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Locating Faults in Cables Buried Below Loaded Structures

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This paper presents a method of improving the accuracy of locating discontinuities in underground multicore cables in partially wet conditions by capacitance measurements on the broken core, as well as intact cores.

Introduction

Measurements of temperature, pressure, load etc. by means of electrical transducers and recording them in a control room farther away, often involves laying of control cables underground. If any cable develops a fault subsequently, quickly locating them will avoid costly consequences. There are several methods available for this purpose, viz., two ammeter method, three ammeter method, fall of potential method, Murray loop test, Blavier's test, induction method, pulse return method etc. depending upon the type of fault and the equipment available.

Recently the technique of remote sensing by means of electrical transducers had been given a rather unusual application viz. to measure the loads of buildings. And when some of the cables failed in the buried portion, the site conditions imposed severe restrictions on the choice of fault locating methods. The present paper describes how a common method had been suitably modified to obtain the location more reliably.

Instrumentation of Building Foundations

Buildings are instrumented mainly to monitor settlements, cracks, tilts, loads etc.. The results obtained serve not merely to understand the behaviour of the building but also to check on the design assumptions. One such measurement is the distinction of contact pressure below footings, for which the Central Building Research Institute has developed transducers known as Soil Pressure Cells. A number of such cells are to be laid below the foundation, at the bottom of the cleaned up excavation, even before the first shovel of concrete is laid. The cells are placed with their faces downwards in contact with virgin soil and the lean concrete, damp-proof course etc. are laid over them in the usual sequence. The cables are led to the instrument room beyond the boundry.

As the construction progresses in stages–foundations, basement, ground floor, first floor etc.–the cells are read periodically. The measurements are continued beyond the completion and occupation of the buildings. From the readings one can determine the distribution of contact pressures below each footing as well as compute the weight of the building.

Project Details

Fig. 1 shows a portion of one such instrumentation project, where the cells were placed below the basement foundations about 7m. below ground level. Water table which was about 4.5m below ground level was lowered below the excavation level by continuous pumping. The cables were laid in a zig-zag manner in channels cut in the ground and led to the instrument room beyond the basement retaining wall. The vertical run of the cable was in steel conduits. The cells as well as the cables were covered with cement-sand mortar before placing the lean concrete.

Cable Failure

All the cells were functioning alright at the time of installation as well as for some months thereafter. Then in the course of next six months, one cell after other started failing by developing discontinuity in the cables, as evidenced by resistance check with a multimeter. By the time the basement was completed, six cells had failed–all because of rupture of cable conducters. Though there was absolutely no scope of repairs, recovery or replacement of the cells, it was decided to investigate the cable failures for future guidance.

Investigations

The problems faced during investigations were:

1. The thickness of concrete abruptly varied from 50 cm to nearly two meters above the cable run, ruling out any surface measurements.
2. There was a heavy reinforcement net above the cable run ruling out any surface detection by induction method.
3. Part of the cable was below water table and part was dry.
4. The farther end of the cable terminated in a resistance bridge inside the cell and was not accessible.
5. Only the free end of the cable was available.

A cut at the bottom of the vertical conduit and splicing of the cable prooved that the discontinuity was below the built-up area only.

Measuring the resistance, capaciance, and quality factor of th three cores with a low voltage bridge yielded the data in Table I. A similar measurement on an unused length of the same cable gave the data in Table. II.

A study of Table I shows that not only some conductors of the cables are broken, but the insulation resistance also has fallen down and the capacitance has increased enormously. This shows that water has entered the cable. This effect is different in different cables indicating different degrees of water penetration.

The usual method of locating the fault of the cable viz., could not be applied here because the capacitance per unit length of the submerged portion was dependent upon the degree of water penetration which was not known.

Hence help was taken from the other measurements from the intact cores, with the recognition that part of this capacitance was due to three cores in parallel, part due to two cores in parallel, part due to dry length and part due to wet length.

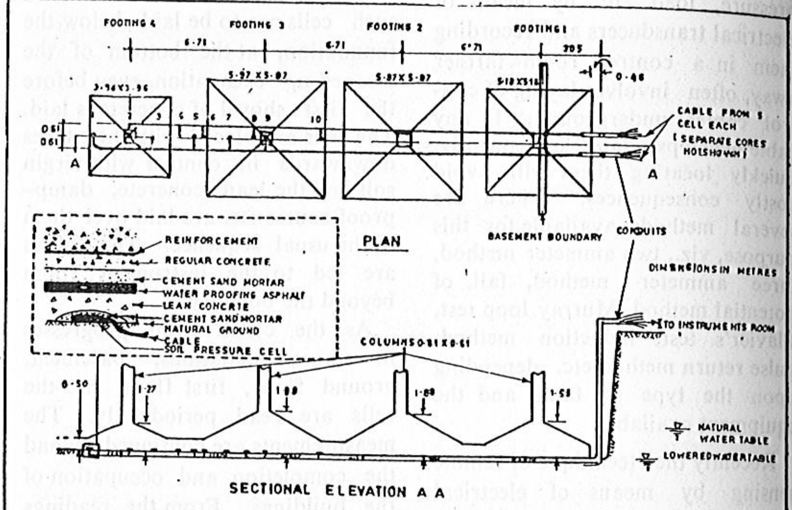

FIG.1 DETAILS OF SOIL PRESSURE CELL INSTALLATION

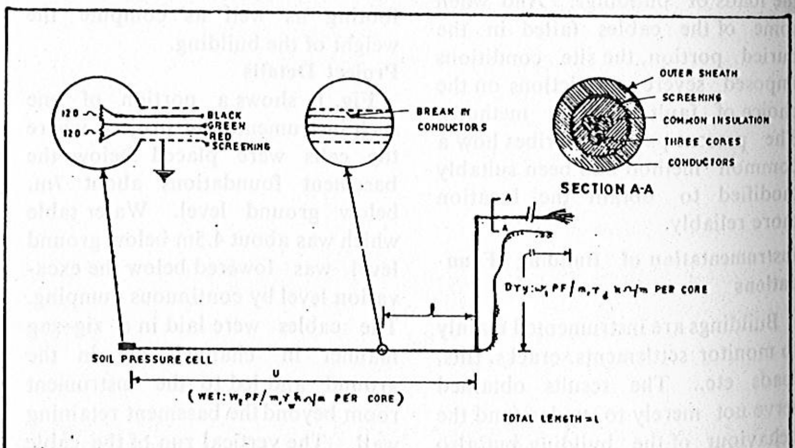

FIG.2. DETAILS OF CABLES.

Table 1. Measurements on faulty cables

Cell No.	Resistance with respect to green core (Ohms) Red	Black	Screening	Capacitance with respect to screening (pf) Red	Black	Green	Quality factor Red	Black	Green
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
5.	260,000	121	8,000	10,000	24,400	24,200	3.30	3.30	3.10
6.	129	20,000	10,000	12,000	8,000	12,500	0.60	0.80	0.80
7.	48,000	48,000	24,000	7,300	6,800	7,400	0.25	0.25	0.25
8.	68,000	62,000	26,000	8,000	8,000	8,000	0.25	0.25	0.25
9.	74,000	74,000	23,000	6,000	6,000	6,500	0.25	0.40	0.35
10.	4,500	122	1,040	180,000	426,000	440,000	3.00	3.80	3.80

TABLE. II. Measurements on sample cable.
(Measured on 40m length and calculated for 1 meter)

1. Conductor resistance.	= .0275	4. Capacitance between any one core and screening	$= w_1 =$ 115 pf
2. Insulation resistance between any core and screening. rd	= 4,000	5. Capacitance between two cores in parallel and screening.	$= w_2 =$ 180 pf
3. Quality factor	= 0.2	6. Capacitance between three cores in parallel and screening.	$= w_3 =$ 230 pf

Table. III. Computation of distance of discontinuity and change in cable properties

Cell No (1)	L (m) (2)	U * (m) (3)	A (pf) (4)	B (pf) (5)	W_1 (pf) (6)	l (m) (7)	A/w_1 (m) (8)	rw (kr) (9)
5	40	21.64	10.000	24,300	579	13.61	86.9	443
6	40	21.03	8,000	12,500	289	20.16	69.6	474
7	40	19.81	6,800	7,400	241	18.57	59.2	609
8	40	18.59	8,000	8,000	298	18.59	69.6	562
9	30	17.98	6,000	6,500	270	17.06	52.2	490
10	30	15.24	180,000	433,000	17,407	10.46	1565	37

* Includes lateral length and extra length for zig zagging.

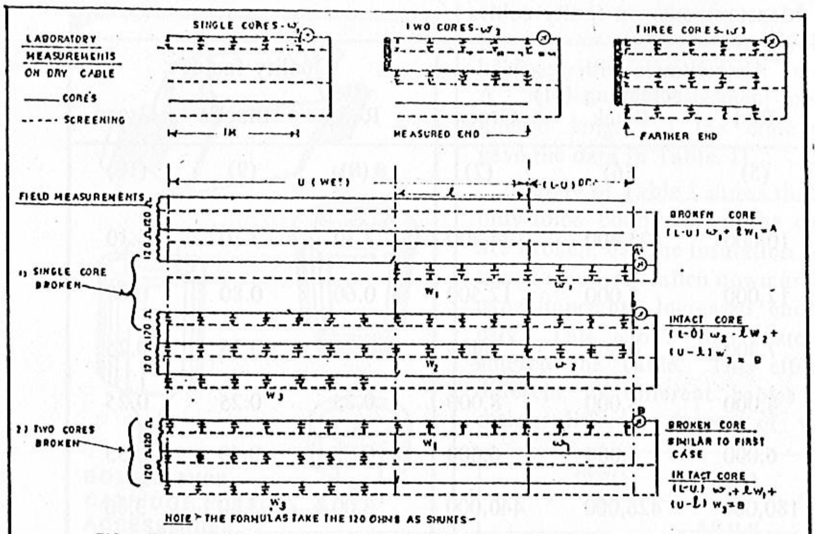

FIG.3. EQUIVALENT CIRCUITS OF CAPACITANCE MEASUREMENTS.

$$\text{Distance of discontinuity from the free end} = \frac{\text{Capacitance of discontinuous core}}{\text{Capacitance per unit length of the single core of similar cable.}}$$

Computations

Refering to Fig. 2, let

L = total length of a cable (m)

U = length of the cable under ground (m)

l = distance of the break from the vertical take-off point (m)

A = measured capacitance of the broken core. (pf)

B = same quantity of the intact core. (pf)

w_1, w_2, w_3 = capacitance per meter length of single core, two cores in parallel, three cores respectively in dry condition (pf)

W_1, W_2, W_3 = same quantities in wet condition (pf)

– all capacitances being with respect to screening.

From Table II,

$w_1 : w_2 : w_3 = 1 : 1.5 : 2$

Assuming the same relationship to hold good in the wet condition (whatever be the degree of wetting)

$W_1 : W_2 : W_3 = 1 : 1.5 : 2$ – I

$(L-U)\,w_1 + lW_1 = A$ – II

$(L-U)w_2 + lW_2 + (U-l)\,W_3 = B$ – III

Substituting for w_2, W_2 and W_3 in terms of w_1 and W_1 and simplifying

$1.5\,(L-U)w_1 + 2\,UW_1 - 0.5\,lW_1 = B$ – IV

solving between II and IV,

$$W_1 = \frac{0.5\,A + B - 2\,(L-U)w_1}{2U}$$

and $$l = \frac{A-(L-U)w_1}{W_1}$$

[Note: when two conductors are broken, $W_1 = \dfrac{A+B-2\,(L-U)w_1}{2U}$; l remains same]

L and U are known from the geometry of installation; w_1, A and B are measured, from which l and W_1 are readily found out.

In a similar manner, the insulation resistance per meter length rw of any core with respect to screening, under the wet condition has been estimated as per the relation.

$$rw = \frac{(3U-l)}{\dfrac{1}{R} - \dfrac{2(L-U)}{rd}}$$

where R = measured insulation resistance–column 4 of Table I

rd = insulation resistance per meter length in dry condition–Table. II

[Note: where two conductors are broken $rw = \dfrac{(3U-2l)}{\dfrac{1}{R} - \dfrac{(L-U)}{rd}}$

Discussion

The distance of discontinuities, so obtained, are compatible with installation details, as seen from columns 7 and 3 of Table III. On the other hand, comparison of columns 8 and 3 shows the failure of the usual method in this case. Since exposing the cables after excavation is ruled out, a direct proof of this method has not been possible. However an indirect proof is obtained from the insulation resistance values obtained based on estimated values of 'l'. Comparison of columns (6) and (9) shows that the increase in capacitance is always accompanied by a decrease in insulation resistance, showing the effect of water penetration.

Conclusions

For the given site conditions, locating the discontinuities by capacitance measurements on both the broken core and intact core improves the accuracy, compared to measurements on broken core only.

Application

This method holds the potentiality of being applied to locate breaks in some conducters of multi-cored cables provided at least one core is intact and the farther ends are bridged with low resistances. This method is independent of the degree of water penetration.

Acknowledgement

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