READY MIXED CONCRETE MANUFACTURERS' ASSOCIATION – (RMCMA)

RMCMA

(Bulletin No. 10)

Concrete Pumping – Blockages and Remedial Measures

PRESIDENT'S MESSAGE

Dear Esteemed Members,

I am delighted to introduce our latest technical bulletin, "**Concrete Pumping – Blockages and Remedial Measures**" which addresses a critical issue faced by our industry, the persistent challenge of concrete pump blockages. As members of our esteemed body, we understand firsthand the detrimental impact that pump blockages can have on construction projects, including significant financial losses, delays in project timelines, and damage to our collective reputation.

Concrete pumping has revolutionized the construction industry, offering unparalleled efficiency and versatility in placing concrete. However, the occurrence of blockages in pumping pipelines remains a persistent and costly problem. When blockages occur, the entire operation is thrown into chaos, with panic setting in as teams scramble to resolve the issue through "firefighting" tactics, often without fully understanding the root cause of the problem.

Our bulletin goes deep into the complexities of concrete pump blockages, offering invaluable insights into their causes and, more importantly, providing practical solutions for preventing and addressing them effectively. We recognize that the consequences of pump blockages extend far beyond the immediate operational disruptions-they jeopardize the success of our projects, erode trust with clients and stakeholders, and undermine our commitment to excellence.

By shedding light on the root causes of pump blockages and equipping our members with the knowledge and tools to tackle them proactively, we aim to empower our industry to overcome this pervasive challenge. From deficiencies in mix design and inadequate pump capacity to operator errors and improper maintenance practices, we leave no stone unturned in our exploration of the factors contributing to pump blockages.

Furthermore, I would emphasize the importance of adopting a systematic and methodical approach to addressing pump blockages, rather than resorting to reactive measures that only serve to aggravate the problem. Through best practices, and practical recommendations, our bulletin serves as a comprehensive guide for optimizing pumping operations and minimizing the risk of blockages.

As members of our esteemed body, we have a collective responsibility to uphold the highest standards of professionalism and efficiency in our industry. By harnessing the insights and recommendations presented in this bulletin, we can overcome the serious challenge of pump blockages and propel our industry towards greater success and prosperity.

I extend my heartfelt gratitude to Mr. A. K. Jain and experts who have lent their expertise to the development of this invaluable resource.

Thank you for your unwavering commitment to excellence and innovation.

Er. Anil Banchhor
(President, RMCMA)

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1. Introduction:

The experience of using concrete as a material for modern construction is almost a century old now. Concrete's versatility, durability, and economy have made it the world's preferred construction material. It is used in highways, streets, parking lots, parking garages, bridges, high-rise buildings, dams, homes, floors, sidewalks, driveways, and numerous other applications. Since, concrete have limited shelf life, it becomes necessary to place the concrete at required location as quickly as possible with minimum number of handling. Therefore, concrete placement becomes important activity in construction of durable RC structures.

Concrete Pumping which has been widely used in the 20th century, has gained momentum since last two decades due to its various advantages over other methods of concrete placement, most notably speed of placement and access. Concrete pumping is globally practiced and most preferred method of concrete distribution vertically, horizontally, inclined or a combination. Placement of concrete in inaccessible areas has necessitated the use of concrete pumps in today's construction world. Placing concrete by pump is more advantageous not only in case of large volume of concrete to be placed into structure but also in smaller quantities, where speed in construction is aimed.

With increase in demand for faster construction from time to time and recent advancement in construction material, concrete pumping to greater height and longer distance has reached a new milestone. New developments in chemical admixture and use of consistent quality of supplementary cementitious materials has met the challenges in pumping successfully than ever before. This has led to pumping of concrete as obvious choice of placement at construction sites for any size of pour. Also, rapid growth in ready mixed concrete industry in the last two decades in the country, the need of pumping of concrete has increased manifold.

2. Basic Theory

Fresh concrete is not a true fluid; hence its flow characteristics are considerably different from liquid, like water. Fresh concrete can offer more frictional resistance since it is heavier than water and also due to its heterogeneous nature. Fluid flow in a pipe depends on the pressure applied, the radius of the pipe and the viscosity of the fluid. For a Newtonian fluid, the flow is directly proportional to the viscosity, which is a constant. Whereas for a non-Newtonian fluid having a viscosity that depends on the shearing stress, like grouts and concretes, the flow rate is a complicated function of the viscosity. Fluid flow is highly dependent on the viscosity of fluids. At the same time for the non-Newtonian fluid the viscosity is determined by the flow characteristics. Figure 1 shows three different velocity profiles depending on the fluid behaviour. For all these fluids, the shear rate at the wall (i.e. the slope of the profile near the wall) determines the viscosity. Successful characterization of viscosity is the key in determining if a fluid is Newtonian or non-Newtonian.

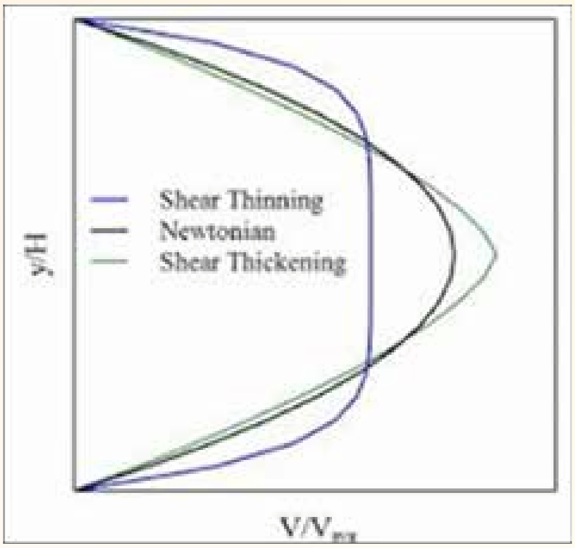

Figure 1 - Flow characteristics (Source: G H Tattersall 2014)

2.2 Flow properties of fresh concrete

Properties of fresh concrete are of great interest for the construction industry since it is to be placed or poured in the forms in plastic form. In its plastic form, flow properties have great influence on the ease of placement, compaction, durability, strength of concrete. Consistency and workability are two terms used to describe the flow properties of concrete. The important function is performance by the lubricating layer and the cohesiveness of the concrete. Both these important parameters are described below.

2.3 Lubricating layer (LL)

During pumping of the concrete, shear induced particle migration (SIPM) leads to moving of coarser ingredients to the centre of the pipe, while less viscous mortar (cement + water + fine aggregates less than 0.25 mm) layer is formed near the wall. This thin layer is called as lubrication layer (LL) or boundary layer. The existence of LL was first suggested by researchers Allekseev in 1952, Weber in 1968 and Morinanga in 1973. It was noted that based on the theoretical flow behaviours of concrete, the pumping of concrete would not be possible without the formation of the LL. In an research by Sakuta in 1979 reported that the flow properties of the bulk material were irrelevant; the only property that matters is the ability of the material to form this layer. The lubrication layer is a major factor in facilitating concrete pumping because of the layer has a significantly lower viscosity and yield stress than the concrete as generally measured by rheometer and also developed a test instrument called a tribometer that measures the friction stress at the wall of the pipe. Jacobsen conducted experimental research with coloured concrete flowing after the ordinary concrete to observe the flow condition in various pipes and pumped some colour concrete in a pipe for a direct observation of flow profiles. Their results demonstrated the existence of a high velocity and paste rich zone at the vicinity of the pipe wall.

Though researchers have consensus regarding the dominating role of lubricating layer in pumping of concrete through the pipeline, the following is a sampling of the division of opinions regarding the friction stress in this layer:

Friction stress is only linear proportional to the normal stress applied (Browne & Bamforth, 1977; Ede, 1957).

- The layer has constant friction stress.
- Friction state is influenced by the flow speed and normal pressure.
- Friction stress of the layer is linearly proportional to the flow speed.

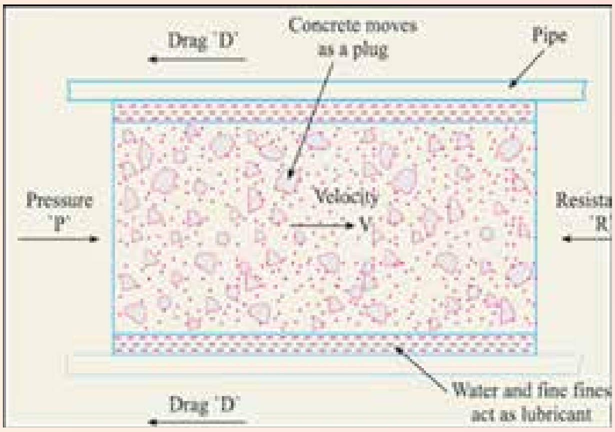

Figure 2 - Force diagram for flow of concrete in a pipe (Tattersall, 2014)

The rheology of concrete mix is predominant for the required pressure in a pumping pipe. Concrete flow in a pipe with applied yield stress will result in three layers: lubricating layer, shearing layer and plug layer (Figure 2). The plug layer depends on the yield stress, shearing layer is governed by yield stress and viscosity, while LL is characterised by the tribology. From these SIPM can be the possible mechanism in which particles in suspension migrate across the streamlines from a region with a higher shear rate to a region with lower shear rate and studied by many researchers. The particle migration should be a function of the particle concentration. In the pipe flow of pumped concrete, the shear stress is highest at the wall of the pipe and linearly decreases to the centre of the pipe. The inhomogeneous distribution of the particles concentration leads to spatially varying rheological properties in the suspension because the higher shear stress near the wall moves the particle of concrete ingredients toward the center of the pipe and LL near the wall is the region where the viscosity and the yield stress become much lower.

Thickness of boundary layer is influenced by number of parameters, an increase of cement paste volume, water to cement/cementitious ratio, super plasticizer content increases the thickness of LL and decreases with increase in fine sand content within concrete mixture (Ngo et al. 2012) which has been deduced by analysing sample from LL. The thickness of the LL was estimated in the range of 1mm to 5mm. Feys and Schutter reported that the thickness and the rheological properties of the layer depend on the mixed proportion of the pumped concrete. Using an Ultrasonic velocity profiler (UVP) in the pipeline while pumping concrete, thickness of LL was determined up to 2mm and does not depend on maximum size of aggregate, concrete strength, or length of pipe circuit. In many of the research work which determine pumpability of concrete mixtures, thickness of LL has been assumed as 2mm based on literature study. In reality, however, the layer has a finite thickness and the rheological properties vary within the thickness.

2.3.1 Cohesiveness

The cohesiveness or the stability of the concrete is the resistance to bleeding and segregation. Bleeding of the concrete is an important property because water is the only ingredient in concrete which can be pumped in its natural state. So to make the concrete move through pipe (pumpable) water needs to transfer the forces to other ingredients of the concrete. If the concrete mixture does not possess good cohesiveness these forces cannot be transferred to other ingredients of the concrete which leads to bleeding. Due to particle interlock a high friction occurs and results in water passing the aggregate leaving a mix in an unsaturated state. Therefore, bleeding of concrete has been found to be a major hindrance in pumpability of concrete. Sometimes, due to pumping pressure, increased bleeding was observed termed as pressurised bleeding. According to Browne and Bamforth concrete in a saturated state has a linear pressure loss. For concrete mixes with too low slump and high pressurised bleeding, the resulting blocking of plug layer (coarse aggregates) depends on the impulse of the piston pump, paste viscosity etc.

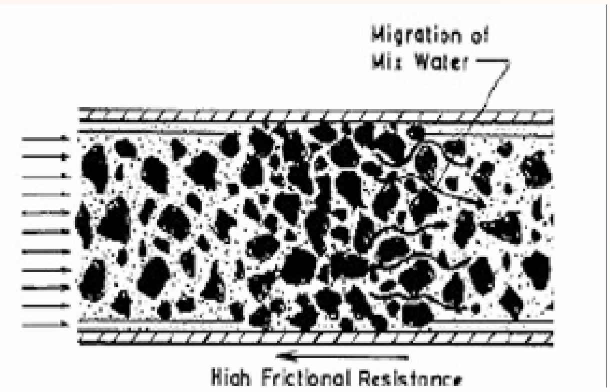

Figure 3 - Bleeding effect while pumping concrete under pressure (Browne & Bamforth, 1977)

The dewatering performance of a pumping mix is not, however, the only factor to define the suitability of the concrete mixture. Even certain saturated mixes can result in high flow resistance which leads to increased pumping pressure and therefore induce great pump and pipeline wear. Such mixes tend to have a high proportion of finer fines either through fine sand or high cement/ cementitious content or both. Thus, to measure the pumpability of a concrete mixture, measurement of two parameters is essential: a) permeability or dewatering characteristics, and b) the flow resistance.

3. Evolution of concrete pumping

A concrete pump is a tool used for transferring liquid concrete by pumping. There is no accurate record exists documenting the first use of concrete pumps. The first patent for a concrete pump established in 1913 by C A Cornell and S A Mckee of U.S. In 1927, after unsuccessfully attempting to lift the concrete to the top of a war memorial in Germany, engineer Fritz Hell started working on a pump that would raise the concrete. Later Germany became the leading technology innovators in concrete pump development and used the methods extensively for the reconstruction efforts after World War II (WWII). After WWII, the steady but noticeable growth in the construction industry has motivated researchers, scientists, and construction engineers to develop the fundamental theories related to flow of fluid, since the behaviour of fluids in the pipes was necessary for understanding the concrete pumping. Many of the largest and most complex construction endeavours since WWII would not have been possible without the unmatched versatility and extended delivery methods provided by the concrete pump units. High rise structures, dams, large bridges, tunnels are poured using concrete pumps.

In the initial period of its invention, concrete pumps were operating at 40-60 bars pressure due to which there was a limitation to pump the concrete to a longer distance. As innovations continued, concrete pumps with more than 100 bar pressure with improved output capacity were developed. Newer modifications as per site requirements in terms of pumping pressure and pumping output were established. In 2007 a new world record height of 601 m for pumping concrete was set by Putzmeister 14000 SHP D a super high-pressure pump at pumping pressure capacity over 300 bars which was used in the construction of Burj Khalifa, Dubai in 2008. In 2009, concrete pumping at a vertical height of 715 m was pumped successfully for Parbati hydro-electric project in India with the help of high-pressure pump manufactured by Schwing. A record long distance pumping of 2.432 kms for one of the hydro-power tunnel lining completed successfully in 2015 in India (Hazaree & Mahadevan, 2015).

List of some of the buildings where concrete was placed through pumping is given below.

Table 1- List of tall buildings constructed since inception of concrete pump

Year	Name	Location	Height	Remarks
1931	Empire state building	New York, U.S	381 m	The tallest building in the world from 1931 until 1972
1973	World Trade Centre I	New York, U.S	399.4 m	
1975	World Trade Centre II	New York, U.S	419.7 m	
1974	Sears (Willis) Tower	Chicago, U.S	442.1 m	It was the tallest building in the world from 1974 until 1998
1998	Petronas Tower	Kuala Lumpur, Malaysia	451.9 m	Tallest twin tower in the world and first tallest building since 1908 outside the U.S
2004	Taipei 101	Taiwan	508 m	World's tallest building from 2004 to 2010
2010	Burj Khalifa	Dubai	828 m	Currently the tallest building in the world

4. Priming of Pipe Lines

Priming refers to the lubrication of the pipeline laid before the concrete is unloaded in pump hopper for pumping. The purpose of this lubrication layer is to decrease the friction between the pipe wall and the flowing concrete by creating a thin LL that significantly reduces the blockages since most of them occur during the beginning of the pumping. Priming also helps in reducing the wear of the pipe wall and the equipment. The necessary amount of the grout required for priming can be calculated based on the thickness of LL (between 2-5mm from various literatures) and total length of the pipeline. A ratio of two parts of cement and one part of fine aggregate is used with water / cement ratio generally not exceeding 0.5.

Synthetic lubricating suspensions for priming purposes have been developed since the early nineties; most of them are based on applying a small amount of aqueous suspension of polymers instead of conventional cement mortar. The use of synthetic lubricating suspension provides a flowable composition exhibiting improved coating and lubrication to the inner wall of pipeline as it passes there through. This lubricating layer disappears with time. Thereafter, a "smooth" pumping operation is conditioned by the concrete mixture which should be generating enough grout for creating the LL and maintains its stability. The use of synthetic primers is promising since their application is easier and cleaner for the site than priming grout.

4.1 Blockages from the view of material perspective

To be pumpable concrete it must satisfy a number of criteria. It must remain homogenous throughout pumping and must be deformable so that it can negotiate the change in direction of flow through the pipeline. Pumping conditions are not easy to reproduce in the laboratory and full-scale tests are relatively expensive. Concrete pumping remains to date an empirical, trial and error process, involving frequent troubleshooting at construction sites. An experimental study conducted by Kaplan, four types of blockages were pointed out and the most frequent blockage happens at priming of the pipeline due to coarse aggregate tend to leave the concrete front and flow through the grout section, eventually forming a dense plug ahead of the flow.

As per study, pumpability is an intrinsic property of concrete and the pumping process is extremely complex. For example, an error on the part of a pump operator can lead to blockage even with concrete that is deemed to be pumpable. The blockages that result from human error (poorly made pipe connections, unsuitable equipment).

- Blockages occur during priming – Priming is a transitory state during which the transition is made from empty pipes to pipes full of concrete. Blockages are very common during priming even in case of concrete mixtures otherwise shows no problem in steady state pumping. According to the concrete pump literature the purpose of priming with grout is to lubricate the pipe. A film of grout is left on the walls of the pipes as it passes through, which prevents the concrete that passes through later drying. A mechanism, that causes some of the coarse aggregate particles to be pushed forward into the grout. The more homogeneous the concrete mix is lesser is the possibility of coarse aggregates expelled from the concrete and move forward in the grout. In a way, the bleeding of concrete characterizes its instability with regard to gravity, the greater its stability, the less it bleeds (for bleeding refer section 2.4.1). There is a general correlation between bleeding rate and risk of blockage. Blockages that occur during the priming are formed as a result of coarse aggregates accumulating in the front of the grout. Therefore, it is essential to avoid mixing of grout with concrete in the pump hopper. The hopper must be emptied once grout has been pumped. To avoid blockages, the piston pump should be controlled differently during the priming which allows concrete to catch up with the particles and gradually reduces at the end of the cycle. This means that the pumping rate must be as low as possible during the priming phase.

- Blockages occur during pumping – Once the pipeline is filled with concrete after the initial stage of priming, the steady state of pumping begins. In the second stage, concrete is unloaded into the pump hopper from the truck mixer and pumped at the pouring point continuously at steady state. Unless disruption in supply of concrete through the truck mixer, very few blockages occur during this stage of pumping. Sometimes the oversize of coarse aggregate (more than 1/4th of the pipe diameter) may lead to blockages in steady state of pumping. Segregation of concrete constituents in the pump hopper leads to increased coarse to fine ratio which can cause the blockage. It's difficult to specify the general mix design rule or pumping procedure that will avoid the blockages while pumping concrete. Knowledge about the causes of blockages, however, considerably reduces risk of their occurrence.

- Blockages occur during stopping and restarting of pumping – Interruptions in concrete pumping are inevitable. Such interruptions may be necessary for reasons like late arrivals of truck mixers at site, redirection of boom placer, change in pipeline in case of stationary pump etc. under these conditions concrete in the pipeline will remain stationary for a period of time that can vary from few minutes to few hours. While concrete in the pipeline remains stationary for some time the force action on concrete constituents is gravity which leads to settling and causes the concrete to segregate and bleed. One more priority is to avoid concrete setting in the pipeline and if this occurs the restarting of pumping becomes extremely difficult. Restarting problems arise when the concrete is highly unstable with respect to gravity. The aggregate particles that settle come in contact with the wall of the pipe and alter the nature of friction. The contact area between the aggregates and the wall of the pipe increases and, in addition the concrete becomes more compacted in the lower part of the pipe's section. Segregation of concrete in the pipeline creates difficulty in steady pumping of concrete and concrete that is prone to segregate can lead to serious blockages.

- Blockages occur during cleaning – Cleaning of pump and pipeline at the end of pumping operation is utmost important so as to keep the entire set up ready for next pour of concrete pumping. Currently two methods of clean-out operations are in use, one is clean-out with compressed air and the other one is clean-out with water. Cleaning with compressed air often causes safety problems but rarely results in blockages. One more limitation with cleaning with compressed air is it can't be effective in case of long length of pipeline. Therefore pipeline length more than 150 meters, cleaning with water should be used, as this techniques is much safer and enough power is always available as pump is used for cleaning with water. Unfortunately, cleaning with water, occasionally encounter with blockage. During the cleaning, water pressure is kept clear of the concrete by separating plug (generally made up of paper bag followed by hard sponge ball). If the separating plug is not sufficiently water tight, water passes through it and mixes with the concrete. This leads to washing out of concrete constituents and causes blockage. The quality of the separating plug is therefore of prime importance for avoiding blockages during the cleaning process.

4.2 Blockages due to human error

Blockages occurring with pumpable concrete are generally to be attributed to human failure. Blockages in or directly after the concrete pump (reducer section) are noticed by a rapid rise in pressure, blockages at the end of the pipeline by a slower rise in pressure. Blockages in concrete pumping are inevitable if the following three reasons are existing;

- Deficiencies in mix design is perhaps the most common blockage issue, when pumping concrete mixture and it does not retain a sufficient amount of water. If the sand used as part of the mix is not graded sufficiently, small channels can form that allow the penetration of water and concrete. Insufficient mixing of ingredients can lead to segregation of concrete mix, and therefore, a proper mixture of concrete is essential. Loss of workability due to the late arrival of concrete at the site or hot weather conditions may cause concrete to set prematurely.
- Pump capacity (motor horsepower or max. hydraulic pressure) and improper pipeline (uncleaned and or damaged) needs a proper evaluation before starting the job will be helpful to avoid any unpleasant situation. Failure to maintain the pipeline is yet another common cause of concrete pump blockage. Pipeline that has been improperly cleaned may cause blockages due to higher resistance offered by concrete flow and/or bleeding and segregation. Defective couplings, gaskets also can result in loss of grout. Performing routine maintenance is much less time consuming and less costly than fixing concrete blockage.
- Operator error – Lack of experience of the pump operator can lead to errors that inhibit the performance of the equipment and cause a blockage. The setting of the pump and laying of a pipeline are the most common errors by the pump operator. Improper handling of flexible rubber hose can cause blockage due to kinking effect. Premature localized wear of the hose and eventual rupture of the hose may also occur at the point where the hose is kinked.
- A forward and reverse movement of concrete blocks in the pipe can sometimes help in removing the blockage. When this fails, the blocked section of the pipeline has to be removed by relieving the pressure on the delivery line by reverse pumping. Delivery lines must never be opened under working pressure as this may cause a threat to safety. If a long pipeline has to be broken and reassembled, it is better to start the work from scratch. In a few cases, compressed air is used for removing blockages from the pipeline. But such operations should be done under the strict supervision of experienced personnel.

5. Conclusion

For placing of concrete, pumping is most commonly used. Concrete should have required cohesiveness and proper mix proportioning using well graded coarse and fine aggregates. The mix should have sufficient fines (particles below 300 microns) it is desirable to have minimum quantity of fines in the range of 400-500 kg/m^3 for natural or crushed stone sand-based mixes respectively. The right choice of equipment, proper laying of pipelines, priming of pipelines and skilled manpower and operative personnel are essential for success of pumping. Proper cleaning of pipeline is very important for ensuring non blockage subsequent pumping operations.

Major problems faced in pumping is blockages of pipeline resulting in disruption of pumping operations. In this bulletin an effort has been made to identify the various causes of blockages and how to avoid and overcome such situations. It is hoped that this bulletin will be found useful by actual users of pumping of concrete.

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