

Principle of mix design for pumpable concrete

Printed On September 23, 2020 in Expert Speaks



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

This article takes a comprehensive look at the simple method of concrete mix design for pumpable concrete. It is based on an extensive range of the concrete per unit volume. The table and figures included are worked out from various BS codes and hand books by the author from a wide range of materials available in the country.

Pumping equipment consists of pumps, which are of three types:

1. Piston type concrete pump
2. Pneumatic type concrete pump
3. Squeegee pressure type concrete pump

Other accessories are rigid pipelines, flexible hose and couplings etc.

A pumpable concrete, like conventional concrete mixes, requires good quality control, i.e. properly graded uniform aggregates, maintain uniformity and consistency batched and mixed thoroughly. Depending on the equipment, pumping rates may vary from 8 to 120 m³ of concrete per hour. Effective pumping rates vary from 90 to 300 meters horizontally, or 30 to 150 meters vertically. Cases have been documented in which concrete has successfully been pumped horizontally upto 600 meters and 400 meters vertically upward. New record values continued to be reported.

Pumping

For the successful pumping of 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 aggregates. In effect, this ensures the pipeline is lubricated. If the pressure is applied on the aggregate, it is highly likely that the aggregate particles will compact together and against the inside surface of the pipe to form a blockage. The force required to move concrete under these conditions is several hundred times that required for a well-lubricated mix.

If, however, the pressure is to be applied on the water, then it is important that the water is not blown through the side 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 retarder, water and air aggregate particles should not be blown through the water 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 the particle must act as a filter to prevent excessive movement of the next smaller size of the material.

Basic Considerations

Cement Content

Concrete without admixtures and of high cement content, lower about 400 kg/m³ are liable to prove difficult to pump, because of high friction between the concrete and the pipeline. Cement contents below 270 to 300 kg/m³ depending upon the proportion of the aggregate may also prove difficult to pump because of segregation within the pipeline.

Workability of pumped concrete

The workability of pumped concrete, in general, has an average slump of between 80 mm and 100 mm. A slump of less than 50 mm being impractical for pumping, and slumps above 120 mm should be avoided. In mixtures with a high slump, the aggregate will segregate from the mortar and paste and cause choking.

The mixing water requirement may vary for different maximum sizes and type of aggregate. The approximate quantity of water for a slump of 80 mm for 100 mm is given in Table 5.

Table 5: Approximate Free Water Content, W₁, Required for a given Workability of Concrete (Based on 100 mm Maximum Size of Aggregate)

Free Water Content, W ₁ (%)		10 mm Aggregate		20 mm Aggregate	
Uncoloured	Coloured	Uncoloured	Coloured	Uncoloured	Coloured
270	260	190	200	170	200

In high strength concrete due to lower water-cement ratio and high cement content, workability is reduced with the given quantity of water per cum of concrete. In such cases, water reducing admixtures are used. In addition to this type of admixtures at normal dosage levels, to obtain 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 usual cover depth. There is generally no loss of cohesion or excess bleeding even when the hydraulic acid-based materials are used.

If this class of product is used to increase 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 yield calculations.

A case of slump during pumping is normal and should be taken into consideration when proportioning the concrete mixes. A slump loss of 20 mm per 300 meters of pipeline length is not unusual. The amount depending upon ambient temperature, height of the mix, the pressure used to pump the concrete, moisture content of aggregates at the time of mixing, touch-holding contacts, whether the mix is kept against during haulage etc. The loss is greater for hose than for pipe and is sometimes as high as 20 mm per 30 m.

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 radial stage aggregates. For uncrushed (rounded) aggregates, the maximum size should be limited to only 1/4th of the pipe 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 particle shape should be avoided. The gradation of coarse aggregate plays an important part.

Difficulties with pump have often been experienced when too large a proportion of coarse aggregate is used in an attempt to reduce economy by reducing the amount of cement. Such mixes are also stiff and costly to treat. The grading of coarse aggregate should be as per IS: 383-1970, if any one nominal size above and then 10 mm and 20 mm shall be combined in the ratio of 1 to 2 to get a 20 mm graded coarse aggregate. In the same way, 30 mm, 20 mm and 10 mm aggregates shall be combined in the ratio of 1 to 2 to get a 20 mm graded coarse aggregate.

Table 2: Gradation of Fine Aggregate Suitable for Pumped Concrete

IS-Sieve Designation	Fine aggregate (sand) (Percentage Passing)
4.75 mm	95-100
2.36 mm	80-90
1.18 mm	65-75
600 micron	40-50
300 micron	15-30
150 micron	5-10

A fine aggregate of Zone II as per IS: 383-1970 is generally suitable for pumped concrete provided 15 to 20% sand should pass the 300 micron sieve and 10 to 15 per cent should pass the 150 micron sieve. A fine aggregate of given in Table 2 is best for pumped concrete. The proportion of the aggregate (sand) to be taken in the mix design is given in Table 3. However, the lowest practical sand content should be established by actual trial mixes and performance runs.

Table 3: Proportion of Fine Aggregate (Percent) with 10 mm, 20 mm and 40 mm maximum size of aggregate and workability, F₁₀₀ (kg/m³)

Coarse aggregate (kg/m ³)	F ₁₀₀ (%)	10 mm Sieve		20 mm Sieve		40 mm Sieve	
		Actual	Adjusted	Actual	Adjusted	Actual	Adjusted
I	0.3	54.66	42.01	40.01	36.47	30.01	26.47
	0.4	56.63	44.03	41.03	37.49	31.03	27.49
	0.5	58.70	46.05	42.05	38.91	32.05	28.91
II	0.6	62.32	49.67	45.67	42.13	35.67	32.13
	0.3	44.48	38.44	37.44	34.44	31.44	28.44
	0.4	46.49	40.49	39.49	36.49	33.49	30.49

In practice, it is difficult to get fine and coarse aggregates of a particular grading. In the absence of the aggregate of required grading they should be blended with selected sands to produce desired grading, and then combined with coarse aggregate to get a total grading as per Table 4.

Table 4: Recommended Combined Aggregate Grading for Pumped Concrete

Nominal Size (mm)	Zone II		Zone III		Zone IV	
	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted
4.75	95	100	95	100	95	100
7.5	85	90	85	90	85	90
10	75	80	75	80	75	80
15	65	70	65	70	65	70
20	55	60	55	60	55	60
25	45	50	45	50	45	50
30	35	40	35	40	35	40
37.5	25	30	25	30	25	30
47.5	15	20	15	20	15	20
60	10	15	10	15	10	15
75	5	10	5	10	5	10
90	0	5	0	5	0	5

Uncrushed Aggregate (River Gravel)

It has become a custom that almost in all the construction sites crushed aggregates are being used. To save environmental pollution as far as possible in colony construction work, uncrushed aggregate (river gravel) if available as a local source including river sand should be used.

Production of crushed aggregates from crushers poses air and noise pollution problems.

Crusher & Air Pollution Problem

When the rocks and river bed boulders are crushed, dry surface are exposed and air borne dust can be created an obligatory process to dust emissions usually begins with the first motor and continues with the conveyor transfer points to and including the succeeding crushers. Here the aggregate is more freely grounded, and dust emissions become greater. As the process continues, dust emissions are again prevented from sources at conveyor transfer points and the final crushers.

In the modern industry, and washing plant in the production of uncrushed (green) aggregate from the river bed, they are not crushed. This is due to the fact that further aggregates are washed to remove oil and dust free material. Therefore, uncrushed (green) aggregate produces less dust than crushed aggregate in a moist condition, hence do not present a dust problem. Whereas the crushed aggregate leaves crushing plant very dry and creates considerable dust when handled. To prevent dust in handling it is not possible to wet each load of crushed aggregate thoroughly before it is shipped from the delivery truck. Attempts to spray the crushed aggregate as it is being pumped have had very little effectiveness.

During crushing of aggregate particles, less than 100 microns remain suspended in the air. The suspension of a particle in the air follows a certain trajectory depending on its size, density, shape and other physical properties. In a nutshell, the dry surface dust has high frequency or suspension time and settling distance to the ground. If a crushing plant is not properly designed and operates without any effective prevention system the "higher" dust may generate an problem.

Air quality due to pollution should be monitored routinely.

Pumping

Before the pumping of the concrete is started, the pipeline should be primed by pumping a batch of mortar through the line to block it. A set of hoses to be pumped 25 lines of mortar for each 10 m length of 100 mm diameter hose, using smaller amounts for smaller sizes of hose or pipe. Dump concrete into the pumping chamber, pump at slow speed and 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 in the line is liable to cause clogging. Of course, inspection is to always ensure concrete in the pump receiving hopper at all times during operation, which makes necessary the careful discharging and loading of ready-mix trucks.

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, should be checked under field conditions.

Field Practices: The pump should be as near the placing area as practicable and the entire surrounding area must have adequate footing support 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 filling of clean-up equipment.

Conclusion

Pumped concrete is common now for almost all construction requiring a large volume of concrete to be placed. It is extremely useful for high-rise buildings, industrial structures like TD Foundations requiring an uninterrupted large volume of concrete to be placed.

Although the ingredients of mass placed by the pump are the same as those placed by other methods, quality control, batching, mixing, equipment and the skill set of personnel with knowledge and experience are essential for successful pumped concrete.

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. Sand having a normal modulus between 2.4 and 3.1 is generally satisfactory provided that the percentage passing the 20 and 150-micron sieves meet the previously stated requirements. Zone II sand as per IS: 383-1970 meets these requirements, and is suitable for pumped concrete.

Author's Bio

Satish Kumar Roy,
Sr. VP Engineering,
RPL (Rustcon/Industries Ltd)