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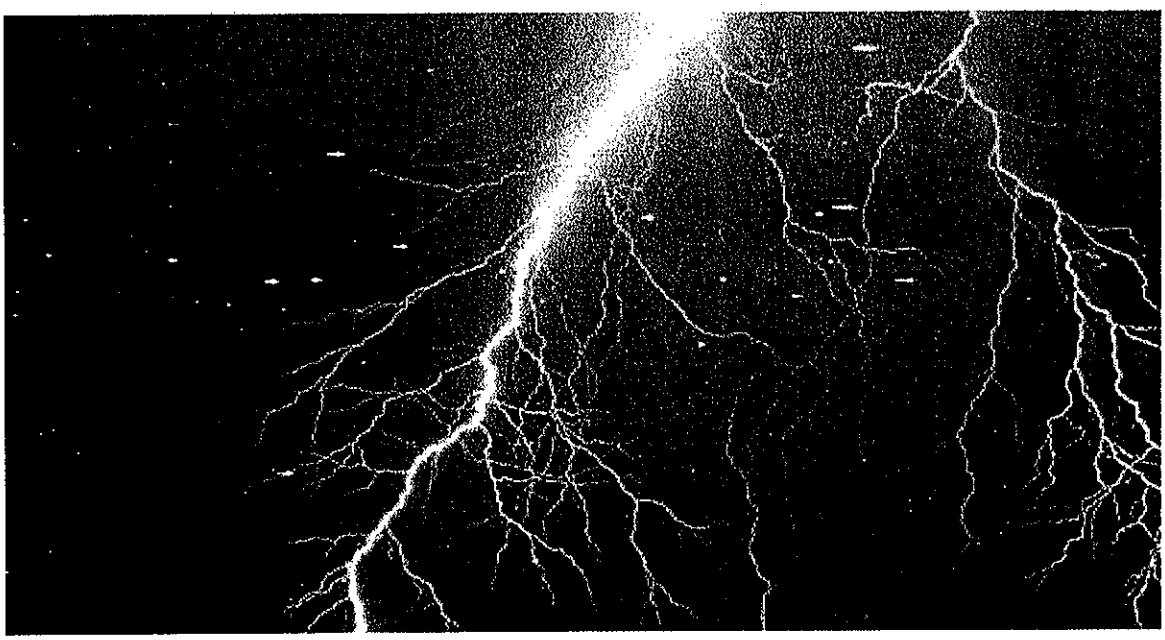
Technical Seminar on

LIGHTNING PROTECTION



Speaker: Mr. Steve Yeo MIEAust CPEng

Venue: The Institution of Engineers, Singapore
70 Bukit Tinggi Road
Singapore 289758

Date: 27 June 2003

Time: 7.00 pm

Accredited by PEB for 3 PDUs

Preface

The Scope of this talk shall cover:

1. Theory of Lightning
2. Conventional Franklin Lightning Rod system.
3. The Early Streamer Emission Devices (ESE)
4. Selection of suitable material for use in lightning protection system.
5. Method of installation
6. Corrosion aspect material used in lightning protection system.

Lightning Protection

The Topic

1. Theory of Lightning
2. The Conventional Franklin lightning rod system
3. The Early Streamer Emission Devices (ESE)
4. Selection of suitable material for use in lightning protection system.
5. Method of installation
6. Corrosion aspect of material used in lightning protection system.

The Speaker

The presenter **Mr. Steve S. K. Yeo** is currently the Managing Director of Unitech Electric Pte Ltd. The Company specializes in manufacturing of lightning protection products.

Mr. Steve Yeo graduated as an electrical and mechanical engineer from Swinburne Institute of Technology Australia.

He has worked as an engineer in electrical switchboard companies in Australia and Singapore and as a research and development engineer for one of the Repco Engineering division in Australia. His other experiences are Engineering Manager for MNC Electronic Component Manufacturing Company in Singapore, Factory Manager for an Australia Electric Motor Manufacturing Company in Singapore. Over the past 20 years, he had carried out research and development and designed many new products for his Company. He has also a few UK patent for some of the products under his name.

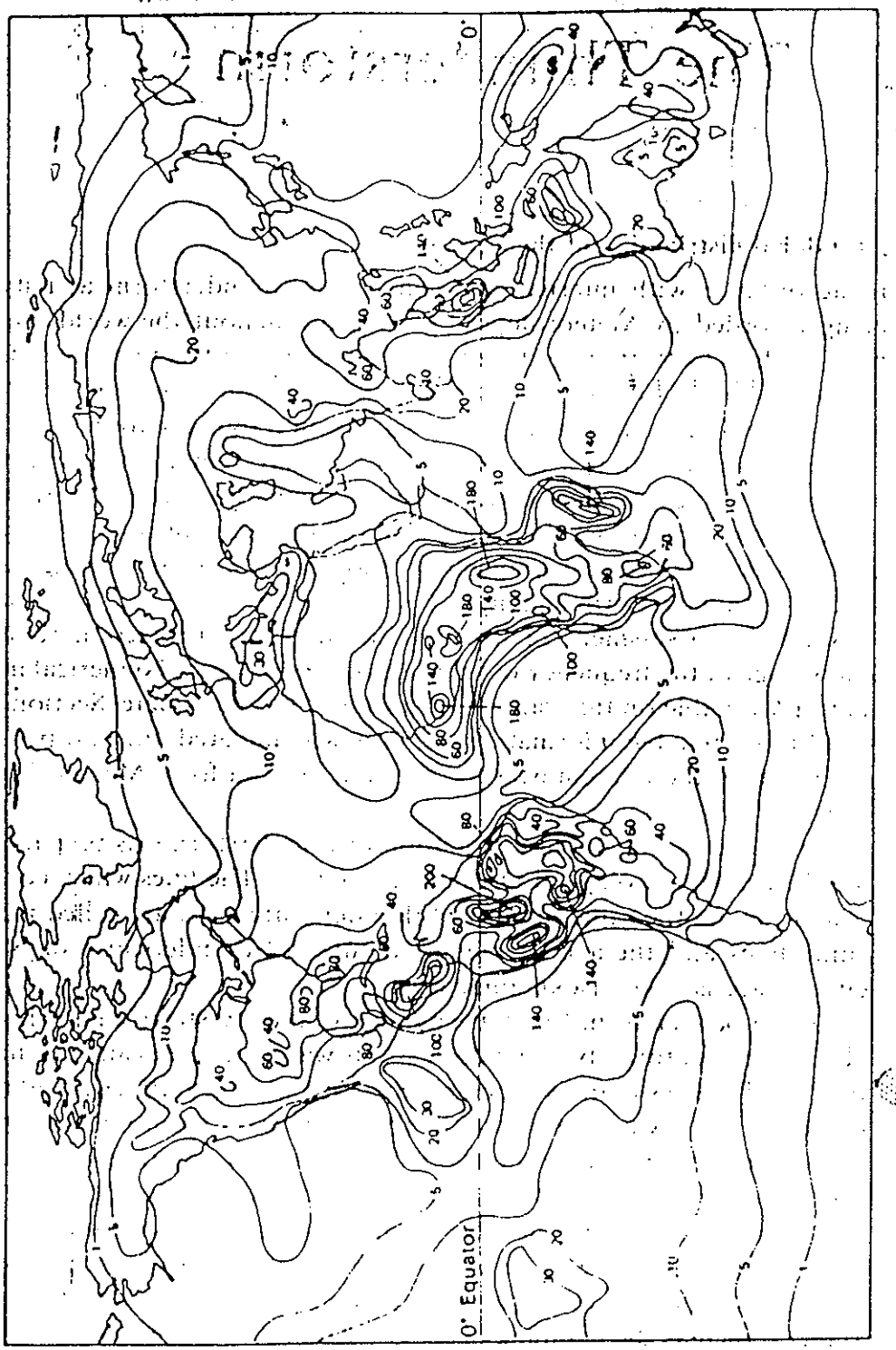
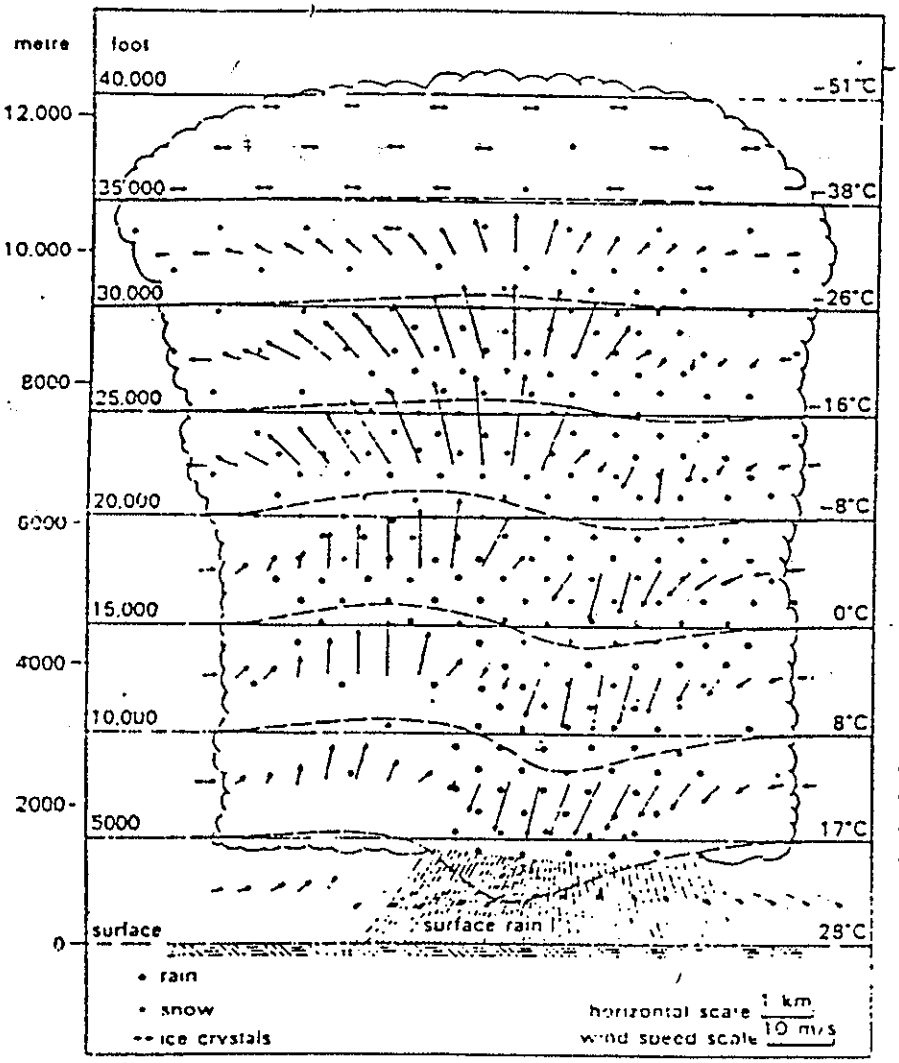


Fig. Annual frequency of thunderstorm days (World Meteorological Organization, 1956)

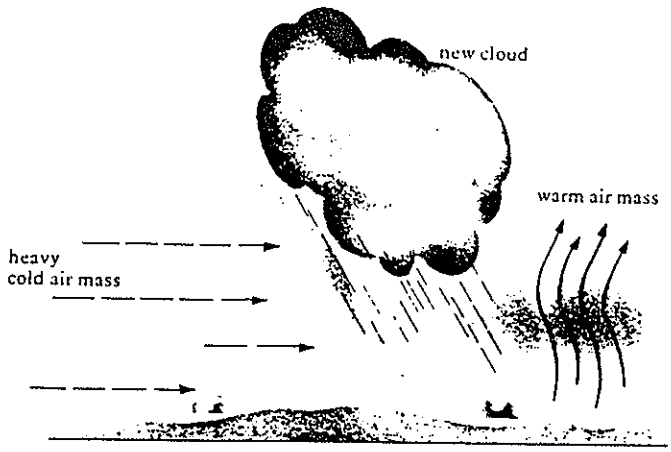
ground and is replaced by cooler air drifting down. As the hot air rises, it is progressively cooled and forms a cloud consisting first of water droplets and, at greater heights, of ice crystals. In this way a single or multiple cloud "Cell" is formed, the top of which may reach a height of 10Km.



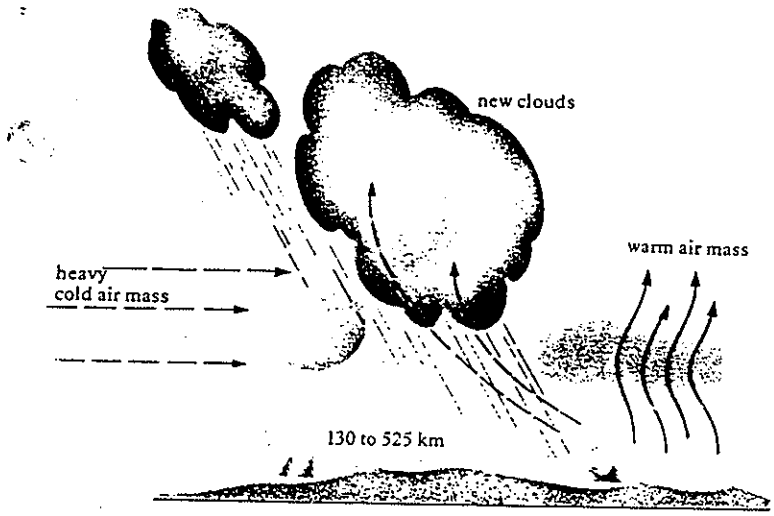
Thunderstorm cell in mature state (Byers and Braham, 1949).

The Mechanism by which a cloud becomes electrically charged is still not yet fully understood, but it can be taken to be associated with the violent updraught of air in the centre of a cell and the resulting impact of super-cooled water droplets on ice crystals. Each cell has a diameter of several kilometers and undergoes a life cycle lasting some 30 minutes during which electric charges are generated and lightning actively continues until the charging mechanism is exhausted.

Figure 2 FRONTAL STORM



Advancing cold air mass can wedge warm air upward to start an updraft at the cold front.



Over-running cold front may cause storms over a wide area.

Frontal Storms (Figure 2) which predominate in temperate regions are caused by the impact of a front of cold air on a mass of warm moist air which is lifted above the advancing cold front. As the warm air rises the process described above is repeated but the resulting cumulo-nimbus clouds may, in this case, extend over several tens of kilometres in width and contain a large number of individual cells with heights of between 7.5 km and 18 km.

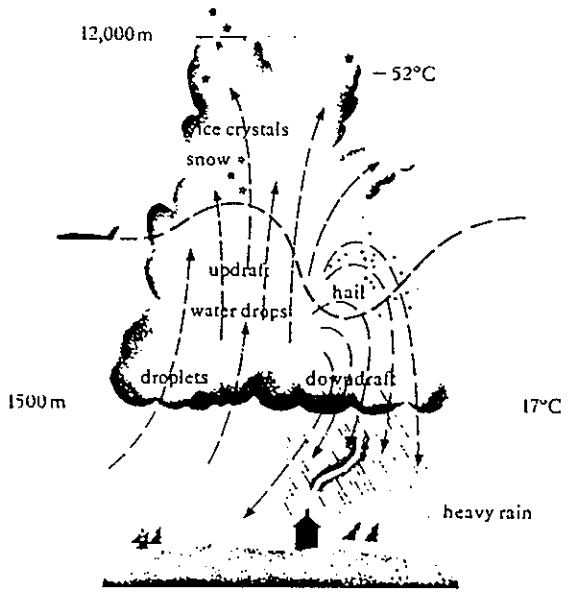
SECTION CONTENTS

Theory of lightning and thunderstorm

Thunderstorms can be conviently subdivided into two main classes: Heat storms ar Frontal storms. The heat or convective storm predominates in the tropics but als frequently occurs in mountainous area. It is due to the fact that, on a hot day, warm a rises from patches of ground and is replaced by colder air drifting down. As the hot a rises, it is progressively cooled and forms a clouds consisting first of water droplets an at greater heights of ice crystal, in this way, a single or multiple cloud "cell " is formed the tope of which may reach a height of 12 Km.

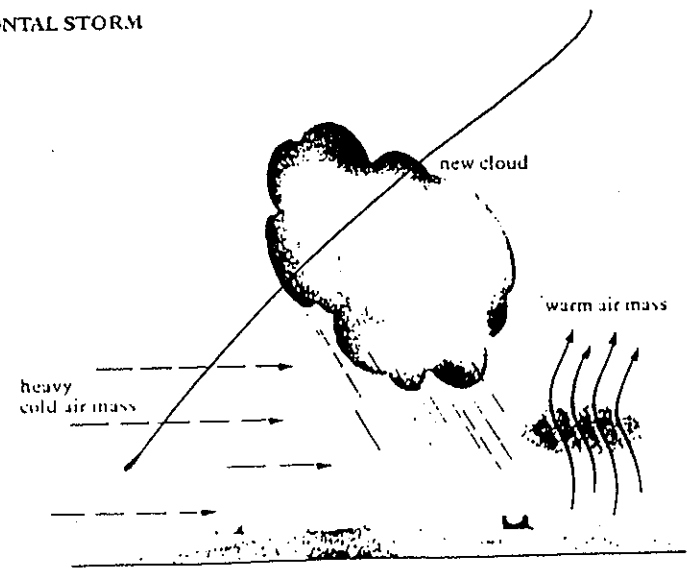
Frontal storms, which predominate in temperate regions, are caused by the impact of a front of cold air on a mass of warm moist air, which is lifted about the advancing cold front. As the warm air rise the process described above is repeated but the resulting cumulonimbus cloud may in this case extend over several tens of kilometers in width and contain a large number of individual cells.

Figure 1 HEAT STORM



The heat or convective storm (Figure 1) predominates in tropical regions and mountainous areas.

Figure 2 FRONTAL STORM



The ice crystals in an active cloud are positively changed while the water droplets usually carry negative charges. A thundercloud thus contains a positive charge center in it upper region and a negative charge center in the lower parts as shown in fig (1).

In undisturbed fine weather, the earth, which is an electrical conductor, carries a negative charge. The corresponding positive charge resides in the upper atmosphere. This layer and the earth thus represent a large spherical condenser. The intermediate atmosphere is subjected to an electric field, which is perpendicular to the earth surface. According to convention, this find weather field has positive polarity and it magnitude is 100v/M (Malan 1963). A thundercloud carries, in it lower part, a heavy negative charge, when such a cloud approaches a given point of the earth 's surface the polarity of electric field is reversed and the characteristic feature can be utilized to give a warning of an approach in thundercloud. The magnitude of the electric field is highest vertically below the negative charge center and rapidly decreases with increasing distance. The negative field may reach a value exceeding 20,000 v/m and even at a distance of 5km from a cloud center.

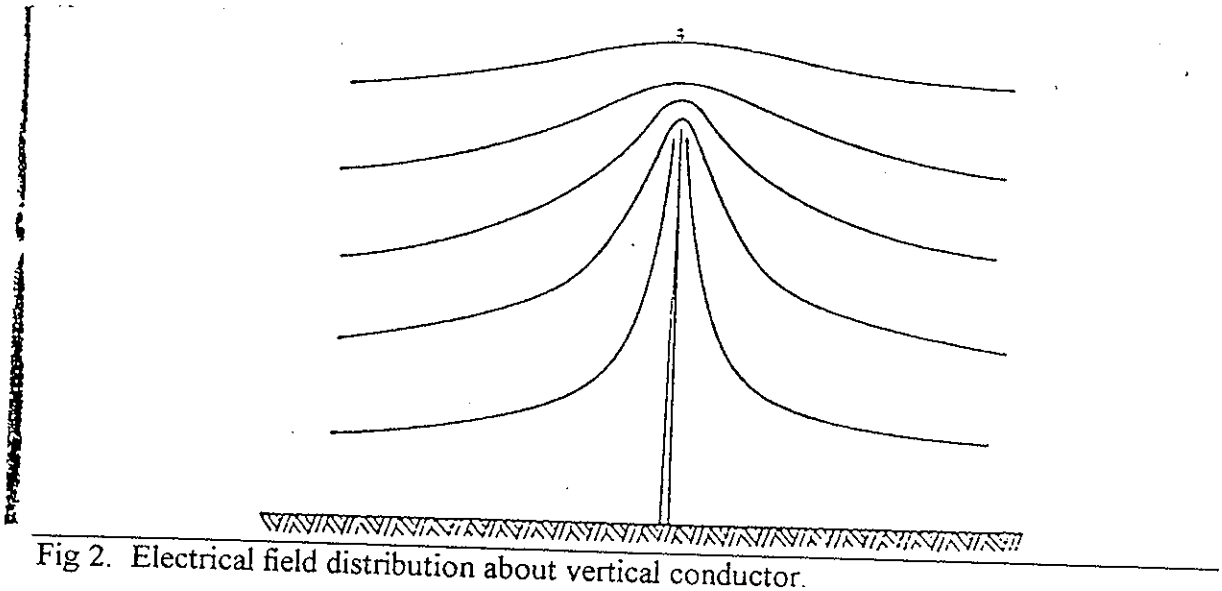
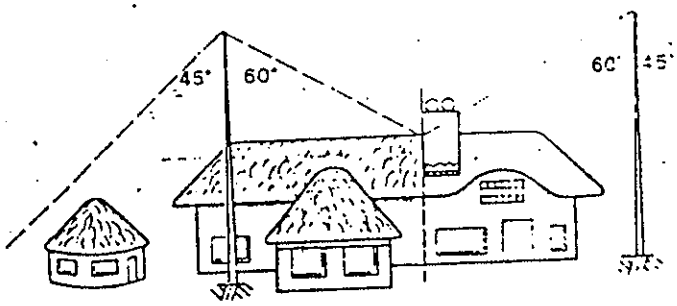


Fig 2. Electrical field distribution about vertical conductor.

A vertical electrical conductor, such as a metallic rod, short circuits part of this electric field so that an intense field concentration is produced at the tip (fig 2). If the filed strength at the tip is high enough, ionization by collision occurs and this leads to positive ions being transported from the earth through the conductor into the atmosphere. The resulting current is called a point discharge current there. The ions produced at or near the tip of the earth conductor move upwards in the pervading electric field. Based on this theory, the father of modern lightning protection. Benjamin Franklin introduced his first lightning rod in 1753. This lightning rod spread very rapidly through out United State and Europe and for many countries. The Franklin rod has proven to be the best and safest system.

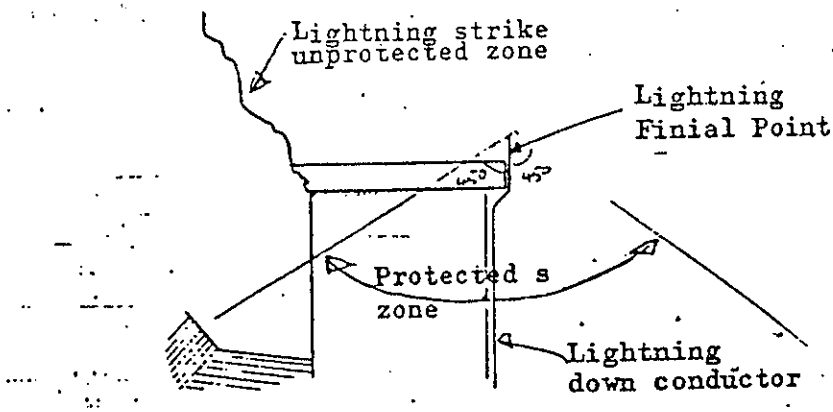
Based on the electric field concentration theory, Benjamin Franklin introduced his first lightning rod in 1753. From the pattern of electric field concentration at the tip of the lightning rod. It is found that, a protective zone can be achieved under the umbrella of 45° angle extend from the tip of the lightning rod as shown in fig 2.1, 2.2 and 2.3

With advancements in modern building technology, tall building of more than 300 metres in height have been built. The 45° angle of protective zone is not able to cover and prevent the mid section of the building from lightning strikes (side flash). A new method has since been developed. This is done by using a sphere of 45 metres radius for a normal building structure and 30 metres for explosive and highly flammable content building structure, known as a rolling sphere method, as shown in fig 2.7, fig 2.8 , 2.9 and fig 3.0.



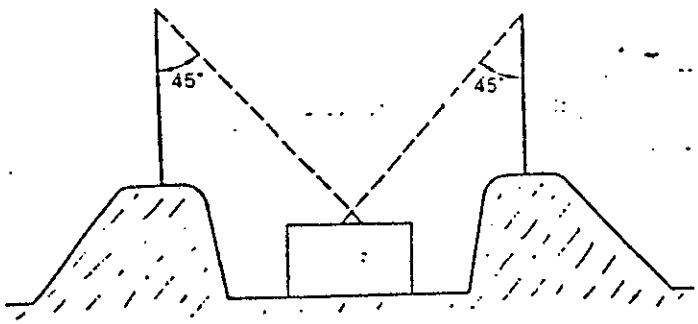
Protection of small dwelling by free-standing vertical lightning rods according to South African Code

fig 2.1



Sketch of damaged chimney with lightning rod (Schwenkhagen, 1959)

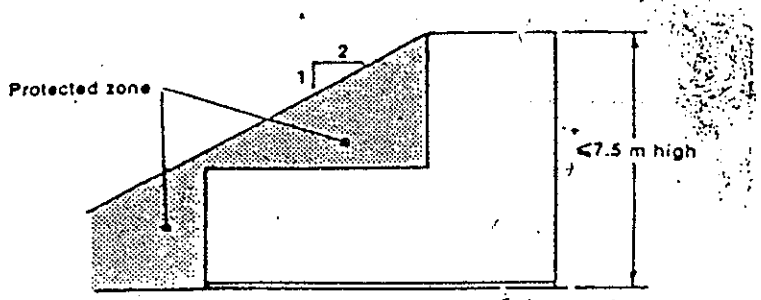
fig 2.2



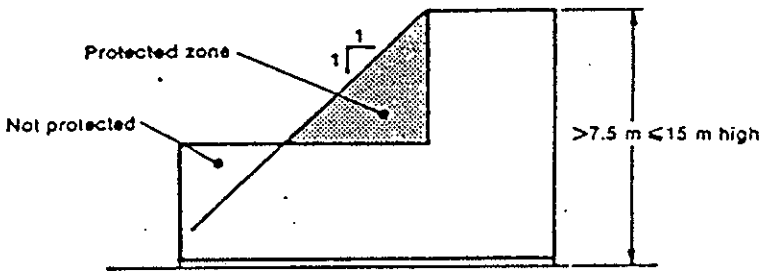
Protection of mounded danger structure

fig 2.3

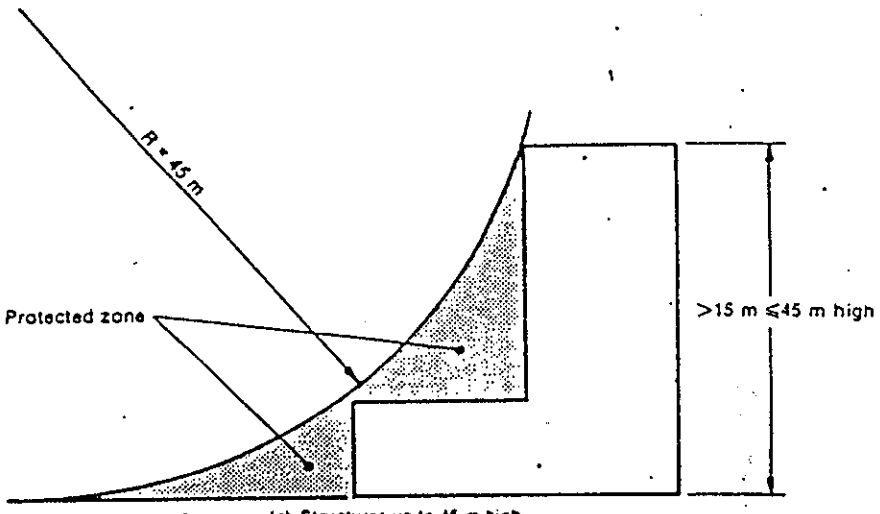
Zones of Protection: AS 1768 - 1983



2.4 (a) Structures up to 7.5 m high

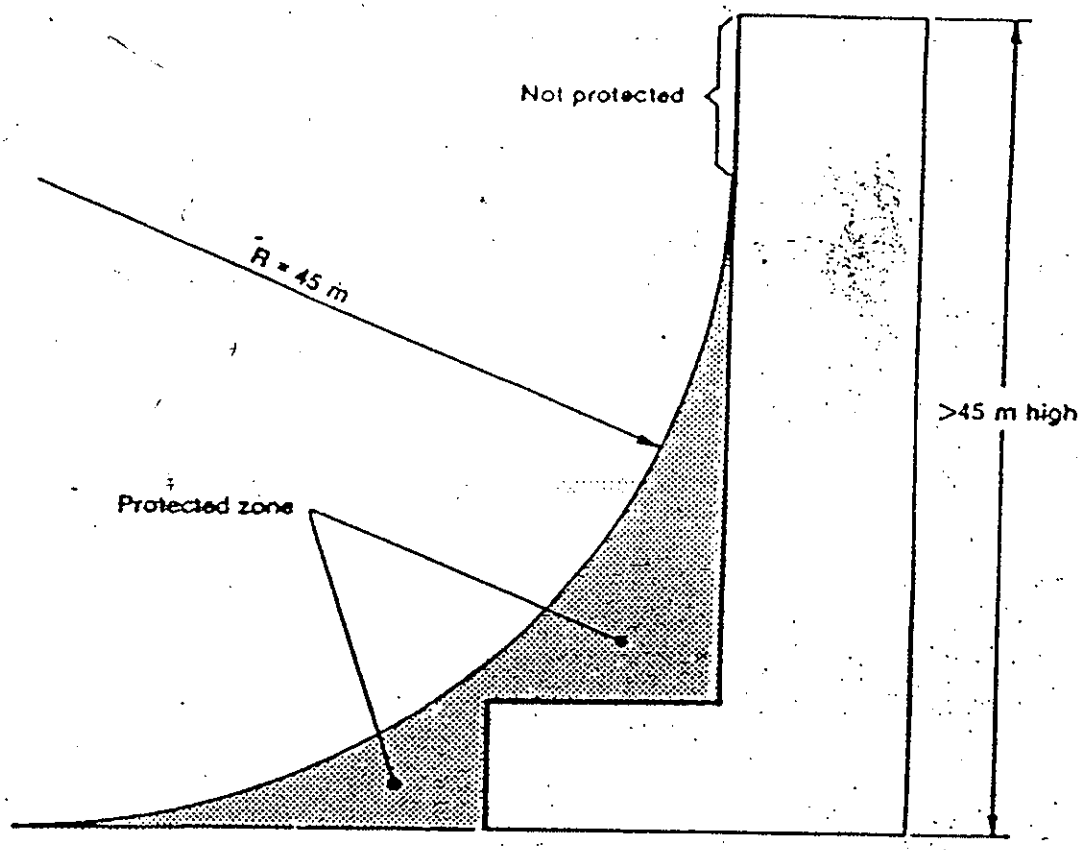


2.6 (b) Structures up to 15 m high



2.7 (c) Structures up to 45 m high

Fig. ~~2.5~~ ZONE OF PROTECTION ESTABLISHED BY AIR TERMINATIONS ON HIGHER PARTS OF A STRUCTURE



2.8
(d) Structures in excess of 45 m high

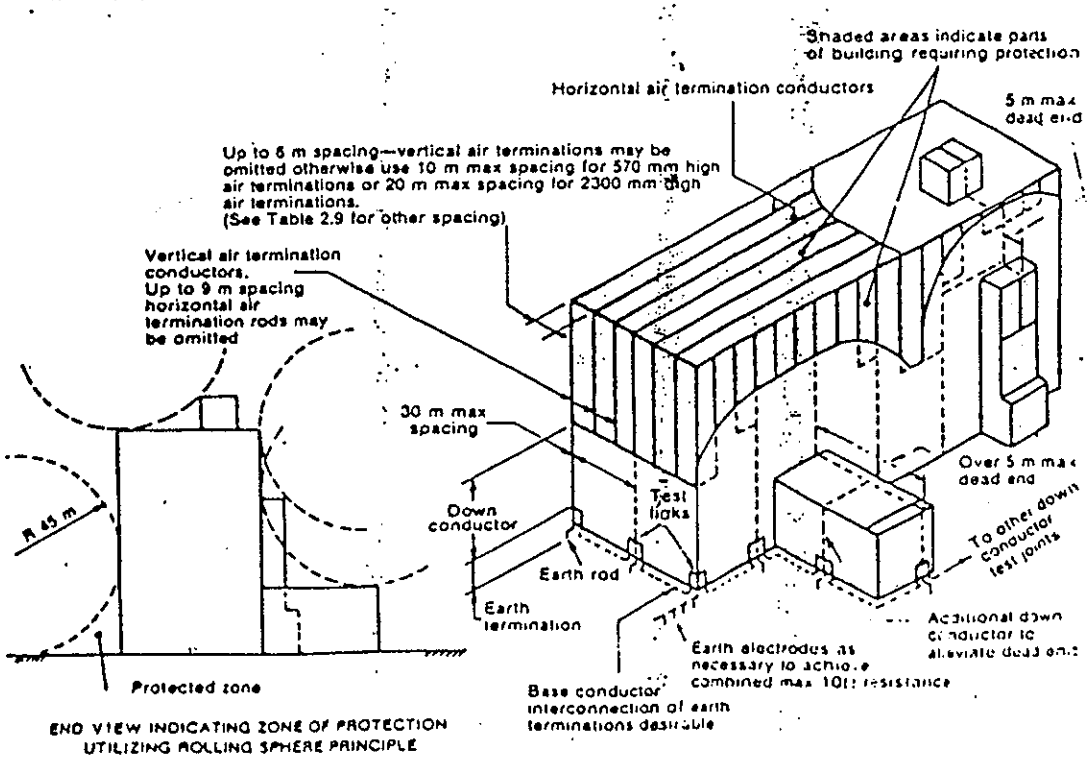
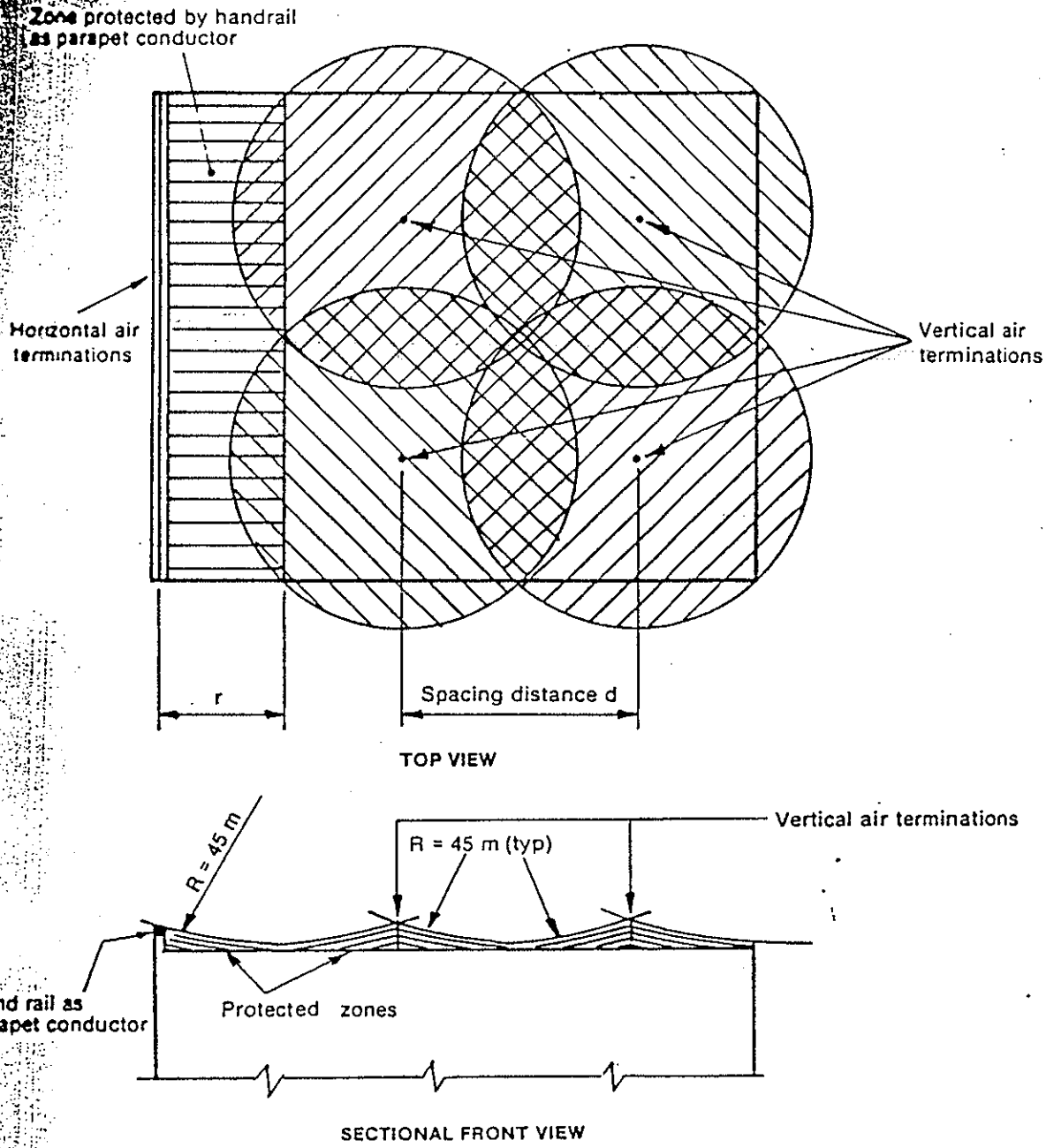


Fig. 2.8. TYPICAL SYSTEM EMPLOYING HORIZONTAL AND
2.9 VERTICAL AIR TERMINATION NETWORK



NOTE: The hatched areas show the zones of protection established by each air termination. In the top view the zones are in the plane of the roof.

Fig. 36 ZONES OF PROTECTION ON A FLAT ROOF

UNTERSUCHUNGEN ZUR WIRKUNG VON IONISIERENDEN FANGEINRICHTUNGEN

Prof. Dr.-Ing. habil. F. Noack, Dipl.-Ing. J. Schönau, cand. A. Barth,
Technical University Ilmenau
(published at "4th VDE/ABB Conference on Lightning Protection", November, 2001, Neu-Ulm, VDE Technical Report 58)

EXAMINATIONS CONCERNING THE EFFECT OF IONIZING AIR TERMINATIONS

1. INTRODUCTION

The use of non-conventional air terminations and their efficiency, known in English speaking countries as ESE devices (**E**arly **S**treamer **E**mission devices), is one of the mostly discussed subjects of lightning protection.

Manufacturers offer different types of equipment (at extremely high prices) which promise a clearly improved protective effect in comparison with the ordinary FRANKLIN air termination rods [1].

The improved protective effect shall be achieved by a carefully directed interception of lightning discharge where a forced upward leader offers a preferential flashover channel. An increased field intensity at the tip of the devices and thus an increased emission current shall be effictive when the downward leader approaches.

Some tests with ionizing air terminations in high-voltage laboratories [2] have shown that the emission of streamers or leaders will be started earlier by a time of $\Delta t = 10 \ldots 50$ µs than with the simple FRANKLIN air termination rods. From this advanced creation of the upward leader G. BERGER [3] concluded, that from an ionizing air termination rod the streamer would have already grown in that time at a supposed constant velocity of $v = 1$ m/µs by a distance of

$$\Delta l = v \cdot \Delta t = 1 \text{ m} / \mu\text{s} \cdot (10...50)\ \mu\text{s} = (10...50)\ \text{m}$$

before the upward leader is started at the FRANKLIN rod. And this would have the same effect as if the ionizing air termination rod were elongated by a length of $\Delta l = 10 \ldots 50$ m compared with the simple rod. With the result of a considerably increased protective area.

Recent measurings in the high-voltage laboratories of independant university institues [4,5,6] neither showed this distinct advance in the time to puncture nor a preference of the ESE equipment against the FRANKLIN rods at puncture. Natural simulation of lightning strike phenomena in laboratory is not possible so far as there is a great difference between discharge parameters in nature and in laboratory [7].

4. CONCLUSIONS

Comparative examinations on the efficiency of ESE air terminations were carried out by different independant institutions.

- The comparative measurings of the emission current behaviour as well as
- the comparative measurings of the flashover behaviour and
- the numerous cases of damage at buildings with ESE installations

lead to the clear conclusion that ESE air terminations neither show a better interception behaviour nor have a better protective effect compared with the simple FRNAKLIN air-termination rods.

If ionizing air terminations are used as provided with the enlarged protective areas, lightning strikes and damage are very likely anyhow.

A further source of danger is the fact that, as often required, lightning current only shall be conducted to earth by one single insulated down conductor. This can on the one hand lead to considerable potential increases at the earthing system, on the other hand very high electromagnetic fields have to be expected due to the undistributed discharge of lightning current.

as shown in fig 10.

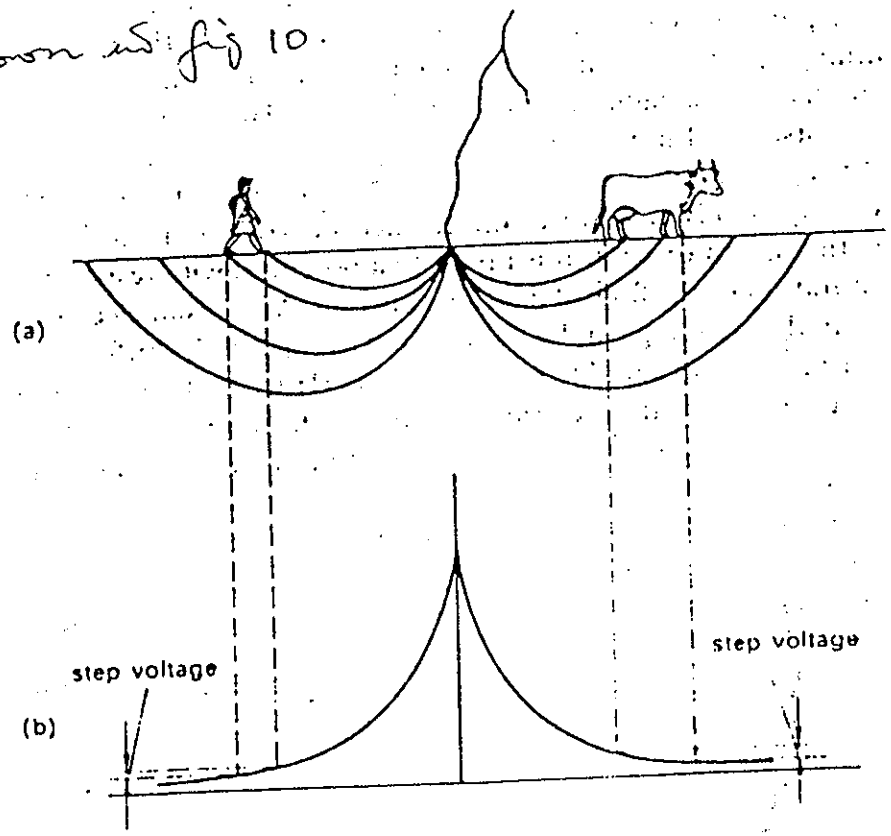


Fig 10 Current distribution in ground (a) and voltage drop along ground surface (b) near point of lightning strike

5. SOURCES

[1] F. Noack: „Über die Wirksamkeit von ESE-Fangeinrichtungen", 3. VDE/ABB-Blitzschutztagung, 28. Oktober 1999 - 29. Oktober 1999, Neu-Ulm, VDE-Fachbericht Nr. 56, VDE-Verlag Berlin Offenbach, S. 9 - 20

[2] G. Berger: „Testing to show a time advantage in production of a lightning up leader - laboratory simulation of the connecting discharge from a lightning conductor", Lightning Protection Workshop, Standards Australia, Hobart, November 1992

[3] G. Berger: „The application of upward leader initiation time advantage into an electrogeometrical model" , Lightning Protection Workshop, Standards Australia, Hobart, November, 1992

[4] N. L. Allen: „Investigation of the principles of early streamer emission devices", Proc. 24th ICLP Birmingham, 1998, S. 406 - 411

[5] I. D. Chalmers, J. C. Evans, W. H. Siew, N. L. Allen, D. A. Greaves, I. Cotton: „Laboratory testing of early streamer Emission air terminals", Proc. 24th ICLP Birmingham, 1998, S. 412 - 417

[6] University of Manchester: „The results of tests of ESE & Franklin terminals", Test Report No. 43427

[7] E. Garbagnati u. a.: "Lightning exposure of structures and interception efficiency of air terminals", CIGRE SC33 WG33.01 (TF 03) 1 IWD, Draft April 1997

[8] G. Berger u. R. Hadaji: "Lightning attachment physics, Experiments and modeling", S. 473 - 494

[9] C. B. Moore, W. Rison, J. Mathis, L. Paterson: "Report on a competition between sharp and blunt lightning rods", NMIT 1997

[10] Z. A. Hartono, I. Robiah: "A Study of non-conventional air terminals and stricken points in a high thunderstorm region", Proc. 25th ICLP 2000, Rhodos, 18. September 2000 - 22. September 2000, S. 357 - 361

[11] Z. A. Hartono: "The collection surface concept as a reliable method for predicting the lightning strike location"

The Semi Conductor Lightning Extender (SLE)

The latest new semi conductor coated fan type lightning protection system know as "Semi Conductor Lightning Extender (SLE) invented by Two Chinese Professors claims to be revolutionary and capable to reduce the discharge voltage from 100 percent to 0.4 percent and cost around S$200,000. (Published in S.T. 23rd Nov 2001).

This so-called revolutionary system contradicts the traditional early theory of creating a conducting path to remove the lightning discharge current to the ground as fast as possible. The SLE system uses high resistance path to slow down the discharge current flowing to the ground, as the result, the electric field in the ground is weaken and lower the potential gradient (V=IR). The negative effect is the highly static charge current carried by the cloud (a large capacitor) is unable to flow through a small SLE path, the excess static charge current will disperse and cause the excess current to spill flash over to the near by objects. The claim of the SLE that it can act as a capacitor to store the lightning discharge current is a fallacy. Many scientists around the world have been studying to find if there is any possibility to tap this natural energy and store it for practical use, up to now, no one is able to achieve the goal.

The inventor of SLE claimed that the SLE is a 消雷器 Their "magical" idea has destroyed the theory of "Conservation of Energy" that stats "Energy can not be created nor destroyed." The system has since been disputed by many Chinese scientists and is now banned in some parts of China.

Rods that take sting out of lightning

A LIGHTNING rod far better than the one invented by Benjamin Franklin in 1752 was introduced to a roomful of electrical engineers here yesterday.

The lightning-intercepting terminal, invented by a couple from China, can reduce lightning currents that hit its rods from 100 per cent to 0.4 per cent.

While radioactive systems and ionising terminals to dissipate lightning have evolved from the original Franklin rod, the new Semiconductor Lightning-current Extender (SLE) is the most revolutionary device to date.

Connected to the top of tall buildings and other structures, the SLE carries massive lightning currents and therefore lessens the potential for lightning damage or death.

Professor Chen Cixuan of Wuhan University in Hubei province, China, who invented the SLE with her husband, Professor Xie Guangrun, explained its features to about 150 electrical engineers at the Riverview Hotel yesterday.

Their main query: How is the SLE superior to the Franklin rod?

Her answer: The SLE, which is coated with a high-resistance semiconductor material, can reduce lightning discharge more effectively than the traditional rod, which is made of a highly-conductive material.

The SLE's three-pronged structure allows current to be shared among the rods so that bigger lightning strokes can be handled. The traditional rod has only one prong.

The system was launched in China in 1978 and has since been adopted in many countries, including Malaysia, Japan, Iran and the United States.

It has been in operation for about a year here, at the Singapore Technologies Assembly Test Services.

It cost about $200,000 to set up the system there.

Engineering consultant Richard Fong, 60, said: "The system is revolutionary and very impressive. But for a lightning rod, $200,000 is a little steep when a normal steel rod costs just a few thousand dollars."



Buy It. Sell It. Find It.

ST- 23/3/2002

15

“铁扇”迎风展 抗雷避电闪

中国防雷专家来新介绍新式避雷针

新式避雷针叫作半导体消雷装置，由武汉大学解广润教授与陈慈萱教授夫妇联合发明。1978年在实验室研究成功，经历12年的测试，90年大规模生产及推出市场。目前，上海东方明珠塔、中国中央电视台、西昌卫星发射站都安装了这种消雷装置。本地只有新科封装测试公司安装了有关装置。

蔡宝卿●报道

如果你看到有些建筑物的天台突然冒出几把“大扇子”，可别把它们当成是装饰环境的棕榈树，这些大扇子也不是孙悟空借来灭火的“铁扇”，而是中国防雷专家发明的革新式避雷针。

这种模样有点像棕榈树的避雷针，名叫半导体消雷装置，由武汉大学陈慈萱教授与她的丈夫解广润教授联合发明。

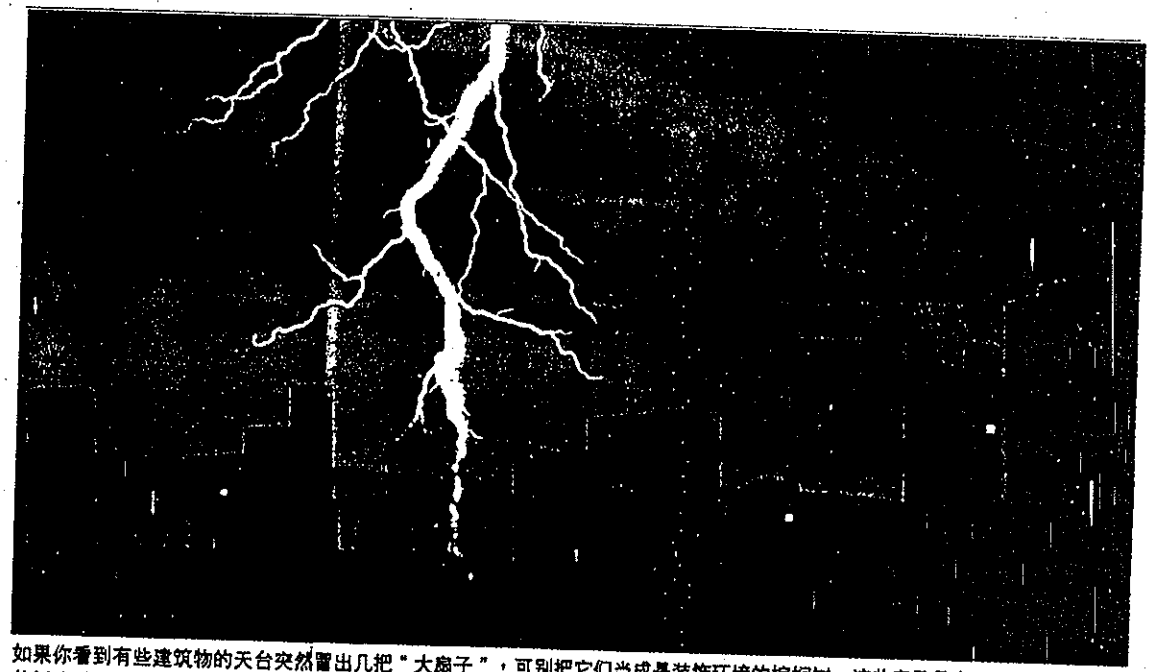
代理半导体消雷装置的都凯国际公司前天邀请陈慈萱教授及新加坡防雷标准委员会主席刘亚财教授，向本地防雷领域的专家与学者介绍半导体消雷装置背后的研发概念及优点。

陈慈萱教授在接受本报访问时说，顾名思义，半导体消雷装置是以半导体材料制成，有别于一般的金属防雷针。它的最大的特点是具有可以限制电流的电阻，功能相当于电容器。

她解释说，一般的防雷针只是将雷击的电流引导到地面，电阻非常微小。半导体消雷装置却具备很高的电阻，使经过的电流降低，更好地保护周围的建筑物及电子设施。

由树木与古塔获得灵感

当电压很高的时候，电流可能会发生“闪络”的现象，一闪络之后，防雷针便失效了。为了防止闪络，陈慈萱与解广润教授把防雷针设计得有如“扇子”，大大增强了防雷针的耐雷电能力。



如果你看到有些建筑物的天台突然冒出几把“大扇子”，可别把它们当成是装饰环境的棕榈树，这些扇子是中国防雷专家发明的革新式避雷针。（照片由都凯国际公司提供）

陈慈萱教授说，她和丈夫从大自然的树木与中国的古塔得到灵感，在一年之内设计出新式的避雷针。

她说：“其实大自然给了我们很多启示。树本身就是一个半导体，如果你看到雷打树的话，有两种现象，一种是树被雷击后树皮剥落，树干没事，这就是电流沿着树的表面走。还有一种是电流从树干的中间走，这时候整棵树就会被炸得粉碎，这些现象告诉我们，雷打下来不一定会发生闪络。”

除了树木之外，中国古塔抗雷害的能力也带给陈慈萱与解广润教授许多灵感。陈慈萱指出，根据调查结果，中国还未建设高层建筑的时候，古塔是最高的，许多古塔存在一千年了，尽管一些地方的雷击活动很多，但是受雷击而损坏的古塔却非常少。

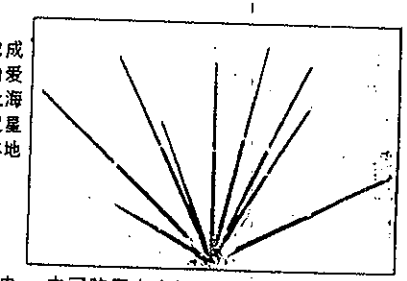
陈慈萱教授指出，古塔也是半导体，有一定的电阻，那也就是说，古塔本身就有一种抗雷害的能力，所以一般能屹立多年而不被雷劈倒。沿着古塔的设计思路，陈慈萱与解广润教授认为有可能找到合适的电阻材料避雷针，把雷害降低。

这项发明于1978年在实验室研究成功，其后经历了12年的测试，于90年由爱劳公司大规模生产及推出市场。目前，上海的东方明珠塔、中国中央电视台、西昌卫星发射站都安装了的半导体消雷装置。在本地只有新科封装测试公司安装了有关装置。

本地防雷标准委员会主席：比一般避雷针更能防雷害

新加坡防雷标准委员会主席兼本地雷电专家刘亚财教授在研讨会上指出，我国和亚细安国家处在雷电地带，一年约有200天有雷电发生，这些雷电对人类的生命和财产造成巨大的威胁。根据媒体过去所作的报道，雷击曾经造成弹药库着火、地铁系统中断、机场控制塔运作失常，甚至造成停电及炼油厂失火爆炸。

刘亚财教授认为，半导体消雷装置是一项革命性的发明，最大的好处是能够降低雷击所造成的巨大电流、电压变换及干扰电子



中国防雷专家把避雷针设计得有如“扇子”，增强了避雷针的耐雷电能力。

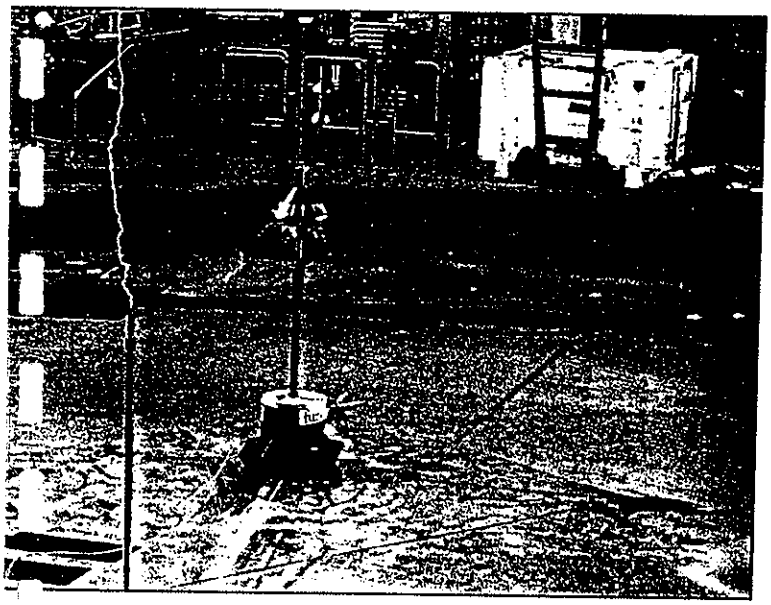
早报中英对照

半导体消雷装置:Semiconductor Lightning Current Extender (SLE)
电容器:capacitor
闪络:flashover

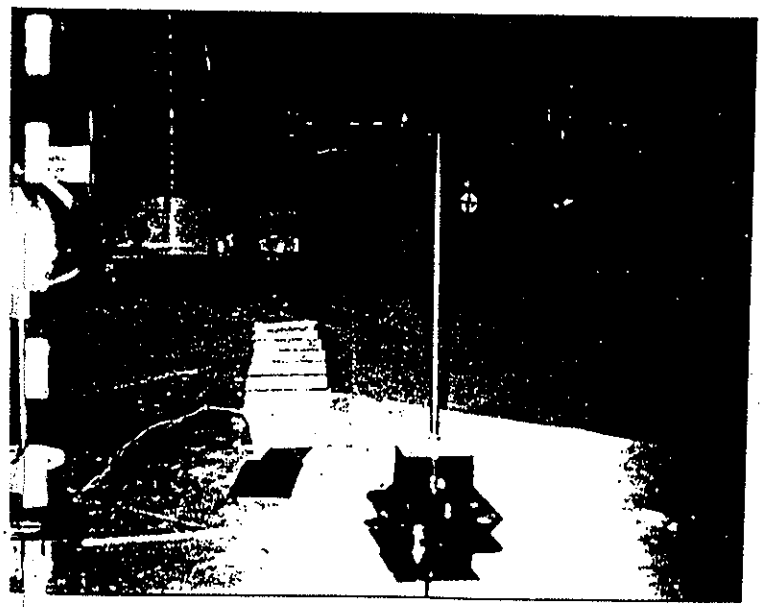
n terminals at UMIST High Voltage Laboratory



?/a) - Strike to Indelec terminal at rear - test 2



)(- Strike to Franklin terminal at front - test 2



- Dynasphere and Franklin terminals - test 4

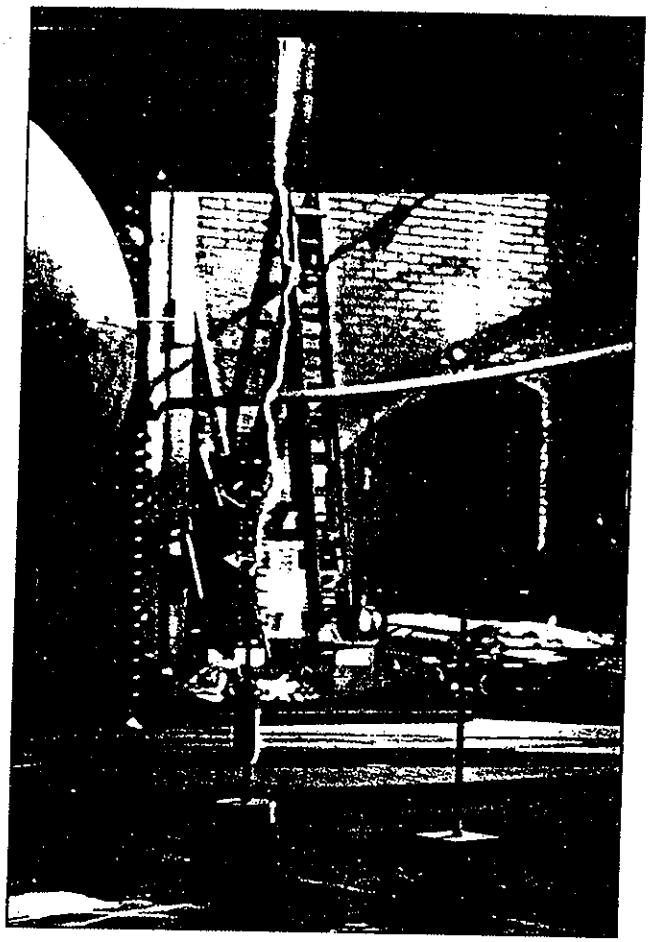


Figure 5(a) - Strike to Helita terminal at rear - test 6

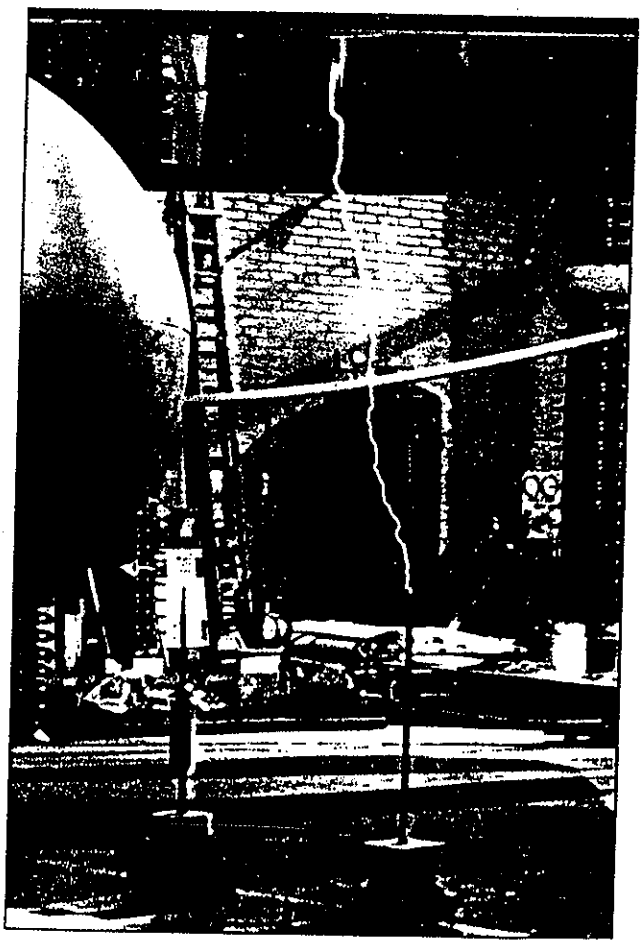


Figure 5(b) - Strike to Franklin terminal at front - test 6

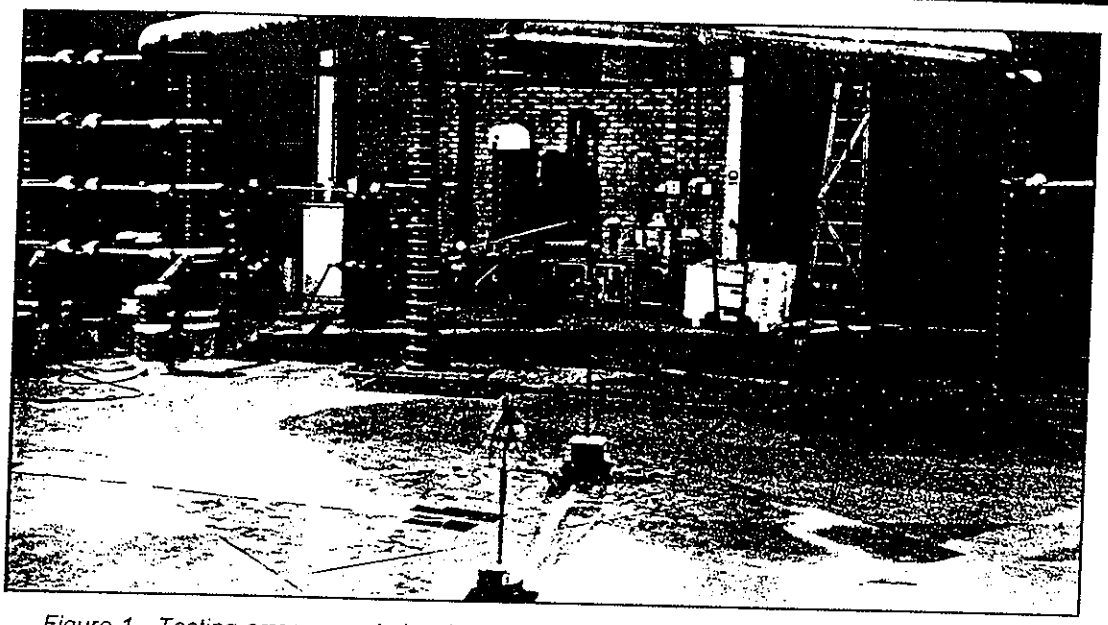


Figure 1 - Testing arrangement showing high voltage plane above equally spaced terminals.

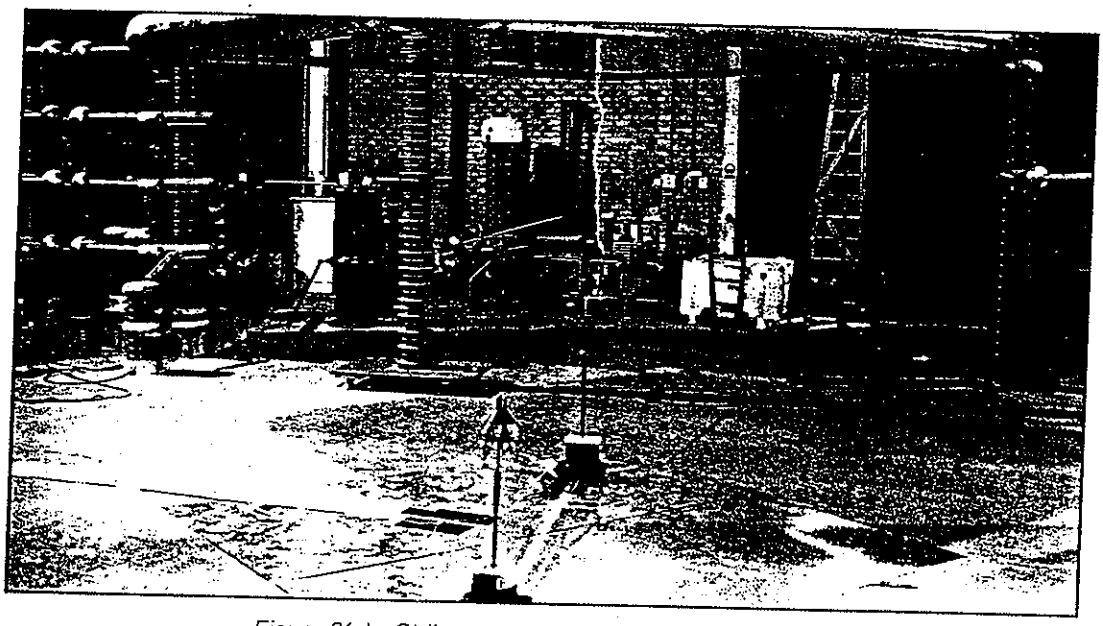


Figure 2(a) - Strike to Franklin terminal at rear - test 1



Figure 2(b) - Strike to Indelec terminal at front - test 1

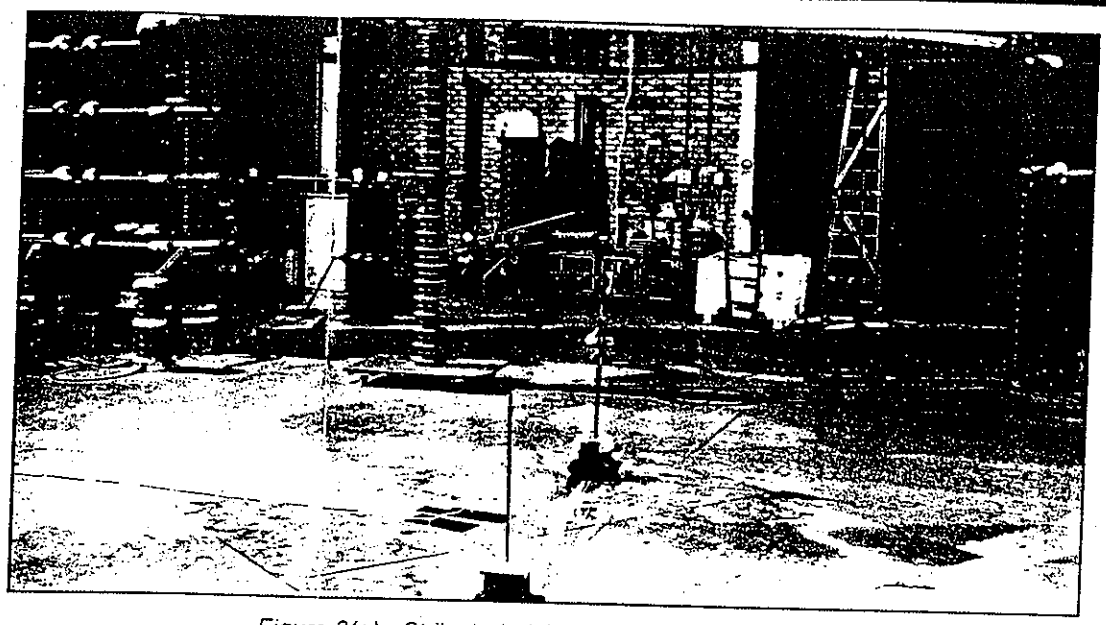


Figure 3(a) - Strike to Indelec terminal at rear - test 2

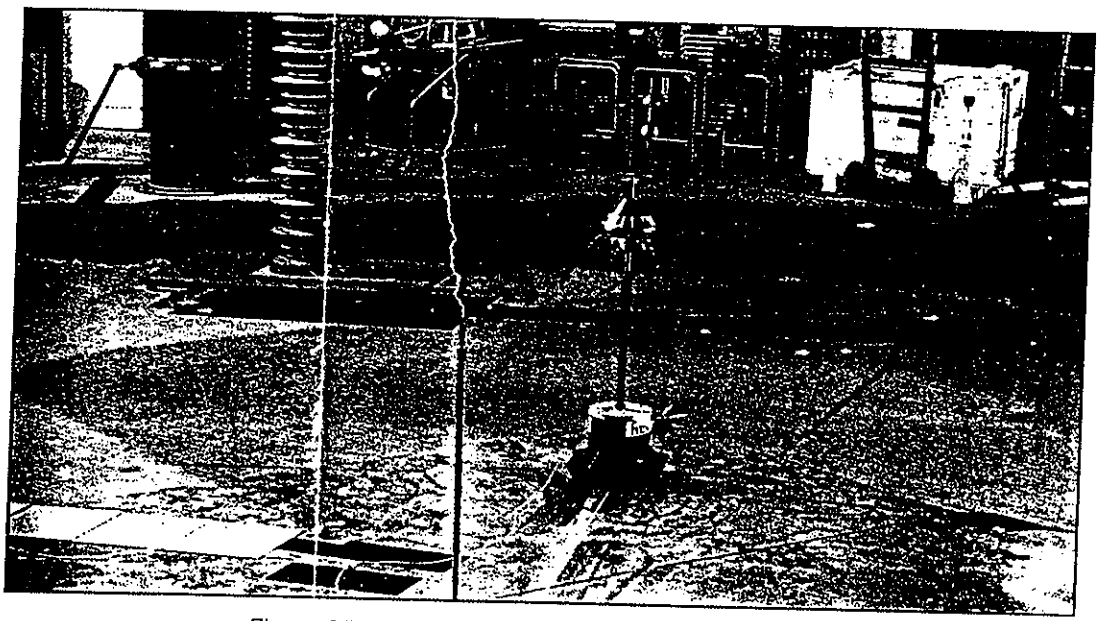


Figure 3(b) - Strike to Franklin terminal at front - test 2

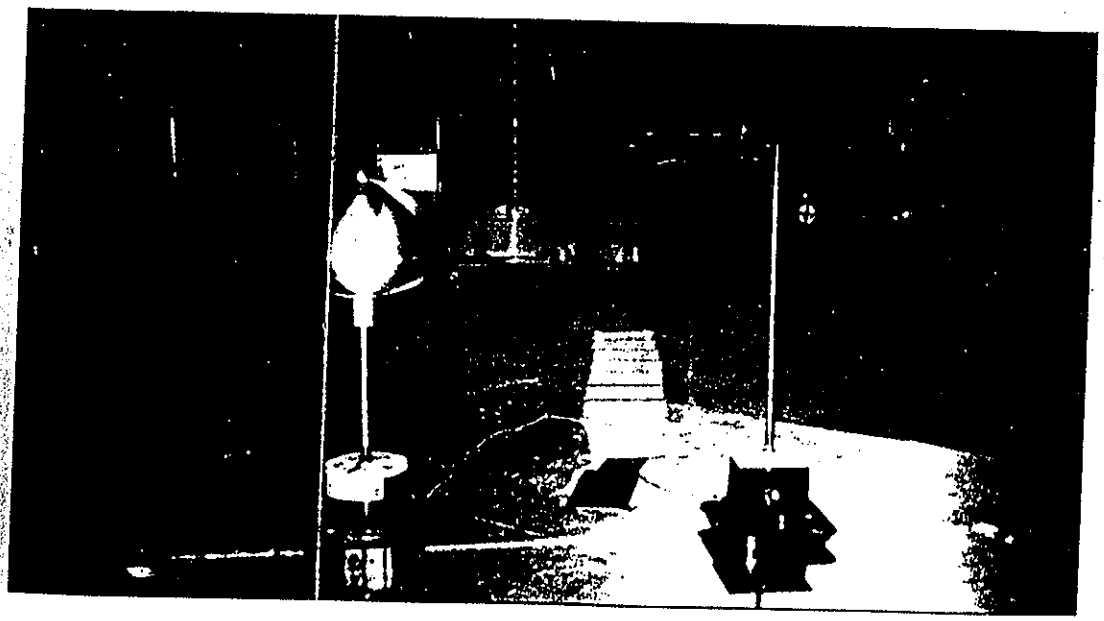


Figure 4 - Dynasphere and Franklin terminals - test 4



Figure 5(a) - Str



Figure 5(b) - Strike t

Configuration

Test No	Terminal Type	Total No of shots	Flashover Front	Flashover Rear	Withstand	Impulse Volt (kV_p) negative polarity	DC Voltage (kV) negative polarity	Comments
1	Franklin Indelec	35	7	17	11	840	-	
2	Indelec Franklin	35	10	15	10	840	-	
Total 1 & 2	Indelec Franklin	70	22 27		21			
3	Dynasphere Franklin	35	13	6	16	840	-	
4	Franklin Dynasphere	35	8	17	10	840	-	
Total 3 & 4	Dynasphere Franklin	70	14 30		26			
5	Franklin Helita	35	14	21	NIL	840	45	
6	Helita Franklin	35	14	21	NIL	840	45	
Total 5 & 6	Helita Franklin	70	35 35		NIL			
7	Dynasphere Franklin	35	15	20	NIL	840	45	
8	Franklin Dynasphere	35	8	27	NIL	840	45	
Total 7 & 8	Dynasphere Franklin	70	28 42		NIL			
9	Franklin Helita	35	12	23	NIL	840	45	1.75m centres
10	Helita Franklin	35	5	30	NIL	840	45	1.75m centres
Total 9 & 10	Helita Franklin	70	42 28		NIL			
11	Franklin Helita	35	10	23	2	570	300	
12	Helita Franklin	35	15	14	6	570	300	
Total 11 & 12	Helita Franklin	70	24 38		8			

NOTE: Unless specified the centres between finials during testing is 1.0m.

Conclusion

Of the 12 sets of tests conducted there was a total of 420 discharges.

- 200 discharges hit the Franklin terminal (47.6%).
- 165 discharges hit the ESE terminals (39.3%).
- 55 discharges did not break down the gap ie Withstand (13.1%).

The results produced from this test show a complete random nature of discharges to the Franklin and ESE terminals under identical electrical and geometrical conditions.
They did not substantiate claims of enhanced properties from the ESE terminals.

References

1 NFC17-102 July 1995. Protection of Structures and Open Areas Against Lightning Using Early Streamer Emission Terminals.

Sources

[1] UMIST: The results of tests of ESE & Franklin terminals, Test Report No. 43427

[2] RAYES, M.N.: Untersuchungen über das Blitzschutzverhalten von "Early Streamer Emission Terminals" (ESET), ELEKTRIE, Berlin 53 (1999) 11/12, p. 401 - 405

[3] NOACK, F.; SCHÖNAU, J.; BARTH, A.: Examinations Concerning the Effect of Ionizing Air Terminations; 4th VDE/ABB Conference on Lightning Protection, November, 2001, Neu-Ulm, VDE Technical Report 58, p. 169 - 179

[4] MOORE, C. B.; AULICH, G.; RISON, W.: Responses of Lightning Rods to Nearby Lightning: Intern. Conference on Lightning and Static Electricity, September, 2001, Seattle, WA, Proc. 2001 Aerospace Congress: 2001-01-2907

[5] HARTONO, Z.A.; ROBIAH, I.: A study of non-conventional air-terminals and stricken points in a high thunderstorm region, Proc. 25th ICLP 2000, Rhodos, September 2000, p. 357 - 361

Selection of suitable materials for Electrical Earthing And Lightning Protection System.

1. Copper Ground Rod

A standard steel rod electro plated with 250 micron radial thickness will have a service life span of 25 to 30 years under normal soil condition. The preferred length is 2.4 Metres or 3 metres non sectional rod (UL467 specification).

Disadvantage of sectional rod are:

- ❖ High contact resistance due to coupling joint.
- ❖ Local corrosion occurs between the two tips of the earth rod inside the coupling joint.

2. Ground rod connection to conductor

Clamps should be made from high corrosion resistance copper alloy with mechanical tensile strength of minimum 380N/mm2. Normal brass will have dezincification problem and is not recommended.

Suitable material :

BS2870-CZ112	BS2874-CZ132	BS2874-CA102
BS2874-PB102	BS2874-CA101	

3. Conductors

Conductors should be of high conductivity copper or aluminium BS1432-C101/103 and BS2898-1350.

4. Conductors saddle of clamps

Should be made from corrosion resistance copper alloy
BS2874-CZ132 BS2874-CZ112 BS1400-LG1/2

Or Aluminium
BS1490-LM6/LM25 BS1474-6082TF

5. Ai Terminal

Should be made from copper plated (250 micron) steel or aluminium rod (BS1474-6082TF)

6. Air Terminal Base

Should be made from corrosion resistance copper alloy and aluminium BS1490-LM6/LM25.

7. Earthing Inspection Pit

Should be made from hot dip galvanized steel for light duty and high strength concrete or cast iron for heavy duty.

Installation

1. Copper ground rod : Non sectional rod of 2.4 metres to 3 metres is preferred for larger contact area to earth eleçtrical resistant should be measured during the ground rod being driven into the ground to determine if there is any further reduction of earth resistance. When ground rods are connected in parallel, the distance between two rods should be spaced greater than the driven length of the rod to obtain minimum effective earth resistance.

2. Air terminal or conductors should be installed at the tallest part of the structure and ring within 30 cm from the perimeter around the buildings. It should not be buried beneath the concrete or wall. Avoid making sharp angle bents.

3. Aluminium material should not be used underground not come in direct contact with mortar.

4. Recommended horizontal conductor spacing should be 10M x 15M for normal structures and 5M x 10M for structures with explosive or highly flammable contents.

5. For structures above 45M height, rolling sphere method should be used to determine the protection zone.

6. The number of down conductors for structure less then 20m tall can be calculated using the following fornula:

$$\text{No. of down conductors} = \frac{\text{2 lengths x 2 width}}{20}$$

(Minimum 2 down conductors)

7. Earth resistance enhancing compound is not recommended, as it is only a temporary solution. Once it has been eroded by rainwater, the earth resistance will increase and the grounding system will become ineffective.

NOTE:

1. Copper material is not suitable for use in environment of incinerator and sewage treatment plant, stainless steel grade SS316 is preferred.

2. Stainless steel is not suitable for permanent immersion in seawater.

To ensure safety, it is recommended that all building and structures should be inspected once a year.