Comparison of Chemical Grout Properties : Which grout can be used where and why?

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1.0 Introduction

Grout is a fluid material which is designed to be introduced into a cavity for the purpose of filling it and which will subsequently harden to give specific physical properties (Fig.1). Grout is generally a mixture of water, cement, sand, often colour tint, and sometimes fine gravel (if it is being used to fill large spaces such as the cores of concrete blocks). Unlike other structural pastes such as plaster or joint compound, correctly-mixed and -applied grout forms a waterproof seal. Although both are applied as a thick emulsion and harden over time, grout is distinguished from its close relative mortar by its viscosity; grout is thin so it flows readily into gaps, while mortar is thick enough to support not only its own weight, but also that of masonry placed on top of it. Grout varieties include tiling grout, flooring grout, resin grout, non-shrink grout, structural grout and thixotrophic grout. Tiling grout is often used to fill the spaces between tiles or mosaics, and to secure tile to its base. Tiling grout is also cement-based, and comes in sanded as well as unsanded varieties. The sanded variety contains finely ground silica sand; unsanded is finer and produces a non-gritty final surface. They are often enhanced with polymers and/ or latex. Structural grout is often used in reinforced masonry to fill voids in masonry housing reinforcing steel, securing the steel in place and bonding it to the masonry. Non-shrink grout is used beneath metal bearing plates to ensure a consistent bearing surface between the plate and its substrate. Grout is also used in construction to embed rebars in masonry walls, connect sections of pre-cast concrete, and fill voids.

Fig. 1: View of flow of a grout material

The various requirements of grouts need to be considered as follows:

- The nature of the void / void system to be grouted.
- The intrinsic properties of the grout to be used including its health and safety requirements.
- The on-site preparation and QC procedures.
- The fluid properties of the grout including its behaviour during and after injection.
- The properties of the hardened grout.
- The test methods for the hardened grout.
- The durability of grout.

2.0 Material Properties

The basic properties of a grout material are dimensional stability, strength, elastic modulus and thermal properties.

- **Dimensional stability:** It refers the property of the material to change in shape or volume.
- **Strength:** The strength of the material refers to the magnitude of a stress, or a load, the material can withstand without rupture. In structural application both compressive and tensile/bond strength are more important. However the strength required to match the required strength or original strength of the structures.
- **Elastic modulus:** The modulus of elasticity refers to the stiffness of the material. Wherever the high strength is required, the elastic modulus of the material should be higher.
- **Thermal properties:** The effect of temperature on resinous grouts varies greatly, therefore must be considered. In extreme temperature variations, special formulations or amending admixtures should be used to negate the effect of temperature on grout materials.

3.0 Grout Rheology

The term rheology is used to describe all the properties of a particular grout, both as initially mixed and in the hardened state.

3.1 Consistency

The consistency is known as ability of grout to flow. Grout can range in consistency from a near-water or very-thin-paint consistency to an almost thick stiff mortar or thixotropic consistency, depending on the application and desired workability.

3.2 Material Behaviour

- **Viscosity:** When the grout is in the form of fluid, its viscosity is the important property. When in solid form, it is characterized by the elastic modulus which denotes stiffness of the substance. When the grouts are in the intermediate group of fluid and solid, its property is described by viscoelastic.
- **Thixotropy:** Many grouts behave thixotropic fluids, which is the behavior of the fluid as an immobile paste or gel when at rest, but as fluid upon application of sufficient energy to start it moving.
- **Flowability:** The grout materials flow freely at lower sustained pressure. Temperature has significant influence on the viscosity of the material.

- **Mobility:** Mobility is the most important property that denotes the property of material to travel through the delivery system and into desired voids. Even some thick and no slump grout can be of higher mobility. The slump test is most commonly used to check workability and mobility of the grout.
- **Penetrability:** Penetrability of the grout depends on viscosity and wetability of the material. The grain size of the grout affects its ability to penetrate.

3.3 Rheological properties

- Cohesion: A low cohesion of the material will help for high penetration. When travel of the material need to be restricted the cohesion of the material should increase.
- Bleeding: The grouts tend to settle out of the solution leaving excess mix water on the top of the settle solids which is known as bleed. This can be reduced by good dispersion of the solids through high shear mixing. To prevent bleeding prior to injection, the grout is agitated continuously after mixing.
- Temperature: Higher the temperature, lower the viscosity and vice-versa and more significant in case of polymer resins. Viscosity of the material decreases as pressure increases, but not significantly as compared to temperature. It also affects setting time, as well as the developed strength and long term durability.
- Setting time: The control of time is required for setting of the grout. Where many holes are to be grouted, the material must set or immobile before adjacent holes are drilled. The admixtures can be added to accelerate or delay the setting time of grout. In most of the cases the grouts are two-components, with the set or hardening time being a function of the proportion of the reactant; i.e. hardener to base.
- Solubility: The rapid dilution of grout materials is essential which decreases the mixing time.

4.0 Grouting in concrete structures

While doing the grouting in concrete structures it is important to consider various parameters such as the purpose of the grouting, understand the defects, width and depth of crack, required strength and other properties of grout material, method of grouting, grouting equipment etc. The different purposes of groutings are as follows:

- Filling structural cavities and voids
- Filling cracks and joints
- Grouting bed plates
- Contact grouting
- Post tension tendon grouting

Due to bad workmanship or improper compaction during the casting of the concrete, the structure may develop honeycombs or cavities. Cementitious grouts are preferable for virtually all voids filling in concrete, as they set up and harden to similar physical properties as host material.

Grouting methods are widely used to fill cracks and joints both in repair of existing structures and in new constructions. The purpose of such work is to block water flow, to provide a structural filler to resist compressive forces, or to bond the two sides of a fault together to create a monolithic section. Portland cement is the most common cementing agent in grout, but urethane- and epoxy-based formulas are also popular depending on location and application of the structure.

4.1 Cementitious Grout

Portland cement-based grouts come in different varieties depending on the particle size of the ground clinker used to make the cement, with a standard size of around 15 microns, microfine at around 6–10 microns, and ultrafine below 5 microns. Finer particle sizes let the grout penetrate more deeply into a fissure. Because these grouts depend on the presence of sand for their basic strength, they are often somewhat gritty when finally cured and hardened.

Ultrafine cementitious grout, also called microfine grout, has been produced for almost 30 years and has been refined over that time span to repair dams, tunnels, and bridge supports. Ultrafine cementitious grouts are composed of a finely ground mixture of Portland cement, pumice, and dispersant. A key characteristic of ultrafine grout is the particle size (typically in microns).

Most cementitious compositions shrink and thus do not develop very high bond strength. So they are employed primarily for filling applications. For opening of less than 3 mm wide, neat cement grouts are used. As the gap widens, sand can be added in the mix.

The particle size is critical in determining the permeability of the ultrafine grout into the structure. Latex type bonding material is added to improve the bond strength. This latex material can act as bond breaker once it has skinned over, which occurs quite rapidly. It should be thus added at last during the mix of ingredients and injected promptly. Usually the open time varies within a range of 10 to 30 minutes but also depend on temperature which affects the setting of the grout. Fly ash and natural pozzolanic materials are added in structural grouts which help in improving the pumpabilty and penetrability and contributes to improve the final compressive strength. Viscosity modified admixtures are also added in the structural grout to provide stability. Properties essential in cementitious grouts are as follows:

- Non-shrink
- High flow
- High strength (early and ultimate)
- Corrosion resistance
- Resistance to high dynamic load

4.2 Epoxy Grouts

Epoxies consist of two components that react with each other forming a hard, inert material. Their bond with most substances is great enough to overcome their very different hardness and modulus. Part A consists of an epoxy resin and Part B is the curing agent, sometimes called the hardener. The curing agent selection plays the major role in determining many of the properties of the final cured epoxy. These properties include pot life, cure or drying time, penetration and wet-ability. Curing agents come in many different chemical flavors, all based on amines or amides. The well known adhesive strength of epoxies is due to strong polar bonds it forms with the surfaces it comes in contact with. On dry surfaces the bond between the surface and the epoxy displaces the air, which is fluid. The same can be true on wet surfaces and even completely underwater. As with all adhesive applications, the cleanliness of the surfaces or cracks to is often the paramount limitation. Underwater applications are becoming more common with the advancement of these types of products.

4.2.1 Required properties of epoxy grout

Viscosity and thixotropy – Low viscosity is required for epoxy to penetrate cracks without using high injection pressure. Typical viscosities for liquid epoxy injection adhesives range from 100 to 500 cps at 25^{o}C. However, if injection adhesives with viscosities lower than 100 cps are used, the adhesive can penetrate into the concrete so far that it leaves a starved bond line. In this case, there must be a continual reservoir of adhesive available to the crack until the adhesive gels fill to the bond line. Liquid adhesives without thixotropic properties will also drain out of a crack, even into sub grades, if all faces of the crack are not sealed prior to filling the crack. For cracks where all faces cannot be sealed; a thixotropic or psuedoplastic adhesive should be used which will stay in the crack without constraint.

Concrete temperature – Cracks in concrete open and close as the temperature of the concrete changes. If a crack cannot be injected while it is in its widest position, an injection adhesive should be chosen that cures fast enough to resist the tensile forces that result when the crack widens from temperature change.

Flexibility – The use of a low modulus flexible adhesive in a crack will not allow any significant movement of the concrete structure. The effective modulus of elasticity of a flexible adhesive in a crack is substantially the same as that of a rigid adhesive.

Creep Resistance – Frequently the adhesive in a bonded crack will be subjected to sustained loads. These loads may be external or they may be caused by restraints on a structure that is undergoing cyclic temperature changes. Unless it can be determined that the adhesive in a crack will not be subject to sustained loads, an adhesive conforming to ASTM, C 88 1 Type IV should be used.

4.2.2 Application

One of the main uses is to repair concrete. These two-component epoxy resins have better expansive properties than some hydrophobic type products. One unique characteristic is that these types of products do not require water for the reaction to begin; this reaction takes place when Part A comes into contact with Part B in the delivery system. The material is non-toxic (0% VOC's).

4.2.3 Limitations

Only mix the amount of epoxy that you can use in ½ the pot life. Materials will start to thicken at this point and are more difficult to work with. Keep in mind that large batches will set up faster than smaller batches. Start by mixing small batches and then increase your batch size slowly, to insure that you do not loosen your mix. It is very important to mix all epoxy thoroughly as is called for in each product's data sheet. When mixing epoxy resins, always mix Part B into Part A, scraping all of the resin out of both containers. Injection epoxies can be mixed with a two component in- line mixer. Do not stir epoxy by hand only; instead use a low speed drill mixer of proper size. Typically warmer epoxies set much faster than cooler epoxies. Generally epoxy resins will have either good chemical resistance or good heat resistance, but not both. Another characteristic of this type of product in its cured state is the lack of flexibility, and the system might be prone to failure if movement occurs due to seismic activity, and or expansion/ contraction.

4.3 Polyurethane Chemical Grouts

Polyurethane chemical resins used for grouting started with only two water activated materials which were and still are used for a wide variety of applications, mainly for sealing active water leaks. These early systems were the basis for what has now evolved into a wide variety of resins, which are available at numerous manufacturers. These first two resins represented both of the systems that are currently available (they are called hydrophobic and hydrophilic) resins while the number of resins with differing properties has grown tremendously. Those products are chemically reacted urethanes and don't use water at all. They can be used as joint fillers which are basically dry at the time of application.

4.3.1 Hydrophilic Grout Systems

Hydrophilic expansive grouts react upon contact with water, absorb water while curing, and cure to a flexible foam or gel. They are generally used to seal leaks in joints or cracks and to repair leaking water-stops. Hydrophilic expansive foam grouts chase and absorb the water in the crack and in all of the fractures that branch off from the main crack. A key characteristic of any liquid is its viscosity (cps) compared to water. Water has a cps of 1, where hydrophilic expansive grouts could range from 300-2500 cps. The lower the cps (the lower the viscosity) of any hydrophilic expansive grout, the better suited it is for tighter cracks (for better penetration) and for applications that might require greater travel. The higher the cps (the higher the viscosity) of any hydrophilic expansive grout, the better suited it is for high flow/high volume applications so as not to become diluted.

4.3.1.1 Applications

Hydrophilic expansive foam grouts have an initial cure and final cure. The initial cure is the time it takes for the polyurethane grout to foam up, and the final cure is the time it takes for the grout to fully expand. This final cure time, which may take up to 12 hours, is critical to the success of the grouting process. Hydrophilic foams have been successfully used in above- as well as below-grade applications, but hydrophilic gels should be used below grade as they will shrink in a dry environment.

Hydrophilic expansive gel grouts can be mixed with large amounts of water to offer an alternative grouting material in areas such as curtain grouting and manhole grouting. Most polyurethane grouts are considered to be "non toxic" although safe handling procedures should be closely followed with these and all other chemicals.

Hydrophilic expansive foam grouts are typically single component products requiring small delivery systems for the injection process. These types of grouts are used in below grade structures, basements, and other areas that are often wet, such as subways and interior portions of a concrete dam. If injecting a hydrophilic gel grout for manhole grouting, or curtain grouting a multi- ratio delivery system would be needed. Pumping systems for hydrophilic foam grouts tend to be high pressure and low volume, while the gels utilize high volume and lower pressure systems.

Some hydrophilic foam grouts are certified to be used with potable drinking water systems.

The expansion rate of hydrophilic foam grouts can be up to 5 to 7 times its original volume and hydrophilic gels typically do not gain volume upon curing.

4.3.1.2 Limitations

Hydrophilic expansive foam grouts will stick to concrete. They will stretch in a moving crack and are generally used for crack sealing or filling voids in joints or sewers and other underground structures. Hydrophilic gel grouts will not stick to concrete and are not recommended for moving cracks. They are used for sealing sewer joints and manholes, and other underground applications. Due to their relatively short gel times and high viscosities compared to the acrylics, they are usually not used in sealing lateral sewers with remote lateral packers.

4.3.2 Hydrophobic Grout Systems

Hydrophobic resins are water activated systems that require roughly 4% water to start the chemical reaction. They have expansive qualities, ranging from 6 to 20 times expansion and are generally referred to as "foams", sometimes as rigid foams. Due to the low water content they are considered non-shrink, as the foam matrix has so little water that even in extremely arid conditions they will maintain their cured form. One of the other characteristics is that they are controllable. Unlike hydrophilic, they have an additive that is referred to as an accelerator, as it allows the applicator to control the IR cure time from 1 to up to 10 min. The accelerator is not to be confused as a catalyst as it does not start the reaction, but allows it to be controlled. Before the reaction can begin, the accelerated resin must still come into contact with water to start the reaction.

Two-component systems can have high expansive properties with many of them capable of curing to a foam density of 96 kg/m^3. Unlike the hydrophobic or hydrophilic systems, they do not require water as a catalyst as the reaction is started when Part A comes into contact with Part B in a static mixing tube. They are generally much faster reacting systems and can reach up to 25 times expansion in as little as 7 to 10 seconds. With the high expansion rates and extremely fast reaction times, they can have the potential to move structures and require extreme care when using.

4.3.2.1 Applications

Typical applications include sealing cracks/joints, creating a water impenetrable barrier between the backside of a structure and the soil matrix from the negative side. A major advantage to sealing active leaking cracks/joints is that material is water activated as opposed to most materials that require the water intrusion to be eliminated before the repairs can be done. The cured resin is designed to accept movement, allowing the materials to be successful in applications subject to movement due to seismic activity, contraction/expansion or movement designed into the structure where a rigid material like epoxy is prone to failure. Many below-grade structures start out with a membrane installed on the positive side as waterproofing. While these systems have proven to be effective, they, like many others, have a lifespan anywhere from 15 to 30 years. Once the systems lifespan is exceeded the owners are faced with the costly replacement that includes excavating to expose the failed system, removing and replacing. With the polyurethane systems a series of holes are drilled through the structure from the negative side and the resin is injected to create a monolithic barrier between the backside of the substrate and the soil. This application provides a long-term repair at a considerable savings.

4.3.2.2 Limitations

As with all materials, Polyurethanes also have limitations. Hydrophobic polymers usually have better chemical resistance. To insure proper cross – linking during the reaction, water should be tested to ensure a pH level of 10 or less. A pH close to neutral (7) produces the most ideally cured polymers. A pH below 7 slows down the reactivity and too far below 7.0 will "kill" the reaction. Higher pH will increase reactivity up to a pH 8-9, but after that will begin to degrade the quality (the water holding ability) of the cured polymer as the pH increases. Recall that pH 7 is neutral and as the pH falls exponentially toward 1, it becomes a stronger acid. As the pH climbs above 7, the same is true for increasing alkalinity up to the maximum of 14. While a water temperature of 10°C or higher is preferred, the materials have been successfully used with water temperatures near freezing. Below 10°C the material will steadily decrease its cure rate as well as its physical characteristics, and once the water begins to crystallize, the resin cannot absorb it and the reaction will not occur.

Hydrostatic pressure has similar effects on the resins. Starting at one atmosphere, the material reaction time as well as the expansion and swelling begins to lessen, and after 10 atmospheres they will still react, but at an extremely slower rate and without any expansion or swelling. The water/diisocyanate reaction creates carbon dioxide and hydrostatic pressure controls the amount of CO_2 that can dissolve into the water column. High pressure and colder water temperature will produce the least amount of foaming in the cured polymer while lower pressure and warmer water increase the foam yield. Grouts that reacted on a "desktop" at room temperature without any containment form the maximum amount of CO_2 hence the larger amount of cured foam. High concentrations of hydrocarbons will not allow proper cross-linking of the molecules and the material will not react. Hydrophobic foams tend to be rigid and some will not stretch, meaning they are not the best product for a moving crack. All urethanes are adversely affected by UV rays and high temperatures, say in excess of 40°C.

5.0 Tools and tackles used for pressure grouting

Following are tools and tackles used for pressure grouting:

- Air compressor with a capacity of 3 to 4 m^3/ min and with a pressure of 3 to 5 kg /cm^2.
- Grout injecting machine or grouting pump with inlet and outlet valves (Fig. 2 & 3). It should be capable of injecting cement grout up to 5 kg/cm^2.
- Hydraulic pressure gauges (Fig. 4) showing pressure commonly in bar(1 bar = 14.5 psi or 0.98 kg/cm^2)
- An air tight, pressure mixer chamber, with stirrer for proper mixing of the grout and keeping it in proper colloidal suspension during grouting.
- Flexible pressure hose pipes for transmitting grout from pressure chamber to ports embedded in the masonry/ concrete (Fig. 2 & 3).
- Drilling equipment, pneumatic or electric (Fig. 5), for drilling of holes up to 25 mm dia.

Fig. 2: Injection packer for high pressure grout

Fig. 3: High pressure injection pump

Fig. 4: Hydraulic pressure gauge

Fig. 5: Electric drill – Heavy duty – power output – 1050 watts and drill speed – 350-600 rpm with variable speed control

- 10–20 mm dia G.I. injection packers with couplers (Fig. 6) or lockable type PVC nozzles as shown in Fig. 7.
- Hand pump for small amount of injection grouts (Fig. 7)
- A metabo special stirrer 31043
- Paddle dimensions – mixing head diameter – 130 mm
- Mixing head length – 180m and Overall length – 600 mm

Fig. 6: Injection Packers

Fig. 7: View showing an Injection Packer/PVC nozzle and Injection Hand Pump

5.1 Pressure grouting procedure for filling cracks/ voids /cavities/leakages

- Cementitious grouts usually require larger holes and nipples for injection than do resinous grouts
- Drill a hole of 4 – 5 mm larger than the dia of injection packer/ nozzle and insert it up to a depth of 80 mm. If cracks are clearly visible, injection ports can be installed at appropriate interval by drilling directly into the crack surface.
- Polymer modified mortar /epoxy putty shall be used to fix and seal the sides of the packer/ nozzle (Fig. 8).

Fig. 8: Fixing the packers in drilled holes

- PVC grouting nozzles of 130 mm length & 10mm outer dia, with a stopper at the outer end, shall be fixed on the concrete surface @ 500 mm to 1m C/C or at the particular location of crack/void/water leakage area.
- If the cracks are more wide between port to port then seal the crack with epoxy putty. Then the surface of the crack between ports is allowed to cure.
- After 24 hrs of fixing of nozzles/packers, grouting operation shall be carried out.
- The cementitious grout shall be prepared with mix of cementitious material & non shrink grouting chemical, W/C ratio shall be maintained not more than 0.45.
- For epoxy and polyurethane injection, Part A which consists of a resin and Part B which is a curing agent or hardener need to be mixed together.
- Both pumping rate and pressure should be monitored during injection. It depends on type of grout materials, crack and void network inside the concrete.
- Grout mix shall be prepared of good consistency by mixing thoroughly with a paddle mixer (Fig. 9) for ease in passing through grouting pipe.
- For two component materials of epoxy or polyurethane, both the components to be mixed as shown in Fig. 10.
- The grouting shall be done under pressure of 3 to 5 kg/cm^2 using grouting pump in normal condition and a pressure of 8 to 10 kg/cm^2 in some specific conditions (Fig. 11 & 12).
- Injection begins with lowest elevation port and proceeds along.

Fig. 9: Mixing paddle - Should be capable of producing high shear during mixing of cementitious grouts

Fig. 10: Mixing for pumping the grout materials

Fig. 11: Grouting hose pipe, Ball valve and Injection packer fixed with epoxy putty and PU grouting in action in a dam project

- Grout shall be pumped till the time it flows into the structure, filling all the gaps/voids/cracks inside. The grouting activity should be stopped once it becomes very difficult to further pump in or at a time when the grout material oozes out from adjacent grout point through the installed perforated nozzles/ packers. The consumption of grout in each hole shall be recorded.
- Once completed and grout is completely set, the projected parts of the nozzles shall be removed, surface shall be cleaned and finished smooth. If PVC nozzle is being used the same should be cut and sealed with epoxy putty.
- Wherever packers are being used the same can be removed, cleaned and reused.
- Seal the grout holes with epoxy putty or polymer modified mortar.

Fig. 12: Grouting in action with a hand pump in a deck slab of highway culvert with epoxy injection grouts

5.2 Pressure grouting for repair of raising dampness

- Pressure injection of non-aqueous silicone injection grouts of water-repellent solutions into tubes sealed into holes in the masonry.
- Drill the holes with a 12 - 15 mm drill bit at 45° angle, penetrating half width of the wall (Fig. 13).
- Start from skirting level with 300 mm distance between each hole horizontally and 300-400 mm vertically from ground level, at c/c.
- Fix the perforated PVC nozzles and seal them secure with instant leak plug material and allow it to set for one day before starting next work.
- Use grouting pump with minimum 2 bar (2 kg/ cm^2) pressure capacity to pump the siliconate based grout (Fig. 14).

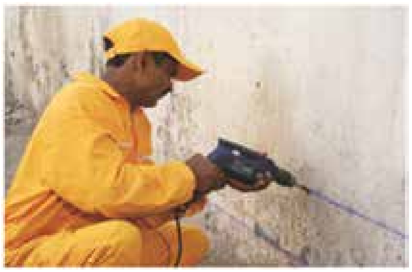

Fig. 13: Drilling the hole by a drill bit at 45^o downward

Fig. 14: Injection with siliconate based injection grouts for raising dampness in masonry wall

5.3 Grouting bed plates

Grouting is often performed under bed plates and machinery bases to ensure uniform and firm support, in many instances, these bases must be set and maintained at precision tolerances. Accordingly, the grout material must be strong and durable, as well as stable, free of bleed, and essentially non-shrinking. Both cementitious and resinous materials are used. The resinous grout should not be used where thickness is more than 13 mm because of its limiting properties. Typically base plate grouts do not require much pressure to be simply forced from one side to the other; however, the quality of the work will be improved if positive pressure can be used and maintained for a short period of time. This will typically be within a range of 0.7 to 1.7 bars.

Generally the grouting under base plates are done in following cases:

- Anchor bolt base plate grouting (Fig. 15)
- Column base plate grouting (Fig. 16)

Fig. 15: View of anchor base plate grouting

Fig. 16: Grouting below a column base plate

The schematic diagram of grouting below base plate and foundation bolt pocket is given in Fig. 17. The step by step application procedure given as follows:

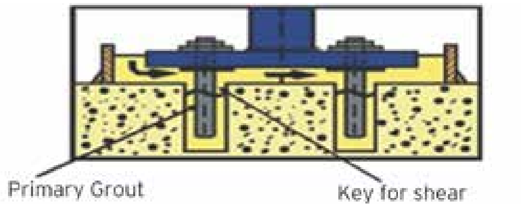

Fig. 17: Schematic diagram of grouting below base plate and foundation bolt pocket

5.3.1 Primary Grouting

- Bolt Pocket Grouting may be done, if possible, below the top level of the concrete foundation.
- Provide a "key" for secondary grouting.

5.3.2 Surface preparation

- Remove the dust, unsound material with air compressor
- Wet the surface with water for at least 24 hours prior to the grouting
- Remove the excess water

5.3.3 Secondary grouting

- Align base plate in line and level.
- Shuttering a must – with a hopper for pouring the grout.
- If length is too long divide into sections.
- Sections can be made of wooden shutters or separations made with mortar containing general purpose grout.
- Always ensure surface saturated dry (SSD) condition.
- After one part hardens, grout the adjacent section in, say, maximum gap of 8 hours.
- Pouring by gravity; increasing height of tremie / hose.

5.3.4 Check during grouting application

- Mix the grout with given water to powder ratio. Add 75% of the water first, mix it for three minutes.
- Add balance water and mix it further for two minutes till it becomes a homogeneous mix.
- Pour the grout from one end only.
- Do not stop until complete grouting is finished.
- Application temperature should be between 5 – 40^{o}C.
- Cure the grout for minimum seven days.

5.4 Anchor fixner Grouting

Anchor fix grout is a two-component polyester resin & hardener-based anchor fixing grout for anchoring of bolts from 8 to 50 mm dia. into concrete.

5.4.1 Viscosity and thixotropy

For vertical holes with the opening upward, a liquid adhesive can be used. A liquid adhesive requires less time to place than a paste or thixotropic or psuedoplastic adhesive and it is much less likely to trap air in the bond line. For vertical overhead and horizontal holes, a thixotropic or psuedoplastic paste adhesive is more suitable because it will not require containment to keep it from running out of the hole. However, it must be capable of being pumped from the bottom (back) of the hole toward the front of the hole to avoid trapping air bubbles in the bond line. Air bubbles would reduce contact area and result in a weakened bond.

5.4.2 Application guidelines

- Hole diameters for anchor fixing normally used are 3 to 12 mm greater than the bolt, dowel, or insert diameter. In all cases, the smaller the annulus between the insert diameter and the hole diameter, the lower the possibility of creep failure. As the annulus dimension increases, the potential for creep failure under constant load increases.
- To develop the full strength of a steel anchor or a reinforcing bar, as opposed to inducing a failure in the concrete, the steel should generally be embedded to a minimum depth of ten times its diameter.
- Anchor spacing should allow a sufficient quantity of anchors to transfer the desired loads from the attached members without development of excessive stress interaction through the concrete between the anchors.

5.4.3 Important strength considerations

- Pullout strength- Pullout strength is generally determined by applying an axial tensile load to the anchorage until tensile failure occurs. The ability of the concrete-anchor system to develop full pullout strength of the anchor as determined by ASTM E 488 depends mostly on the bond strength of the adhesive and the cleanliness of the hole. This test evaluates the ability of the adhesive to bond and cure under the conditions of moisture and surface preparation actually encountered in application.
- Creep resistance- Many inserts that are bonded into concrete are put under a constant load. Examples are fixtures being hung from anchorages and torqued anchor bolts. Therefore, creep resistance should be carefully considered. For critical applications pre-testing of a mockup is recommended because no standard test methods are currently available.

5.5 Contact grouting

It involves the filling of generally small voids behind or under a rigid lining or conduit. The grout is injected through holes that penetrate the lining. Voids typically filled by contact grouting are relatively thin and cementitious suspension or slurries. Generally, the intent of contact grouting is to increase the structural integrity of the structure. Examples of where contact grouting may be used include the following:

- Within pressure tunnels to prevent expansion of the tunnel liner under pressure

- Within sewer tunnels to prevent sulphate attack of concrete liners from behind the liner

5.6 Post tension tendon grouting

Prior to the stressing of post tensioned tendons, they must not be bonded to the concrete. This is typically prevented by encapsulation within a snugly fitting encasement or by installing the tendons into ducts consisting of pipe or similar tube. To bond these tendons to the surrounding structure and to protect them from corrosion, the ducts are normally grouted following the stressing operation (Fig. 18).

Fig. 18: View of post tension tendon duct for grouting

6.0 Grouting in Masonry

Voids in masonry are far more common. They tend to be more continuous, and represent a larger amount of a section's volume than those in concrete. Injection of significant quantities of grout is thus common in these structures, so the further weight added often becomes critical and must be carefully evaluated. The most important factor for grouting in masonry structures is improving the fixity of the individual units in order to reduce the risk of their becoming loose and falling during earthquakes or other dynamic loading events.

The older masonry structures are bonded with lime mortar, which become loosened over a period of time due to ageing, environmental distresses, etc. In such cases, both cementitious and resin-based grouts are used to a large extent. While doing injection grouting, cementitious grouts are more suitable since they bond very well to older masonry structures. The injection pressure should be very low from 0.3 to 0.7 bars in old masonry structures to avoid any displacement of elements that may occur with high pressure. For larger voids and cavities, resinous foam injection grout would be more suitable. For leaking at joints in masonry structures, it is wise to do repointing or resealing of the joints with cementitious grouts. Tile grouting should be done with polymer-modified cementitious or epoxy grouts.

7.0 Quality Control and Quality Assurance

While doing grouting, different colours should be marked for primary as well as secondary grouting points. Each hole should be numbered for identification. The consumption of material during injection varies at each grouted location, which depends upon the size and nature of voids and cracks inside the concrete structures. After injection is completed, the consumption of material has to be noted and signed by the contractor and engineer-in-charge. All the records and forms related to grouting should be made available at each location, such as grout pressure, volume injected, and the time at regular intervals. Other data should be noted, such as date, time, hole number, etc. The detailed method statement should be given to the contractor, showing what to do and how to do it. The detailed technical specification should include layout of grout points, spacing/location, number of holes, angle of holes to be drilled, diameter and depth of holes that are to be accepted, grout mixer requirements, material requirements satisfying desired properties as per the standards, pumping rates, grout pressure required and method of pressure selection for individual holes, requirement for monitoring and recording the injection parameters during grouting, and requirement of skilled personnel. The performance specifications after the grouting need to be mentioned clearly. The effectiveness of grouting must be monitored by some non-destructive test such as ultrasonic pulse velocity or by taking a core sample at the grouted location and checking the compressive strength of the core sample before and after grouting at that particular location. This will help in monitoring the improvement of the quality of concrete after the grouting.

Wherever there is leakage, the same technique can be used to check if leakage has stopped after the grouting is completed. There may be some locations where leakage might occur even after grouting is done and this can be stopped after the secondary grout at the leakage spots. The extreme environment poses challenges to grouting activities. Virtually all grout mixtures will react, set, or cure more rapidly as the temperature increases. Beyond a certain temperature, an immediate or flash set will occur. Conversely, reactions are much slower as the temperatures decreases. In such extreme environments, chemical solutions of resinous categories should be added as modifying agents to control the reactions. The specification is the most important part of any job, which describes the method of working, quality parameters, acceptance limit, method of measurement, method of payment, etc. In the absence of detailed general and technical specifications of the job, disputes can arise between the owner and the contractor.

8.0 Conclusion

The grouting offers many services such as control of water leakages, strengthening of structural and non structural elements along with a wide range of structural applications for both concrete and masonry structures. Understanding the properties of different grout materials, specifications, formulation, step by step application methods, required pressures, types of pumps & mixers, limitations of each type of grouting methods will help to increase the durability of each grouting system.