IS 9012 (1978): Recommended practice for shotcreting [CED 2: Cement and Concrete]

BLANK PAGE

IS : 9012 - 1978
(Reaffirmed 2002)

Indian Standard

RECOMMENDED PRACTICE FOR SHOTCRETING

(Fourth Reprint NOVEMBER 1995)

UDC 666·97·033·14

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 5 *May* 1979

Indian Standard

RECOMMENDED PRACTICE FOR SHOTCRETING

Cement and Concrete Sectional Committee, BDC 2

Chairman	*Representing*
DR H. C. VISVESVARAYA	Cement Research Institute of India, New Delhi
Members	
ADDITIONAL DIRECTOR, STANDARDS (B & S)	Research, Designs & Standards Organization (Ministry of Railways), Lucknow
DEPUTY DIRECTOR, STANDARDS (B & S) (*Alternate*)	
SHRI K. C. AGGARWAL	Hindustan Prefab Ltd, New Delhi
SHRI C. L. KASLIWAL (*Alternate*)	
SHRI B. C. BANERJEE	Cement Corporation of India Ltd, New Delhi
SHRI A. U. RIJHSINGHANI (*Alternate*)	
SHRI K. P. BANERJEE	Larsen & Toubro Ltd, Bombay
SHRI HARISH N. MALANI (*Alternate*)	
SHRI R. N. BANSAL	Beas Designs Organization, Nangal Township
SHRI T. C. GARG (*Alternate*)	
DR N. S. BHAL	Structural Engineering Research Centre (CSIR), Roorkee
CHIEF ENGINEER (PROJECTS)	Irrigation Department, Government of Punjab, Chandigarh
DIRECTOR, IPRI (*Alternate*)	
DIRECTOR (CSMRS)	Central Water Commission, New Delhi
DEPUTY DIRECTOR (CSMRS) (*Alternate*)	
ENGINEER-IN-CHIEF	Central Public Works Department, New Delhi
SUPERINTENDING ENGINEER, DELHI CENTRAL CIRCLE No. 2 (*Alternate*)	
SHRI AMITABHA GHOSH	National Test House, Calcutta
SHRI E. K. RAMACHANDRAN (*Alternate*)	
DR R. K. GHOSH	Central Road Research Institute (CSIR), New Delhi; *and* Indian Roads Congress, New Delhi
SHRI Y. R. PHULL (*Alternate* I)	Central Road Research Institute (CSIR), New Delhi
SHRI M. DINAKARAN (*Alternate* II)	Central Road Research Institute (CSIR), New Delhi

(*Continued on page* 2)

(*Continued from page* 1)

Members	*Representing*
SHRI B. R. GOVIND	Engineer-in-Chief's Branch, Army Headquarters, New Delhi
SHRI G. R. MIRCHANDANI (*Alternate*)	
SHRI A. K. GUPTA	Hyderabad Asbestos Cement Products Ltd, Hyderabad
DR R. R. HATTIANGADI	The Associated Cement Companies Ltd, Bombay
SHRI P. J. JAGUS (*Alternate*)	
DR IQBAL ALI	Engineering Research Laboratories, Hyderabad
SHRI M. T. KANSE	Directorate General of Supplies & Disposals, New Delhi
SHRI S. R. KULKARNI	M. N. Dastur & Co (Pvt) Ltd, Calcutta
SHRI S. K. LAHA	The Institution of Engineers (India), Calcutta
SHRI B. T. UNWALLA (*Alternate*)	
DR MOHAN RAI	Central Building Research Institute (CSIR), Roorkee
DR S. S. REHSI (*Alternate*)	
SHRI K. K. NAMBIAR	In personal capacity (*'Ramanalaya' 11 First Crescent Park Road, Gandhinagar, Adyar, Madras*)
DR A. V. R. RAO	National Buildings Organization, New Delhi
SHRI K. S. SRINIVASAN (*Alternate*)	
SHRI R. V. CHALAPATHI RAO	Geological Survey of India, Calcutta
SHRI S. ROY (*Alternate*)	
SHRI T. N. S. RAO	Gammon India Ltd, Bombay
SHRI S. R. PINHEIRO (*Alternate*)	
SECRETARY	Central Board of Irrigation and Power, New Delhi
DEPUTY SECRETARY (I) (*Alternate*)	
SHRI N. SEN	Roads Wing, Ministry of Shipping and Transport
SHRI J. R. K. PRASAD (*Alternate*)	
SHRI K. A. Subramaniam	The India Cements Ltd, Madras
SHRI P. S. RAMACHANDRAN (*Alternate*)	
SUPERINTENDING ENGINEER (DESIGNS)	Public Works Department, Government of Tamil Nadu, Madras
EXECUTIVE ENGINEER (S M & R DIVISION) (*Alternate*)	
SHRI L. SWAROOP	Dalmia Cement (Bharat) Ltd, New Delhi
SHRI A. V. RAMANA (*Alternate*)	
SHRI B. T. UNWALLA	The Concrete Association of India, Bombay
SHRI T. M. MENON (*Alternate*)	
SHRI D. AJITHA SIMHA, Director (Civ Engg)	Director General, BIS (*Ex-officio Member*)

Secretary

SHRI M. N. NEELAKANDHAN
Assistant Director (Civ Engg), BIS

(*Continued on page* 19)

Indian Standard

RECOMMENDED PRACTICE FOR SHOTCRETING

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 30 November 1978, after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Shotcrete is mortar or concrete conveyed through a hose and pneumatically projected at high velocity on to a surface. The force of the jet impinging on the surface compacts the material. Generally a relatively dry mixture is used, and so the material is capable of supporting itself without sagging or sloughing, even for vertical and overhead applications.

0.3 Shotcrete has been referred to generally as gunite, pneumatically applied mortar or concrete, sprayed concrete, spraycrete, air-blown mortar and concrete, gunned concrete, etc. In this standard the term shotcrete will be adhered to right through as it is internationally accepted and conveys the intended meaning implicitly.

0.4 Shotcrete is suitable for a variety of new construction and repair work, but its properties and performance are to a great extent dependent on the conditions under which it is placed, the capability of the particular equipment selected, and in particular on the competence of the operating staff. Shotcreting work can be either plain or reinforced.

0.5 This standard covers the recommended practice for general shotcrete using two shotcreting processes, namely dry-mix process and wet-mix process. The practices recommended in this standard generally reflect the standards and practices prevailing in different countries and also the practices in the field in this country.

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

*Rules for rounding off numerical values (*revised*).

1. SCOPE

1.1 This standard covers the recommended practice for two shotcreting processes, namely, dry mix process and wet mix process.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Shotcrete — Mortar or concrete conveyed through a hose and projected at high velocity on to a surface; also known as air-blown mortar, also pneumatically applied mortar or concrete, sprayed mortar and gunned concrete.

2.2 Dry-Mix-Shotcrete — Pneumatically conveyed shotcrete in which most of the mixing water is added at the nozzle.

2.3 Gunite (Trade Name) — Method of applying dry-mix shotcrete.

2.4 Wet-Mix Shotcrete — Shotcrete wherein all ingredients, including mixing water, are mixed in the equipment before introduction into the delivery hose; it may be pneumatically conveyed or moved by displacement.

3. MATERIALS

3.1 Cement — The cement used shall be any of the following, with the prior approval of the engineer-in-charge:

a) Ordinary or low heat Portlant cement conforming to IS : 269-1976*.

b) Rapid hardening Portland cement conforming to IS : 8041-1978†.

c) Portland slag cement conforming to IS : 455-1976‡.

d) Portland Pozzolana cement conforming to IS : 1489-1976§.

e) High strength ordinary Portland cement conforming to IS : 8112-1976‖.

f) Hydrophobic cement conforming to IS : 8043-1978¶.

NOTE — Low heat Portland cement conforming to IS : 269-1976* shall be used with adequate precautions with regard to removal of formwork, etc.

*Specification for ordinary and low heat Portland cement (*third revision*).
†Specification for rapid hardening Portland cement (*first revision*).
‡Specification for Portland slag cement (*third revision*).
§Specification for Portland Pozzolana cement (*second revision*).
‖Specification for high strength ordinary Portland cement.
¶Specification for hydrophobic Portland cement (*first revision*).

3.2 Aggregates

3.2.1 Sand for shotcrete shall comply with the requirements given in IS : 383-1970* and graded evenly from fine to coarse as per Zone II and Zone III grading of IS : 383-1970*. Sand failing to satisfy this grading may, however, be used if preconstruction testing (*see* **6**) establishes that it gives good results. Further, sand for finish or flash coats may be finer than the above grading. However, the use of finer sands will generally result in greater drying shrinkage, and coarse sands, in more rebound.

3.2.2 *Coarse Aggregate* — Coarse aggregates when used shall comply with the requirements of IS : 383-1970*. It shall, generally conform to one of the gradings given in Table 1.

TABLE 1 GRADING OF COARSE AGGREGATES

IS Sieve Designation	Percentage by Mass Passing for Aggregate of Nominal Maximum Size		
	10 mm	12·5 mm	20 mm
(1)	(2)	(3)	(4)
mm			
25	—	—	100
20	—	100	90-100
12·5	100	90-100	—
10	85-100	40-70	20-55
4·75	10-30	0-15	0-10
2·36	0-10	0-5	0-5
1·18	0-5	—	—

3.2.2.1 All oversize pieces shall be rejected by screening, since they are likely to cause plugging of the hose.

3.3 Water — Water used for shotcrete shall conform to the requirements of IS : 456-1978†.

3.4 Admixture — Admixture shall only be used when so specified. Admixture when used, shall meet the requirements of IS : 456-1978† and IS : 9103-1979‡.

3.5 Reinforcement — Reinforcing bars if used shall conform to IS : 432 (Part I)-1966§ or IS : 1139-1966‖ or IS : 1786-1966¶. Welded wire fabric conforming to IS : 1566-1967** also may be used.

*Specification for coarse and fine aggregates from natural sources for concrete (*second revision*).

†Code of practice for plain and reinforced concrete (*third revision*).

‡Specification for admixtures for concrete.

§Specification for mild steel and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement: Part I Mild steel and medium tensile steel bars (*second revision*).

‖Specification for hot-rolled mild steel, medium tensile steel and high yield strength steel deformed bars for concrete reinforcement (*revised*).

¶Specification for cold twisted steel bars for concrete reinforcement (*revised*).

**Specification for hard-drawn steel wire fabric for concrete reinforcement (*first revision*).

4. SHOTCRETING PROCESS

4.0 The two basic shotcreting processes are:

a) Dry mix process, and
b) Wet mix process.

4.1 Dry Mix Process — In this process, a mixture of cement and moist sand is conveyed through the delivery hose to a nozzle where most of the mixing water is added under pressure. This process consists of the following steps:

a) The cement and moist sand are thoroughly mixed;
b) The cement-sand mixture is fed into a special mechanical feeder or gun referred to in this standard as delivery equipment (*see* **7**);
c) The mixture is forced into the delivery hose by a feed wheel or distributor;
d) The mixed material is carried in suspension by compressed air through the delivery hose to a nozzle, which is filled inside with a perforated manifold through which water is introduced under pressure and intimately mixed with the other ingredients; and
e) The mortar is jetted from the nozzle at high velocity on to the surface to be shotcreted.

4.2 Wet Mix Process — In this process, all the ingredients including water are mixed before they enter the delivery hose. It consists of the following steps:

a) All the ingredients (including mixing water) are thoroughly mixed;
b) The mortar or concrete is introduced into the chamber of the delivery equipment;
c) The mixture is forced into the delivery hose and conveyed by compressed air or other means to a nozzle;
d) Additional air is injected at the nozzle to increase the velocity and improve the shooting pattern; and
e) The mortar or concrete is jetted from the nozzle at high velocity on to the surface to be shotcreted.

4.3 Shotcrete suitable for normal construction requirements may be produced by either process. However, difference in cost of equipment, maintenance and operational features may make one or the other method more attractive for a particular application.

5. PROPERTIES OF SHOTCRETE

5.1 Properly applied shotcrete is a structurally adequate and durable material capable of excellent bond with concrete, masonry, steel and other materials. However, these favourable properties are contingent on proper planning and supervision, and on the skill and continuous attention by the operating staff.

5.2 The water cement ratio for shotcrete in place normally falls within the range of 0·35 to 0·50 by mass which is somewhat lower than for most conventional concrete mixes. In general the physical properties of sound shotcrete in place are comparable to those of conventional mortar or concrete of the same composition. Most reported values for 28-day strength are in the range of 20 to 50 N/mm^2. It is recommended that strength higher than 25 N/mm^2 be specified only for the most carefully executed shotcrete jobs.

5.3 The drying shrinkage of shotcrete depends somewhat on the mix proportions used, but generally falls within the range of 0·06 to 0·10 percent. This is rather higher than for most low-slump conventional concrete, which is generally placed in heavier sections using larger aggregate and leaner mixes. It will tend to give more shrinkage, cracking, and may require a closer joint spacing. The durability of shotcrete in laboratory tests and under field exposure has generally been good.

5.4 Shotcrete offers advantages over conventional concrete in a variety of new construction and repair work. It is frequently more economical because of the lesser forming requirements, and because it requires only a small, portable plant for manufacture and placement.

6. PRECONSTRUCTION TESTING

6.1 The mix proportions, grading and quality of aggregate, amount and spacing of reinforcing steel, position of the work, design and condition of delivery equipment, and the quality of workmanship all affect the quality of shotcrete in place. A laboratory investigation shall, therefore, be carried out prior to the commencement of the work in order to check the operation of the equipment and the skill of the operating staff, and also to verify that the specified quality of shotcrete may be expected in the structure. The procedure for preconstruction testing shall be as recommended in **6.1.1** to **6.1.6**.

6.1.1 Test panels simulating actual job conditions shall be fabricated by the operating staff, using the equipment, materials and mix proportions proposed for the job.

6.1.2 For the dry mix process, the amount of water added at the nozzle is adjusted so that the in-place shotcrete appears to be adequately compacted and neither sags nor shows excessive rebound. Where justified by the size and importance of the job or lack of previous experience with the materials, it may be advisable to test two or three mixes, generally within the range of 1 part of cement to 3 to 4½ parts of sand, before deciding on the final mix proportions.

6.1.3 The procedure for the wet mix process is similar to the dry mix process (*see* **6.1.2**) except that the entire mix is premixed to give a workability judged to be appropriate for the work, before it is introduced into the chamber of the delivery equipment. Tests on more than one mix design are usually recommended where it is desired to include coarse aggregate in the mix. Normally 20 to 40 percent of coarse aggregate is first tried, with subsequent mixes adjusted to reflect the results of the first trial.

6.1.4 The panels are fabricated by gunning on to a back form of plywood. A separate panel shall be fabricated for each mix design being considered, and also for each gunning position to be encountered in the structure, that is, slab, vertical and overhead sections. At least part of the panel shall contain the same reinforcement as the structure, to show whether sound shotcrete is obtained behind the reinforcing rods. The panel shall be large enough to obtain all the test specimens needed, and also to indicate what quality and uniformity may be expected in the structure. Generally the size of panel shall be not less than 75 × 75 cm. The thickness shall be the same as in the structure except that it shall normally be not less than 7·5 cm.

6.1.5 Cubes or cores shall be taken from the panels for testing. The cores shall have a minimum diameter of 7·5 cm and a length-diameter ratio of at least 1, if possible. The specimens shall be tested in compression at the age of 7 or 28 days or both.

6.1.6 The cut surfaces of the specimens shall be carefully examined and additional surfaces shall be exposed by sawing or breaking the panel when it is considered necessary to check the soundness and uniformity of the material. All cut and broken surfaces shall be dense and free from laminations and sand pockets.

7. EQUIPMENT

7.1 Dry Mix Process

7.1.1 *Batching and Mixing Equipment* — Batching by mass is to be preferred and is strongly recommended. Sand may be batched by volume if periodic checks are made to ensure that the masses are maintained within the required tolerance.

The moisture content of the sand shall be such that the sand-cement mixture will flow at a uniform rate, without slugs, through the delivery hose. The optimum moisture content will depend upon the delivery equipment being used, but it is generally within the range of 3 to 6 percent. The sand shall be moistened or dried as required to bring the moisture content to a satisfactory level. Fluctuations in moisture content shall be avoided.

The mixing equipment shall be capable of thoroughly mixing the sand and cement in sufficient quantity to maintain continuity of placing. The mixing time shall be not less than 1 minute in a drum-type mixer; where other mixers are proposed, satisfactory evidence shall be presented that they are capable of thorough mixing. The mixer shall be self-cleaning, capable of discharging all mixed material without any carryover from one batch to the next. It shall be inspected and thoroughly cleaned at least once a day (and more often if necessary) to prevent accumulations of batched material.

7.1.2 *Delivery Equipment or Guniting Equipment* — The delivery equipment shall comply with the requirements given in 6433-1972*.

7.1.3 *Air Supply* — Properly operating air compressor of ample capacity is essential for a satisfactory shotcreting operation. The compressor shall be fitted with a moisture extracter to keep up a supply of clean, dry air adequate for maintaining a sufficient nozzle velocity for all parts of the work while simultaneously operating a blow pipe for clearing away rebound.

The operating pressure is the pressure driving the material from the delivery equipment into the hose, and is measured by a gauge near the material outlet of the gun. The air pressure shall be uniformly steady (non-pulsating).

For lengths of hose up to 30 m, air pressure at the gun shall be 0·3 N/mm^2 or more. Where the length exceeds 30 m, the pressure shall be increased by 0·035 N/mm^2 for each additional 15 m of hose required, and by 0·035 N/mm^2 for each 7·5 m that the nozzle is raised above the gun.

7.1.4 *Water Supply* — The water pressure at the discharge nozzle shall be sufficiently greater than the operating air pressure to ensure that the water is intimately mixed with the other materials. If the line water pressure is inadequate, a water pump shall be introduced into the line. The water pressure shall be uniformly steady (non-pulsating).

*Specification for guniting equipment.

7.2 Wet Mix Process

7.2.1 *Batching and Mixing Equipment* — Batching by mass is to be preferred and is strongly recommended. Aggregates may be batched by volume if periodic checks, are made to ensure that the masses are maintained within a required tolerance. Water may be batched either by mass or by volume.

The mixing equipment shall be capable of thoroughly mixing the specified materials in sufficient quantity to maintain continuous placing. The required mixing time will depend on the mix being used and the efficiency of the mixer. Delivery of concrete at the desired workability and uniformity from batch to batch is essential to a good shotcreting operation especially in vertical and overhead applications.

7.2.2 *Delivery Equipment* — The pneumatic feed type of wet mix delivery equipment is capable of applying high quality, low-slump mortar or concrete with the reliability needed for general construction and repair work. From a pressurised vessel in the equipment, the premixed materials and compressed air are discharged into the delivery hose. The material and air pass through the hose to the gunning nozzle which is fitted with an air ring for injecting additional compressed air.

The wet mix delivery equipment shall be of a design and size which have given good results in similar work. It shall be capable of delivering the premixed materials accurately, uniformly, and continuously through the delivery hose. The size of the hose is generally within the range of 32 to 65 mm. Recommendations of the equipment manufacturers shall be followed with regard to the type and size of nozzle to be used, and the cleaning, inspection, and maintenance of the equipment.

7.2.3 *Air Supply* — The air compressor shall be capable of keeping up a supply of clean air adequate for maintaining sufficient nozzle velocity for all parts of the work and for simultaneous operation of a blow pipe for clearing away rebound.

8. APPLICATION OF SHOTCRETE

8.1 Preparation of Surface — A good base or foundation is necessary for proper and successful application of shotcrete. Where the shotcrete is to be placed against earth surfaces as in canal linings, such surfaces shall first be thoroughly compacted and trimmed to line and grade. Shotcrete shall not be placed on any surface which is frozen, spongy, or where there is free water. The surface shall be kept damp for several hours before applying shotcrete.

8.1.1 In the case of repairs to existing deteriorated concrete, all unsound material shall be first removed. Chipping shall continue until there are

no offsets in the cavity which will cause an abrupt change in the thickness of the repaired surface. No square shoulders shall be left at the perimeter of the cavity; all edges shall be tapered. The final cut surface shall be critically examined to make sure that it is sound and properly shaped. Improper preparatory work is more often responsible for failures of shotcrete in repair work than any other single factor.

8.1.2 After it has been ensured that the surface (whether concrete, masonry or steel) to which shotcrete is to be bonded is sound, it shall be cleaned of all loose and foreign materials. If necessary, the surface shall be chiseled or sand-blasted to make it rough to receive shotcrete. Exposed reinforcement shall be cleaned free of rust, scales etc. Porous surfaces shall be kept damp for several hours before shotcrete is applied.

8.2 Formwork — The forms shall be plywood sheating or other suitable material, true to line and dimension. They shall be adequately braced to protect against excessive vibration, and shall be constructed so as to permit the escape of air and rebound during the gunning operation; this is of particular importance in the case of thick structural members. Short removable bulkheads may be used at intersections. Forms shall be oiled or dampened, and they shall be cleaned just before gunning.

Adequate and safe scaffolding shall be provided so that the operator can hold the nozzle at the optimum angle and distance from the surface for all parts of the work as described in **8.5**. The scaffolding shall be also given easy access to the shotcrete surface for screeding and finishing, if such is specified. Scaffolding shall be constructed to permit uninterrupted applications of the shotcrete wherever possible.

8.3 Reinforcement — The soundest shotcrete will be obtained where the reinforcing steel is designed and placed to cause the least interference with placement. Depending on the thickness and nature of the work, reinforcement may consist of either round bars, or welded wire fabric. Small sizes of bars shall be used, a 16 mm diameter bar being the normal maximum size. Where large bars are necessary, exceptional care shall be taken in encasing them with shotcrete.

8.3.1 Sufficient clearance shall be provided around the reinforcement to permit complete encasement with sound concrete. The clearance needed depends on the maximum size of aggregate in the mix and the size of reinforcement. The minimum clearance between the reinforcement and the form or other backup material may vary between 12 mm for the case of a mortar mix and wire fabric reinforcements to 50 mm for the case of a concrete mix and 16 mm diameter reinforcing bars. The minimum wire mesh spacing shall be 50 mm by 50 mm. Clear spacing between parallel bars shall be at least 65 mm. Minimum cover to reinforcement shall be

as per IS : 456-1978*. As far as possible the bars shall be arranged so as to permit shooting from opposite side.

8.3.2 Laps for bars and wire fabric shall receive special attention to prevent weak sections in the shotcrete. Lapped reinforcing bars shall not be tied together; they shall be separated by at least 50 mm, wherever possible. Wire mesh shall be lapped $1\frac{1}{2}$ squares in all directions. A continuous chair shall not follow along directly underneath a reinforcing bar since this will probably result in a sand pocket under the bar. The minimum requirements of lap length shall be as specified in IS : 456-1978*.

8.3.3 For repair work, the reinforcement shall be fixed to existing masonry and concrete by wiring to nails driven into walls and secured rigidly so that the vibration resulting from the deposition of shotcrete will not impair or displace them.

8.4 Alignment Control — Adequate ground wires shall be installed to establish thickness and surface planes of the shotcrete build-up. Both horizontal and vertical ground wires shall be installed at corners and offsets not clearly fixed by the formwork, for example, at exterior corners of walls, column or beam corners, and other locations. They may also be used as screed guides. Ground wires shall be tight and true to line, and placed in such a manner that they may be further tightened.

8.5 Placing the Shotcrete — Each layer of shotcrete is built up by making several passes or loops of the nozzle over the working area. This may be done by moving the nozzle rythmically in a series of loops from side to side and up and down (*see* Fig. 1 and 2). The shotcrete shall emerge from the nozzle in a steady, uninterrupted flow. If the flow becomes intermittent due to any cause, the operator shall direct it away from the work until it again becomes constant. The distance of the nozzle from work (usually between 0·5 and 1·5 m) shall be such as to give the best results for the working conditions. The nozzle shall be held perpendicular to the surface of application. However, when gunning through and encasing reinforcing bars, the nozzle shall be held closer and at a slight angle from the perpendicular. Also the mix shall be little wetter than normal, but not so wet as to cause sloughing behind the bar. This procedure forces the plastic shotcrete behind the bar while preventing build-up on the front face of the bar. Where bars are closely spaced, more than one bar may be shot from each position. Fig. 3 shows effects of correct and incorrect nozzle operation in encasing reinforcement with shotcrete.

*Code of practice for plain and reinforced concrete (*third revision*).

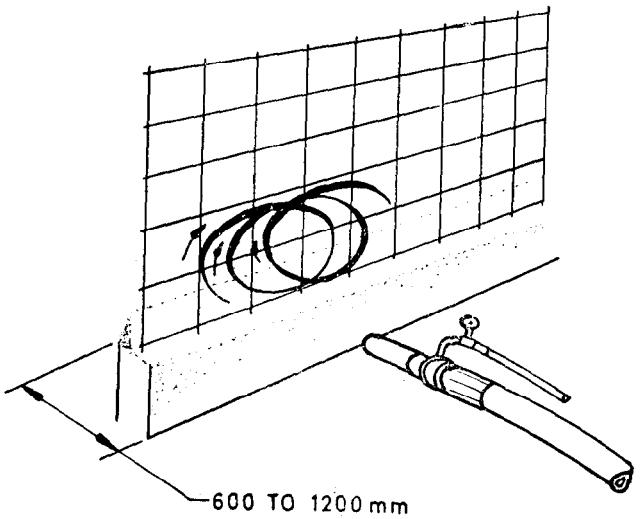


FIG. 1 CORRECT USE OF THE NOZZLE

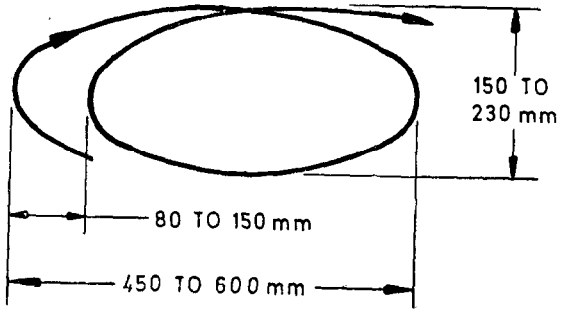
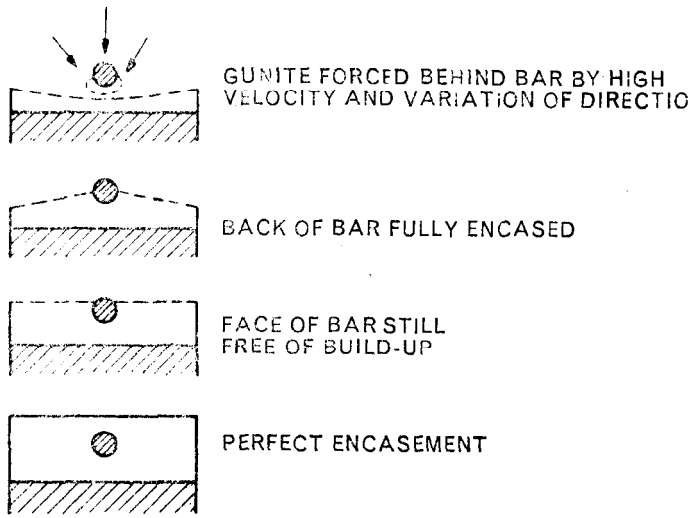
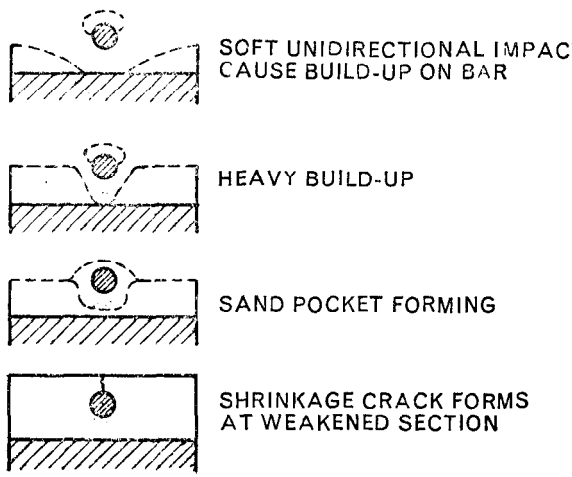


FIG. 2 APPROXIMATE SIZE OF THE LOOP



3A Correct Nozzle Operation



3B Incorrect Nozzle Operation

FIG. 3 THE EFFECT OF CORRECT AND INCORRECT NOZZLE OPERATION IN ENCASING REINFORCING BARS WITH SHOTCRETE

8.5.1 For walls, columns and beams, the application shall begin at the bottom. The first layer shall at least completely embed reinforcement adjacent to the form. The thickness of layer is governed mainly by the requirement that the shotcrete shall not sag. Where thick layers are applied, it is important that the top surface is maintained on a 45° slope approximately, and that rebound is kept out of the work. Fig. 4 shows a shotcreting operation on a vertical wall, the top surface of the shotcrete is kept at 45° so that the rebound falls clear of the work. In shooting slabs, the nozzle shall be held at a slight angle from the perpendicular so that rebound is blown on to the completed portion from where it can be removed.

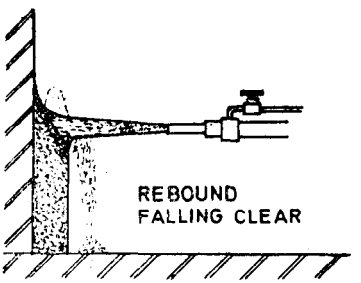


FIG. 4 SHOTCRETING ON VERTICAL WALL FROM BOTTOM TO TOP

8.6 Rebound — Rebound is aggregate and cement paste which ricochets off the surface during the application of shotcrete due to collision with the hard surface, reinforcement, or with the aggregate particles themselves. The amount of rebound varies with the position of the work angle of the nozzle, air pressure, cement content, water content, size and grading of aggregate, amount of reinforcement and thickness of layer. Depending on the position of the work, the variation in the amount of rebound may be as below:

Surface	*Percentage of Rebound*
Floor or slabs	5-15
Sloping and vertical walls	15-30
Overhead work	25-50

Figure 5 indicates the effects of the angle at which the shotcrete hits the wall on the percentage of rebound. A small circular motion with the gun held in such a way as to provide 90° impact provides minimum rebound (*see* Fig. 6). Initially the percentage of rebound is large, but it

becomes less after a plastic cushion has been built up. Rebound is much leaner and coarser than the original mix. The cement content of the in-place shotcrete is, therefore, higher because of rebound; this increases the strength but also the tendency towards shrinkage cracking.

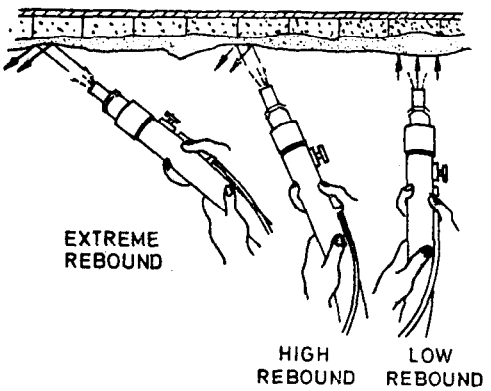


FIG. 5 EFFECT OF NOZZLE ANGLE ON REBOUND

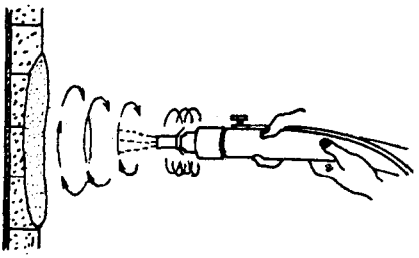


FIG. 6 METHOD OF SHOTCRETING OPERATION FOR MINIMUM REBOUND

8.6.1 Rebound shall not be worked back into the construction. If it does not fall clear of the work, it shall be removed. Rebound shall not be salvaged and included in later batches because of the danger of contamination; also it may affect the cement content, state of hydration, and the grading of the aggregate.

8.7 Construction Joints — Construction joints are generally tapered to a thin edge over a width of about 300 mm. A joint of somewhat better appearance 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. However, when the joint is likely to be subjected to compressive stress, square joints are commonly required; in such a case steps shall be taken to avoid or remove trapped rebound at the joint. The entire joint shall be thoroughly cleaned and wetted prior to the application of additional shotcrete.

8.8 Preparation for Succeeding Layers — Where a layer of shotcrete is to be covered by a succeeding layer, it shall first be allowed to take its initial set. Then all laitance, loose material and rebound shall be removed by brooming. Any laitance which has attained final set shall be removed by sand-blasting and the surface cleaned with an air water jet.

In addition the surface shall be thoroughly sounded with a hammer for drummy areas resulting from rebound packets or lack of bond. Drummy areas, sags, or other defects shall be carefully cut out and replaced with the succeeding layer. Surfaces to be shot shall be damp.

8.9 Finishing — The natural gun finish is normally preferred from both the structural and durability considerations. There is danger that further finishing may disturb the section, harming the bond between the shotcrete and reinforcement, and between the shotcrete and the underlaying material, and creating cracks in the shotcrete. Additional finishing may also be difficult to accomplish, especially for the drier mixes.

8.10 Suspension of Work

8.10.1 The application of shotcrete shall be suspended in condition of likely exposure to high winds, freezing or rain.

8.10.2 At the end of each day work, or on stopping work for any other reason, the shotcrete shall be slopped off to a thin edge and then the work shall be resumed on next day after cleaning the surface.

8.11 Curing — Good curing is particularly important for the very thin sections, rough surfaces, and mixes of low workability normally associated with shotcrete. It is generally recommended that surfaces be kept continuously wet for at least 7 days (*see* IS : 456-1978*).

8.12 Quality Control — 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 shotcrete.

8.12.1 It is generally not feasible or desirable to core the structure to obtain specimens for regular control tests. Therefore small unreinforced

*Code of practice for plain and reinforced concrete (*third revision*).

test panels, at least 30 cm square and 75 mm thick, shall be periodically gunned, and cores or cubes extracted for compressive tests and visual examination (*see* **6**).

8.12.2 Test cores shall also be taken from the completed work as often as necessary to ensure that the control tests reflect the quality of material in the structure.

8.12.3 Concrete cubes prepared by directly gunning into 15 cm cube moulds may also be used for day to day quality control tests. In such cases, the results should be correlated to the results from tests of cubes made from panels (*see* **8.12.1**).

8.12.4 Frequency of sampling of shotcrete for the purpose of quality control shall be as agreed upon between the engineer-in-charge and the contractor.

8.13 Inspection — The shotcreting operation shall be continuously inspected by a qualified supervisor who shall check materials, forms reinforcing, ground wires, delivery equipment, application of material, curing, and protection against high or low temperature. Each layer of shotcrete shall be systematically sounded with a hammer to check for drummy areas. Cores shall be taken from the structural shotcrete; such cores shall be taken as early in the job as practicable so that the data obtained can be used to effect improvements in later work.

8.13.1 The permissible tolerance on the thickness of the work executed by shotcrete shall be $^{+8}_{-3}$ mm.

9. SKILL OF OPERATOR

9.1 The quality of shotcrete depends to a great extent on the skill of the operator in much the same way as the quality of a weld depends on the welder. The foreman, nozzleman, and delivery equipment operator shall be experienced in similar capacities for a sufficient period to be fully qualified to perform his duties.

9.2 A method used for checking the qualifications of a nozzleman is to gun test panels 60 cm or 90 cm square, and 50 mm or more thick, using typical reinforcement for the job. Compressive strength tests are made on cubes of various sizes sawed from these panels. When the test panel is cored, cut up, or broken open, it will indicate not only the strength, but also of suitability of the mix, the effectiveness of the reinforcement, and the skill of the nozzleman.

(*Continued from page* 2)

Concrete Subcommittee, BDC 2 : 2

Members	*Representing*
SHRI C. R. ALIMCHANDANI	Stup Consultants Ltd, Bombay
SHRI M. C. TANDON (*Alternate*)	
SHRI D. CHAKRAVARTY	Engineers India Ltd, New Delhi
DEPUTY DIRECTOR, STANDARDS (B & S)	Research, Designs and Standards Organization (Ministry of Railways), Lucknow
ASSISTANT DIRECTOR, STANDARDS (M/C) (*Alternate*)	
DIRECTOR	Engineering Research Laboratories, Hyderabad
DIRECTOR (C & MDD)	Central Water Commission, New Delhi
DEPUTY DIRECTOR (C & MDD) (*Alternate*)	
SHRI V. K. GHANEKAR	Structural Engineering Research Centre (CSIR), Roorkee
SHRI A. S. PRASADA RAO (*Alternate*)	
DR R. K. GHOSH	Central Road Research Institute (CSIR), New Delhi
SHRI M. R. CHATTERJEE (*Alternate*)	
SHRI V. K. GUPTA	Engineer-in-Chief's Branch, Army Headquarters, New Delhi
SHRI S. V. TIGARE (*Alternate*)	
SHRI J. S. HINGORANI	Associated Consulting Services, Bombay
SHRI A. P. REMEDIOS (*Alternate*)	
SHRI P. J. JAGUS	The Associated Cement Companies Ltd, Bombay
SHRI M. R. VINAYAKA (*Alternate*)	
SHRI G. C. MATHUR	National Buildings Organization, New Delhi
SHRI G. T. BHIDE (*Alternate*)	
SHRI K. K. NAMBIAR	In personal capacity (*'Ramanalaya' II First Crescent Park Road, Gandhinagar, Adyar, Madras*)
SHRI N. S. RAMASWAMY	Roads Wing (Ministry of Shipping and Transport)
SHRI R. P. SIKKA (*Alternate*)	
SHRI T. N. S. RAO	Gammon India Ltd, Bombay
SHRI S. R. PINHEIRO (*Alternate*)	
SHRI M. P. GAJAPATHY RAO	Public Works and Housing Department, Bombay
SUPERINTENDING ENGINEER, DELHI CENTRAL CIRCLE NO. 2	Central Public Works Department, New Delhi
SHRI S. G. VAIDYA (*Alternate*)	
DR C. A. TANEJA	Central Building Research Institute (CSIR), Roorkee
SHRI B. S. GUPTA (*Alternate*)	
SHRI B. T. UNWALLA	The Concrete Association of India, Bombay
SHRI T. M. MENON (*Alternate*)	
DR H. C. VISVESVARAYA	Cement Research Institute of India, New Delhi
DR A. K. MULLICK (*Alternate*)	

BUREAU OF INDIAN STANDARDS

Headquarters :

Manak Bhavan, 9 Bahadur Shah Zafar Marg, NEW DELHI 110002

Telephones : 331 01 31
331 13 75

Telegrams : Manaksanstha
(Common to all Offices)

Regional Offices : *Telephone*

Central	: Manak Bhavan, 9, Bahadur Shah Zafar Marg, NEW DELHI 110002	331 01 31 331 13 75
* Eastern	: 1/14 C.I.T. Scheme VII M, V.I.P. Road, Maniktola, CALCUTTA 700054	37 86 62
Northern	: SCO 445-446, Sector 35-C, CHANDIGARH 160036	53 16 40
Southern	: C.I.T. Campus, IV Cross Road, MADRAS 600113	235 23 15
† Western	: Manakalaya, E9 MIDC, Marol, Andheri (East), BOMBAY 400093	632 92 95

Branch Offices :

'Pushpak', Nurmohamed Shaikh Marg, Khanpur, AHMADABAD 380001	2 63 48
‡ Peenya Industrial Area, 1st Stage, Bangalore-Tumkur Road, BANGALORE 560058	39 49 55
Gangotri Complex, 5th Floor, Bhadbhada Road, T.T. Nagar, BHOPAL 462003	55 40 21
Plot No. 21, Satyanagar, BHUBANESHWAR 751007	40 36 27
Kalai Kathir Building, 6/48-A Avanasi Road, COIMBATORE 641037	21 01 41
Plot No 43, Sector 16A, Mathura Road, FARIDABAD 121001	8-28 88 01
Savitri Complex, 116 G. T. Road, GHAZIABAD 201001	8-71 19 96
53/5 Ward No. 29, R.G. Barua Road, 5th By-lane, GUWAHATI 781003	4 11 37
5-8-56C L. N. Gupta Marg, (Nampally Station Road) HYDERABAD 500001	20 10 83
R14 Yudhister Marg, C Scheme, JAIPUR 302005	52 13 74
117/418 B Sarvodaya Nagar, KANPUR 208005	21 68 76
Plot No. A-9, House No. 561/63, Sindhu Nagar, Kanpur Road, LUCKNOW 226005	5 55 07
Patliputra Industrial Estate, PATNA 800013	26 23 05
C/o Smt. Sunita Mirakhar, 66 D/C Annexe, Gandhi Nagar, JAMMU (TAWI) 180004	—
T. C. No. 14/1421, University P. O., Palayam, THIRUVANANTHAPURAM 695034	6 21 04

Inspection Offices (With Sale Point) :

Pushpanjali, First Floor, 205-A West High Court Road, Shankar Nagar Square, NAGPUR 440010	52 51 71
Institution of Engineers (India) Building, 1332 Shivaji Nagar, PUNE 411005	5 24 35

*Sales Office Calcutta is at 5 Chowringhee Approach, P. O. Princep Street, CALCUTTA — 27 99 65

† Sales Office is at Novelty Chambers, Grant Road, BOMBAY — 309 65 28

‡ Sales Office is at Unity Building, Narasimharaja Square, BANGALORE — 22 39 71

Printed at Dee Kay Printers, New Delhi, India