
Mix Design and Pumped Concrete

A simple method of concrete mix design for pumpable concrete based on an estimated weight of the concrete per unit volume is described in the paper. The tables and figures presented are worked out by the author from a wide range of Indian materials. The method is suitable for normal weight concrete with admixture.

INTRODUCTION

Pumped concrete may be defined as concrete that is conveyed by pressure through either rigid pipe or flexible hose and discharged directly into the desired area. Pumping may be used for most all concrete construction, but is especially useful where space or access for construction equipment is limited.

Pumping equipment consists of pumps which are three types

- a) piston type concrete pump
- b) pneumatic type concrete pump
- c) and squeeze pressure type concrete pump.

Other accessories are rigid pipe lines, flexible hose and couplings etc.

A pumpable concrete, like conventional concrete mixes, requires good quality control, i.e., properly graded uniform aggregates, materials uniformly and consistently batched and mixed thoroughly. Depending on the equipment, pumping rates will vary from 8 to 70 m³ of concrete per hour. Effective pumping range will vary from 400 to 1900 meters horizontally, or 100 to 600 meters vertically. Cases have been documented in which concrete has been successfully pumped horizontally 2432 meters and beyond 600 meters vertically upward.

CONCRETE FOR PUMPING

For the successful pumping of a concrete through a pipeline it is essential that the pressure in the pipeline is transmitted through the concrete via the water in the mix and not via the aggregate, in effect, this ensures the pipeline is lubricated. If pressure is applied via the aggregate it is highly likely that the aggregate particles will compact together and against the inside of the pipe to form a blockage; the force required to move concrete under these conditions is several hundred times that required for a lubricated mix.

If, however, pressure is to be applied via the water, then it is important that the water is not blown through the solid constituents of the mix; experience shows that water is relatively easily pushed through particles larger than about 600 microns in diameter and is substantially held by particles smaller than this.

In the same way, the mixture of cement, water and very fine aggregate particles should not be blown through the voids in the coarse aggregate. This can be achieved by ensuring that the aggregate grading does not have a complete absence of material in two consecutive sieve sizes – for example, between 10 mm and 2.36 mm. In effect any size of particle must act as a filter to prevent excessive movement of the next smaller size of material.

BASIC CONSIDERATIONS

(a) Cement content

Concrete without admixtures and of high cement content, over about 460 kg/m³ are liable to prove difficult to pump, because of high friction between the concrete and the pipeline. Cement contents below 270 to 320 kg/m³ depending upon the proportion of the aggregate may also prove difficult to pump because of segregation within the pipe line.

(b) Workability

The workability of pumped concrete in general have a average slump of between 50 mm and 100 mm. A concrete of less than 50 mm slumps are impractical for pumping, and slump above 125 mm should be avoided. In mixtures with high slump, the aggregate will segregate from the mortar and paste and may cause blocking in the pump lines.

The mixing water requirements vary from different maximum sizes and type of aggregates. The approximate quantity of water for a slump of 50 mm and 100 mm is given in table 4. In high strength concrete due to lower water-cement ratio and high cement concrete workability is reduced with the given quantity of water per cu.m of concrete. In such case water reducing admixtures are useful. In the addition of this type of admixtures at normal dosage levels to obtain a higher workability for a given concrete mix, there is no necessity to make any alteration to the mix design from that produced for the concrete of the initial lower slump. There is generally no loss of cohesion or excess bleeding even when the hydroxycarboxylic acid materials are used.

If this class of product is used to decrease the water cement ratio, again no change in mix design will be required, although small alterations in plastic and hardened density will be apparent and should be used in any yield calculations.

A loss of slump during pumping is normal and should be taken into consideration when proportioning the concrete mixes. A slump loss of 25 mm per 300 meters of conduit length is not unusual, the amount depending upon ambient temperature, length of line, pressure used to move the concrete, moisture content of aggregate at the time of mixing, truck-haulage distance, whether mix is kept agitated during haulage etc. The loss is greater for hose than for pipe, and is sometimes as high as 20 mm per 30 meter.

(c) Aggregates

The maximum size of crushed aggregate is limited to one-third of the smallest inside diameter of the hose or pipe based on simple geometry of cubical shape aggregates. For uncrushed (rounded) aggregates, the maximum size should be limited to 40 percent of the pipe or hose diameter.

The shape of the coarse aggregate, whether crushed or uncrushed has an influence on the mix proportions, although both shapes can be pumped satisfactorily. The crushed pieces have a larger surface area per unit volume as compared to uncrushed pieces and thus require relatively more mortar to coat the surface. Coarse aggregate of a very bad particles shape should be avoided.

Difficulties with pump mixed have often been experienced when too large a proportion of coarse aggregate is used in an attempt to achieve economy by reducing the amount of cement such mixes are also more difficult and costly to finish.

The grading of coarse aggregate should be as per IS: 383-1970. If they are nominal single sized then 10 mm and 20 mm shall be combine in the ratio of 1:2 to get a graded coarse aggregate. In the same way 10 mm, 20 mm and 40 mm aggregates shall be combine in the ratio of 1:1.5:3 to get a graded coarse aggregate.

Fine aggregate of Zone II as per IS: 383-1970 is generally suitable for pumped concrete provided 15 to 30 percent sand should pass the 300 micron sieve and 5 to 10 percent should pass the 150 micron sieve.

Fine aggregate of grading as given in Table 2, is best for pumped concrete. The proportion of fine aggregate (sand) to be taken in the mix design is given in Table 8. However, the lowest practical sand content should be established by actual trial mixes and performance runs.

In practice it is difficult to get fine and coarse aggregates of a particular grading. In absence of fine aggregate of required grading they should be blended with selected sands to produce desired grading, and then combine with coarse aggregates to get a typed grading as per Table 3.

(d) Pumping

Before the pumping of concrete is started, the conduit should be primed by pumping a batch of mortar through the line to lubricate it. A rule of thumb is to pump 25 litres of mortar for each 15 meter length of 100 mm diameter hose, using smaller amounts for smaller sizes of hose or pipe. Dump concrete into the pump-loading chamber, pump at slow speed until concrete comes out at the end of the discharge hose, and then speed up to normal pumping speed. Once pumping has started, it should not be interrupted (if at all possible) as concrete standing idle in the line is liable to cause a plug. Of great importance is to always ensure some concrete in the pump receiving hopper at all times during operation, which makes necessary the careful dispatching and spacing of ready-mix truck.

(e) Testing for pumpability

There is no recognized laboratory apparatus or precise piece of equipment available to test the pumpability of a mix in the laboratory. The pumpability of the mix therefore be checked at site under field conditions.

(f) Field practices

The pump should be as near the placing area as practicable and the entire surrounding area must have adequate bearing strength to support the concrete delivery trucks, thus assuring a continuous supply of concrete. Lines from the pump to the placing area should be laid out with a minimum of bends. For large placing areas, alternate lines should be installed for rapid connection when required.

When pumping downward 15 m or more it is desirable to provide an air release valve at the middle of the top bend to prevent vacuum or air buildup. When pumping upward it is desirable to have a valve near the pump to prevent the reverse flow of concrete during the fitting of clean up equipment, or when working on the pump.

ILLUSTRATIVE EXAMPLE ON CONCRETE MIX DESIGN

- Characteristic compressive strength required in the field at 28 days = 35 N/mm²
- Type and size of coarse aggregate = 20-10 mm and 10-5 mm crushed aggregates as per grading given in Table 1.
- Fine aggregate = River sand of Zone II as per IS: 383-1970. The sand grading is given in Table 1.
- Degree of workability = 50 – 100 mm slump at pour after 90 Minutes.
- Minimum cement content = 340 kg/m³
- Maximum free water/cement ratio = 0.45
- Standard deviation for good site control = 5.0 N/mm²
- Accepted proportion of low results= 5%, Value of t = 1.65

Note: For informations at e,f,g and h refer IS: 456-2000 or follow specifications of the tender documents/Department specifications.

- Type of cement and 7 days Compressive strength. = OPC, 7 days compressive strength = 37.5 N/mm²
- Specific gravity of :
10 mm aggregate = 2.7
20 mm aggregate = 2.7
Fine aggregate (river sand)= 2.7

k) Retarder Superplasticizer = With the given requirements of workability a dosage of 1% bwc will give 15% reduction in water.

The step-by-step operations in mix design are enumerated below:

Step 1 TARGET MEAN STRENGTH OF CONCRETE

$$35 + 5.0 \times 1.65 = 43.3 \text{ N/mm}^2$$

Step 2 SELECTION OF WATER-CEMENT RATIO

From Fig. 1 the free water-cement ratio required for the target strength of 43.3 N/mm² with crushed aggregates and 7 days cement strength of 37.5 N/mm² (curve D) = 0.43 for first trial

Step 3 SELECTION OF FREE-WATER CONTENT

From Table 4 for 20 mm crushed aggregate, river sand and 50 - 100 mm slump found to be:

$$\frac{2}{3} \times 190 + \frac{1}{3} \times 220 = 200 \text{ kg/m}^3, \quad \frac{15}{100} \times 200 = 30$$

$$200 - 30 = 170 \text{ kg/m}^3$$

Step 4 DETERMINATION OF CEMENT CONTENT

$$\frac{170}{0.43} = 395 \text{ kg/m}^3$$

Step 5 DETERMINATION OF DENSITY OF CONCRETE

Density from Table 6 found to be 2453 kg/m³ for cement content of 330 kg/m³. For cement content of 395 kg/m³ density =

$$2453 + 9.75 = 2460 \text{ kg/m}^3 \text{ say}$$

Step 6 DETERMINATION OF QUANTITY OF AGGREGATES

$$2460 - 170 - 395 = 1895 \text{ kg/m}^3$$

Step 7 DETERMINATION OF FINE AGGREGATE CONTENT

From Table 8 proportion of fine aggregate (percent) found to be 38 – 47 for trial mix say 43%.

$$\text{Fine aggregate content} = 1895 \times 0.43 = 815 \text{ kg/m}^3$$

Step 8 COARSE AGGREGATE CONTENT

$$1895 - 815 = 1080 \text{ kg/m}^3$$

The coarse aggregates are in two fractions 10 – 5 mm and 20 – 10 mm. Let these single sized coarse aggregates be combine in the ratio of 1:2 to get a graded coarse aggregate as per IS: 383-1970.

The obtained grading of combined aggregates is given in Table 1.

Thus quantities of materials per cu.m of concrete on the basis of saturated surface dry aggregates obtained:

Water = 170 kg

Cement, OPC = 395 kg

Fine aggregate (43%) = 815 kg

10 mm aggregate (19%) = 360 kg

20 mm aggregate (38%)= 720 kg

Retarder superplasticizer = 3.950 kg

CONCLUSIONS

1. Pumped concrete may be used for most all concrete construction, but is especially useful where space or access for construction equipment is limited.
2. Although the ingredients of mixes placed by pump are the same as those placed by other methods, depending quality control, batching, mixing, equipment and the services of personnel with knowledge and experience are essential for successfully pumped concrete.
3. The properties of the fine normal weight aggregates (sand) play a more prominent role in the proportioning of pumpable mixes than do those of the coarse aggregates. Sands having a fineness modulus between 2.4 and 3.0 are generally satisfactory provided that the percentage passing the 300 and 150 micron sieves meet the previously stated requirements. Zone II sand as per IS: 383-1970 meet these requirements, and is suitable for pumped concrete.
4. Pumped concrete should not require any compromise in quality. To be pumpable, a high level of quality control for assurance of uniformity must be maintained.
5. A simple method of concrete mix design will normal weight aggregates for pumped concrete is described in the paper. The author had worked out tables and figures from Indian materials by numerous trials. Therefore the proportions worked out with the help of these tables and figures will have quite near approach to the mix design problems of the field.

Table 1 Grading of aggregates.

I.S. Sieve designation	Percentage passing by mass						Combined grading obtained	Required grading as per Table 3
	Grading of aggregates			% combine in example				
	Fine aggregate	10 mm aggregate	20 mm aggregate	Fine aggregate	10 mm aggregate	20 mm aggregate		
40 mm	100	100	100	43	19	38	100	100
20 mm	100	100	100	43	19	38	100	100
10 mm	100	90	8	43	17	3	63	60-73
4.75 mm	98	6	—	42	1	—	43	40-58
2.36 mm	87	—	—	37	—	—	37	28-46
1.18 mm	61	—	—	26	—	—	26	18-35
600 micron	39	—	—	17	—	—	17	12-25
300 micron	16	—	—	7	—	—	7	7-15
150 micron	5	—	—	2	—	—	2	2-6

Table 2 Suitable gradation of fine aggregate for pumped concrete

Percentage passing IS; sieve designation percentage

4.75 mm 2.36 mm 1.18 mm 600 micron 300 micron 150 micron

Fine aggregate (sand)

95-100 80-90 65-75 40-50 15-30 5-10

Table 3 Recommended combine aggregate gradation for pumped concrete.

Maximum size of aggregate	Percentage passing IS-sieve designation								
	40 mm	20 mm	10 mm	4.75 mm	2.36 mm	1.18 mm	600 micron	300 micron	150 micron
40 mm	100	67-77	47-60	37-52	28-42	18-32	12-22	7-14	2-4
20 mm	100	100	60-73	40-58	28-46	18-35	12-25	7-15	2-6

Table 4 Approximate free-water contents (kg/m³) required to give a workability of 50 mm – 100 mm slump for non-air entrained concrete.

Maximum size of aggregate					
10 mm aggregate		20 mm aggregate		40 mm aggregate	
Uncrushed	Crushed	Uncrushed	Crushed	Uncrushed	Crushed
215	245	190	220	170	200

Note: When coarse and fine aggregate of different types are used, the free-water content is estimated by the expression $\frac{2}{3} W_f + \frac{1}{3} W_c$

where W_f = free-water content appropriate to type of fine aggregate.
and W_c = free-water content appropriate to type of coarse aggregate.

**Table 5 Estimated wet density of fully compacted concrete, (kg/m³).
Maximum size of aggregate 10 mm**

Free-water content (kg/m ³)	Specific gravity of combined aggregates on saturated and surface-dry basis					
	2.4	2.5	2.6	2.7	2.8	2.9
180	2197	2267	2337	2407	2477	2547
190	2181	2251	2321	2391	2461	2531
200	2165	2235	2305	2375	2445	2515
210	2149	2219	2289	2359	2429	2499
220	2133	2203	2273	2343	2413	2483
230	2117	2187	2257	2327	2397	2467

The table is worked out for concrete having cement content of 330 kg/m³. For each 20 kg difference in cement content from 330 kg correct the weight per m³ 3 kg in the same direction.

**Table 6 Estimated wet density of fully compacted concrete, (kg/m³).
Maximum size of aggregate 20 mm**

Free-water content (kg/m ³)	Specific gravity of combined aggregates on saturated and surface-dry basis					
	2.4	2.5	2.6	2.7	2.8	2.9
160	2259	2329	2399	2469	2539	2609
170	2243	2313	2383	2453	2523	2593

180	2227	2297	2367	2437	2507	2577
190	2211	2281	2351	2421	2491	2561
200	2195	2265	2335	2405	2475	2545
210	2179	2249	2319	2389	2459	2529

The table is worked out for concrete having cement content of 330 kg/m³. For each 20 kg difference in cement content from 330 kg correct the weight per m³ 3 kg in the same direction.

Table 7 Estimated wet density of fully compacted concrete, (kg/m³).
Maximum size of aggregate 40 mm

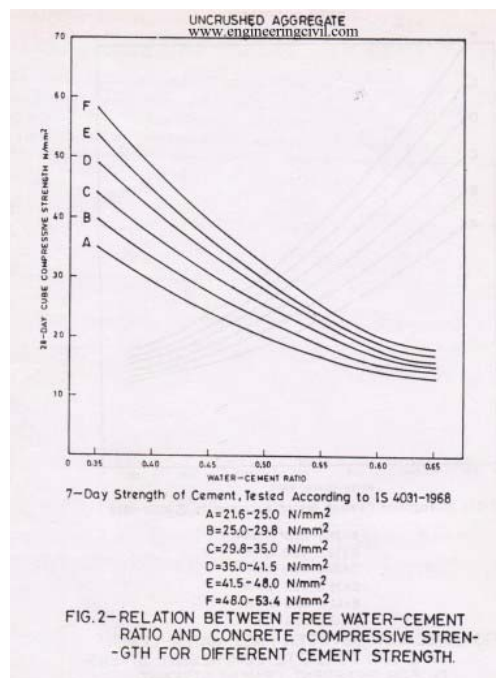
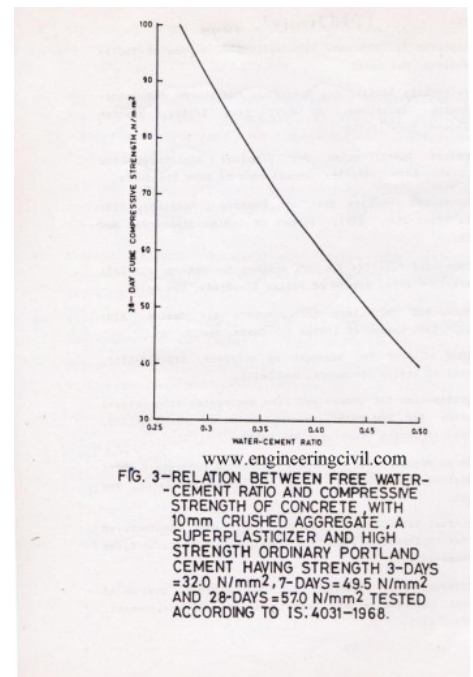
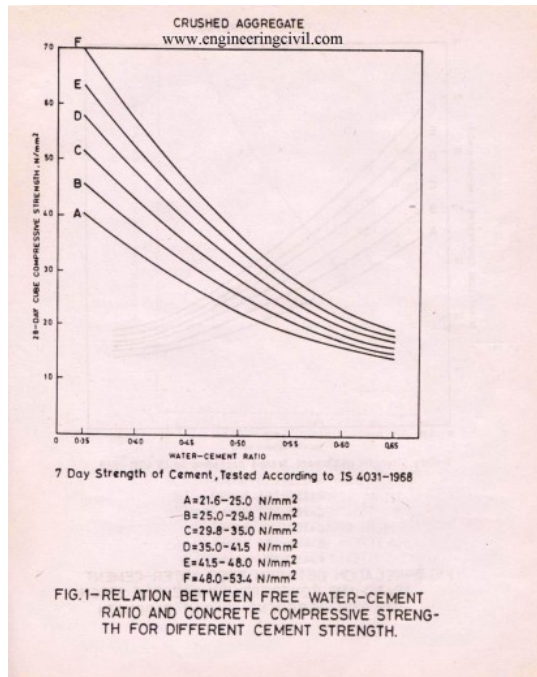
Free-water content (kg/m³) Specific gravity of combined aggregates on saturated and surface-dry basis

	2.4	2.5	2.6	2.7	2.8	2.9
140	2321	2391	2461	2531	2601	2671
150	2305	2375	2445	2515	2585	2655
160	2289	2359	2429	2499	2569	2639
170	2273	2343	2413	2483	2553	2623
180	2257	2327	2397	2467	2537	2607
190	2241	2311	2381	2451	2521	2591

The table is worked out for concrete having cement content of 330 kg/m³. For each 20 kg difference in cement content from 330 kg correct the weight per m³ 3 kg in the same direction.

Table 8 Proportion of fine aggregate (percent) with 10 mm, 20 mm and 40 mm maximum size of aggregate and a workability of 50 – 100 mm slump.

Grading Zone of fine aggregate	Free W/C ratio	10 mm maximum size of aggregate	20mm maximum size of aggregate	40 mm maximum size of aggregate
II	0.4	46-57	37-46	32-41
	0.5	47-59	39-48	34-43
	0.6	49-62	41-50	36-45
	0.7	51-64	43-53	38-47



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