Pumped Concrete with Admixtures

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1. INTRODUCTION

The technique of pumping concrete has been in general and continuous use of over sixty years. Considerable progress which has been achieved in the past decade has undoubtedly made concrete transportation and placing using the concrete pump, potentially one of the most economical and attractive methods available.

The typical size of pour is currently quite small, around 50 m^3, nevertheless the modern concrete pump, together with its associated hydraulically operated placing boom will be able to increase the pour sizes considerably.

The equipments are costly and operation requires highly skilled trained people. Therefore, levels of utilisation of these pumps have to be very high, emphasizing the need of effective collaboration between parties involved.

2. WHEN TO PUMP

Obviously this will be guided by economics i.e. when a cost analysis of the contract as a whole shows a saving. It is usually economical when used over long uninterrupted periods. We have to take into account materials, labour, plants, overheads and time e.g.

(a) For high speed placing or when large volumes have to be poured in limited time.

(b) When concrete needs to be placed in inaccessible positions or there are no other means available at the time.

(c) When accuracy and control are vital.

(d) When good concrete finishes are called for.

(e) To reduce plant requirements or release existing plant for other work. This also reduces capital requirements.

3. ADVANTAGES

(a) Concrete can be delivered to points over a wide area otherwise not easily accessible, with the mixing plant clear of the site. This is especially valuable on congested sites or in special applications e.g. tunnel linings etc.

(b) Pumping delivers the concrete direct from the mixer to the form and so avoids double handling. Placing can proceed at the rate of the output of the mixer and is not held back by the limitations of the transporting and placing equipment.

(c) Pumped concrete is unseggregated as in order to be able to pump the mix must satisfy some specific requirements, the details of which we shall discuss a little later.

(d) The pump is its own QC unit. The remix and pumping gauges constantly monitor the concrete as it passes through the machine. Similarly the pressure delivered by the main hydraulic pump indicates the total resistance to pumping. These gauges indicate the increasing likelihood of trouble if the concrete becomes marginal in its properties.

4. EQUIPMENTS

It shall perhaps be relevant here to very briefly touch upon the pumping equipment before we go on to the concrete. A mobile concrete pump comprises three basic components:

(a) The pump including its method of mounting on some form of carrier.

(b) The concrete placing boom

(c) Associated pipelines, both rigid and flexible sections and pipe couplings.

There is also a hopper into which concrete is discharged from the mixer. Piston displacement system of pumping is the most commonly accepted method. Squeeze pumps are also used for pipes upto 75 or 100 mm dia.

Squeeze pumps move concrete for distances up to 90 m horizontally or 30 m vertically. However using piston pumps concrete can be moved upto about 450 m horizontally or 40 m vertically or to proportionate combinations of distance & lift.

5. PUMPABLE CONCRETES

We shall discuss this at greater length a little later but pumpable concrete can be summarised as well graded concrete of medium workability. It has a slump between 40 mm to 100 mm and aggregate size above 20 mm are not recommended when using a concrete line of 100 mm informal dia. Generally the cement content will be between 280 to 500 kg/m^3.

The additional criterion which has to be kept in mind when designing a mix would be:

1) The concrete must be capable of receiving pressure and moving ‘en bloc’ i.e. with ‘plug flow.’ The grading of the aggregates must therefore be close and continuous to prevent water and/ or the finer materials being forced through the coarser elements. A void- meter may be used to aid the appraisal of this requirement.

2) The concrete must be plastic enough to prevent excessive inter particle interference and to ensure that adequate lubrication is provided. For most aggregates a slump of 75 mm (±25 mm) is found to be most suitable and special attention must be paid to the amount of finer elements below 300 m micron sieve (i.e. fine sand particles and cement).

6. CONCEPT OF “PLUG FLOW”

During pumping the force (P) exerted by the pump must overcome the resistance (R) caused by the following factors:

(a) The energy required to move the concrete and to accelerate it is a horizontal direction.

(b) The resistance of the internal components of the concrete to readjust amongst themselves at tapers, bends, etc.

(c) The energy required to lift the concrete vertically

(d) The energy used in changing direction.

In addition then drag (D) between the pipe walls and the concrete is a further factor, its value increasing with increasing velocity of the concrete through the pipe.

The plug moves at a constant velocity across its section, water acting as lubricant against the pipe walls. Concrete pumping will be possible if $P > (R+D)$. Blockage occurs when $P < (R+D)$. The solution is either to increase P or decrease (R+D), the later being desirable.

7. BLOCKAGES

Two types of blockages can occur:

(a) Water escapes through the mix so that pressure is not transmitted to the solids, which therefore do not move. This occurs when the voids in the concrete are not small enough to provide sufficient internal friction within the mix to overcome the resistance of the pipeline. Therefore an adequate amount of closely packed fines is essential to create a “blocked filter” effects, which allows the water phase to transmit the pressure but not to escape from the mix. In other words, the pressure at which segregation occurs must be greater than the pressure needed to pump the concrete. It should be remembered of course that more fines mean a high surface area of the solids and therefore a higher frictional resistance in the pipe.

(b) If the fines content is too high the friction resistance of the mix can be so large that the pressure exerted by the piston through the water phase is not sufficient to move the mass of concrete, which becomes stuck. This type of failure is more common in high strength mixes or in mixes containing a high proportion of very fine materials such as crusher dust or fly ash, which the segregation failure is more apt to occur in medium or low strength mixes with irregular or gap grading.

8. CHARACTERISTICS OF CONCRETE TO BE PUMPED

Broadly speaking, the following are the salient features:

(a) Concrete should be well mixed before feeding into the pump and sometimes remixing in the hopper by means of stirrer is carried out.

(b) Concrete should not be harsh or sticky, too dry or too wet i.e. its consistency is critical.

(c) A slump between 40 mm to 100 mm or CF of 0.90 to 0.95 or vebe time of 3 to 5 seconds is recommended. Pumping produces a partial compaction so that at the point of delivery the slump may be decreased by 10 mm to 25 mm.

(d) **Mix constituents and Mix design**

i. **Water:** Water content, if low, the solid particles instead of moving longitudinally in a coherent mass in suspension would exert pressure on the walls of the pipe. When the water content is at the correct or critical value, friction develops only at the surface of the pipe and in a thin 1 to 2.5 mm layer of the lubricating mortar. Thus nearly all the concrete moves at the same velocity i.e. by the way of plug flow.

ii. **Fine particles:** These are materials below 300 microns in size. These may be cement, fine sand, stone dust or pulverised ash and is that portion of solids by which their void size and surface are to control the liquid under pressure. The finer they are greater is the control, although they must be graded within the range of sizes. If there is sufficient fine material then will be a lack of control over the liquid phase and segregation will result. If there is an excess the liquid will be over controlled and high pipe friction will be produced.

iii. **Sand:** The third part relates in general terms to the sand and covers the particle sizes between 5 mm and 600 microns. This portion of the mix provides a support function to the finer solids by producing voids of a size which, although they have little effect on passage of water, do contain or support the fine particles.

9. DESIGN PROCEDURE

How then does one achieve concrete with a pumpable consistency in particle? The concrete is designed normally and it is then modified as necessary to give pumpable qualities. The following procedure has therefore proved to be effective.

1) Design for compressive strength or other requirements in the usual way.

2) Check the grading of the aggregates available and ensure that the grading of the combined aggregates is as uniform as possible. This requirement is vital because gaps, or partial gaps are the basic reasons for segregation under pressure, particularly if accentuated by high frictional resistance or internal shear stresses.

3) Determine the optimum sand content for 75 mm slump and add up to 4% in addition as a degree of protection against understanding due to mix variations. Recheck the minimum sand content.

4) Examine the total 'fine fines' content of the mix (i.e. cement and sand below 300 mm) and micron adjust if necessary. A very rich mix with zone 4 sand will be as problematical as zone 1 sand with a lean mix.

5) Re-appraise the grading if the particle shape of any particular fraction is such as may cause excessive voids. Readjust as required, if necessary examining the void ratios of various combinations, using the void meter to achieve minimum voids at the expense of sufficient **'fine fines'** content.

6) If dissatisfied with 1 to 5 above, consider what remedial action may be taken to overcome the troublesome factor. For example, the following two cases may occur:

   (a) If the sand is zone 1, it is worth considering the addition of a proportion of finer sand, or if zone 4 the addition of a coarser fraction addition or reduction of cement may help, but the correct solution is to overcome the gap in overall grading in the first way mentioned.

(b) In a 20 mm maximum size mix, if there is an excess of 10-5 mm fraction and this fraction is flaky with unduly large surface area, either increase the sand content to reduce the possibility of segregation and to reduce the inter-particle stresses, or (better) re-grade using single sized aggregates.

7) At the trial-mix stage variations can be made, preferably in the light of pressures on, and observed performances through the pump. In certain cases admixtures may be economically and beneficially used to improve or eliminate circumstances that cannot readily be overcome by other means. In general, the addition of an admixture does not necessarily make any justifiable improvement in the pumpable qualities, and one should only be used with a full understanding of the shortcomings of a particular combination and of the results of the addition.

At the same time the coarser fraction by particle interference allows the controlled bleeding so necessary for lubrication. Grading, shape and surface texture qualities are important. Natural river sand between zone 2 and 3 have been found to be most suitable.

COARSE FRACTION: The fourth part of the mix is this. This contributes little to the control of water, main function being that of a space filler to control of water, main function being that of a space filler to control or hold the sand. The grading is important as it becomes much easier to manipulate to produce required compatibility. The 10 mm fraction of the grading can be used to eliminate or create particle interference so as to accommodate high cement or fine particle contents.

In practice it is difficult to divide the constituents of a mix at the 300 micron point in order to assess pumpability. It is however convenient to measure the void content of the combined sand & CA. Generally, the volumetric cement content (at an assumed density of 1450 kg/m^3) has to be at least equal to the void content of aggregate and sand but very fine material other than sand can be included with the later.

USE OF PUMPING AIDS:

Purpose:

(a) Increase in the range of mix designs which may be successfully pumped.

(b) Reduction in the risk of pipeline blockages.

(c) Improved flow of concrete through pipelines.

(d) In long term produce high density, impermeable concrete.

ADMIXTURES:

USE OF SPECIAL PUMPING AIDS OF ADMIXTURE TYPE

The idea of using special admixtures as pumping aid in concrete is yet to create awareness among users in India. In fact the use of poor aggregate grading or aggregate with continuous change in grading during concreting-operation will make such special pumping aids quite useful in overcoming the main difficulty like blockage in pumping. These admixtures would be incorporated in pumpable concrete to aim at the following improvement:

a) Increase in the range of mix designs which may be successfully pumped.

b) Reduction in the risk of pipeline blockage by preventing segregation of concrete mix.

c) Improved flow of concrete with increased water retention property through pipelines.

d) To produce high density and/ or impermeable concrete in the long run.

TYPE OF ADMIXTURE:

The type of admixture to be used will depend on the cement content of the concrete which may be considered in three broad classes:

(a) Low cement content mixes with cement content upto 200 kg/m^3.

(b) Medium cement content between 200 and 350 kg/m^3.

(c) High cement content above 359 kg/m^3.

Generally speaking there are three different types of pumping aids available:

(a) Thickening type: increases viscosity of water/ flocculate cement particles. Polyethylene oxides, cellulose, ether, etc.

(b) AEP type: Natural or synthetic materials which have surface active structures. Wood resin and alkyl sulphonate covers surface tension of water.

(c) NAEP type: Better dispersion of cement particles in suspension. Lignosulphates.

MECHANISM:

Low cement:

This is the most significant contribution that admixtures have made to the pumping concrete. In such concretes without the use of admixtures, the flow of grout through the void channels is extremely rapid and escape of grout occurs under pumping pressure along the concrete pipeline interface.

The use of a thickening agent/ admixture reduces the problem of pressure segregation by way of increased water retention property.

Medium Cement:

Many concretes within this range will have satisfactory cement paste flow properties. It is possible however that consistent supplies of CA and particularly sand may not be easily obtained or may vary in the course of a pumping operation. Such changes will adversely affect the grout volume and the aggregate void space. These condition may lead to difficulty in pumping operations in lower and higher echelons of the medium cement range.

With the use of admixtures of AEP type, it is possible to release mixing water to the paste and simultaneously to control the consistency. Air content should not be more than 5% because compression of air in the pipeline will reduce the output of the pump, especially in the very long lines. Low UWC and air entrainment improves impermeability of concrete.

High Cement above 350 kg/m^3

These mixes tend to have cement pastes of stiff consistency and do not have the required lubrication characteristics. The grout film formed does not easily allow the control plug of concrete to move down the pipeline and low pumping speed results. In the extreme case, the total frictional force balances pumping pressure and slow of concrete is stopped.

Admixture used for improving the pumping characteristics possesses a plasticising action which will release extra mixing water to the cement grout. Non AEP are best suited to be used for this purpose. Low UWC increases density with minimum pores and increase impermeability of final concrete.

Design procedure:

At present the use of special pumping aids in concrete is limited. The admixture used most widely in pumped concrete is the normal NAEP type. The use of special admixtures of the thickening agent type or AEP type may well increase in the future if there is increased demand for pumping lightweight aggregate concrete and concrete with lower cement contents made with poor aggregate grading.

CONCLUSION:

1. Distinct advantages:

    a. Concrete can be delivered to points over a wide area otherwise not easily accessible, with the mixing plant clear of the site. This is especially valuable on congested sites or in special applications e.g. tunnel linings etc.

    b. Pumping delivers the concrete direct from the mixer to the form and so avoids double handling. Placing can proceed at the rate of the output of the mixer and is not held back by the limitations of the transporting and placing equipments.

    c. Pumped concrete is unsegregated as in order to be able to pump the mix must satisfy some specific requirements.

    d. The pump is its own QC unit. The remix and pumping gauges constantly monitor the concrete as it passes through the machine. Similarly the pressure delivered by the main hydraulic pump indicates the total resistance to pumping. These gauges indicate the increasing likelihood of trouble if the concrete becomes marginal in its properties.

2. Methods of design of concrete structures can be universally acceptable, whereas methods of construction have to be tailormade to suit the resource capacity of a country.

    Our present methods of operation using small machines and unskilled workers will have to give way to substantially different methods. Wider use of slip forms and lift forms; pumping of concrete at the rates of 80 to 100 m^3 per day per machine; supply of concrete to match the pumping etc are some of the ways to achieve industrialisation of concrete construction in the coming decades. The per capita consumption of concrete on world average is around 2000 kg (cement component 250 kg). India per capita consumption is only 350 kg. This is bound to increase and hence the necessity on the part of all of us to gear ourselves up as practising engineers to meet up the quantum leap.