CHAPTER 23
RIGID PAVEMENT DESIGN
SECTION 100-PAVEMENT QUALITY CONCRETE SLABS

General

2301. A pavement develops considerable local flexural rigidity through tensile strength is called concrete or rigid pavement**.** Concrete/Rigid pavements must be designed to endure frequently repeated traffic loadings. The typical designed service life of a rigid pavement is between 30 and 40 years, lasting about twice as long as a flexible pavement. Concrete is better able than bituminous construction to resist fuel and oil spillage. Concrete road pavements are often found in established port and industrial areas. Concrete roads can be built to carry all types of heavy traffic in any climatic conditions. Construction is slow, and repair work involves interruption of traffic owing to the need for curing but it is long lasting structure.

Figure 23-1: Concrete Road

2302. Portland cement concrete (PCC) is the most common material used in the construction of rigid pavement slabs. The reason for its popularity is due to its availability and the economy. Characteristics of materials and details of mixing, transporting, placing. Compacting, curing, and testing concrete are dealt with in RESPB No. 2 (wo code No 8642).

Design

2303. Concrete roads are generally constructed in three layers - a prepared subgrade, base or sub-base, and a concrete slab. For operational purposes, plain concrete slabs from 4 to 8 ins thick have been used successfully over inform good sub grads. For long-term use steel reinforcement recommended to increase tensile strength to control crack and to reduce slab thickness. Recommended slab thicknesses based on traffic loads and intensities, are given in Table 23.1.

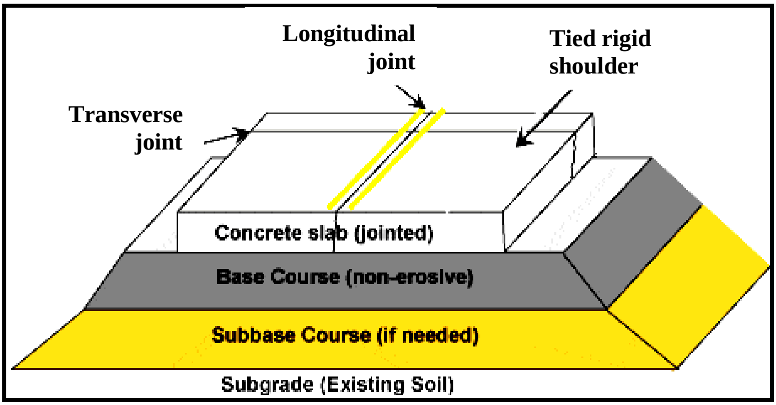

Figure 23-2: Parts of Concrete Road

2304. Mix design. Where economy is important and time available, mix design should be based on strength of concrete and its durability, workability local materials and conditions. It is best undertaken by a soils laboratory. For urgent operational work the mix proportions given it Table 23.2 may be used as a guide.

2305. Batching and proportioning methods. The most suitable aggregate/cement and water/cement rations can be determined as follows:-

a. Select from Table 23.2 the mix appropriate to the work and to the available aggregate and check from Table 23.3 that it will give adequate strength in the prescribed curing period.

b. Prepare a trial gauging of the proportions selected.

c. Examine the mix for the faults listed in Table 23.4.

d. Taking the remedial action shown in Table 23.4 makes one or more revised trial mixes.

e. Check the selected gauging by the slump test (see Table 23.2 column (m)). The test described in RESPB No. 2. Section 13.

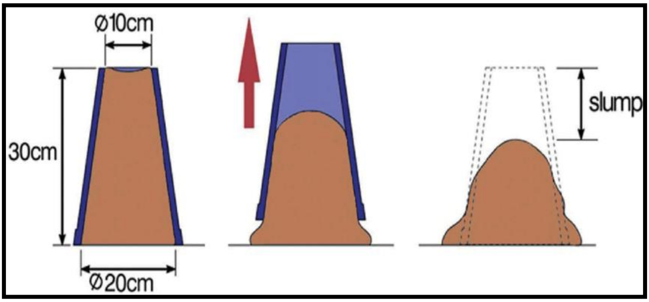

Figure 23-3 (a) : Slump Test

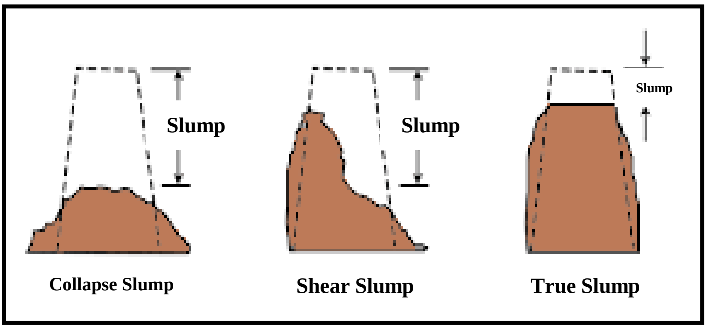

Figure 23-3 (b) : Slump Test

TABLE 23.1-RECOMMENDED THICKNESS OF CONCRETE SLABS FOR MILITARY ROADS

Serial No	Sub-grade condition	Thickness of sub-base (i) (ins)	Recommended thickness of reinforced concrete slab, using 7 to 10 lb of steel per sq yd (ii) (ins)		
			Traffic intensity (iii)		
			Heavy (iv)	Medium	Light
(a)	(b)	(c)	(d)	(e)	(f)
1.	Thoroughly compacted stable sub-grade	Nil	8	7	6

2.	Sound sub-grade not susceptible to frost action or non-uniform movement	3	8	7	6
3.	Non-stable sub-grade of low CBR value and susceptible to non-uniform movement e.g. organic or plastic clays.	Up to 6	10	9	8

Note:

(i)If a lean-mix concrete sub-base is used, thickness may be reduced by 3 percent. Thermal movement of the overlying slab must be unrestricted and all sub-base except lean-mix concrete should be topped with up to one inch of coarse sand.

(ii) For plain concrete slabs thickness should be increased be two inches in all cases.

(iii) Load intensity.

(1) Heavy. Class 100 roads with max intensity 36,000 tons/day.

(2) Medium. Class 80 roads with mix intensity 24,000 tons/day.

(3) Light. Class 30-40 roads with mix intensity 12,000 tons/day.

(iv) Plain concrete slabs are not recommended for heavy traffic intensities RC slabs should always be used.

2307. Example of batching and proportioning method. For a one bag concrete mix of rounded aggregate with a water/cement ratio of 0.5 and with very low workability, the aggregate/cement ratio should be 8 : 1 (see Table 23.2, Serial No. 1, column (d)). Of the aggregate 40 per cent should be fines (see Note (i) to Table 23.2) The mix proportion should therefore be:-

Cement	. .	. .	1
Fine aggregate	..	. .	$\frac{40}{100}$ x8 = 3.2
Coarse aggregate	. .		$\frac{60}{100}$ x8 = 4.8
Water . .	. .	. .	0.5

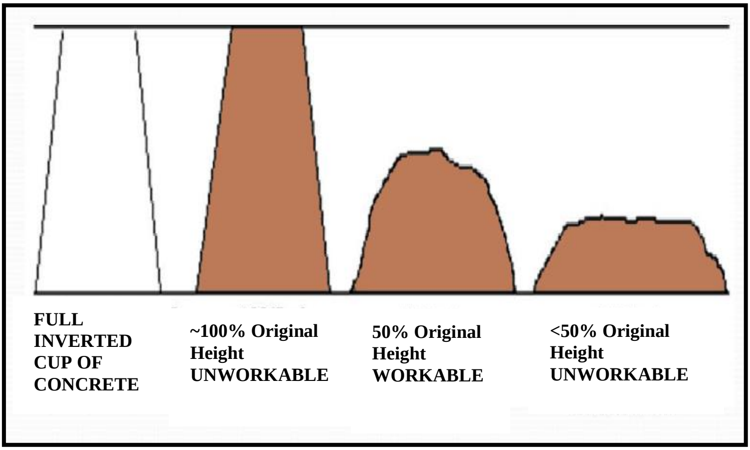

Figure 23-4 : Workability of the Concrete

2308. <u>Factors affecting strength of concrete</u>.

a. Water/cement ratio.
b. Degree of compaction.
c. Aggregate/cement ratio.
d. Aggregate properties.
   (1) Shape of aggregate.
   (2) Size and grading of aggregate.
e. Age of the concrete.

Practical methods of batching this mix are:-

Material	Batching by weight	Batching by volume
Cement	1 bag = 112 lb	1 bag = 1.25 cu ft
Fines	112x3.2 = 358 lb	at 100 lb (dry) per cu ft $= \frac{358}{100} = 3.6$ cu ft
Coarse aggregate	112x4.8 =538 lb	at 100 lb (dry) per cu ft $= \frac{538}{100} = 5.4$ cu ft
Water		

	112x0.5 =56 lb =$5\frac{1}{2}$ gals	at 10 lb per gal = $5\frac{1}{2}$ gals

* Bulking of sand must be considered for concrete mix. On all jobs requiring more than $\frac{1}{2}$ cu yd concrete, volume batching is permissible only on the basis of one or more whole bags of cement. For moist sand see Para 472.

2309. Moisture content control. Determine the moisture content of the aggregate by weight (by means of the pycnometer test), and subtract that amount from the added water. Referring to the example in Para 471, if the sand is found to contain 4 per cent by weight or water this is equivalent to:

$\frac{4}{100}$ x358 = 14.3 lb = $1\frac{1}{2}$ gals of water (approx)

In this case $14\frac{1}{2}$ lb of sand should be added to replace the deficiency of soft material and $1\frac{1}{2}$ gals less water should be used in the mx. The adjusted batch weights should be:-

Cement 112 lb

Fines 358 = $14\frac{1}{2}$ = 372 lb

Coarse aggregate 538 lb

Water $5\frac{1}{2}$ -$1\frac{1}{2}$ = 4 glas

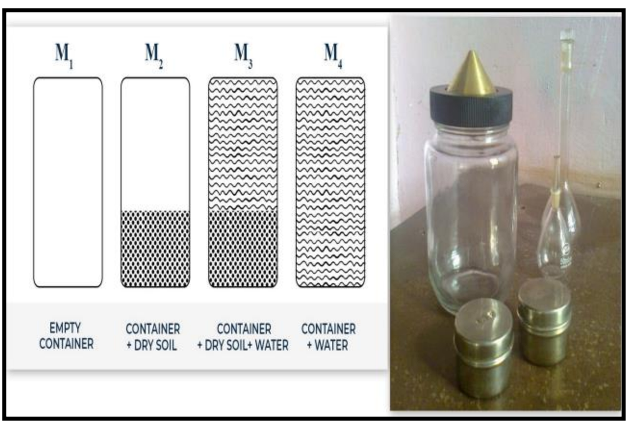

Figure 23-5: Pycnometer Test

2310. All in aggregate. For very hasty work it may be necessary to use available all in aggregate as found by selecting in most suitable of several trial gauging made up with varying aggregate/cement ration. When possible, the proportion given in Table 72 should be adhered to, after determining the content of fines by sieve analysis. Excess fines should be screened out, or any deficiency made good.

TABLE 23.2 CONCRETE MIX DESIGN BATCHING AND PROPORTIONING METHODS

(Coarse and fine aggregates from separate sources)

Serial no	Purpose for which concrete is suitable	Water/ cement ratio	Aggregate/ cement ratio (i)			Water/ cement ratio	Aggregate/ cement ratio (i)			Workability (ii)	Slump (ins)
			Type of aggregate				Type of aggregate				
			Rounded	Irregular	Crushed rock		Rounded	Irregular	Crushed rock		
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)	(k)	(l)	(m)
1.	Machine vibrated plain concrete in roads or other large sections	0.5	8	6.5	5.4	0.6	Not suitable	8	6.6	very low	0 to 1
2.	Mass concrete without vibration or simple reinforced sections with vibration	0.5	7	5.4	4.5	0.6	Not suitable	6.7	5.6	low	1 to 2
3.	Normal reinforced	0.5	5.9	4.8	3.9	0.6	8	6.0	4.9	Medium	2 to 4

	work without vibration or heavily reinforced work with vibration										

Note: (i) The optimum proportion of fines, passing 3/16 in BS sieve, varies slightly with the shape and maximum size of the course aggregate; In general, about 40 per cent of the aggregate should be fines.

(ii) Assessment of workability is based on full compaction without segregation.

TABLE 23.3: MINIMUM STRENGTH OBTAINABLE IN CONCRETE MIXES GIVEN IN TABLE 23.2

Serial no	Time of curing after full compaction	Minimum strength in lb/sq in * water/cement ratio 0.5		Minimum strength in lb/sq in * water/cement ratio 0.6	
		Normal Portland cement	Rapid hardening cement	Normal Portland cement	Rapid hardening cement
(a)	(b)	(c)	(d)	(e)	(f)
1.	1 day	900	1,500	500	900
2.	3 days	2,000	3,200	1,500	2,400
3.	7 days	3,500	4,600	2,700	3,500
4.	28 days	5,500	6,200	4,200	5,000

*It is inadvisable to open roads for normal military traffic below strength of 3,500 lb/sq in.

TABLE 23.4: FAULTS IN CONCRETE MIXES AND THEIR REMEDIES

Serial No	Fault	Remedy
1.	Mix too dry	Slightly reduce quantities of coarse and fine aggregate and slightly increase of water.
2.	Mix too wet	Slightly increase quantities of coarse and fine aggregate.
3.	Mix harsh and lacking plasticity	Slightly increase quantity of fine and slightly reduce quantity of coarse aggregate.
4.	Mix excessively plastic and “fat”	Slightly decrease quantity of fine and slightly increase quantity of coarse aggregate.

Construction

2311. Prerequisites.

a. Sub-grade. Must be well drained, toughly compacted and correctly shaped. Normal camber or cross fall- 1 in 48. For rigid pavement design purposes, subgrades are divided into three classes: weak, normal and very stable. In the last case, the subgrade is considered to be strong enough to carry the concrete slab without any intervening sub-base. Despite the fact that a concrete pavement exhibits sufficient beam and slab action to bridge irregularities in the subgrade, it is still important that the latter generally provides uniform support for the slab. If this is not the case, the provision of a sub-base may still be necessary even when the subgrade is very stable.

b. Sub base. Usually required (see table 23.1, Note (i)). Gravel is the best material/ Clinker, crushed brick, slag or sand can be used. In addition to providing uniform support for the concrete slab, gives the following advantages:

(1) Prevention or Minimization of Frost Action. The addition of a sub-base helps produce a total pavement thickness of 450 mm, this being the minimum pavement thickness required when the subgrade is frost susceptible.

(2) Improvement of Drainage. Water must not be allowed to collect under the slab on a subgrade of impermeable soil. A granular sub-base may be required under such circumstances

(3) Prevention of Mud-pumping. When a concrete slab is laid directly on a subgrade of a fine grained plastic soil, it is possible that a mixture of water and soil may be ejected at the edge of the slab and through joints in it. This is known as ‘mud-pumping’ and can occur when three factors are present simultaneously; namely, the presence of free water, the frequent passage of heavy vehicles, and a soil that can go into suspension in water. It can be prevented by the use of a sub-base of either open- graded granular material, connected to a subsidiary

drainage system or a dense-graded granular material. Mud-pumping can also be prevented by stabilising the subgrade.

(4) Reduction of the Effect of Subgrade Volume Changes. Changes in moisture content of the subgrade can lead to differential movement of a concrete slab leading to either a poorly supported slab or warping of the slab because of swelling of the subgrade soil. This can be minimised by either stabilising the subgrade or laying a granular sub-base. The latter may vary in depth between 75 mm and 300 mm.

c. Prime coat. A prime coat is an application of a low viscosity asphalt to a granular base in preparation for an initial layer (or surface course layer) of asphalt. The purpose of the prime coat is; to coat and bond loose material particles on the surface of the base, to harden or toughen the base surface to provide a work platform for construction equipment, to plug capillary voids in the base course surface to prevent migration of moisture, and to provide adhesion between the base course and succeeding asphalt course. After applying the prime coat, it must cure for a minimum of 48-72 hours before asphalt is placed, with no rain in the forecast.

d. Waterproof layer. Waterproofing is the process of making an object or structure waterproof or water-resistant so that it remains relatively unaffected by water or resisting the ingress of water under specified conditions. Requirement of waterproof layer:

(1) It represents the first line of defense and prevents the ingress of water, road de-icing salts, and aggressive chemicals which would corrode the steel reinforcing bars in the concrete causing severe structural damages.

(2) Concrete will always have some degree of porosity and allied with surface wear and hair line cracking, will allow water and corrosive materials to penetrate and attack the steel reinforcement.

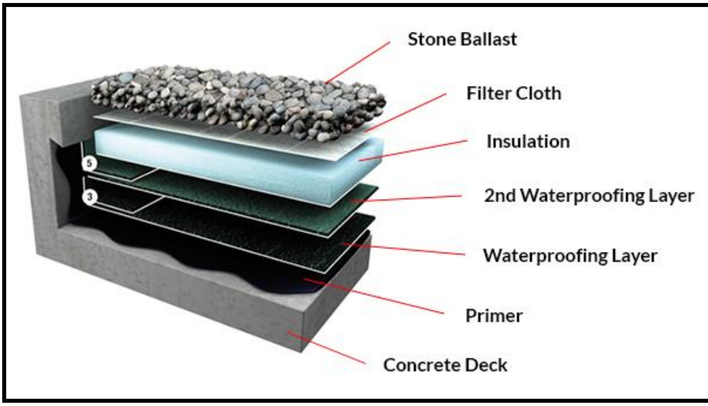

Figure 23-6: Various Layer of Waterproofing

Waterproof paper, plastic paper, water proofing spray and bituminous membrane sheet are few of the water proofing material. It should be laid on the prepared surface before the concrete mix is placed. The new category of spray applied waterproofing products is seamless, rugged, fast curing, impervious to water and capable of lasting decades without extensive maintenance.

Figure 23-7 (a): Waterproof Paper Layout

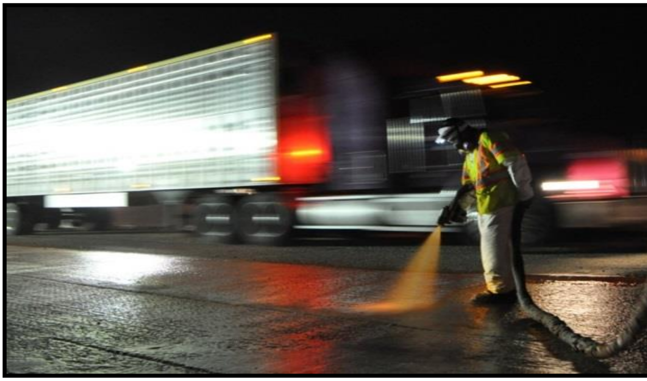

Figure 23-7 (b): Spray Applied Waterproofing

Figure 23-7 (c): Waterproofing Material

2312. Types of construction.

a. Plain slab, single course. Maximum thickness depends upon the compaction method, Limits are:

(1) Hand compaction	:	7 inches
(2) Holman compactor	:	9 inches
(3) Mobile plant compactors	:	12 inches plain concrete 18 inches concrete

b. Plain slab, two- course. This method is used:

(1) When the required slab thickness exceeds the compaction limit (see sub Para (a)).

(2) When a special wearing surface is required.

(3) When using colored cement (2 in top layer).

The top course should be laid within 30 minutes of completing the bottom course.

c. Reinforced slab: 7 to 10 lb of steel should be used per sqyd, using either ¼ or 3/8 in MS bars or 5 mm to 12 mm or prefabricated mesh. Steel must be clean and free from grease. A single layer is normally used, but double reinforcement with L-shaped bars is desirable at each slab corner. The bulk of the steel should lie in the longitudinal direction. Reinforcement should be placed in the top one third of the slab, but set between course (maximum time lag between placing lower and upper course 30 minutes).

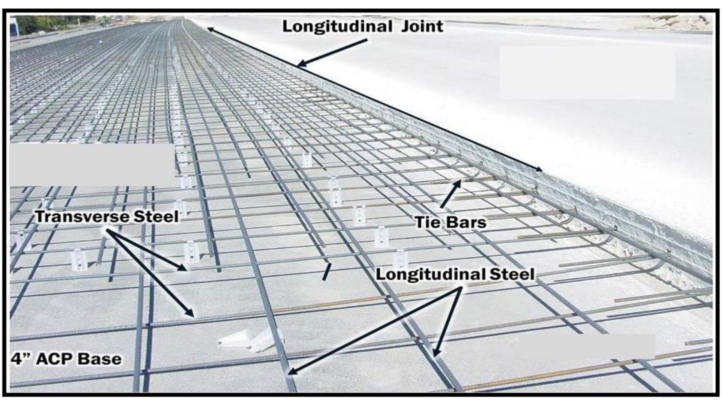

Figure 23-8 (a): Single and Double Reinforcement

Figure 23-8 (b): Single and Double Reinforcement

Figure 23-9: Wire Mesh

2313. Methods of construction.

a. Continuous construction. Used when very large quantities of concrete can be mixed at on time and whenever mechanical spreaders and finishers are employed. When laid by machine, expansion joins must be formed in advance.

b. Alternate bay construction. Often used in hand laying, but should be avoided when moisture changes in the sub-grade may occur during construction. The size of each bay depends upon joint spacing (see section 101). 14 days should elapse between the placing of adjoining bays.

2314. Curing. Methods of curing are given in RESPB No 2, section 17, Para 6, 7 and 8. Decrease of strength in uncured concrete may be as much as 30 percent. Preliminary curing of soft concrete by screens etc, is most important, to prevent evaporation from an exposed slab surface. Curing periods for road slabs are given in table 23.5.

TABLE 23.5 CURING PERIODS FOR CONCRETE ROAD SLABS

Serial No	Type of cement	Minimum curing period (days)	Standard curing period (days)	Remarks
1.	Normal Portland	7	10	
2.	Rapid hardening	4	7	Special care needed in early stages, because of extra heat.
3.	High alumina	1	3	Must be kept well soaked for 24 hours.

* In all cases freezing must be prevented throughout the standard curing period (see Para 554).

2315. Quantity control. Practical measures for controlling quality are tabulated in Table 23.6.

2316. Concrete in freezing weather.

a. Unless special precautions are taken, concreting work should stop at 38°F on a falling thermometer. It can re-start at 34°F on a rising thermometer.

b. Concrete should be protected as soon as it is laid, as the most critical period is the first hour after placing before the initial setting. The best method is to protect it with 6 ins of straw under waterproof covers.

c. The following precautions may be beneficial:

(1) Protect the formation after compaction, or thaw it out with fires.

(2) Heat water and aggregates.

(3) Increase proportion of cement to generate additional heat while setting.

(4) Add 2 lb calcium chloride per cwt of cement.

(5) Use high alumina cement.

<u>TABLE 23.6 CONCRETE PAVEMENTS PRACTICAL MEASURES FOR CONTROLLING QUALITY</u>

Serial No	Process	Action required	Remarks
(a)	(b)	(c)	(d)
1.	Checking materials	a. water- Inspect for cleanliness and carry out filed test b. Cement- Check freshness and moisture condition c. Aggregates- Check cleanliness, grading, organic content.	See RESPB No 2 Section 4
2.	Batching	a. Cement- Protect from damp. If in the open, place on raised platform and cover with tarpaulins. b. Aggregates: (i) Ensure that they come from the approved source (ii) Site stock piles to minimize re-handling. (iii) Place on firm base. (iv) Partition off different sizes. (v) Prevent segregation by forming flat-topped Stockpiles.	b. (ii) and (iii) when possible retain the bottom 1 to 2 feet stockpiles as a drainage layer.

3.	Batching	a. Use weigh- batching whenever possible. b. If using volume batching allow for bulking of sand.	a. Keep weighing devices clean: grease bearings b. See RESPB No-2 section4. Use deep gauge boxes of small cross section.
4.	Mixing	a. Water/cement ratio is vitally important. Measure the water added to mix b. Mix each batch for a specified period (2 mins at 18 to 20 rpm recommended) c. Check that mixer blades are not unduly worn and that drum is clean. d. Do not overload mixer. e. Empty the drum in one continuous operation. f. Check workability.	a. See RESPB No.2, Section 10 c. If mixer stops for more than 1 hour, it must be washed out e. This helps to prevent segregation. f. Slump test (see RESPB No.2. Section-15)
5.	Placing	a. Place and finish off concrete before initial set (30 mins for Portland cements, 2 hours for high alumina cement) b. Prevent segregation, paying special attention to transit between mixer and job c. Unless using machine spreader, dump concrete in small heaps, spread by hand and screed off with template, allowing for compaction.	b. Avoid unsprung containers and solid wheels

(a)	(b)	(c)	(d)
6.	Compacting	a. Hand tamping. Best done with steel or steel shod timber beam, weighing not more than 110 lb, handled by two men. Use small rectangular rammers for slab corners b. Hand operated mechanical compactors. (i) Vibratory beams will require very low workability (ii) Obtain full compaction, but avoid segregation through over compaction (iii) When placing, screed off allowing sufficient surcharge of concrete above side forms to permit full compaction c. Mobile machine compactors. Details in (b) above apply	(i) See table 23.2 (iii) Correct dimension found by trial.
7.	Finishing	a. Form a proper arris at all edges. b. Pay particular attention to finishing near joints. c. Smooth surface – Use wooden floats or belts d. Rough surface- Hand tamper leaves a satisfactory surface. e. Nonskid, anti-glare surface. Brush surface with a hard broom at right angles to side forms, to remove excess grout.	e. This provides a nonskid, smooth riding surface.
8.	Curing	a. For curing periods see table 23.5 b. For methods see RESPB No 2, Section 17	