New technologies for strengthening damaged reinforced concrete structures

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The aim of the study is to find new technologies for the rehabilitation of reinforced concrete structures damaged by earthquake. After analysing the shortcomings of standard types of concrete guniting equipment, new devices were tested and developed in order to improve the flow batching of the aggregate-cement mixture. A batching chamber device was designed to create a separate area where each part of the mix is continuously taken, thus determining a continuous flow. A nozzle was provided at the end of the flow for better mixture. The nozzle was equipped with an area, where water is pushed in at a pressure exceeding that of the air in the discharge pipe. Tests were also conducted to develop new methods of cutting down material loss by bouncing, to improve adherence between the support surface and the gunited concrete layer and to find new procedures for controlling pre-compression force.

Keywords: Concrete mix, damaged structures, gunite.

CONCRETE application methods for strengthening damaged structures may be grouped into two categories: the standard placing method and the guniting procedure. The guniting method comprises special concrete preparation followed by placing and compacting technological procedures which involve blowing compressed air into the mixture by means of special devices called gunite machines. The most frequently used method is the dry process which involves contact between cement and necessary amount of water at the end of the flow by means of a special device.

It was observed that gunited concrete has higher compactness, high compression, stretching strength and low permeability. For these reasons, its use is recommended in reinforced concrete waterproofing and for protection against aggressive factors[1]. This procedure is most appropriate for concrete reinforced with dispensed fibres. Gunited concrete is also used for construction of new buildings with specially shaped elements; it is used for lining tunnels, for making the wearing course of intensely used railways; this method is also used for slope stabilization. Gunite can be considered the most efficient method for concrete structures strengthening, from the point of view of the strength achieved and also for adhesion to the support surface[2].

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Guniting is the only procedure which allows concrete application in areas which are hardly accessible through standard placing, such as coating columns at the upper part of structural walls, side areas of girders, the lower side of plates and girders, and overhead guniting.

According to the construction features and functional parameters, gunite machines can be grouped into two types: (i) machines with cylindrical drum and batching cylinders and (ii) machines with pressure chamber and batching disks.

Gunite machines with cylindrical drums have several cylindrical holes at its ends. The volume of a cylinder is between 600 and 1000 cm^3. A pipe system enables the flow of the cement–aggregate mixture from the filling container to the discharge hose. The engine driven cylindrical drum spins and successively brings each cylinder to the mixture filling area and then to the pipe area where heading occurs under air pressure[3].

The spinning cylindrical drum has to be tightened both at the upper and at the lower end by means of perfectly flat and smooth steel plates and rubber stuffing.

Due to friction, stuffing is easily worn-out and must be replaced frequently; in addition, holes are usually not perfectly sealed, so the machine will have compressed air, dust and cement loss.

The main functional parameters consist of an output rate of gunite concrete equal to 3–5 m^3/h and the feed rate of air necessary for the functioning is 10–20 m^3/min under a pressure of $5–7 \times 10^5$ Pa.

The main shortcoming of this type of machine is the fact that the mixture does not have a continuous and homogeneous flow. It has a pulse functioning. This occurs because of the large volumes of batching cylinders and mixture quantity of about 600–1000 cm^3. During its passage through the discharge hose, the mixture has various densities and contact with water occurs with difficulty. On discharge from the machine, dust is present; the quality of the concrete on the support surface is not consistent and on account of the variable spraying pressure, the surface of the gunite concrete has large uneven areas.

In gunite machines with pressure chamber, the lower area of the machines is equipped with a disc with cells on its edge. The upper area comprises two chambers separated from one another and from the outside by valves tightened with rubber stuffing[4]. Through the two valves, the chambers, which are under pressure, can receive the aggregate–cement mixture from outside. These machines do not have an individual batching system; the mixture is taken by the discharge pipe from the aggregate amount which lies in the lower chamber, the cells having the sole function of carrying the mixture.

The main parameter is the output rate of the gunite concrete of 2–3 m^3/h; the proper function of the machine requires an air feed of 10–12 m^3/min under a pressure of $4–6 \times 10^5$ Pa.

The main deficiency of this type of machine is the fact that the output rate is not constant because it depends on the quantity of mixture in the area of the outlet port.

After studying the shortcomings of the two types of equipment, various devices were conceived and tests with the following objectives were performed.

- Batching continuous cement–aggregate mixture flow.
- Mixing and homogenization of the components: aggregate–cement–water.
- Concrete flow should be as homogeneous as possible, well defined and have a long truncated cone shape.
- Pressure at the contact with the support surface should be as uniform as possible.
- Surface of the gunited concrete should have minimum uneven areas.

In order to carry out the batching of the continuous cement–aggregate mixture flow, the device is composed of a dosing chamber which creates a separate area in which each amount, isolated through a cell, is continuously taken from there; the cells are small and measure 30–50 cm^3 in volume.

A homogeneous mixture with the transportation agent, air is obtained whose access inside the dosing chamber is achieved through a pipe placed off-centre, thus creating vortices of the transportation through the discharge hose and diminishing friction.

To realize the best composition of the dry aggregate–cement components with water, a nozzle is provided at the end of the flow; the nozzle has an area where the water flows at a pressure which is higher than air from the discharge hose. This area comprises a pierced ring, with 20–30 holes with diameter of 0.6–0.8 mm; through this ring water is sprayed into the aggregate–cement mixture[5].

The end of the nozzle is shaped like a truncated cone with an opposite side ratio between 1.2 and 1.8, with *in situ* testing of the quality and shape of the gunited mixture flow.

Figure 1 shows discharge hoses with an internal diameter varying between 22 and 48 mm.

Following the tests performed in laboratories to measure the quantity of the aggregate–cement–water components, and the *in situ* studies to observe the quality of the flow of gunited mixture, we have seen an improved quality in relation to its homogeneity, the constant long truncated cone shape and the flow of gunite concrete at the contact with the support surface varying between 80 and 200 mm.

The flow of the gunite concrete at the contact with the support surface and the suitable size of the print may be achieved by varying the parameters mentioned here.

Though many experiments were conducted *in situ* to produce tens of metres of gunited concrete, impure dusty air from the guniting room could not be eliminated despite improvizations. This makes it difficult to visualize the guniting process and at the same time is harmful to the operator. A new area was conceived for improving the homogeneity of the aggregate–cement–water mixture, next to the water mixing area. This area consists of a turbine with a number of blades which are moved by the stream of air pressure (Figure 2). Therefore a more close contact between components is achieved.

The designed assembly works as a small concrete mixer with forced mixing. The onsite experiments showed no traces of dust in the air, enabling the operator to clearly see the quality of the guniting process (Figure 3).

The improvement of the gunite equipment also enabled energy savings. The guniting process may occur with an air consumption of 3–5 m^3/min.

The design of new devices which significantly improve the performances of concrete guniting made possible the

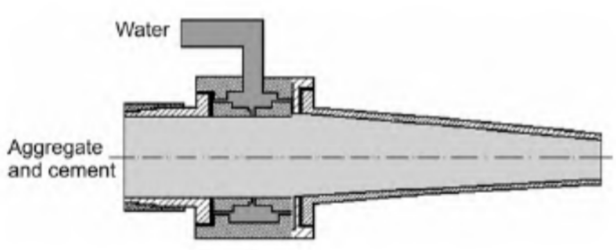

Figure 1. Heading hose.

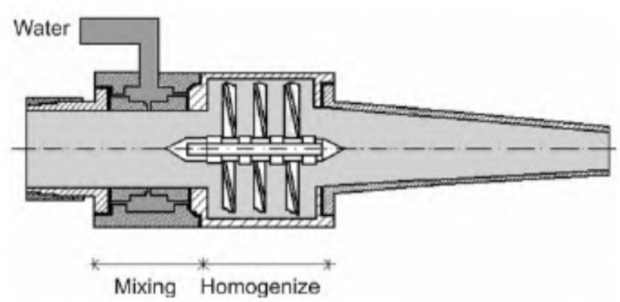

Figure 2. Turbine with a number of blades.

Figure 3. Air without dust.

strengthening of linear elements. It also triggered the possibility of achieving limited concrete areas according to the level of damage and selective strengthening needs (Figure 4).

It is well known that at the beginning of concrete hardening, calcium hydroxide migrates towards the outside of the components and in time it is carbonated; then it changes into calcium carbonate creating a layer with reduced mechanical properties. Within a couple of years this layer becomes 3–4 mm thick and then expands with passage of time.

Concrete guniting in an area where the carbonated layer is not removed does not guarantee any bonding. To test the quality of the gunite–support surface bonding, a gunite layer was applied to a support surface made of carbonated concrete. While trying to remove it after the hardening process, the breaking was through the carbonated concrete layer and not at the contact between the gunite and the support surface. It is therefore necessary to clean-off the carbonated concrete layer from the support surface. Trying to remove this layer with a wire brush, by bush hammering, chiselling or sand blasting was not helpful.

In the experiments, a number of striking devices having a key-type breaking of the carbonated concrete layer were used. A well processed, coarse surface with cleaved aggregate granules was obtained (Figure 5).

Guniting the concrete layer determines significant losses of the material used[6]. When applying the gunited concrete on a vertical area, the amount of aggregate–cement material which does not settle within the layer is 15–25%. When applying the gunited concrete on the lower side of the elements and overhead guniting, the losses are nearly 30–40%.

During experiments, when studying the causes bringing about large material losses which usually occur in the first stage of gunited concrete placing, it was seen that this was determined by the maximal size of aggregate particles which bounce back from the support surface. And this occurs in the first stage because the support surface does not have a mortar layer where particles may settle (Figure 6).

During the experiments, a layer of mortar was placed before guniting; the layer was as thick as the diameter of the largest particles. The aggregate particles settle in the

Figure 4. The guniting process of a horizontal strap.

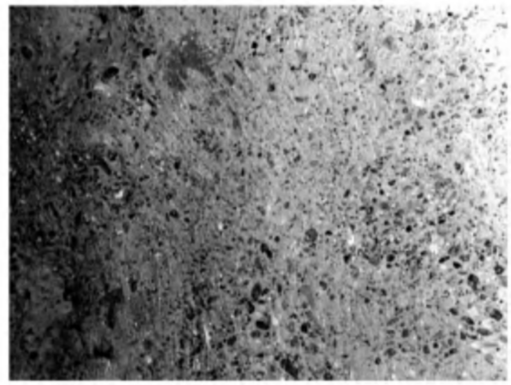

Figure 5. Cleaved aggregate particles after removing the concrete carbonated layer.

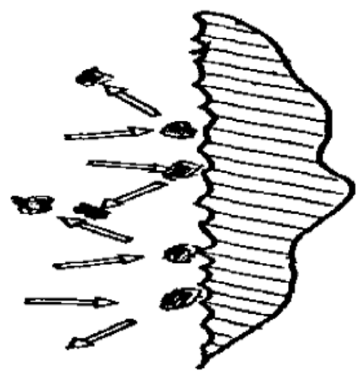

Figure 6. Bouncing of aggregate particles at their impact with the support surface.

Figure 7. Determining the pre-compressive force with a torsion dynamometer.

Table 1. Standard concrete compositions

Code	Concrete type	W (l/m^3)	W/C	C (kg/m^3)	Fl (l/m^3)	A_g (kg/m^3)	ρ'_b (kg/m^3)
SC	C16/20–P_8^{10}–T_3/T_4–II/A–S32,5R/0–31/II	205	0.50	410	–	1740	2355
CAF	C16/20–P_8^{10}–T_4/T_5–II/A–S32,5R/0–31/II–FL	165	0.40	410	0.60	1725	2300
GC1	C16/20–P_8^{10}–T_3/T_4–II/A–S32,5R/0–16/II–gunite	180	0.44	410	–	1815	2405
GC2	C16/20–P_8^{10}–T_3/T_4–II/A–S32,5R/0–7/II–gunite	165	0.40	410	–	1855	2430

SC, Standard concrete; CAF, Concrete with additives; GC1, GC2, Gunited concretes.

Table 2. Concrete resistance

	Concrete type			
Resistance (MPa)	SC	CAF	GC1	GC2
R_2^{N8}	36.0	36.0	36.5	36.7
R_9^{N0}	42.0	44.6	44.0	45.0
R_{28+g}^{N}	42.8	44.3	45.0	45.5
R_{28+g}^{N+g}	38.7	41.1	42.2	44.1
R_{90+g}^{N}	44.0	46.1	47.5	48.5
R_{90+g}^{N+g}	41.0	44.2	46.3	47.4

Table 3. Concrete permeability

	Concrete type			
Permeability (cm)	SC	CAF	GC1	GC2
P_{8-28}^{N}	4.03	2.96	2.03	1.83
P_{8-28+g}^{10-N+g}	5.30	4.72	2.76	2.10
P_{8-90+g}^{10-N+g}	4.72	2.25	2.10	1.98

N, The medium temperature of the results θ_{bm} = 20°C in laboratory; g, The period of time, expressed in days, of the gelation test G_{50}.

Figure 8. Gunited concrete immediately after application.

mortar layer, while the additional mortar migrates towards the outside of the gunited concrete layer. The additional mortar forms the outside surface of gunited concrete and may be used in finishing works. By applying this layer of mortar, losses were cut down to 40–50%.

In the case of selectively strengthening certain areas of the damaged elements by using straps, the possibility of introducing controlled stress to favour co-working was tried[7].

Pre-compressive forces were controlled by two methods: (i) with a torsion dynamometer and (ii) with a designed and calibrated device which measures the arrow of the loaded strap perpendicularly acted by a force (Figure 7).

Experiments were conducted using standard concrete compositions with super water-reducer placed concrete in opposition with gunited concrete which, although having the same quantity of cement differed in the W/C ratio, through the quantity of mixing water and the diameter of aggregate particles (Table 1).

Mechanical and durability performances of gunited concrete have been compared to the performances of standard concrete and with those of concrete with additives, placed concrete or compacted by vibration (Tables 2 and 3).

Compression strengths for 28 days, respectively 90 days are higher (with 12.5–15%) than minimal values enforced by standards. This was determined by the waterproofing requirement P_8^{10} which limits the value of the water–cement ratio to maximum 0.50 for standard concrete (W/C = 0.53 in order to fulfil the class condition) and the water–cement ratio equal to 0.40–0.44 for gunited concrete or that with additives.

The compression strength of concrete undergoing the G_{50} gelation test diminishes by 7–10% in the case of standard concrete, 4–8% in the case of the concrete with super water-reducer and 3–7% in the case of the gunited concrete, which has the best behaviour during this test. It is significant that the compression strengths of all types of concrete subjected to the G_{50} frosting–defrosting test are higher than the minimum required strength provided under standard CP 012/1-2007.

Gunited micro-concrete as well as concrete with super plasticizers display a good behaviour as far as permeability is concerned – the value of permeability is approximately 5–6 times smaller than the required one. Even after the G_{50} frosting–defrosting test was performed, the value of permeability of gunited micro-concrete is nearly 4–5 times smaller than the regulated limit. The best behaviour at the permeability test was that of gunited micro-concrete with 0–7 mm aggregate at the lower limit of granularity. The permeability of the micro-concrete undergoing the frosting–defrosting test increases by 6% up to 20%, but it is 4–5 times smaller in the case of the gunited micro-concrete in comparison with the allowed limit.

Gunited concrete with the use of newly designed devices (composition GC_2, Table 1) leads to the best performances (Figure 8). The result was a well-compacted concrete with firm consistency, which does not deform when pressed.

Concrete structures are designed and manufactured in order to meet a set of functional requirements for a long length of time, without involving high costs of maintenance and overhaul. This period of time, representing the designed service length is provided by a good initial quality. When degradation due to unforeseen factors is observed, the need to intervene becomes compulsory.

According to the type of deterioration, to its position and location, there are various methods of overhaul.

One of these procedures is achieved with a special device for placing the designed mixture by using compressed air.

The tests conducted in laboratories to measure the quantity of the components, and on site to observe the quality of the jet of gunited material showed an improved quality of concrete homogeneity.

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Inhibitory effects of vermicompost produced from agro-waste of medicinal and aromatic plants on egg hatching in *Meloidogyne incognita* (Kofoid and White) Chitwood

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Experiments were conducted to determine the efficacy of various vermicomposts produced from agro- and distillation-waste of medicinal and aromatic crops on hatching of eggs of *Meloidogyne incognita* (Kofoid and White) Chitwood and root-knot disease development in tomato. Results revealed that considerable inhibition in hatching of eggs occurs in the aqueous extracts of vermicompost produced from wastes of menthol mint (*Mentha arvensis*), chamomile (*Matricaria recutita*), geranium (*Pelargonium graveolens*), qinghao (*Artemisia annua*) followed by pyrethrum (*Chrysanthemum cinerariaefolium*), isabgol (*Plantago ovata*), African marigold (*Tagetes minuta*), Boerhavia (*Boerhavia diffusa*), mustard (*Brassica compestris*), lemongrass (*Cymbopogon flexuosus*) and garden mint (*Mentha viridis*). In a pot experiment, vermicomposts of menthol mint, African marigold, qinghao, isabgol and pyrethrum effectively reduced the root-knot infection in tomato.

Keywords: Hatching, medicinal and aromatic plants, *Meloidogyne incognita*, vermicompost.

PLANT parasitic nematodes are important plant pests causing enormous loss to agricultural crop productivity and it is difficult to manage them even with chemical nematicides. Adverse effects of chemical nematicides on environment, human health and non-target organisms, restrict their use in nematode management. There are several alternate methods for managing plant parasitic nematodes[1–3] but none provides a satisfactory control. Closer examination of life cycle of damaging phytonematodes has opened up the possibilities to manage these nematodes by inhibiting their reproduction by creating an environment unfavourable for nematodes to survive, lay eggs or hatch. Crop residues and other agro-waste from medicinal and aromatic plants (MAPs) have been found to be effective soil supplements in reducing intensity of root-knot nematode infection[1]. Further, a technology has been developed at our institute where crop waste from medicinal and aromatic plants has been utilized for production of vermicompost rich in macro- and micronutrients (US Patent no. 6488733)[4]. Application of

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