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SYNOPSIS

The paper deals with general principles of application of sprayed concrete in prestressed hydraulic and related structures viz. water tanks, swimming pools, dams and other retaining structures, tunnels etc. Basic methods of spraying have been highlighted. Problems faced during design, construction and quality control of the sprayed concrete works have been discussed, with a particular reference to durability and water tightness, consideration for selection of materials, field control, equipment and process selection and control testing have been covered in the Paper.

INTRODUCTION

Sprayed concrete is a mixture of cement, aggregate and water which may, circumstantially, include fibers and/or admixtures. This mixture is projected at high velocity from a Nozzle onto a prepared surface to produce a dense homogeneous mass. The force of the jet, impacting on the surface, compacts the material placed. A relatively dry mixture is generally used and the deposit is capable of supporting itself without sagging or sloughing, even for vertical and overhead applications.

Terms like shotcrete, gunite, pneumatically applied mortar or concrete, spray Crete, air blow mortar or concrete, gunned concrete and alike refer to application of concrete of mortar by spraying.

Today, sprayed concrete is extensively used in new construction (canal, reservoir and tunnel linings, swimming pools and other water containment structures, prestressed tanks, curved or folded section roofs, shell roofs, etc.), restoration and repair of old concrete, repair of damage due to fire, earthquake and environmental deterioration, water proofing of walls, long term steel corrosion protection of piling, coal bunkers, oil tanks, smoke stacks, steel building frames and other structures, encasing structural steel for fire proofing, slope stabilization, temporary and permanent tunnel supports, refractory applications and production of natural looking sculptures and statues over wire forms.

The material presented in this Paper gives information regarding various technical aspects of spraying. This should be of use for writing specifications, for field inspection, and to the actual Shot Crete operator. An attempt has been made to highlight major problems and a careful attention to these will prevent costly field errors. All details of

each operation and coverage of many finer points is, of course, not the object of this Paper.

SPRAYING PROCESS

The following are the two basic spraying processes :-

a. *Dry-mix Process :* The process consists of the following steps :-

- Cement and damp aggregate, weight or volume batched, are thoroughly mixed dry.
- The Cement-aggregate mixture is fed into a purpose-made machine wherein the mixture is pressurized
- The mixture is metered into a delivery hose by a feed value or distributor.
- The mixture is carried by compressed air through the delivery hose to a special nozzle. The nozzle is fitted inside with a perforated manifold through which water is introduced under pressure and intimately mixed with other ingredients to hydrate the mix.
- The hydrated mix the jetted from the nozzle at high velocity on to the surface without interruption.

b. *Wet-mix Process :* The process consists of the following steps :-

- Weight batched cement and aggregate are thoroughly hydrated at site or in a mixer truck.
- The hydrated mix is introduced into the chamber of a purpose-made delivery equipment.
- The mix is metered into the delivery hose and conveyed by compressed air or other means to a nozzle.
- Additional air is injected at the nozzle to increase the velocity and improve the gunning pattern.
- The mix is jetted from the nozzle at high velocity onto the surface without interruption.

Dry mix process has been found suitable in a large variety of conditions of construction for over fifty years in various parts of the world. Handling of dry-mix composition does not cause an unsurmountable problem even in remote areas or in tunnels with extreme long haulage distances, nor in adverse weather and climatic conditions. Interruption in the application process does not necessarily result in the loss of the batched dry mix. A further positive aspect is the comparatively low equipment cost and low maintenance cost. The dry mix process also offers saving of expenses that are incurred by prolonged equipment downtimes as can occur with the wet-mix process. The material presented hereafter refers mainly to the dry-mix process.

SPRAYING EQUIPMENT

For proper spraying of concrete, the equipment must be designed and operated to provide a smooth uniform flow of material through the hose to the nozzle and from the nozzle to the point of deposit. Any slugging of material from the nozzle will create sand pockets (poorly hydrated areas, porous and low in cement content). If the equipment does not operate smoothly, it should be given such attention as will correct the problem.

The hose should be of good quality. It should be flexible for ready handling by nozzleman and hose draggers. The overall length of hose from gun to nozzle should be kept to the minimum. Whenever possible, extra lengths should be removed from the hose line as the nozzleman move closer to the equipment. All unnecessary bends, curves and kinks should be avoided and hose laid in as straight a line as possible. These precautions help to reduce slugging or non uniform delivery of material at the nozzle.

An air compressor of sufficient size for the hose used and the output desired should be provided. For nozzle size 25 mm ID, the compressed air approximately 20 cub.mtr./mm at 6 kg./cm.sq. is required. The more pressure is required for longer length of material hose. To shoot floors, a large nozzle tip is used to reduce back pressure. Sometimes compressed air pressure must be reduced to enable nozzle man to handle the hose. A sand dryer or sand heater should be available if there is a possibility of wet sand [moisture content more than 5 per cent]. Excess moisture causes cement build up inside the gun and an initial small length of hose, frequent plugging of the hose, and prevents material falling freely into the gun. It ius impossible for a nozzle man to shoot good Shot Crete under these conditions.

Properly designed scaffold should be provided which will permit the nozzle man to move close enough for shooting behind reinforcing steel and yet enable him to get back far enough for smooth shooting with a minimum of rebound scaffold, braces, posts etc. between the nozzle man and his work. A well designed scaffold can be mounted on wheels and moved up and down with the nozzle-man to provide all types of movements without interruption.

MATERIALS

Normally shotcrete mixes consist of good quality Portland cement and coarse well graded concrete and preferably with a fineness modulus greater than 2.5. The mix for a specific job application should be properly designed for required strength, workability and durability. The workability requirements for a mix for shotcrete are different than those of ordinary concrete mixes. All types of small aggregate fine sand can be satisfactorily used in sprayed concrete. Fine sands have hose line clogging characteristics and should be used along with coarse aggregates only.

THE PROBLEM OF REBOUND AND OVERSPRAY

Rebound is aggregate, cement and water [mixed] which does not adhere to the point of application but falls by gravity to a resting place. If sufficient rebound accumulates at one place, it becomes a loose, uncompacted, porous mass. If permitted to harden through setting of the contained cement and water, it becomes solid and appears quite like sprayed concrete but it will not have the desired strength and durability. Once final set occurs, rebound can only be removed by chipping, scrapping and sand blasting. If rebound is covered with good shotcrete, it then becomes a sand pocket.

The nozzle spray consists of concrete mix and considerable compressed air. The object is to deposit the mix into a desired location and permit the compressed air to escape freely. Some of the ingredients of mix are carried by the escaping air perpendicular to the nozzle stream and parallel to the surface of application all around the point of application. This material carried by the air stream is 'overspray'. Overspray will adhere to almost and surface against which it may strike. Shooting strips and wires, reinforcement, pipes, anchor bolts and inserts of any kind can be quickly coated with overspray if they are not in the direct nozzle impact area. In addition, if such objects are below the nozzle impact area, rebound will also build on the top surfaces of such objects. Overspray which falls by gravity to a point of rest becomes rebound.

Both overspray and rebound are low strength porous material which will not protect against moisture penetration, corrosion, freeze-thaw and other attacks. Bond strength of this material is poor. An encased overspray also becomes a sand pockets can be completely avoided in the work area by employing proper shooting techniques.

PREPARATION OF SURFACE FOR SHOTCRETING

Sound shotcrete should have perfect bond to whatever bondable material it is applied [reinforcement surfaces in new construction and old surfaces of old construction] including itself. It should not have laminations or hollows within its structure. To achieve perfect bond, the surface on which spraying is to be done should be clean and free of

bond breaking substances such as dirt, grease, oil, curing agents, points or deteriorated material. Adequate surface preparation should be accomplished.

Once a surface is properly cleaned ready for spraying, a shooting technique must be employed which does not foul or dirty the clean surface. An initial coat of spray should be rapidly applied to the selected work area before it can be contaminated with overspray or rebound. The work area should be selected of such size that its surface can be kept wet with fresh spray without initial set occurring until after shooting of the area is completed. The selection of the size of area for one shooting depends on sun, temperature, wind velocity, humidity, admixtures, accessibility, equipment, energy and ability of the nozzleman. An area of about 10 to 20 sq.mtr. is often a convenient size for one spray application without contamination.

Certain shooting areas require special care. For example, in shooting a vertical area which extends right into the floor, the initial application of bond coat would be directly into the floor-wall corner at 45 Deg. To floor and wall. The nozzleman would start at one end of the work area, shooting directly into the corners. He should move very quickly along the length of the floor-wall joint applying the light bond coat into the corner. If this is not done, overspray will have built against the projecting face of the corner before the nozzleman arrives and a sand pocket will be incorporated into the wall at the corner.

After the initial light bond coat is quickly applied into the corner, a second pass is made beginning the build up for a curve, Fig. 1. Again the nozzleman must move rather rapidly along the corner, as at the base of the wall, there will be a problem of falling rebound onto the floor and into the corner in addition to the overspray. The second or third pass into the corner should seek to build a long curve up the wall at least as thick as the intended thickness of the full layer to be applied to the wall at a time. The full curve will help to shed the falling rebound and give the finishers a nice surfaced to keep scraped clean.

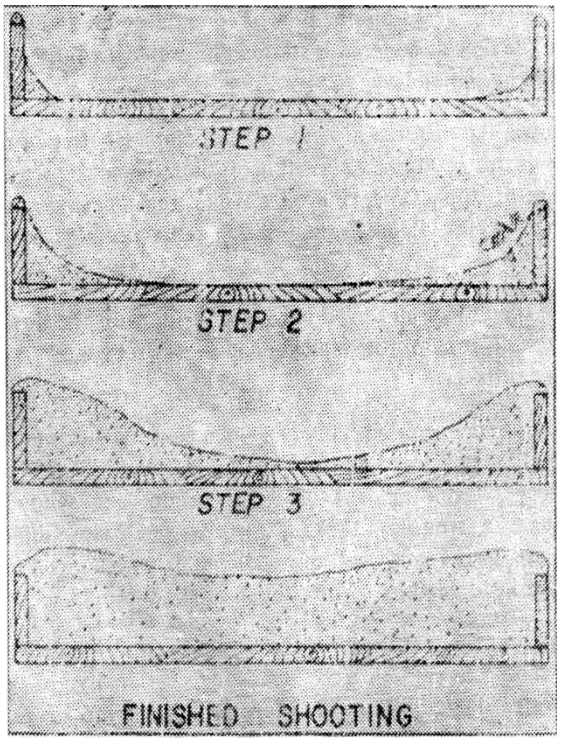

Fig. 1 : Proper procedure to avoid edge build-up and overspray

NOZZLE WATER SUPPLY FOR HYDRATION

The nozzle water supply line should be so sized and the water pressure such that when the nozzle water valve is fully opened during the maximum material flow, the mix being placed will quickly be overly hydrated. When shooting at a good rate of production, the air pressure at the compressor may be 6 kg./cm.sq. and the water pressure 3-4 kg./cm.sq. Often, to secure such pressure, an auxiliary booster pump is required on the job. All holes in the water ring should be of sufficient size that they are not readily blocked by small sand particles or debris in the water. Hose nipples, fittings etc. should be of full size to permit adequate flow of water.

GENERAL PLACEMENT TECHNIQUES

The nozzleman check-up the flow of compressed air and water coming out of the nozzle. The flow of material is started and water is adjusted to match the material flow and hydration level.

At shut down, the material hose should be completely free of material before the air supply is turned off. In normal operation, the nozzle stream is perpendicular to the place of application. Fig. 2. While remaining perpendicular to the surface, the nozzle is moved constantly, often in a circular pattern, to distribute the uniformly.

The nozzle should not be waved back and forth or up and down changing the angle of impact. This improper technique increases rebound and overspray and results in rougher surfaces.

With the dry-mix operation, the nozzleman controls the amount of water for hydration, adding just sufficient water so that the surface of application develops a slight gloss laitance, lesser amount of water produces a sandy surface while increasing rebound, a tendency for sand pockets, and a more difficult surface to finish. Greater amount of water will cause sliding or sloughing off in the deposit, particularly in overhead deposits. Any slough or slides should be removed.

With proper equipment, materials and trained crew, the delivery of material from the nozzle should be smooth and steady. Occasionally, however, slugs of improperly hydrated material may be deposited on the receiving surface. Such material should be cut from the work.

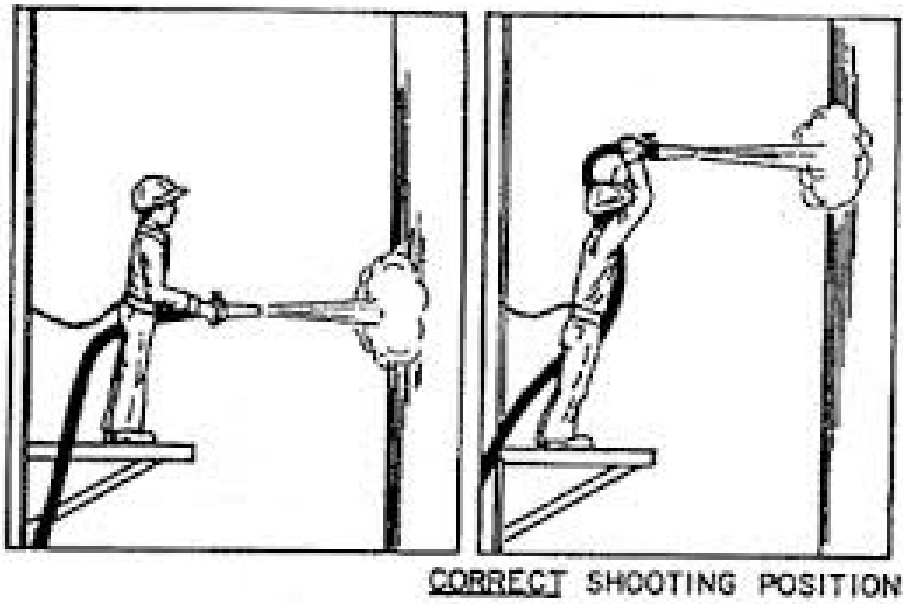

Fig. 2 : Correct shotcrete shooting positions

Usually the required thickness of sprayed concrete is build up by making several passes of the nozzle over the working area. Thickness per pass will vary for shooting downward [as on a floor], horizontally [against vertical surfaces] and overhead [as on ceilings]. The importance of avoiding sand pockets, overlay wet placement and excessive thicknesses which slough, creating internal cracking and hollows can hardly be overstated. Such flaws make sprayed concrete vulnerable to water penetration, freeze-

thaw damage, loss of bond and diminish its unique and desirable properties. The nozzleman should try to minimize rebound and overspray by proper technique and absorb small amounts of overspray and rebound within the shotcrete without creating sand pockets. Thin layers and frequent passes over the area will prevent an accumulation of sand on the wet surfaces. The nozzle distance is governed by type of receiving surface, required smoothness of placement and equipment employed.

ENCASING REINFORCEMENT

The greatest skill and closest attention is required in encasement of reinforcement, pipes, inserts etc. The correct nozzle distance has to be determined only by observation of the results being obtained in the placement of concrete around reinforcement. The size of the air compressor, the condition of equipment, the moisture content of the mixing sand, the size and length of material hose, the wind velocity, the size of the nozzle tip, all affect the concrete placement.

The nozzle should be held close enough to the reinforcement and the mix should contain sufficient by hydration water to keep the face of the bar washed clean, but still dry enough so that the concrete behind the bar will be fairly firm to prevent sloughing or drips. Knobs of material should never be permitted to build up on the front face of the bar as shown in Fig. 3

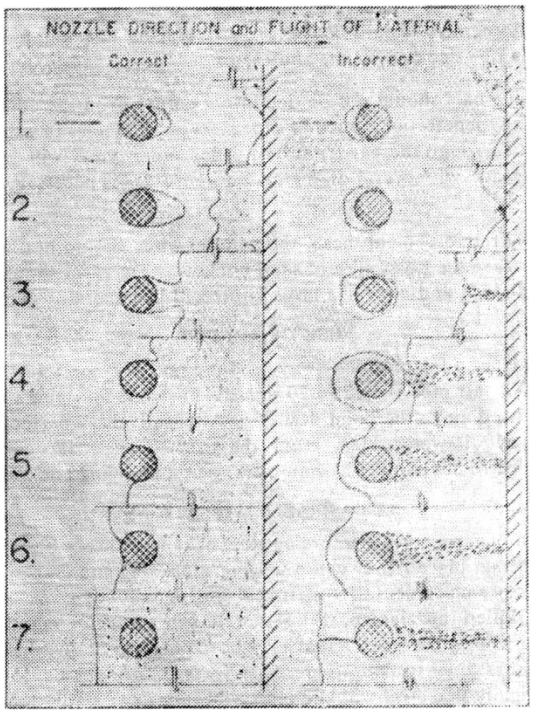

Fig.3 : Correct and incorrect method of encasing reinforcing bar with shotcrete

Until completion of encasement and during shooting, the deformations on the front side of the bar should be visible until concrete on both sides of the bar becomes level with

the front of reinforcing bar, Fig. 3. Holding the nozzle close enough to the bar will cause the concrete to flow around behind the bar and should provide good solid material in back of the bar.

Shooting at a depressed angle may cause improper encasement of steel. As the angle of the nozzle increases in a downward direction, the soft shotcrete begins to roll in waves and becomes very rough. Such roughness will trap rebound and overspray and cause a porous concrete even in large open surface areas.

It is important that the steel be free of overspray and encased in dense impervious concrete. If the steel is not broomed, brushed and air-water blasted clean while the overspray is soft, the steel should be chipped and sand blasted clean of hardened overspray before encasement.

Sand pockets behind reinforcing bars, whether caused by improper shooting, overspray or steel placement details, will cause a weakened section. Normal shrinkage will often cause cracks at such weakened sections along the face of the bar through the entire section. Long straight cracks in a sprayed concrete surface parallel to the reinforcement is an almost sure indication of such faulty shotcrete application.

Knowledgeable attention to installation of reinforcing bars can reduce encasement problems and potential for major sand pocket voids. It is necessary to keep all obstacles to the flow the spray to a minimum possible size.

It is a common practice in reinforced concrete work to the lapped reinforcing bars together. Such a practice in sprayed concrete is wrong. The two bars can cause a major void. Reinforcing bars should be spaced a minimum of several diameters clear. If possible, any substantial thickness of shotcrete behind a curtain of reinforcement should be shot before placing the reinforcement. The bars should then be tied against the shotcrete.

Reinforcing bars should not be tied into a corner or inside contact with wall, floor or ceiling penetrations such a pipe sleeves, manholes or other. The spray deposit cannot surround the bar from both sides and a void will develop behind the bar. A space of several diameters on bo0th sides is necessary for proper bar encasement.

In splicing reinforcement mesh, the parallel wires should not be tied together as this will increase the possibility of sand pockets.Tie wires should be bent flat in the plane of mesh and not form large knots will become sand pocket voids.

USE OF AIR PIPE

Air pipe is used for cleaning away rebound and overspray just ahead of the nozzleman. An air pipe is a 12 to 20 mm dia. Hose line and pipe with valve which carries

compressed air to the point desired. Alternatively, a perfect cleaning can be achieved by air-water blast from the nozzle itself. Hardened rebound and overspray can be removed only by hammers, picks, chipping and sand blasting.

UNDESIRABLE VIBRATIONS

Vibration of formwork, reinforcing steel or any other object against which shotcrete is being placed may cause sagging, sloughing and cracking of the plastic material at the time of placement. Sometime during shooting, ins pite of the best efforts of a skilled nozzleman, the shotcrete will slough or sag particularly from underneath horizontal bars, often leaving a horizontal crack just behind or below the bar. This is due to vibration of the formwork or the bar. Adequate form bracing and rigidly tied steel will eliminate vibrations and avoid long cracks.

CONSTRUCTION JOINTS

Construction joints are generally tapered to a thin edge over a width of about 30 cm. A somewhat better appearing joint is constructed by sloping the shotcrete surface to a shallow edge form, usually a 25 mm thick board laid flat. Ordinary square construction joints are generally avoided in shotcrete construction because they form a trap for rebound and overspray. However, where the joints will be subjected to compressive stress, square joints are commonly required in which case necessary steps must be taken to avoid or to remove trapped rebound at the joint. The entire joint should be thoroughly cleaned and wetted prior to the application of additional shotcrete.

PREPARATION OF SUCCEEDING LAYERS

Where a layer of shotcrete is to be covered by a succeeding layer, it should first be allowed to take its initial set. Then all laitance, loose material and re bound should be removed by sand blasting and the surface cleaned with air-water jet. In addition, the surface should be thoroughly sounded with a hammer for drummy areas resulting from sand pockets or lack of bond. Drummy areas, sags or other defects should be carefully cut out and replaced with the succeeding layer. Surfaces to be shot should be damp.

THICK STRUCTURAL MEMBERS

From quality and cost point of view, sprayed concreter is best suited to thin lightly reinforced sections. However, it is sometimes advantageous to shoot certain heavy structural members in new construction and to bond columns, girders or walls to existing construction.

Careful planning, skill in formwork and continuous care in application is required for successful use of shotcrete in structural sections. The nozzle size and rate of feed

should be limited as necessary to permit full nozzle control and produce a uniform dense application even in light places.

To permit the escape of air and rebound during the gunning operation, columns should be formed only on two adjacent sides where practicable. Pilasters may be formed on two adjacent or opposite sides. The soffit and one side of the beam should be formed. Shores should be provided below the soffit in a manner such that no deflection will occur under the load to be imposed.

Where the section contains two curtains of reinforcement, it may be desirable to delay the placement of the second curtain until the first curtain has been embedded with shotcrete.

It is generally not advisable to spray concrete in narrow slots or holes. They should be filled with conventional concrete or mortar. These areas may then be overlaid with shotcrete along with the surrounding areas. Shotcrete should not be used for spirally reinforced columns and piles.

SUSPENSION OF WORK

Shooting should be temporarily suspended if :

a. High wind prevents the nozzleman from proper application of the material.

b. Weather approaches freezing and work cannot be protected.

c. Rain occurs which may wash cement out of freshly placed material and cause sloughing in the work.

CONTROL TESTING

Quality control of shotcrete is more difficult than for conventional concrete since it is affected not only by the accuracy of batching but also by the skill and continued care of the crew applying it. It is generally not feasible or desirable to core the structure to obtain specimens for regular control tests. Small unreinforced test panels, at least 30 cm square and 75 mm thick are periodically gunned, and coarse or cubes extracted for compressive tests and visual examinations.

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