



GOVERNMENT OF MAHARASHTRA

WRD HANDBOOK CHAPTER NO. 2

COLGROUT MASONRY WORKS



MAHARASHTRA ENGINEERING RESEARCH INSTITUTE, NASHIK-04
WATER RESOURCE DEPARTMENT

PREFACE

Colgrout masonry is a new technique for construction of masonry for massive structures like Gravity dams, Weirs, Barrages, Foundations, Retaining walls etc. which satisfies the requirement of strength and durability and at the same time, being impervious, is particularly suitable for water retaining structures in Indian conditions. Based on the experiments conducted at Maharashtra Engineering Research Institute, Nashik, Water Resources Department, Government of Maharashtra vide Circular No. MISC/ 1094/ (160/90)/ MP/ Adm dated 17-02-1995, has taken decision to use colgrout masonry in upstream septum of masonry dams in lieu of UCR masonry (CM 1:3) and M10 concrete. Since then, in many dams, colgrout masonry has been constructed either in upstream septum or in full section. No Indian Standard is available for colgrout masonry.

As there is no literature or consolidated compiled information available for the guidance of field engineers in spite of the work of colgrout masonry being carried out, it is felt necessary to prepare the handbook. Accordingly, the PWD handbook chapter no. 39 has been published named as Colgrout Masonry works in 2010. But now there are approximately 8 years over. In WRD more than 50 dams have been constructed by using colgrout masonry. Meanwhile new concept has been originated in this field by various organizations like use of crushed stone sand in lieu of natural sand, use of flow meter, use of batching plant in place of conventional colgrout mixer, non destructive testing etc. So it is necessary to revise this handbook. Accordingly, the committee to review the handbook was formed by the Director General, Design, Training, Hydrology, Research and Safty, Maharashtra Engineering Research Institute, Nashik as follow (As per latest office order no. 7 / 2015 MTRL/MERI/582/2015 Dat 30/06/2015.)

Sr.No.	Designation	Organization
1	Chairman	Chief Engineer, Central Design Organization, Nashik
2	Member	Chief Engineer, Mechanical Circle, Nashik
3	Member	Shri. Chandramohan Hangekar Retired Chief Engineer, Water Resource Department
4	Member	Superintending Engineer and Joint Director, Maharashtra Engineering Research Institute, Nashik
5	Member	Superintending Engineer, Dam, Central Design Organization, Nashik
6	Member	Superintending Engineer, Quality Control Circle, Pune
7	Member	Shri. K.C.Tayde, Executive Engineer and Principal, Regional Training Centre, Nagpur.
8	Member Secretary	Scientific Research Officer, Material Testing Referral Laboratory, MERI, Nashik

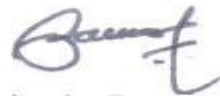
The committee conducted three meetings and undertook preparation of the draft copy of this handbook. Draft handbook was discussed in details with the field engineers right from Junior Engineers upto the Chief Engineers and engineers working in Maharashtra Engineering Research Institute, Nashik and Central Design Organization, Nashik. Their useful and practical suggestions are included in this handbook. In second meeting of this committee, the discussion session are conducted with experienced person from colgrout masonry field. These persons are 1) Shri. Gattani, Retired Executive Engineer, WAN project, Shegaon, 2) Shri. Pradakshine, Executive Engineer, Minor Irrigation Project, Sangamner and 3) Shri. Vaijapurkar, Executive Engineer. Certain paragraphs, formulas, tables included in this handbook have been taken from various Indian Standards.

This handbook will serve as a reference book to field engineers. This WRD handbook chapter no. 02 is divided in to nine parts as below –

- (1) Introduction
- (2) Terminology
- (3) Materials.
- (4) Equipment and tools.
- (5) Colgrout mortar.
- (6) Colgrout masonry.
- (7) Work tests on materials, mortar and colgrout masonry.
- (8) Benefits of colgrout masonry
- (9) Guidelines for safe transportation of Colgrout Masonry Cores

This handbook would not have come to the finalization without the keen interest and the efforts taken by all the committee members.

We hope use of the colgrout masonry shall increase in large dams in lieu of UCR masonry with better quality standards.



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- 1.Materials.
- 2.Masonry.
- 3.Reinforced Concrete Construction.
- 4.Prestressed Concrete.
- 5.Plastering and Pointing.
- 6.Preparation of Projects and Engineering Geology.
- 7.Surveying.
- 8.Excavation.
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- 10.Building.
- 11.Town Planning.
- 12.Roads.
- 13.C.D.Works and Bridges.
- 14.Ports and Harbours.
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- 16.Electrical Works Connected with Buildings.
- 17.Soil Mechanics.
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- 19.Hydrology and Water Planning.
- 20.Masonry and Concrete Dams,
- 21.Earth and Composite Dams.
- 22.Instrumentation.
- 23.Spillways, Outlets, Gates and Hoists.
- 24.Canals.
- 25.Irrigation and Irrigation Management
- 26.Soil Survey of Irrigation Command, Land Drainage and Reclamation.
- 27.Hydro-power Scheme.
- 28.Construction of Tunnels.
- 29.Urban Water Supply.
- 30.Rural Water Supply.
- 31.Sanitary Engineering.
- 32.Construction Machinery.
- 33.Quality Control:
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- 34.Labour Laws.
- 35.Rate Analysis.
- 36.Construction Planning.
- 37.Part-I -Land Acquisition Part-II- Valuation.
- 38.Mathematical Data and Miscellaneous Information.
- 39.Colgrout Masonry works.
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- WRD1.Ferrocement Technology
- WRD2.Colgrout Masonry Works

W.R.D. HANDBOOK CHAPTER NO. 02

COLGROUT MASONRY WORKS

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1.0 INTRODUCTION

Uncoursed rubble masonry for dams and other massive structures was extensively used till the closing of 20th century. However, the quality of conventional masonry is deteriorating day by day and is not coming up to expected standards. The root cause of the deteriorating quality of masonry is non-availability of good, experienced and or well trained masons. With a view to keep pace with construction speed and to get expected performance from masonry works, more advanced techniques were investigated.

Based on the experiments conducted at Maharashtra Engineering Research Institute, Nashik as well as on few masonry dams in the state, WRD, Government of Maharashtra vide Circular No. MISC/ 1094/ (160/90)/ MP/ Adm dated 17-02-1995 directed to use colgrout masonry in upstream septum of masonry dams in lieu of UCR masonry (CM 1:3) and M10 grade concrete. Since then over a period of 23 years, more than 50 gravity dams have been constructed in colgrout masonry either in upstream septum or in full section. Its use for modern structures is increasing steadily.

The present method of mixing mortar or concrete is not perfect, as every particle of the cement in the mix does not get thoroughly mixed with water during very short mixing time like 3 minutes or so. The cement particles are very fine (normal fineness of the cement available in the market is 3000 to 4000 cm²/gm). Furthermore these innumerable tiny cement particles are covered with micro air films or micro air bubbles, which are attached to cement particles with surface tension. Unless the surface tension is broken air bubbles will not get dispelled and the cement particles will not come fully in contact with water.

To secure this objective, mix the two essential components, cement and water in a mixer with 1500 to 2000 rpm. In this mixer, due to very fast movement of water molecule and cement particles, the surface tension is broken, air bubbles are removed and cement water solution gets converted into “Colloidal Cement” wherein maximum gel formation takes place. This colloidal cement when mixed with sand, the resultant grout is called “Colgrout or Colloidal Grout”. This colgrout is then introduced or injected in preplaced aggregate, or masonry forming “Colcrete or Colgrout Masonry”.

2.0 TERMINOLOGY

- 2.1 Fine Aggregate** - Natural sand or sand prepared from crushed stone, gravel or such inert materials.
- 2.2 Bedding plane** – The planes which separate the different layers of stone and are at right angles to the pressure which acts on the stone mass during its formation in nature
- 2.3 Bond** – An interlocking arrangement of structural units in the masonry to ensure stability.
- 2.4 Bond stone** – Selected long stones used to hold the masonry together transversally.
- 2.5 Coefficient of permeability** - The rate of flow of water under laminar flow conditions through a unit cross sectional area of porous medium under a unit hydraulic gradient and at a standard temperature of 27⁰ C.
- 2.6 Colgrout double drum mixer** - The mixer used for preparing colgrout mortar
- 2.7 Colgrout flow meter** – Flow meter used for measuring the flow of colgrout mortar.
- 2.8 Colgrout masonry** - Resultant masonry by injection of colgrout mortar in pre-packed stones.
- 2.9 Colgrout mortar or Colloidal grout** - A homogeneous mixture of cement, fine aggregate and water and admixture, if any, mixed at high speed in colgrout double drum mixer.
- 2.10 Exit pipe of mixer** - The outlet for releasing the colgrout mortar from second drum of colgrout mixer.
- 2.11 Form work** – A temporary erection of timber or steel framing with boarded platform at levels suitable for construction in stages.
- 2.12 Grout** – Mixture of cement, sand and water used for filling the voids.
- 2.13 Colgrouting** – Inserting colloidal grout with some suitable pressure to fill up voids, if any, in the pre-packed stones.
- 2.14 Hammer dressing** - Rough surfacing to a stone by means of a Spall hammer.
- 2.15 Hardening** - The physical and chemical changes observed in mortar/ masonry due to effect of setting of cement and loss of water.
- 2.16 Homogeneous masonry** - Masonry which has no voids.
- 2.17 Interstice** – Void or space between adjacent placed stones.
- 2.18 Laitance** – An extremely fine film of material of little hardness which may form on the surface of freshly laid masonry.

- 2.19 Lugeon** - It is the water loss in litres per minute per meter depth of the hole under a pressure of ten atmosphere maintained for ten minutes in a drilled hole of 46 to 76mm diameter.
- 2.20 Natural sand** - A fine aggregate produced by natural disintegration of rock and which has been deposited by streams or glacial agencies.
- 2.21 Natural stone** - Lump of igneous rock.
- 2.22 Pozzolana** - An essentially siliceous material which in itself possessing no cementitious properties, in finely divided form and in the presence of water, react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.
- 2.23 Stretcher stone (Pin header)** - Selected long stones embedded vertically in the interior of masonry to form a bond between successive courses.
- 2.24 Sand** - A fine aggregate which is either natural sand or crushed stone sand or crushed gravel sand.
- 2.25 Setting** - The physical and chemical changes observed in mortar/ masonry mainly due to the hydration of constituents of mortar or due to the interaction of some of constituents or a combination of both the types of reactions.
- 2.26 Slurry** – Paste of cement and water.
- 2.27 Workability** - The working consistency of a mortar as judged by the worker from its behavior during application such as its easy spreading without separation of water or segregation of the solid material of the mix.
- 2.28 Quoins** – Dressed stones used for corners.

3.0 MATERIALS

3.1 Cement

Ordinary Portland cement, Portland slag cement, Portland Pozzolana cement and Super sulphated cement used for stone masonry works in dams and other massive structures shall comply with the requirements of IS: 269-1976 (Revision 2015), IS: 455-1976 (Revision 2015), IS: 1489 -2015 and IS: 6909 - 1990 (Reaffirmed 2016) respectively. Special cements may also be specified for use in dam masonry.

3.2 Sand

3.2.1 Natural river sand - The sand shall conform to IS: 2116 – 1980 (Reaffirmed 2017) and IS: 383-1970 (Reaffirmed 2002)

a) Quality The sand shall be of hard, dense, durable, and uncoated by gritty material derived from rock fragments. Sand shall not contain harmful impurities such as iron pyrites, alkalis, salts, coal or other organic impurities, mica, shale or other laminated materials, soft fragments, sea shells in such a quantity as to affect adversely the strength and durability of mortar.

The maximum percentage of deleterious materials in sand as delivered for use in mortar shall not exceed the following values:

Table no. 1: Deleterious substances in sand

Sr. No.	Deleterious substances	Maximum permissible limit by weight	
		Natural sand	Crushed sand
1	Material finer than 75 micron IS sieve	3%	15%
2	Shale	1%	--
3	Coal & Lignite	1%	1%
4	Clay lumps	1%	1%
5	Cinders and clinkers	0.5%	--
6	Total % of all above deleterious materials.	5%	2% (excluding 75 micron materials)

Note: The sum of percentages of all deleterious substances shall not exceed 5% by weight for both sands and percentage of coal & lignite and clay lumps shall not exceed 2% for crushed sand.

Sand shall be free from injurious amounts of organic impurities. If the impurities are beyond the acceptable limits, the sand shall be washed or otherwise cleaned to the entire satisfaction. Such sand may be used, provided that, when tested for the effect of organic impurities on the strength of mortar, the relative strength at 7 and 28 days, reported in accordance with clause 7 of IS: 2386 (Part VI) – 1963 (Reaffirmed 2016), shall not be less than 95%.

b) Mechanical analysis: Sand shall be well graded and passing through 4.75mm sieve, oversize shall not exceed 5% and no fraction shall exceed 35%. Fineness Modulus shall be within 2.6 to 3.0. If the sand quarried happens to be coarser, the sand will have to be corrected before use by necessary sieving or by adding missing sizes in requisite quantity. The missing sizes can, also, be obtained by crushing of stones after necessary tests.

The sand shall be well graded and when tested as per IS: 2386 (Part I)-1963 (Reaffirmed 2016), shall conform the following limits of gradation of IS: 2116 – 1980 (Reaffirmed 2017)

Table no. 2: Required gradation of sand and Fineness Modulus.

Sieve size	Percentage passing on the sieve by weight
4.75 mm	100
2.36 mm	90 - 100
1.18 mm	70 - 100
600 micron	40 - 100
300 micron	5 - 70
150 micron	0 - 15
Fineness Modulus	Min. 2.60, Max. 3.00

For crushed sand, the permissible limit on 150 micron IS sieve is 20%. This does not affect the 5% allowance permitted to other sieves.

The gradation shown in table above is indicative only. The best gradation will be determined after experiments and tests. The various sizes of particles of which the sand is composed shall be uniformly distributed throughout the mass.

3.2.2 Crushed sand

The crushed sand obtained by crushing acceptable quality of stone or natural gravels by rod mills may be permitted to use. The crushed sand, however, shall satisfy the requirements specified for natural sand as per IS: 383-1970 (Reaffirmed 2002) and IS: 2116 – 1980 (Reaffirmed 2017). In addition, suitable experiments will have to be conducted first to ascertain suitability of such crushed sand with reference to workability, strength, impermeability and other characteristics considered necessary for cement mortars.

Use of combination of crushed sand and natural sand is permitted with proper blending, however, the combination satisfies the requirements specified above.

3.2.3 Storage

Arrangements shall be made to store the sand in a way that would protect it from being contaminated with dust, organic matter or other deleterious substances. Varying amount of moisture in sand contribute to lack of uniformity in mortar consistency. Efforts should be made to ensure uniform and stable moisture content in the sand as batched. Stock pile drainage may take 48 hours to reduce moisture in sand to uniform and stable amount. It is desirable to maintain three stockpiles for sand – one receiving wet sand, second under drainage and third for use in construction.

3.3 Stone

3.3.1 Stone for masonry

- a) **Quality:** Common types of stone used for colgrout masonry are trap and Basalt. Stones shall conform to the properties laid down in IS 1121 to 1126 and IS: 8605 – 1977 (Reaffirmed 2013). Stones shall be hard, dense, durable, tough, sound and clean. They should be free from decay, weathered faces, soft seams, adhering coatings, sand holes, veins, flaws, cracks, stains and other defects. Stones shall have, as far as possible, uniform colour and texture. Stones not uniform in colour, texture and/or with stains may be permitted after proper tests.

- b) **Size:** The size of stones shall normally vary from 0.05 to 0.01 m³. The stone shall be taken from quarries approved from geological and engineering considerations. No stone shall weigh less than 25 kg. The stone used in the hearting shall be roughly cubical in shape. No stone weighing between 75kg and 150kg shall be less than 225 mm and no stone weighing between 25kg to 75kg shall be less than 150 mm in any direction.
- c) **Spalls:** Spalls with the minimum dimension of 200 mm to 100 mm shall be used to wedge in to the interstices of stones. They shall not, normally, exceed 10 percent of the volume of colgrout masonry.

3.3.2 Stones for Coursed Face Work

The height of stone for exposed face work shall be uniform and recommended to be 300mm including mortar joint. The length and depth of face stone shall not be less than the height of the stone. At least 50% of stones shall have length more than twice the height of the stone. At least $\frac{1}{3}$ of the remaining stones shall be bond stones projecting not less than $2\frac{1}{2}$ times the height in to the masonry. The remaining shall be header stones with depth not less than $1\frac{1}{2}$ times the height of the stone. The stones shall be hammer dressed on bed, top and sides for a minimum depth of 75mm up to which the stone shall be true and rectangular. Beyond 75mm depth, the stone may be tapered but the tail end of the stone shall have at least half the area of the face. Bushing on the face of the stones shall not project more than 40 mm.

Header stones – The header stones shall not be less than 300mm in length and one and half times the height in depth.

Stretcher stones – The stretcher stones shall not be less than 600mm in length and not less than its height in depth.

Bond stones – The bond stones shall not be less than 300mm in length and two and half times the height in depth.

Quoins – Quoin stones shall be of the same height as the face stones, but shall be true and rectangular on two faces with one line dressing for 75mm depth in beds and sides. The stones shall be at least 300 mm long on one face and 450 mm on the other face.

3.3.3 Stones for Uncoursed Face Work

The stones for uncoursed face work shall be selected stones meeting the requirement of stones for coursed face work masonry (refer 3.3.2) except that the stones shall be hammer dressed. The stones shall be nearly rectangular.

3.4 Water

Water used for mixing mortar, grout and also washing stones and curing masonry shall conform to the requirements of IS: 456 – 2000 (Reaffirmed 2016), due considerations being given to seasonal variation. It shall be reasonably clean and free from objectionable quantities of silt, organic matter, alkali, salts and other injurious materials. Turbidity of water for mixing mortar shall not be more than 2000 parts per million.

3.5 Fly Ash

Fly ash is generally finer than or as fine as Portland cement. An Indian Fly ash has specific gravity between 1.46 to 2.66 and fineness between 2000-6000 cm^2/gm with main chemical constituents as SiO_2 (45% - 60 %), Al_2O_3 (10% - 20%) and Fe_2O_3 (4% - 6%) which are responsible for its pozzolanic activity. Besides these, it contains small amount of un-burnt carbon, CaO, MgO and SO_3 . Fly ash is alkaline in nature and safe against corrosion. Fly ash is non-plastic, although liquid limit is high. Fly ash does not show excessive swelling or shrinkage. It gives value of angle of friction of about 30 - 35 degrees. Generally, it is a freely draining material.

One of the most important parameters which govern the use of fly ash for various applications in construction is its pozzolanic reactivity. Its measure is Lime Reactivity value. As per the established data, the hydration of Ordinary Portland Cement yields approximately 75% strength rendering mineralogical phases. The balance 25% is liberation of Ca(OH)_2 which is vulnerable for deleterious effects rather than contributing for the strength and impermeability. The same Ca(OH)_2 is a resource for pozzolanic reaction of fly ash to form secondary mineralogical phases contributing additional strength, more or so at later ages. Thus, curing period of construction shall be extended beyond 21 days. The Lime reactivity of Indian fly ashes, generally, varies between 3.5 to 6.5 N/mm^2 . Reactiveness depends on fineness of fly ash – higher the fineness, more reactive the fly ash.

Fly ash is used as an admixture/part cement replacement to improve the properties of mortar. It reduces water requirement, improves the workability and improve strength at later days due to pozzolanic property. Construction cost can be reduced by part replacement of cement by fly ash. Fly ash shall be collected as per IS: 6491 – 1972 (Reaffirmed 2016), tested in accordance with IS: 1727 – 1967 (Reaffirmed 2013) and shall conform to the following limits of physical and chemical requirements for use in mortar/ concrete as laid down in IS: 3812 (Part I) – 2013 (Reaffirmed 2017).

Table no 3 : Physical and chemical requirements of fly ash

Sr. no.	Properties	Permissible limits
	Physical properties	
1	Fineness	> 3200 cm ² /g
2	Lime Reactivity	> 40 kg/cm ²
3	Cement reactivity	> 80% of cement mortar
	Chemical contents	
4	Silicon Di-oxide (SiO ₂)	Min. 35%
5	Magnesium Oxide (MgO)	Max. 5%
6	Sulphur Tri-oxide (SO ₃)	Max. 5%
7	Silicon Di-oxide(SiO ₂) + Aluminum Oxide(Al ₂ O ₃) + Iron Oxide(Fe ₂ O ₃)	Min. 70%
8	Loss on Ignition	Max. 5%
9	Sodium Oxide (Na ₂ O)	Max. 1.5%

Based on the results of laboratory studies at M.E.R.I., Nashik, WRD, GoM vide circular no. MISC 1105/ 2606/ (630/2005) MP-1 dated 19-06-2006 directed to use 20% cement replacement by fly ash in colgrout masonry and concrete of dams and massive structures. However, before application, fly ash shall be get tested for its conformity as per Indian Standard and exact percent of cement replacement by fly ash, depending upon its pozzolanic reactivity, determined by mortar mixing test.

Worldwide it is proven fact that fly ash mortar attains its full strength up to 90 days in comparison of 28 days strength of cement mortar. Since hydration process of cement is longer in fly ash mortar, fly ash is most suited for mass works. These works are of the nature of not fully loaded even after 90 days. The structures which are not expected to develop early strength or structures which can not put to use immediately (say up to 3 months) after its casting, the percentage replacement of cement can go up further.

Part replacement of cement by fly ash in colgrout masonry shall be used only with Ordinary Portland Cement and not with Portland Slag cement or Portland Pozzolana cement or Super sulphated cement as they already contains pozzolana.

In colgrout application, fly ash shall be mixed by weight with cement and water in first drum of colgrout mixer. Fly ash colgrout masonry must be cured for longer period, improper curing damages the masonry.

3.6 Admixture

The admixture including pozzolana, air entraining agents, wetting agents, etc. shall be used only under specific authorization and wherever so permitted; proportions and methods of use shall be specified by engineer-in-charge. The chemical admixture shall be tested as per IS: 6925 - 1973 (Reaffirmed 2013) for chloride ion content and as per IS: 9103 – 1999 (Reaffirmed 2013) for relative density and pH value and conform to IS: 9103 – 1999 (Reaffirmed 2013).

Materials permitted as admixtures shall have established merit for improving any specific quality of the mortar without causing deleterious effects. They are aids to help modify good mixes and good construction practices to achieve certain specific requirements.

Exact proportion of admixture to be added shall be ascertained by carrying out mortar mix design.

4.0 EQUIPMENTS AND TOOLS

4.1 Equipments

4.1.1 Colgrout mixer

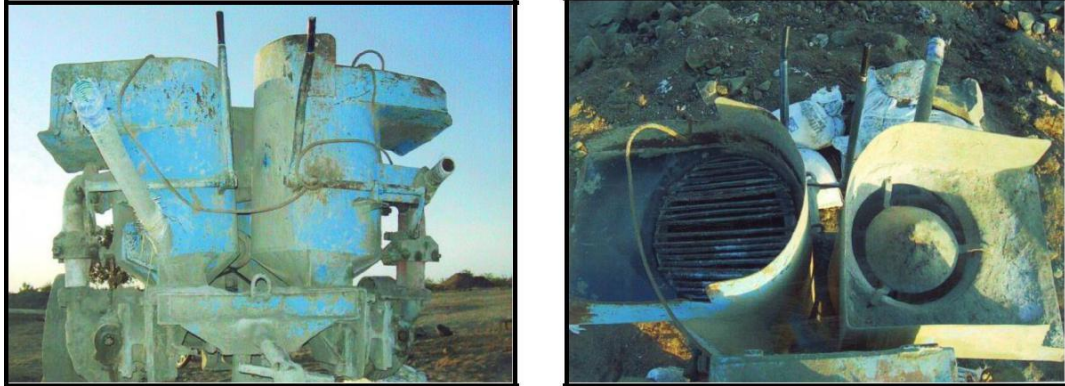


Photo no.1: Colgrout double drum mixer – side and top view.

Double Drum Mixer consists of two mixing units and a power unit mounted on a suitable chassis. Each mixing unit consists of a hopper tank connected by means of a trap to a casting similar to that of a centrifugal pump.

The first mixing unit produces water + cement slurry which transferred to the second unit where sand is added to produce a Cement + Water + sand grout. In the body of the cement mixing unit, a solid rotor disk rotates at the speed of 1500 to 2000 rpm in close proximity to the stator. This rotor produces a pumping action which induces water + cement slurry to pass at high speed through the narrow gap between the rotor and the stator. It also causes a rapid circulation through the hopper tank where a strong vortex is formed and it serves to transfer the slurry to the other mixing unit.

The rotor in the sand mixing unit is in the form of a star designed for wetting the sand with the cement + water slurry and also for discharging the colgrout at a suitable pressure through a hose. Means are provided in each hopper tank to cause the cement or sand to fall evenly in to the vortex which ensures that materials may be charged rapidly. Water is gauged by a separate water measuring tank or meter. The water/cement ratio is under definite control, allowance being made for moisture in the sand.

Whilst the sand being added to one mix of cement slurry in the second mixing unit, following cement + water mix is being made in the first unit. The mixer is, therefore, in semi-continuous batch operation. The complete mixing cycle takes from 60 to 90 seconds, depending upon the method of charging. No improvement in mixing efficiency will be gained by increasing the mixing time. The standard models deal with a mixed volume of either 4 cu. ft. (0.11 cum) or 8 cu. ft. (0.22 cum).

4.1.2 Colgrout Flow Meter -

This apparatus is used to determine and maintain the fluidity of the colgrout at the mixer. Its use ensures that the colgrout is of the correct consistency for the purpose required and it provides a very quick method, requiring no special skill, of checking that the water and sand contents of the mix are constant.

Flow meter consists of a sheet metal channel fitted with a spirit level, a graduation in centimeters, a tundish & pug and a quart measure.



Photo no. 2 : Colgrout flow meter

Flow meter is wetted, allowed to drain for a minute and set up level. A quart measure of colgrout is placed in to the tundish and pug is withdrawn. The point to which colgrout flows is read.

Generally, flow meter reading should be 60 to 70cm for colgrouting by gravity penetration, 50 to 60cm for underwater work and 40 to 50cm for upward penetration of mass work. Since, upward penetration method is used for colgrout masonry, the consistency of colgrout mortar shall be within 40 to 50 cm.

4.2 Construction Tools

The tools used by mason for construction of colgrout masonry are as below:-

- (1) **Trowel** – This is used for spreading mortar and is similar to the bricklayer's trowel.
- (2) **Square** – This is made of flat iron and each arm is about 50 cm long. It is used in setting out right angles.
- (3) **Bevel** – This is made of two blades of iron slotted and fastened with thumbscrew.
- (4) **Spirit level** – This is used for checking the horizontality of masonry courses.
- (5) **Plumb rule and bob**- This is similar to a bricklayer's plumb rule and is used to check the verticality of walls.
- (6) **Mallet** - This is a wooden headed hammer and is used for driving wooden headed chisels.
- (7) **Iron hammer** – This is used for carving stones.
- (8) **Pick** – This has a long head pointed at both ends. This is used for rough dressing of granites.
- (9) **Spalling hammer** – This is a heavy hammer used for rough dressing of stones in the quarry.
- (10) **Chisels** – They are used with mallets and with hammers. They have got different shape and have pointed heads.
- (11) **Claw tool** - This has an edge with a number of teeth from 3 mm to 9 mm width and is used for dressing the surface of stones.
- (12) **Pitching tool**- This has a long edge with a thick head and is used for reducing the size of stones.
- (13) **Jumpers**- These are sued for boring holes.
- (14) **Wood handled chisels** – These are sued for dressing soft stones.
- (15) **Wedge and feathers** - These are small conical wedges and curved plates. They are used for cutting the stones after they have been bored with a jumper.
- (16) **Gads** – These are small iron wedges for splitting of stones.
- (17) **Saws** – These may be double saw, a framed saw or a hand saw. They are used for cutting stones with hands.
- (18) **Mason's hammer** - This is a medium hammer used for dressing of stones used by masons at pre-packing the stones.

5.0 COLGROUT MORTAR

5.1 Colgrout mortar

Normally, the speed of mixer is about 20 to 30 rpm in conventional concrete/ mortar preparation. At this speed, some of the cement particles get in contact with water and stick together forming large particles. They are like minute particles of sand and do not take part in binding the fine and coarse aggregate together. In other words, only a part of cement quantity is useful in binding the aggregates in a strong mass.

When speed of mixing is increased to 1500 to 2000 rpm, the air around the cement particles get removed by the high speed shearing action of the mixer and cement with water form a uniform paste which remain stable because the force of attraction between cement particles and molecules of water, prevent separation of cement. It has some colloidal characteristics resulting from the maximum gel formation of the cement. This makes it nearly immiscible in water and reduces bleeding to a minimum. This paste is called as 'gel' or 'slurry'. When this slurry is mixed with sand in separate drum with high speed, the mortar produced is in colloidal grout form, called as 'colgrout mortar' or simply 'colgrout'.

Gammon India Ltd., first time in India, manufactured special type of mixers called as colgrout mixers which has two mixing drums having mixing speed of 1500 to 2000rpm. Details of the mixer are given in 4.0.

This colgrout mortar has some ejecting force due to high speed mixing. Its stability and fluidity permits it to be passed through delivery pipe of colgrout mixer at considerable distance and inserted at the bottom of pre-packed stones until the mortar comes at the surface. The resultant homogeneous masonry is known as Colgrout Masonry. Its impermeability index is high and attains high strength in comparison with UCR masonry.

5.2 Mortar proportion

The colgrout mortar shall consist of cement, sand and approved admixtures as required, each complying respective specifications in accordance with clause 3.1 to 3.6.

All materials forming the mortar should be measured by mass except for water which may be measured by mass or by equivalent volume. Where weigh-batching is not possible, due consideration to bulking of sand and its water content shall be given. It is normally be regulated in accordance with IS:2386(Part III)-2016 as under:

Table no. 4: Bulking of sand

Bulking observed	Additional volume of sand to be added
Below 5%	Nil
5 to 10%	5%
10 to 15%	10%
15 to 20%	15%
Above 20%	20%

The proportion of cement and sand for colgrout mortar is recommended as 1:3. The real criterion governing the mix will be the strength specified and actual proportion of the ingredients to give the requisite strength and impermeability. Mortar mix tests shall be carried out in the project laboratory well in advance.

5.3 Water cement ratio

It is important to maintain the water-cement ratio constant at its correct value. The quantity of water shall be as less as possible just enough to make mortar sufficiently viscous to penetrate and fill the voids in the pre-packed stones. Trial mixes shall be run at the project laboratory for obtaining the desired flow with the help of following table.

Table no. 5 : Water cement ratio and water requirements for trial mortar mix.

Cement : sand proportion	Water/Cement ratio	Water for 50 kg cement in litres
1 : 2	0.62 – 0.70	31 - 35
1 : 3	0.76 – 0.84	38 - 47

Moisture content of sand shall be taken in account while fixing the quantity of water. The moisture content of sand shall be tested in accordance with IS:2386 (Part III)-1963 (Reaffirmed 2016). The surface water carried by the sand is normally as below:

Table no. 6 : Moisture content of sand

Sand	Approximate quantity of water	
	% by mass	Litre/m ³
Very wet sand	7.5	120
Moderately wet sand	5.0	80
Moist sand	2.5	40

5.4 Preparation of mortar

- a) **Type of mixer:** Colgrout double drum mixer shall be used.
- b) **Placement of mixer:** Colgrout mixer shall be placed at higher elevation, preferably 2.0m and above, from top level of compartment for getting additional gravity flow to colgrout.
- c) **Wetting of mixer at the start of work:** At the starting of work, the mixer shall be wetted firstly by water, then by cement slurry and passed through delivery pipe for priming and lubricating the system.
- d) **Quantity of water and sand:** Requisite quantity of water is taken in the calibrated water tank attached with mixer. Measured quantity of sand is kept ready.
- e) **Mixing of cement & water:** Measured water is taken in first drum and cement (or cement + fly ash in case of fly ash colgrout mortar) is poured. First drum is mixed for 15 to 20 seconds and mix is transferred to second drum by opening the trap between the drums by the lever arm.
- f) **Addition of sand:** Measured quantity of sand is poured in the mix in second drum and allows the mixing for 40 to 60 seconds.
- g) **Measure of consistency of mortar:** Open the exit pipe of second drum by lever arm. Take a quart of colgrout and measure the flow by flow meter. If consistency is satisfactory (i.e. between 40 to 50cm), place the delivery hose pipe in pre-packed stones for starting the work. Otherwise, discard the mix outside the work place and prepare another mix by adjusting the proportion to get required consistency.

Consistency of colgrout mortar is an important parameter which influences the strength and durability of colgrout masonry.

h) Total time for complete cycle of mixing: The total mixing time for the complete cycle shall normally be 60 to 90 sec. The mixing time shall be increased at the discretion of the engineer-in-charge when operation fails to produce the required colloidal ness or uniformity of composition within the batch and batch to batch.

5.5 Time for use

Colgrout mortar shall be used in the masonry within the time specified for initial set. Any colgrout mortar which has not been used within the time specified or mortar which has set or hardened shall be considered unfit for use and removed from the work site.

6.0 COLGROUT MASONRY

Before laying colgrout masonry, it shall be ensured that the preparation of foundation/ old colgrout masonry/ concrete surface is completed as given in 6.15. The structure shall be built to line, plumb or curved or as directed in a workman like manner. Suitable aids like templates, formworks etc. shall be used. In case of opening, the concrete of appropriate grade shall be used instead of colgrout masonry.

6.1 Monolith

The dam shall be longitudinally divided into monoliths of suitable sizes as shown in the drawing or as directed by the engineer-in-charge. Smooth joints shall be provided between two adjacent monoliths. For this purpose, the vertical surface of the monoliths constructed first shall not have a face projection above 15mm and should be provided with smooth plaster in cement mortar 1:3 of minimum thickness of 20mm. The difference in level of masonry lifts should not, normally, be more than 1.5 m.

6.2 Partition wall compartments

Colgrout masonry shall normally be constructed in compartments of different size and shapes so as to avoid continuous horizontal and vertical joints in the body of dam. Area of each compartment shall be so fixed that it can be colgrouted in one shift of working.



Photo no. 3 : Partition wall compartments for construction of colgrout masonry

The area of compartments shall not be more than 25 to 30 sqm and height not exceeding 1.0m. Compartments shall be in staggered manner. At each lift, position of wall compartment shall be changed so that compartment of consecutive lift shall not be overlapped. For Upstream & Downstream faces of the dam utmost care shall be taken. Face work may be in wall compartment fashion or in colgrout masonry using shuttering.

6.2.1 Partition walls

Partition walls on all four sides of compartment shall be 45 cm thick UCR masonry without regular face work, height not exceeding 1.0m and in mortar proportion as used in colgrout masonry. They act as a shuttering for colgrout masonry and later become integral part of colgrout masonry. Adequate header and stretcher stones shall be provided for ensuring horizontal and vertical bond with the colgrout masonry. The minimum number of headers shall be at the rate of one per square meter of face work. Masonry walls shall be constructed in accordance with IS: 1597(Part I) – 1992 (Reaffirmed 2016) and P.W.D. Handbook Chapter no. 2 “Masonry works”.

6.3 Face work

The upstream and downstream face work may be constructed either in wall compartment fashion or using shuttering. The outer face wall shall consist of stones hammer-dressed on face and one line chisel dressed on bed, top and sides for 75mm from the front face built with the course normal to the face batter. The work shall be in parallel courses of uniform thickness. In each course, stones shall be in header and stretcher fashion and joints shall be broken in courses above and below by at least half the height of the course. In case of uncoursed rubble masonry, the header stones shall be placed at about 1m centre-to-centre. The joints in face work shall be as minimum as possible and not be thicker than 15mm for single-line chisel-dressed stones or 20 mm for hammer dressed stones.

Bond stones in each course shall be so provided that every sixth stone or third header stone is a bond stone. In case of uncoursed face work, the bond stones shall be placed at about 2.5m centre-to-centre. The bond stones shall be staggered and marked for identification. The face masonry shall preferably be constructed simultaneously with hearting masonry.

6.3.1 Pointing to face work

The face work shall be struck neatly and smoothen off with a trowel before the mortar takes the final set.

All pointing shall be finished with cement sand mortar 1:3 or richer mix. The sand shall be fine, passing through 600-micron IS sieve (see IS: 460 – 1985 (Reaffirmed 2013) and conforming in all respects to IS: 2116 – 1980 (Reaffirmed 2017)).

The joints in masonry to be pointed shall be raked square, for a minimum depth of two times the thickness of the joint within 24 hours of laying masonry. In special circumstances, this period may be released to 48 hours. The refilling and pointing shall be done within three days of raking of the joints so as to ensure good adhesion between the two mortars.

The joints shall be finished neat, defined, regular and of uniform width. The joints may be filled either flush or raised as required. The surface pointed should be kept wet for 21 days after pointing is completed.

6.4 Form works:

6.4.1 Formwork fixing and general

Forms, wherever required, to confine the colgrout masonry and shape it to the required line shall be used. The forms shall have sufficient strength and rigidity to hold masonry and sustain the pressure of colgrout mortar being injected without excessive deflection from prescribed lines. The tolerance of line and level shall not exceed 3mm. Form work made up of only steel shuttering shall be allowed. It should be free from warping and fabricated true to line and shape. The inside surface shall be clean, rigid, watertight, smooth and free from dirt, shavings, chippings or other foreign matter. Inner surface shall be treated with a suitable non-staining oil to prevent adherence. Suitable devices shall be used to hold corners, adjacent ends and edges of panels of other forms together in accurate alignment. They shall be reusable and shall be checked for line, shape and strength before reuse.

Care shall be taken to see that all forms are in proper alignment and the supports and fixtures are thoroughly secured and tightened. The forms shall fit tightly so as to prevent leakage of slurry from the masonry.

6.4.2 Removal of formwork

Removal of forms shall never be started until colgrout is thoroughly set and hardened adequately to sustain its own weight and live load, if any. Heavy load shall not be permitted until after the colgrout masonry has reached its final set. In normal circumstances, shuttering shall be struck on expiry of 48 hours from injection of colgrout mortar. Where formwork is used, all faces of masonry shall be smooth and sound, free from voids and air holes when formwork is struck. Any roughness or irregularity on the exposed surface shall immediately filled up while masonry is green, with cement mortar 1 :1½, properly trawled and finished. Such patching of surface shall be carried only with permission of engineer-in-charge.

6.5 Laying stones in compartment and workmanship:

6.5.1 Stones to be wetted

Stones and spalls shall be thoroughly moistened by wetting before being laid. Saturation of stones shall be ensured before insertion of colgrout mortar. Otherwise fluidity of mortar is reduced due to absorption of some of the water of the mortar mix by the stones.

6.5.2 Dressing of stones

The stones shall be placed in the work after knocking off weak corners and edges with a mason's hammer and after clearing scales of foreign matter, if any.

6.5.3 Laying

- a) **Stones:** Stones shall be placed manually and interlocking in a layer in the compartment so that bigger dimension is along horizontal plane and they may not act as wedge and force out the adjutant Stones. If stones once kept in position are to be adjusted, they shall be lifted clear and reset; they shall not be moved one over the other.



Photo no. 4: Laying of stones in compartment

Headers - Adequate headers shall be provided for proper horizontal and vertical bond with next surrounding layers. The minimum number of headers shall be more than one per 4 sqm area to be bonded.

Stretcher stones (pin headers) - A row of vertical pin headers shall be erected at about 2m centre to centre both ways so that there is at least one vertical stone for every 4 sqm area or as directed by the engineer-in-charge for the bond with next lift.

- b) Spalls:** Stone spalls of 200mm to 100mm size shall be wedged in to the interstices between the adjacent stones whenever necessary to avoid thick beds or joints and to achieve maximum density. Use of chips shall be restricted to the filling of interstices only. There shall be a good collection of chips within easy reach of each mason to enable proper selection for laying and they should be kept continuously replenished.
- c) Layers:** The thickness of layer shall normally be 35 cm. Such layers shall be continued to be arranged till the predetermined height of the compartment or panel is reached.

d) Placing of G.I. Pipes: 75mm diameter perforated GI pipes shall be placed at 1.5m center to center (or at least one pipe per 2.15 sqm area) or as directed by engineer-in-charge and about 25mm above the bottom while pre-packing the stones. Pipes shall be withdrawn simultaneously as colgrouting of each hole is in progress.

6.6 Mortar injection

The colgrout mortar shall be injected by upward penetration method through each perforated GI pipe placed in pre-packed stones. The insertion of mortar shall proceed from one end in direct sequence so as to achieve uniform height of the mortar in all pipes in any section of colgrouted masonry and GI pipe shall be withdrawn as hole is getting filled up.

The mortar shall not be brought up to the top level of the stones, but to about half the height of the top stones so as to ensure a good key for next lift.

6.7 Construction schedule

Colgrout masonry should invariably be done during day light hours.

6.8 Limit of height of masonry in a lift

The maximum height of masonry lift allowed to be constructed in one working shift shall not exceed 1.0 m. No fresh masonry shall be laid over the previous lift within 24 hours of its being laid.

6.9 Quantity of colgrout mortar in masonry

Every effort shall be made to see that proper quantity of colgrout mortar is used. The acceptable quantity of colgrout mortar shall normally be 40% to 45% by volume of masonry laid.

6.10 Colgrout masonry in U/S septum

When colgrout masonry is used in upstream septum of dam only, the hearting masonry downstream side of the septum shall be constructed first. Adequate protruding headers shall be provided in hearting masonry for proper horizontal bond with colgrout masonry in the septum so that question of separation of U/S septum from the hearting masonry does not arise.

6.11 Cleaning of laitance

On filling the compartment, the slurry shall be made rough by rods, punjas, wire brushes etc. It shall be ensured that all the smooth surfaces are roughened. The laitance that comes to the surface after initial setting shall be cleaned out by wire brush and removed by water jetting the surface.

6.12 Protection of fresh masonry

Fresh masonry shall be protected against vibrations, any other movements and rains which might injure it before its final set. Curing shall be started after 4 to 12 hours of construction. Stones shall not be dumped over the fresh masonry.

6.13 Curing

Curing is the process of preventing the loss of moisture from the masonry whilst maintaining a satisfactory temperature regime. The curing also prevents the development of high temperature gradient within the masonry. Exposed surface of the masonry shall be cured after 4 to 12 hours of construction. All colgrout masonry as it progresses, shall be kept continuously moist on the entire surface for a minimum period of 21 days from the date of its being laid. Masonry shall, on no account, be allowed to present dry surface during curing period. Should the mortar perish i.e. become dry or powdery through neglect of watering, the relevant work shall be demolished and rebuilt.

Curing is, particularly, important when pozzolana, slag or supersulphated cement is used as their hydration period is longer.

6.14 Defective work

If any portion of colgrout masonry is found to be defective either in materials or in construction, it shall be removed and rebuilt.

6.15 Preparation of foundation.

6.15.1 Colgrout masonry in contact with rock foundation

a) Cleaning of the foundation

After completion of rough excavation of foundation, scaling and trimming for final removal of all scabby or drummy rock or any loosened mass shall be done by chiseling, picking, barring and wedging. Any weathered or decomposed rock

remaining should be removed, the doubtful areas cleaned out to sufficient depth and back-filled with concrete or masonry in richer mortar. If foundation conditions required, consolidation grouting may be carried out after laying one lift of colgrout masonry.

Final prepared foundation shall present rough surface in cross section to give added assistance to binding, all smooth surface shall be roughened artificially. Surface shall be free from steep angles. Edges of benches shall be chamfered or sharp edges shall be knocked off and prominent knobs flattened out. Neither along the length nor across the dam shall foundation normally have a slope in excess of the angle of friction between the rock and masonry.

Foundation, finally, should be cleaned, by jets of water and air at high pressure and/or sand blasting followed by thoroughly washing. All corners, crevices and joints shall be cleared of all dirt clinging to them. The pressure jets of water shall not be less than 15 meter and air pressure shall not be less than 5 kg/cm². The nozzle shall be of approved design. The washing and scrubbing by stiff wire brushes shall be continued until all deleterious material is removed and clean water flows. All water is removed by using sponge.

b) Bottom layer

Immediately prior to placing a layer of masonry, the foundation shall be wetted for 24 hours. Foundation shall be coated with brush by thick cement slurry (1 cement : 2 or 3 water by volume) just few minutes before laying the masonry. The slurry shall be spread only on a small area of about 1.0 m² at a time. A layer of mortar 50 to 75mm thick, shall be spread over the slurry and worked into all irregularities of the rock surface by trowels, bars or brushes. The composition of this mortar shall be same as used in colgrout masonry work. The first course of stones shall be carefully interlocked and pressed into the mortar so as to force the mortar around the corners. The layer of mortar shall be made thicker, if required, to suit stones of sizes larger than 0.06cum. The voids of this stone packing shall be filled with smaller stones and chips. The colgrout mortar shall be filled by means of nozzles or any other approved method as directed by engineer-in-charge.

6.15.2 Colgrout masonry in contact with fresh colgrout masonry

Surface of masonry shall be treated as follows before laying fresh masonry over it. Loose stones, if any, shall be removed. Mortar joints shall be scraped with iron rods and the exposed faces of stone shall be wire brushed. The surface shall be cleaned with air-water jet. The water collected in the depressions of masonry shall be removed by sponge or cloth. Older surface shall be coated with brush by thick cement slurry (1 cement: 2 or 3 water by volume) just few minutes before laying the next lift.

6.15.3 Colgrout masonry in contact with old colgrout masonry

Surface of masonry which has been exposed for more than three calendar weeks or beyond curing period or over which the flow of water is permitted and to which new masonry is to be bonded shall be treated as follows. Loose stones, if any, shall be removed. Mortar joints shall be scraped to a depth of 15 to 25mm or wet sand blasted and washed with air-water jet. Immediately prior to placing of new masonry, the old masonry surface shall be treated in the same way as for rock foundation described in 6.15.1.

6.15.4 Colgrout masonry in contact with concrete

Concrete surface, which has hardened shall be roughened by chipping to a depth of 25 mm to 40 mm so as to remove top mortar film and get a rough surface for starting masonry and surface shall be treated in the same way as for rock foundation described in 6.15.1.

6.16 Precautions to be taken during colgrout construction

Apart from the specification of materials, mixing methodology and construction technique, following precautions shall be taken to make good colgrout masonry.

- i. Stones shall normally be of 0.05 to 0.01 m³ size and saturated before colgrouting. Care shall be taken while construction of face works.
- ii. Spalls shall be wedged in to the interstices between adjacent stones and they shall not exceed 10% of the volume of colgrout masonry.

- iii. Maximum size of sand shall be less than 4.75mm having fineness modulus within 2.6 to 3.0. If necessary, sand shall be get screened. Sand shall be weigh batched. Moisture content shall be determined and accordingly water content shall be fixed for every shift.
- iv. Cement shall be weigh batched. It shall be used within 3 months from the date of manufacturing; else fresh mortar mix design shall be done to get required properties of mortar.
- v. Water shall be volume batched and conform to IS: 456-2016.
- vi. Area of masonry wall compartment shall be of 25 to 30 sqm with height not exceeding 1.0m so that construction can be completed in one working shift only. At each lift, position of wall compartment shall be changed so that compartment of consecutive lift shall not be overlapped.
- vii. Only double drum colgrout mixer should be used for preparing colgrout mortar. The speed of mixer should be 1500 to 2000rpm and it shall be checked frequently. This is the special important phenomenon in preparation of colgrout mortar. Mixer shall be rotated until the colloidal state is reached
- viii. The mixer shall be placed 2.0m and above height above the level of compartment. The delivery pipe of the mixer shall be straight and have uniform slope towards compartment. Sagging of pipe is avoided; else it reduces the delivery pressure of mortar.
- ix. The mortar of requisite flow should be permitted to pass in the compartment.
- x. At the start of the work, mixer shall be wetted and first load shall be made of cement slurry only for priming and lubricating the mixer and delivery pipe.
- xi. At the end of work, the mixer and delivery pipe shall be cleaned by cement slurry which carried the sand particles adhered and then washed by the water. The cement slurry may be passed in the compartment, but the waste water should be taken outside the construction area.
- xii. If chocked, the delivery pipe shall be cleaned by forcing water and these waste contents should be passed outside of the construction area.
- xiii. The insertion of mortar in the compartment shall proceed from one end in direct sequence so as to achieve uniform height of the mortar in all perforated GI pipes in any section of colgrouted masonry and pipes shall be withdrawn as hole is getting filled up.

- xiv. Care should be taken to avoid any type of activity on the top of fresh masonry constructed at least for 24 hrs.
- xv. All colgrout masonry as it progresses shall be kept continuously moist on the entire surface for a minimum period of 21 days from the date of its being laid. Masonry shall, on no account, be allowed to present dry surface during the curing period.
- xvi. Samples of the materials shall be collected and tested regularly as per respective Indian standards. Mortar tests shall be regularly carried out and review of results shall be taken periodically.

7.0 WORK TESTS ON MATERIALS, MORTAR AND MASONRY.

7.1 Tests on materials

7.1.1 Cement

One sample per 50 ton cement shall be collected for testing in accordance with IS: 3535 – 1986 (Reaffirmed 2013). Ordinary Portland cement, Portland slag cement, Portland pozzolana cement and Super sulphated cement shall be tested in accordance with IS: 4031 - 1996 (Reaffirmed 2016) and shall conform to IS:8112-2013 for 43 grade and IS:12269-2013 for 53 grade, IS: 456 – 2000 (Reaffirmed 2016), IS:1489-2015 and IS: 6909 – 1990 (Reaffirmed 2016) respectively.

7.1.2 Sand

Sand samples from the work site shall be collected in accordance with IS: 2430 – 1986 (Reaffirmed 2014) and shall be tested as per IS: 2250 –1981 (Reaffirmed 2015) and IS:2386 (Part I to VII)-1963 (Reaffirmed 2016) regularly to test its quality. One sample of every 500 cum of colgrout masonry or one sample in a week whichever is earlier shall be tested. If sand is measured by volume, bulkage of sand shall be tested per shift.

7.1.3 Stones

Samples of stone from approved quarry or new quarry shall be tested for compressive strength in accordance with IS: 1121 (Part-I) -1974 (Reaffirmed 2017). The compressive strength shall be conducted with the load parallel to the bedding plane and also perpendicular to the bedding plane. The stone samples shall also be tested for water absorption in accordance with IS: 1124 –1974 (Reaffirmed 2017), and for soundness in accordance with IS: 1126 – 2013 to ensure suitability of stones for masonry.

7.1.4 Fly ash

Fly ash samples shall be collected as per IS: 6491 – 1972 (Reaffirmed 2016), tested for its physical properties as per IS: 1727 – 1967 (Reaffirmed 2013) and chemical properties as per IS: 4032 – 1985 (Reaffirmed 2014) before use. Fly ash shall conform to IS: 3812 (Part I) – 2013 (Reaffirmed 2017), the permissible limits of physical and chemical properties are given in para 3.5 above. During construction, one sample per 50 ton of fly ash shall be tested.

7.1.5 Chemical Admixture

Chemical admixture shall be tested as per IS: 6925 - 1973 (Reaffirmed 2013) for its chloride content for each drum of admixture to be used at site.

7.1.6 Water

Water shall be tested in accordance with IS: 456 – 2000 (Reaffirmed 2016) per season or as directed by the engineer-in-charge.

7.2 Tests on Colgrout Mortar

7.2.1 Flow meter tests

Minimum three flow meter tests shall be taken per mixer per working shift. The records of tests shall be maintained in a separate register.

7.2.2 Use of RPM sensor

The solid rotor disk of colgrout mixer rotates at the speed of 1500 to 2000 rpm. These rotations shall be checked by Tachometer. These rpm can be measured by RPM sensor, jointly attached to the colgrout mixer such that if required rpm is achieved then colgrout mixer is ready to function.

7.2.3 Weigh batcher for mortar

Weigh batcher can be attached to colgrout mixer. With the help of this weigh batcher, materials like cement, sand, admixtures (if any) and water are weighted and then mixed.

7.2.4 Tests on Mortar cubes

Tests on mortar shall be regularly conducted on 15cm size cubes and shall comprise of compressive strength and permeability at 28 days age.

7.2.4.1 Frequency of sampling of cubes: For work tests, mortar samples shall be taken at placement location for every 100cum of colgrout masonry work per day at one sample per mixer per shift and for every additional 100 cum masonry work per day at one sample per mixer per shift. At the time of each sampling, three cubes of 15cm size shall be cast.

7.2.4.2 Curing of cubes: Cube moulds shall be placed in 90% relative humid environment or under wet gunny bags in a closed room for 24 hours. Then cube moulds are de-moulded. Cubes are submerged in clean water and keep there until just prior to testing. Renew the water every 7 days and maintained the temperature at $27^0C \pm 2^0C$. The curing tank shall be in closed room, away from sunlight.

7.2.4.3 Tests: Cubes shall be tested in surface saturated dry condition. They should neither tested in wet condition nor allow becoming dry. Test for compressive strength and permeability at 28 days shall be conducted as per IS: 2250 –1981 (Reaffirmed 2015) and IS: 3085 - 1965(Reaffirmed 2016) respectively. Record of test results shall be kept in separate register. Where specimen of different sizes is used such as 15cmx30cm cylinder, necessary correlation shall be applied.

7.2.4.4 Standard of Acceptance

Strength The strength at 28 days of one sample shall be taken as average of at least three test specimens taken from single batch of mortar, provided individual strength of three specimens are within $\pm 15\%$ of average strength. If individual specimen result differs by $\pm 15\%$ of average strength, average of remaining two specimens shall be taken. If results of two specimens differs $\pm 15\%$ of the average strength, the sample result shall be rejected from the analysis. Over a given period of time as specified by the engineer-in-charge, not more than 10% of specimens tested shall have a compressive strength less than 80% of the required strength and average of all tests shall equal or exceed the required strength. Test samples shall have strengths equal or higher than the strength stipulated below:

Table no. 7: Standard of acceptance of strength of mortar

Sr. no.	Proportion of Cement : sand in colgrout mortar	Compressive strength in kg/cm^2 of 15cm size cubes at 28 days	
		Lab. Strength	Field strength
1	1 : 2	190	153
1	1 : 3	150	117

Permeability

Permeability of mortar as used on work shall not give a coefficient of permeability greater than 2.5×10^{-8} mm/sec when tested as per IS: 3085 - 1965(Reaffirmed 2016).

7.3 Tests on Colgrout Masonry

7.3.1 In-situ permeability



Photo no. 5 : Drilling of hole and testing for in-situ permeability

In-situ permeability shall be carried out as per IS:11216 -1985 (Reaffirmed 2013) on constructed colgrout masonry.

Test holes of 76 mm diameter and appropriate depth (say 4 to 6m) shall be drilled on the built up colgrout masonry after 28 days hardening. Every monolith, where fresh masonry is laid, shall be tested once every year. Drilling by rotary (diamond) drill shall be preferred in order to have least disturbance of the masonry already constructed. The hole shall be kept 300 to 600mm above the bottom level of the masonry to be tested. These holes shall be drilled vertically in two rows. One row shall be at 1.5m from axis of dam. The second row shall be at about one third of the width of dam from the rear face excluding the front impervious face. The holes shall be provided in staggered manner and it should be seen that at least one hole each in upstream and downstream portion in each monolith is provided. Holes may be closure if found necessary on the basis of the permeability test results. In locating the holes, position of any embedded parts, instruments, galleries and other opening shall be kept in view. The holes thus drilled shall be cleaned, filled with water and saturated for 48 hours.

The in-situ permeability shall be tested by double packers in stages of 1.50m or so, as directed by the engineer-in-charge. A grout pump or reciprocating pump of suitable capacity delivering the required pressure shall be used.

These holes shall be subjected to a water loss to determine lugeon value. Notwithstanding the test pressures specified for lugeon value, the actual test pressure should not be so high as to cause disturbance to masonry. Then assuming a linear variation of water loss with respect to pressure applied, the water loss in lugeon value may be interpreted. The details of procedure and test equipment reference may be made to IS:5529 (Part 2)-2006 (Reaffirmed 2015).

When a colgrout masonry septum is used on the upstream face of a conventional masonry dam, the upstream hole for water loss test shall be drilled at the center of the septum in each monolith.

Standard of impermeability shall be a water loss not more than 2.5 lugeons.

If the test results indicate water loss greater than the specified values, grouting should do as a remedial measure and confirmatory tests carried out. Grouting pressure should be kept such that it does not damage the constructed masonry.

7.3.2 Non destructive test by Ground Penetrating Radar:

Ground Penetrating Radar is a useful technique widely used in India. . It is non destructive technique to show the subsurface features inside the structure at maximum 1 meter to 2 meter depth. GPR uses radar technology to locate subsurface features in colgrout masonry. This technique shall be used on dam site. This technique is available at Non destructive lab.

7.3.3 Tests on drilled cores

Quality of in-situ colgrout masonry shall normally be tested by drilling the cylindrical cores of size 90cm dia. x 90cm height by using calyx drilling machine (IS:5529 (Part 2)-2006 (Reaffirmed 2015)). Drilling by rotary drill shall be preferred in order to have least disturbance of the masonry. Using 75mm diameter diamond drill bit, a hole shall be drilled at centre of core for testing permeability at laboratory.

7.3.3.1 Drilling and capping

Drilling: Drilling may be started after sufficient hardening of colgrout masonry, preferably after 90 days. Core of height more than 90cm shall be drilled.



Photo no. 6 : Drilling core by drilling machine at site

Capping of cores: Both end surfaces of the core shall be capped before testing. The capped surfaces shall be made plain with smooth finish. The capping shall be done with rich mortar 1:2 or M20 grade concrete. Caps shall be made as thin as possible and shall not flow or fracture before failure of specimen to be tested. The capped surface shall be cured for at least 14 days. The capped surfaces shall be at right angles to the axis of the specimen. The plainness of the caps shall be checked by means of a straight edge and feeler gauge making a minimum of three measurements on different diameters. Height of core shall not be less than 90cm after capping.

Procedure of capping:

- a) Erect the core on plain platform.
- b) Make core exactly vertical by using plumb-bob and wedges.
- c) Strip of 18 gauge GI sheet is rapped around the top end of core. Adjust the strip to have the requisite cap cover over the rough surface of core and tightened it by a movable circular ring.
- d) Top of GI sheet is made perfectly horizontal by spirit level and straight edge making of minimum of three measurements on different diameters.
- e) Finish the top surface in rich mortar 1:2 or concrete of M20 grade. The plainness of cap shall be checked by means of a straight edge and spirit level, making a minimum of three measurements on different diameters. Cap shall be made as thin and smooth as practicable.
- f) Cure the surface for 14 days and then capping is carried out for other end surface.

Necessity: Cap preparation is required to fit the faces of core in the jaws of compression testing machine without any gap and to exert the even pressure at any point on the core face while applying load for ultimate crushing of the core.

7.3.3.2 Frequency of cores to be drilled One core upto and for every 10,000 cum of colgrout masonry constructed during the season must be taken.

7.3.3.3 Tests: There is no specific Indian Standard available for testing of colgrout masonry. Therefore, usual tests done on concrete as per IS: 516-1959 (re-affirmed in 1999) are also performed on colgrout masonry.

7.3.3.3.1 Density - Density is obtained by measuring the volume of core and weighing the core. The density shall be more than 2.40 gm/cc.

7.3.3.3.2 Permeability – Drilled core shall be tested for laboratory permeability.

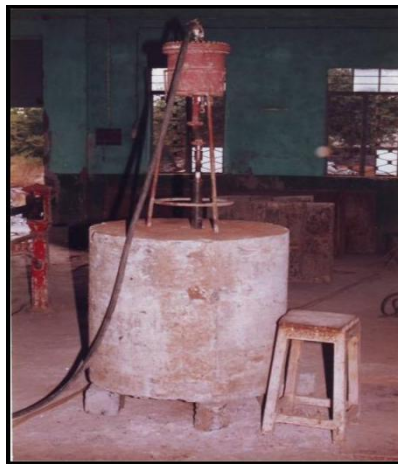


Photo no. 7: Permeability test on the core in laboratory.

Permeability test is conducted by central injection method, with double rubber packers placed at 60cm apart in central hole of the core. A vertical water tank capable of exerting pressure up to 3.5 kg/cm^2 is erected at top of injection pipe. Initially, 0 kg/cm^2 pressure is applied and permeability is observed for steady state condition. Permeability is measured for pressures in sequence of 0 to 3.5 kg/cm^2 with increment of 0.5. If permeability more than 0.5 lit/min/m^2 (i.e. 2.5 lugeon) is observed at any pressure, test for further pressures are aborted and core is said to be permeable.

Permeability shall not be more than $0.5 \text{ lit/minute/m}^2$ (i.e. 2.5 lugeon).

7.3.3.3.3 Compressive strength - Compressive strength is obtained by ultimate crushing of core on 2000 Ton capacity Compression Testing Machine. This is the only machine available in central India at M.E.R.I., Nashik. It is fully automatic and computerized.



Photo no. 8: 2000 ton compression testing machine, control panel and computer system at M.E.R.I., Nashik

The compressive strength obtained on cylindrical core of 90cm x 90cm with $L/D = 1$ is then converted for $L/D = 2$ using conversion curve given in IS: 516 – 1959 (Reaffirmed 2013). The compressive strength of 90cm x 90cm colgrout masonry cylindrical core shall not be less than 90 kg/cm^2 for L/D ratio as 2.

7.3.3.3.4 Split tensile strength - The core is placed centrally with its axis horizontal on 2000 ton Compression Testing Machine and load is applied till the core splits along the diameter. The split tensile strength is computed using following formula;

$$T = (2 \times P) / (3.14 \times L \times D) \quad \text{where } P - \text{Applied load in } \text{kg/cm}^2,$$

$$L - \text{Length of core in m,}$$

$$D - \text{Diameter of the core in m.}$$

7.3.3.3.5 Modulus of Elasticity (E) - Elasticity test is carried out after knowing compressive strength of the core. Two Elasticity rings are fixed to the core at 60cm apart and equidistant from the edges of the core by screw arrangement. Batty dial gauges are fixed on each of the two vertical arms which in turn are fixed to the top ring at diametrically opposite points on the core. The movable arm of the gauges rested on another small attachment fixed to the bottom ring

suitably. Procedure of elasticity test shall be as per IS: 516 – 1959 (Reaffirmed 2013) for concrete. The deformation of the core while gradually loading and unloading is measured at an interval of 50 ton up to 40% of compressive strength load. The average of two dial gauge readings is taken at each loading. Graph of stress against strain is plotted and slope of line graph gives elasticity value.



Photo no. 9: Arrangement for testing of Modulus of Elasticity on the core in laboratory.

In absence of sufficient data on E value for colgrout masonry, E values for concrete between 1.4 to 5.0×10^5 kg/cm² as per IS: 516 – 1959 (Reaffirmed 2013) are considered for colgrout masonry.

7.3.4 Standard of Acceptance for colgrout core test results

- a) Density shall be more than 2.40 gm/cc.
- b) Permeability value shall not be more than 0.5 lit/min/ m² (2.5 lugeons) as per IS:11216 -1985 (Reaffirmed 2013) .
- c) Compressive strength shall not be less than 90 kg/cm² for L/D ratio as 2.
- d) Modulus of elasticity shall be comparable to that of concrete. It shall be 1.4 to 5.0×10^5 kg/cm² as per IS: 516 – 1959 (Reaffirmed 2013).

7.3.5 Calibration of equipments – Periodical calibration of all the testing and measuring instruments / equipments, shall be carried out.

8.0 BENEFITS OF COLGROUT MASONRY

- 8.1** Speed of colgrout masonry construction is fast as compared to conventional masonry construction in dams and specifically so, when mass work is involved. As the rate of construction is faster, the project can be commissioned earlier, thus time and money can be saved and benefits of the project can be gained earlier.
- 8.2** Construction technology is standardized.
- 8.3** Man power required is less as compared to the conventional masonry works.
- 8.4** Masonry being homogeneous and dense, permeability is very less. Thus, this impermeability further reduces the cost of grouting and maintenance due to seepage and leaching of materials.
- 8.5** Colgrout masonry is cheaper than concrete.
- 8.6** Further economy can be achieved by replacement of approximately 20 % of cement by fly ash vide circular no. MISC 1105 / 2606 / (630 / 2005) MP-1 Dated 19/06/2006.

9.0 GUIDELINES FOR SAFE TRANSPORTATION OF COLGROUT MASONRY CORES

9.1 Measures during removing colgrout core from dam body

For removal of 90 cm diameter and approximately 100 cm height colgrout cores from specified location of dam body, special drilling machine is required to be used. This drilling machine is available at Mechanical Circle, Pune.

9.2 Measures during loading process of colgrout cores at dam site

For loading of colgrout cores in trucks at dam site, special machine like hydra is used. Before loading, sand layer of about 50 mm (minimum) should be placed inside the truck.

9.3 Measures during transportation of colgrout core from dam body to MERI, Nashik

Colgrout cores are required to be transported from dam body to MERI, Nashik by means of Trucks. For safety of colgrout cores, during transportation, the drilled cores are kept above sand to avoid any damage. The cores while transporting, are required to be arranged in horizontal axis position and sufficient distance (minimum 500 mm) should be kept between two cores.

9.4 Measures during unloading process of colgrout cores at MERI, Nashik

While unloading of colgrout cores at MERI, Nashik, soft ground is necessary. For this purpose, waste rubber tyres / tubes or sand layers should be used.

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