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Some issues related to pumping of concrete

Bhupinder Singh, S.P. Singh and Bikramjit Singh

With the establishment of more than 80 commercial batching and mixing plants set up in metropolitan and other cities in India, the practice of pumping of concrete is becoming common. In this write-up, attention has been drawn to the various parameters having a bearing on the pumping of concrete with particular relevance to the appurtenances involved thereof. The influence of these parameters on determining the capacity of concrete pumps has been discussed and an example has been presented on calculations for selection of a concrete pump for conditions obtained on a typical construction site.

Recent years have seen a substantial increase in the use of pumped concrete, especially in infrastructure projects in the country. Ready-mixed concrete (RMC) suppliers have played a major role in popularising the concept of concrete pumping in India. Invariably, most of the applications are concentrated in and around the metros and it is only lately that the concept and application of pumped concrete is percolating to the mofusil areas where more often then not, pumped concrete is viewed as an unaffordable luxury. These skewed perceptions stem not so much from indifference as they do from sheer ignorance. More than enough has been said and written about the characteristics and requirements of pumpable concrete. Plenty of specialist literature on pumpable concrete[1] is available in the public domain though the same cannot be said about the specifications, capacity and selection of pumps to be employed for pumping of concrete. An attempt has been made here to discuss some of the issues related to characteristics of concrete pumps so as to enable the reader to make an informed choice of pumps for pumping concrete. The parameters of interest are pump capacity, power requirements and characteristics of the delivery pipelines.

Concrete pumps have been known for more than 50 years. In modern times, large quantities of concrete can be transported by means of pumping through pipelines over appreciable distances, often to locations that may not be easily accessible by other means of delivery. The system for pumping concrete essentially consists of a hopper into which the concrete is discharged from the mixer, which in turn, feeds the concrete pump itself and finally the delivery pipelines through which the concrete is delivered.

Direct acting pumps

A majority of the concrete pumps are of the direct-acting, horizontal piston-type with semi-rotary valves, *Fig*1[1]. The operation of the direct-acting pump is rather simple. The concrete is fed into the pump by gravity and partly by suction created due to the reciprocating motion of the horizontally-acting piston, while the semi-rotary valves open and close alternately. Suction pressure of the order of 0.08 N/mm^2 is developed in the pumping cylinder under favourable conditions. Best suction conditions are obtained if the diameter of the suction pipe is the same as that of the pumping cylinder so that the concrete can flow unhindered. Concrete should be able to flow freely through the full cross section of the suction pipe and possible blockages due to over-sized aggregates should be avoided. Ideally, the

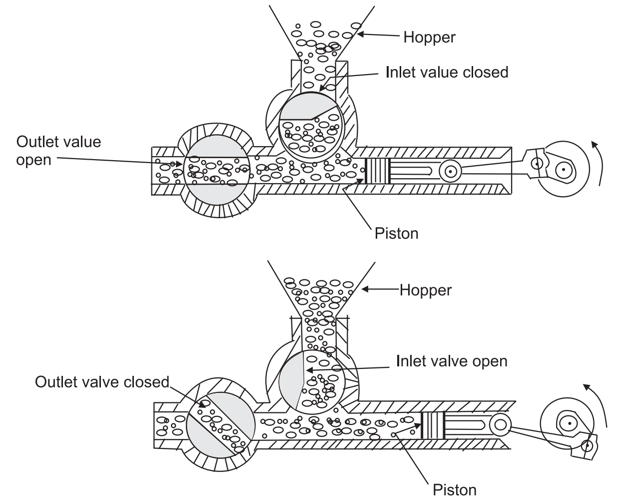

Fig 1 Direct acting concrete pump[1]

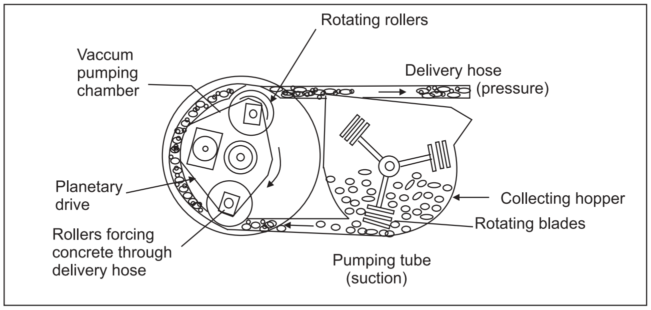

Fig 2 Squeeze type concrete pump[1]

diameter of the suction pipe should be at least three times the maximum size of the aggregate in the concrete to be pumped. The diameter of the suction pipe therefore controls the maximum size of aggregate, which can be used in a given mix of concrete to be pumped.

During the 'suction stroke' the inlet-valve opens and concrete is admitted into the pumping cylinder, the outlet valve remaining closed. In the 'delivery stroke' the outlet valve gets opened and the inlet valve being closed, the concrete gets pushed into the delivery pipeline. The concrete moves in a series of impulses, the delivery pipe always remaining full. Outputs of up to 60 m^3/h can be achieved in modern pumps through 220-mm diameter delivery pipes. Conventional pumps are equipped with an agitator in the feeding hopper. The agitator maintains the flowability of the concrete and prevents the setting of the concrete or building-up of aggregate bridges across the opening of the suction pipes. In case the pump is required to be shut down temporarily for some reason it may be possible to remix the concrete at the commencement of pump operations using the agitator.

Direct-acting concrete pumps may be static or portable, in the latter case the pump can be mounted on lorries. Lorry-mounted concrete pumps operate with relatively shorter delivery pipelines. The pump feeds concrete to the delivery pipeline attached to a hydraulically-maneuvered articulated telescopic arm known as the placing boom. The pipeline length thus corresponds to the horizontal reach of the placing boom. Using direct acting pumps, concrete can be readily pumped up to distances of 450 m horizontally or 50 m vertically. For larger distances, relay pumping using pumps in series may be adopted.

Squeeze pumps

Besides direct-acting pumps, smaller portable peristaltic type pumps, called as squeeze pumps are also available for pumping concrete, *Fig* 2[1]. The concrete from the collecting hopper is fed by rotating blades into a flexible pipe connected to the pumping chamber, which is under a vacuum of about 0.08 N/mm^2. The vacuum ensures that, except when being squeezed by the rotating rollers, the pipe shape remains cylindrical and thus permits a continuous flow of concrete. The two rotating rollers mounted on planetary drives progressively squeeze the flexible pipe and thus push the concrete into the delivery pipe. Outputs of up to 20 m^3/h can be obtained with squeeze pumps using 75-mm diameter pipelines. Squeeze pumps may be lorry mounted and deliver concrete using a placing boom. Squeeze pumps can transport concrete up to a maximum distance of 90 m horizontally or 30 m vertically. Due to the cumbersome mechanics of squeeze pumps, direct acting pumps find greater field applications compared to squeeze pumps.

Criteria for selecting a concrete pump

The two primary parameters, which should be known prior to selection of a pump, are the maximum desired volumetric output of concrete per hour and the peak pumping pressure, p. A nominal output of 30 m^3/h is considered sufficient for routine concreting operations related to most civil engineering applications. For specialised jobs where greater output is desired, pumps with a capacity in excess of 120m^3/h have been known to be deployed. The required power of the drive unit (prime mover) of the concrete pump depends on the desired delivery output of concrete, Q, and the pumping pressure, p. The delivery output and the pumping pressure are co-related by the expression for the hydraulic output, H, of the concrete pump:

$$H = Q \times p = \text{constant}$$

If Q is expressed in m^3/h and p is expressed in bars (1 bar = 0.1 N/mm^2) and assuming a system efficiency of 75 percent, the required power, P, of the drive unit (prime mover) of the concrete pump can be expressed in kilowatts (kW) as :

$$\text{P} = \frac{H}{25} = \frac{Q \times p}{25}$$

Pumping pressure

The maximum pressure, which a concrete pump is able to generate, depends on the mechanical design of the unit in question, particularly the concrete valves, taper sections, delivery pipelines etc. Lorry-mounted concrete pumps which invariably have short delivery pipelines will require pumps generating maximum pressures of around 7 N/mm^2 (70 bars). Hence, it follows that a typical lorry-mounted pump with a 90-kW prime mover can deliver a maximum of $\frac{90 \times 25}{70} = 32.14\ m^3/h$ of concrete. If under certain circumstances, a pumping pressure of say 4.5 N/mm^2 is deemed enough for the above unit, then a peak output of $\frac{90 \times 25}{45} = 50\ m^3/h$ of concrete can be obtained. Therefore, it follows that the pumping pressure and the peak concrete output are inversely proportional to each other. Portable concrete pumps which may place concrete at horizontal distances of up to 1000 m or vertical distances of up to 400 m may require pumping pressures of the order of 20 N/mm^2 (200 bars).

To be able to achieve a targeted output of concrete at site it is imperative to determine as accurately as possible the required pumping pressure so that together with the desired concrete output, a rational basis for selecting a pump can be developed. The volumetric output of concrete desired would depend on the type of job at hand and the desired progress of work. The primary variables on which the pumping pressure is dependent can be listed as the total lead, delivery pipeline diameter, delivery output, concrete consistency and directional changes in the pipeline. The pumping pressure decreases from a maximum at the concrete pump to zero at the output end of the delivery pipeline.

The maximum lead will include the total maximum horizontal and/or vertical distance over which the concrete is to be pumped. The maximum lead in terms of the horizontal and vertical placing distance has to be calculated by taking into account likely increase in the pumping distance due to bends and directional changes in the delivery pipe. Directional changes in the flow of pumped concrete will undoubtedly place excess demand on the pumping unit and these are accounted for by adding an equivalent horizontal length of the pipeline for different types of pipe bends.

One of the established manufacturers of pumping equipment recommends that, independent of the pipeline diameter, 90-degree bends with a radius of 1 m may be replaced by an equivalent horizontal pipeline length of 3 m[2]. Hence, a 30-degree bend with a radius of 1-m is equivalent to a length of 1 m. If for example, bends totaling 630 degrees are installed in a pipeline system, then the equivalent length can be computed as $\frac{630}{30}$ = 21= 21 × 1m = 21m. For 90-degree bends in delivery pipelines mounted as for example, on placing booms, a radius of 0.25 m is usually adopted[2]. The equivalent length for such elbow bends is recommended as 1 m[2]. Therefore, the horizontal pumping distance for a placing boom will be its outer reach plus the equivalent lengths for each of the 90-degree bends in the three articulated sections usually found in placing booms.

The vertical pumping distance is accounted for by adding a pressure increment of approximately 0.025 N/mm^2 (0.25 bars) for every metre difference of elevation to the pumping pressure computed for the horizontal placing distance.

For a given output of pumped concrete, the flow velocity and hence the flow resistance increases with reducing delivery pipeline diameter as does the associated pumping pressure. For the purpose of illustration, for a nominal concrete output of 40 m^3/h, as the delivery pipeline diameter decreases in the order 150 mm, 125 mm, 112 mm and 100 mm the corresponding flow velocities increase in the order 0.6 m/s, 0.8 m/s, 1.1 m/s and 1.39 m/s, respectively. To limit the pumping pressure and to minimise pipeline wear and tear it is always advisable to use larger pipeline diameters whenever higher delivery outputs are desired. The difficulty with pipelines of larger diameter is that they are difficult to handle, especially when they are filled with concrete. Both rigid and flexible pipes can be used for pumping concrete though rigid pipes are more popular because of the additional frictional losses and cleaning problems associated with flexible pipelines. Rigid pipelines made of steel are available in varying lengths and wall thicknesses.

Individual delivery pipe lengths are available in lengths of 1 m, 2 m or 3 m with the most common wall thickness of the pipes for the range of pumping pressures usually employed (7 to 10 N/mm^2) being 4 mm. For higher pumping pressures (20 N/mm^2 and more) pipes with wall thickness of more than 7 mm are usually recommended. Quick-locking couplings connect individual pipe lengths. A 100-mm diameter pipeline is considered ideal for short and medium placing distances (up to 200 m) and concrete outputs of up to 25 m^3/h. For longer placing distances and higher outputs, 125-mm diameter pipeline is considered to be the best and this pipeline size is considered to be ideal for most site applications. Pipelines of 150 mm diameter are generally used for placing concrete with a maximum aggregate size greater than 40 mm or for placing large quantities of concrete at longer distances. Relatively larger pipe diameters result in lower pumping pressures and reduced power requirements of the prime mover though at the cost of reduced maneuverability of the pipe network.

The consistency of the concrete mix has an important bearing on the pumping pressure. A slump between 40 and 100-mm or a compacting factor of 0.90 to 0.95 or Ve be time of 3 to 5 s or concrete within the consistency range K3 is generally recommended for the mix in the hopper[1,3]. The right consistency of the concrete mix is essential to avoid excessive frictional resistance in the delivery pipe due to stiff mixes or segregation with too wet mixes. Stiff concrete is difficult to deform and requires higher pumping pressure to pass through bends and tapered sections in the delivery pipeline.

It may be noted that any variation in mix consistency or workability can easily be detected at the pumping point by observing pumping pressures. The concrete pump is thus one of the greatest aids to quality concrete; it acts as a silent quality control equipment refusing to handle any concrete which is unduly harsh, inadequately mixed, non-cohesive and not correct in consistency[4]. Pumpable concrete requires sufficient amount of fines, enough slump (about 80 to 100 mm), continuous grading of aggregates and uniformly and thoroughly mixed materials.

It is to be appreciated that if it is desired that pumping is to be carried out at the rate of 40 m^3/h, a concrete pump with a maximum pumping capacity of 40 m^3/h can achieve the desired output only if it works continuously for one hour. This is seldom the case in view of conditions obtained at construction sites. Actual pumping time may be 45 minutes or even lesser. Taking an actual pumping time of say 45 minutes into account, if the pump is to achieve a nominal out put of 40 m^3/h, it must be able to place $\frac{45}{0.75}$ = 60 m^3/h. The actual pumping time of 45 minutes in this illustration can be represented in the form of a 'work factor' for the concrete pump which in the above case works out to be $\frac{45}{60}$ = 0.75[2]. It is reasonable, for the conditions typically prevailing in sites, to take a work factor of 0.75 to 0.80 while ascertaining the actual capacity of a concrete pump.

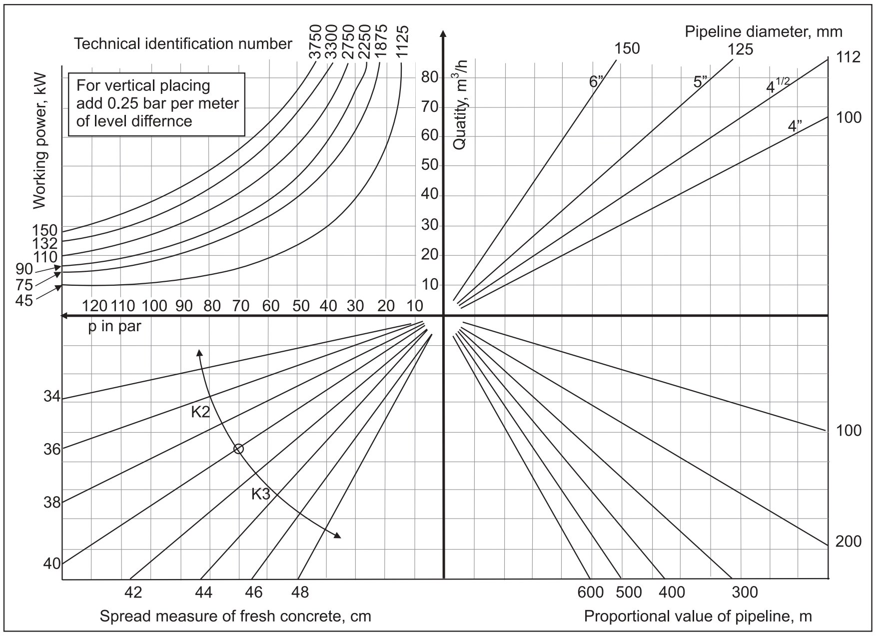

Fig 3 Nomograph concrete pumping[2]

Fig 4 The transit mixer in the foreground discharges concrete into the lorry mounted concrete pump in the background **(Note: The articulated telescopic placing boom delivering concrete to the desired location)**

In conclusion, the selection of a concrete pump for a given job will depend primarily on the desired concrete output, the consistency of the concrete to be pumped, the maximum lead in terms of the horizontal and vertical placing distance and the diameter of the delivery pipeline. Once all these parameters are known, the problem reduces to determining the pumping pressure. Knowing the peak pumping pressure and the desired output of concrete, the power of the pump prime mover can be determined, as is illustrated with the help of the following example.

Example on pump selection

It is required to place an average of 40 m^3/h of concrete at a multistoried building construction site. A placing boom with a horizontal reach of 27 m distributes the concrete. Work factor for the concrete pump may be assumed as 0.75. The length of the 125mm delivery pipeline with 5 bends of 90 degrees and 2 bends of 30 degrees is 110-m. The maximum height of the building is 65 m and the end of the placing boom is approximately 4 m above the pouring point for the top most floor. The concrete slump is 100mm. For determining the required pumping pressure and hence the prime mover capacity of the concrete pump the following steps are suggested.

Required concrete output (given) = 40 m^3/h

Work factor (given) = 0.75

Slump of concrete (given) = 100 mm

Delivery pipe line diameter (given) = 125 mm

Nominal concrete output = Q = $\frac{40}{0.75}$

= 53.3 m^3/h

Delivery pipeline horizontal length (given) = 110 m ...(a)

Number of 90 degree bends = 5; Angular measure of 90 degree bends = $90 \times 5 = 450^o$

Number of 30 degree bends = 2; Angular measure of 30 degree bends = $30 \times 2 = 60^o$

Total angular measure of bends = $450^o + 60^o = 510^o$

Number of equivalent 30^o bends

= $\frac{510}{30} = 17$

Equivalent horizontal pipe lengths at 1 m for each 30^o bend = 17×1 m = 17 m ...(b)

Horizontal reach of placing boom (given) = 27 m ...(c)

Equivalent pipe length due to standard bends in placing boom (assumed) = 10 m ...(d)

Total equivalent horizontal pipe length = (a) + (b) + (c) + (d) = 110 m + 17 m + 27 m + 10 m = 164 m

From the nomogram in *Fig* 3, for 53.3 m^3/h concrete output, concrete slump 100 mm, delivery pipe line length 164 m and pipeline diameter 125 mm, the pumping pressure works out to be 34 bars (3.4 N/mm^2).

Vertical lead = 65 m + 4 m = 69 m

Equivalent static pressure due to vertical lead of 69 m at 0.25 bars (0.025 N/mm^2) per metre difference in elevation = 0.25×69 = 17.25 bars (1.72 N/mm^2)

Therefore, maximum pumping pressure = $\rho = 34 + 17.25 = 51.25$ bars, say 52 bars (5.2 N/mm^2).

Hence, required power of pump

$= \frac{Q \times p}{25} = \frac{53.3 \times 52}{25} \approx 110$ kW or say 140 HP.

Knowing the required power of the prime mover, the required concrete output and the maximum pumping pressure, the pump with specifications nearest to the desired ones can be selected, *Fig* 4.

Conclusion

The influence of various parameters related to concrete characteristics and mechanical appurtenances on the pumping of concrete have been presented. The concrete output, concrete consistency, horizontal and vertical lead and the diameter of the delivery pipeline have an important bearing on the pumping pressure, which is a critical design parameter. The required power of the pump prime mover can be estimated from the desired concrete output and the pumping pressure.

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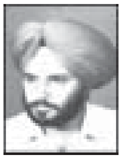
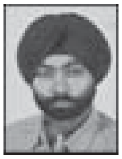
Mr Bhupinder Singh started his professional career as a design engineer with Gammon India Ltd, New Delhi and subsequently shifted to academics and has taught at Birla Institute of Technology and Science, Pilani and Regional Engineering College, Jalandhar. He has a keen interest in the analysis, design and detailing of reinforced concrete structures.



Dr S.P. Singh is an assistant professor in the department of civil engineering, National Institute of Technology Jalandhar. He holds a Ph.D. from the University of Roorkee in the area of fatigue behaviour of concrete structures and maintains a close interest in the behaviour and design of reinforced concrete structural elements.



Mr Bikramjit Singh is a mechanical engineer by training and is presently serving as a deputy general manager (plant & equipment) with Punj Lloyd Ltd, New Delhi. He has extensive experience in the procurement, erection, operation and maintenance of heavy construction equipment with particular emphasis on concrete pumping and slipforming systems.

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