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Free flow engineering grouts & grouting

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1. INTRODUCTION

Definition of Free flow Grout: A material which, in its liquid state, will flow and fill a void totally displacing all air and which, thereafter, will set and harden to form a material with defined engineering strengths and characteristics and continue to fill the void in which it was placed, without shrinkage.

The Vital link between foundation and equipment: No matter how carefully the construction of an engineering base for equipment is executed, it is impossible to produce a finished surface which is sufficiently level for the majority of medium and heavy machines or places of equipment to be mounted directly upon it. It is, therefore, common practice to accept this situation and to level such equipment to precision tolerances by raising it above the surface of the foundation by means of supports of one kind or another.
In order to finally locate the equipment, the gap between the level base plate must be filled with a suitable material. This material is not merely to fill the space but it is, in fact, to transfer the operational load on the plate to the foundation and must continue to do this for the life of the installation.
In many cases the equipment is physically attached to the foundation by means of bolts which may alternatively be integrally cast into the concrete foundation or set into holes or pockets, and subsequently fixed by means of an anchoring grout. In this latter situation the function of a grout will be to ensure the necessary anchorage, as a separate requirement.

International development history of base plate grouts: Originally, simple mixtures of sand and cement were made on the construction site and rendered sufficiently fluid by the addition of water to enable them to pour and fill the gaps described above. It was rapidly discovered that a typical shrinkage factor of between 1% and 2% by volume occurs in the most carefully made sand/cement grouts and this invariably results in excessive voids and unsupported areas beneath base plates.
The next development step was to incorporate a small percentage of aluminium powder with such sand/cement grouts in anticipation that the hydrogen gas formed by reaction between the aluminium and the cement would create positive expansion and eliminate the former problem. This proved a partial solution but unless specially selected and processed aluminium particles

were employed, the expansion process tended to be completed too rapidly and long before the grout had started to set.

With the advent of modern machinery and equipment where high precision and very much heavier machines are employed than ever before, the inadequacies of site-manufactured grouts became apparent. Firstly, it is quite impossible to reproduce material of identical strength and quality from one batch to the next and this is unacceptable in a quality conscious society. Furthermore, the maximum compressive strengths obtainable are generally extremely low and much less than that of the concrete foundation itself. When it is realized that the size and extent of the grout beneath the equipment is very much smaller than the relatively massive and structurally designed foundation, it is obvious that the grout needs to be, in effect, very much stronger than the foundation concrete itself and, in general terms, it is internationally accepted that it should attend at least twice the compressive strength.

This means that a machine mounted on a foundation consisting of M200 concrete requires a grout with a compressive strength of not less than 400 kg/cm2, and one with a base of M350 requires a grout of not less than 700 kg/cm2.

Once this become accepted and demanded by both machine manufactures and Civil Engineers alike, the modern engineering grouts emerged. The first one being developed in the U.S.A in approximately 1950 but today are manufactured in every industrialized and a majority of semi-industrialized countries in the world.

Engineering Characteristics: A modern engineering grout must have the following characteristics.

1. It must flow freely under its own hydro-static head and be capable of traveling without assistance an acceptable distance through a definite gap. Without such flow characteristics and definition, it is impossible for the design and installation engineer to determine the acceptable gap beneath his equipment for successful grouting, and conversely enable him to excessive gap and thereby cut the cost of material required.

2. The grout must display a positive degree of expansion over a sufficient period of time to ensure that no shrinkage occurs whilst it is in a plastic state. This ensures that contact between the foundation surface and the underside of a base plate is maintained during the hardening process. In the event that a plate is subsequently removed, it is generally accepted that some minor voids will occur for inescapable practical reason, but the overall efficiency of contact surface should not be less than 92 – 95 %.

3. The grout must subsequently harden to defined engineering strengths within equally defined time periods. For example, a grout which may reach a compressive strength of the categories mentioned above, should be capable of reaching more than 50% of such strength within, say, 72 hours to enable machine testing and commissioning to commence with the minimum loss of time. In general terms, it should be possible to actually commission a machine with in one week of grouting and this would normally be expected with a modern engineering grout.

Practical and commercial considerations: It is clearly impossible for materials which will meet the characteristics described above to be made on a construction site. The combination of a

material which will flow with the ease of thick soup and will still set, and acquire strengths far in excess of those obtainable with normal concrete, can obviously only be formulated and made under the most controlled production condition. Further more they are impossible to make by simple cement or concrete technology and require modern chemistry for their successful and reliable construction and performance. Necessarily, such material will be more costly than straightforward sand and cement mixtures but these costs must be read in the right context.
Firstly, great care and considerable expense goes into the design and basis and construction of the machine or equipment foundation on the basis that the engineer and those responsible cannot afford for it to fail.
Secondly, the machine or equipment itself frequently has a value out of all proportion to even the cost of the foundation, and even to the entire building itself. This is amplified by the cost for example, of a modern turbo generator, which can frequently exceed that of the building, by two or three times.

MECHANICAL PROPERTIES OF TYPICAL FREE – FLOW NON-SHRINK GROUTS

Products: DURAGROUT-GP, & GP2

TABLE 1: Typical flow distance related to gap width under baseplate and hydrostatic pouring head.

GAP WIDTH	Hydrostatic Head	Max. Flow Distance
12mm	100mm	500mm
20	100	1000
30	100	3000

Time for Expansion : Starts approximately in 20 mins.
Finishes approximately in 2 – 3½hours.

Degree of Free expansion: 2 – 4½within the recommendation at FIP/RILEM joint committee for grouting, U.K 1963)

Pressure to restrain expansion: Approx. 0.004 $N.mm^2$

TABLE 2: Pullout / shear strengths for deformed shank bolts grouted into concrete. Direct shear strength of grout across section. Average values.

Time in Days	1	7	28
Pollout Shear Strength. (N / mm2)	8.2	11.0	15.0
Direct Shear Strength (N / mm2)	3.7	5.1	6.1

TABLE 3: Compressive Strengths values obtained with DURAGROUTS mixed at recommended water / powder ratios and used under restraint at pourable free-flow consistency.

PRODUCT/GRADE	TEMPERATURE	COMPRESSIVE STRENGTH N / mm2			
		1day	3days	7days	28days
DURAGROUT-GP	30ºC	10	27	35	45
DURAGROUT-GPS	30ºC	25	50	62	76
DURAGROUT-GP2	30ºC	40	55	70	85

Lastly, it must be appreciated that in order to carry out job of grouting, the cost of time involved in preparation, formwork, provision of equipment and manpower is exactly the same for a low cost poor quality material as it is for a high cost, high quality material. When the cost of the completed grouting job is assessed, any different in fundamental material costs are considerable evened out in any case. More importantly, the cost of the grout beneath the base plate or in the holding down bolt pockets of a modern piece of machinery or structure is a tiny fraction of the total cost foundation and machinery together. It will, in fact, be measured in several decimal points of a percent. Yet, if a turbine generator goes out of true; a compressor loosens on its foundation or a crane rail sinks, the economic consequences may be, and often have been, excessive.

To seek to save money on grout or grouting is not only a false economy; it is to court expensive failure.

2. **HOLDING DOWN BOLTS**.

Machine and equipment bases are normally anchored to the designated foundation with bolts which are fixed into the foundation by one means or another. The principal technical requirement is:

a) The bolts must locate precisely in the base plate holes or anchoring devices.
b) The strength of the anchorage in the foundation must be adequate for the operating loads, inclusive of safety factors.
c) The bolts themselves must be of sufficient strength and have adequate engineering qualities to meet the loads imposed on them.

There are three common alternative methods of bolts being attached to the foundation:

i. **Cast in bolts**: Bolts are located by means of a temple and fixed in position before the foundation concrete is poured. After pouring they become an intergral part of the foundation. Such bolts may, if necessary actually be attached to reinforcement steel in the foundation and the strength of the anchorage therefore can be put beyond any doubt.
The main problems are the difficulty in accurate location and maintaining the bolts in position during concreting. It must be remembered that once a bolt has been cast into the concrete it is impossible to move it or re-align it in any way. For these reasons cast-in bolts are the least popular and least commonly used.

ii. **Pre-formed bolt pockets:** This is the most popular method employed. Over-size holes are formed in the foundation concrete at the time of casting which have enough cross-section to permit a degree of lateral movement during the final positioning of bolts. When the bolts are positioned, the hole or pocket is filled with non-shrink engineering grout to ensure that the bolt is bonded to the foundation concrete thoroughly and reliably.
The main advantages of pre-forming pockets is that less critical positioning tolerances are necessary compared with cast-in bolts and there is a choice of pocket size, shape and method of forming.

Holding-down bolt design: All too frequently it is assumed that some special and elaborate shape or anchoring devices are required on holding-down bolts to guarantee their security when grouted into the pockets. For example, it is common to see bolts of considerable length with either a large hook formed at the end or with some large securing plate assembly welded or otherwise attached. In many of these cases, the same diameter bolt simply made from a straight piece of high tensile deformed reinforcing bar such as Tor steel, would provide at least the same strength of reliably into the concrete. This should always be given considerable thought because it would enable the cross-sectional area, e.g. diameter of the bolt pocket, to be reduced to a minimum. The diameter of the bolt, plus 100mm would give 50mm. Of movement in every direction and this will usually be more than adequate for the precision positioning of a base plate, providing the Contractor has placed the bolt pocket formers with reasonable care.
It must be stressed however, that bolts with a total de-formed shank or even those with large plates or other devices on the bottom are not necessarily the best design or the most desirable under all circumstances.
In spite of adequate diameter and strength of steel and apparent length of into the foundation, bolts, or rather the anchorages of them, do frequently fail, where the base plate is subjected to heavy dynamic or vibratory forces such as compressors, forging hammers, metal shearing equipment etc. The reason for such failures is quite clear:

a) Where the load on the bolt is whole or largely static, on upward forces are imposed upon it and length of bolt between the top nut and washer and the top of the grout can resist the said force.
b) When a dynamic load is applied to the bolt however, this short ungrouted length of bolt is required to absorb all the stresses and transfers them directly to the top of the grout to which the remainder or the length of bolt is firmly bonded.
c) When a bolt is bonded for the full length of its shank into the foundation and heavy dynamic loads are applied, the bond between the bolt and the grout starts to facture pregressively and as the stresses continue, the fracture progresses down the length of the bolt shank until, eventually, whole assembly is loose and the anchorage is destroyed.

The main problems are that pockets are frequently designed far too large and of the wrong shape and consequently result in excessive usage and cost of grout, with less efficient performance.
For example, a square pocket is usually formed by embedding a timber box in the concrete and later removing it. This leaves a smooth sided hole with a concrete surface which is usually a rich in latence and therefore weak and needs to be chipped or otherwise roughened

in order to ensure that the grout bonds to give sound concrete. Furthermore, the reason for the hole is to allow sufficient movement of the bolt in any direction to align the machine plate. The concers of a square pocket cannot actually be used and a circular one of the same diameter would reduce the volume of the grout by 21%immediately. If careful consideration is really given to the amount of bolt movement required, it is likely that the diameter of most holes could be reduced significantly and the volume of the grout prorates.

The forming of circular pockets of high bonding efficiency is, in fact, the easiest of all. It simply requires a suitable cage of say, 20 or 25 mm. Steel mesh to be rolled around a former and wired into a tube. The tube is set in the foundation by attachment to convenient reinforcing members and the concrete cast around it. Some of the concrete will bond into the mesh and protrude slightly through it in places and provide a first-class mechanical bonding key for the anchor grout. Wherever possible this should be considered in the interests of economy and efficiency.

iii. **Drilled anchor holes:** In situation where a line of concrete can be provided in the foundation free of reinforcing steel, one of the most efficient methods of locating anchor bolts is simply to drill the holes in the precise positions required, by marking them through the base plate, or a template made from it. Such holes must be drilled with a rotary percussive air drill, which has hole automatic water or air flushing to blowout the chippings from the hole as it is drilled. The holes only need to be a few mm. Larger in diameter than the anchor bolts and are grouted in using polyester resin anchor grouts. As opposed to the normal bolt pocket method however, such grouts are poured into the hole first before inserting the bolt, as the difference in diameter is so small that it would be impossible to pour the grout around the bolt.

This method is specially favoured for the installation of very long plates such as on cranes, steel rolling beds and similar production lines. There is a simple remedy for this which is employed worldwide and it is:

To use a smooth shank in this case, with a suitable anchorage device on the bottom, which can be as simple as two nuts and a washer tightened together. But, then for the entire shank of the bolt, from the bottom anchorage to the nut and washer on top of the plate, to be sleeved, using a plastic tube or some other similar material which will prevent the grout from bonding to the shank at any point along its length. The anchorage is obtained by the larger diameter of the bottom anchorage device, i.e., two nuts and a washer.

When loads are applied, the whole length of the bolt is under stress but its total elasticity is available to absorb it. The stress forces are now transferred to the anchorage at the bottom from which they travel at a 45º, upward angle back to the surface of the foundation. Provided the bolt is embedded deeply enough it is quite impossible for the anchorage to fail. Furthermore, both grout and the concrete of the foundation is placed in its strongest mode, i.e., compression from the bottom upwards, rather than in tension from the top downwards, which is the case when it is bounded continually along the length of the bolt.

iv. **Special circumstances:** Obviously many specialized circumstances can arise where the attachment bolts have to be removed for inspection or replacement or to permit the machine or equipment itself to be removed with minimum problems. Special techniques exist to deal with such requirement but are too numerous to itemise in these notes.

3. **BASEPLATE – LEVELLING METHODS.**

a. **Loose Shims**: The most common method of leveling base plates. A series of carefully machined small steel plates or shims are wedged under the base plate, at intervals around its edge. Using a combination of thicknesses shims are inserted or withdrawn until the entire plate is leveled.

Advantages:
Familiar technique - understood by installation workmen.
Suitable even for very heavy equipment.

Limitations:
Necessitates a range of shim thicknesses being available.
May require special machining of shims for tolerance work.
May need leveling equipment to raise the base plate for repeated adjustment until level.

b. **Pre-set shims**: This system utilized one size and thickness of steel shim only. Each shim is embedded on a polyester resin mortar pad and levelled to the next using a steel strength edge whilst the mortar is still plastic. When the mortar has set the baseplate may be lowered directly on to the pre-levelled shims allowing anchor bolt and underplate grout to proceed immediately.

Advantages:
One size/thickness of metal shim required.
Base plate/machine lowered directly onto pre-levelled shims.
No repeat lifting and adjustment.
Very repid and accurate particularly for long bed plate assemblies.

Limitations:
Less economical than individual shims for small light equipment bases.
Care needed to avoid disturbing shims whilst polyester mortar is setting (2 hrs.)

c. **Underplate nut leveling:** A nut, followed by a washer, is run, down the shank of each previously anchor bolt. The baseplate is lowered onto the nuts and washers and leveling is carried out by adjustment of the nut beneath the plate. When level the top nuts and washers are fitted and tightened down.

Advantages:
Avoids use of shims.
Relatively accurate mechanical method of leveling.

Limitations:
May be difficult – necessitating operatives lying on the ground. Under plate nut entrapped in bed completely grouted – no subsequent tightening down is possible. Necessitates pre – grouting of bolts in precise positions.

d. **Machine springs:** The holding –down bolts are first pre-grouted and set in position. A suitable heavy-duty spring is placed over the shank of each bolt and the base plate lowered onto the spring. Top nuts and washers are fitted and leveling is carried out the simple adjustment of the nuts by compressing the spring beneath the plate.

Advantages:

Very easy, rapid and accurate levelling Bolt shanks can be sleeved for transferring of dynamic loads.

Limitations:

The springs may be more costly than shims. Only suitable for light/medium weight baseplates-controlled by strength of springs available.

Necessitates pre-grouting and anchoring of bolts in precise positions.

SUMMARY :

Loose shims:

+ Familiar technique suitable for all sizes/weights of baseplates.

- Time consuming – necessitates much lifting or baseplate during levelling.

Pre-set shims:

+ Single size only, pre-set on high-strength mortar requires baseplate to be lifted and positioned once only.

- May be more costly than loose shims and less suitable for very heavy bases.

Under – plate nut levelling:

+ Entirely mechanical, avoids use of shims.

- Frequently difficult and awkward, less technically efficient.

Machine Springs:

+ Easy, rapid and high accuracy levelling.

- Suitable for relatively light weight plates, governed by spring capacity.

4. THE MECHANISM OF GROUTING.

Formwork: In order to fill the cavity beneath a machine base plate it is necessary to make formwork which will force the liquid grout to follow a defined path and fill the cavity required and ensure that it remains filled whilst the grout sets and hardens. In general terms the formwork must have certain physical characteristics:

a) It must totally surround the area to be grouted and it must be grout tight. This means that where the formwork is bedded on to the ground or top of the foundation, no grout must be able to leak out underneath it nor must there be any leakage at joints where these occur. LEAKAGE OF LIQUID GROUT MEANS LOSS OF GROUT UNDER THE PLATE:

b) The grout must always be poured from one side in order that it can flow in a single wave under the plate driving all air in front of it, and eventually emerging on the opposite side and rising up to a level above the underside of the plate. There must, therefore, be a hydrostatic head formed on the pouring side which, when kept filled, will have sufficient driving force to keep the grout flowing underneath the plate until it emerges on the opposite side.

c) The formwork must not bond to the grout so as to make it impossible to remove it easily and without damage after the grout has set. This means that if it is made of timber or other similar hard material, it must be treated with a suitable release agent.

The most common used formwork materials are timber or plywood or a combination of bolt. Following the principles outlined above, it is normal to build the wooden formwork around the base plate which will be relatively close or even tight to the plate on two parallel sides and on the other two sides will be set a sufficient distance away from the plate to enable grout to be poured in a hydro-static head on one side and the emerge on the opposite side and rise up above the level of the underside of the plate.

As a general guideline the following should be followed:

a) Because modern non-shrink engineering grouts can expand in an unrestrained state and will have lower strength than where they are trapped and confined under the plate, the amount of free surface area must be kept to an absolute minimum. In general terms this means that the gap on the pouring or hydro-static head side of the formwork should never exceed 150 mm. And on the mergent or opposing side should not exceed 50 mm. In cases of narrow plates, the hydro-static head can usually be formed in less space because of the reduced volume of grout necessary and wherever possible, in other cases, even on the pouring side a lesser gap of 150 mm. should be aimed for.

b) The gap on the two sides parallel to the direction of flow of grout should be kept to a minimum. It is difficult to define precise dimensions because much depends on the size of the base plate. It is a basic risk that if the side formwork is too far away from he plate, the grout will tend to flow along the sides and take the easiest route and this could leave a gap under the centre of the plate. In general terms, side formwork should not be more than 25 mm. from the plate, and preferably close to it.

c) The height of formwork must be sufficient to allow the finished grout level to be an adequate height above the underside of the plate. Where the plate thickness is up to, say, 50 mm. then it is generally accepted that half to the upper surface of the plate. Where much thicker plates exist, there is no advantage in the finished level of grout being greater than, say 25 mm. to 5 mm. above the underside.

d) The hydro-static head which can either be formed in with the timber formwork or may be a separate hopper which can be lifted and slotted into position where repeated operations are involved, should, in general terms, have a minimum height of 150 mm. When the grout is actually being poured into the hopper, its rate of flow will be such that an effective liquid height of 100 mm. will be maintained. It will normally not be possible to fill the hopper to the very top under practical conditions.

Special circumstances may make it impossible to carry out a grouting operation with a single formwork construction. It is a golden rule that must always be remembered.

GROUTING MUST BE CARRIED OUT IN ONE CONTINUOUS POURING OPERATION AND THE GROUT MUST NEVER BE ALLOWED TO STOP FLOWING UNTIL THE CAVITY IS FILLED AND THE GROUT HAS REACHED ITS ENENTUAL LEVEL.

This means that where the amount of grout that can be mixed and held ready for pouring is inadequate, the space under a plate will have to be sub-divided into one or more smaller bays which can be grouted individually with the volume possible.

A typical case is a crane rail which is long and narrow and obviously if grout was simply poured from one side it can run infinitely along the length, without control. In such cases, the work is divided up by formation of bunds or ‘stop ends’ at selected intervals. Each bay is then grouted in successive pours until completion and the work can conveniently stop at any stage.

In the case of very large single base plates, these may also have to be sub-divided and where the formation of bunds is not possible than some other means such as inflatable tubes or pneumatic packers will have to be employed.

5. PREPARATION FOR GROUTING.

a. In order to ensure a satisfactory bond between the grouting and the two components, i.e. the foundation and base plate, the contact surfaces must be thoroughly clean.
b. The foundation concrete must be free from any contamination such as oil or grease and weak surface material such as cement laitance must be removed by wire brushing, chipping or grit blasting. The importance of this cannot be overstressed, as the bonding of the grout can only be as strong as the surface to which it is applied. Having designed an engineering foundation with great care, it makes no sense at all if the grout does not bond to actual structural concrete forming that foundation.
c. Bolt pockets must be completely and carefully cleaned out before grouting. It must be remembered that they are easily filled with loose debris, rubbish etc., during the proceeding work and operations. The only way of making sure they are clean is by high pressure air blasting. This is obviously most easily done before the bolts are positioned.

Wetting of foundation: Before any cementitious based grout is used, the foundation concrete and bolt pockets MUST BE flooded with water between 3 – 6 hours before grouting, and preferably up to 24 hours. The reason for this is to satisfy the thirst of the dry concrete and ensure that when the grout is placed, water will not be sucked from it, causing it to stop flowing and defeating the whole objective. Immediately before grouting, all surplus water remaining MUST be removed by one means or another and finally the area blown out with a compressed air line.

6. GROUTING OPERATIONS.

Planning: It is essential that all the grout required to fill a planned void is poured in one continuous operation and once pouring has commenced, it must NEVER stop. To ensure this, planning or materials, equipment and manpower is necessary.

a. **Grout materials:** A double check should be made using the actual gap size dimensions and volumes measured on site, to determine the amount or grout required. A minimum additional allowance of between 5% and 10% should be added to allow for operational loss and wastage. Sufficient water must be available before mixing commences.
b. **Equipment.** The mixing equipment must be capable of producing sufficient volume of grout to enable pouring to be carried out as a continuous operation. It should be borne in mind that the minimum mixing time for one batch of grout, allowing for practicalities, is between 7-8 minutes. Once mixed the grout must be poured within a maximum of 20 min. and if the gap/flow distance is critical, then immediately it has been mixed. Where very large volumes are involved, it may therefore be necessary for additional mixing equipment to be available.
c. **Pouring facilities.** Where grout is to be hand-poured into the hydro-static head or hopper, there must be sufficient buckets, pails, drums etc., available for the operatives to keep the hydro-static head filled with grout until the void is completely filled. In other words, additional vessels filled with grout must be immediately to hand as soon as the previously ones have been emptied.
d. **Manpower.** The number of operatives should be calculated on a basis of time and amount of grout required to be mixed, the filling of the pouring vessels and the actual pouring of the grout. Bearing in mind the necessity of continuous pouring, the job should NEVER be stared with inadequate labour.

Grout Mixing: A precision free-flow engineering grout, e.g., DURAGROUT type, is designed to give reproducible characteristics in both its liquid and hardened state. This can only be achieved providing certain basic rules are followed and these are ESSENTIAL:

1. Mixing MUST be carried out by mechanical means. UNDER NO CIRCUNSTANCES MUST ATTEMPTS EVER BE MADE TO MIX FREE FLOW GROUT BY HAND.

2. The PRECISE amount of water specified by the manufacturer MUST be used.

3. Mixing procedures and time of mixing MUST BE followed implicitly.

Most particularly, once all water and grout powder have been mixed to a smooth and even consistency, the grout MUST BE mixed continuously for a full five minutes. These disciplines are extremely simple in their requirements, but all too often they are ignored or considered unnecessary. It must be remembered that all he time, trouble and money that has been expended in designing special foundations and in the machinery and equipment itself can be to no avail if the grout under the base plate or in the bolt pockets, fails, and the machinery or structure concerned is seriously damaged in consequence.