" AN INVESTIGATION INTO CONCRETE POLE DAMAGE TO THE INWABI PLATEAU DISTRIBUTION LINE "

by

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Abstract

The use of pre-stressed concrete poles for the Inwabi Plateau rural distribution line has presented unforseen problems for the Durban Electricity Service Unit, such as poor line performance and structural damage to the poles. The effects are thought to be due to lightning. This dissertation deals with an investigation into the cause of the damage as well as recommendations regarding the repair and prevention of future damage. To achieve this, an evaluation of the line Basic Insulation Level (B.I.L.) together with a review of the existing literature on the effects of lightning to overhead lines was used in order to establish what the specific damage mechanisms are. Field and laboratory tests were also undertaken as part of the investigation. Based on the results obtained, the overhead line was modified in terms of it's B.I.L. A preliminary evaluation of the modifications was done, with recommendations regarding further work to be done in the future.

Preface

When Durban Electricity first started using pre-stressed concrete poles, the manufacturer offered to provide an integral earth cast within the pole as an optional extra for system earthing. After making enquiries with the manufacturer regarding the electrical properties and ratings of the integral earth, I was not satisfied that what was being specified was electrically adequate. This led me to think about the effects of electrical current flowing through the pole re-inforcing and ultimately what the impulse withstand of the pole would be considering it's composition and re-inforcing. Soon after Duban Electricity started using the poles for rural distribution lines, the problems with the Inwabi Plateau distribution line were discovered. As I had already obtained four credits towards the Masters Diploma in Technology, an investigation into the problems with the line provided a good opportunity to complete the dissertation component of my diploma and to provide insight into the problem with the line.

This work was undertaken by me whilst in the employ of the Durban Metro Electricity Service Unit under the mentorship of Norman Kurz, Pr. Tech. Eng.

S. Turner

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CHAPTER 1 - Introduction

1.0 Introduction

The Durban Electricity Service unit has traditionally used wood gum poles for the construction of its 11000/400-volt overhead distribution lines. Due to advances and improvements in concrete pole design and the scarcity of wood poles during the "electricity for all" electrification campaign, D.E. adopted the use of a new pre-stressed concrete pole developed in New Zealand and produced locally under license by Grinaker Duraset. The poles which range from between two to four times the cost of a conventional wood pole provide the benefit of being maintenance free and are free standing within their design capabilities, thereby eliminating the requirement and additional cost of stays [1,2]. Initially the poles were used exclusively to support low voltage aerial bundle distributors but the scope of their application was later increased to include medium voltage aerial bundle and bare copper overhead lines as well.

The use of these poles proved very successful in their application to low voltage lines, but not enough thought had been given regarding their application to medium voltage overhead lines, particularly from an insulation co-ordination point of view. It became apparent that their performance was problematic with regard to the effects of lightning [3]. Hundreds of kilometres of medium voltage overhead lines had been installed but in certain areas there was structural damage occurring on the poles while in other areas the problem was not evident. One overhead line in particular appeared to be susceptible to such damage and that was the Inwabi Plateau 11000/400-volt distribution line [4]. It was decided to use this line to investigate the damage occurring to poles.

1.1 The Inwabi Plateau 11000 volt distribution line

The Inwabi Plateau distribution line is located on the Inwabi Plateau and supplies approximately 200 customers within the rural area. The Inwabi Plateau is situated approximately 30 Km's Southwest of Durban. The Plateau is fairly elevated in comparison with the surrounding area with elevations that vary between 660m to 580m above sea level [5] (See plate 1). The surrounding areas drop off to about 280m above sea level. The distribution line is approximately 16 km's in length and is a radially fed combined 11000/400-volt line with a number of medium and low voltage tee-offs. The main line runs along the top of the plateau, where its elevation is highest , the tee-offs run down to the lower surrounding areas – See plate 2. In addition to the 16 km's of 1100/400-volt line, there is an additional 6 km's of low voltage radial feeds, which are supplied from the main line. Of the 16 km's of medium voltage line 12 km's is built using concrete poles and the remaining 4 km's using traditional gum poles. The 6 km's of low voltage radial feeds use concrete poles.

Plate 1 - The Inwabi Plateau

Plate 2 - The Inwabi Plateau Distribution Line

1.2 Line Performance

The line was built and commissioned in September 1994 in order to provide the rural people of the Zwelibomvu area with electricity. Between September 1994 and September 1996 a total of 28 power outages were recorded [3] (see appendix F). The Power outages always involved complete line patrols to locate and repair faults before power could be fully restored. More often than not the cause of the tripouts was unknown and supply was usually restored without further tripouts. According to field staff, most outages occurred during lightning activity and rain. A local resident, Phillip Phewa commented that during storms he had seen "fire" on the lines. The reporting of numerous insulator failures by field staff during line inspections (see plate 3) was initially thought to be the cause of the high outage rate, but further inspections revealed that a significant number of pre-stressed concrete poles also exhibited structural damage, ranging from slight to severe.

1.3 Insulator Damage

The damage to the insulators, specifically the class B cycloaliphatic pin insulators was thought to be a result of a problem with their design and manufacture. The mode of failure in the majority of cases was a puncture through the insulating material to the spindle (see plates 32 & 33, pg. 104). By comparison, however, the section of medium voltage lines constructed on gum poles using identical insulators had no reported insulator failures.

Plate 3 - Insulator damage

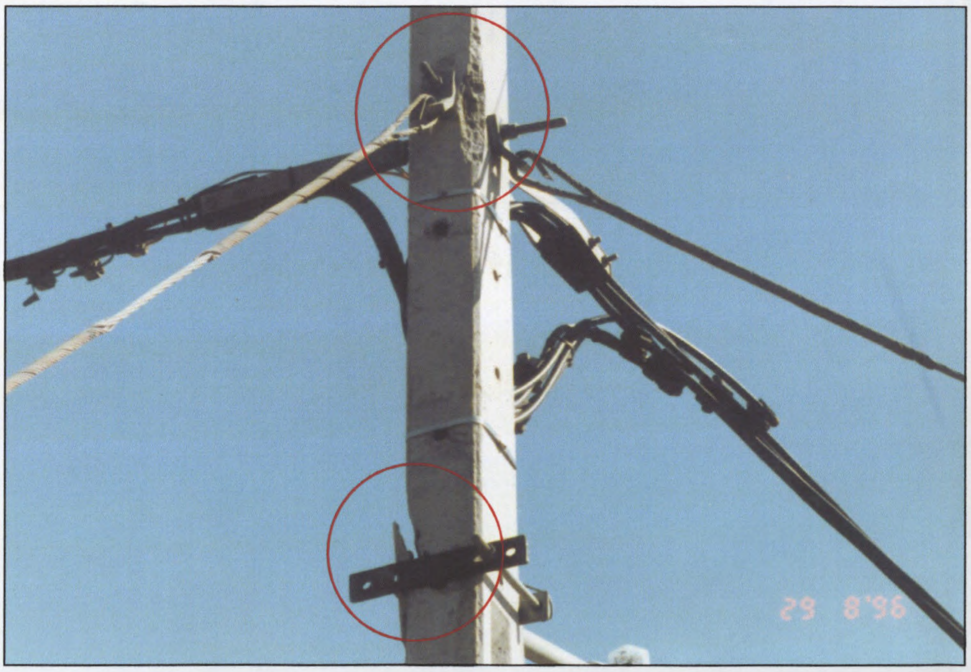


Plate 4 - Structural damage to concrete pole

1.4 Structural Damage to concrete poles

Further inspections during and after power outages revealed structural damage to the concrete poles (See plate 4). Prior to the line being commissioned it had been fully inspected after construction and found to be free from any structural defects. The structural damage varied in severity and appeared at random positions on the pole. In some cases the damage was severe enough to visibly expose the internal re-inforcing wires. This was cause for concern as the damage and subsequent corrosion of re-inforcing could ultimately render the pole unsafe and unserviceable.

1.5 Scope of Investigation

An investigation into the cause of the damage was necessary not only in an attempt to carry out preventative and remedial repairs to the line but also to re-assess the philosophy of using pre-stressed concrete poles for 11000 volt distribution lines. The extent of the damage to the entire line was quantified. There appeared to be a link between the structural damage to the poles, the insulator failures and the power outages during lightning storms. As a first step, a study of the lightning performance of distribution lines was necessary in order to gain an insight into the possible reasons for such damage. As the use of pre-stressed concrete poles for 11000-volt distribution lines is fairly recent, little or no research had been done on this problem. By comparison the effects of lightning on traditional wood pole distribution lines has been well-documented [6,7,8,9,10]. A review of this research was done as much of the theory and practices could be applied to the concrete poles, which used the same, or similar pole hardware and line configurations as the traditional wood pole construction.

Finally, remedial measures based on the findings of the investigation were partially implemented on a trial basis for evaluation. The collection of data and results require at least a couple of lightning seasons. Only preliminary results are covered over the first season following the implementation of the remedial measures. Further action will be required in the future.

CHAPTER 2 – Review of existing literature

2.0 Introduction

A lot of research has been done by organisations such as Eskom , the C.S.I.R. and others into the effects of lightning on overhead distribution lines [6,7,8,9,10]. In order to try to evaluate the causes of damage to the Inwabi Plateau distribution line an understanding of the lightning process and it's effects together with a review of the existing work done to date is necessary.

2.1 The Lightning Discharge

Electrical charge separation occurs within clouds due to the presence of strong updrafts and the interaction between water and ice particles. Usually this results in a concentration of negative charge at the cloud base with an equivalent positive charge concentrated at the top of the cloud. This separation of electrical charge also induces a positive charge on the earth beneath the cloud base [11].

A lightning discharge between an electrically charged cloud base and ground occurs when the electrical field strength between cloud and ground becomes large enough to ionise the air beneath the cloud. The lightning discharge is initiated by the descent of a "stepped Leader" which moves in a random direction from the cloud towards earth. As the "stepped leader" moves down towards earth it effectively brings the cloud potential with it, thereby increasing the electric field strength between the leader and earth as it descends. This process is self-proliferating and a step leader once it has moved to within 200m of earth has a potential of

$2x10^7$ volts with respect to earth [11]. As the leader approaches earth, the high resultant electric field results in the production of "upward streamers" originating from protruding earth bound objects such as high masts, trees etc. These "upward streamers" move up towards the downward moving "stepped leader" under the influence of the strong electric field & once they meet a conductive channel is established between the cloud & earth. The leader stroke is then followed by return strokes, which constitute the main discharge between cloud and ground. A ground flash can consist of multiple successive return strokes using the same conductive channel. Usually the first return stroke is of a far higher magnitude than subsequent return strokes [10].

The return strokes can transport negative current (negative flash) or positive current (positive flash) from the cloud to earth . Research in South Africa has shown that over 95% of discharges transport negative charge to ground in the first return stroke [10].The effects of such discharge currents to earth and their secondary effects such as the associated magnetic and electric fields are significant in the study of electrical power lines.

2.2 Discharge Current

A sixty-meter mast was erected by the C.S.I.R. to gather statistics on the magnitude of lightning discharge currents in South Africa. Fig. 2.1 shows the strikes to the mast collected over a ten-year period [12].

The peak discharge current is specified in kiloamps. There is a cumulative probability that only 3.5% of all first strokes are greater than 100kA, with 96 % being greater than 7kA. The median stroke current is around 40kA for the C.S.I.R. tower and 34 kA for the CIGRE statistics [12].

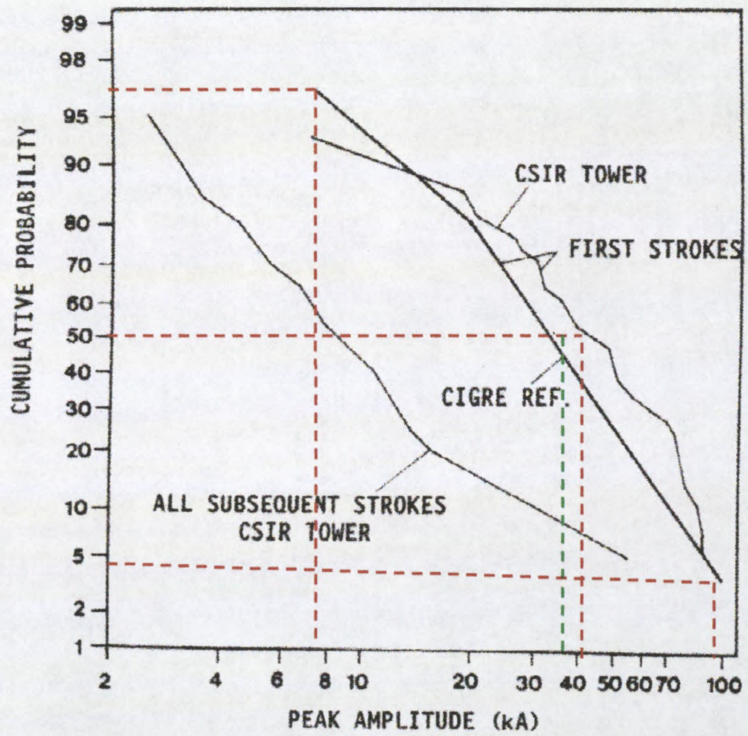


Fig. 2.1 – Cumulative probability Vs Peak amplitude

The rate of rise of the lightning current is high with peaks being reached within one or a few microseconds. Generally the first return strokes have lower rates of rise than the successive strokes but are of higher magnitude.

2.3 Lightning Ground Flash density (N_g)

This is the number of expected lightning ground flashes per square kilometre per year. In South Africa this data has been recorded by the C.S.I.R. over an 11-year period and varies significantly from area to area as well as seasonally [10,12]. See fig 2.2

2.4 The Effects of Lightning on Overhead Lines

In 1978 a dedicated 10km 11kv test line was commissioned on the Highveld about 30km's outside of Pretoria in a joint venture between the CSIR and Eskom. The purpose was to study the effects of lightning on distribution lines. The test line has by now yielded valuable information regarding the effects of lightning on distribution lines [9].

Lightning affects an overhead line either as a result of a direct strike, or indirectly by electromagnetic induction due to nearby ground strikes.

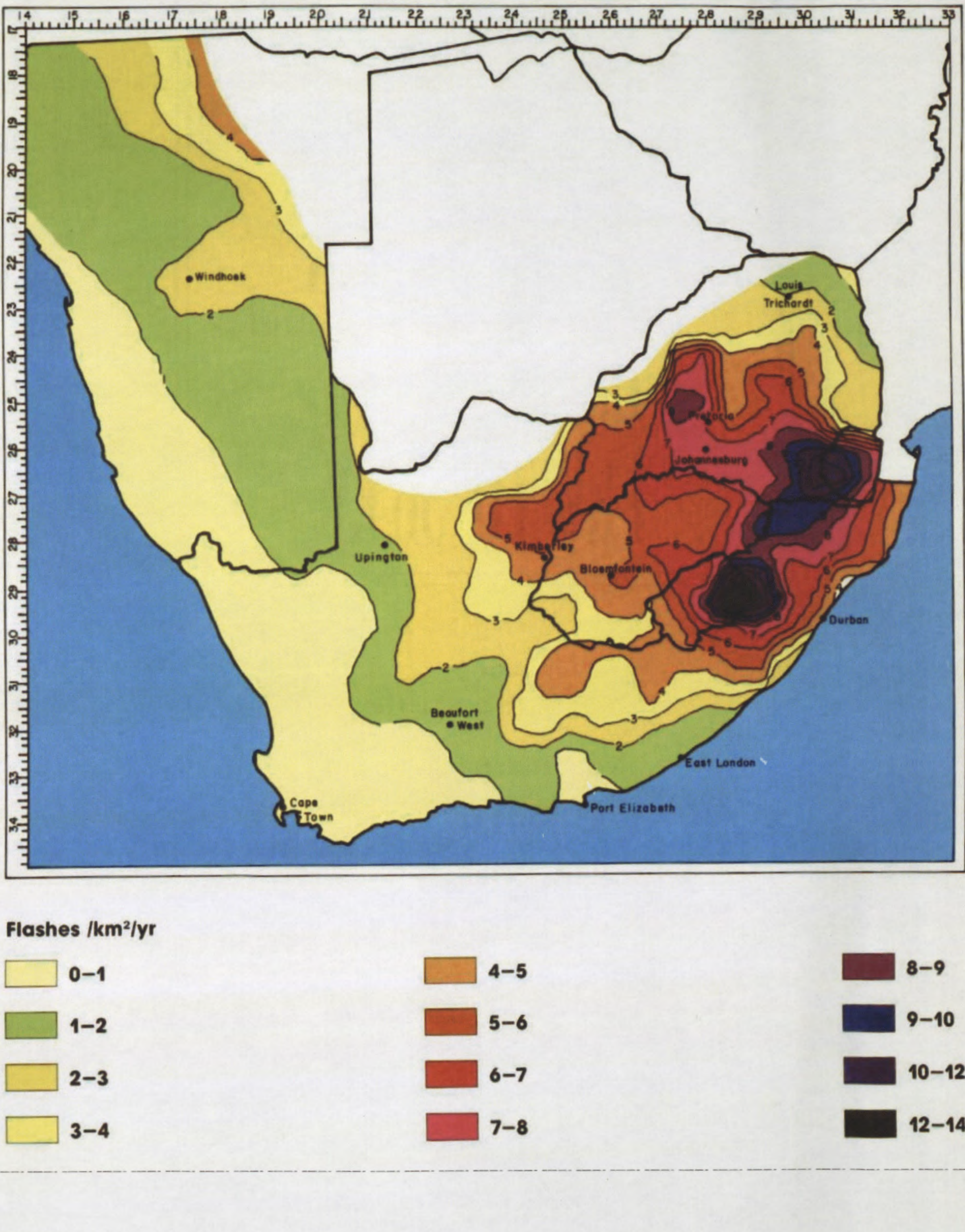


Fig. 2.2 - Lightning ground flash density in South Africa

2.4.1 Direct Strikes

Lightning strikes involve a rapid transfer of electrical charge between the clouds and ground. If a descending leader is intercepted by an upward streamer being emitted from a pole or an overhead line conductor, then the conductive channel is established and the return strokes will strike the pole or overhead line conductors. This constitutes a direct strike. Direct strikes into a line result in a steep fronted travelling voltage wave of high magnitude which can result in failure of the system insulation either through external flashover or internal puncture [10].

The probability of a direct strike to a line depends on a number of factors such as the ground flash density, the height of the line above ground and the overall length of the line. An average number of direct strikes to an overhead line per km per year has been defined by Eriksson [6] as:

$$N_d = N_g \,.\, (28H^{0.6} + w) \,.\, LX10^{-3} \qquad (2.1)$$

Where

N_g = average annual ground flash density ($km^2.Yr^{-1}$)

W = width of the overhead line (m)

H = average height of the poles (m)

L = Length of line (km)

The previous equation can be simplified to,

$$N_d = 0{,}028 \, . \, N_g \, . \, H^{0.6} \, . \, L \qquad (2.2)$$

For a distribution line without significant loss of accuracy.

The above equation does not consider the effects of possible shielding afforded by nearby objects such as trees, buildings and other lines.

2.4.2 Magnitude of Surge Voltages

When lightning strikes an overhead line directly, the lightning current that flows into the line splits and travels along the line in opposite directions. The lightning current flowing through the surge impedance of the line gives rise to an associated voltage surge which is propagated along the line in opposite directions .The peak magnitude of the surge is dependent on the peak lightning discharge current and the surge impedance of the line. The wave front or steepness of the voltage surge is similar to that of the current in the lightning discharge. The wave front usually has a rise time of between 1 and 10 μs. The decay period of the voltage surge or tail is dependent on the line impedance. The amplitude of the resultant voltage surge is given by [10]:

$$V_s = 0{,}5 \, . \, Z_0 \, . \, i \qquad (2.3)$$

Where

Z_0 = the surge impedance of the line, typically 400 ohms for a distribution line.

I = the peak lightning current in amps

If one considers a median peak discharge current of 40 kA into a distribution line of surge impedance of 400 ohms, then the resultant surge peak voltage would be 8 MV. Flashover at several poles would occur where the impulse withstand insulation level is below this value. On 11000-volt distribution lines such impulse withstand insulation levels are practically impossible to achieve. Even smaller values of lightning currents lead to large surge voltages on distribution lines. Fig 2.3 below shows the wave shape of a standard simulated lightning Impulse [13].

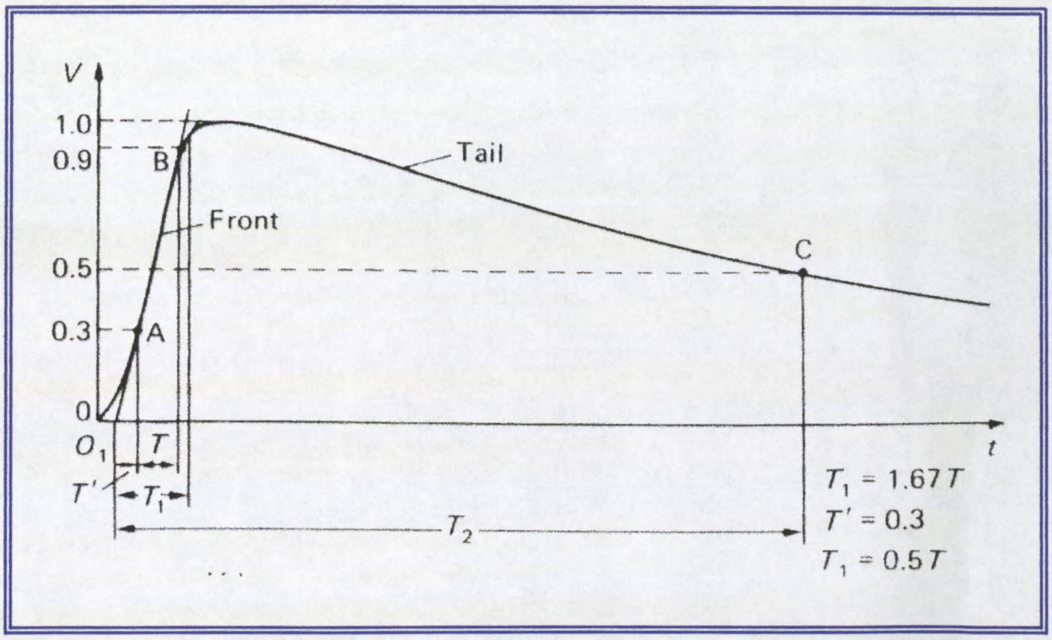


Fig. 2.3 – Standard Simulated Lightning Impulse

The standard simulated lightning impulse test voltage is produced using surge generators with varying specifications and parameters depending on the magnitude of the voltage required The time T_1 defines the front steepness and is the time taken from the virtual origin O_1 to 90% of the peak voltage. The virtual origin is obtained by projecting a line from the 30% and 90% peak voltage co-ordinates through to the x-axis. The virtual origin is used due to the practical difficulty in defining the slope over the first 30% due to voltage oscillations. T_2 is the time taken from the virtual origin O_1 to 50% of the peak voltage. I.E.C. 60-1 defines the virtual front time T_1 as 1,2μs and the virtual tail time T_2 as 50μs [13]. A tolerance of +/- 30% is allowable on the virtual front time and +/- 20% on the virtual tail time. The standard lightning impulse is therefore defined as a 1,2/50μs wave.

2.4.3 Induced Voltages

Lightning flashes to ground involve the rapid redistribution of electrostatic & electromagnetic energy; this leads to induced voltages on nearby overhead lines through electromagnetic coupling (transformer action). By comparison to the voltage surge associated with a direct strike these are less severe and the associated energy is small in comparison. The magnitude of the induced voltage can still however give rise to a flashover or breakdown of system insulation which when followed by power system current can result in excessive damage. As about 95 % of groundstrokes are negative the resulting induced voltage on a line is positive in polarity and is of equal magnitude on all exposed conductors [10]. The magnitude of induced surges is basically dependent on the peak lightning discharge current to ground, the distance of the line from the strike, the height of the conductors above ground and the velocity of the return stroke [6]. The available energy due to an induced surge is limited & negligible in comparison to that of a direct strike but nevertheless it can cause a breakdown in the line insulation due to the magnitude of the Peak surge voltages induced. This often results in system faults where power frequency fault current then causes permanent damage to the system insulation leading to power outages. On a typical unshielded distribution line 8-10 m high these induced voltages can occasionally exceed 200kV and have a maximum order of about 250kV. Flashover would be expected at structures having lower insulation strength than the induced voltage or where reflection at terminal points results in voltage reinforcement [10]. This may be sufficient to either puncture the insulators or to cause flashover across the insulator, thereby leading to power outages. Fig 2.4 overleaf shows the incidence and magnitude of induced voltages recorded on the Eskom test line [10].

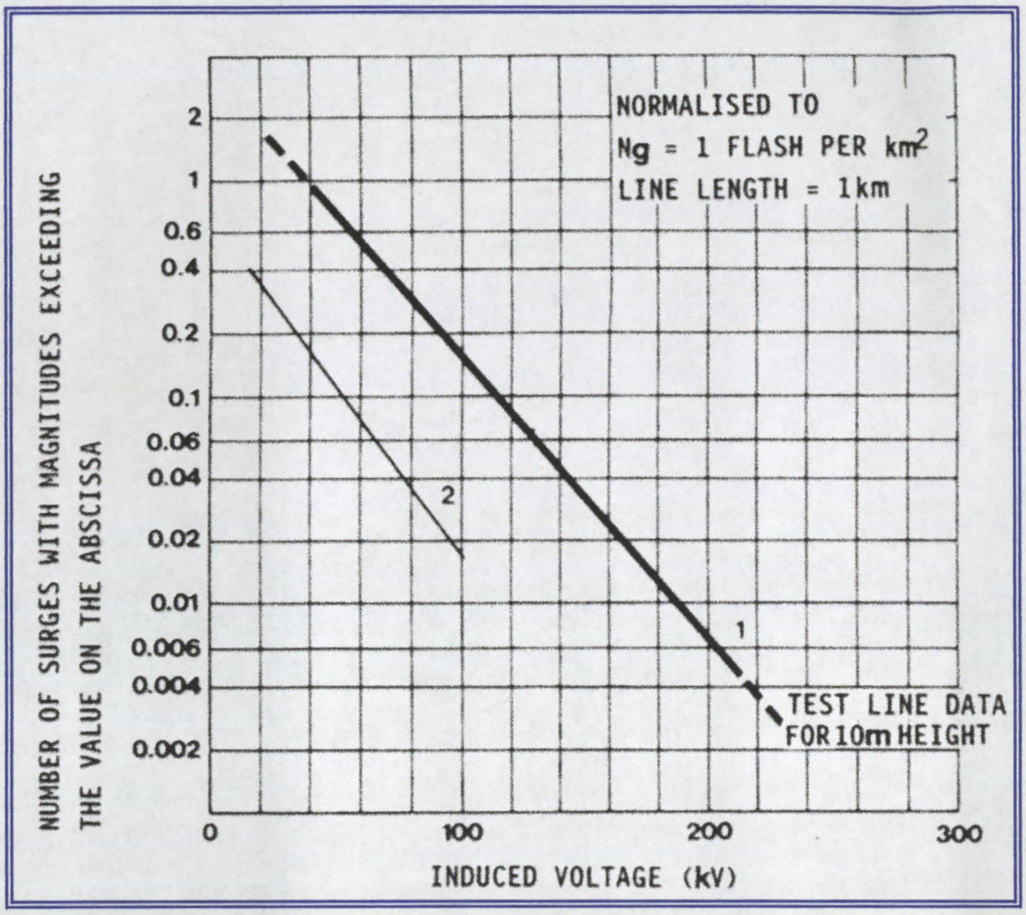


Fig. 2.4 – Incidence of Induced voltages on the test line

Referring to fig 2.4, the number of induced voltages exceeding 95 kV to a line per year is given by [10]:

$$N_i = 0.15 \cdot N_g \cdot L \qquad (2.4)$$

Where

N_g = Lightning ground flash density

L = Length of overhead line in kilometres

2.4.4 Overhead Line Basic Insulation Level (BIL)

This is the lightning impulse withstand voltage that the insulation system on overhead line is designed to withstand without a flashover or breakdown occurring when subjected to a lightning impulse. On overhead distribution lines the B.I.L. is normally a composite value that is made up from the insulator B.I.L. and any other components connected between the line and earth such as the pole itself. Wood poles serve to increase the line B.I.L., whereas steel poles are conductive and provide no addition to the B.I.L. Pole mounted equipment such as transformers and switchgear have limitations in terms of their own lightning impulse withstand and therefore constitute weak links in terms of the overall B.I.L. of the overhead line. As a result additional protection such as lightning arresters need to be installed at weak link points in order to protect such equipment. Owing to the relatively low lightning impulse withstand voltage of distribution insulators and equipment it is not easy to protect a distribution voltage overhead line from the effects of direct strikes.

2.5 Lightning Protection of Overhead lines

Due to the magnitude of voltage surges transmitted along overhead lines as a result of direct strikes, it is practically impossible to design an insulation system capable of withstanding such voltages at the distribution level. There is however methods available for minimising and limiting damage which are discussed below.

2.5.1 Overhead Shield wires

Shield wires are installed above the phase conductors of an overhead line and are designed to intercept a direct strike. For distribution lines a single overhead shield wire is normally erected above the phase conductors throughout the entire line route. The effectiveness of the shield wire depends largely on how effectively it is earthed. The shield wire is normally earthed at intervals using a down conductor and earth electrode at the base of the pole. More frequent intervals of earthing improves the overall earthing on the shield wire and therefore it's effectiveness. The local soil resistivity also affects the quality of earthing that is achievable on the shield wire. A lightning strike into a shield wire will propagate a surge voltage in both directions along the shield wire. The magnitude of the surge voltage appearing on the earthed downwire is basically dependent on the surge current flowing to earth and the earth resistance of the down wire. At poles where the earth resistances are high *backflashover* from the earth wire to the phase conductors may occur if the voltage on the downwires exceeds the B.I.L. of the line. To avoid *backflashover* the ratio of the line B.I.L. in kV to the pole footing resistance in ohms should be greater than 20:1 [10]. For example, for a pole footing resistance of 15 ohms the line B.I.L. should be greater than 300 kV.

Shield wires can also fail to intercept a direct strike particularly where low peak lightning discharge currents are involved, this is known as a shielding failure.Shield wires are also effective in limiting the magnitude of induced voltages. Statistics obtained from the Eskom test line [10] have shown that an overhead shield wire can reduce the magnitude of the induced voltage by between 10 and 60% depending on how often and how well the shield wire is earthed [10].

2.5.2 Lightning Arresters

Lightning arresters connected between line and ground can prevent flashover at poles and equipment by discharging lightning surge currents to ground. These are normally installed at weak link structures such as transformer and switchgear positions as well as terminal positions where high voltages may arise due to the changes in line impedance. The protective level of the arrester, U_p in kV, is the voltage at which the arrester starts conducting current. A typical value of U_p for a 10,2kV mcov (maximum continuos operating voltage) is 31kV [18]. Another important parameter of the lightning arrester is the residual voltage. This is the voltage appearing across the terminals at full rated discharge current. The standard 10kA MOV (metal oxide varistor) arresters used by D.E. have a residual voltage of 46kV. This voltage basically determines the protective characteristic of the lightning arrester.

In summarising, a lightning arrester limits the transient overvoltages due to lightning by conducting lightning surge currents to earth. This prevents damage to installed equipment due to flashover or puncture of insulation and subsequent damage by power follow through current.

2.5.3 Dissipation Array Systems

Dissipation array systems such as the "Spline Ball Ioniser " (SBI) [14] as applied to overhead lines are installed on the top of each pole. The SBI consists of a metallic sphere with many sharp splines attached to the sphere. The manufacturers claim that under the influence of the strong electric fields associated with lightning, the SBI becomes an efficient radiator of positive charge from the earth into the surrounding air above the line. The SBI reduces the possibility of a strike to the line within it's sphere of influence or alternatively "collects" strokes within it's strike zone, thereby protecting the line [14]. Independent research has shown that SBI's when applied to short span distribution lines afford protection to the lines by diverting the strokes from the lines to the "Spline Balls" themselves [15].

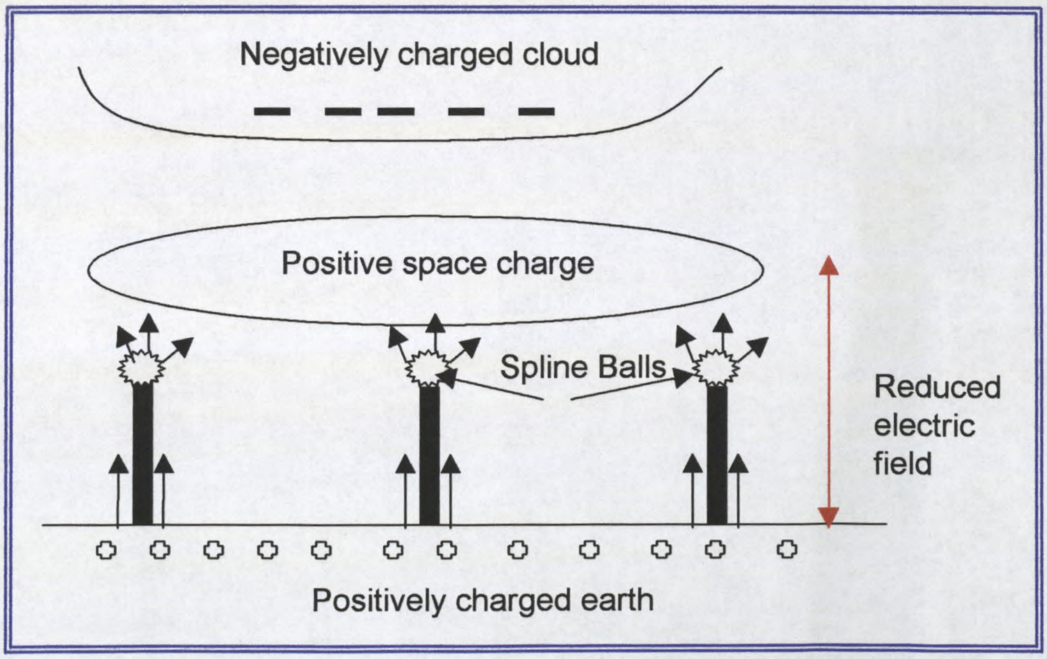


Fig. 2.5 – Spline Ball Ioniser

There is little information available on the application and performance of such devices in South Africa.

2.5.4 Increasing the line B.I.L.

As mentioned previously the line B.I.L. is composite, being made up of the individual components connected in series between the line conductors and ground. Typically these are the line insulators, pole and any ground wires. The traditional construction for 11kV rural distribution lines consists of overhead conductors supported by 11kV strain, post or pin insulators on wood crossarms and wood poles. The standard impulse withstand of 95 kV for a class B pin insulator is small compared to the impulse contribution made up by the wood path to ground, which if includes the entire length of the pole, can be in the order of 1 to 2 MV [10]. The disadvantage of such a high B.I.L. is that the high overvoltages may be transmitted to transformers and other equipment, which if not well protected by means of surge arresters may fail.

The Durban Electricity standard [1] for high impulse construction is as described above but includes the bonding of all phase insulator spindles mounted on wood in areas of high atmospheric pollution or within 10km's of the coast. This is essentially to prevent pole top fires due to the wood being ignited by leakage currents flowing between phases across wood path. The leakage currents are a result of a reduction in phase to phase insulation due to insulator contamination.

Research done by Eskom has shown that limiting the line B.I.L. to 300kV provides good overall performance for induced overvoltages and direct strikes [8]. This is achieved by ensuring that the phase to ground flashover is across a short wood path and not the entire pole length. The flashover path from phase to ground is now essentially across the insulator plus the short wood path and then to earth via a down wire. The dry positive impulse of wood is about 500kV/m. The overall impulse withstand of the series combination of the insulator and wood path is given by [19]:

$$U_t = \sqrt{(U_w + U_I)} \qquad (2.5)$$

Where

U_w= U50 flashover voltage of the wood path

U_I = U50 flashover voltage of the insulator

For an overall impulse of 300kV (based on an 11kV pin insulator with a dry impulse of 95kV), a wood path of approximately 570mm is required. Values under wet conditions may be up to 40% lower [19]. This B.I.L. is not effective for direct strikes but is for induced surges where less than 1% of strikes exceed 200kV. (see fig. 2.4)

2.5.5 Installation of an Earthed downwire

The inclusion of an earthed downwire effectively lowers the impulse withstand of the pole structure. This results not only in more frequent flashover at poles, but also in lower magnitudes of surge voltages being transmitted along the line to installed equipment. With a wood pole the downwire basically short-circuits the wood path, this effectively reduces the residual voltage between the line and ground once flashover has taken place. The residual voltage is determined by the volt drop across the wood path plus the volt drop due to the earth resistance of the downwire. A low enough earth resistance of the downwire is essential, as a high residual voltage may result in flashover at other poles [8,10].

2.6 Earth electrodes

The design of earthing grids for distribution plant such as transformers is generally done by installing a number of vertically driven copper coated steel rods [1]. The rods are driven down to an upper depth of 500mm below the surface. The rods are interconnected using bare copper and the number used is dependent on the soil resistivity and the desired earth resistance. The performance of the earthing system can be significantly affected by seasonal variations in the soil resistivity largely due to the moisture content of the soil [10].

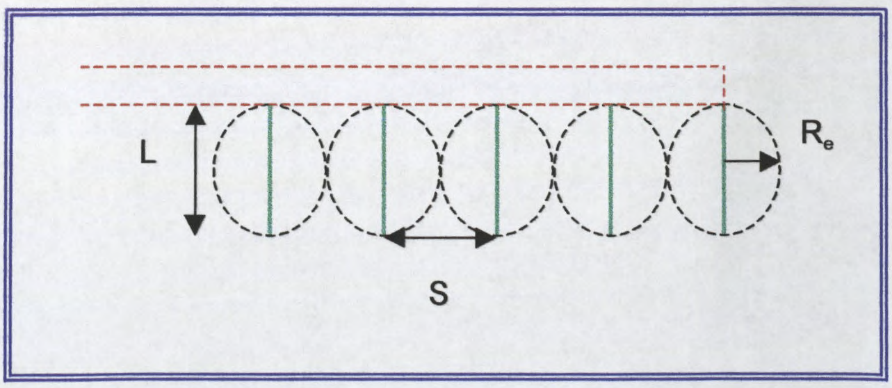


Fig. 2.6 – Interconnected vertically driven earth rods

Figure 2.6 shows a group of five interconnected vertically driven earth rods each of length, L and separated by distance, S. The hemispheres surrounding each rod represent the earthing interface between the rod and the surrounding soil and it is within this area that the earth resistance is practically determined. It is important that the spacing of the rods are not too close, as this will result in the overlapping of the hemispheres and will therefore lead to a higher earthing resistance than could be achieved with the optimum spacing. The interconnecting copper wire also contributes to the overall resistance and must also be considered.

Resistance of a single rod

The earth resistance of a single vertically driven rod is given by [16]:

$$R_0 = \rho / [2\Pi L] . \ln[4L / d] \qquad (2.6)$$

Where

ρ = The soil resistivity in ohm.meters

L = The effective length of the buried vertical rod

d = The diameter of the vertical rod

The resistance of n interconnected rods

The earth resistance of n vertical rods of equal effective length L and equal spacing S in a straight line is given by [16]:

$$R = R_0 . [1+k.m] / n = R_0 . Y_n \qquad (2.7)$$

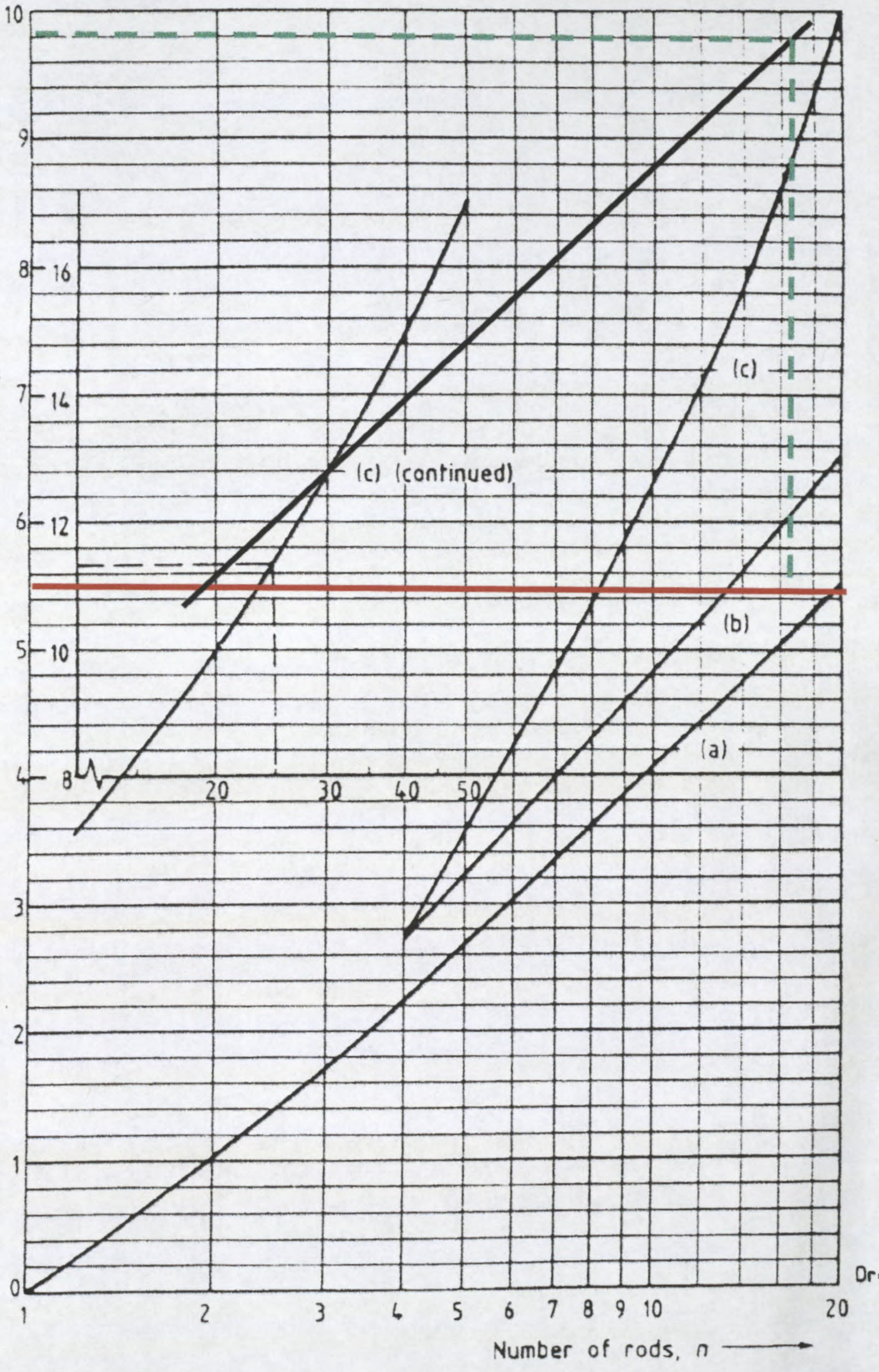
Where

k = The geometric factor given in figure 2.5 overleaf

$$m = L / \{ [\ln(8L/d) - 1] . s \} = r_e / s \qquad (2.8)$$

r_e = the radius of the equivalent hemispherical electrode, m

Figure 2.7 overleaf shows how the geometric factor, K, varies with the different arrangement of the rods and the number of rods used. The rods within the array must be electrically connected.



(a) – rods arranged in a straight line
(b) – rods arranged in open square
(c) - rods arranged in solid square

Fig 2.7 – Factor k in equation 2.7

The resistance of a buried straight horizontal conductor

The resistance of a round conductor buried horizontally in a trench is given by [16] :

$$R = \rho / [\Pi . L] . [Ln(2L / \sqrt{d.h}) - 1] \quad (2.9)$$

Where

h = The depth of the buried conductor

L = The length of the buried conductor

d = The diameter of the buried conductor

The resistance of a combination of vertical rods and horizontal conductor

When a number of vertical rods are interconnected by means of a horizontal conductor the combined resistance is given by [16]:

$$R = [Rh . Rd - Rm^2] / [Rh + Rd - 2Rm] \quad (2.10)$$

Where

Rh = The earth resistance of the total length of buried horizontal conductor alone.

Rd = The combined earth resistance of the vertical rods alone.

Rm = The mutual resistance of horizontal and vertical earthing systems and is given by [16] :

$$Rm = \rho / [\Pi . Lh] . Ln [2Lh / Lo] \quad (2.11)$$

Where

Lh = Total length of the buried horizontal conductor

Lo = Buried length of each rod

2.6.1 Earth electrodes encased in concrete

Encasing an electrode in concrete is done to enhance the earth resistance of the electrode. Encasing in concrete effectively increases the effective diameter of the electrode within the soil. Re-inforcing within concrete foundations is often used for earthing purposes. Concrete is hygroscopic and it's specific resistivity is influenced by the moisture content of the surrounding soil. Resistivities can vary between 30 and 300 Ω.m depending on moisture content [16,17]. For a single electrode encased in concrete there are two interface resistances to consider, i.e. the electrode to concrete resistance and the concrete to soil resistance . The overall resistance of the electrode to earth is the sum of both.

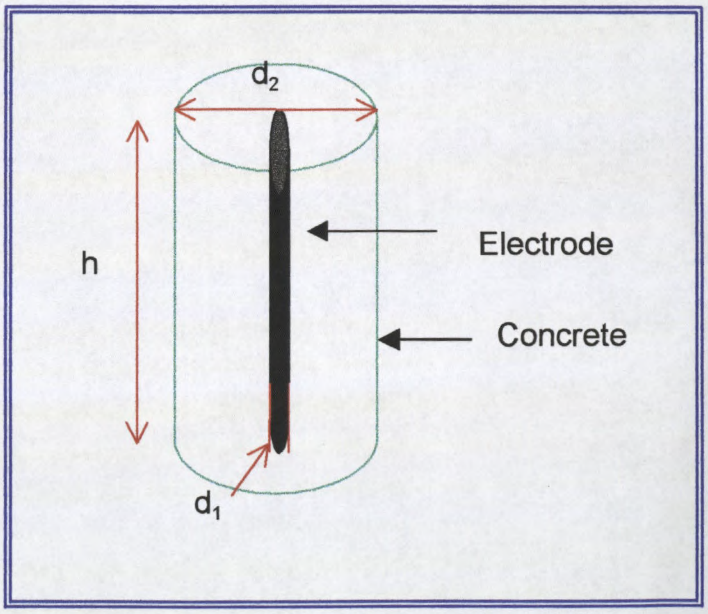


Fig. 2.8 – Single electrode encased in concrete

The resistance of single concrete encased rod is given by [16] :

$$R = \rho_c / (2.\Pi.L) \times Ln (L.d_2 / H.d_1) + \rho_e / (2.\Pi.H) \times Ln (4H / d_2) \quad (2.12)$$

where

ρ_c = Resistivity of concrete

ρ_e = Resistivity of earth

L = Length of Rod

H = Depth of concrete

d_1 = Diameter of Rod

d_2 = Diameter of concrete

The resistance of a concrete foundation consisting of an array of steel re-inforcing rods is influenced by the number and geometric arrangement of the rods within the concrete and is given by [17] :

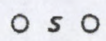
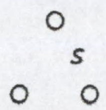
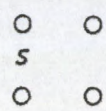
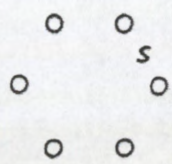
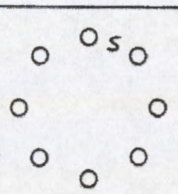
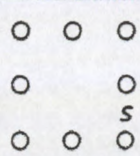
$$R = 1 / (2.\Pi.L) \times [(\rho_c - \rho_e) \times Ln (1 + \delta / Z) + \rho_e \times Ln (2.L / Z)] \quad (2.13)$$

Where

δ = the thickness of the concrete between the rods and soil in metres ;

Z = the geometric mean distance of the rod cluster in metres

Fig. 2.9 gives the geometric mean distance Z, for different rod arrangements that are electrically bonded and encased in concrete.

Number of rods	Arrangement of rods	z
2		m $\sqrt[2]{(as)}$
3		$\sqrt[3]{(as^2)}$
4		$\sqrt[4]{(\sqrt{2}as^3)}$
6		$\sqrt[6]{(6as^5)}$
8		$\sqrt[8]{(52as^7)}$
8		$\sqrt[8]{(23as^7)}$

Key
a = radius of a reinforcing rod, in m.
s = distance between adjacent rods, in m.

Fig. 2.9 – Geometric mean distance for closely spaced re-inforcing rods

CHAPTER 3 – Investigation of line damage

3.0 Introduction

The Inwabi Plateau distribution line is a radial fed combined medium voltage (MV) and low voltage (LV) overhead line construction supplying about 200 customers [4]. The total 11kV route length is approximately 16 km's. There are 14 pole mounted 11000/400-volt distribution transformers installed on the line. Refer to fig 3.1 overleaf. Of the 16 km's, approximately 12 km's consist of concrete poles and the remaining 4 km's consist of wood poles. The wood poles were used in areas where the terrain and access were difficult for vehicles. In addition to the 16 km's of combined MV/LV line, there is also a total of 6 km's of low voltage radial feeds connected to the main line (not shown in fig 3.1) These LV radial feeds are supported on concrete poles.

3.1 Medium Voltage Line

The MV line consists of 11kV 40mm^2 bare copper overhead conductors constructed in a Delta formation. The red and blue phase conductors are supported on pin insulators mounted on a 1.2 metre galvanised steel channel crossarm. The white phase conductor, which is the highest conductor, is supported on the pole tip by means of a pin insulator mounted on an L-shaped steel bracket (See plate 5). Where wood poles have been used, the entire structure including crossarms are wood. The same line configuration and insulators apply to the wood pole construction.

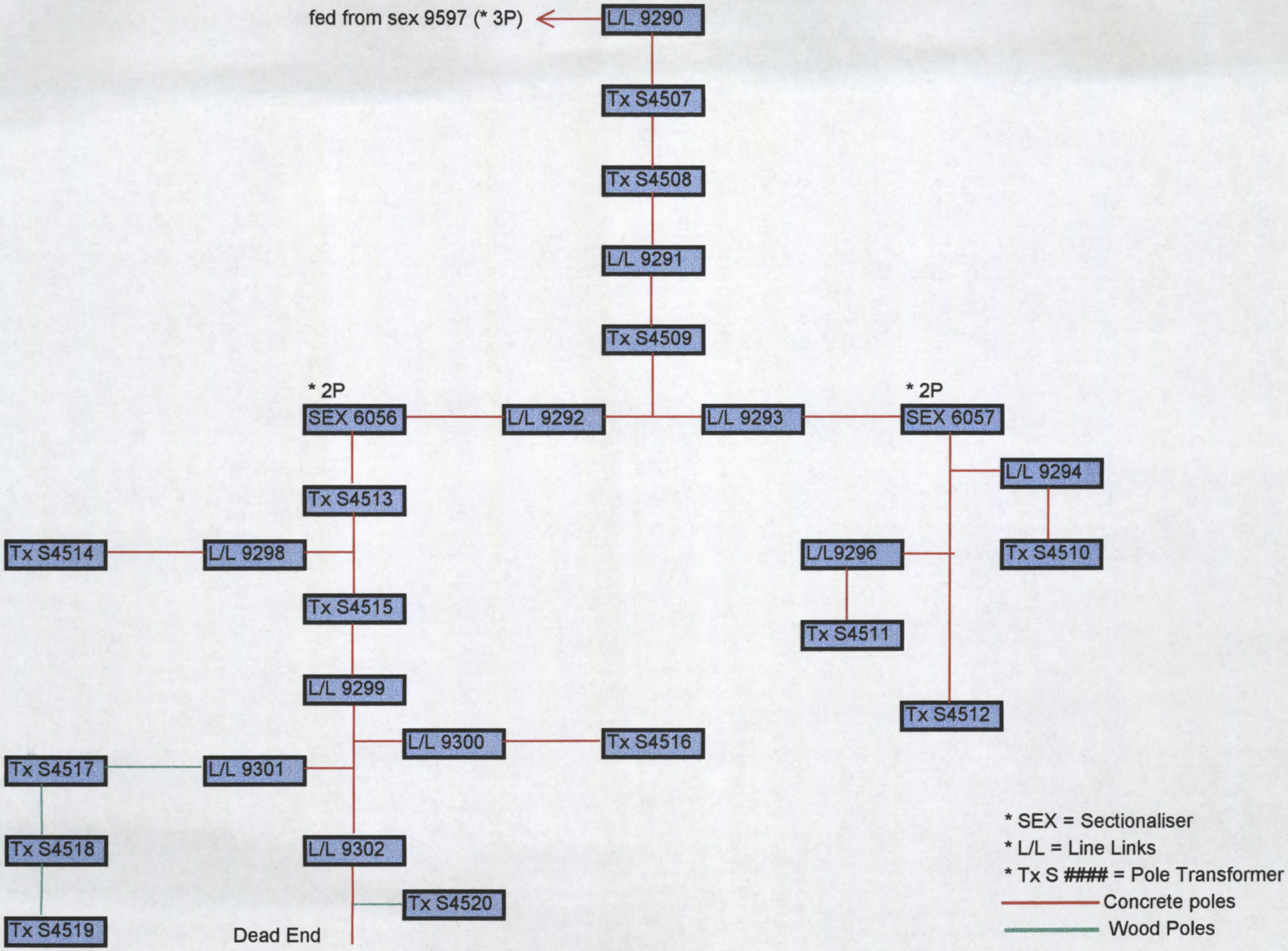


Fig. 3.1 - The Inwabi Plateau single line diagram

3.1.2 Line Protection

The line is protected by three pole mounted automatic sectionalising switches which are controlled by a remote upstream auto reclosing switch, auto recloser 9533. The sectionalisers have standard overcurrent and earth fault protection which grade with each other and the upstream auto recloser. Sectionaliser 9597, which is in series with sectionalisers 6056 and 6057, is a 3 pulse. Both downstream sectionalisers are 2 pulse thereby providing the correct discrimination. The transformers are protected by means of 30amp pole mounted dropout fuse links on the MV side.

3.1.3 Insulators

Two types of insulators are used. The strain insulators at line termination points are cycloaliphatic resin of the class A type with a dry impulse withstand voltage of 150kV. The insulators at the intermediate positions are cycloaliphatic resin class B pin insulators with a dry impulse withstand of 95kV. (See plate 6).

3.1.4 Stays

The MV stays are stranded galvanized steel wire. The stay insulators are the fibreglass continental guy type with a dry withstands impulse of 350kV. These are used on poles that support only MV conductors. On poles that support both MV and LV conductors, two lower impulse porcelain insulators are used.

Plate 5 - 11kV Delta construction

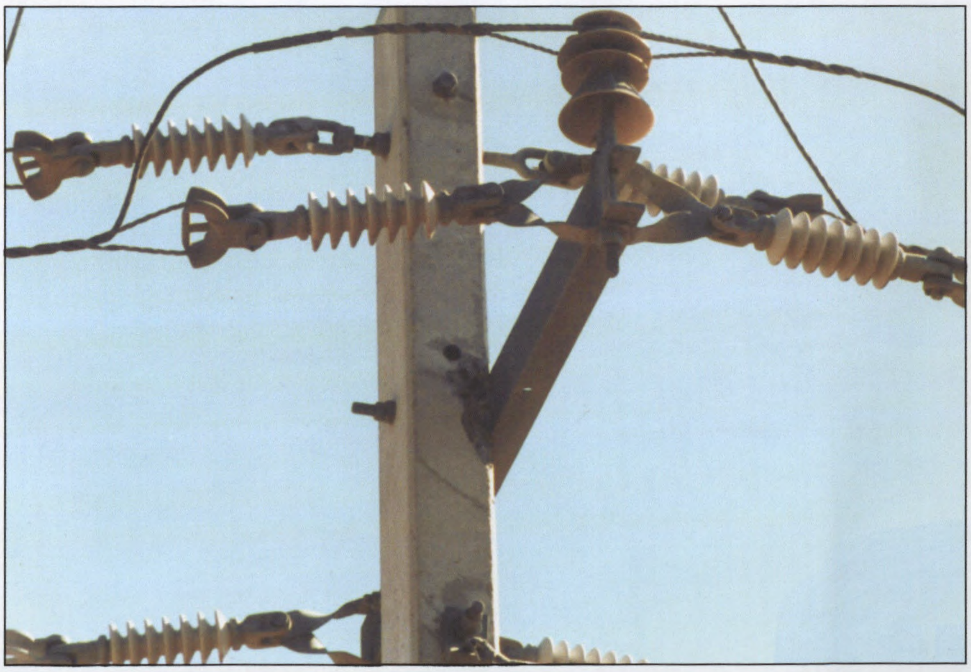


Plate 6 - 11kV Line insulators

3.1.5 Transformers

There are a total of 14 transformers installed on the line. The transformers are either 100 or 50 kVA, 3 phase, 11000/400 volt, Dyn11, mounted on single poles.

3.1.6 MV Earthing and Bonding

Pole structures are earthed at pole transformer, Auto-recloser, Sectionaliser, lightning arrester and Line link positions. At pole transformer positions the medium voltage and low voltage earths are separated. Both the medium voltage and low voltage earths at the transformer positions are designed for 20 ohms or less.

3.1.7 Lightning Arresters

Standard 10kA MOV Lightning arresters are installed at all pole transformer, Auto-recloser & sectionaliser positions for lightning protection.

3.2 Low voltage Line

The low voltage distributor is comprised of 4 x 95mm^2 aerial bundle conductors (ABC) of the self-supporting system (German System). The system is a 3 phase combined neutral earth system. Consumer distribution units (CDU's) are mounted directly below the LV ABC on poles that supply customers. Streetlights are also installed along the main route on poles supporting LV ABC. Each LV circuit is protected by means of 200 amp fuses mounted on crossarms at the pole transformer positions.

3.2.1 LV Earthing

The ABC neutral conductor and the star point of the low voltage winding are earthed at each transformer position. The ABC neutral is also earthed at the remote ends of all low voltage circuits. The earthing at the transformer positions is designed for 20 ohms or less. The neutral earthing at the remote ends of the low voltage circuits are unmeasured and consist of a single 1.5 metre vertically driven earth rod. Streetlights and consumer distribution units (CDU's) are earthed via the ABC neutral conductor.

3.2.2 Customer Connections

There are approximately 200 customers connected to the low voltage ABC using 10mm^2 split concentric overhead cable (Airdac). The customer's cable is provided with a separate neutral and earth, but both the neutral and earth are connected to the combined neutral earth conductor of the low voltage distributor. All energy meters are of the pre-payment card type.

3.3 Pre-stressed concrete Poles

The poles are Grinaker pre-stressed concrete poles categorised by ultimate tip strength and length [2] (appendix D). Each pole has eight by 8mm diameter pre-stressed wires that are pre-tensioned within the mould prior to the addition of the 60Mpa strength concrete. The poles are cast with pre-determined holes in order to facilitate the attachment of fixing bolts for pole top hardware. The pre-stressing wires after the casting of the concrete are embedded in the concrete and have a minimum concrete coverage of 25mm, however, at the pre-determined hole positions where a standard 25mm conduit is set in the concrete, this may be as little as 10mm (See plates 7 and 8). The pole dimensions and mass vary between the various tip strength categories of the poles. The following pole categories have been used:

- 9 mtr/4kN – used in straight line suspension applications to support LV ABC only.
- 9 mtr/7kN – used in suspension applications to support LV ABC where the angle of line deviation is less than 30 degrees.
- 9,3 mtr/17.5kN – used at terminal positions to strain off LV ABC and for line deviation angles in excess of 30 degrees.
- 10 mtr/8 kN – used to support both the MV and LV conductors along common routes and at pole transformer platform positions. Stays are necessary due to the additional mechanical loading of the MV conductors.

Plate 7 - Concrete pole moulds showing pre-stressed wires and pre-cast hole positions

Plate 8 - Pole casting

3.4 Classification of pole damage

Initial inspections of the line revealed that the concrete poles had been structurally damaged in different places and to differing degrees. The damage consisted mainly of pieces of concrete that had been cracked and broken away from the pole. The depth of the cracks varied from between 0 to 25mm where the internal pre-stressed wires were clearly exposed and visible. (See plates 9 and 10). Most of the damage appeared to be concentrated in areas adjacent to earthed hardware. Prior to the hand over and commissioning of this line it was inspected and was found to be free of structural defects. By comparison, the 4 km's of line built using the wood poles exhibited no damage.

It was decided to undertake a complete "Damage Inventory" (See appendix A) on the 12 km's of concrete pole line in order to quantify and classify the extent of the damage to the overhead line. The inspection only included poles that were supporting medium voltage conductors or poles supporting both medium voltage and low voltage conductors. The inspection of the line and recording of the damage involved a pole to pole inspection of the entire line and was conducted over a period of 3 days, concluding on the 26/08/96. The damage at each pole was recorded and classified in terms of its position and degree of severity.

3.4.1 Classification of Damage Position

The position of the damage on the pole was considered important, as this would provide evidence as to where insulation breakdown was occurring.

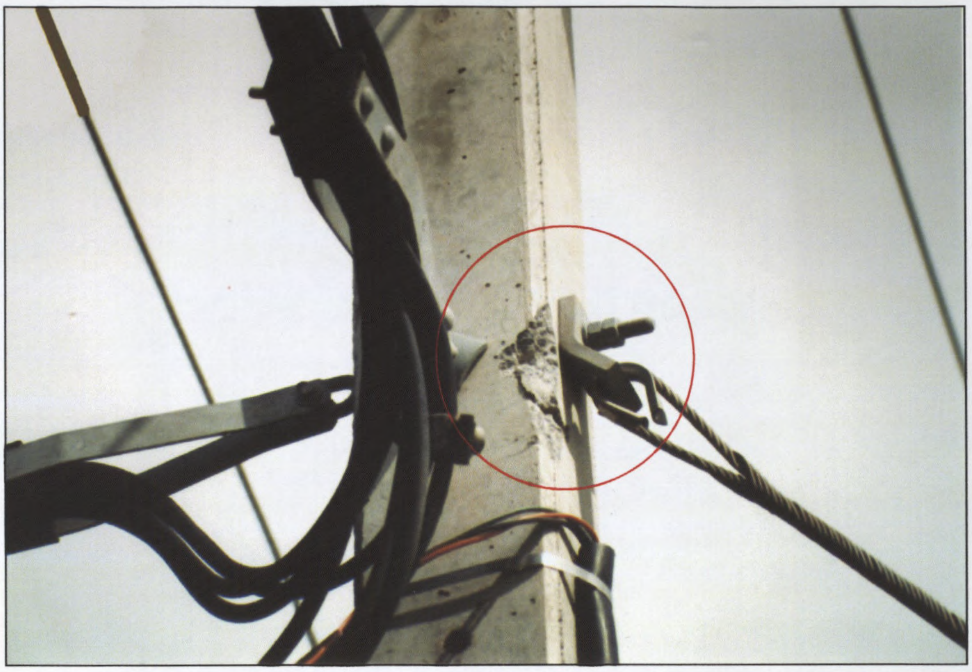


Plate 9 - Structural damage

Plate 10 - Structural damage showing exposed re-inforcing

Based on initial observations of damage it was decided to use the following positions on the pole in order to classify the position of the damage with respect to the line hardware:

- **Pole Tip** – The area in the vicinity of the top of the pole including the fixing points of the L-shaped insulator bracket. This includes the white phase pin insulator (See plate 11).
- **MV Cross arm** – The area in the vicinity of the attachment of the cross arm to the pole (See plate 12)
- **Cross arm bracing** – The area in the vicinity of the attachment of the cross arm bracing strap to the pole beneath the MV crossarm (See plate 13).
- **CDU** (Consumer distribution units) – The area in the vicinity of the attachment of the consumer distribution unit (See plate 14).
- **Other**– Any other areas other than the above. The specific areas of damage were recorded on the damage inventory sheet at the time of the inspections.

Plates 11 to 14 on the following pages show the positional classification for each category.

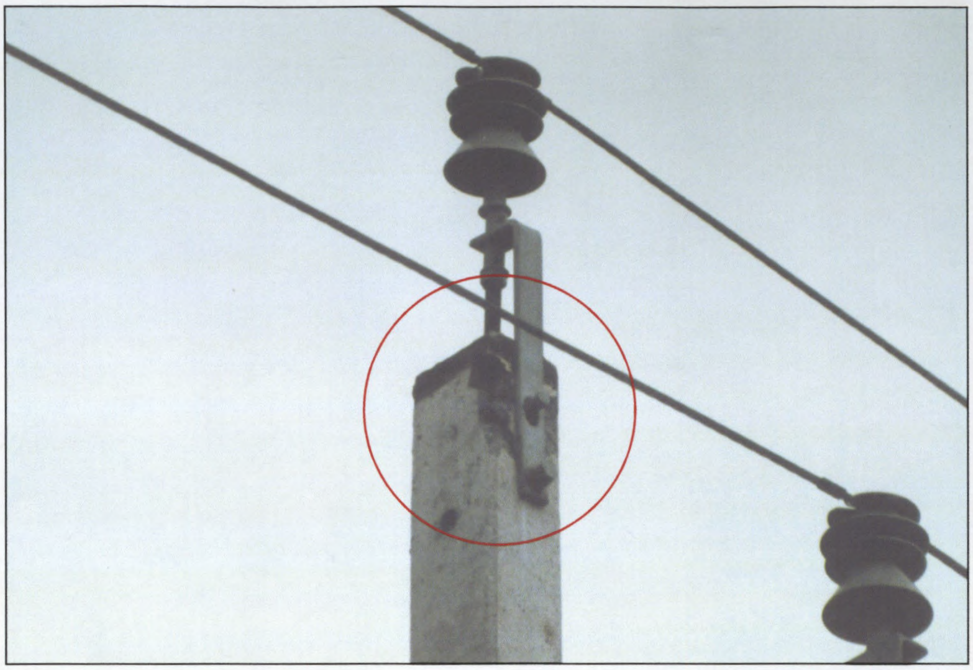


Plate 11 - Positional classification of pole tip damage

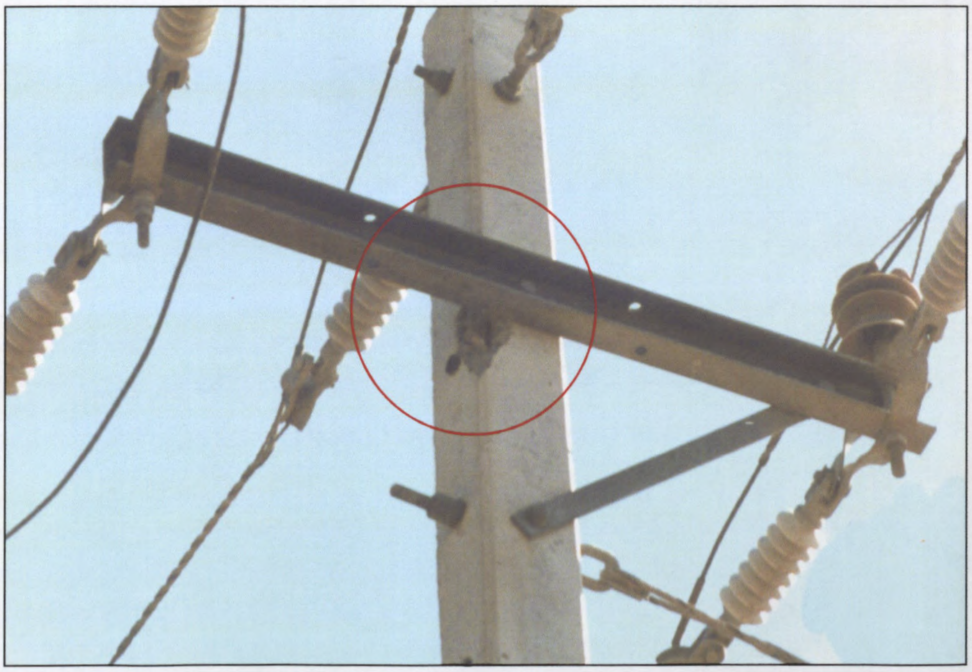


Plate 12 - Positional classification of crossarm damage

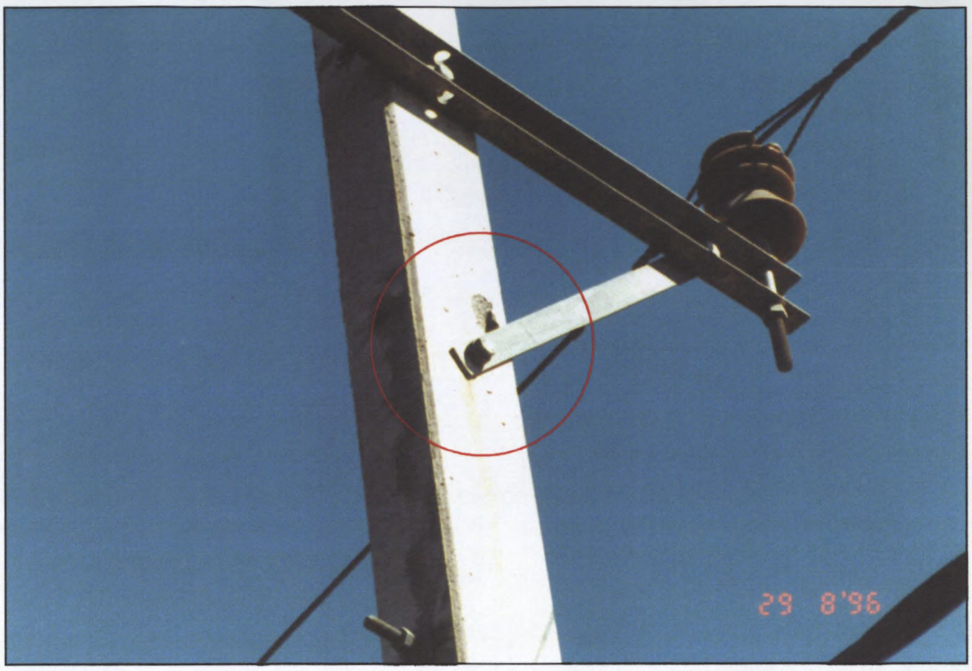


Plate 13 - Positional classification of bracing strap damage

Plate 14 - Positional classification of CDU damage

3.4.2 Classification of the Severity of Damage

Classifying the severity of damage together with positional classification was considered important as this could yield information regarding predominant dissipation paths for flashovers. The damage mostly consisted of fragments of concrete that had been broken away from the pole. The depth and area of concrete removed varied. The following classification was used based on the observed damage:

Slight Damage	concrete removed to depth 0 to 10mm
Moderate Damage	Concrete removed to depth 10 to 25mm
Bad Damage	Concrete removed to depth greater than 25mm (reinforcing visible)

3.5 Pole damage

Table 3.1 provides a summary of what was discovered during the initial inspection and provides an overall indication as to the extent of the damage. Figs 3.2 and 3.3 on page 48 give a graphical representation of table 3.1. Fig. 3.4 on page 49 shows the distribution of damage throughout the line.

NO. OF POLES INSPECTED	**204**
No. of poles structurally damaged	89 (44%)
Incidence of bad damage	48 *
Incidence of moderate damage	60 *
Incidence of slight damage	18 *
Total Incidence of damage	126

Table 3.1 – Summary of damage on first inspection

Referring to table 3.1, the total incidence of damage exceeds the number of poles structurally damaged as a number of poles exhibited damage in more than one position, and to differing degrees.

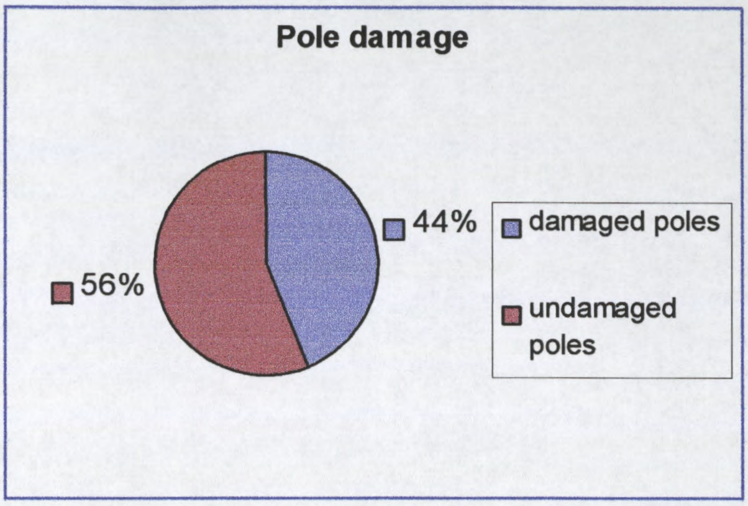


Fig. 3.2 – Pole damage statistics

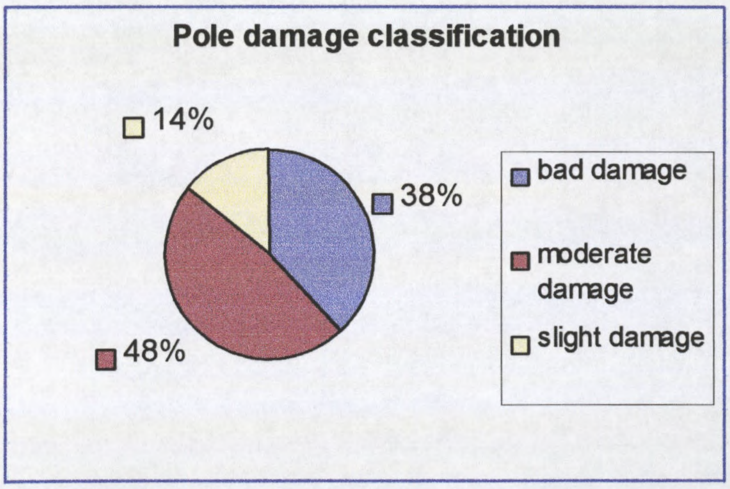


Fig. 3.3 – Damage classification

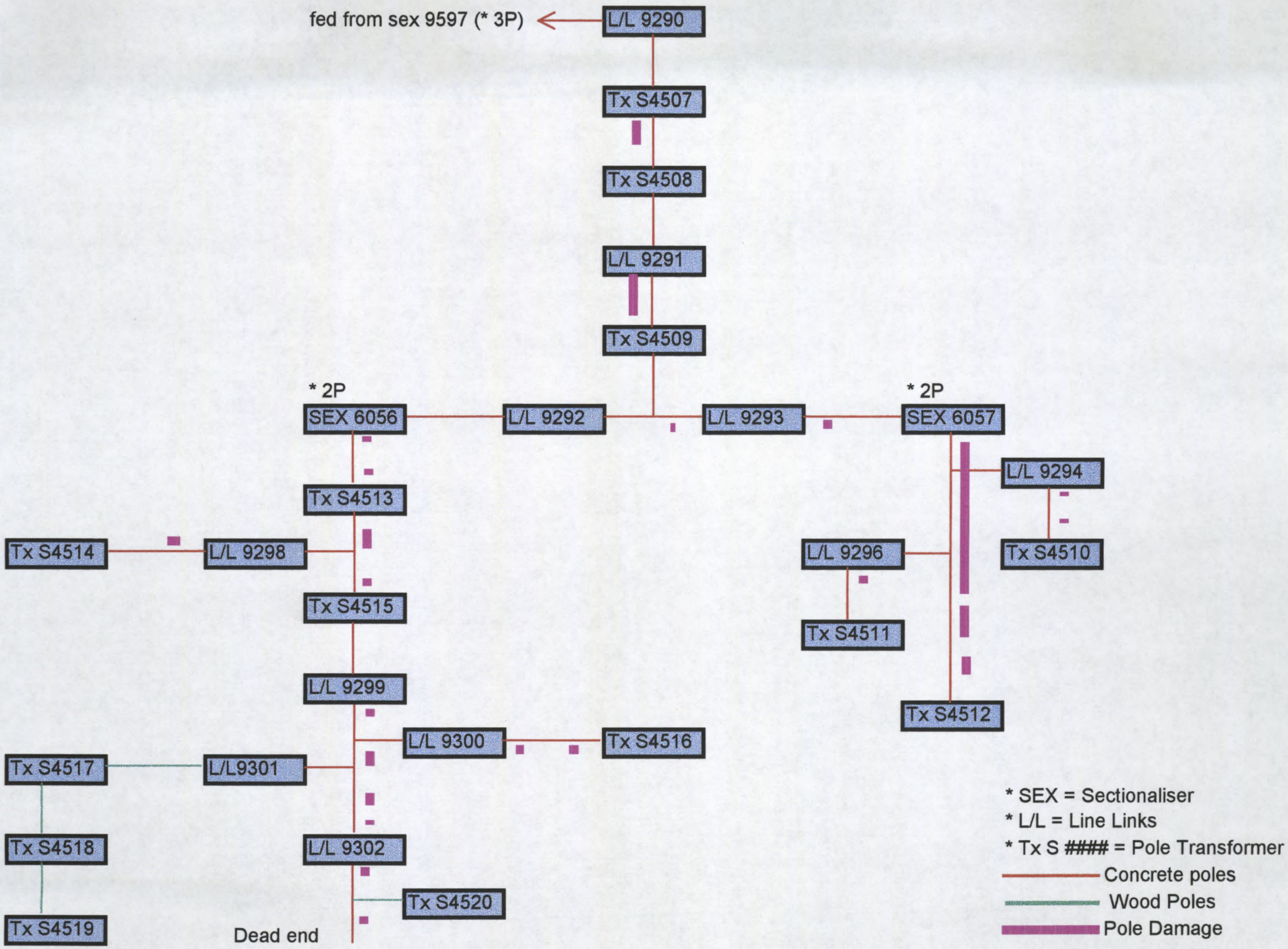


Fig 3.4 - Pole damage distribution

3.5.1 Damage to MV and combined MV/LV poles

Following the completion of the damage inventory the results were analysed in order to try identifying any trends or commonality. This was considered important when considering whether the poles were carrying MV conductors only or carrying both MV and LV conductors due to the different lightning dissipation paths involved.

TOTAL POLES INSPECTED	**204 (100%)**
Total poles damaged	89 (44%)
Poles inspected carrying MV only	56 (27%)
Poles damaged carrying MV only	23 (41%)
Poles inspected carrying MV & LV	148 (73%)
Poles damaged carrying MV & LV	66 (45%)

Table 3.2 – Analysis of damaged poles for MV and Combined MV/LV

Referring to table 3.2, the total number of poles damaged at 44% is cause for concern. The comparison of the incidence of damage to poles carrying MV conductors only and combined MV & LV poles is similar. See fig.'s 3.4 and 3.5 overleaf.

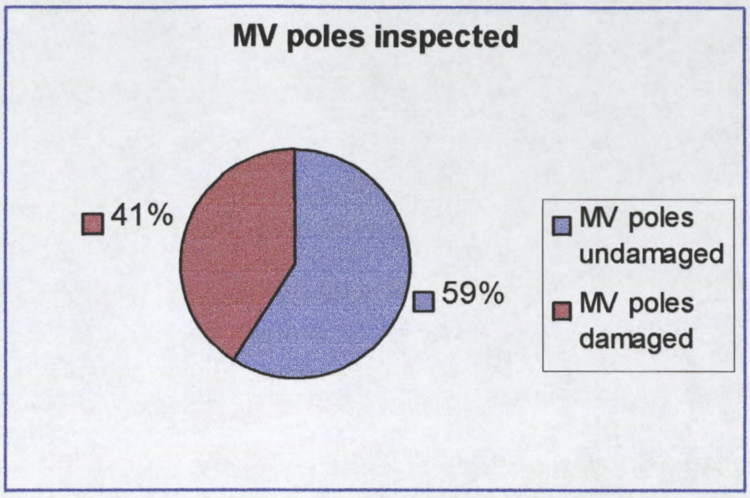


Fig. 3.5 – MV pole damage

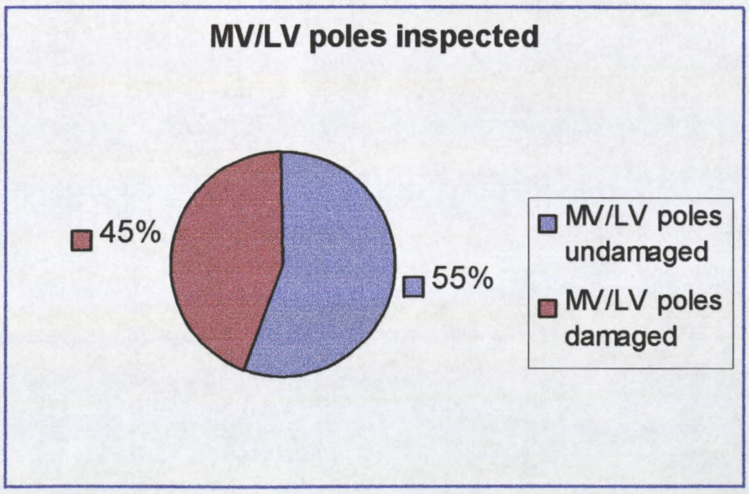


Fig. 3.6 – Combined MV/LV damage

3.5.2 Degree of damage

Analysing and comparing the degree of damage between the MV and combined MV/LV poles provides further important information regarding possible lightning dissipation paths for both types of arrangements. More severe damage would be indicative of a higher localised concentration of discharge current and therefore a relatively lower impedance path to ground. Table 3.3 gives a breakdown of the different degrees of damage relative to the type of line configuration on the individual poles.

Total incidence of bad damage	**48 (38%)**
Incidence of bad damage MV only	15(12%) (31%)*
Incidence of bad damage MV & LV	33 (26%)
Total incidence of moderate damage	**60 (48%)**
Incidence of moderate damage MV	11(9%) (23%)*
Incidence of moderate damage MV & LV	49 (39%)
Total incidence of slight damage	**18 (14%)**
Incidence of slight damage MV	4 (3%) (8%)*
Incidence of slight damage MV & LV	14 (11%)
Total incidence of damage	**126**

Table 3.3 – Degree of Damage

* Normalised percentage to compensate for the difference in the number of MV poles inspected (58) to the number of combined MV/ LV poles inspected (148). (31% = 12% x 148 / 58)

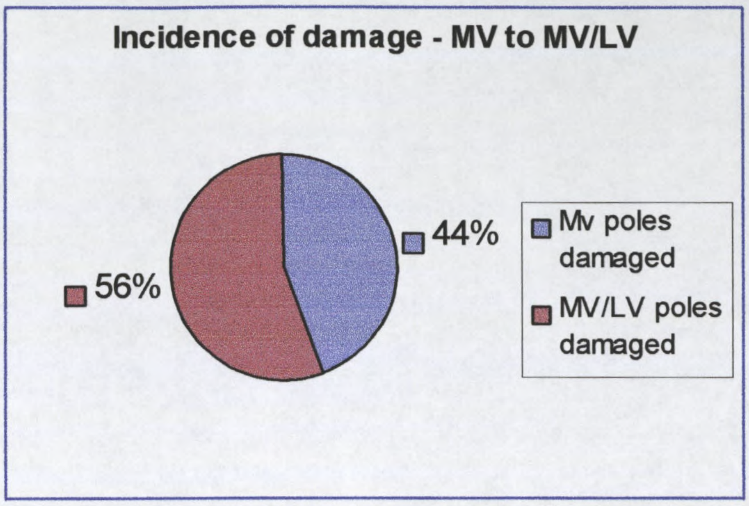


Fig. 3.7 – Incidence of damage - MV to combined MV/LV

After compensating for the differences in the number of poles inspected between the MV poles and the combined MV/LV poles, overall there is a higher incidence of damage on the combined poles. However, in the case of bad damage, the incidence of to the MV poles is statistically slightly higher after compensation (31%) as compared to combined MV & LV poles (26%). This is contrary to expectation as it is assumed that due to the lower impulse level of the LV system that these poles would sustain more damage. The incidence of moderate damage & slight damage is statistically higher on the combined MV & LV poles. This is as expected although the margins are small.

3.5.3 Damage in the vicinity of MV Hardware

An analysis of the damage in the vicinity of the various MV hardware positions was considered important as trends could again be identified thereby providing further information regarding the possible breakdown paths.

TOTAL INCIDENCE OF DAMAGE	68 (100%)
Pole Tip – see plate 11	14 (21%)
MV cross arm - see plates 15,16	26 (38%)
MV cross arm strap – see plate 17	4 (6%)
MV Insulators – plate 18	17 (25%)
MV Stay attachment	5 (7%)
Bow cross arm	2 (3%)

Table 3.4 – Damage in vicinity of MV hardware

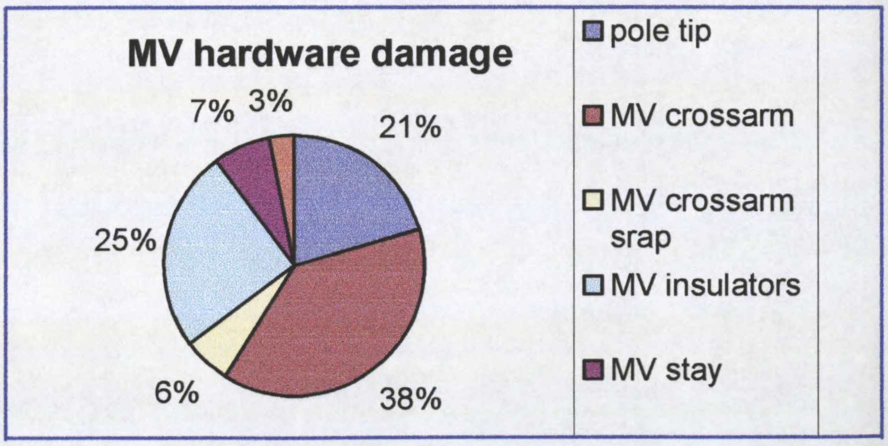


Fig. 3.8 – Damage in the vicinity of MV hardware

Referring to table 3.4 and fig. 3.8, it can be seen that most of the damage at the various hardware positions occurs in the vicinity of the

MV crossarm. By comparison the highest point on the pole (pole tip) accounts for 21 %. This is significant, as the crossarm is located about 800mm below the pole tip. Referring to the classification "MV insulators", this is at pole positions where the strain insulators are attached directly to the pole without a crossarm and the conductors are configured in a vertical formation (see plate 18 on page 58).

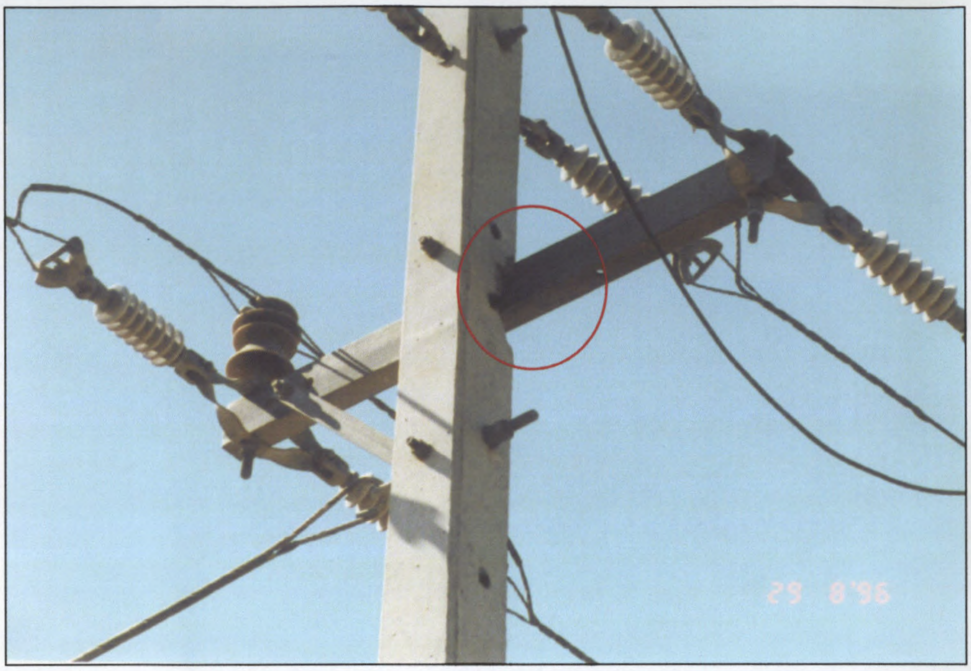


Plate 15 - Typical damage in vicinity of MV crossarm

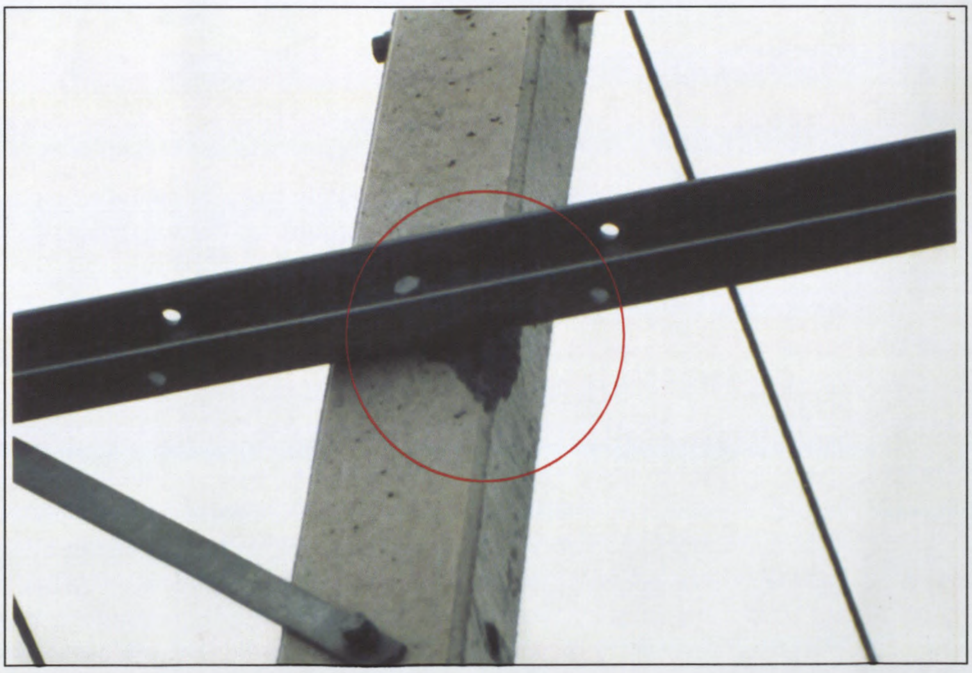


Plate 16 - Typical damage in vicinty of MV crossarm

Plate 17 - Typical damage in vicinity of crossarm strap

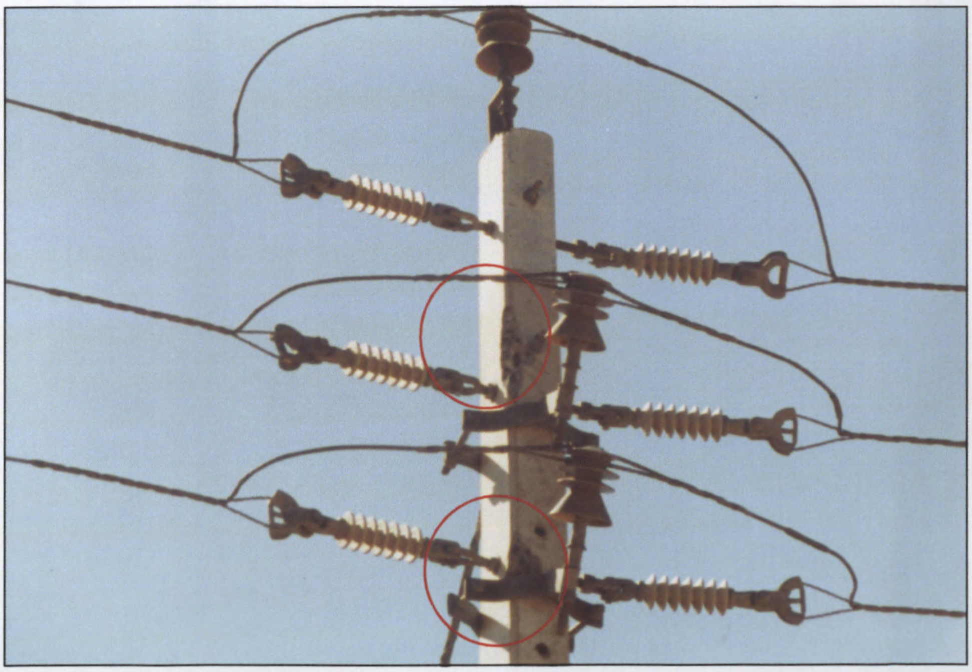


Plate 18 - Damage in vicinty of MV insulators

3.5.4 Damage in the vicinity of LV Hardware

A similar analysis to that of the MV hardware was done on the LV hardware in order to identify trends.

TOTAL INCIDENCE OF DAMAGE	46 (100%)
CDU - plate 19	5 (11%)
Streetlight - plate 20	22 (48%)
LV ABC strain clamp – plate 24	17 (37%)
LV Stay attachment – plate 22	2 (4%)

Table 3.5 – Damage in vicinity of LV hardware

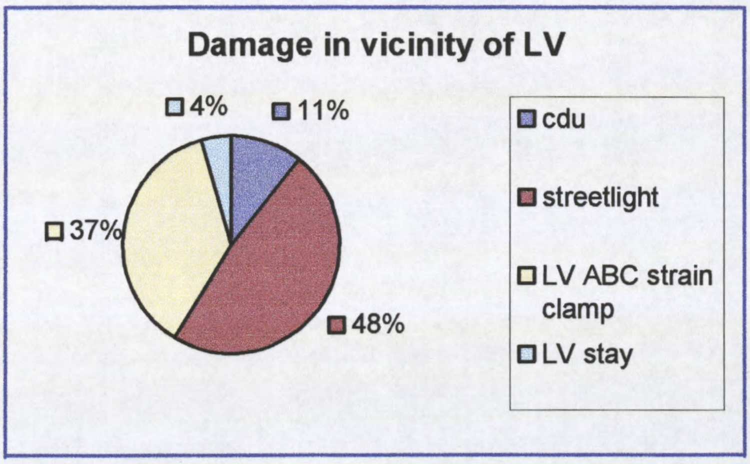


Fig. 3.9 – Damage in the vicinity of LV hardware

Referring to table 3.5 and fig. 3.9, the majority of damage is concentrated around the streetlight and LV ABC strain clamp. In the case of the streetlight this is significant as the streetlight hardware is earthed via the LV ABC combined neutral earth conductor. Damage in this area is consistent in terms of a low impulse dissipation path for lightning.

3.5.5 Damage below the LV ABC & ground level

Damage occurring between the low voltage ABC and ground level was also recorded on the damage inventory under "Other". This was considered important as the remainder of the pole below the ABC and ground is effectively a shunt path to ground in parallel with the earthed LV ABC above. The total incidence of visible damage was twelve. Apart from one incidence the damage to the pole between the ABC and ground level was slight in all cases. It should also be noted that for practical reasons only the visible portion of the pole at ground level could be examined for damage.

Plate 19 - Typical damage in vicinity of CDU

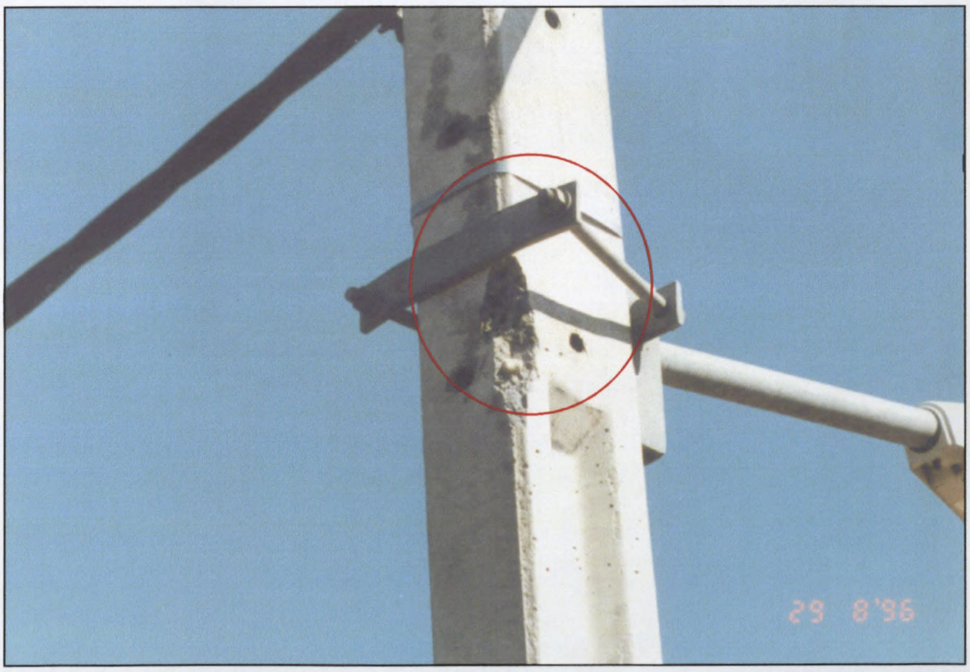


Plate 20 - Typical damage in vicinity of streetlight

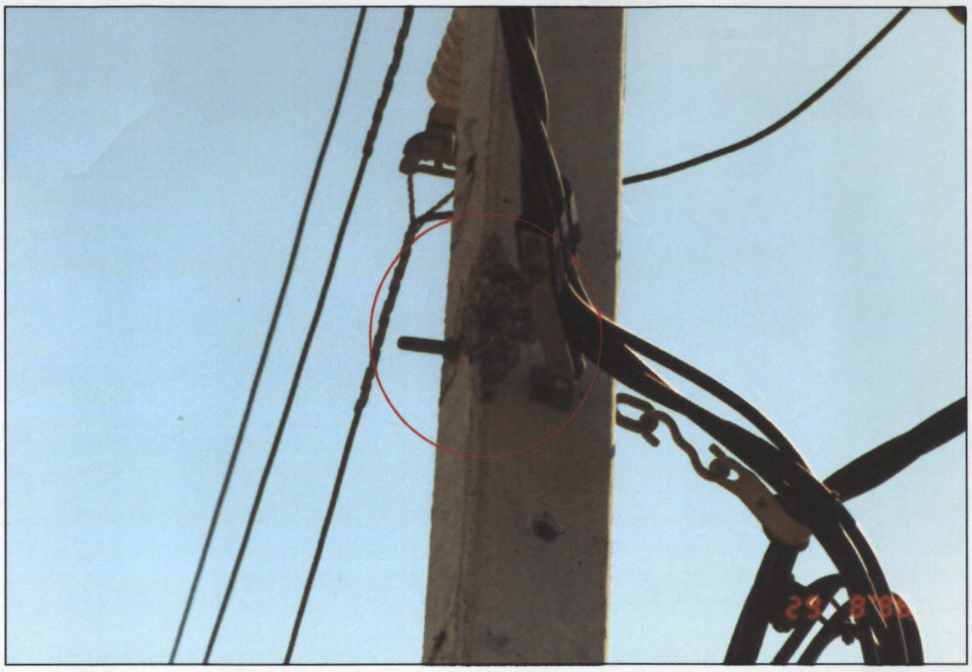


Plate 21 - Typical damage in vicinity of LV ABC strain clamp

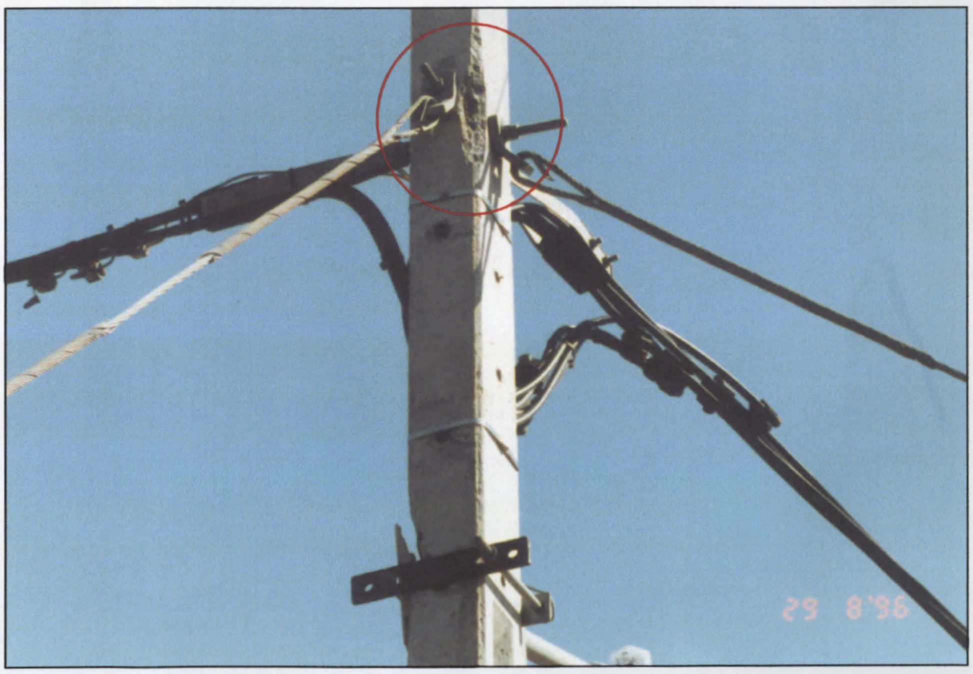


Plate 22 - Typical damage in vicinity of LV stay attachment

3.6 Comments on damage

- Damage occurring at the MV cross arms & streetlight fittings are significantly higher than damage at the other positions. This suggests breakdown from the MV conductors to the LV ABC combined neutral earth system.
- There appears to be two predominant areas of breakdown associated with the flashover viz.; Breakdown of the MV insulation and damage to the concrete in the vicinity of the MV and LV hardware.
  - Breakdown at the pole tip (21%), MV crossarm (38%) and MV insulators (25%) represent the majority of concrete damage associated with a breakdown of the MV insulation system.
  - Breakdown at the streetlight fitting (48%) and LV ABC strain clamp (37%) account for the majority of concrete damage in the vicinity of earthed LV components. It should be noted that the streetlight fittings are earthed via the LV ABC combined neutral earth conductor.
  - The combined MV/LV poles appear to be more susceptible to damage than the MV poles.
  - There appeared to be little evidence of damage at the pole ground level, however, this is not conclusive, as there may well be damage below ground level. This can only be verified upon excavation of the pole under examination.

3.6.1 Possible breakdown paths

For poles supporting both MV and LV conductors, the two main areas where damage is concentrated is in the vicinity of the MV insulation and in the vicinity of the earthed low voltage components. The relevant points of breakdown appear to be the MV insulators and the concrete layer that separates the pole re-inforcing from the insulator hardware and the concrete layer that separates the re-inforcing from the earthed LV hardware.

The probable path for a lightning discharge therefore, appears to be a flashover or puncture of the MV insulators, together with breakdown or puncture of the concrete to the re-inforcing and finally, exiting the pole re-inforcing in the vicinity of the earthed LV system. This would represent a relatively low impulse path for lightning discharge currents. Typically, the exit points of the discharge current are at the streetlight fittings & the LV ABC. Plate 23 on page 65 shows the discharge path as described above. There is damage at the concrete bracing strap where the discharge current may have entered the pole reinforcing after breakdown of the MV insulation. The exit from the pole re-inforcing appears lower down at the earthed streetlight fitting. Another path exists in parallel with the one just described. As before, there is a breakdown of the MV insulation and flashover to the pole re-inforcing, the re-inforcing then conducts the discharge current down the pole and then into the surrounding earth. In a lot of cases there was visible damage in the vicinity of the earthed LV hardware but with no apparent damage in the vicinity of the MV hardware. The reason for this may be that the puncture or breakdown of the concrete has taken place within the pre cast hole through which the crossarm mounting bolt is fitted. Practically this was not possible to verify. On Poles that support MV conductors only, the only possible dissipation path for lightning current is a flashover or puncture of the MV insulation, together with a flashover to the re-inforcing wires and then flowing into the surrounding earth below ground level. The excavation shown in plates 24 and 25 on page 66 verified this. Plate 24 shows what appears to be a classical 3-phase flashover to the pole due to an equally induced overvoltage on all 3 phases. The pole is seriously damaged and re-inforcing wire is visible. The stay wires shown are insulated to earth using 350kV continental guy insulators, these are not visible in the plate. There was no damage detected on the stay insulators. The only other low impulse path for the discharge is down the pole re-inforcing wires and into the earth. Plate 25 shows the pole butt after excavation where damage and carbonising is visible. It must also be noted that the extent of the damage to the pole may not be entirely due to lightning current alone, but may be due to power follow through current immediately following insulation failure as a result of the lightning overvoltage.

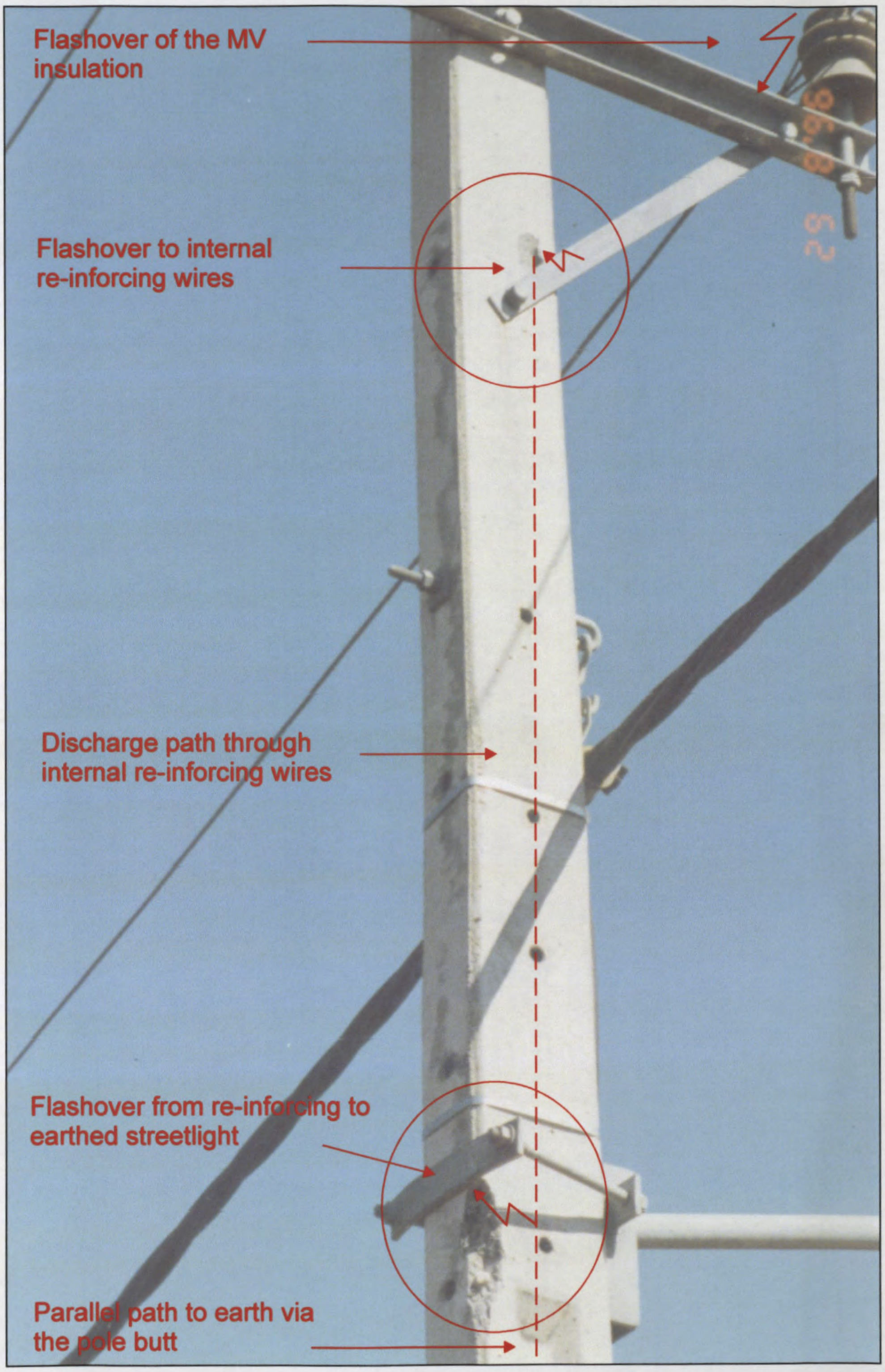


Plate 23 - Possible breakdown paths to earth

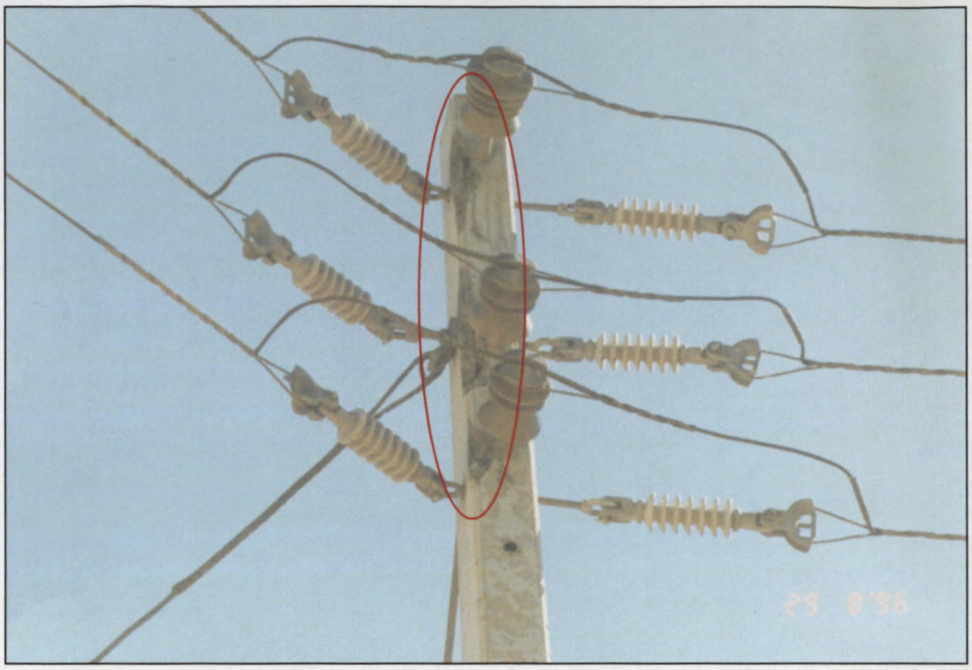


Plate 24 - 3-phase flashover (MV conductors only)

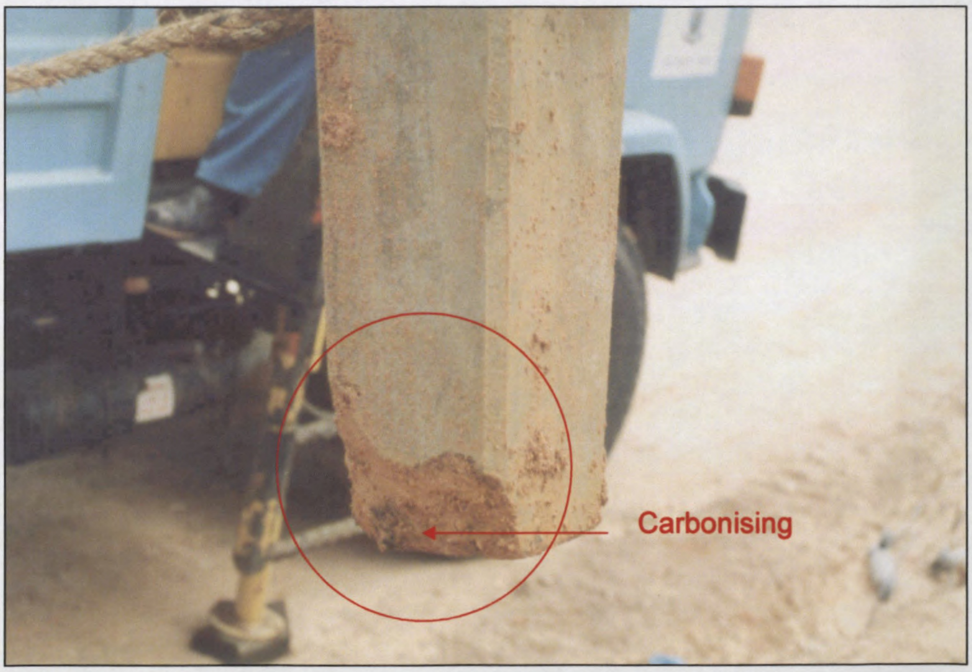


Plate 25 - Damage and carbonising at the pole butt

3.7 Inspection of the Low Voltage radial feeds

During inspections of the main MV line, it was noticed that there appeared to be very little damage to concrete poles supporting only LV ABC conductors. This appeared interesting as both lines are located in the same area and are presumably both subject to the same lightning activity. It was therefore decided to inspect the 6-km's of low voltage line for comparison and correlation. A pole inspection was conducted over 3 days, concluding on 10/09/96. A damage inventory was compiled using the same damage classification as for the MV line.

NO. OF POLES INSPECTED LV ONLY	213 (100%)
No. of poles structurally damaged	16 (8%)
Incidence of bad damage	2 (1,3%)
Incidence of moderate damage	0
Incidence of slight damage	14 (6,7%)

Table 3.6 – Damage to LV poles

3.7.1 Comments on damage

Referring to table 3.6, only 8% (16) of the total poles inspected exhibited damage. There were only 2 incidences of bad damage to the LV poles. Both of these were recorded on the same pole, which is shown in plates 26 and 27 on page 70 .The damage is more than likely a result of a direct strike. The pole tip is severely damaged, as is the base of the pole. It appears that the lightning struck the pole tip and exited at the pole base. The damage to this pole is by far the worst recorded out of all the MV and LV poles inspected. This suggests that the other damage recorded has may be a result of insulation breakdown due to high induced voltages and subsequent power follow through current causing most of the damage. The distinction between whether the damage is being initiated by induced overvoltages or direct strikes is crucial, as the insulation co-ordination and philosophy applied to lines differ accordingly.

Fig. 3.10 shows the comparison between the incidence of damage

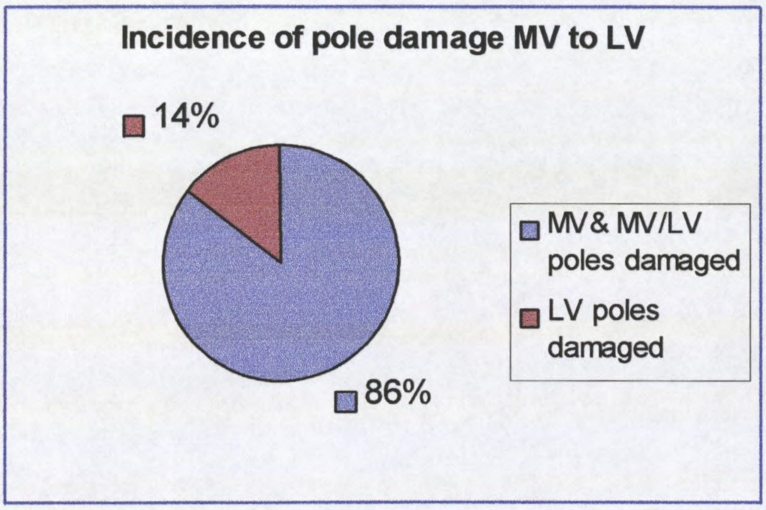


Fig. 3.10 – Comparison of damage between MV & LV poles

recorded on MV and MV/LV poles (any pole carrying MV conductors) to the incidence of damage recorded on LV poles (poles carrying LV only). The difference is significant given the fact that these poles are all located in the same area. The lack of damage on the LV poles can possibly be explained by considering the effects of an induced overvoltage on both LV and MV lines in turn.

The LV ABC combined neutral earth conductor may act as an earthed shield wire. As mentioned previously, the magnitude of induced voltages may be reduced by between 10 and 60% due to an earthed shield wire [10]. As a result, the induced voltages on the LV ABC are therefore lower and would not necessarily result in a flashover to the pole. The LV system voltages are also not high enough to then cause additional damage by power follow through current.

By comparison flashover of the MV poles as a result of induced surges result in a breakdown of insulation followed by 11kV power follow through current. As the system voltages to earth are much higher, they are able to sustain power follow through current after the initial breakdown due to the induced overvoltage. The power follow through current will be interrupted by the system protection, but not before it has inflicted damage to the pole.

Most of the remaining damage to the LV poles appeared slight and there is doubt as to whether this was caused by mechanical damage or lightning. If direct strikes were frequent, then one would expect more recordings of similar damage to both MV and LV poles as shown in plates 24 and 25. Knowing whether direct strikes or induced overvoltages are responsible, or both, is crucial in establishing and implementing measures to minimise future damage. The following sections cover observations made with respect to direct strikes and induced overvoltage.

Plate 26 - Pole tip damage to LV ABC pole

Plate 27 - Damage at pole base (same pole)

3.8 Observations with respect to direct Strikes

- Direct strikes would tend to strike the highest conductor, except for low discharge currents where a strike to the lower conductors is possible. The statistics reveal that only 21 % of the damage associated with the medium voltage were at the pole tip. Damage at these positions was found to be moderate to low. The damage recorded was significantly less than that shown in plate 25.
- A direct strike to the conductor would result in a surge voltage being propagated in both directions; this would cause flashover at successive poles along the direction of surge propagation. Seven direct strikes can be expected to the line per annum (eq. 5.1) This would result in flashover at numerous successive poles either side of the strike. Damage distribution recorded on the line indicates flashover at successive poles. Successive flashovers occurred at the following poles:
  - Poles 166 to 172 (4 poles)
  - Poles 176 to 182 (4 poles)
  - Poles 186 to 190 (3 poles)
  - Poles 202 to 206 (3 poles)
  - Poles 202 to 206 (3 poles)
  - Poles A21 to A29 (5 poles)
- The moderate to low damage recorded on the MV pole tips may be due to a division of energy as a result of the flashover occurring at several poles. Power follow through current will still create additional damage.

3.9 Observations with respect to induced flashover

- 14 induced voltages in excess of 95 kV (eq. 5.2) can be expected on the line per annum. This could also lead to flashover at multiple poles as mentioned above.
- Power follow through current would flow resulting in damage until the line trips out.
- Assuming that, in the case of direct strikes, the highest conductor would be mostly struck, Induced flashover would account more readily for the more random distribution of damage in the vicinity of the MV hardware.
  - Pole tip 21 %
  - MV cross arm 38 %
  - MV Strain Insulators 25 %
- Plate 27 shows an example of a classical 3-phase flashover due to an equal induced voltage on all three phases. Another example of this is shown in plate 18 on page 57. Only two phases had flashed over, possibly due to a greater jumper clearance to the pole on the top conductor.
- Statistically only 8 % of the low voltage poles inspected exhibited damage as opposed to 48 % for the medium voltage poles. This may be due to the shielding effect of the earthed neutral conductor on the LV ABC.

3.10 Remedial Measures

It is still uncertain as to whether the damage is being caused by direct strikes to the MV conductors or induced overvoltages combined with power follow through current or both. Observations made, however, tend to lean more to induced overvoltages. As mentioned there are different approaches and methods for protecting a line from the effects of induced and direct strikes, additional information is therefore required prior to specifying remedial measures. This is dealt with in the following chapter.

Following discussions with Grinaker regarding structural repairs to the damaged poles, a subcontractor "Pro Struct" inspected the damage and quoted on repairs. It is intended that these repairs should be undertaken in the future but not before remedial modifications are implemented as such repairs may otherwise be wasted.

CHAPTER 4 - Tests

4.0 Introduction

In order to fully evaluate the lightning performance of the pre-stressed poles and to recommend remedial measures, an assessment of the line B.I.L. for concrete pole needs to be done. There are two main issues that fundamentally effect the B.I.L. that need to be looked at. Firstly, the effects of a transient overvoltage on the concrete pole and it's breakdown strength. Secondly, whether a pre-stressed concrete pole will behave in a similar manner as an electrode encased in concrete as reviewed in chapter 2. Both laboratory and field tests were undertaken in order to shed some light on both these issues.

4.1 Impulse testing of pre-stressed concrete

Following the analysis of the damage and the statistics it was apparent that the concrete pole was forming part of the discharge path for lightning. As the pole together with the line insulation comprised the basic impulse level of the line to earth, it would prove useful to establish what effect the concrete pole made to the overall BIL of the line. The all wood pole construction has a 1 to 2 MV impulse level due to the long flashover path across the wood. Considering the damage statistics, It appears that the lightning impulse withstand of the concrete line is a lot lower than that of the equivalent wood pole construction. Grinaker were requested to supply samples of pre-stressed concrete for laboratory impulse tests.

4.1.1 Samples

The manufacturer supplied three concrete samples in the form of cubes with the 8mm re-inforcing wire set in the concrete at different depths to ensure a covering of 15 mm and 7 mm respectively between the wire and the outside surface of the concrete as shown in fig. 4.1 below.

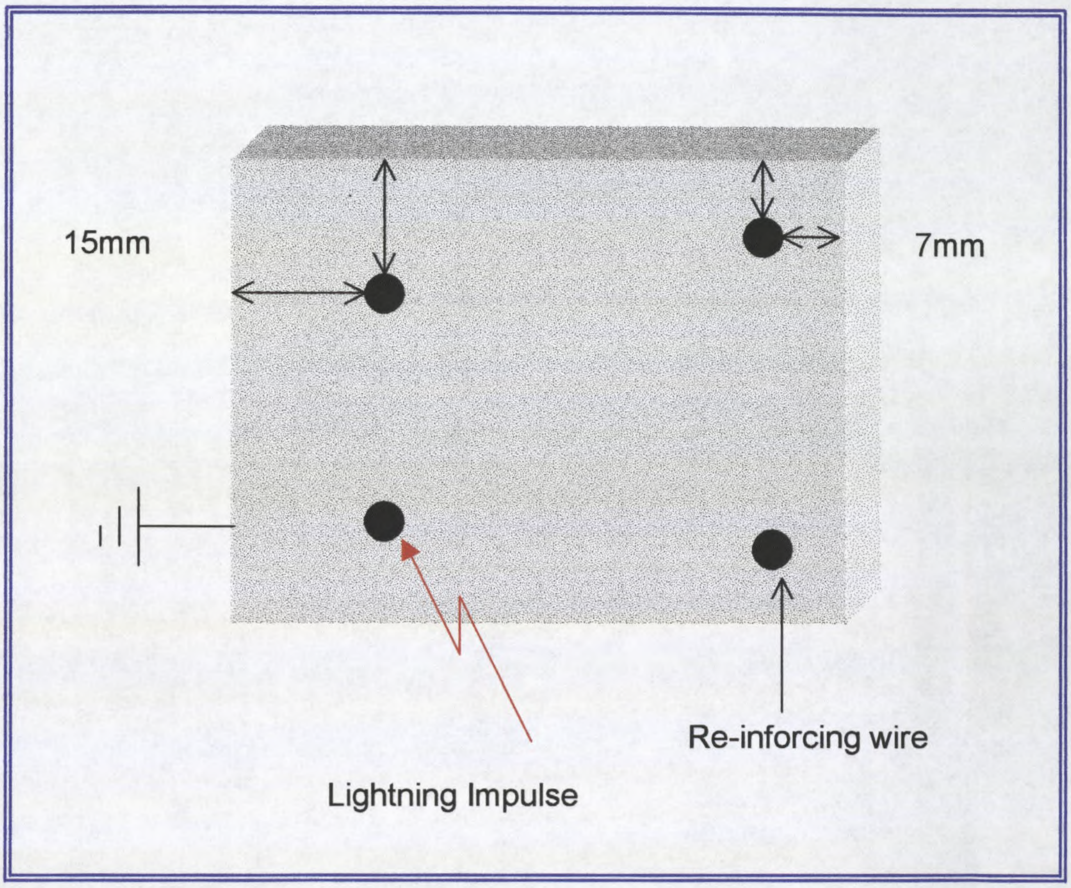


Fig. 4.1 – Test sample with re-inforcing

A simulated lightning impulse was applied between the re-inforcing wire and the outside surface of the concrete cube in order to establish a lightning withstand value for the concrete. As concrete is hygroscopic both dry and wet samples were tested.

4.1.2 Generation of Impulse voltage

A single stage 100kV impulse generator at the ML Sultan Technikon was used to generate the impulse voltages. The basic circuit diagram is

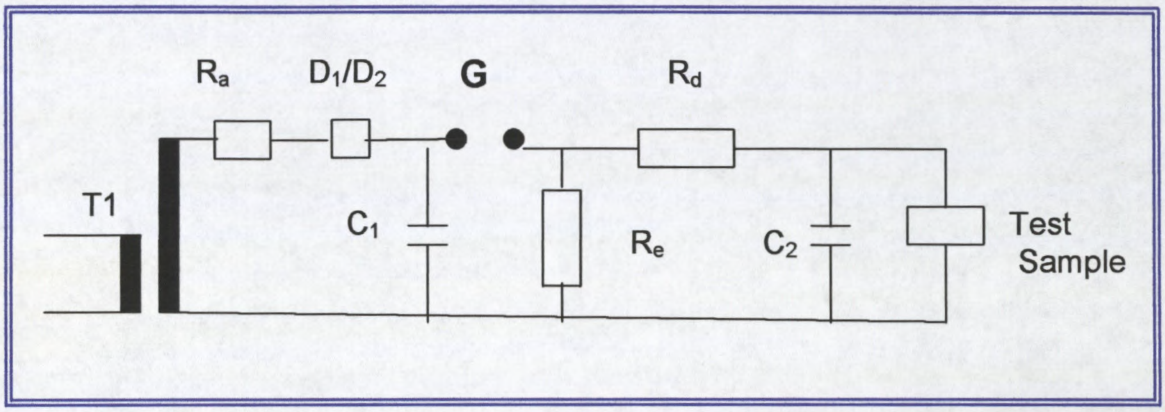


Fig. 4.2 – Impulse generator test circuit

shown below.

C_1 = 10 000 pf , C_2 = 1 200 pf R_d = 375 Ω R_e =6100 Ω

The step-up transformer T1 steps up from 220V to 100KV. The Capacitor C_1 is charged up via the current limiting resistor R_a (10MΩ) & diodes d_1 & d_2 with a peak inverse rating (P.I.V.) of 140KV & current rating of 20mA.

The Spark gap G is variable & can be mechanically adjusted to discharge capacitor C_1 over the full output range of the generator (0 - 100KV). The spark gap acts as a voltage limiting & voltage sensitive switch, whose ignition time (time to voltage breakdown) is very short compared to t_1 (Wave front).

R_d, R_e , & C_2 form the wave shaping elements of the circuit. R_d will essentially damp the circuit & will therefore determine the rise time or steepness of the wave front. R_e discharges both capacitances & will therefore determine the decay time or wave tail. The capacitance C_2 ensures that there is no large variations between t_1 and t_2 due to varying capacitances of the test objects.

The output voltage of the generator is given by [13]:

$$V(t) = V_o / K / (\alpha_2 - \alpha_1) . \{ \exp(-\alpha_1.t) - \exp(\alpha_2.t) \} \quad (4.1)$$

Where

α_1, α_2 are the roots of the eqn. $S^2+aS+b = 0$

$\alpha_1, \alpha_2 = a / 2 +/- \sqrt{\{(a / 2)^2 - b\}}$

$K = R_d . C_2$

$a = \{1/ (R_d . C_1) + 1/ (R_d . C_2) + 1/ (R_e . C_1) \}$

$b = \{ 1 / (R_d . R_e . C_1 . C_2) \}$

The standard lightning impulse is defined as a 1,2 / 50μs wave. See fig 2.3. IEC 60-1 allows a tolerance of 1.2μs +\ - 30% on the wave rise time i.e. between 0.84μs & 1.56μs. The permissible tolerance for the wave tail is 50μs + \ - 20% i.e. between 40μs and 60μs.

Appendix B gives the generator output for variable wave dimensioning resistors, R_d & R_e. From the calculations it can be seen that for R_d

values of 541, 455 & 375 ohms, the IEC 60-1 specified rise time is complied with. Similarly selection of R_e = 6100 Ω also satisfies the specified decay time.

4.1.3 Setting up the test circuit.

The test set was connected as shown in plates 28 and 29. In order to prevent flashover directly between the exposed re-inforcing and the earthed work top, the concrete sample was balanced on top of a porcelain pin insulator with an impulse withstand of 95 kV. The positive electrode was connected to the re-inforcing rod & the outer surface of the concrete cube was earthed via lead strips secured to the concrete surface with copper wire.

4.1.4 Test Procedure

Impulse tests were conducted on samples with 7mm and 15mm coverings of concrete surrounding the steel re-inforcing. Starting with the 7mm samples, an impulse voltage was progressively applied to the test sample until breakdown occurred from the re-inforcing through the concrete to the earthed lead strip. Six tests were conducted on each sample and the results were recorded.

In addition to the above tests which were conducted to determine an initial breakdown value for concrete, a determination of whether the concrete had any self restoring properties in terms of it's breakdown strength was considered important. After initial breakdown, the impulse

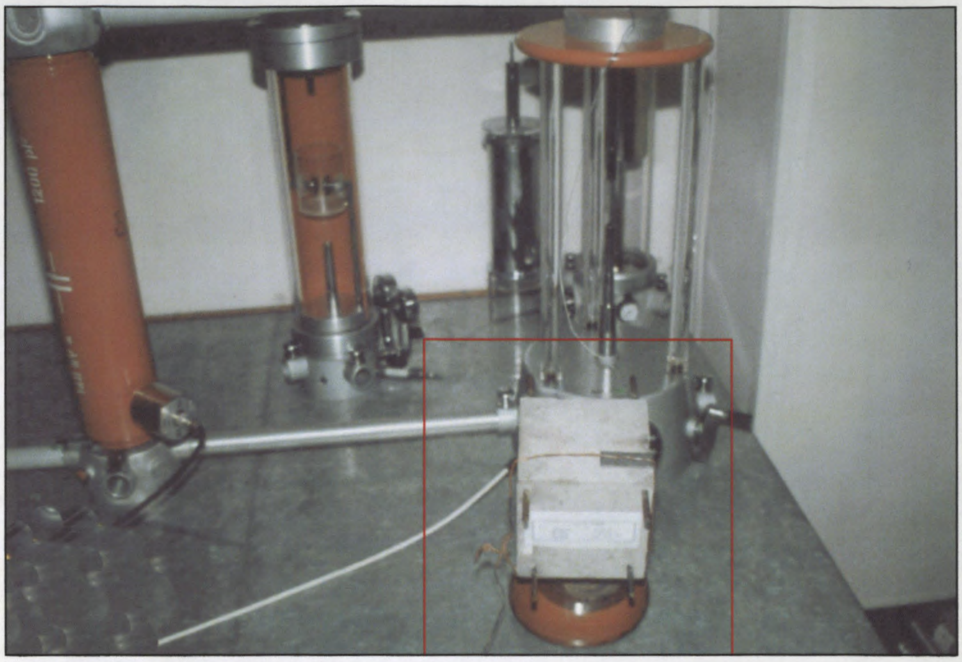


Plate 28 -Impulse generator and test sample

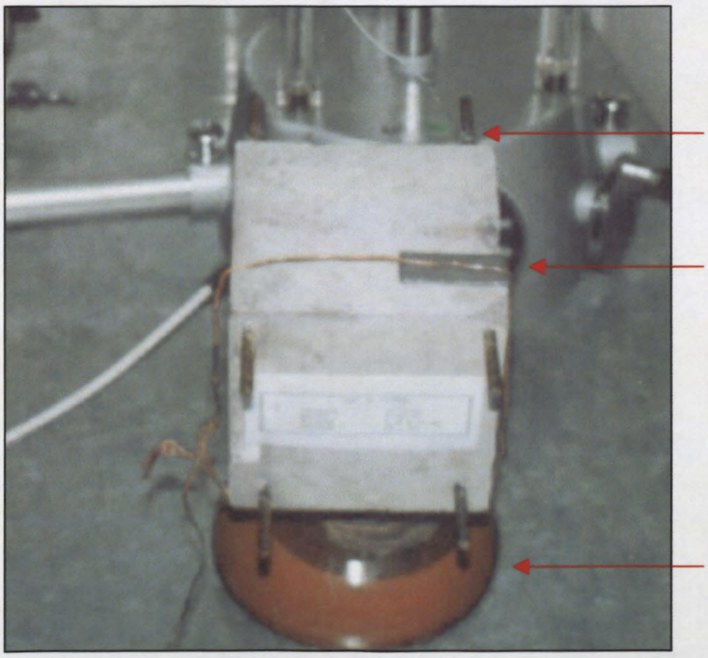


Plate 29 - Test sample and connections

value was progressively reduced until breakdown of the sample ceased.

The final breakdown values were also recorded.

4.1.5 7mm dry concrete with re-inforcing

SAMPLE NO.	INITIAL BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
1	47.5 kV	5 kV
2	35 kV	2kV
3	45 kV	6kV
4	39 kV	3kV
5	49 kV	2kV
6	32 kV	8kV

Table 4.1 – Impulse breakdown for 7mm dry concrete with re-inforcing

Referring to table 4.1, the average initial breakdown value for the 7mm sample of 41.25kV. The final average breakdown value is 4. 33kV.

4.1.6 7mm wet concrete with re-inforcing

SAMPLE NO.	INITIAL BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
1	45 kV	6 kV
2	31 kV	3 kV
3	38 kV	10 kV
4	41 kV	2 kV
5	29 kV	5 kV
6	30 kV	15 kV

Table 4.2 – Impulse breakdown for 7mm wet concrete with re-inforcing

Referring to table 4.2, the average initial breakdown value for the 7mm sample of 35.67kV. The final average breakdown value is 6.83 kV.

4.1.7 15mm dry concrete with re-inforcing

SAMPLE NO.	INITIAL BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
1	68 kV	14 kV
2	58 kV	5 kV
3	67 kV	16 kV
4	59 kV	21 kV
5	55 kV	9 kV
6	71 kV	13 kV

Table 4.3 – Impulse breakdown for 15mm dry concrete with re-inforcing

Referring to table 4.3, the average initial breakdown value for the 15mm test sample is 63 kV. The average final breakdown for the concrete is 13 kV.

4.1.8 15mm wet concrete with re-inforcing

SAMPLE NO.	INITIAL BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
1	69 kV	7 kV
2	42 kV	12 kV
3	68 kV	4 kV
4	61kV	15 kV
5	59 kV	9 kV
6	69 kV	10 kV

Table 4.4 – Impulse breakdown for 15mm wet concrete with re-inforcing

Referring to table 4.4, the average initial breakdown value for the 15mm test sample is 61.3 kV. The average final breakdown for the concrete is 9.5 kV.

Following the tests on the samples containing re-inforcing, the manufacturer was requested to submit additional samples of concrete without any steel re-inforcing. This was done in order to ascertain what effect the steel re-inforcing had on the breakdown values. The samples supplied were in the form of slabs 150mm x 150mm x 15mm thick and 150mm x 150mm x 23mm thick as shown below.

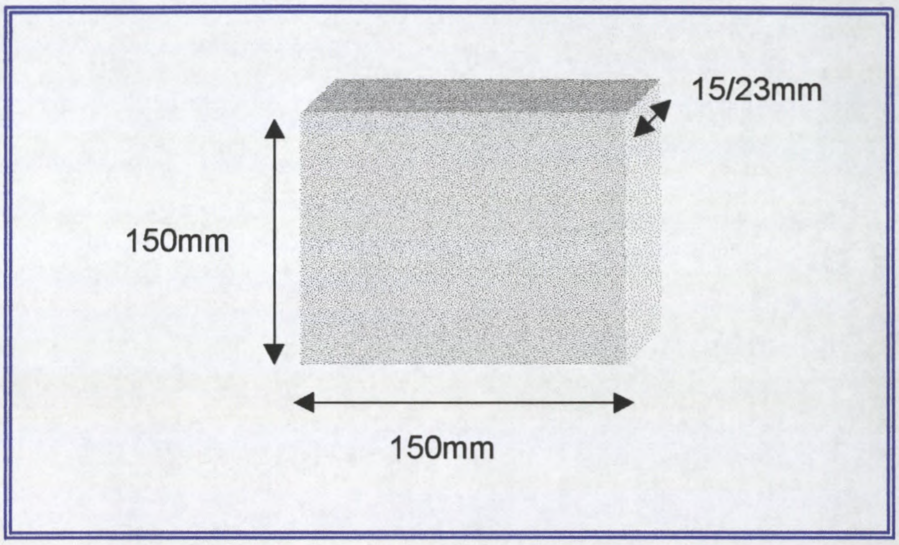


Fig 4.3 – Test sample without re-inforcing

Additional impulse tests were then conducted with the sample set up between 2 sphere electrodes as shown in plate 30 overleaf. The simulated lightning impulse was applied to the upper electrode with the lower electrode being at earth potential. These tests also included wet samples, which were left immersed in a bucket of water for 24 hrs prior to testing.

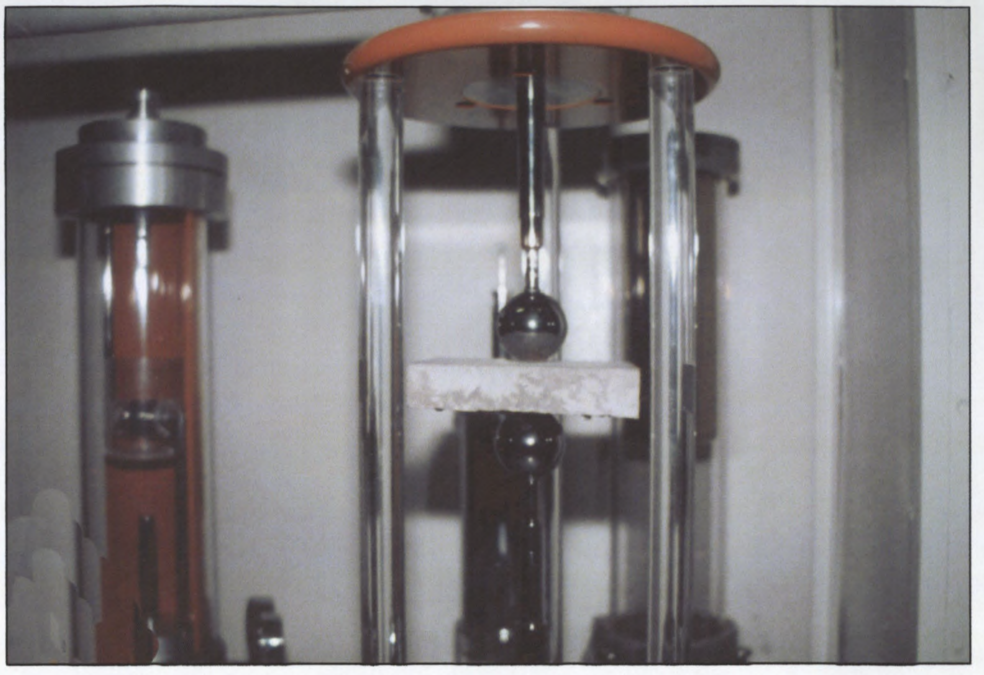


Plate 30 - Concrete sample between test electrodes

Plate 31 - Puncture due to impulse breakdown

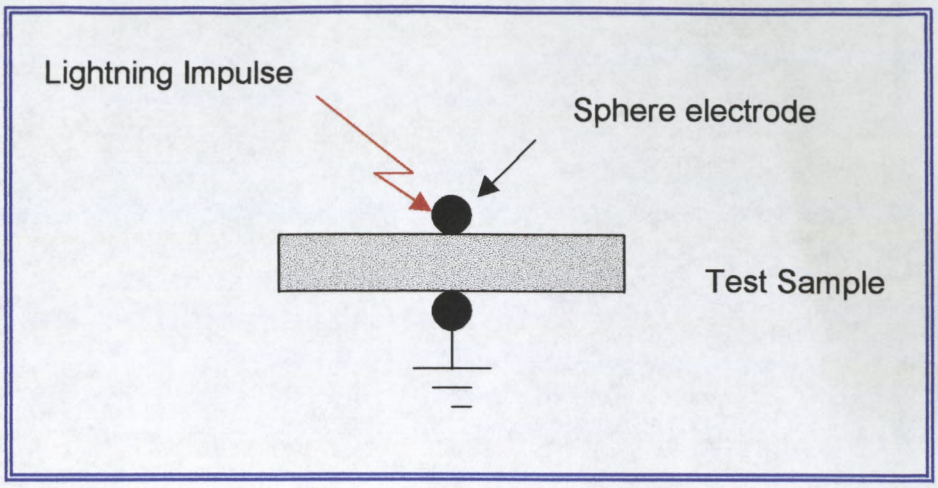


Fig. 4.4 – Test circuit for sample without re-inforcing

4.1.9 15mm dry concrete with no re-inforcing

SAMPLE NO.	INITIAL BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
1	64 kV	59 kV
2	74 kV	42 kV
3	68 kV	48 kV
4	62 kV	55 kV
5	65 kV	61 kV
6	70 kV	38 kV

Table 4.5 – Impulse breakdown for a 15mm dry sample with no re-inforcing

Referring to table 4.5, the average initial value of breakdown is 67.17 kV.

The average final value of breakdown is 50.5 kV.

4.1.10 15mm wet concrete with no re-inforcing

SAMPLE NO.	INITIAL BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
1	62 kV	51 kV
2	68 kV	62 kV
3	65 kV	65 kV
4	71 kV	36 kV
5	66 kV	43 kV
6	73 kV	48 kV

Table 4.6 – Impulse breakdown for a 15mm wet sample with no re-inforcing

Referring to table 4.6, the average initial breakdown value is 67.5 kV. The average final breakdown value is 50,83 kV.

4.1.11 23mm dry concrete with no re-inforcing

SAMPLE NO.	INITIAL BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
1	82 kV	68 kV
2	80 kV	56 kV
3	74 kV	70 kV
4	78 kV	31 kV
5	80 kV	65 kV
6	77 kV	74 kV

Table 4.7 – Impulse breakdown for a 23mm dry sample (no re-inforcing)

Referring to table 4.7, the average initial breakdown voltage is 78.5 kV.

The average final breakdown voltage is 60.67 kV.

4.1.12 23mm wet concrete with no re-inforcing

SAMPLE NO.	INITIAL BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
1	79 kV	44 kV
2	82 kV	66 kV
3	72 kV	68 kV
4	75 kV	39 kV
5	80 kV	55 kV
6	78 kV	72 kV

Table 4.8 – Impulse breakdown for a 23mm wet sample with no re-inforcing

Referring to table 4.8, the average initial breakdown voltage is 77.67 kV. The average final breakdown voltage is 57.33 kV.

4.1.13 Review of breakdown voltages

TABLE NO.	AVERAGE BREAKDOWN VOLTAGE	FINAL BREAKDOWN VOLTAGE
4.1 (7mm dry with reinforcing)	41.25 kV	4.33 kV
4.2 (7mm wet with reinforcing)	35.67 kV	6.83 kV
4.3 (15mm dry with reinforcing)	65.67 kV	13 kV
4.4 (15mm wet with reinforcing)	61.3 kV	9.5 kV
4.5 (15mm dry no reinforcing)	67.17 kV	50.5 kV
4.6 (15mm wet no reinforcing)	67.5 kV	50.83 kV
4.7 (23mm dry no reinforcing)	78.5 kV	60.67 kV
4.8 (23mm wet no reinforcing)	77.67 kV	57.33 kV

Table 4.9 – Review of impulse breakdown values

4.2 Conclusions

- The average breakdown voltages do not show a linear increase with respect to concrete thickness, which is contrary to expectation. The breakdown values within the six tests in the case of re-inforced samples show a wide spread. This may be a due to fact that the concrete is not homogenous in nature and this may be exaggerated as result of compaction problem around the re-inforcing wires. The range of samples tested in terms of concrete thickness was limited due the output of the surge generator being 100kV, however coverage of concrete over the re-inforcing wires at positions of breakdown on the concrete poles are definitely within the range of 7mm to 23mm.

- The final breakdown strengths for samples with re-inforcing are significantly lower than those samples without re-inforcing. The final breakdown strengths exhibited a wide spread within the six tests done on each sample. The significantly higher final breakdown values of the thicker samples without re-inforcing may be due to the fact that the concrete is more homogenous as there are no re-inforcing wires to create compaction problems or voids. The limited surge energy from the generator may not be enough to result in a carbonised or low resistance breakdown path after initial breakdown in the case of the samples without re-inforcing. The opposite may be true for samples with re-inforcing.

- There doesn't appear to be a significant reduction in breakdown strengths between dry and wet, except for the 7mm samples with re-inforcing, where a reduction of approximately 13.5% was recorded. Discussions with Grinaker indicated that the concrete was unlikely to absorb much water due to the addition of additives and the high strength and compaction.

- Based on the results, particularly considering the re-inforcing and the destructive nature of the breakdown, the concrete pole cannot be expected to add significantly to the line B.I.L. Although initial impulse breakdown values may be in the order of several tens of kilovolts, subsequent to initial breakdown and the establishment of carbon tracks, the breakdown voltage and therefore the line B.I.L. may be a lot lower.

4.3 Soil Resistivity Tests

In order to assess a concrete pole in terms of the concrete encased earth electrode discussed in chapter 2; soil resistivities along the line route need to be known. Soil resistivity tests were undertaken at various positions along the line in order to assess the pole footing resistances This would also assist with the implications of obtaining low earthing resistances should the application of an overhead shield wire as a remedial measure be considered.

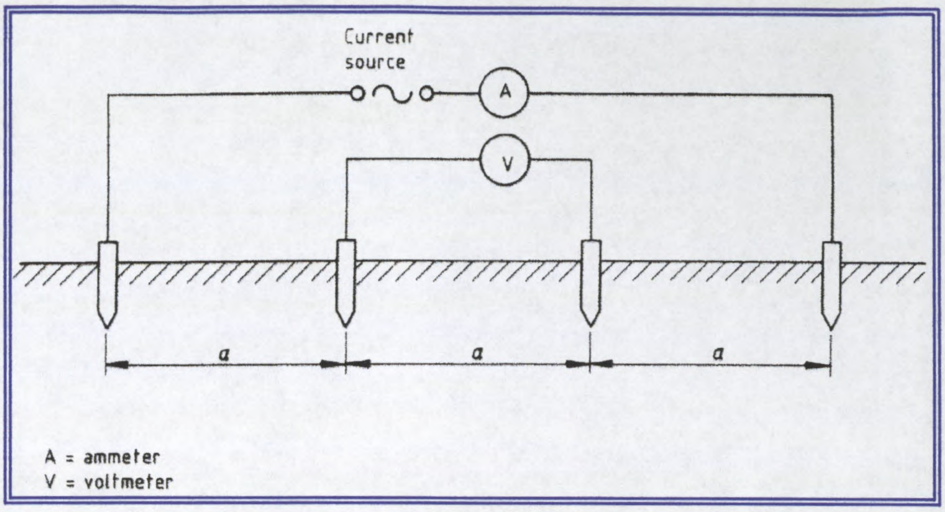


Fig 4.5 – The schlumberger method for soil resistivity tests

Figure 4.5 shows the standard 4-probe method known as the Schlumberger array. The distance "a" between the probes gives the apparent resistivity of the soil at a depth equivalent to "a" from the surface. Soil soundings using a TERR243E earth meggar were done at 1 metre and 2 metre depths, as these are practically the ranges within which a standard 1.5metre earth electrode would be installed. The concrete pole planting depth is 1,8 metre, which is also within the 1 to 2-metre depth range. Seven different locations were chosen as shown in fig. 4.6. overleaf. The resistivity varied between 169 Ω.m and 2090 Ω.m. Readings were repeated at monthly intervals at the same locations in order to check for seasonal variations – refer to appendix C.The overall average soil resistivity for the area was found to be 935 Ω.m and this figure was used for calculation purposes.

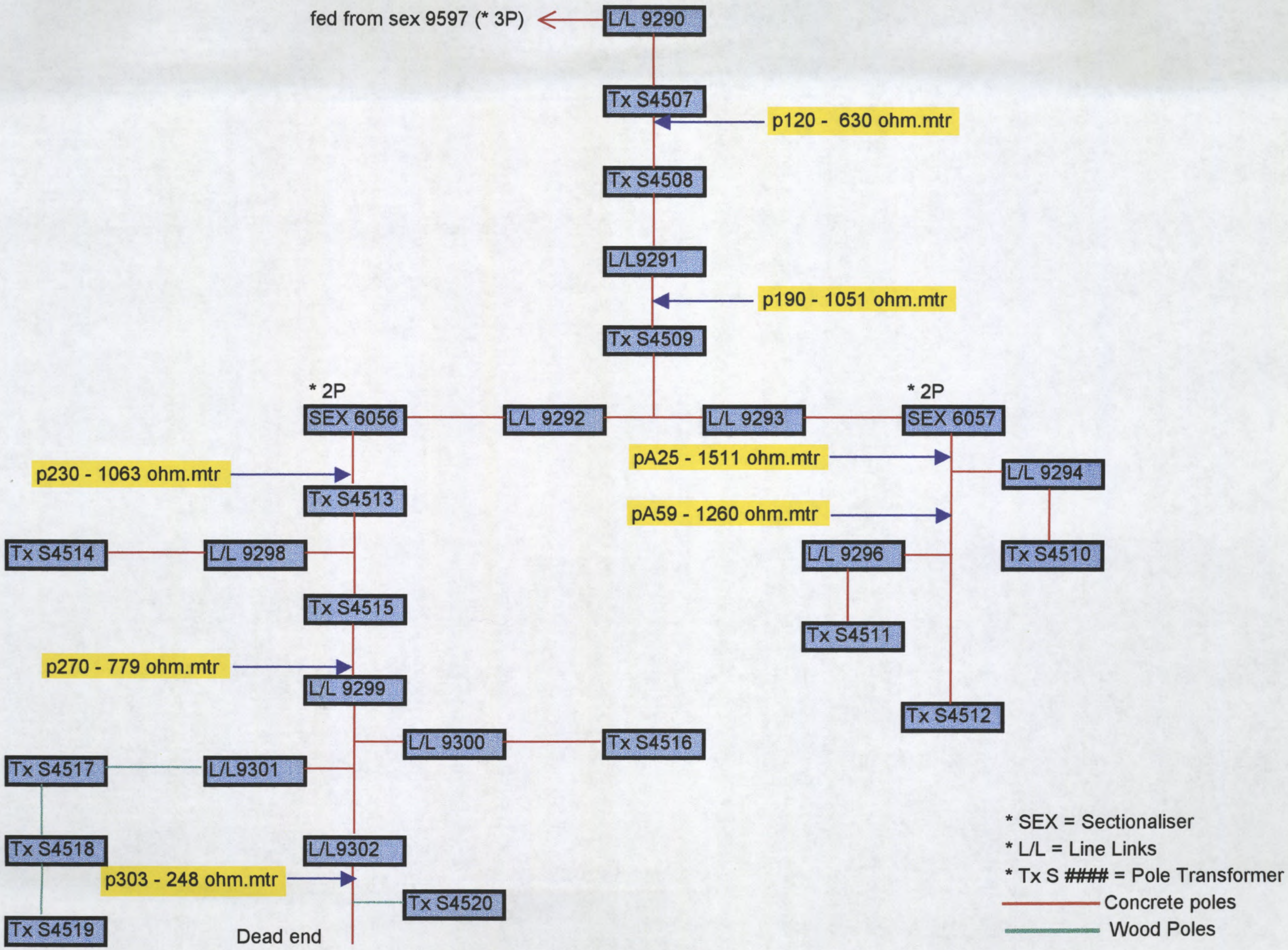


Fig. 4.6 - Earth resistivity measurements

4.4 Effects of a concrete pole in soil

As discussed in chapter 2, an array of re-inforcing rods encased in concrete and buried in soil acts as a composite earth electrode. The resistance is dependent on the re-inforcing geometric arrangement, the thickness of concrete between the re-inforcing and soil, the depth buried in the soil and the soil resistivity. An important distinction between the concrete pole and an array of electrodes encased in concrete used for earthing purposes is that there is no bonded connection between the internal pole re-inforcing and the external pole hardware. Nevertheless, it is worth calculating the overall resistance to earth of the internal re-inforcing wire based on the theory discussed in chapter 2 as this essentially forms a shunt path to earth, which is in parallel with earthed hardware components. It should be noted however, that the theory described in chapter 2 is based on steady state (D.C.) theory and that the transient impedance due to lightning may be higher.

Appendix D1, pg1 shows the underground pole profile and the resultant variation in concrete thickness due to the taper. Appendix D1, pg2 shows the re-inforcing rod positions at the pole butt and pg3 the positions at the midpoint planting depth. The calculation is simplified by only considering the 4 outer re-inforcing rods in a square formation. The concrete thickness between the re-inforcing wires and the soil varies with the pole taper, therefore an average thickness has been determined at the midpoint depth. An average spacing between the rods has also been used as the dimensions vary. As concrete is hygroscopic its resistivity when buried can vary between 30Ω.m and 90Ω.m depending on moisture. [17]

The following parameters are used in the calculation :

Concrete resistivity	ρ_c	= 60 Ω.m
Soil resistivity	ρ_e	= 935 Ω.m
Re-inforcing length (pole planted depth)	L	= 1,8 metres
Radius of re-inforcing	a	= 4mm
Distance between wires	s	= 62mm
Thickness of concrete	δ	= 51,63mm

From fig 2.7 the geometric mean distance for four rods in a square formation is given by:

$$Z = \sqrt[4]{(2.a.s^3)}$$

$$= \sqrt[4]{(2 \times 0{,}004 \times 0.062^3)}$$

$$= 0{,}0372 \text{ m}$$

From eq 2.12;

$$R = 1 / (2.\Pi.L) \times [(\rho_c - \rho_e) . Ln(1 + \delta / Z) + \rho_e . Ln(2.L / Z)]$$

$$= 1 / (2 \times \Pi \times 1{,}8) \times [(166 - 935) \times Ln(1 + 0.0516 / 0{,}0372) +$$

$$935 \times Ln(2 \times 1{,}8 / 0{,}0372)]$$

$$= 310{,}7\ \Omega$$

In order to establish whether the concrete pole had any measurable D.C resistance to earth as calculated on page 97, 3 tests were conducted at different sites on poles supporting medium voltage conductors only. There were no stay wires or any other connections between the pole and ground. The test circuit is shown below:

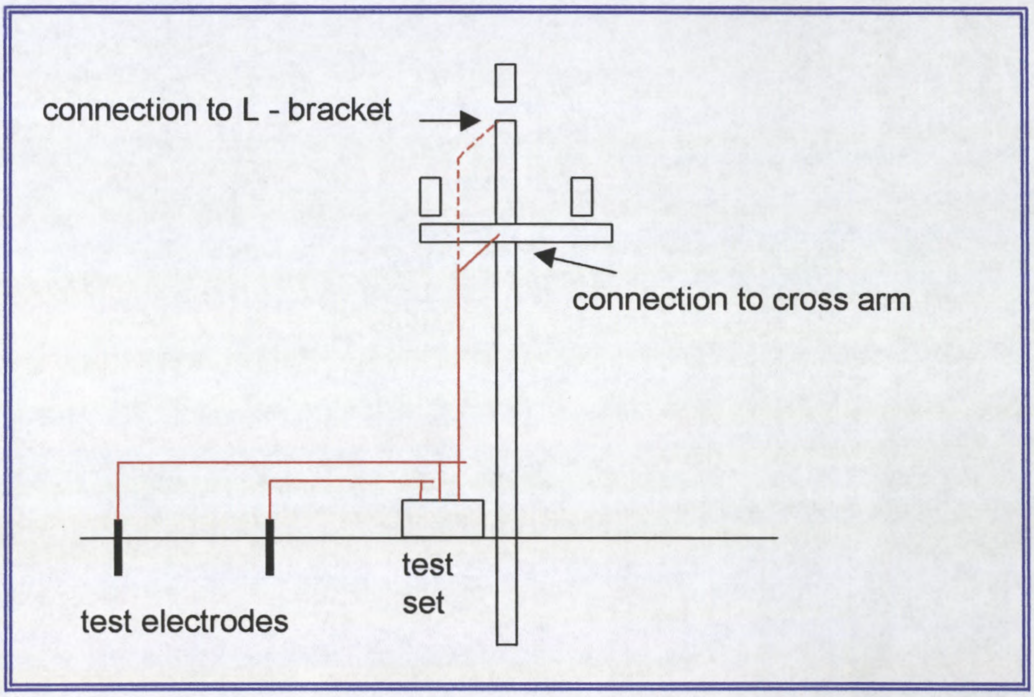


Fig. 4.7 – Earth resistance of a concrete pole

The test set was first connected to the pole via the steel crossarm, which is bolted to the pole and testing was carried out. A second test was done by connecting to the L-bracket, which is also bolted to the pole. At all three poles there was no measurable result as the reading was greater than 999 ohms, which is beyond the range of the test set. The soil resistivities at each site were recorded and were found to be 182, 532 and 530Ω. meters respectively. The difference between the calculated and the test measurement is that, in the case of the test, it was not possible to connect the test set directly to the internal re-inforcing wires. As the connection of the test set was made externally to the crossarm and the L-bracket, this effectively introduces another resistance component into the measurement. This additional resistive component is the resistance represented by the cross-section of concrete between the crossarm/L-bracket and the internal re-inforcing wires. A representation of this is shown in fig 4.8 overleaf, this is for a pole without LV ABC or other earthed hardware. Referring to fig 4.8, it is effectively Z_2 + Z_3 which are under test. The results of this test (> 999 Ω) suggests that an external down wire of suitable buried depth and relatively lower resistance to earth could be used to short-circuit the concrete pole to ground. This may prevent the lightning from discharging through the pole to ground.

Fig. 4.8 shows the individual elements that influence the line B.I.L. for a pole supporting only medium voltage conductors with no down wires to earth or any other earthed hardware components

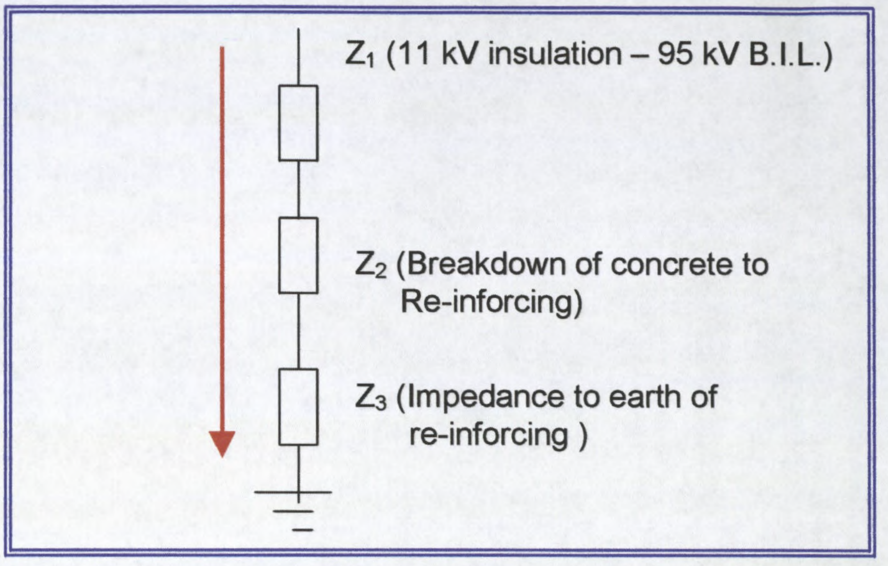


Fig. 4.8 – Representation of the line B.I.L. for a medium voltage pole without downwires

The line B.I.L for a pole that supports both medium voltage and low voltage conductors differs in that there is an additional shunt path made up of a concrete component in series with the low voltage system impedance to ground. This was discussed previously in chapter 3, section 3.6.1 (possible breakdown paths). A representation of this is given in fig. 4.9 overleaf.

Fig 4.9 shows the individual elements that influence the overall pole structure impulse withstand to earth for a pole carrying LV conductors

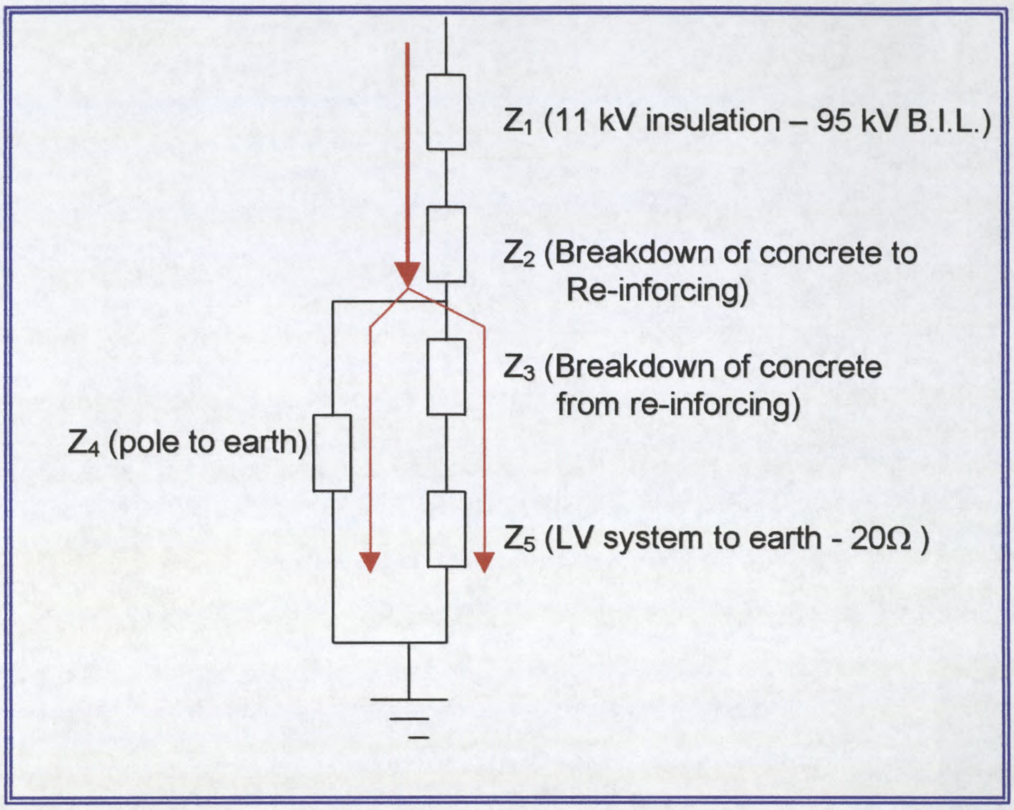


Fig. 4.9 – Representation of the line B.I.L. for a combined MV/LV pole

and other earthed hardware components, such as streetlight fittings etc. The branch Z_3 and Z_5 represents the impedance to earth through the LV system. In parallel with this branch is Z_4, which is the impedance to earth of the pole itself (as calculated in eq. 4.3).

4.5 Transient breakdown of concrete

The impedances in fig. 4.9 represent transient values of breakdown between the concrete and re-inforcing wires. Based on the impulse testing done on the concrete samples and the results in table 4.3, the impulse impedances Z_2 and Z_3 may be considered to be around 63kV each. This is based on the test values obtained for 15mm concrete. The 15mm concrete is in line with the concrete coverage on the poles (10 to 25mm). It is probable that once breakdown has occurred through a pole that sufficient carbonisation will have taken place due to the high concentrated current, thereby effectively reducing the impulse withstand of the pole. The breakdown damage on the test samples was very slight in comparison to the damage found on the poles due to the limited energy available from the impulse generator. The impedance Z_4 may behave differently to the impedances Z_2 and Z_3 in fig. 4.9 as the concrete is completely surrounded by soil over its entire surface area. The specific soil resistivity being as high as it is may result in a high transient impedance in comparison with the series impedance $Z_3 + Z_5$. This may account for the concentration of damage around the low voltage system, which is earthed through the LV ABC neutral conductor. As stated previously, the impedances Z_4 and Z_5 are steady state or D.C. measurements and that the transient impedance due to lightning frequency current could be significantly higher.

4.6 Insulators

The dry impulse withstand of the pin insulators is 95 kV. There had been numerous pin insulator failures reported on the concrete line. By comparison, the section of wood pole line with identical insulators had no reported failures. Other wood pole lines elsewhere in DE's system were also not prone to the same failures. This may be further evidence that supports the idea of a low overall impulse value for the concrete poles and can be explained as follows:

The main mode of failure is a puncture through the insulation to the metal spindle. See plates 32 and 33 overleaf. Examination of a section cut through the resin revealed the presence of "voids" within the resin casting. As the electric field strength across the insulating material is greater for insulators mounted on a low impulse structure (i.e. low phase to phase and phase to earth impulse withstand), this may be sufficient to start ongoing partial discharge across the voids within the resin. It should be noted that in the case of the concrete poles, the insulators are mounted on a common steel crossarm. This results in a higher phase to phase electric field strength across the insulator as compared to the equivalent wood crossarm. Continual partial discharge may result in cumulative degradation of the insulation, until under a transient overvoltage condition, the insulator may fail due to the high resultant electric field across the degraded insulation between the conductor and spindle. In the case of the wood poles and crossarms, the electric field across the insulator is greatly reduced due to the high insulation strength afforded by the wood. The resultant electric field strength is probably not sufficient to initiate partial discharge and therefore insulator degradation. The fact that the overall withstand to earth can be as high as 1 to 2MV for wood poles [10] would account for the lack of insulator failures on these poles.

Plate 32 - Pin Insulator failure

Plate 33 - Pin insulator failure

4.7 Conclusions on the B.I.L. of a concrete pole

- Although the impulse tests indicate moderate breakdown values between the concrete and re-inforcing wires, the pole cannot be relied on to provide any significant long-term addition to the line B.I.L. due to the destructive effect of a flashover.
- The line B.I.L. should be determined using the impulse withstand voltage of the insulators.
- Poles that carry both medium and low voltage conductors appear more susceptible to damage. This may be due to a lower impulse withstand to earth as a result of the earthed low voltage components on the pole.
- A line B.I.L. equivalent to 95kV is assumed to exist for the present configuration of the Inwabi Plateau concrete line.

CHAPTER 5 – Line modifications

5.0 Introduction

Due to the ongoing costs to Durban Electricity in terms of loss of power and repairs, modifications to the line need to be considered in order to negate such costs. As it is assumed that the line is of low impulse, it will therefore be susceptible to the effects of both direct strikes and induced voltages. The cost of any proposed modifications relative to the benefits in performance and limitation of future damage needs to be carefully considered.

5.1 Review of Lightning statistics

Before discussing specific modifications a review of the lightning statistics for the Inwabi line needs consideration in order to distinguish between the number of direct strikes and induced voltages that may be expected.

5.1.1 Lightning ground flash density N_g

The ground flash density N_g according to the CSIR statistics given in Fig 2.2 for the Inwabi area is about 6 strikes per Km^2 per annum.

5.1.2 Direct strikes to the line N_d

The number of direct strikes to the Inwabi Plateau line is given as:

$$N_d = 0.028 N_g . H^{0.6} L \qquad (5.1)$$

For an average line height of 8 metres, a line length of 12 km's

and $N_g = 6$,

$N_d = 0.028 \times 6 \times 8^{0.6} \times 12$

$= 7.02$ per annum

Referring to fig. 2.1 in chapter 2, 96% of all direct strikes are in excess of 7kA. A 7kA lightning discharge into a line of surge impedance of 400 Ω will result in a 1,4 MV surge along the line. As the assumed line B.I.L. is 95 kV, all direct strikes to the line will cause flashover at several poles.

5.1.3 Induced Lightning surges

The number of induced voltages exceeding 95 kV, which will cause flashover at one or more poles, is given by :

$$N_i = 0.15 \times N_g \times L \qquad (5.2)$$

For the line under consideration $N_g = 6$ and $L = 12$ km's

$N_i = 0.15 \times 6 \times 12$

$= 10.8$ say 11

5.1.4 Total number of expected outages

The total number of lightning effects which would lead to a power outage is $N_i + N_d$ which is equal to 18. This equates to 1.5 per month. This agrees reasonably well with the 40 power outages recorded between September 1994 and September 1996 (1.67 per month).

5.2 Lightning protection for the Inwabi Plateau distribution line

Direct strikes to the line result in the propagation of a surge voltage travelling in opposite directions along the line and will result in flashover at one or more poles. Induced overvoltages if high enough will result in flashover at a number of poles. In both cases power follow through current is likely as no arc quenching will take place due to the low impulse level of the pole. This will result in further damage to the pole. The following options are considered:

- Installation of an Overhead Shield wire
- Bond all pole hardware & provide a downwire to earth.
- Installation of a Dissipation Array System
- Installation of lightning arresters.
- Increase the impulse level by a combination of re-insulation & insulated cross-arms.

5.2.1 Installation of an Overhead shield wire

A shield wire provides protection from both direct and induced overvoltages. The installation of a shield wire would require a reconfiguration of the line. Normal practice is to position the shield wire above the phase conductors at the pole tip. In order to accommodate this, the line would have to be re-configured. A practical configuration would be a horizontal formation as shown below. The shield wire is earthed at certain intervals by running a conductor from the shield wire down to an earth electrode installed at the base of the pole. In areas of poor soil resistivity more frequent earthing of the shield wire will be

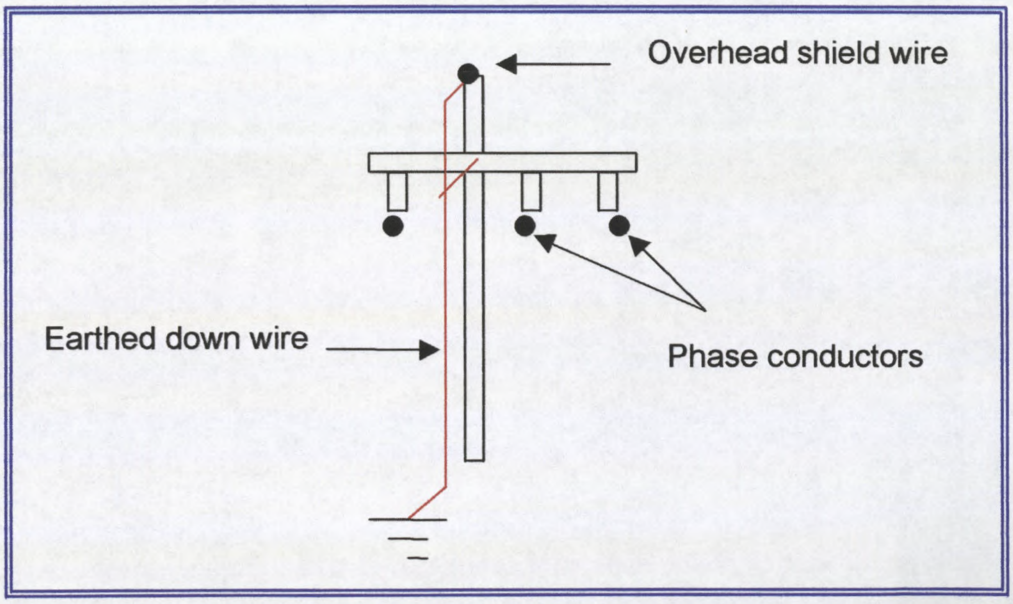


Fig 5.1 – Line configuration with an overhead shield wire

required. As all the phase conductors must be positioned below the shield wire, both horizontal and vertical configurations are possible. Practically the horizontal formation is preferable in order to ensure compliance with conductor ground clearance statutory requirements which is 6,5 metres for an un-insulated 11kV conductor . As the existing formation is delta and the existing crossarm is only 1.2m in length, the 3 phase conductors cannot be accommodated on the same horizontal plane, due to possible conductor clashing at mid span under windy conditions. A horizontal separation of at least 900mm is required to eliminate possible conductor clashing at midspan. A standard crossarm of 2.4 m would provide adequate clearance in this regard.

Apart from the mechanical aspects of this modification there are also important electrical implications that require consideration. A further problem arises in that a relatively high impulse level between the phase conductors and the shield wire needs to be obtained in order to prevent a back flashover between the shield wire and the phase conductors. Research has shown that a ratio of 20:1 between the line impulse level in kV and the pole footing resistance is required to prevent backflashover [10]. i.e. for a footing resistance of 20 ohms an impulse level of 400kV needs to be achieved. Alternatively for an impulse level of 300kV, a footing resistance of 15 ohms would need to be achieved. During line construction the earthing at the transformer positions proved difficult and costly due to the poor soil resistivity.

The design of a footing resistance for a line B.I.L. of 95kV is considered below using standard 1.5 metre, 16mm diameter copper coated steel rods, with 3 metre spacing and interconnected with $40mm^2$ bare copper wire. The following calculation gives an indication as to the cost involved in obtaining such a small footing resistance.

Required resistance $= 95 \div 20$

$= 4.75\ \Omega$

(i) Resistance of a single rod

$R_0 = \rho / [2\Pi L] . \ln[4L / d]$ (5.3)

$= 935 / [2\Pi \times 1.5] . \ln [4 \times 1.5 / 0.016]$

$= 588.3\ \Omega$

(ii) Resistance of 165 rods at 3 metre spacing from eq 2.6

$R = R_0 . [1+k.m] / n$ (5.4)

From fig. 2.5 for n = 165 , k = 9,8

First solve for m

$m = L / \{ [\ln(8L/ d) – 1] . s \}$ (5.5)

$= 1.5 / \{ [\ln(12/ 0.016) – 1] . 3\}$

$= 0.089$

Solving for Y_n

$Y_n = [1 + k.m] / n$ (5.6)

From fig. 2.5, for n = 165 , k = 9.8, substituting,

$Y_n = [1 + 9,8 \times 0.089] / 165$

$= 0.0113$

(iii) The resistance of 165 rods connected in parallel at 3-metre spacing

$R = R_0 . Y_n$ (5.7)

$= 588,3 \times 0,0113$

$= 6,68\ \Omega$

(iv) Resistance of total length of buried horizontal wire

$$R = \rho / [\,\Pi.L\,]\,.\,[\,Ln\,(\,2L / \sqrt{d.h}\,) - 1\,] \qquad (5.8)$$

$$= 935 / [\,\Pi.\ 492\,]\,.\,[\,Ln\,(\,2 \times 492 / \sqrt{0.012 \times 0.5}) - 1\,]$$

$$= 5,81\ \Omega$$

(v) Resistance of rods and wire combined

$$R = [\,Rh\,.\,Rd - Rm^2\,] / [\,Rh + Rd - 2Rm\,] \qquad (5.9)$$

$$Rm = \rho / [\,\Pi.Lh\,]\,.\,Ln\,[\,2Lh / Lo\,] \qquad (5.10)$$

Solving for Rm first,

$$Rm = 935 / [\,\Pi \times 492]\,.\,Ln\,[\,2 \times 492 / 1.5\,]$$

$$= 3,5\ \Omega$$

now solving for R ,

$$R = [\,5,81 \times 6,68 - 3.5^2\,] / [\,5,81 + 6.68 - 2x\,3,5\,]$$

$$= 4,83\ \Omega$$

This indicates that 165 earth rods together with 492 metres of interconnecting bare copper wire will not give the required pole footing resistance.

The aspect of achieving the required impulse level between the phase conductors and earth also presents a problem on the concrete pole due to the apparent low impulse withstand of the concrete. The damage statistics showed that only 21% of the damage associated with the MV hardware occurred at the pole tip. The majority of damage occurred below on the lower crossarm (38%) and this casts doubt on the effectiveness of having an overhead shield wire in the same position as the white phase conductor. As discussed in chapter 3, there is also doubt as to whether the pole damage can be attributed to direct strikes.

5.2.2 Bonding of Pole Hardware and installation of downwire

Bonding of the hardware and the provision of an external downwire buried in the ground at the pole base may result in a lower impedance path to earth, which is in parallel with the breakdown path through the concrete pole as discussed in chapters 3 and 4.

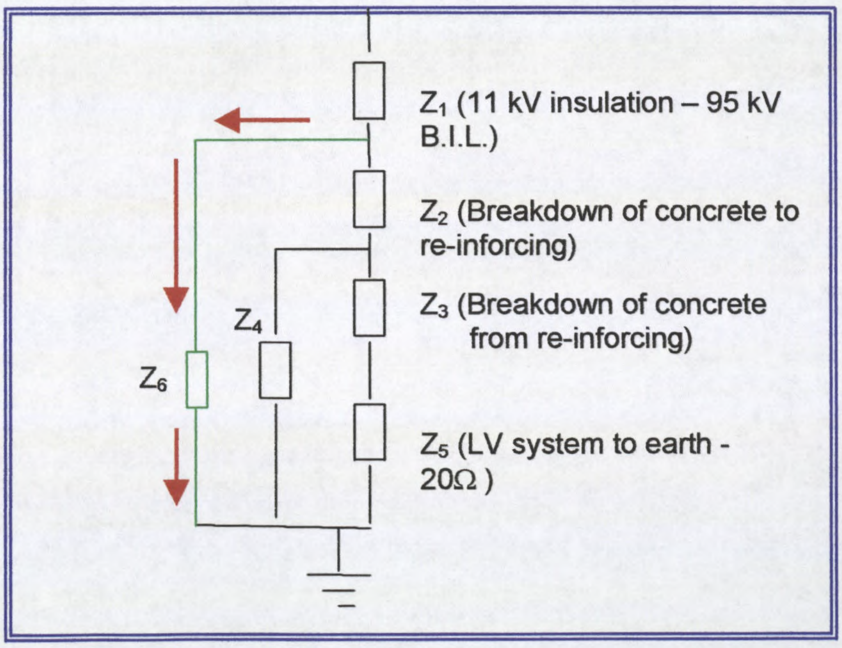


Fig. 5.2 – Representation of an earthed downwire (MV/LV pole)

Fig. 5.2 shows a representation of the earthed downwire for a pole supporting both MV and LV conductors. The downwire is in parallel with the pole discharge path, Z_2 and Z_4 and the LV system discharge path, Z_2, Z_3 and Z_5. Based on the test impulse values for concrete in the lab tests (63kV) and the field measurements of the pole's resistance to earth (>999 Ω), the impedance of the downwire, Z_6 may effectively short-circuit the other discharge paths. This may prevent current entering and damaging the pole. For a pole supporting only MV conductors, the LV system discharge path, Z_3 and Z_5 is not applicable.

This modification can be done relatively inexpensively, but the compromise would be at the expense of line performance as tripouts could be expected for every induced surge in excess of 95kV. If however proper auto reclosing is used with sufficient dead time to allow for arc quenching, this option could be feasible. This is also providing that the flashovers are transient, and that insulators are not permanently damaged or punctured during flashover. With the existing insulators, the insulation level would be limited to 95kV. Considering the worst case, that each lightning related event on the line resulted in a flashover with subsequent power follow through current, then the theoretical number of trip outs expected would be the total direct strikes plus the total induced strikes per year, 18. With properly co-ordinated auto reclosing the number of permanent lockouts may be minimal.

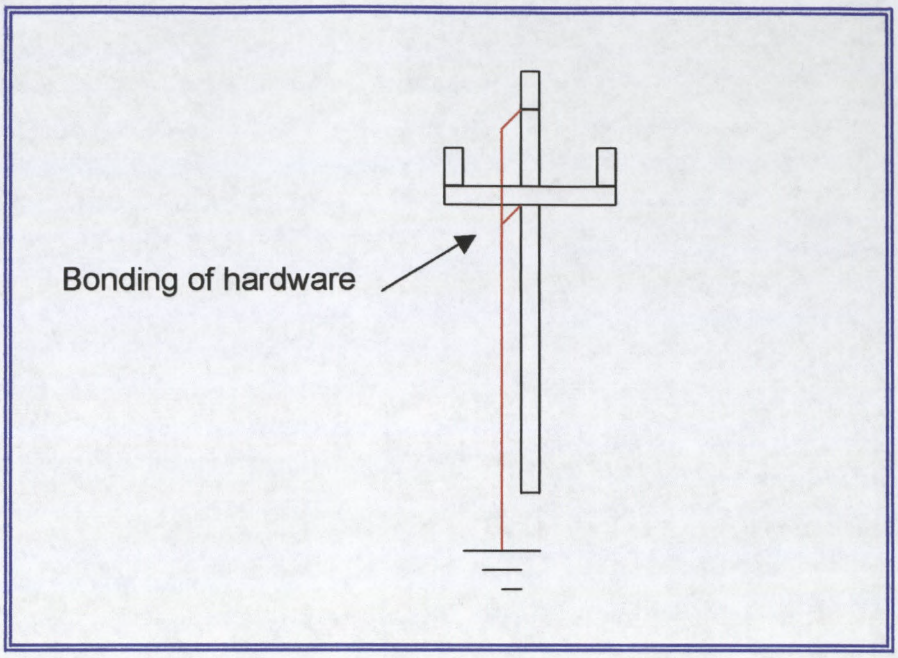


Fig. 5.3 – Bonding of hardware and provision of a down wire

5.2.3 Installation of a Dissipation Array System

The inclusion of a dissipation array system on the poles such as the "Spline Ball Ioniser", as discussed in chapter 2, is claimed to offer protection against direct strikes. The installation of this system will involve similar problems regarding the hardware reconfiguration as mentioned for the overhead shield wire. In order to afford complete protection a spline ball needs to be installed at each pole. Laboratory tests conducted at the Mississippi State University [15] have shown that "Spline Ball Ionisers" attract lightning strikes rather than eliminate them. Enquiries made regarding the cost and availability of this system proved difficult and, together with the fact that there is limited information regarding the success of dissipation array systems in South Africa, it was not considered any further.

5.2.4 Lightning Arresters

Lightning arresters are normally installed to afford protection to weak link structures such as transformers and switchgear. The installation of additional lightning arresters to protect the poles will prove costly due to the number of poles under consideration. Apart from the initial cost of the additional arresters (3 per pole), the longer term costs such as ongoing replacement and maintenance make this option less attractive.

5.2.5 Increasing the Line B.I.L.

A line insulation level of 300kV to earth would adequately protect from flashovers due to induced surges [10,19]. As mentioned in chapter 2, a method of achieving this would be to include 570mm of wood path in series with the insulator (eq. 2.5). A standard 2,4m wood crossarm in conjunction with a reconfiguration of the line hardware would facilitate this. The arrangement of the hardware is shown in fig 5.4 below. It can be seen that the white phase insulator (closest to the pole) must be positioned 570mm from the earth wire in order to achieve a 300kV B.I.L. on this phase. It should be noted that the corresponding B.I.L. for the two outer phases (red and blue) would be significantly higher due to the longer wood paths.

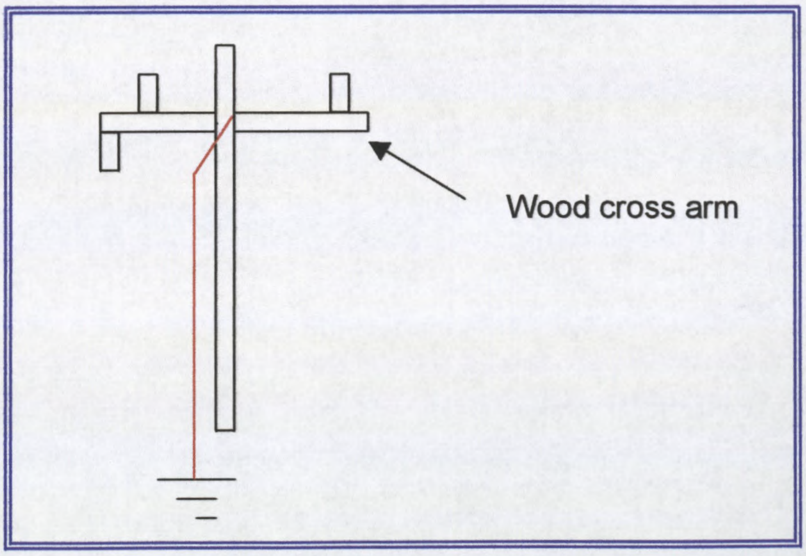


Fig 5.4 – Increasing the line B.I.L. to 300kV

The vertical offset of the red and white phase conductors is necessary to eliminate the possibility of midspan conductor clashing. In addition to the minimum 570mm wood path, an installed downwire may provide a relatively lower impedance parallel path with the pole to ground. This could hopefully prevent flashover through the pole. Arc rings in the form of stainless steel bandit strapping is used to bond the external downwire to the wood crosarm on either side of the pole. This is necessary to ensure that any arc due to a flashover across the wood path will terminate on the down wire and not into the concrete pole. Practically, a wood path of 600mm for the white phase and 800mm for the red and blue phases would be suitable. The resulting dry impulse withstand voltages are 315kV and 411kV respectively (eq 2.5).

5.2 Summary of options

- The installation of a shield wire will prove costly and its effectiveness is doubtful given the high soil resistivities and low line B.I.L. A lower incidence of damage at the pole tips also implies that its effectiveness may be limited.
- The installation of an external downwire is relatively inexpensive and although the line will still be susceptible to the effects of direct strikes and induced voltages, the downwire may prevent structural damage to the pole. Properly co-ordinated auto reclosing could minimise permanent line lockouts, providing that the insulators are not permanently damaged during flashover.

- The installation of lightning arresters will be costly and is not practical as a means of protecting the concrete poles
- Dissipation array systems are not readily available in SA and there is doubt regarding their effectiveness .
- Increasing the line B.I.L. using wood cross arms should eliminate flashovers due to induced voltages. The provision of an earthed down wire may also afford the concrete pole protection from damage due to flashovers from direct strikes.

5.4 Recommendations on line modifications

- The bonding of the hardware and installation of a downwire and increasing the line B.I.L. to 300kV appear to be reasonable solutions. It is recommended that both of these modifications be applied to the line .
- The twelve kilometres of line be divided up into 3 equal portions. Two sections of the line are to be modified using the above 2 solutions and the remaining portion to be left unmodified as a control for evaluation purposes.
- Proper fault recording and protection co-ordination is installed by upgrading the line controlling sectionaliser to a KYLE KFME auto recloser with fault event recording.
- The performance of each modification is properly monitored over a number of lightning seasons before definite conclusions are arrived at. As field information becomes available further changes to this strategy may become necessary.

5.5 Line Modifications

Quotations were obtained from contractors for each option and the modifications were carried out between November 1996 and January 1997. The line was divided up into 3 sections and the modifications allocated as follows:

- Unmodified line - 3909 metres
- Hardware bonded and earthed downwire - 3903 metres
- Wood crossarms and earthed downwire - 3852 metres

The modifications were arranged such that there was a spread of each of the three configurations within similar areas and that no one option was geographically remote from the others in terms of it's altitude and possible susceptibility to lightning. Fig. 5.5 on page 122 shows the modifications on the single line diagram.

5.5.1 Bonding of pole hardware and installation of an earthed downwire

The L-bracket and steel crossarm were bonded to a galvanised steel down wire using 40mm^2 annealed copper wire. The copper wire was joined to the 16mm diameter steel wire using a '"C" crimp. The downwire was secured to the pole by means of nylon strapping at 500mm intervals. On poles supporting LV ABC, the down wire was looped out away from the pole in order to minimise the risk of backflashover from the downwire to the LV ABC or earthed components. See plate 34 on page 123.

At the pole base, 3,5 metres of the steel wire was laid out radialy from the pole and buried at a depth of 500mm below the surface. Assuming a soil resistivity of 935 Ω.m, this gives a calculated resistance of 286 Ω (eq. 2.8). After modifications, 5 poles were measured over a 6 month period, the average footing resistances are included in fig. 5.5 for the 5 different pole positions (see also appendix C). When compared with the specific soil resistivities as measured in the field tests (see fig. 4.6 page 95), the measured resistances vary as expected.

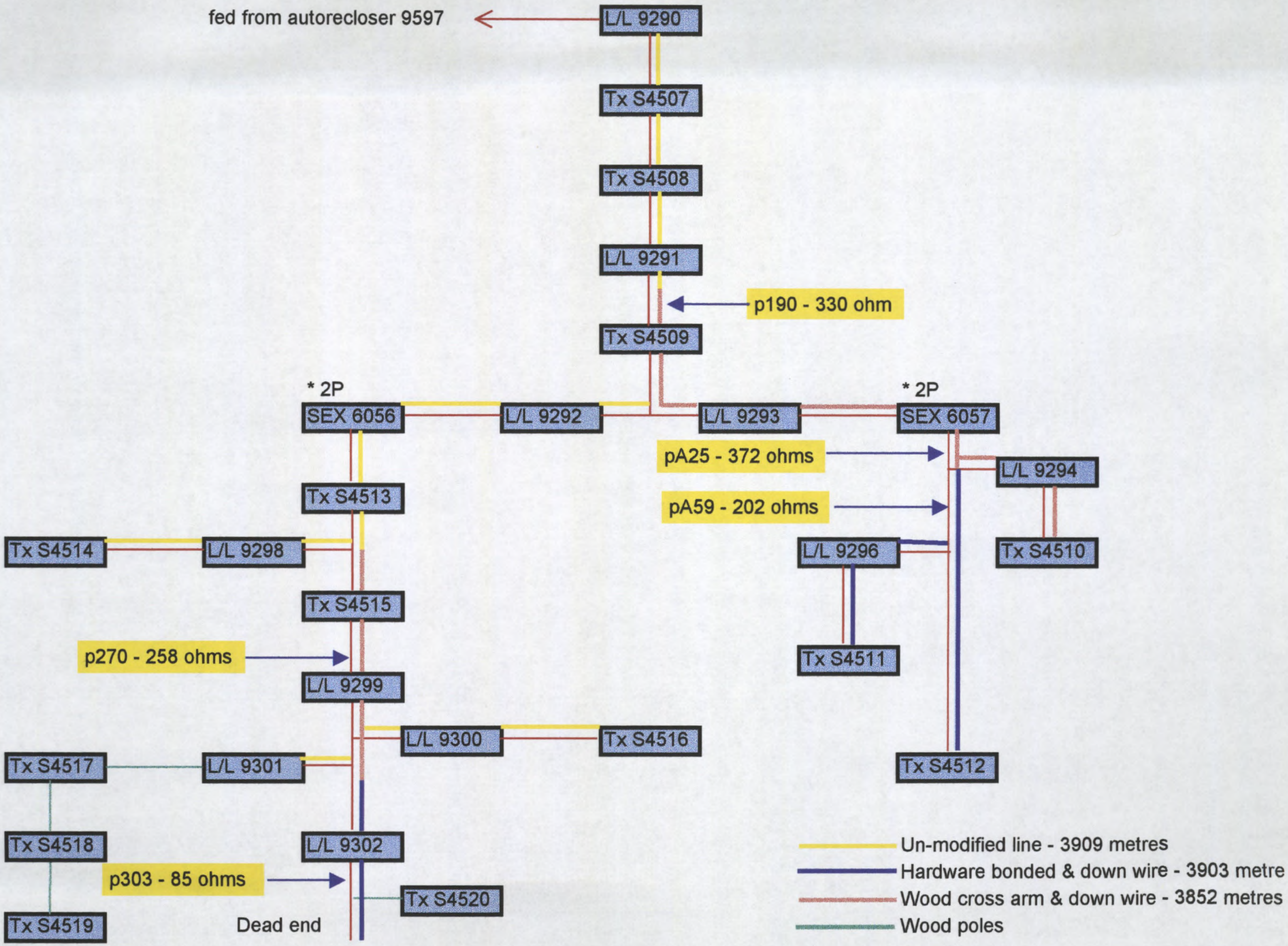


Fig. 5.5 - Line modification layout

Plate 34 - Bonded hardware and downwire

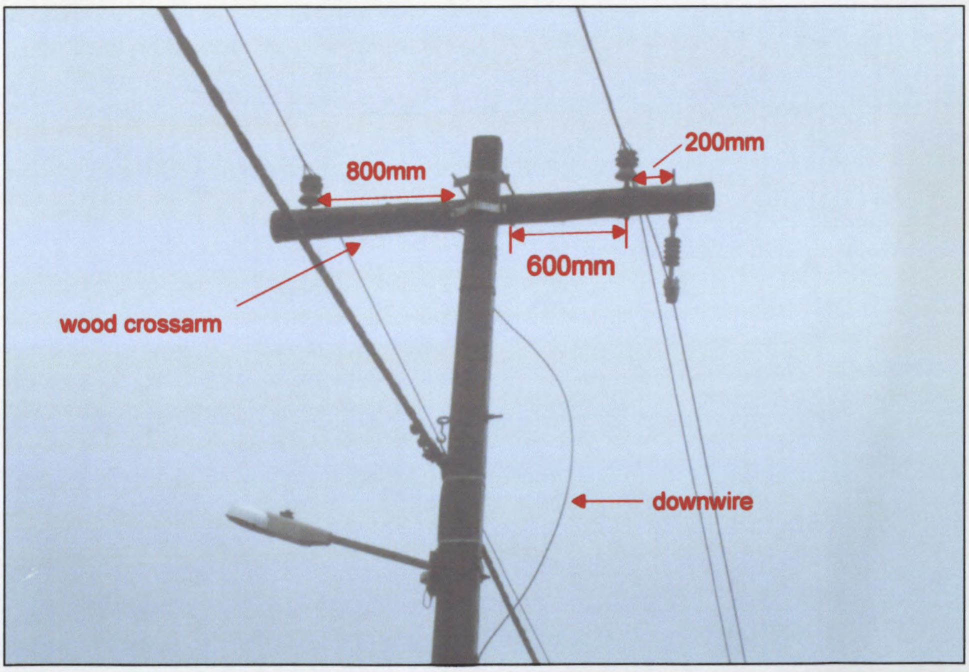


Plate 35 - Wood crossarm and downwire

5.5.2 Increasing the line B.I.L.

The line was reconfigured to an offset horizontal arrangement as shown in plate 35. The 2.4 metre wood crossarm was secured to the pole using 20mm galvanised u-bolts. An earthed downwire was installed in the same way as for the other modification. The annealed copper wire was splayed at the ends and bound onto the wood crossarm on the outer sides of each u-bolt using stainless steel strapping. This was done as a means of arc control to ensure that any flashover across the wood crossarm would terminate on the bandit strapping and therefore on the earthed downwire. This arrangement guarantees a minimum wood path distance of 500mm between the insulator spindle and the earthed downwire.

5.5.3 Installation of KYLE KFME autorecloser

In order that the Inwabi line could be easily monitored electrically for line faults the existing 3-pulse sectionaliser 9597, which fed the Inwabi line, was uprated to a KYLE KFME autorecloser with fault and disturbance recording. As this autorecloser would only respond to faults on the line and, that it only controlled sectionalisers 6056 and 6057, monitoring would be a lot easier. The auto recloser was installed on the 11/09/96 prior to the line modifications being carried out.

5.6 Monitoring Line performance

It was decided to monitor each modification over the course of the next few lightning seasons and to gather enough information in order to evaluate the success or failure of each modification. Further modifications may then become necessary depending on the outcome. Monitoring the performance of the modified line was done using the same damage inventory system as used for the initial damage analysis. Prior to the first inspection following modifications, each pole that had previously incurred damage had the areas of damage painted over with black paint thereby allowing easier identification of any new damage.

5.6.1 Lightning Positioning and Tracking System (LPATS)

Durban Electricity had recently purchased the LPATS system for the monitoring of lightning activity in the vicinity of its power transmission lines. It was decided to use this system as an additional monitoring tool. This could provide details on the lightning activity in the vicinity of the Inwabi line. From the "as built" drawings and co-ordinates, the line was entered onto the LPATS system. This made it possible to collect a database of lightning activity in terms of position, time of strike, magnitude and polarity of the strike relative to the geographic position of the line. This information could also be reconciled with the fault recording data provided by the autorecloser which is also date and time "stamped". Plate 36 overleaf shows lightning stroke positions recorded in South Africa over a 24-hour period on the LPATS. The area in white represents the position of the strokes. Plate 37 shows the Inwabi line on the LPATS system. The individual white dots represent individual lightning strokes. The latitude, longitude, magnitude, polarity and time of the stroke are all recorded on the system.

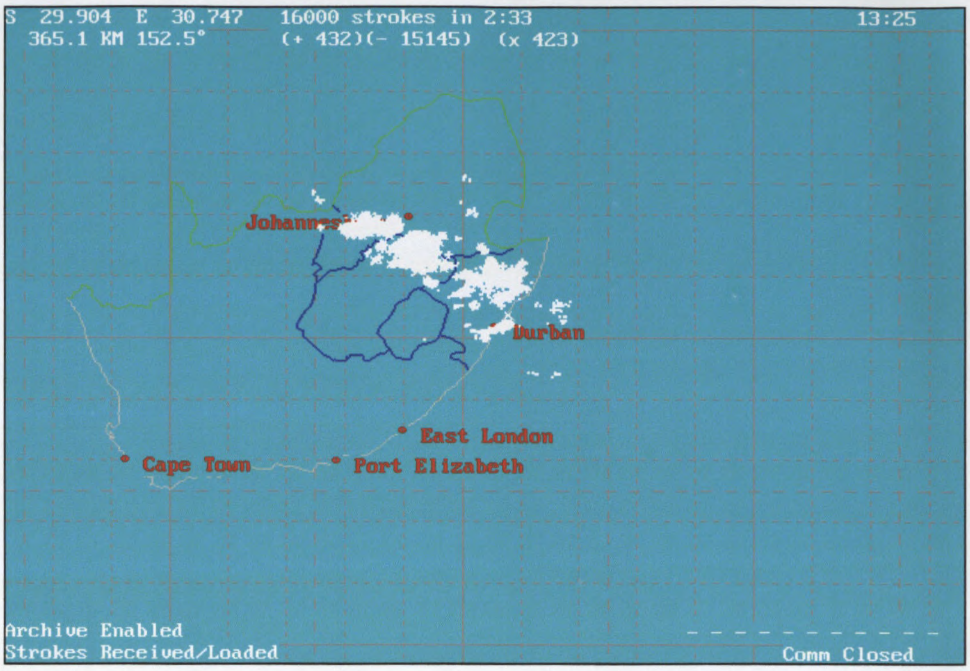


Plate 36 - The lightning positioning and tracking system (LPATS)

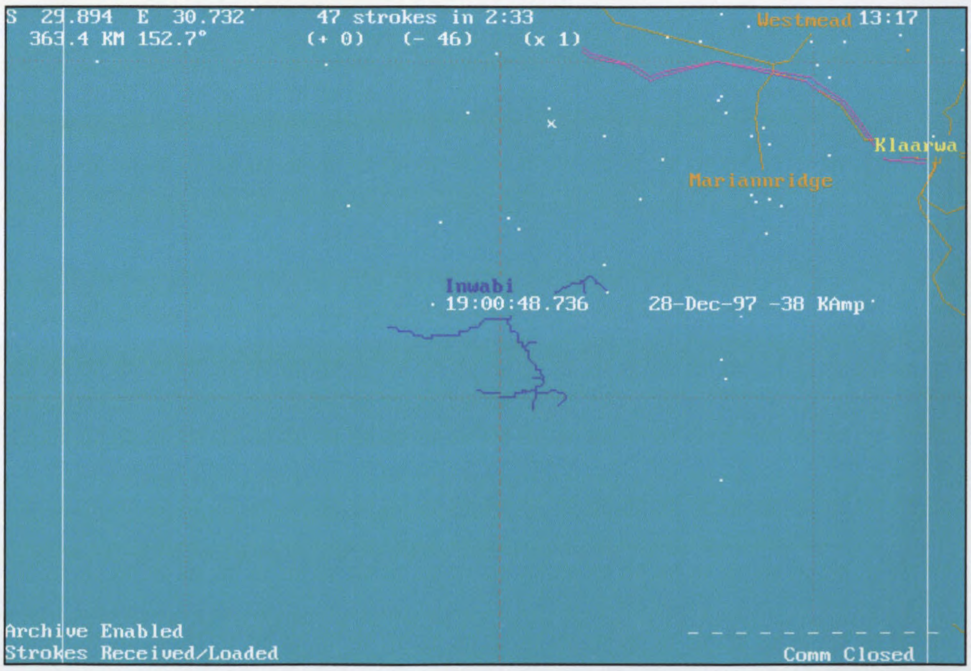


Plate 37 - Lightning stroke monitoring of the Inwabi line

CHAPTER 6 – Preliminary evaluation of modifications

6.0 Introduction

The trial modifications to the line were completed by the middle of December 1996. To date there have been an additional 5 inspections carried out on the medium voltage line since the completion of the modifications. The last inspection was carried out on the 22/02/98. Appendix "A" includes the initial inspection and the 5 subsequent inspections.

6.1 Fault event recording on autorecloser 9597

Appendix E provides a summary of the faults recorded on the event recorder of autorecloser 9597. Unfortunately, the events recorded only cover the period 12/02/97 until 13/06/97, thereafter problems were experienced with the data reader and software.

Referring to appendix E, some of the information on the event recorder appears to be inaccurate. For instance, the fault current recording on the 04/04/97 at 08h15: 27 indicates 1-amp earth fault current and 0-amp fault current for the phases. These are clearly incorrect current recordings or the trip event did not occur. The subsequent 3 records associated with this particular fault appear to be acceptable. Another apparent inaccuracy is recorded on both the 06/04/97 and 07/04/97. Both recordings indicate in excess of 4 successive trips on each fault. Scrutiny of the setting parameters confirm that the autorecloser is set up for 2 instantaneous trips, followed by 2 time-current curve trips for the phase faults before lockout. The earth fault is set up for 4 instantaneous trips before lockout. Further discrepancies arise in that the time interval between some of the successive trips are recorded as one second, whereas the "dead time" parameter is set to 2 seconds. The setting currents are 100 amps and 20 amps for the phase fault trip and earth fault trip respectively. Apart from this, the information for these particular faults appears acceptable. The event recorded on the 2nd of May 1997 is clearly incorrect and can be ignored. Considering the overall information in appendix E, and ignoring the event on 02/05/97, eleven distinct fault occurrences are apparent. Of the 11 faults, 8 involved a combination of phase(s) to earth faults and the remaining 3 were phase to phase faults.

6.2 Power outages recorded on the DE Complaint system

From the time when the line modifications were completed in the middle of December 1996 until the 19/02/98, a total of 16 power outages occurred on the line. This information was derived from the D.E. complaint recording system (appendix F), which records customer complaints. Out of the 16 outages, 15 of these occurred on the section of line beyond sectionaliser 6056. Only one outage occurred beyond sectionaliser 6057. This difference is significant, but the reasons therefore are not apparent, as there is an even distribution of each modification and the control within each section of line (fig 5.5). Only on one occasion, which was on 22/03/97, was the actual cause for the fault discovered. This was a damaged white phase pin insulator. Unfortunately the faultsman, who repaired the fault, did not specify the pole number, therefore a check against the modified poles was not possible. In general, the recording of relevant information on the complaint forms was inadequate as depot staff had stated that a number of insulators had been replaced, yet this could not be verified on the complaint records.

6.3 Correlation between event recordings and complaints

A comparison was made between the information recorded in appendix E (autorecloser event summary) and appendix F (complaint records), over the period 12/02/97 to 13/06/97. There are only 3 complaints recorded on appendix F during this time period, 19/03/97, 22/03/97 and 08/04/97. It is not possible to obtain an exact date correlation between these faults and the faults recorded in appendix E. However, the fault recorded on the 20/03/97 in the event recorder may be the same fault recorded on the 22/03/97 in appendix F. A possible reason for this may be due to delays by customers in reporting power failures. Experience has shown that faults in rural areas are often reported days later, due to customers not having ready access to telephones. Further to this, the event recording for the 20/03/97 indicates 2 trip operations and appendix F indicates a lockout of sectionaliser 6056. Sectionaliser 6056 has a 2 pulse to lockout setting; this is therefore correct protection discrimination for a fault beyond sectionaliser 6056. Similarly, the fault recorded at 14h19: 45 on the 07/04/97 on the event recorder and the lockout of sectionaliser 6056, as recorded in appendix F on the 08/04/97, may be explained in the same way. The trips recorded on the 07/04/97 and the 20/04/97 on the event recorder are single trips followed by single reclosures, which would not have resulted in a lockout of either sectionaliser. This would account for no complaints being recorded in appendix F for these instances. While the above may explain the lack of an exact date and time correlation in the particular instances mentioned, there is no possible explanation for the complaint recorded on the 19/03/97 in appendix F. There is no autorecloser event recording on or closely preceding this date. The possible correlation is highlighted in green print in both appendix E and F for ease of reference.

There are also faults recorded on the event recorder that indicate 4 or more successive trips, which should have resulted in a power outage, yet they have no corresponding records in appendix F. These are discussed below. It should also be realised that any number of trip operations of the autorecloser in excess of 2 implies that the fault has occurred upstream of the 2 pulse sectionalisers. This is assuming that the grading and discrimination is correct.

04/04/97: The fault recorded on the event recorder for 04/04/97 shows 4 operations, the autorecloser should have then locked out, thereby resulting in a power outage. The first recorded trip at 08h15: 27 is suspect, as mentioned earlier. If this is not a genuine trip, then there would have been only 3 operations before the fault cleared and therefore no resulting power outage. This may explain why there is no associated recording in appendix F, but this obviously cannot be verified. On the other hand, there is the possibility that this was a genuine trip and that the current recordings were defective. The autorecloser may not have locked out after it's 4th successive trip and the fault may have cleared. This may also explain why there is no corresponding record in appendix F. This argument also applies to all of the events that consist of 4 or more successive trips.

06/04/97: The fault recorded on the 06/04/97 shows 6 successive trip operations. As the time interval between certain of the trips is only I second, which is less than the 2-second dead time, it is uncertain as to whether some of the trips are genuine trip operations. It is possible that the autorecloser only went through 3 genuine trip operations and therefore did not lockout. This may explain why there is no associated record in appendix F, but this also cannot be verified.

07/04/97: The fault recorded on the 07/04/97 commencing at 09h19: 16, shows 8 successive operations. Once again there are instances where the time interval between trips is less than the selected dead time. There are, however, a sufficient number of operations with the required dead time interval to ensure lockout of the autorecloser. It cannot be verified if the autorecloser locked out, if it had, then this should have been recorded in appendix F.

13/06/97: There are 4 successive trips recorded. Once again, the time interval between successive trips is less than the set dead time. The recorded fault currents, however, show a fair measure of variation, which implies 4 genuine trips.

This raises another possibility that the autorecloser is not operating according to the set dead time of 2 seconds before reclosing. If the time delay between reclosures was in sufficient and not long enough to ensure de-ionisation of the flahover path, then the fault might re-strike. Once again, it is not possible to determine whether lockout had occurred or not, although the fault seems pretty well defined. If the fault cleared and lockout did not occur, this may explain why there is no associated record in appendix F.

6.4 Ground flash statistics using LPATS

The Inwabi plateau line was zoned off on the LPATS system within a square border of 10km by 10km, thereby allowing the monitoring of lightning activity over an area of 100 km^2. Plates 38 and 39 overleaf, show the Inwabi line and lightning strikes in the vicinity of the line. The square white border surrounding the line defines the 100 km^2 zone. The details of the individual strikes, which include, stroke magnitude, polarity and date/time stamping, can also be seen. The latitude and longitude of the strike can also be determined. The supplier claims a positional accuracy of +/-0,5 km.

Daily lightning data files from the LPATS system were reviewed from the period 01/09/96 until 31/12/97 (see appendix G). A total of 719 ground strokes were recorded within the zone during this period.

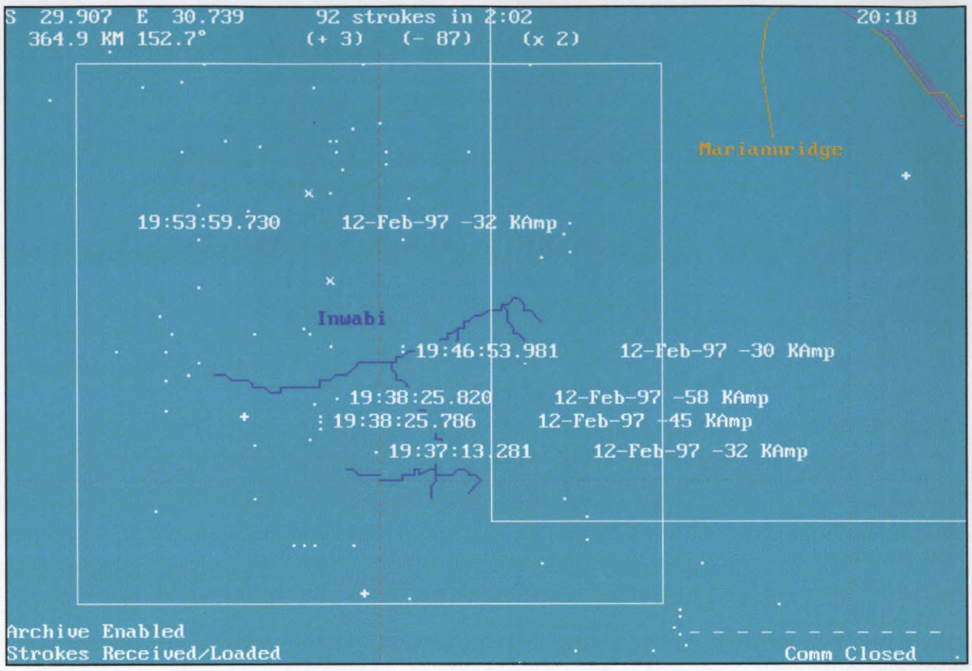


Plate 38 - The Inwabi line zone and LPATS data for 12/02/97

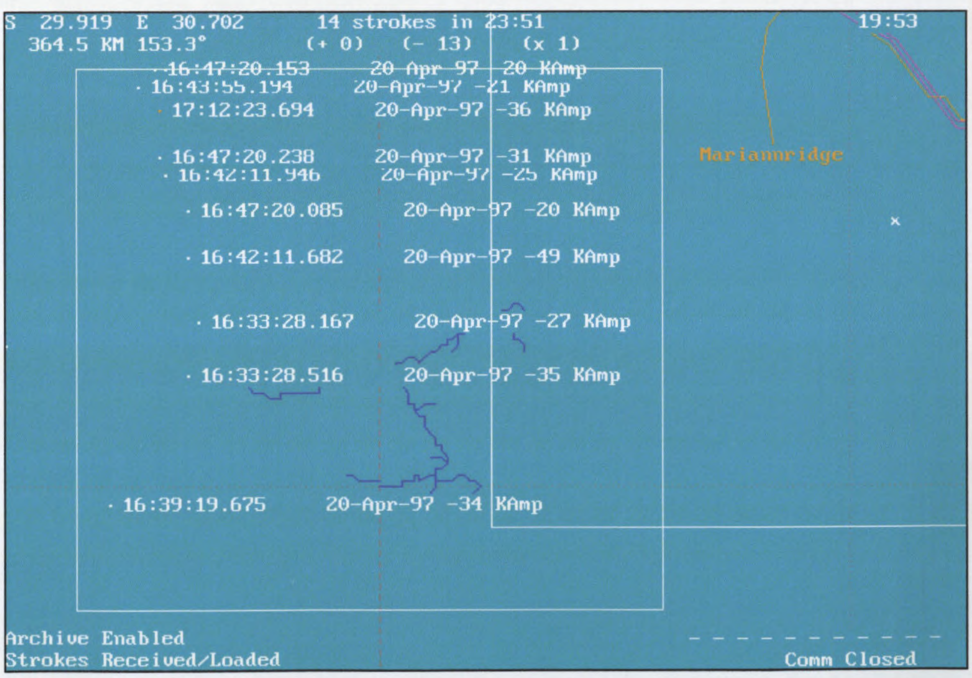


Plate 39 - LPATS data for 20/04/97

Considering that the assessment period was over 16 months, this equates to approximately 5,4 flashes per km^2 per year. This compares favorably with the assumed 6 flashes per km^2, per year (fig. 2.2) used for calculation purposes in chapter 5.

6.5 Correlation of power outages with lightning activity

A comparison was made between the lightning activity data on the LPATS (appendix G), the event recorder of autorecloser 9597 (appendix E) and the complaint records (appendix F).

6.5.1 Correlation between LPATS and the event recorder

The LPATS records (appendix G) and the event recorder were compared between the 12/02/97 and 13/06/97. Out of the 11 overcurrent tripouts of the autorecloser, only 4 could be linked to lightning activity within the line zone in terms of position and time of event.

DATE	LIGHTNING DURATION	AUTORECLOSER TIME STAMP	LPATS CLOSEST MATCH
12/02/97	19h37 to 20h18	19h45:03	19h45:06 @ 0,8 km
12/02/97	19h37 to 20h18	19h46:19	19h46:53 @ 0,1 km
20/04/97	16h33 to 17h12	16h46:31	16h47:20 @ 3,2 km
20/04/97	16h33 to 17h12	16h55:11	16h47:20 @ 4,2 km

Table 6.1 – Comparison between event recordings and LPATS

Unfortunately further records from the autorecloser were unavailable due to problems with the data reader software. Table 6.1 on the previous page shows the date and time correlation between the 4 autorecloser trips and the lightning activity within the zone. The lightning duration shows the time duration where lightning strokes occurred within the zone. The column titled "LPATS closest match" gives the LPATS date and time stamp for a ground stroke which best compares with the autorecloser date and time stamp within the lightning activity duration period. The distance from the strike to the nearest point on the line is also shown, the LPATS accuracy should also be considered when analysing the position of the strike with respect to the line. As the two recording systems were not time synchronised, allowance must be made for this. The time discrepancy between both systems was also unknown.

Although the autorecloser trips occurred within reasonable time limits of lightning strikes to the ground, it is not possible to conclude that the strokes shown in table 6.1 definitely resulted in the autorecloser trips. This is due to slight inconsistencies in time and also proximity of the stroke to the line.

6.5.2 Correlation between the LPATS and the Complaint records

The LPATS records were compared with the complaint records (appendix F) between 01/09/96 to 31/12/97. There are 4 dates where there may be correlation between both sets of records, these are highlighted in blue print on both appendices, and are as follows:

24/09/96 (LPATS) and 25/09/96 (Complaint records)

25/11/96 (LPATS) and 26/11/96 (Complaint records)

10/12/97 (LPATS) and 11/12/97 (Complaint records)

28/12/97 (LPATS) and 29/12/97 (Complaint records)

As mentioned previously, the later date appearing on the complaint records (appendix F) may be explained due to possible delays in customers reporting power failures.

6.6 Line trip statistics

The line tripout statistics in appendix F were analysed for the periods before and after line modifications. Fig. 6.1 shows the comparison before and after modifications. There has been an increase of 10% in the number of tripouts after modification.

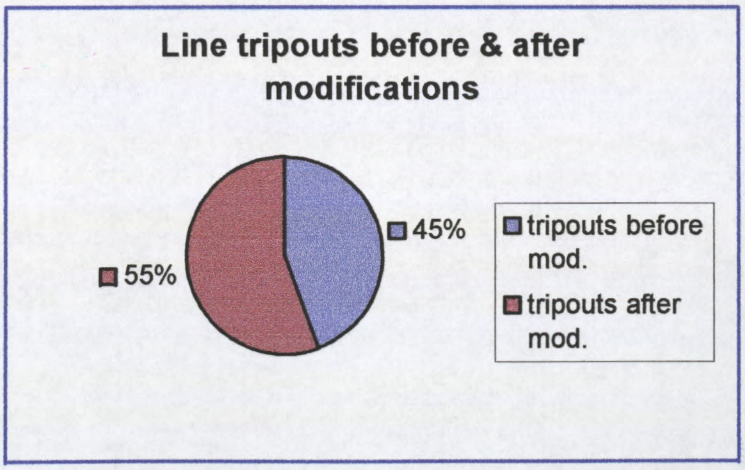


Fig. 6.1

6.7 Incidence of new pole damage

Data extracted from the damage inventory (appendix A) was used to compile the analysis of damage before and after modifications. The line modifications were completed in the middle of December 1996 and the data recorded on inspections 1 & 2 were recorded prior to this date.

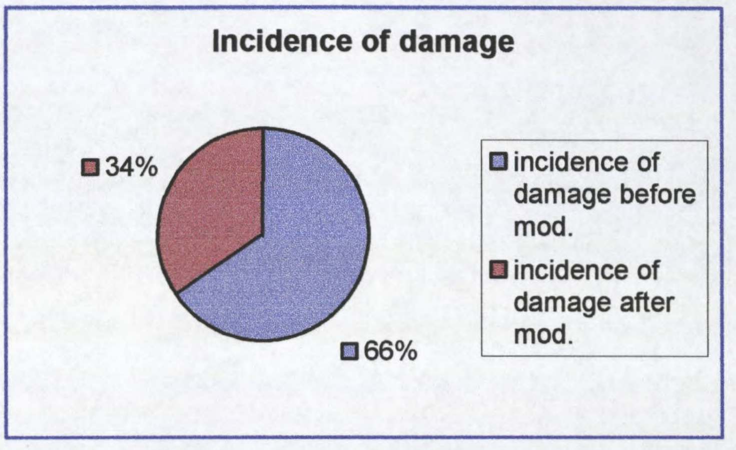


Fig. 6.2

The cumulative damage recorded on inspections 1 and 2 was therefore used to establish the damage prior to modifications and the cumulative damage recorded on inspections 3 through 6 was used to establish the damage after modifications. Fig. 6.2 shows the incidence of damage before and after modification. A total of 95 new incidences of damage were recorded on inspections 3 through 6, compared 175 recorded in inspections 1 and 2. It should be pointed out that the cumulative damage recorded prior to modifications, was accumulated over the period 30/09/94 until 20/11/96, whereas the cumulative damage after modifications only covers the period 20/11/96 until 22/02/98. This may explain to some extent why the difference between the damage before and after modifications is as large as it is.

6.8 Comparison of damage before and after modifications

A comparison of the incidences of damage that occurred before and after the modifications for the 3 categories; bad, moderate, and slight, provides a quick assessment on the impact of the modifications. Once again, cognisance must be taken of the different time periods over which the data was complied.

6.8.1 Comparison of bad damage before and after modifications

There were 10 new incidences of bad damage recorded on inspections 3 through 6, compared with 49 recorded on inspections 1 and 2. This is shown in fig. 6.3 below. Despite the difference in the time periods over which the damage was recorded, there is still a marked decrease in the incidence of bad damage.

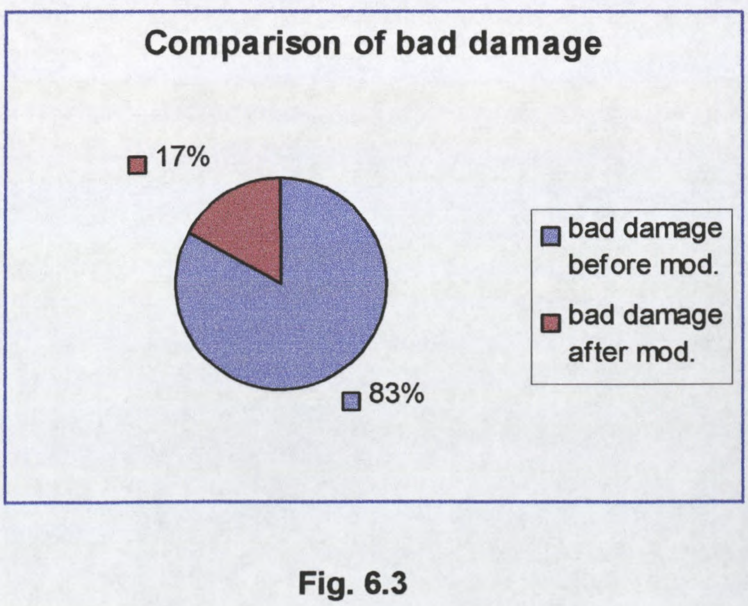


Fig. 6.3

6.8.2 Comparison of moderate damage before and after modifications

The comparison of moderate damage is shown in fig. 6.4 below. Similarly, in the moderate damage category, there were 60 recorded incidences of moderate damage prior to modification and 12 new incidences of moderate damage recorded on inspections 3 through 6. Once again, the improvement is significant, despite the time periods involved.

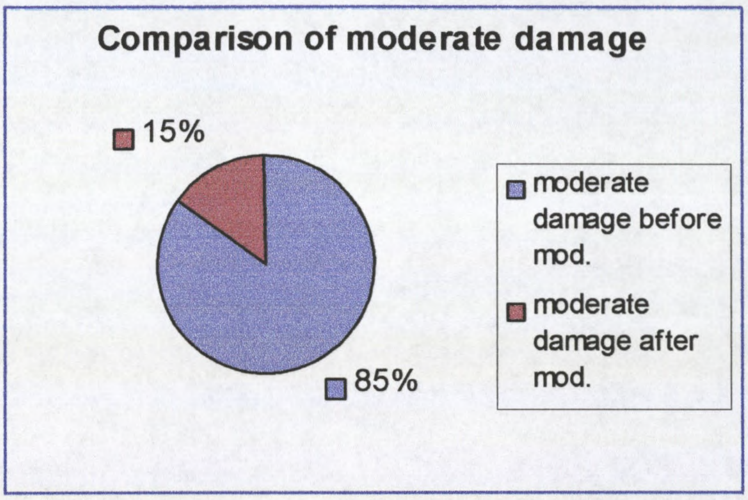


Fig. 6.4

6.8.3 Comparison of slight damage before and after modifications

In the slight damage category, shown in fig. 6.5 below, there were 59 incidences of slight damage recorded on prior to the modifications. There were 73 new incidences of slight damage recorded after the modifications. This represents an increase of 10%. It appears that the improvements gained in the bad and moderate categories come at the expense of an increase in slight damage.

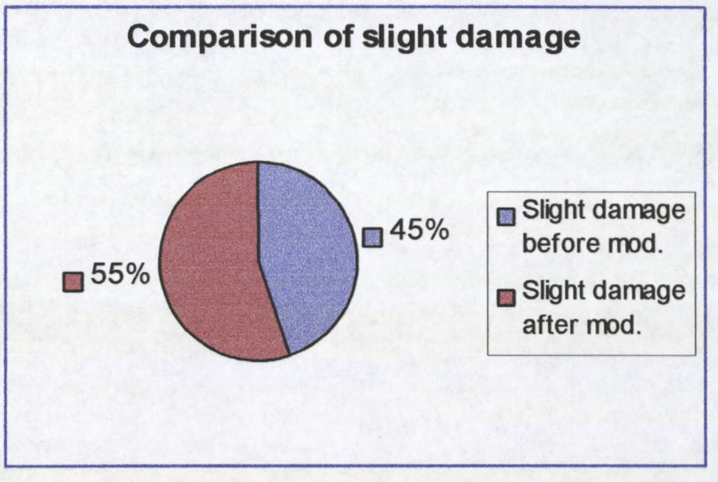


Fig. 6.5

6.9 Damage distribution after modifications

In order to obtain a true picture on what effects the modifications may have had on the damage occurring on the poles, it is necessary to examine the damage recorded on the modified poles against the reference (unmodified poles). This comparison is more accurate as the data for each type of modification and the reference is evaluated over the same time period and subject to the same physical conditions on the site, such as lightning activity. Fig. 6.6 shows the overall distribution of new damage recorded on inspections 3 through 6 between the modified and the unmodified poles.

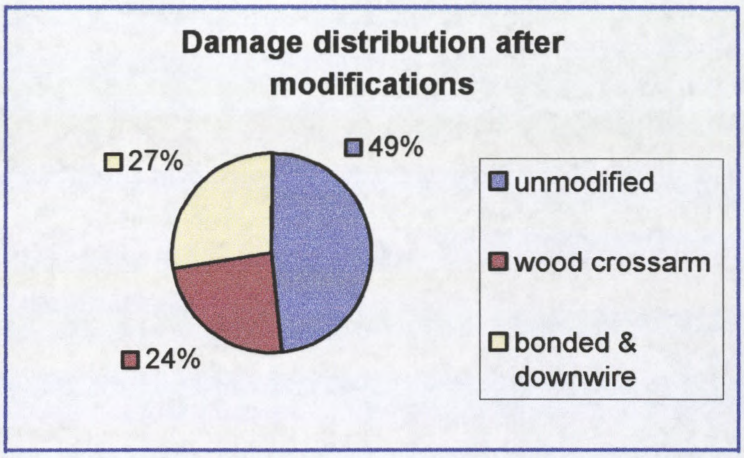


Fig. 6.6

The amount of damage that has occurred on the unmodified poles is significantly higher than for both types of modified poles.

6.9.1 Bad damage distribution after modifications

Fig. 6.7 below shows the bad damage distribution between each modification and the unmodified poles (reference). There were 6 new incidences of bad damage recorded on the unmodified poles on inspections 3 through 6. There was 1 new incidence of bad damage recorded on the wood crossarm with downwire poles and 3 new incidences on the bonded hardware with downwire poles. Most of the damage has occurred on the unmodified poles. Both types of modifications show a significant reduction, especially the wood crossarm with downwire poles.

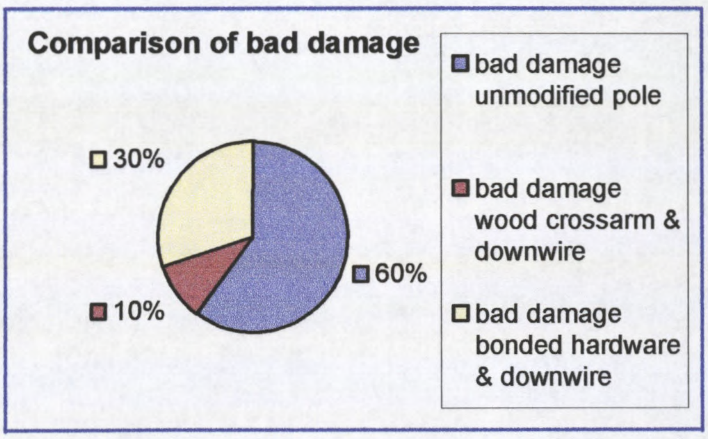


Fig. 6.7

6.9.2 Moderate damage distribution after modifications

Fig. 6.8 shows the moderate damage distribution between each modification and the control reference (unmodified pole). There were 4 new incidences of moderate damage recorded on the unmodified poles, 5 on the wood crossarm poles and 3 on the bonded hardware poles. There is a higher relative incidence of moderate damage to the wood crossarm with downwire poles, which is difficult to explain.

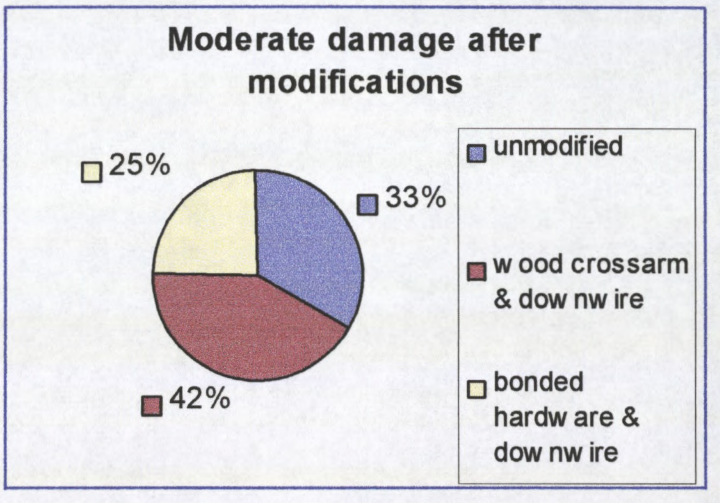


Fig. 6.8

6.9.3 Slight damage distribution after modifications

Fig. 6.9 below, shows the slight damage distribution between each modification and the control reference (unmodified pole). There were 36 new incidences of slight damage recorded on the unmodified poles. There were 17 and 20 new incidences of slight damage recorded on the wood crossarm with downwire poles and the bonded hardware with downwire poles, respectively. Similar to the bad damage category, there has been a significant reduction in damage occurring to both types of modified poles over the reference.

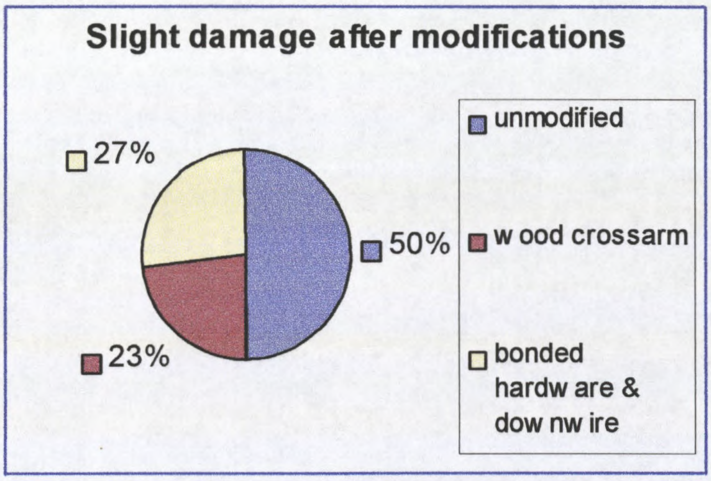


Fig. 6.9

6.10 Comments on damage

- Both types of modified poles have shown a significant reduction in the incidence of bad damage when compared with the unmodified poles. (fig.6.7). Reductions of 27% and 23% for the wood crossarm with downwire and bonded hardware with downwire poles respectively, have been recorded. This reduction in bad damage may be possibly due to the downwire diverting current to ground as opposed to flowing into the pole.

- Contrary to the above, there has been a slight increase in moderate damage recorded on the wood crossarm with downwire poles over the other modification and control (fig. 6.8). This is contrary to expectation as flashover on these poles should only occur for direct strikes to the line. If there were direct strikes to the line, then the incidence of moderate damage on the bonded hardware with downwire poles should be similar to the wood crossarm with downwire poles. There is therefore uncertainty as to the reliability of this statistic.

- The slight damage after modifications has also shown a reasonable improvement on the modified poles over the unmodified poles (fig. 6.9).

- During inspections 3 through 6, two separate incidences of damage were discovered, which are interesting and involve each type of modified pole:

  The first case involves pole A77, which has bonded hardware with a downwire, and is shown in plates 40 and 41 overleaf. Bad damage has occurred in the vicinity of the copper jumper (Plate 40) and also lower down in the vicinity of the LV eyebolt (plate 41). There was no other damage above this point on the pole. It appears that a flashover has taken place from the jumper and into the pole and then flashed back through onto the LV system below. As there was a downwire

Plate 40 -Damage to pole A77

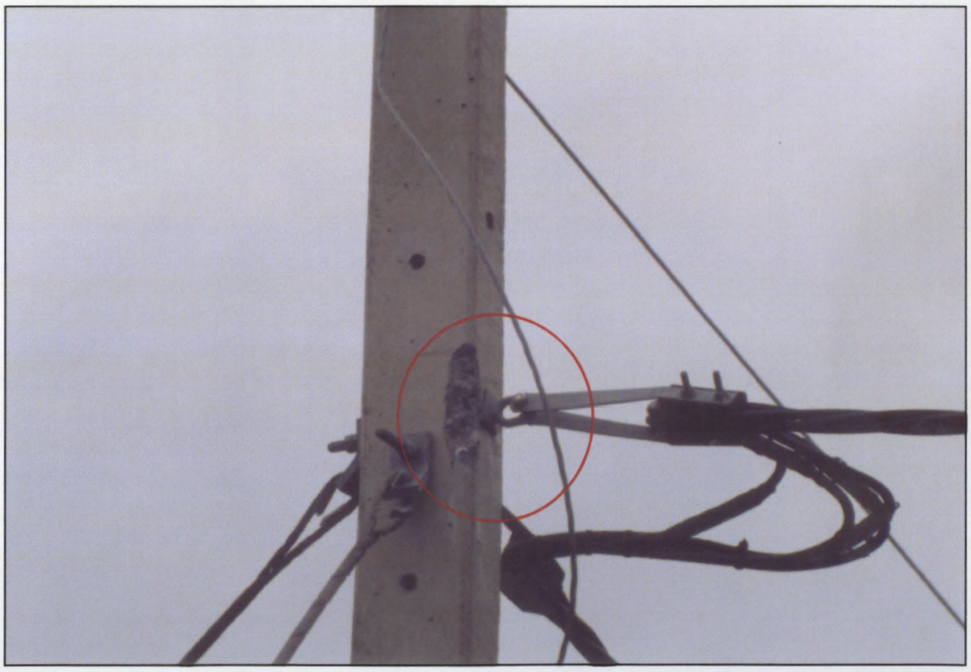


Plate 41 - Damage to pole A77

installed on this pole, it clearly didn't prevent damage to the pole. This may be possibly due to the earth resistance of the downwire being too high.

The second case involves pole A19, which has a wood crossarm and down wire and is shown in plate 42 on page 147. Close inspection of the underside of the crossarm between the pin insulator and the stainless steel strapping shows a surface splitting of the crossarm. Pieces of wood were discovered on the ground underneath the crossarm. This appears to be wood splitting due to a flashover across a wood path [19]. The dry flashover voltage to earth for this phase is 411kV (red phase). The wet flashover voltage, however, may be up to 40% lower (247kV) [19]. Considering the magnitude of voltages involved to cause flashover, there is a high probability that this occurred as a result of a direct strike. This is further supported by the fact that the flashover occurred along an 800mm wood path and not the 600mm wood path as would be expected for an induced flahover. The other interesting fact is that the flashover across the wood path is between the insulator spindle and the stainless steel strapping. This raises the possibility that the insulator may have been punctured. This insulator should be removed in order to check on this aspect. Another point to note is that there was no structural damage to the pole, this implies that the downwire may have been effective in this instance. The reason for this may be that the arc quenching properties of the wood prevented the formation of a power arc and therefore power follow through current [19].

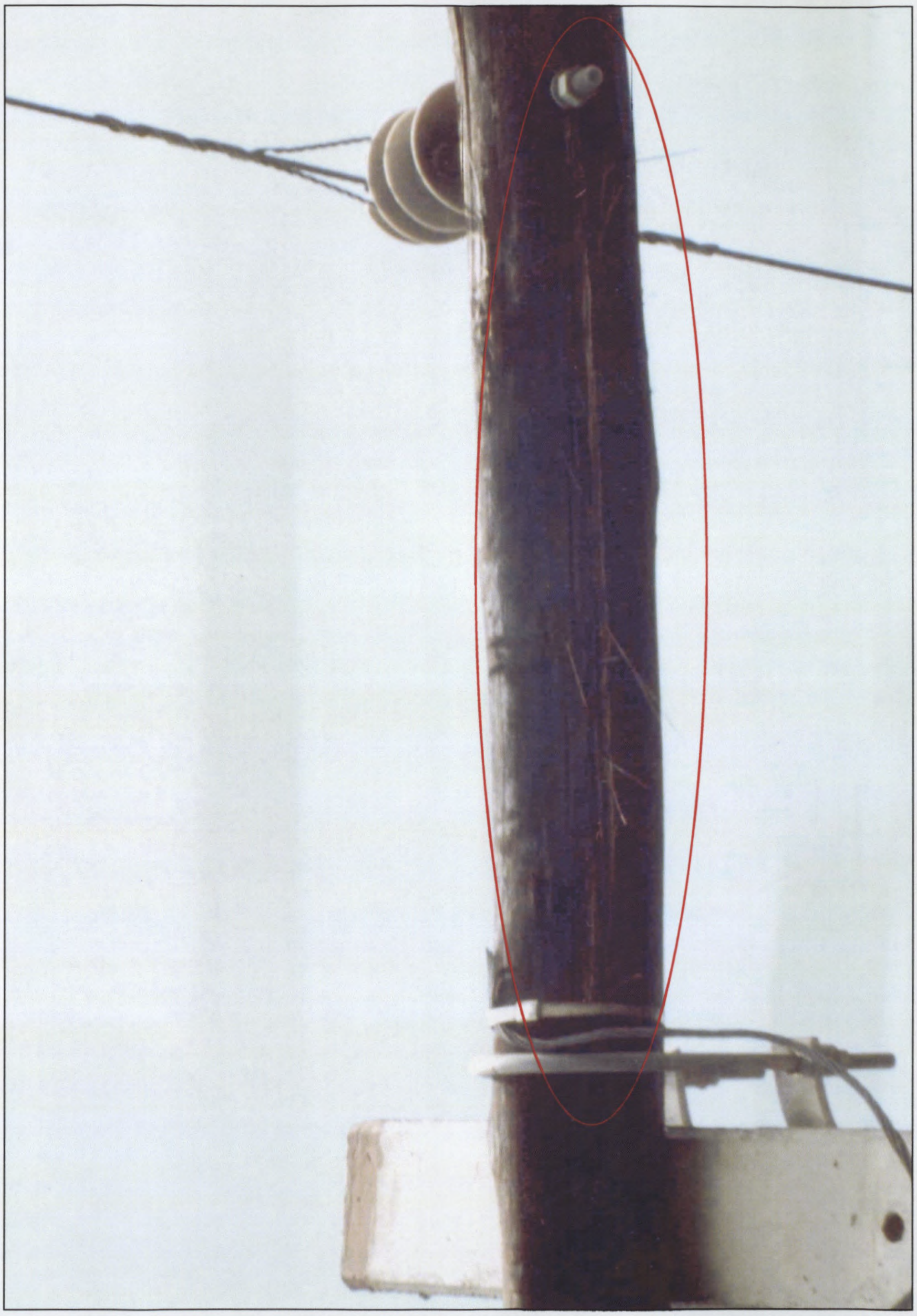


Plate 42 - Damage to pole A19

6.11 Conclusions

- There are definite discrepancies on the autorecloser 9597 event recordings. It is unclear as to whether it is functioning correctly on a consistent basis.
- Of the 11 separate faults recorded for autorecloser 9597, there were 4 occasions where there was definite lightning strikes in the vicinity of the line. There is an acceptable correlation between the time of the strikes and the time of the trip. It is reasonable to assume that there are faults arising out of the effects of lightning.
- Based on the damage observed on pole A19, and as discussed, there are direct strikes occurring on the line.
- The other faults that occurred on the line could not be linked to lightning. These faults must be arising as a result of insulation failure, although a defective insulator was found on only one occasion. The fact that the line is later re-energised successfully without a cause for the initial trip having been established, may be indicative of intermittent breakdown of pin insulators which are self-restoring. This type of fault has been experienced previously with pin type insulators installed on DE rural overhead distribution lines. Lightning excluded, there appears to be no other possible explanation for these faults.
- The majority of faults recorded were earth faults, thereby confirming the damaged positions in the vicinity of earthed hardware. The earth fault currents recorded varied in magnitude, the average is approximately 62 amps. It is reasonable to conclude that this fault

current is responsible for the structural damage to the poles, whether lightning induced or due to insulator failure.

- There has been no definite solution to the damage through the two modifications used, although both modifications show an improvement in limiting bad damage, and slight damage. Pole A77 is an obvious exception however.

- Overall, there has been no significant improvement in line performance. This is particularly true of the section of line beyond sectionaliser 6056, where 15 out of the 16 power outages occurred. Closer examination this section of line is imperative.

6.12 Recommendations

- As this is a preliminary evaluation, there will be benefit in collecting additional data. Collection of data from the field should be continued before the initial trends as discussed above can be verified or otherwise. At least another full lightning season or more is desirable.
- Other options to be considered based on the latest available information from the line.
- Autorecloser 9597 needs to be checked for full and correct functionality.
- An assessment of the protection grading for the line needs to be done to ensure that the protection co-ordination between the autorecloser and downstream sectionalisers is correct.
- The recording of all relevant information by field staff needs to be accurate and complete.

- Special consideration needs to be given to the insulators. A pole top inspection of the insulators should be carried out on the poles downstream of sectionaliser 6056. Punctures through the insulators may be difficult to detect and would ideally require the conductor to be unbound and lifted off the insulator. Where doubt exists, this must be done. If a high failure rate is discovered then the insulators should be upgraded to class "A" throughout.
  - Any defective insulators found should be clearly labeled, giving the date, time of replacement and the pole number. These should be forwarded to the Maintenance Manager: South-Western Distribution Area.
  - Further investigation into specific damage at the modified poles such as poles A19 and A77 needs to be done. Particular emphasis to be placed on pole footing resistances as these may be the key to the success of an earthed downwire in limiting damage.
  - The subcontractor "Pro-struct" should undertake the repairs to the poles as quoted.
  - Pre-stressed concrete poles should not be used for 11000-volt rural distribution lines.

References

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[4] Durban Electricity Distribution layout drawings for Inwabi Plateau DL. AAB33006000/A1 sheets 1 to 12.

[5] Topographic Maps for Inwabi Plateau
Map numbers : FTSY #'s 212,213,216,221,224,225,227,228
FTST #'s 439,444,445,447,448

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[19] Britten AC: "Insulation co-ordination of lines" Chapter 9 of an Eskom pulication, 1992

Appendices

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

INSPECTION DATES

1. 28/08/96
2. 20/11/96
3. 06/02/97
4. 07/05/97
5. 24/06/97
6. 22/02/98

KEY

S - SLIGHTLY DAMAGED (0mm to 10mm)
M - MODERATELY DAMAGED (10mm to 25mm)
B - BADLY DAMAGED (greater than 25mm / reinforcing showing)

			DETAILS AND DEGREE OF DAMAGE										POLE HARDWARE DETAIL						
LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
0	L/L 9290 52		N	N							N	GUM POLE	658m	Y	DELTA		N		
88	106	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y			S						MV C/ARM							
144	108	1	N	N							N	BLACK TRACKING FROM C/ARM TO STAY ATTACHMENT		Y	DELT	Y	N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
236	110	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N									NO VISIBLE DAMAGE							
336	112	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
415	114	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	Y							POLE - S		SLIGHT DAMAGE +\- 1m BELOW C/ARM R-PHASE SIDE							
		6	Y							POLE - S									
504	S4507 116	1	N	N							N	PHOTO CELL DAMAGED	635m	Y	DELTA		N		
		2	N																
		3	Y						S	POLE - S		SLIGHT DAMAGE ABOVE S/L BRACKET R Ph SIDE							
		4	Y							POLE - S		SLIGHT DAMAGE BEHIND TRFR R-PHASE SIDE							
		5	N																
		6	N																
90	118	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
182	120	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
273	122	1	Y	N			M			POLE BASE - M	N	DAMAGED IN VIC OF C/ARM STRAP ATTACHMENT TO POLE & AT THE POLE BASE		Y	DELTA		N		
		2	Y							POLE - S		SLIGHT DAMAGE 1,5m BELOW MV C/ARM R Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
369	124	1	Y	N		M					N	DAMAGED AT MV C/ARM B-phase SIDE		Y	DELTA		N		
		2	Y							POLE - M		MODERATE DAMAGE 1,5m ABOVE G/L R Phase SIDE							

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		3	N																
		4	N																
		5	N																
		6	N																
449	126	1	Y	N		M					N	DAMAGED AT MV C/ARM R-phase SIDE		Y	DELTA		N		
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE 500mm ABOVE G/L B Phase SIDE							
		4	N																
		5	N																
		6	Y			M						MODERATE DAMAGE AT MV C/ARM							
523	128	1	Y	N		S					Y	C/ARM GALVANISING BURNT VIC ATTACHMENT BOLT, CARBON VISIBLE ABOVE C/ARM		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
590	130	1	Y	Y		M					Y	VIC. C/ARM b-phase SIDE & VIC. BACKSTAY EYEBOLTS		Y	DELT	Y	Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y						M	POLE - S		VIC S/L BRACKECT & 0.5m ABOVE G.L. ON POLE							
630	132	1	Y	Y		M					Y	DAMAGED AT MV C/ARM R-phase SIDE		Y	DELTA		Y	ABC	
		2	N																
		3	Y						M			MODERATE DAMAGE S/L BRACKET R Phase SIDE							
		4	N																
		5	N																
		6	N																
673	134	1	Y	Y		S			B	STAY EYEBOLT - B	Y	SMALL CRACK VIC. MV C/ARM, BADLY DAMAGED VIC. STAY EYEBOLT & AT S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																
		3	Y		S							SLIGHT DAMAGE POLE TIP							
		4	N																
		5	N																
		6	N																
718	136	1	N	Y							Y	NO VISIBLE DAMAGE	608m	Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 1m BELOW S/L B Phase SIDE							
		4	N																
		5	N																
		6	Y							POLE - S		+/- 0.5m ABOVE G/L B PHASE SIDE							
766	138	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y						S			SLIGHT DAMAGE NEAR S/L BRACKET							
		4	N																
		5	N																
		6	N																
814	140	1	N	Y							N	PHOTOCELL BLOWN		Y	DELTA		Y	ABC	
		2	Y							POLE BASE - S		SLIGHT DAMAGE POLE BASE R Phase SIDE +/- 300m ABOVE G/L							
		3	N																
		4	N																
		5	N																
		6	N																
853	142	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE BASE - S		SLIGHT DAMAGE POLE BASE R Phase SIDE							
		3	N																
		4	Y							POLE - S		SLIGHT DAMAGE ABOVE S/L R\PHASE SIDE							
		5	N																
		6	N																
896	144	1	Y	Y		M					N	CARBON VISIBLE VIC. C/ARM EYEBOLT ?		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
942	S4508 146	1	N	Y							N	PHOTOCELL BLOWN		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y							BELOW FUSE LINKS - S		SLIGHT DAMAGE BELOW FUSE LINKS R/PHASE SIDE							

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
49	L/L 9291 148	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
89	150	1	Y	Y					M		N	DAMAGED VIC. S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y							BELOW LV - S		BELOW LV ABC B/PHASE SIDE							
137	152	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
177	154	1	Y	Y					S	W-phase INS. DAMAGED - M	N	WHITE PHASE INSULATOR DAMAGED, SLIGHT DAMAGE VIC. S/L BRACKET R/PHASE SIDE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
222	156	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							VIC. LV STAY - B		BADLY DAMAGED VIC. STAY NEAR LV ABC R/PHASE SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
262	158	1	Y	Y	S				M		Y	SLIGHT DAMAGE VIC. L-BRACKET & DAMAGE VIC. S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
305	160	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y						M			MODERATE DAMAGE VIC. S/L BRACKET							
		3	N																
		4	Y							POLE - S		SLIGHT DAMAGE +/- 3m ABOVE G/L R-PHASE SIDE							
		5	N																
		6	N																
353	162	1	N	Y							Y	NO VISIBLE DAMAGE, PHOTOCELL BLOWN		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y							POLE NUMBER - S		SLIGHT DAMAGE ABOVE POLE NUMBER B/PHASE							
402	164	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE VIC S/L B PHASE SIDE							
		3	N																
		4	Y							POLE - S		SLIGHT DAMAGE +/- 2m BELOW S/L BRACKET R-PHASE SIDE							
		5	N																
		6	N																
445	166	1	Y	Y						LV ABC EYEBOLT - M	Y	DAMAGED VIC. LV ABC EYEBOLT		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
490	168	1	Y	Y		M					Y	DAMAGED VIC. MV C/ARM RED PHASE SIDE		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE BELOW S/L BRACKET R PHASE SIDE							
		4	N																
		5	N																
		6	N																
538	170	1	Y	Y					M	BEHIND S/L - M	Y	DAMAGED BEHIND S/L FITTING & AT S/L BACKSTRAP, PHOTOCELL BLOWN		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		5	N																
		6	N																
582	172	1	Y	Y					M		Y	DAMAGED AT S/L BRACKET RED PHASE SIDE		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 1,5m ABOVE G/L R PHASE SIDE							
		4	N																
		5	N																
		6	N																
628	174	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L R-PHASE SIDE							
		5	N																
		6	N																
672	176	1	Y	Y		M			M		Y	DAMAGED VIC. MV C/ARM RED PHASE SIDE. DAMAGED VIC. S/L BRACKET		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 1m & 2m ABOVE G/L B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
720	178	1	Y	Y					M	STAY EYEBOLT - M	Y	DAMAGED VIC. STAY EYEBOLTS. DAMAGED VIC. S/L BRACKET		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y	B						POLE R/PHASE		S/L & BRACKET BADLY DAMAGED							
805	180	1	Y	N		M					N	DAMAGED VIC. MV C/ARM RED PHASE SIDE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
872	182	1	Y	Y					M	MV STAY EYEBOLT - M	N	DAMAGED AT MV STAY EYEBOLT. DAMAGED VIC. S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
926	184	1	N	Y						PHOTOCELL	N	PHOTOCELL DAMAGED OTHERWISE NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
988	186	1	Y	Y			B		M	PHOTOCELL- MV B PH. PIN CHANGED	N	BADLY DAMAGED VIC. C/ARM STRAP B PH. SIDE. B PH. MV PIN CHANGED. S/L DAMAGED		Y	DELTA		Y	ABC	
		2	N																
		3	Y							LV EYEBOLT - S		SLIGHT DAMAGE LV EYEBOLT R Phase SIDE							
		4	N																
		5	N																
		6	N																
1034	188	1	Y	Y		M			M	WHITE PH. PIN CHANGED	N	DAMAGED VI. MV C/ARM RED PH. SIDE. W PH. MV PIN INSULATOR CHANGED.		Y	DELTA		Y	ABC	
		2	Y							POLE - S		+/- 1m ABOVE G/L B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
1080	190	1	Y	Y						BURNING VIC. S/L BRACKET	Y	BURNING VIC. S/L BRACKET OTHERWISE NO VISIBLE DAMAGE.		Y	DELTA		Y	ABC	
		2	Y							LV EYEBOLT - S		SLIGHT DAMAGE LV EYEBOLT R Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
1118	192	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y		S							SLIGHT DAMAGE POLE TIP - POSSIBLE DAMAGE GUMPOLE C/ARM							
		4	N																
		5	N																
		6	Y							POLE-S		+/- 1.5m ABOVE G/L.B/PHASE SIDE							
1167	194	1	Y	Y		B			M		Y	HOLE & CARBON VIC. MV C/ARM STRAP B PH. SIDE. DAMAGED AT S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +/- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		3	Y							STAY - M		MODERATE DAMAGE STAY EYEBOLT							
		4	N																
		5	N																
		6	N																
1213	196	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
1258	198	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1311	200	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y						M	POLE - M		MODERATE DAMAGE S/L BRACKET & +/- 1m ABOVE G/L R Phase SIDE							
		3	N																
		4	Y		S							POSSIBLE SLIGHT DAMAGE TO POLE TIP							
		5	N																
		6	N																
1405	202	1	Y	Y						LV ABC EYEBOLT - M	N	DAMAGED VIC LV ABC EYEBOLT R PH. SIDE. DAMAGED VIC. LV EYEBOLT EAST SIDE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1453	204	1	Y	Y					M		N	DAMAGED VIC S/L BRACKET		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE ABOVE ABC EYEBOLT R Phase SIDE							
		4	N																
		5	N																
		6	N																
1505	206	1	Y	Y	M					LV ABC EYEBOLT - M R/PHASE	N	DAMAGED VIC. L-BRACKET. DAMAGED VIC. LV ABC EYEBOLT.		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1534	208	1	N	Y							N	NO VISIBLE DAMAGE	582	Y	DELTA		Y	ABC	
		2	Y						S			SLIGHT DAMAGE AT S/L BRACKET R Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
1607	210	1	N	N							N	PHOTOCELL DAMAGED OTHERWISE NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y						S			SLIGHT DAMAGE AT S/L BRACKET R Phase SIDE							
		4	N																
		5	N																
		6	N																
1697	212	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1739	S4509(214)	1	N	Y							N	NO VISIBLE DAMAGE	585	Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 1m & 2,5m ABOVE G/L B Phase SIDE							
		4	N																
		5	Y		S							SLIGHT DAMAGE AT POLE TIP							
		6	N																
38	L/L 9292(216)	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 2,5m BELOW C/ARM B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

APPENDIX A

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
77	218	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	Y		S							POSSIBLE SLIGHT DAMAGE TO POLE TIP							
		5	N																
		6	N																
167	SEX 6056 (220)	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	Y							POLE - S		SLIGHT DAMAGE +/- 500mm ABOVE G/L R Phase SIDE							
		3	N																
		4	N																
		5	Y		S							SLIGHT DAMAGE AT POLE TIP							
		6	N																
254	222	1	Y	Y						LV ABC EYEBOLT - M	N	DAMAGED VIC. LV ABC EYEBOLT		Y	DELTA		Y	ABC	
		2	N																
		3	Y			B				POLE - B		BADLY DAMAGED MV C/ARM & +/- 1m BELOW MV EYEBOLT R Phase SIDE							
		4	N																
		5	N																
		6	N																
319	224	1	Y	Y					M		N	DAMAGED VIC. S/L B/STRAP. P.C. BLOWN	583m	Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 2,5m ABOVE G/L B Phase SIDE							
		4	N																
		5	N																
		6	N																
345	226	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							LV EYEBOLT - S		SLIGHT DAMAGE LV EYEBOLT B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
390	228	1	N	Y							N	P.C. DAMAGED. OTHERWISE NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
0	S4513 230	1	N	Y							N	NO VISIBLE DAMAGE	578	Y	DELTA		Y	ABC	
		2	Y		S					POLE - S		SLIGHT DAMAGE NEAR SECTIONALIZER BRACKET							
		3	Y		S					POLE - S		SLIGHT DAMAGE +/- 500mm ABOVE G/L R Phase SIDE							
		4	N																
		5	N																
		6	N																
45	232	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	Y							LV EYEBOLT - B		BADLY DAMAGED AT LV EYEBOLT							
		5	N																
		6	N																
95	234	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	Y							STAY EYEBOLT - B		BADLY DAMAGED AT STAY EYEBOLT							
		5	N																
		6	N																
185	236	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L R Phase SIDE							
		3	N																
		4	Y			B						BADLY DAMAGED AT MV C/ARM							
		5	Y		S							SLIGHT DAMAGE AT POLE TIP							
		6	N																
275	238	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	Y			M						MODERATE DAMAGE AT MV C/ARM							
		5	N																
		6	N																
365	240	1	Y	N		M					N	DAMAGED OPP SIDE OF C/ARM STRAP (lower end)		Y	DELTA		N		
		2	N																
		3	N																
		4	N																

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		5	N																
		6	N																
410	242	1	Y	Y				B			N	BADLY DAMAGED BELOW AERIAL CDU R PH. SIDE VIC. GALVANISED DOWN PIPE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
455	244	1	Y	Y						MV STRAIN INSUL - M ABC EYEBOLT - M	N	DAMAGED VIC. MV INSULATOE EYEBOLT ON T-OFF. DAMAGED VIC. ABC EYEBOLT		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 2,5m ABOVE G/L R Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
500	246	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
545	248	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
590	250	1	Y	Y						BELOW ABC - M	N	SLIGHT DAMAGE BELOW ABC		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
635	252	1	Y	Y				M			N	DAMAGED VIC. CDU		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
675	254	1	Y	Y							N	CARBON VISIBLE ON POLE OPP. ABC		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
715	256	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
756	258	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
797	260	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE 1,5m ABOVE G/L R Phase SIDE							
		4	N																
		5	N																
		6	N																
842	262	1	Y	Y						ABC EYEBOLT - M	N	DAMAGED VIC. ABC EYEBOLT		Y	DELTA		Y	ABC	
		2	N																
		3	Y		S							SLIGHT DAMAGE POLE TIP							
		4	N																
		5	N																
		6	N																
887	264	1	Y	Y		M					N	DAMAGED VIC. C/ARM STRAP EYEBOLT		Y	DELTA		Y	ABC	
		2	N																

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		3	N																
		4	Y		S							POSSIBLE SLIGHT DAMAGE TO POLE TIP							
		5	N																
		6	N																
932	S4515 266	1	N	Y							N	NO VISIBLE DAMAGE	552m	Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 500mm BELOW C/ARM B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
45	268	1	Y	Y						ABC EYEBOLT - M	N	DAMAGED VIC. ABC EYEBOLT	552m	Y	DELTA		Y	ABC	
		2	N																
		3	Y					S				SLIGHT DAMAGE CDU B/STRAP							
		4	N																
		5	N																
		6	N																
90	270	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
135	272	1	Y	Y					M	MV STAY EYEBOLT - M	N	DAMAGED VIC MV BACKSTAY. DAMAGED VIC. S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
225	L/L 9299 274	1	N	N							Y	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	Y		S							SLIGHT DAMAGE TO POLE TIP							
		5	N																
		6	N																
270	276	1	N	N							Y	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 3m ABOVE G/L R Phase SIDE							
		4	N																
		5	N																
		6	N																
322	278	1	N	N							Y	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
360	280	1	Y	N		B					N	BADLY DAMAGED MV C/ARM R PH. SIDE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	Y		B							BADLY DAMAGED AT POLE TIP							
		6	N																
432	282			N							N	WOOD POLE		Y	DELTA		N		
532	284			N							N	WOOD POLE		Y	DELTA		N		
582	285	1	Y	N						W PH. OFFSET SERVICE CLIP - B	N	BADLY DAMAGED VIC. WHITE PH. OFFSET CLIP		Y	DELTA		N		
		2	Y							POLE - S		SLIGHT DAMAGE POLE BASE							
		3	N																
		4	N																
		5	N																
		6	N																
602	286	1	Y	Y					M	B PH.MV INSUL. EYEBOLT - B	N	BADLY DAMAGED VIC. B PH MV EYEBOLT. DAMAGED VIC. S/L FITTING		Y	VERTICAL		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE RANDOM UP POLE							
		3	N																
		4	N																
		5	N																
		6	N																
662	288	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		3	N																
		4	N																
		5	N																
		6	N																
722	290	1	Y	Y					B		N	BADLY DAMAGED VIC. S/L FITTING		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	Y							POLE - S		SLIGHT DAMAGE BELOW S/L BRACKET							
		5	N																
		6	N																
782	291	1	N	Y							N	NO VISIBLE DAMAGE		Y	VERTICAL		Y	ABC	
		2	N																
		3	Y							PIN INSULATOR - S		SLIGHT DAMAGE LOWER PIN INSULATOR							
		4	N																
		5	N																
		6	N																
872	292	1	Y	N						3 PIN INSULATORS - B	N	BADLY DAMAGED ON POLE VIC ALL 3 PIN INSUL. - 3 PHASE FLASHOVER RESULTING IN 3 PHASE FAULT, HENCE DEGREE		Y	VERTICAL		N		
		2	Y							3 PIN INSULATORS - B		MORE DAMAGE AS BEFORE							
		3	Y							POLE - S		SLIGHT DAMAGE HALF WAY UP POLE							
		4	N																
		5	N																
		6	N																
961	294	1	Y	N		B					N	BADLY DAMAGED VIC MV C/ARM		Y	DELTA		N		
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 3m ABOVE G/L R Phase SIDE							
		4	N																
		5	N																
		6	N																
1031	L/L 9302 296	1	N	N							N	NO VISIBLE DAMAGE		Y	VERTICAL		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1121	297	1	Y	N	M						N	DAMAGED VIC. L-BRACKET - MECHANICAL DAMAGE ?		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1211	299											WOOD POLE							
1301	301											WOOD POLE							
1391	303	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1434	305	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1469	307	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 2,5m ABOVE G/L NON ROAD SIDE							
		4	N																
		5	N																
		6	N																
1538	309	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1614	311	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	Y							POLE - S		SLIGHT DAMAGE +/- 2m BELOW C/ARM B Phase SIDE							

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

APPENDIX A

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		3	N																
		4	Y							POLE - S		SLIGHT DAMAGE NEAR STAY EYEBOLT							
		5	N																
		6	N																
1704	313	1	Y	N						VIC B PH. & R PH. OFFSET CLIPS - B	N	BADLY DAMAGED VIC. B PH. & R PH. SERVICE CLIPS		Y	VERTICAL		N		
		2	Y									MORE DAMAGE AS ABOVE							
		3	N																
		4	N																
		5	N																
		6	N																
1748	314	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L							
		4	N																
		5	N																
		6	N																
1748	315	1	Y	Y						MV W PH. INSUL. - M	N	DAMAGED VIC. W PH. INSULATOR		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1834	316	1	Y	Y						MV R PH. INSUL. - B	N	BADLY DAMAGED VIC. R PH STRAIN INSUL. EYEBOLT		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1880	318	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							LV EYEBOLT - S		SLIGHT DAMAGE LV EYEBOLT (ROADSIDE)							
		3	N																
		4	N																
		5	N																
		6	N																
1970	320	1	Y	Y				B	B			BADLY DAMAGED VIC. CDU. BADLY DAMAGED VIC. S/L		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - M		MODERATE DAMAGE POLE BASE R Phase SIDE							
		4	N																
		5	N																
		6	N																
2060	322	1	N	Y								NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y			M						MODERATE DAMAGE BEHIND POLE C/ARM							
		3	N																
		4	N																
		5	N																
		6	N																
2157	324	1	N	Y								P.C. DAMAGED OTHERWISE NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y						S	POLE - S		SLIGHT DAMAGE S/L BRACKET & +/- 2,5m ABOVE G/L B Phase SIDE							
		3	Y				S					SLIGHT DAMAGE C/ARM STRAP EYEBOLT							
		4	Y		S	M						SLIGHT DAMAGE AT POLE TIP AND MODERATE DAMAGE AT MV C/ARM							
		5	N																
		6	N																
45	A1 (OFF 214)	1	Y	Y	M						N	DAMAGED VIC L-BRACKET SUSPECT MECHANICAL DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - M		MODERATE DAMAGE +/- 3m ABOVE G/L R Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
87	L/L 9293 A3	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 2m BELOW C/ARM R Phase SIDE							
		3	N							LV EYEBOLT - S		SLIGHT DAMAGE LV EYEBOLT							
		4	N																
		5	N																
		6	N																
139	A5	1	Y	Y		B			M		N	BADLY DAMAGED VIC. MV C/ARM RED PH. SIDE. DAMAGED VIC. S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	Y		M							MODERATE DAMAGE TO POLE TIP							
		5	N																
		6	Y							POLE - S		BASE							

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
183	SEX 6057 A7	1	N	Y							N	SEX MOUNTING BRACKET & TANK BADLY CORRODED		Y	DELTA		Y	ABC	
		2	N																
		3	Y		S							SLIGHT DAMAGE POLE TIP							
		4	N																
		5	N																
		6	N																
232	A9	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - M		MODERATE DAMAGE POLE BASE R Phase SIDE							
		3	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L R Phase SIDE							
		4	N																
		5	N																
		6	N																
275	A11	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
321	A13	1	Y	Y					B	MV B/STAY EYEBOLT - B	N	BADLY DAMAGED VIC MV B/STAY EYEBOLT. BADLY DAMAGED VIC. S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
410	A15	1	Y	N						MV STAY - B	N	BADLY DAMAGED +/- 1m BELOW MV SIDE STAY NO OTHER HARDWARE BELOW. CURRENT FLOWING TO GND THROUGH		Y	DELTA		N		
		2	Y		S							SLIGHT DAMAGE POLE TIP							
		3	Y							POLE - M		MODERATE DAMAGE HALFWAY UP POLE R Phase SIDE							
		4	N																
		5	N																
		6	N																
453	A17	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y							POLE - M		MODERATE DAMAGE B/STAY R/PHASE							
531	A19	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	Y							POLE - S		SLIGHT DAMAGE +/- 500mm ABOVE G/L R Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	Y			S				WOODEN C/ARM - S		SPLITTING OF WOOD BETWEEN CROSSARM & INSULATOR SPINDLE							
615	A21	1	Y	N						VIC. RED PH. INSULATOR - B	N	BADLY DAMAGED VIC. MV RED PH. STRAIN INSULATOR		Y	VERT		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
708	A23	1	Y	N			M				N	DAMAGED VIC C/ARM 0.5m BELOW (WOODEN)		Y	DELTA		N		
		2	N																
		3	Y		M							MODERATE DAMAGE TO POLE TIP							
		4	N																
		5	N																
		6	N																
802	A25	1	Y	N		B					N	BADLY DAMAGED VIC. MV C/ARM R PH. SIDE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
892	A27	1	Y	N		B					N	BADLY DAMAGED VIC. MV C/ARM R PH. SIDE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
984	A29	1	Y	N	M					DAMAGED HALFWAY DOWN POLE - M	N	DAMAGED VIC. L-BRACKET & HALFWAY DOWN POLE. CURRENT FLOWING TO GND?		Y	DELTA		N		
		2	N																
		3	N																
		4	N																

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		5	N																
		6	N																
1076	A31	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1202	A33	1	Y	N	B					POLE BASE - M	N	BADLY DAMAGED ON POLE TIP. CRACKED AT BASE - DIRECT STRIKE ?		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1255	A35	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1348	A37	1	Y	N	B						N	BADLY DAMAGED ON POLE TIP. - DIRECT STRIKE ? EXAMINATION OF POLE BASE MAY BE REQD.		Y	DELTA		N		
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE HALF WAY UP POLE R Phase SIDE							
		4	N																
		5	N																
		6	N																
1441	A39	1	Y	N		S				+/- 2m FROM GL. VIC. GL - S	N	SLIGHT DAMAGE VIC. C/ARM EYEBOLT. SLIGHT DAMAGE 2m FROM G.L. & VIC G.L. - MECHANICAL DAMAGE?		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1494	A41	1	Y	Y						RED PH. INS. - B LV ABC EYEBOLT - S	N	BADLY DAMAGED VIC. R PH. MV INSULATOR. SLIGHT DAMAGE VIC. LV ABC EYEBOLT	574	Y	VERT		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 3m ABOVE G/L							
		3	Y					S				SLIGHT DAMAGE CDU B/STRAP							
		4	N																
		5	N																
		6	N																
1539	A43	1	Y	Y	S					VIC. POLE NUMBERS - S	N	SLIGHT DAMAGE VIC. POLE NUMBERS		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1584	A45	1	Y	Y					S		N	SLIGHT DAMAGE ABOVE S/L B/STRAP		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1632	A47	1	Y	Y	B					VIC.LV ABC EYEBOLT & BELOW - S	N	BADLY DAMAGED VIC L-BRACKET. SLIGHTLY DAMAGED VIC. LV ABC EYEBOLT & BELOW THIS POSITION		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1679	A49	1	N	Y							N	PHOTOCELL DAMAGED OTHERWISE NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE AT G/L B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
1723	A51	1	N	Y							N	CARBON BELOW C/ARM STRAP EYEBOLT ? OTHERWISE NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE HALFWAY UP POLE B Phase SIDE							
		4	N																
		5	N																
		6	N																
1769	A53	1	Y	Y						W PH. INSUL. - B ABC STRAIN CLAMP - M	N	BADLY DAMAGED VIC. W PH. STRAIN INSUL. DAMAGED VIC. LV ABC STRAIN CLAMP OPP. LV STAY & BELOW THIS POSITI		Y	DELTA		Y	ABC	
		2	N																

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		3	N																
		4	N																
		5	N																
		6	N																
1812	A55	1	N	N							N		570	Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L & 2,5m BELOW C/ARM B Phase SIDE							
		3	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L R Phase SIDE							
		4	N																
		5	N																
		6	N																
1852	A57	1	N	Y							N	NO VISIBLE DAMAGE	570m	Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L R Phase SIDE							
		3	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L R Phase SIDE							
		4	N																
		5	N																
		6	N																
1892	A59	1	Y	Y						HALFWAY DOWN POLE - S	N	SLIGHT DAMAGE HALFWAY DOWN POLE - MECHANICAL ?		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1932	A61	1	Y	Y		B					N	BADLY DAMAGED VIC. MV C/ARM R PH. SIDE. BADLY DAMAGED BELOW LV ABC EYEBOLT.		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	Y		S							SLIGHT DAMAGE TO POLE TIP							
		6	N																
1983	A63	1	Y	Y	S	B					N	BADLY DAMAGED VIC. MV C/ARM R PH. SIDE. SLIGHT DAMAGE VIC. L-BRACKET. BADLY DAMAGED BELOW LV ABC EYEB		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y							POLE - B		BADLY DAMAGE L/V EYE BOLT							
2015	A65	1	Y	Y		B				1M BELOW ABC - B 2M BELOW ABC - M	N	BADLY DAMAGED VIC. MV C/ARM BADLY DAMAGED +/- 1m BELOW ABC. DAMAGED +/- 2m BELOW ABC.		Y	DELTA		Y	ABC	
		2	Y							POLE - S									
		3	Y							LV EYEBOLT - B		BADLY DAMAGED AT LV EYEBOLT							
		4	N																
		5	N																
		6	N																
2047	A67	1	Y	Y						S POLE NUMBER - B	N	BADLY DAMAGED VIC. POLE NUMBER - CURRENT MUST BE FLOWING TO GND.		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2114	A69	1	N	N							N	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2239	A71	1	Y	N						VIC. POLE NUMBER - S	N	SLIGHT DAMAGE +/- 500mm ABOVE POLE NUMBER		Y	DELTA		N		
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2314	A73	1	N	N							N	NO VISIBLE DAMAGE		Y	VERTICAL		N		
		2	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L							
		3	Y							PIN INSULATOR - M		MODERATE DAMAGE PIN INSULATOR R Phase SIDE							
		4	N																
		5	N																
		6	N																
2404	A75	1	Y	N						POLE +/- 2.5m ABOVE GL - B	N	BADLY DAMAGED +/- 2.5m ABOVE GL - CURRENT FLOW TO GND ?		Y	DELTA		N		
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE ABOVE POLE NUMBER							
		4	N																
		5	N																
		6	N																

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
2494	A77	1	N	N							N			Y	DELTA		Y	ABC	
		2	N																
		3	Y				B					BADLY DAMAGED NEAR MV C/ARM & LV EYEBOLT							
		4	N																
		5	N																
		6	N																
2539	A79	1	Y	N							N	SLIGHT DAMAGE +/- 500mm ABOVE POLE NUMBER		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2584	A81	1	Y	N		S					Y	SLIGHT BURNING ON THE C/ARM B PH. SIDE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2629	A83	1	N	Y							Y	NO VISIBLE DAMAGE - TREE TRIMMING URGENTLY REQD.		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2674	A85	1	Y	Y	M						N	MODERATE DAMAGE ON POLE TIP VIC. L-BRACKET		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2719	A87	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 500mm ABOVE G/L B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
2764	A89	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6																	
2809	A91	1	Y	Y						LV EYEBOLT - M	N	DAMAGED VIC. LV EYEBOLT		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 500mm BELOW LV B Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
2854	A93	1	Y	Y						LV EYEBOLT. - M POLE - M	N	DAMAGED AT. LV EYEBOLT. DAMAGED +/- 2.5m FROM GL R PH. SIDE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y							POLE - S		BEHIND NUMBER R/PHASE							
2899	A95	1	Y	Y						POLE - S	N	SLIGHT DAMAGE +/- 3.5m FROM GL R PH. SIDE		Y	DELTA		Y	ABC	
		2	Y							CARBON TRACKING - S		POSSIBLE CARBON TRACKING NEAR C/ARM R Phase SIDE							
		3	N																
		4	N																
		5	N																
		6	N																
2944	A97	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 2,5m ABOVE G/L							
		4	N																
		5	N																
		6	N																
2989	A99	1	N	Y							Y	NO VISIBLE DAMAGE - TREES REQ. URGENT TRIMMING		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE NEAR POLE No. B Phase SIDE & NEAR G/L R Phase SIDE							
		3	N																
		4	N																

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		5	N																
		6	N																
3034	A101	1	N	Y							Y	NO VISIBLE DAMAGE - TREES REQ. URGENT TRIMMING		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
3079	A103	1	Y	Y						POLE - S	Y	SLIGHT DAMAGE +/- 1.5m BELOW ABC B PH. SIDE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
3124	A105	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
3169	A107	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE ABOVE & BELOW POLE NUMBER							
		3	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L							
		4	N																
		5	N																
		6	N																
3214	S4512 A109	1	Y	Y		Y					Y	SLIGHT DAMAGE BELOW MV C/ARM R PH. SIDE - MECHANICAL ?	475m	Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2352	C1(A73)	1	N	N							Y	NO VISIBLE DAMAGE		Y	DELTA		N		
		2	Y			S						SLIGHT DAMAGE BELOW MV C/ARM SUPPORT							
		3	N																
		4	N																
		5	N																
		6	N																
2403	L/L 9296 C3	1	Y	Y						BOW C/ARM - B	N	BADLY DAMAGED AT BOW C/ARM ATTACHMENT TO POLE - IS THERE AN EXTERNAL EARTH ?		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2448	C5	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE NEAR POLE NUMBER							
		4	N																
		5	N																
		6	N																
2493	C7	1	N	Y							Y	NO VISIBLE DAMAGE - POLE UNDERPLANTED		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2538	C9	1	Y	Y						POLE - M	Y	DAMAGED +/- 300mm BELOW ABC		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	Y							POLE - S		DAMAGED +/- 2m ABOVE G/L							
2583	C11	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2628	C13	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - M		MODERATE DAMAGE AROUND POLE NUMBER & SLIGHT DAMAGE +/- 2m FROM C/ARM							

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

APPENDIX A

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		3	N																
		4	N																
		5	N																
		6	N																
2673	C15	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2718	C17	1	N	Y							Y	NO VISIBLE DAMAGE	522	Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2763	C19	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y			S				CARBON TRACKING		POSSIBLE CARBON TRACKING AT MV C/ARM							
		3	N																
		4	N																
		5	N																
		6	Y							POLE - S		DAMAGE POLE BASE R/PHASE							
2808	C21	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L							
		4	N																
		5	N																
		6	N																
2853	C23	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
2898	C25	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L							
		4	N																
		5	N																
		6	N																
2942	C27	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 1m ALL AROUND G/L & +/- 1m BELOW CDU							
		3	N																
		4	N																
		5	N																
		6	N																
3003	C29	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L							
		3	Y							POLE - S		SLIGHT DAMAGE +/- 500mm & +/- 3m ABOVE G/L							
		4	N																
		5	N																
		6	N																
3048	C31	1	N	Y							Y	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
3092	C33	1	N	Y						POLE - B	Y	NO VISIBLE DAMAGE - POLE UNDERPLANTED & LEANING		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	Y							ABC EYEBOLT - B		BADLY DAMAGED AT ABC EYEBOLT							
		6	N																
3122	S4511 C35	1	Y	Y						W PH. STRAIN INSUL. - M	Y	DAMAGE VIC. W PH. STRAIN INSUL. - MECHANICAL DAMAGE ?	360	Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE BELOW CDU							
		3	Y		S							SLIGHT DAMAGE TO POLE TIP							
		4	N																
		5	N																
		6	N																

POLE DAMAGE INVENTORY- INWABI PLATEAU DISTRIBUTION LINE (MV LINES)

APPENDIX A

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
1539	L/L 9294 B1(A41)	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1584	B3	1	Y	Y		B		B			N	BADLY DAMAGED VIC. MV C/ARM R PH. SIDE. BADLY DAMAGED VIC. CDU		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 500mm ABOVE G/L B Phase SIDE							
		4	N																
		5	N																
		6	N																
1629	B5	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1674	B7	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 500mm BELOW S/L							
		3	N																
		4	N																
		5	N																
		6	N																
1719	B9	1	Y	Y	M				M		N	DAMAGED VIC. L-BRACKET. DAMAGED AT S/L BEHIND FUSE PLATE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N									C/ARM NOT STRAIGHT							
		6	N																
1764	B11	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
1809	S4510 B13	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
498	L/L 9298 B1(244)	1	N	N							N	NO VISIBLE DAMAGE - POLE EARTHED		Y	DELTA		N		
		2	Y							POLE - S		SLIGHT DAMAGE JUST BELOW C/ARM							
		3	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L B Phase SIDE							
		4	N																
		5	N																
		6	N																
627	B3			Y							N	WOOD POLE		Y	DELTA		Y	ABC	
662	B5	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
697	B7	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	Y		S							POSSIBLE DAMAGE TO POLE TIP							
		6	N																
732	B9	1	Y	Y			B	B			N	BADLY DAMAGED VIC. MV C/ARM B PH. SIDE. BADLY DAMAGED UNDER BANDIT STRAPS ABOVE CDU		Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE NEAR LV ABC EYEBOLT							
		4	N																
		5	N																
		6	N																
772	B11	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																

LINEA REF.	POLE NO.	INSPECTION NO.	POLE DAMAGED	LV	POLE TIP	MV C/ARM	C/ARM STRAP	CDU	S/L	OTHER	TREES +\- 20m	REMARKS	ELEV	MV	CONF	MV STY	LV	CONF	LV STY
		3	Y							POLE - S		SLIGHT DAMAGE JUST BELOW LV ABC EYEBOLT							
		4	N																
		5	N																
		6	N																
812	B13	1	N	Y							N	NO VISIBLE DAMAGE - TRIAL EARTHING DONE BY SIVA HERE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
852	B15	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
892	S4514 B17	1	N	Y							N	NO VISIBLE DAMAGE	555m	Y	DELTA		Y	ABC	
		2	Y							POLE - S		SLIGHT DAMAGE +/- 300mm ABOVE G/L							
		3	N																
		4	N																
		5	N																
		6	N																
647	L/L 9300 2861	1	Y	Y						BOW C/ARM - B	N	BADLY DAMAGED VIC. BOW C/ARM. SLIGHTLY DAMAGED AT 3 POSITIONS BELOW ABC TOWARD GL. NOTE THERE I	478m	Y	DELTA		Y	ABC	
		2	N																
		3	Y							POLE - S		SLIGHT DAMAGE +/- 1m ABOVE G/L							
		4	N																
		5	N																
		6	N																
692	2863	1	N	Y							N	NO VISIBLE DAMAGE		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	N																
		5	N																
		6	N																
782	S4516 2865	1	Y	Y	B						N	BADLY DAMAGED AT POLE TIP. DAMAGED VIC. EYEBOLT SECURING Tx.		Y	DELTA		Y	ABC	
		2	N																
		3	N																
		4	Y							POLE - S		SLIGHT DAMAGE +/- 2m ABOVE G/L							
		5	N																
		6	N																

SURGE GENERATOR OUTPUT VOLTAGE

C1 = **1E-08** **Rd =** **260**
C2 = **1.20E-09** **Re =** **6100**

S*S+AS+B=0 ,a1, a2 (roots) 1.055E+11
2.59E+13

A=(1/R1/C1)+(1/R1/C2)+(1/R2/C1) 3606137
B=1/R1/R2/C1/C2 5.254E+10
K=Rd*C2 3.12E-07

a1 = A/2+SQRT ((A/2*A/2)-B) 14629.815
a2 = A/2-SQRT ((A/2*A/2)-B) 3591507.2

Tm = Ln(a2/a1)/(a2-a1) 1.539E-06

V(t) = Vo/K*(1/(a2-a1))*(EXP(-a1*t)-EXP(-a2*t))

Vp = 87255.5679
90% Vp = 78530.0111
50% Vp = 43627.7839

	(t)	V(t)		(t)	V(t)
1	8.40E-07	84125.7838	29	2.90E-05	58625.366
2	1.20E-06	86843.5199	30	3.00E-05	57773.931
3	1.56E-06	87254.5415	31	3.10E-05	56934.861
4	2.79E-06	86019.0313	32	3.20E-05	56107.978
5	5.00E-06	83286.2109	33	3.30E-05	55293.104
6	6.00E-06	82076.6201	34	3.40E-05	54490.065
7	7.00E-06	80884.5952	35	3.50E-05	53698.688
8	8.00E-06	79709.8824	36	3.60E-05	52918.805
9	9.00E-06	78552.2303	37	3.70E-05	52150.248
10	1.00E-05	77411.3912	38	3.80E-05	51392.854
11	1.10E-05	76287.1209	39	3.90E-05	50646.459
12	1.20E-05	75179.1787	40	4.00E-05	49910.904
13	1.30E-05	74087.3275	41	4.10E-05	49186.032
14	1.40E-05	73011.3336	42	4.20E-05	48471.688
15	1.50E-05	71950.9668	43	4.30E-05	47767.718
16	1.60E-05	70905.9999	44	4.40E-05	47073.972
17	1.70E-05	69876.2095	45	4.50E-05	46390.302
18	1.80E-05	68861.375	46	4.60E-05	45716.561
19	1.90E-05	67861.2793	47	4.70E-05	45052.605
20	2.00E-05	66875.7083	48	4.80E-05	44398.291
21	2.10E-05	65904.451	49	4.90E-05	43753.481
22	2.20E-05	64947.2996	50	5.00E-05	43118.035
23	2.30E-05	64004.0493	51	5.10E-05	42491.818
24	2.40E-05	63074.4981	52	5.20E-05	41874.696
25	2.50E-05	62158.447	53	5.30E-05	41266.536
26	2.60E-05	61255.7001	54	5.40E-05	40667.209
27	2.70E-05	60366.064	55	5.50E-05	40076.586
28	2.80E-05	59489.3484			

SURGE GENERATOR OUTPUT VOLTAGE

C1 =	**1E-08**	**Rd =**	**375**
C2 =	**1.20E-09**	**Re =**	**6100**

S*S+AS+B=0 ,a1, a2 (roots)	7.329E+10
	1.248E+13
A=(1/R1/C1)+(1/R1/C2)+(1/R2/C1)	2505282.3
B=1/R1/R2/C1/C2	3.643E+10
K=Rd*C2	4.5E-07
a1 = A/2+SQRT ((A/2*A/2)-B)	14626.619
a2 = A/2-SQRT ((A/2*A/2)-B)	2490655.7
Tm = Ln(a2/a1)/(a2-a1)	2.075E-06

V(t) = Vo/K*(1/(a2-a1))*(EXP(-a1*t)-EXP(-a2*t))

Vp =	86555.2916
90% Vp =	77899.7624
50% Vp =	43277.6458

	(t)	V(t)		(t)	V(t)
1	8.40E-07	77576.4905	29	2.90E-05	58724.0776
2	1.20E-06	83669.1583	30	3.00E-05	57871.3940
3	1.56E-06	85881.3894	31	3.10E-05	57031.0915
4	2.79E-06	86074.5151	32	3.20E-05	56202.9904
5	5.00E-06	83419.6990	33	3.30E-05	55386.9134
6	6.00E-06	82208.7471	34	3.40E-05	54582.6860
7	7.00E-06	81015.0884	35	3.50E-05	53790.1362
8	8.00E-06	79838.7377	36	3.60E-05	53009.0943
9	9.00E-06	78679.4659	37	3.70E-05	52239.3932
10	1.00E-05	77537.0267	38	3.80E-05	51480.8684
11	1.10E-05	76411.1759	39	3.90E-05	50733.3574
12	1.20E-05	75301.6727	40	4.00E-05	49996.7004
13	1.30E-05	74208.2796	41	4.10E-05	49270.7399
14	1.40E-05	73130.7628	42	4.20E-05	48555.3204
15	1.50E-05	72068.8917	43	4.30E-05	47850.2889
16	1.60E-05	71022.4391	44	4.40E-05	47155.4945
17	1.70E-05	69991.1813	45	4.50E-05	46470.7888
18	1.80E-05	68974.8974	46	4.60E-05	45796.0250
19	1.90E-05	67973.3702	47	4.70E-05	45131.0590
20	2.00E-05	66986.3853	48	4.80E-05	44475.7483
21	2.10E-05	66013.7316	49	4.90E-05	43829.9529
22	2.20E-05	65055.2011	50	5.00E-05	43193.5345
23	2.30E-05	64110.5885	51	5.10E-05	42566.3571
24	2.40E-05	63179.6919	52	5.20E-05	41948.2864
25	2.50E-05	62262.3120	53	5.30E-05	41339.1901
26	2.60E-05	61358.2527	54	5.40E-05	40738.9381
27	2.70E-05	60467.3204	55	5.50E-05	40147.4018
28	2.80E-05	59589.3247			

C1 =	**1E-08**	**Rd =**	**455**
C2 =	**1.20E-09**	**Re =**	**6100**

S*S+AS+B=0 ,a1, a2 (roots)	6.048E+10
	8.49E+12
A=(1/R1/C1)+(1/R1/C2)+(1/R2/C1)	2067675.5
B=1/R1/R2/C1/C2	3.002E+10
K=Rd*C2	5.46E-07
a1 = A/2+SQRT ((A/2*A/2)-B)	14624.39
a2 = A/2-SQRT ((A/2*A/2)-B)	2053051.1
Tm = Ln(a2/a1)/(a2-a1)	2.426E-06

V(t) = Vo/K*(1/(a2-a1))*(EXP(-a1*t)-EXP(-a2*t))

Vp =	86099.7627
90% Vp =	77489.7864
50% Vp =	43049.8813

	(t)	V(t)		(t)	V(t)
1	8.40E-07	72736.1676	29	2.90E-05	58792.8874
2	1.20E-06	80637.5955	30	3.00E-05	57939.3339
3	1.56E-06	84169.8438	31	3.10E-05	57098.1722
4	2.79E-06	85964.2369	32	3.20E-05	56269.2225
5	5.00E-06	83510.2002	33	3.30E-05	55452.3074
6	6.00E-06	82300.4831	34	3.40E-05	54647.2523
7	7.00E-06	81105.9911	35	3.50E-05	53853.8850
8	8.00E-06	79928.5407	36	3.60E-05	53072.0357
9	9.00E-06	78768.1460	37	3.70E-05	52301.5373
10	1.00E-05	77624.5929	38	3.80E-05	51542.2250
11	1.10E-05	76497.6412	39	3.90E-05	50793.9364
12	1.20E-05	75387.0505	40	4.00E-05	50056.5114
13	1.30E-05	74292.5834	41	4.10E-05	49329.7923
14	1.40E-05	73214.0056	42	4.20E-05	48613.6237
15	1.50E-05	72151.0867	43	4.30E-05	47907.8524
16	1.60E-05	71103.5991	44	4.40E-05	47212.3275
17	1.70E-05	70071.3190	45	4.50E-05	46526.9002
18	1.80E-05	69054.0255	46	4.60E-05	45851.4239
19	1.90E-05	68051.5010	47	4.70E-05	45185.7542
20	2.00E-05	67063.5311	48	4.80E-05	44529.7486
21	2.10E-05	66089.9046	49	4.90E-05	43883.2669
22	2.20E-05	65130.4131	50	5.00E-05	43246.1708
23	2.30E-05	64184.8516	51	5.10E-05	42618.3241
24	2.40E-05	63253.0176	52	5.20E-05	41999.5924
25	2.50E-05	62334.7120	53	5.30E-05	41389.8435
26	2.60E-05	61429.7383	54	5.40E-05	40788.9468
27	2.70E-05	60537.9031	55	5.50E-05	40196.7740
28	2.80E-05	59659.0154			

C1 =	1E-08	Rd =	541
C2 =	1.20E-09	Re =	6100

S*S+AS+B=0 ,a1, a2 (roots)	5.093E+10
	6.015E+12
A=(1/R1/C1)+(1/R1/C2)+(1/R2/C1)	1741593.7
B=1/R1/R2/C1/C2	2.525E+10
K=Rd*C2	6.492E-07
a1 = A/2+SQRT ((A/2*A/2)-B)	14621.988
a2 = A/2-SQRT ((A/2*A/2)-B)	1726971.7
Tm = Ln(a2/a1)/(a2-a1)	2.79E-06

V(t) = Vo/K*(1/(a2-a1))*(EXP(-a1*t)-EXP(-a2*t))

Vp =	85966.4919
90% Vp =	77369.8427
50% Vp =	42983.2459

	(t)	V(t)		(t)	V(t)
1	8.40E-07	67770.5399	29	2.90E-05	58866.9869
2	1.20E-06	77066.8244	30	3.00E-05	58012.4969
3	1.56E-06	81845.6324	31	3.10E-05	57170.4104
4	2.79E-06	85632.9284	32	3.20E-05	56340.5472
5	5.00E-06	83597.7710	33	3.30E-05	55522.7300
6	6.00E-06	82397.2164	34	3.40E-05	54716.7839
7	7.00E-06	81203.4679	35	3.50E-05	53922.5366
8	8.00E-06	80025.1588	36	3.60E-05	53139.8183
9	9.00E-06	78863.6178	37	3.70E-05	52368.4616
10	1.00E-05	77718.8775	38	3.80E-05	51608.3017
11	1.10E-05	76590.7432	39	3.90E-05	50859.1759
12	1.20E-05	75478.9825	40	4.00E-05	50120.9241
13	1.30E-05	74383.3594	41	4.10E-05	49393.3885
14	1.40E-05	73303.6399	42	4.20E-05	48676.4136
15	1.50E-05	72239.5931	43	4.30E-05	47969.8459
16	1.60E-05	71190.9916	44	4.40E-05	47273.5345
17	1.70E-05	70157.6112	45	4.50E-05	46587.3305
18	1.80E-05	69139.2309	46	4.60E-05	45911.0872
19	1.90E-05	68135.6331	47	4.70E-05	45244.6599
20	2.00E-05	67146.6031	48	4.80E-05	44587.9062
21	2.10E-05	66171.9294	49	4.90E-05	43940.6857
22	2.20E-05	65211.4038	50	5.00E-05	43302.8601
23	2.30E-05	64264.8207	51	5.10E-05	42674.2928
24	2.40E-05	63331.9779	52	5.20E-05	42054.8496
25	2.50E-05	62412.6758	53	5.30E-05	41444.3979
26	2.60E-05	61506.7180	54	5.40E-05	40842.8074
27	2.70E-05	60613.9107	55	5.50E-05	40249.9493
28	2.80E-05	59734.0631			

INWABI PLATEAU - EARTH RESISTIVITY TESTS

Test Equipment: TERR234E Earth Meggar

Key

A - Unmodified pole
B - Wood crossarm with downwire
C - Steel crossarm with downwire

Pole No.	Apparent Depth (a) (m)	Soil Resistivity (ohm.m)	Footing Resistance (ohms)	Modifcation Code	Test Date
120	1m	593	n/a	A	14-02-97
-do-	-do-	615	n/a	A	07-03-97
-do-	-do-	693	n/a	A	14-04-97
-do-	-do-	629	n/a	A	16-05-97
-do-	-do-	619	n/a	A	19-06-97
120	2m	723	n/a	A	14-02-97
-do-	-do-	193	n/a	A	07-03-97
-do-	-do-	779	n/a	A	14-04-97
-do-	-do-	751	n/a	A	16-05-97
-do-	-do-	713	n/a	A	19-06-97
190	1m	1213	305	B	14-02-97
-do-	-do-	1306	357	B	07-03-97
-do-	-do-	1209	327	B	14-04-97
-do-	-do-	1223	309	B	16-05-97
-do-	-do-	1297	351	B	19-06-97
190	2m	1050	n/a	B	14-02-97
-do-	-do-	304	n/a	B	07-03-97
-do-	-do-	961	n/a	B	14-04-97
-do-	-do-	1012	n/a	B	16-05-97
-do-	-do-	941	n/a	B	19-06-97
230	1	2090	n/a	A	14-02-97
-do-	-do-	929	n/a	A	07-03-97
-do-	-do-	886	n/a	A	14-04-97
-do-	-do-	911	n/a	A	16-05-97
-do-	-do-	925	n/a	A	19-06-97
230	2	958	n/a	A	14-02-97
-do-	-do-	299	n/a	A	07-03-97
-do-	-do-	1295	n/a	A	14-04-97
-do-	-do-	1217	n/a	A	16-05-97
-do-	-do-	1123	n/a	A	19-06-97
270	1	975	341	B	14-02-97
-do-	-do-	999	232	B	07-03-97
-do-	-do-	1069	233	B	14-04-97
-do-	-do-	989	237	B	16-05-97
-do-	-do-	992	246	B	19-06-97

INWABI PLATEAU - EARTH RESISTIVITY TESTS

Test Equipment: TERR234E Earth Meggar

Key

A - Unmodified pole
B - Wood crossarm with downwire
C - Steel crossarm with downwire

Pole No.	Apparent Depth (a) (m)	Soil Resistivity (ohm.m)	Footing Resistance (ohms)	Modifcation Code	Test Date
270	2	476	n/a	B	14-02-97
-do-	-do-	351	n/a	B	07-03-97
-do-	-do-	721	n/a	B	14-04-97
-do-	-do-	698	n/a	B	16-05-97
-do-	-do-	524	n/a	B	19-06-97
303	1	270	79	C	14-02-97
-do-	-do-	375	93	C	07-03-97
-do-	-do-	253	78	C	14-04-97
-do-	-do-	291	82	C	16-05-97
-do-	-do-	303	92	C	19-06-97
303	2	169	n/a	C	14-02-97
-do-	-do-	213	n/a	C	07-03-97
-do-	-do-	202	n/a	C	14-04-97
-do-	-do-	208	n/a	C	16-05-97
-do-	-do-	205	n/a	C	19-06-97
A25	1	1233	116	B	14-02-97
-do-	-do-	1809	451	B	07-03-97
-do-	-do-	1815	421	B	14-04-97
-do-	-do-	1792	429	B	16-05-97
-do-	-do-	1819	442	B	19-06-97
A25	2	1170	n/a	B	14-02-97
-do-	-do-	1301	n/a	B	07-03-97
-do-	-do-	1437	n/a	B	14-04-97
-do-	-do-	1348	n/a	B	16-05-97
-do-	-do-	1386	n/a	B	19-06-97
A59	1	1284	247	C	14-02-97
-do-	-do-	1583	193	C	07-03-97
-do-	-do-	1438	190	C	14-04-97
-do-	-do-	1472	185	C	16-05-97
-do-	-do-	1493	195	C	19-06-97
A59	2	1084	n/a	C	14-02-97
-do-	-do-	1016	n/a	C	07-03-97
-do-	-do-	1092	n/a	C	14-04-97
-do-	-do-	1037	n/a	C	16-05-97

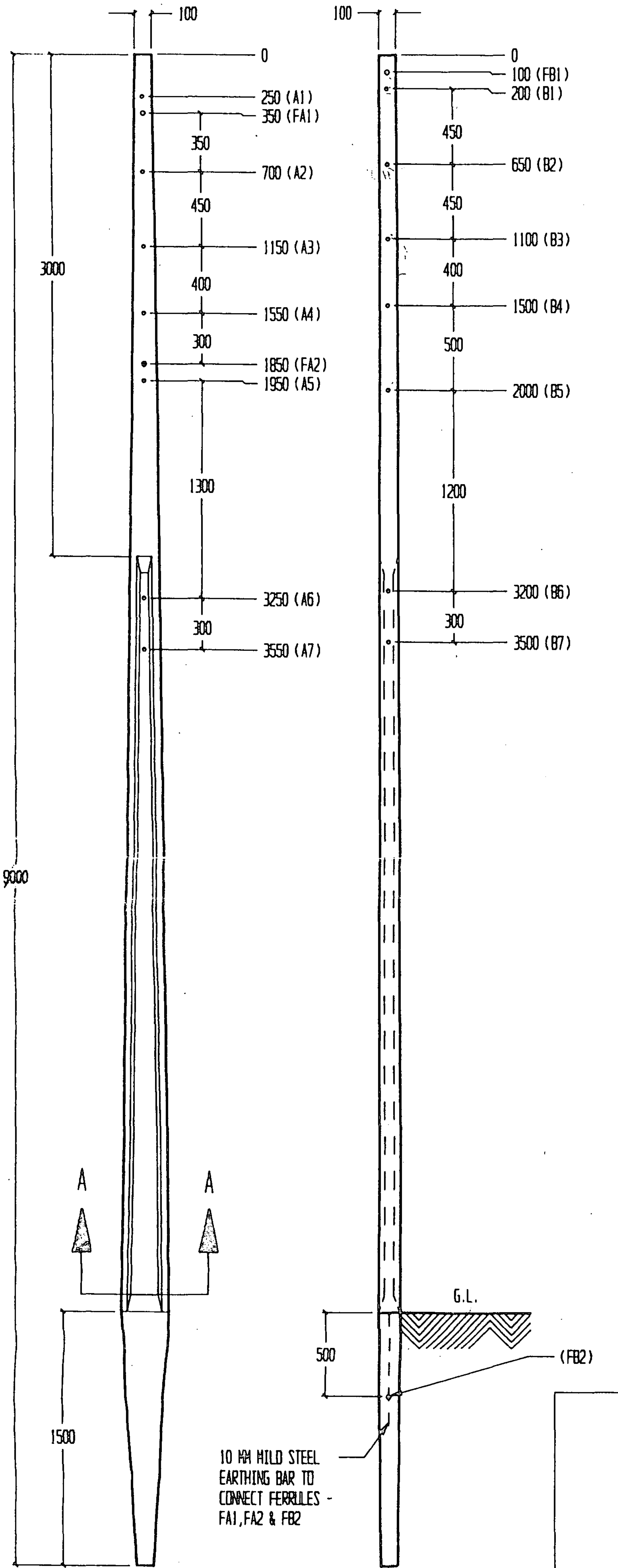
Test Equipment: TERR234E Earth Meggar

Key

A - Unmodified pole
B - Wood crossarm with downwire
C - Steel crossarm with downwire

Pole No.	Apparent Depth (a) (m)	Soil Resistivity (ohm.m)	Footing Resistance (ohms)	Modifcation Code	Test Date
-do-	-do-	1029	n/a	C	19-06-97

Pole Type :9/4

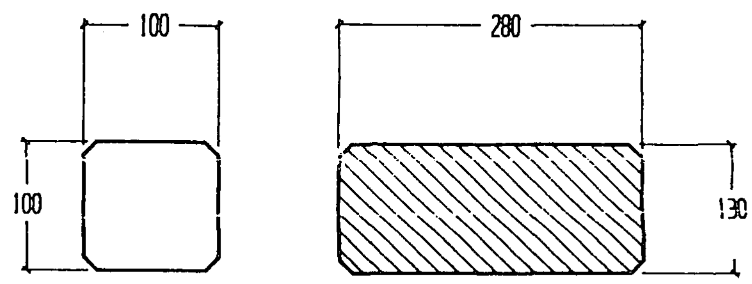


NOTES & DESIGN LOADINGS

Pole Length -:		9 m	
Planting Depth -:		1.5 m	
ULTIMATE LOADS :			
Transverse -: (strong)	400kg	4 kN -	
Down Line -: (weak)	140kg	1,4 kN	/ 35%
CRACK LOADS :			
Transverse -:	220kg	2,2 kN	
Down Line -:	44kg 0,44	0,6 kN ?	
Loads applied at 300 mm from top			
SAFETY FACTOR		x2	
Weight of Pole (@ 2400 kg/m³)		409 Kg	
All holes to have a 22 mm I.D. PVC sleeve			

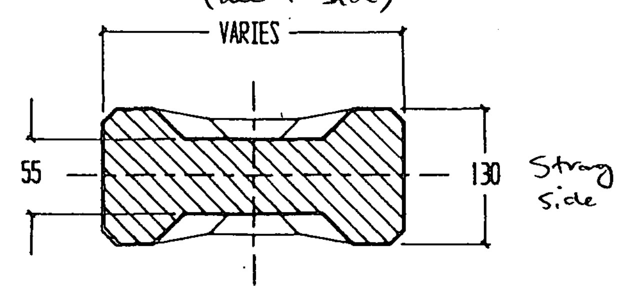
Exposed wind load Area
weak 1,575 m²

12 mm Stainless Steel Earthing Ferrules
(FA1 & FA2 & FB2)
Fixing Ferrule -FB1



Tip & Butt Ground level

(weak side)

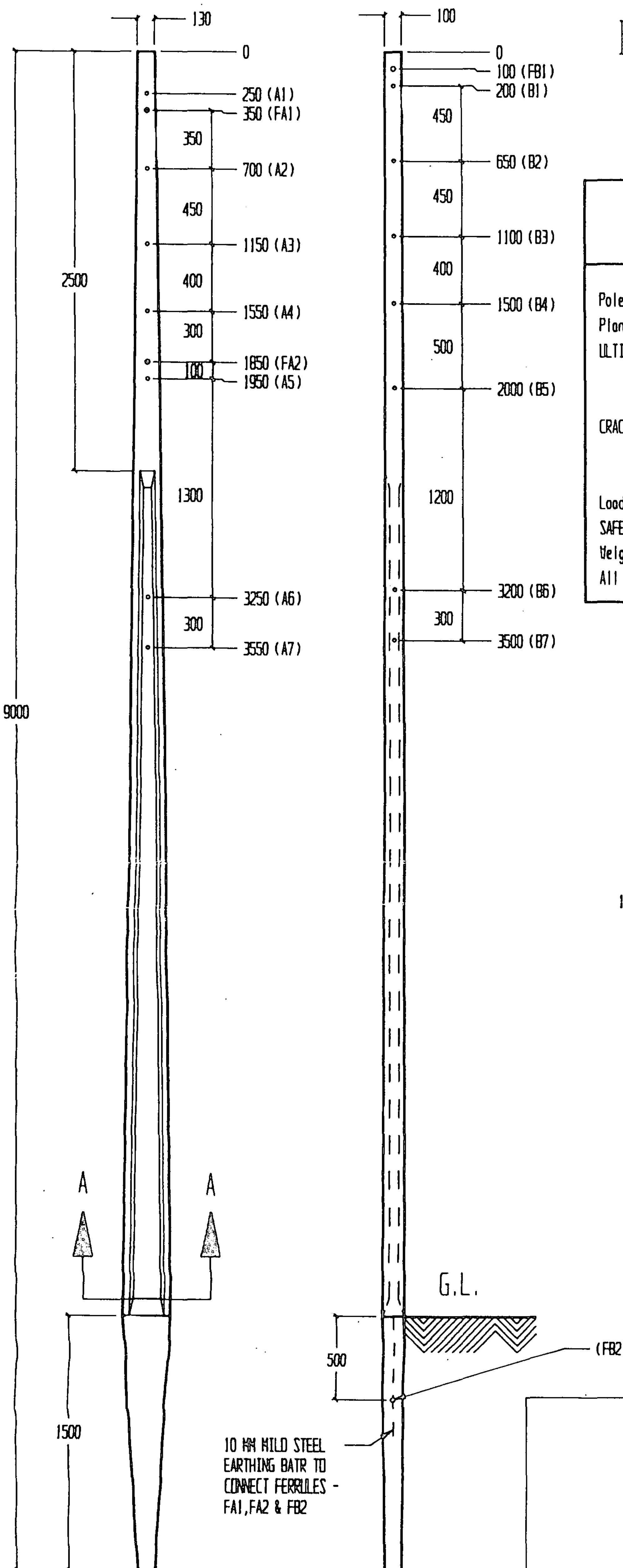


Section A-A

GRINAKER DURASET

ENGINEERS IN PRECAST CONCRETE - VOORAFGEGIETE BETON INGENIEURS

CLIENT	DURBAN CORPORATION		
TITLE	9 M -4 kN POLE		
DRAWN	02/11/92	REF. DRWG.	
CHECKED		DRAWING No.	REV
APPROVED			
SCALE	VARIES	GDG-999-5055/10	G-93/02/03



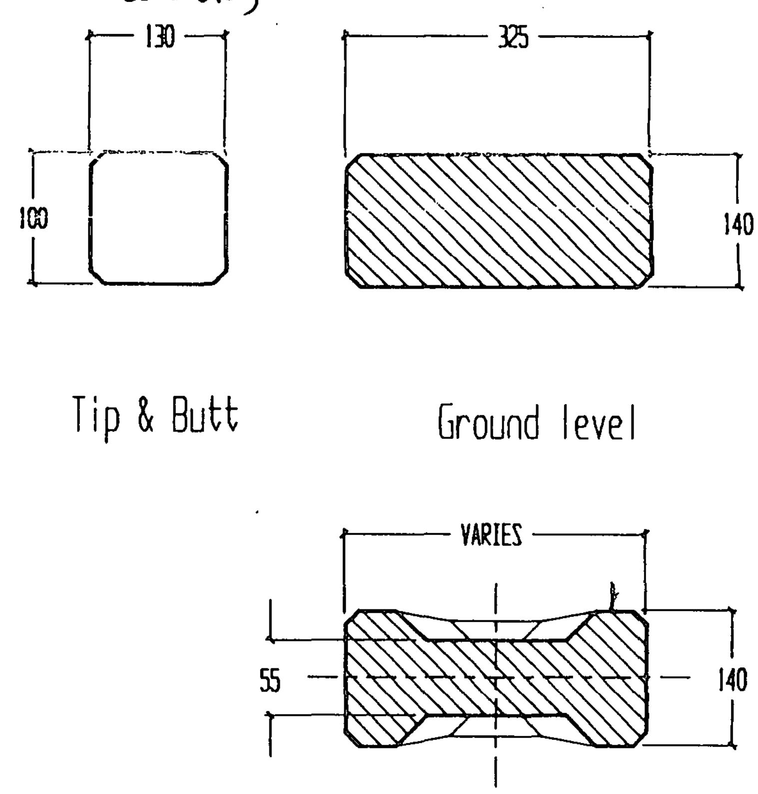
Pole Type : 9/7

NOTES & DESIGN LOADINGS

Pole Length -:		9 m	
Planting Depth -:		1.5 m	
ULTIMATE LOADS :			
Transverse -: (strong)	700 kg	7 kN	
Down Line -: (weak)	230 kg	2.3 kN	32%
CRACK LOADS :			
Transverse -: (strong)	390 kg	3.9 kN	
Down Line -: (weak)	80 kg	0.8 kN	✓
Loads applied at 300 mm from top			
SAFETY FACTOR		x2	
Weight of Pole (@ 2400 kg/m³)		488 Kg	
All holes to have a 22 mm I.D. PVC sleeve			

12 mm Stainless Steel Earthing Ferrules
(FA1 & FA2 & FB2)
Fixing Ferrule - FB1

Exposed wind load Area (weak) 1,71 m²



Tip & Butt

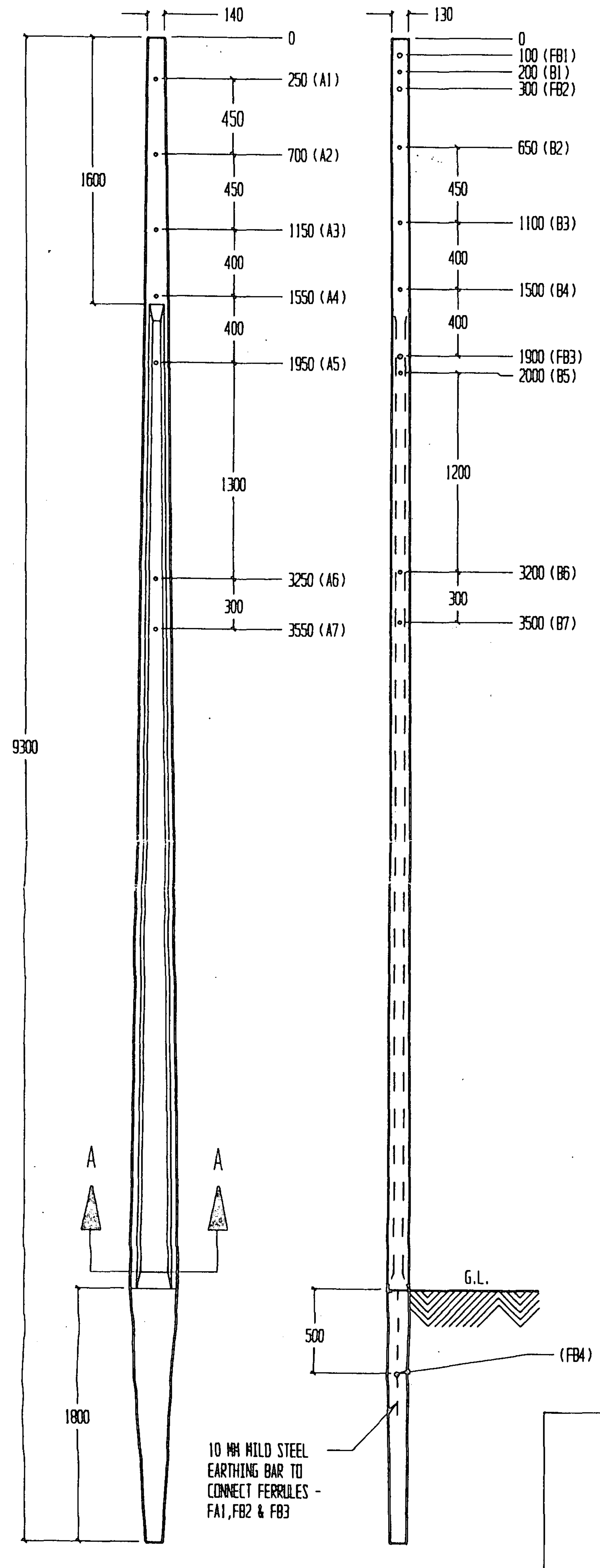
Ground level

Section A-A

GRINAKER DURASET

ENGINEERS IN PRECAST CONCRETE - VOORAFGEGIETE BETON INGENIEURS

CLIENT	DURBAN CORPORATION & ESKOM		
TITLE	9 M -7 kN POLE		
DRAWN	02/11/92	REF. DRWG.	
CHECKED		DRAWING No.	REV
APPROVED	[signature]		
SCALE	VARIES	GDG-999-5055/1	1-93/02/04



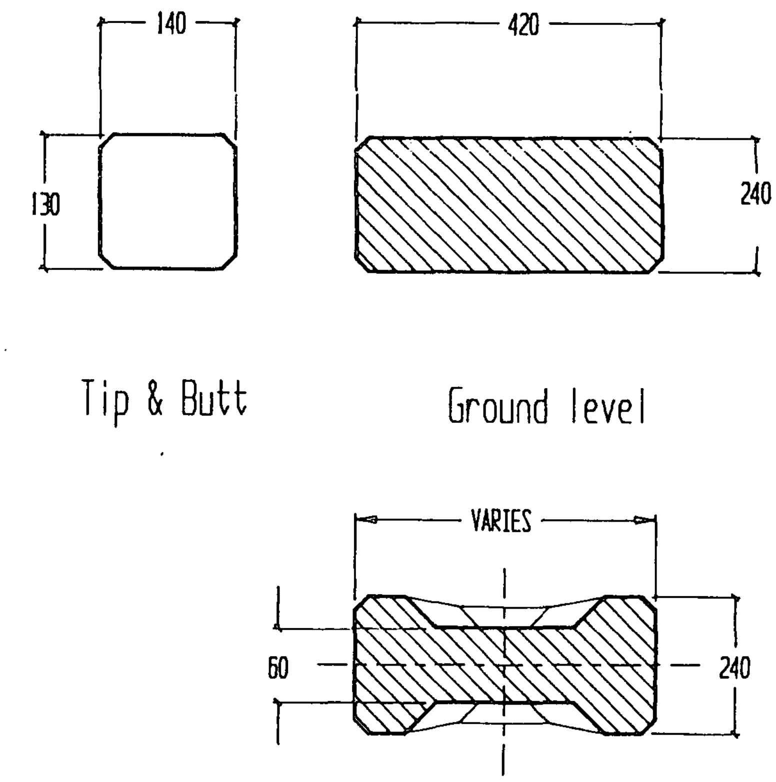
Pole Type :9.3/17.5 A

NOTES & DESIGN LOADINGS

Pole Length -:		9,3 m	
Planting Depth -:		1.8 m	
ULTIMATE LOADS :			
Transverse -: (strong)	1750 kg	17,5 kN	
Down Line -: (weak)	810 kg	8,1 kN	46%
CRACK LOADS :			
Transverse -:	860 kg	8,6 kN	
Down Line -:	210 kg	2,1 kN	✓
Loads applied at 300 mm from top			
SAFETY FACTOR		x2	
Weight of Pole (@ 2400 kg/m³)		838 Kg	
All holes to have a 22 mm I.D. PVC sleeve			

12 mm Stainless Steel Earthing Ferrules
(FB2 & FB3 & FB4)
Fixing Ferrule - FB1

Exposed wind load Area (weak) 2,1 m²



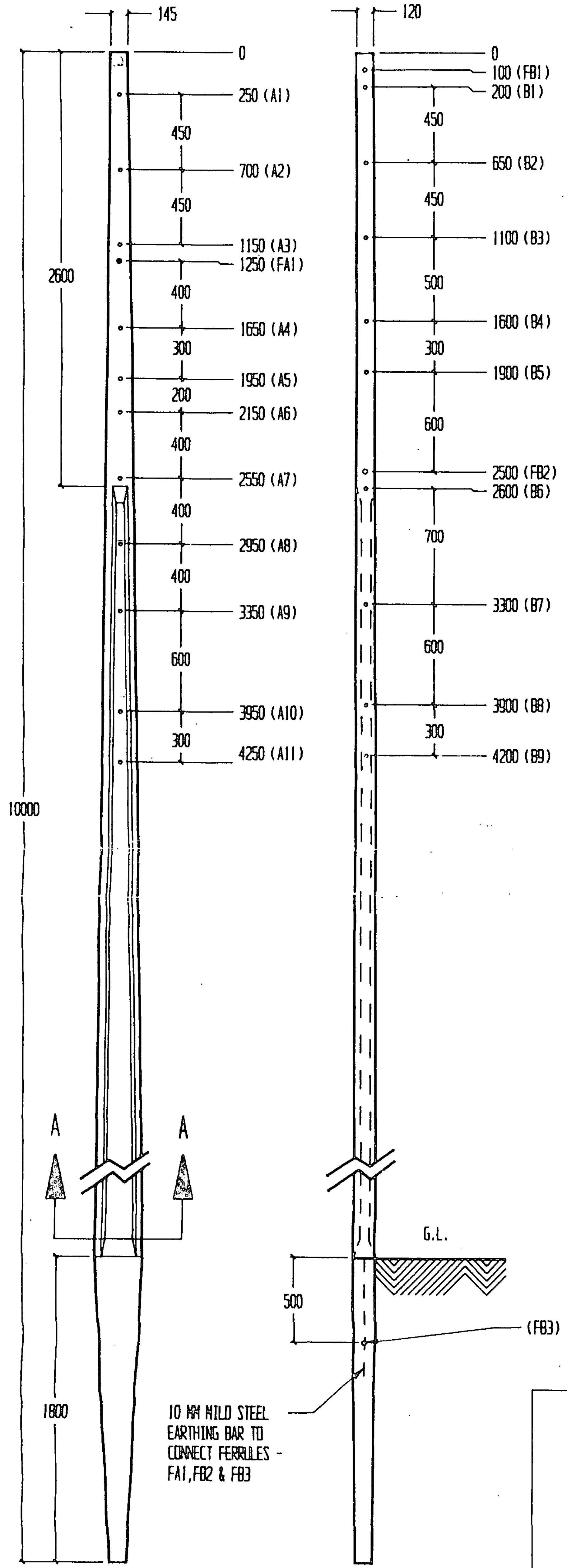
Section A-A

GRINAKER DURASET

ENGINEERS IN PRECAST CONCRETE - VOORAFGEGIETE BETON INGENIEURS

CLIENT	DURBAN CORPORATION		
TITLE	9.3 M -17.5 kN POLE (REV A)		
DRAWN	02/11/92	REF. DRWG.	
CHECKED		DRAWING No.	REV
APPROVED			
SCALE	N.T.S.	GDG-999-5055/3	A

Pole Type :10/8 A

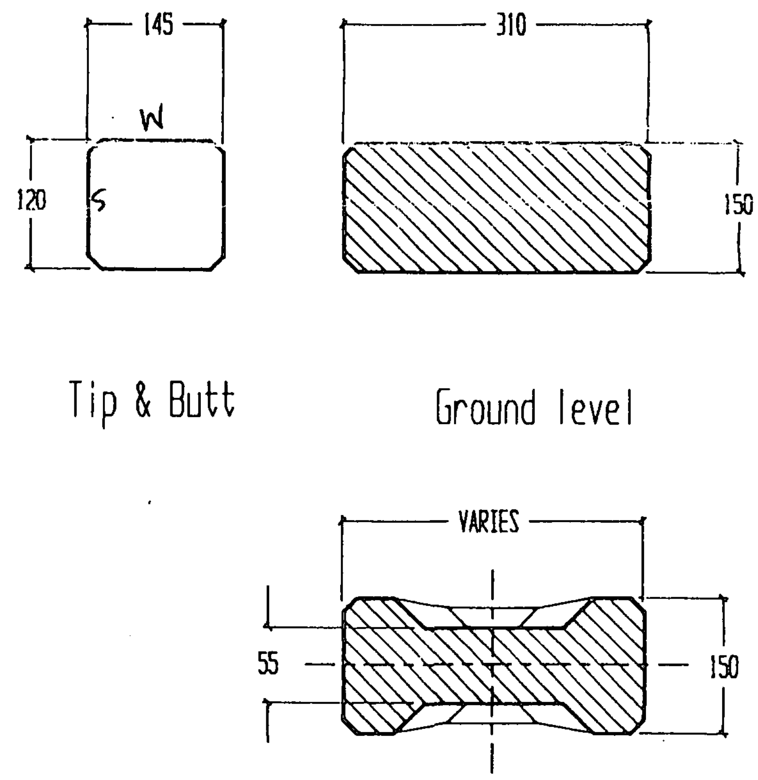


NOTES & DESIGN LOADINGS

Pole Length -:		10 m
Planting Depth -:		1.8 m
ULTIMATE LOADS :		
Transverse -: (Strong)	800kg	8 kN
Down Line -: (weak side)	280kg	2,8 kN 35%
CRACK LOADS :		
Transverse -:	440kg	4,4 kN
Down Line -:	90kg	0,9 kN
Loads applied at 300 mm from top		
SAFETY FACTOR		x2
Weight of Pole (e 2400 kg/m³)		603 Kg
All holes to have a 22 mm I.D. PVC sleeve		

12 mm Stainless Steel Earthing Ferrules
(FA1 & FB2 & FB3)
Fixing Ferrule - FB1

Exposed wind load Area (weak) 1,86 m²



Tip & Butt

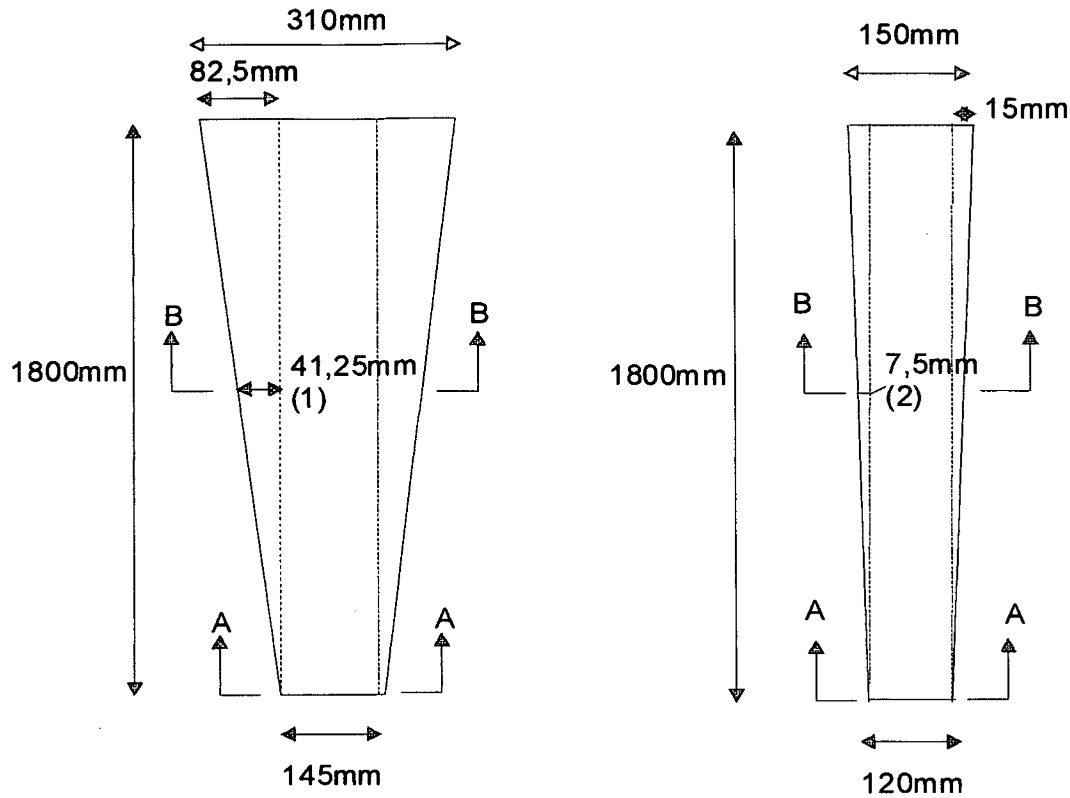
Ground level

Section A-A

GRINAKER DURASET

ENGINEERS IN PRECAST CONCRETE - VOORAFGEGIETE BETON INGENIEURS

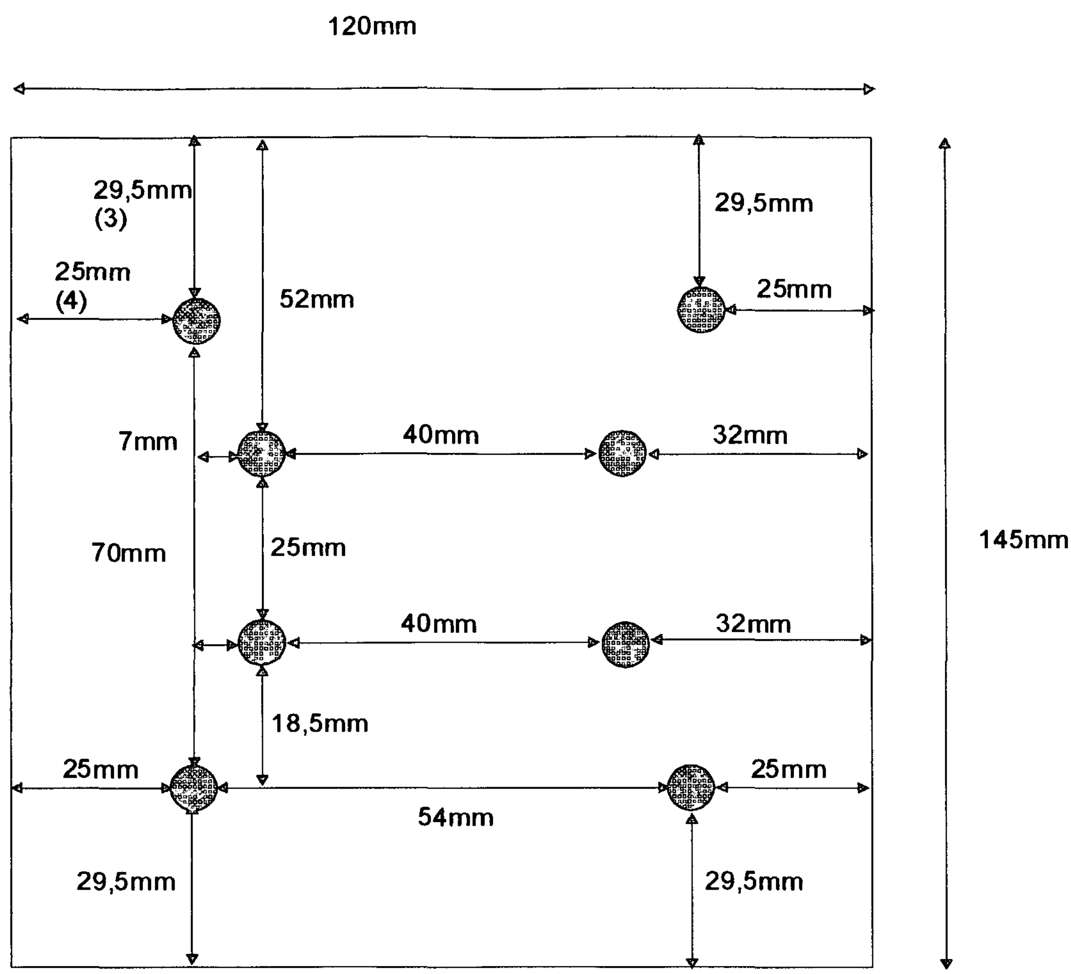
CLIENT	DURBAN CORPORATION & ESKOM		
TITLE	10 M -8 kN POLE (REV A)		
DRAWN	02/11/92	REF. DRWG.	
CHECKED		DRAWING No.	REV
APPROVED			
SCALE	VARIES	GDG-999-5055/6	0-93/01/11



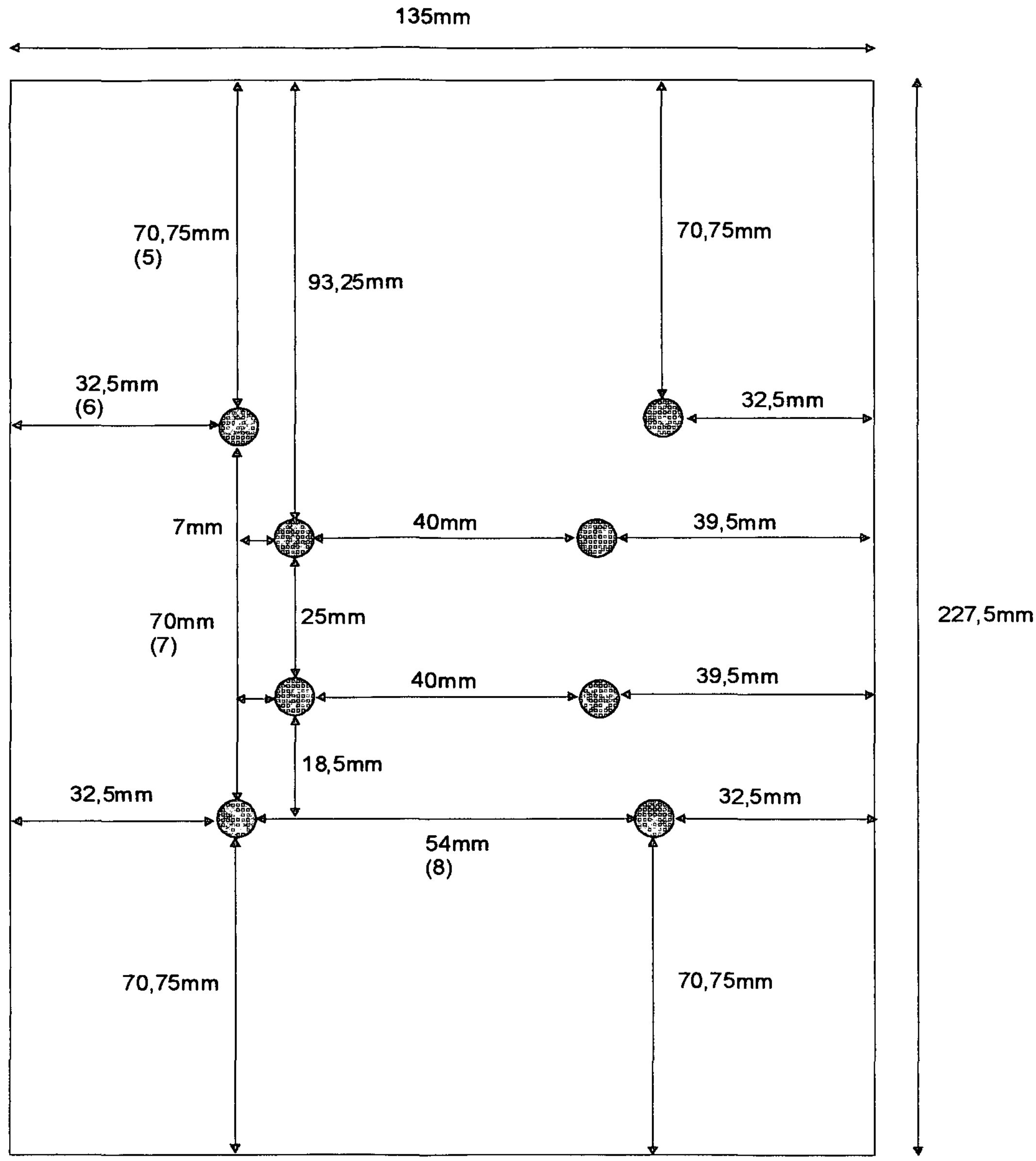
10m/8kN underground pole profile showing the pole taper and variation in concrete thickness

Notes:

1. Section A-A taken at the pole butt
2. Section B-B taken at the midpoint position



Cross-section A-A of a 10m8kN pole showing the relative positions of the re-inforcing rods



Cross-section B-B of a 10m8kN pole showing the relative positions of the re-inforcing rods

Notes:

1. The positions of the 4 outer re-inforcing wires relative to the outer surface of the concrete (dimensions 5 & 6) are determined by adding dimensions (1) & (2) on pg 1 to the dimensions (3) & (4) shown on pg 2.
2. An averge depth of concrete covering over the 4 outer rods is determined using (5) & (6) (51,63mm)
3. An average separation between the 4 outer rods is determined using (7) & (8) (62mm)

AUTORECLOSER # 9597 EVENT SUMMARY

Date	Time	Event	In	Ia	Ib	Ic	Fault
2/12/97	19h45:03	overcurrent trip	16	0	18	9	Ia-Ic-earth
2/12/97	19h45:19	overcurrent trip	26	603	606	564	Ia-Ib-Ic-earth
3/20/97	18h09:55	overcurrent trip	35	0	37	0	Ib-earth
3/20/97	18h09:58	overcurrent trip	35	0	37	0	Ib-earth
4/4/97	08h15:27	overcurrent trip	1	0	0	0	?
4/4/97	08h15:30	overcurrent trip	181	0	177	20	Ib-Ic-earth
4/4/97	08h15:32	overcurrent trip	215	0	199	0	Ib-earth
4/4/97	08h15:34	overcurrent trip	239	0	259	0	Ib-earth
4/6/97	15h21:38	overcurrent trip	40	0	0	41	Ic-earth
4/6/97	15h21:39	overcurrent trip	41	0	0	46	Ic-earth
4/6/97	15h21:41	overcurrent trip	41	9	0	44	Ia-Ic-earth
4/6/97	15h21:42	overcurrent trip	42	0	0	46	Ic-earth
4/6/97	15h21:45	overcurrent trip	42	0	0	43	Ic-earth
4/6/97	15h21:46	overcurrent trip	42	0	0	41	Ic-earth
4/7/97	09h19:16	overcurrent trip	40	0	0	42	Ic-earth
4/7/97	09h19:19	overcurrent trip	39	0	0	43	Ic-earth
4/7/97	09h19:21	overcurrent trip	40	0	0	37	Ic-earth
4/7/97	09h19:22	overcurrent trip	40	0	0	39	Ic-earth
4/7/97	09h19:23	overcurrent trip	41	0	0	41	Ic-earth
4/7/97	09h19:25	overcurrent trip	39	0	0	35	Ic-earth
4/7/97	09h19:26	overcurrent trip	40	0	0	37	Ic-earth
4/7/97	09h19:27	overcurrent trip	40	0	0	37	Ic-earth
4/7/97	14h17:14	overcurrent trip	0	498	0	502	Ia-Ic
4/7/97	14h19:45	overcurrent trip	0	498	0	500	Ia-Ic
4/7/97	14h19:47	overcurrent trip	0	495	0	486	Ia-Ic
4/20/97	16h46:31	overcurrent trip	103	0	379	428	Ib-Ic-earth
4/20/97	16h55:11	overcurrent trip	9	607	499	557	Ia-Ib-Ic-earth
5/2/97	19h15:12	overcurrent trip	0	0	0	0	?
6/13/97	05h05:16	overcurrent trip	0	504	0	500	Ia-Ic
6/13/97	05h05:17	overcurrent trip	0	450	0	444	Ia-Ic
6/13/97	05h05:17	overcurrent trip	0	477	0	485	Ia-Ic
6/13/97	05h05:18	overcurrent trip	0	406	0	402	Ia-Ic

INWABI DISTRIBUTION LINE - COMPLAINT RECORDS

Appendix F

Line tripout complaints
30/09/94 to 30/01/97
(before modifications)

no	Date	Protective Device	Fault
1	11/22/94	sect 9597	
2	12/14/94	sect 9597	
3	12/17/94	sect 9597	
4	12/22/94	sect 9597	
5	1/3/95	sect 9597	
6	2/22/95	sect 9597	
7	6/20/95	sect 9597	
8	9/16/95	sect 9597	
9	10/22/95	sect 9597	
10	11/30/95	sect 9597	
11	12/10/95	sect 9597	
12	12/20/95	sect 9597	
13	12/22/95	sect 9597	
14	12/26/95	sect 9597	
15	12/31/95	sect 9597	
16	1/3/96	sect 9597	
17	1/6/96	sect 9597	
18	1/8/96	sect 9597	
19	1/10/96	sect 9597	
20	1/14/96	sect 9597	
21	1/15/96	sect 9597	
22	7/15/96	sect 6056	
23	7/31/96	sect 6057	
24	8/11/96	ar 9597	unknown
25	9/4/96	ar 9597	unknown
26	9/13/96	ar 9597	unknown
27	9/25/96	ar 9597	insulators/storm
28	9/30/96	ar 9597	insulators/arrester
29	10/16/96	sect 6057	unknown
30	11/26/96	sect 6057	unknown

Line tripout complaints
30/01/97 to 14/01/98
(after modifications)

no.	Date	Protective Device	Fault
1	3/19/97	sect 6056	unknown
2	3/22/97	sect 6056	insulator
3	4/8/97	sect 6056	unknown
4	11/13/97	sect 6056	unknown
5	11/15/97	sect 6057	unknown
6	12/11/97	sect 6056	unknown
7	12/12/97	sect 6056	unknown
8	12/15/97	sect 6056	unknown
9	12/20/97	sect 6056	unknown
10	12/23/97	sect 6056	unknown
11	12/25/97	sect 6056	unknown
12	12/29/97	sect 6056	unknown
13	1/1/98	sect 6056	unknown
14	1/9/98	sect 6056	unknown
15	1/13/98	sect 6056	unknown
16	1/14/98	sect 6056	unknown

Period from 96/09/01 to 97/12/31

Date	no. of strokes	negative polarity	positive polarity	cloud
9/23/96	2	2	0	0
9/24/96	24	23	1	0
10/3/96	8	6	1	1
10/4/96	2	2	0	0
10/5/96	1	1	0	0
10/6/96	13	12	1	0
10/8/96	27	26	0	1
11/4/96	58	56	2	0
11/12/96	12	10	2	0
11/19/96	28	27	0	1
11/21/96	136	134	2	0
11/25/96	4	4	0	0
11/29/96	3	3	0	0
12/2/96	36	36	0	0
12/5/96	1	1	0	0
12/6/96	1	1	0	0
12/21/96	4	3	1	0
12/22/96	1	1	0	0
12/23/96	3	3	0	0
12/31/96	53	52	0	1
1/3/97	152	149	3	0
2/12/97	92	87	3	2
2/18/97	1	1	0	0
2/25/97	5	4	1	0
3/30/97	1	1	0	0
4/1/97	10	9	1	0
4/3/97	5	5	0	0
4/6/97	2	2	0	0
4/15/97	10	10	0	0
4/20/97	8	7	1	0
9/6/97	1	1	0	0
12/10/97	1	1	0	0
12/16/97	11	10	1	0
12/28/97	10	9	0	1
Total	**726**	**699**	**20**	**7**
%	100	96.28099	2.754821	0.964187