rising it within 600 mm of the formation level, both during construction and during the life of the road.

Traffic

In the structural design, only the numbers of commerical vehicles and their axle loadings are considered. The commerical vehicle is defined as a goods or public service vehicle of unladen weight exceeding 1500 kg. This document shows the equivalence factors and damaging power of different axle loads for simplicity. Those were developed from the AASHO Road Test to convert each exle load to an equivalent number of passenger of a standard axle (18 kip).

Minimum Crushing Strength for Concrete

28MN/m^2 at 28 days using ordinary Portland cement.

(2) Design Procedure

Fig 6.1gives the thickness required for unreinforced concrete slab in terms of the cumulative number of standard axle to be carried for three types of subgrade.

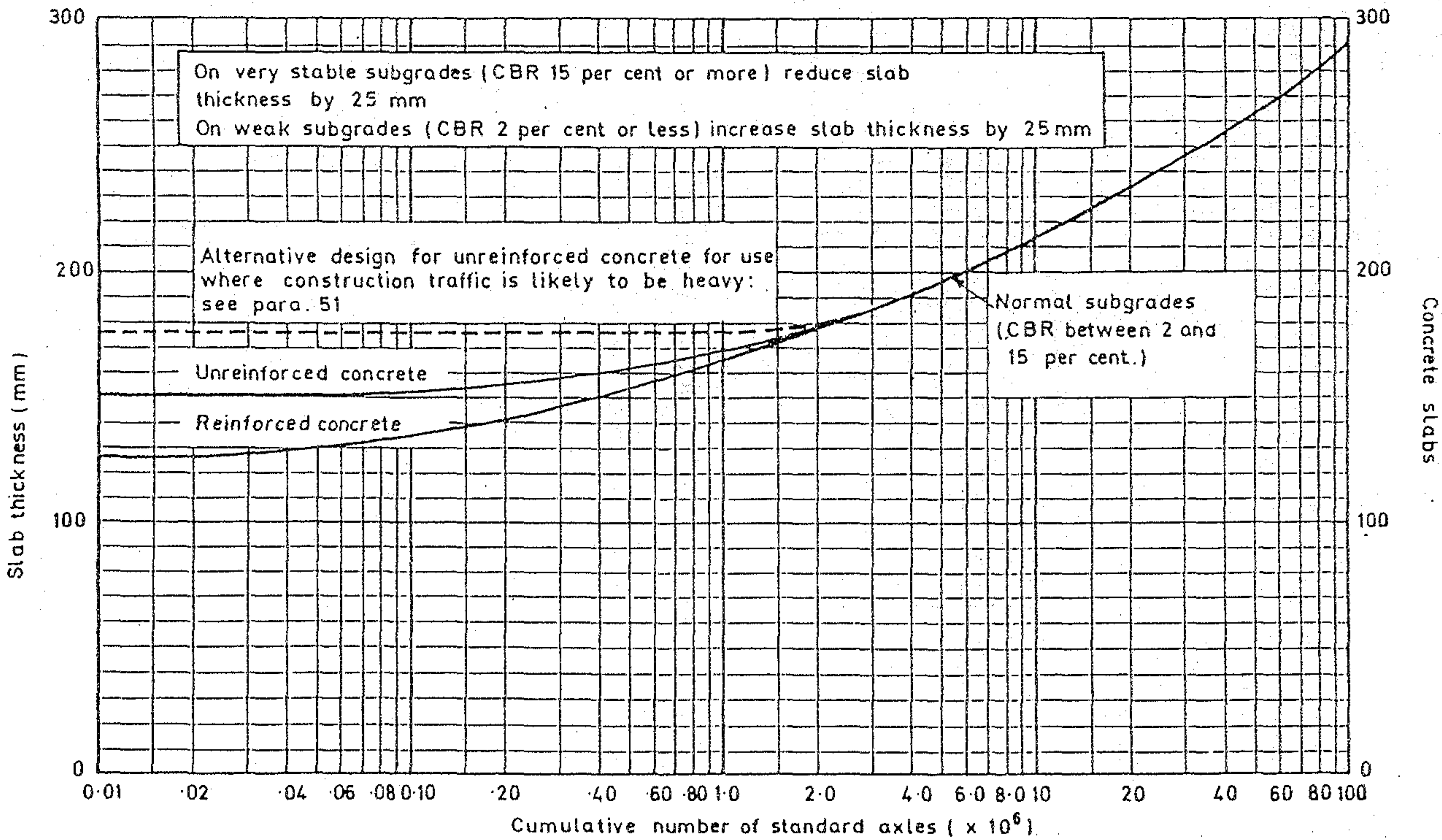


FIGURE 2.1 CONCRETE MOVEMENT THICKNESS OF SLABS

3. JRA Method

Source; Manual for Cement Concrete Pavement, 1984 Japan Road Association

(1) Design Factors

Subgrade and Subbase

Thickness of Subbase

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

Concrete

Flexural strength of concrete at 28 days by Third Point Loading = 45 kg/cm^2
Wire Mesh 3 kg/m^2 (6mm Deformed Reinforcing Bar)

Traffic

Vehicles considered in the design are only these heavier than trucks.

Design Life

More or less 20 years.

(2) Required Thickness of Concrete Slab

Traffic Class	Number of Truck ※1	Thickness of Slab (cm)
L	less than 100	15 (20) ※2
A	100 - 250	20 (25) ※2
B	250 - 1000	25
C	1000 - 3000	20
D	more than 3000	30

※1 Number of truck per day per one direction

※2 for concrete with 40 kg/cm^2

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