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CONCRETE FOR MAGNETIC SHIELDING

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ABSTRACT

The use of steel paper clips in the amount of 5 vol.% in concrete was found to result in concrete with magnetic shielding (60 Hz) ability comparable to steel mesh. Furthermore, the paper clips did not affect the compressive strength of the concrete. The paper clips were discontinuous enough for mixing with the concrete mix, while their intertwining tendency allowed sufficient continuity for magnetic shielding.

Introduction

The magnetic field resulting from underground transmission lines and other underground electric facilities (transformers, switches, etc.) is of perceived increasing national health concern. In 1988, the Public Service Commission issued a commission order directing utilities in New York State to investigate technologies for electromagnetic field (EMF) reduction or mitigation. Magnetic shielding (i.e., EMF encasement) is commonly achieved by using steel mesh [1,2]. Although steel mesh is effective, its continuous nature does not allow it to be incorporated in the concrete mix during mixing. The development of a concrete mix that is capable of magnetic shielding while being structurally acceptable is of great value to help facilitate widespread and low-cost implementation of magnetic shielding. As the mix must comprise discontinuous components, and magnetic shielding has been achieved by continuous material forms only, the achievement of a mix that is capable of magnetic shielding seems physically impossible. In this work, this seemingly impossible task was achieved by the use of a discontinuous magnetic component that is capable of linking up in the mix. This component is simply paper clips (as used in offices) made of steel. Although paper clips are discontinuous, they link up easily. We found that concrete containing 5 vol.% paper clips was able to provide as much magnetic shielding as a steel mesh, provided that the concrete slab was cured while being horizontal. Furthermore, the paper clips did not affect the compressive strength of the concrete.

Experimental

Materials

The paper clips were made of steel with zinc plating, as supplied by ACCO for office use. Their length was 1.25 in (3.18 cm). Their width was 0.25 in (0.64 cm). The wire diameter was 0.031 in (0.079 cm). The steel mesh used for comparison was made up of 0.6 mm diameter wires, such that the distance from the center of a hole to that of an adjacent hole in the mesh was 5.64 mm.

The concrete mix involved water/cement ratio 0.50, and cement/fine aggregate/coarse aggregate ratio 1 : 1.5 : 2.5 (by weight). The fine aggregate all passed through #4 U.S. sieve; the coarse aggregate all passed through 1 " sieve. A water reducing agent (TAMOL SN, Rohm and Haas Co., Philadelphia, PA; sodium salt of a condensed naphthalenesulphonic acid) was used in the amount of 2% of cement weight. All ingredients were mixed in a stone concrete mixer for 15-20 min. Curing of the concrete was allowed to occur in air at a relative humidity of 33%. The concrete slab for magnetic shielding testing measured 420 x 420 x 60 mm. During curing, the slab was either horizontal or vertical. The concrete cylinder for compressive testing (ASTM C39-83b) measured 4 in (102 mm) diameter x 8 in (203 mm) length.

Magnetic shielding effectiveness testing

Magnetic shielding effectiveness testing was conducted by placing the source of the magnetic field (i.e., the transmitter) on one side of the slab and touching the slab (placed vertically during testing) and placing the receiver (which measured the field that leaked through and around the slab) on the other side, such that, by moving the receiver, the distance between the near ends of transmitter and receiver was varied from 3 to 7 in (7.6 to 18 cm) and the transmitter and receiver were centered along the same axis, which was perpendicular to the slab and 115 mm above the mid-point of the bottom edge of the vertically placed slab. For each slab, four data were obtained by placing the slab consecutively on its four edges, such that the slab remained vertical for each position. For the sake of comparison, the magnetic shielding effectiveness of two layers (held together by adhesive tape) of steel mesh (without any matrix) was measured. The mesh sheet size was 290 x 275 mm. The double mesh was placed consecutively on its four edges, such that the mesh was vertical for each position and the center of the transmitter/receiver was 115 mm above the mid-point of the bottom edge of the vertically placed mesh. The transmitter was made of #12 wire coiled 100 times around a plastic cylinder (7 cm diameter); the wire carried an AC (60 Hz) current of 8.5 A during testing. The magnetic induction is given by the equation

$$B = \frac{\mu_o n I}{2r} \tag{1}$$

where

B = the magnetic induction at the center of the coil,
μ_o = permeability of air,
n = number of turns,

I = current (8.5 A), and
r = average radius of the coil (3.5 cm).

The receiver comprised 2000 turns of #40 wire wound concentrically around a 4 in. diameter polyvinyl chloride pipe. The output voltage is related to the magnetic induction by the equation

$$V_{out} = wBAn\ , \tag{2}$$

where

V_{out} = output voltage,
w = frequency (60 Hz)
B = magnetic induction (T)
A = area (m^2), and
n = number of turns

Eq. (1) is valid only for points at zero distance from the coil. For points at a distance z from the coil, B is given by

$$B = \frac{\mu_o I r^2}{2(r^2+z^2)^{3/2}}\ , \tag{3}$$

where r = radius of the coil (m), and
z = axial distance (m) from coil.

Results

The 7-day compressive strength, based on at least three specimens of each type, is shown in Table 1 for paper clip volume fractions from 0% to 5%. The compressive strength was not affected by the paper clip addition. The volume fraction of 5% was chosen for magnetic shielding effectiveness testing.

The magnetic shielding result at 28 days of curing is shown in Fig. 1 in terms of V_{out} vs. distance between the near ends of the transmitter and receiver. The lower is V_{out}, the greater

Table 1 Compressive strength at 7 days of curing

Paper clip volume fraction	Compressive strength (MPa)
0%	22.2 ± 4.2
3%	20.1 ± 0.8
5%	24.2 ± 0.8

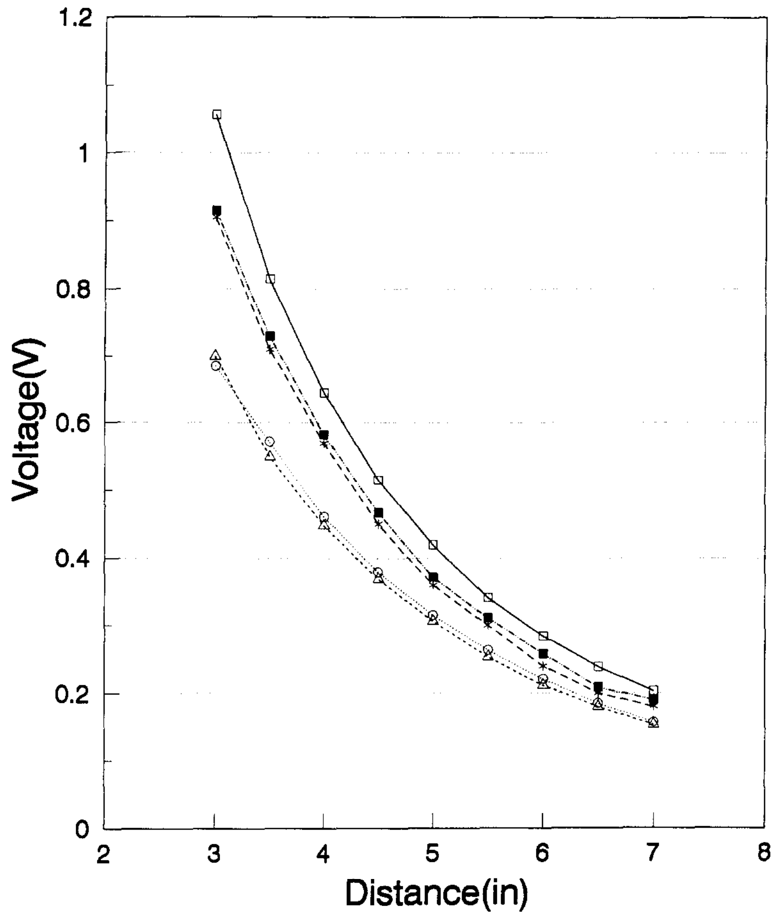

Fig. 1 Voltage detected by receiver as a function of distance between transmitter and receiver. □: no shielding material; Δ: steel mesh; ○ concrete with paper clips, cured horizontally; *: concrete with paper clips, cured vertically; ■ plain concrete. The voltage scatter was ± 0.7% for each data point in the case of concrete with paper clips, cured horizontally, and in the case of plain concrete. The voltage scatter was ± 7% for each data point in the case of concrete with paper clips, cured vertically. The voltage scatter was ± 0.4% for each data point in the case of steel mesh.

is the shielding effectiveness. Included in Fig. 1 for the sake of comparison are data for no shielding material, steel mesh, plain concrete (i.e., 0 vol.% paper clips), and concrete with 5 vol.% paper clips (slab cured horizontally and slab cured vertically). At a given distance between transmitter and receiver, the concrete with paper clips and cured horizontally exhibited essentially the same shielding effectiveness as steel mesh. The concrete with paper clips and cured vertically exhibited essentially the same shielding effectiveness as plain concrete. Plain concrete provided some shielding, but more was attained by adding 5 vol.% paper clips and curing horizontally.

The partial linking up of the paper clips was visually observed both during concrete mixing and after curing.

Discussion

In companion work [3], a variety of discontinuous fillers (without any matrix) were tested for their magnetic shielding ability. Each filler was loosely packed in a cardboard box (11 x 8.5 x 0.5 in) and tested as described above. These fillers included steel thumb tacks (20 vol.%), steel washers (0.25 in or 0.64 cm O.D., 0.31 in or 0.79 cm I.D., 50 vol.%), steel BB's (0.18 in diameter, 61 vol.%), and the paper clips (17 vol.%). The paper clips were found to be the most effective for magnetic shielding, in spite of their lowest volume fraction. The thumb tacks and BB's were similar in their effectiveness.

The origin of the effectiveness of the paper clips for magnetic shielding lies on the tendency for the paper clips to link up due to mechanical intertwining. This intertwining tendency is clear from everyday life experience, and was observed in this work visually. The attractive aspect of the paper clips is that, in spite of the intertwining tendency, they remain effectively discontinuous during mixing.

The orientation of the concrete slab with paper clips during curing is believed to affect the preferred orientation of the paper clips due to gravity, the effect of which was enhanced by vibration of the concrete mix when the mix was in the mold. Due to the difference in mold design between horizontal and vertical curing positions, the vibration was more thorough for the case of the horizontal curing position. Thus, the difference in preferred orientation between slabs cured horizontally and vertically is partly due to the difference in vibration thoroughness. A horizontal preferred orientation (i.e., the long axis in the plane of the slab) is more effective than a vertical preferred orientation for the slab's shielding ability. This dependence on orientation means that the paper clip reinforced concrete is most suitable for use as an overlay for concrete structures with underground transmission lines or other underground electric facilities. The use of paper clip reinforced concrete in place of steel mesh lowers the processing cost, as the latter requires an extra step of laying down the steel mesh prior to laying down the concrete overlay. Although this work used good quality paper clips, paper clips that are off specifications can be used instead for the purpose of cost saving.

Conclusion

Concrete's magnetic shielding effectiveness was enhanced to the level of steel mesh by the addition of steel paper clips in the amount of 5 vol.%, while the compressive strength was not affected. The paper clips were discontinuous enough for mixing with the concrete mix, but their intertwining tendency allowed the continuity required for magnetic shielding.

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