Comparative Electric Field Calculations and Measurements

INTRODUCTION

The ability to calculate the electric field strength and potentials on insulators rather than having to perform laboratory experiments would be very helpful. Several computer software packages to perform such calculations based on electrostatic field and applicable to AC are available.

COMPARATIVE ELECTRIC FIELD CALCULATIONS AND MEASUREMENTS

Working Group 03 (Insulators) of Study Committee 22.
This report was prepared by R. PARRAUD (France), on the basis of results and comments made by all the members.

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Approved by WG 03 members, *i.e* :

Messrs. S. CURLIER (France) Convenor; H. BOOT (Netherlands); A. CIMADOR (France); R. HOULGATE (United Kingdom); G. KARADY (USA); J. KINDERSBERGER (Germany); F. KUELLER (Brazil); G. LIMBOURN (Australia); V. LONGO (USA); G. MARRONE (Italy); P. MONGE (Spain); K. NAITO (Japan); T. PINKHAM (USA); R. PARRAUD (France); J. REYNDERS (South Africa); B. STAUB (Switzerland); C. DE TOURREIL (Canada); J. VAN NAME (USA).

INTRODUCTION.

The ability to calculate the electric field strength and potentials on insulators rather than having to perform laboratory experiments would be very helpful. Several computer software packages to perform such calculations based on electrostatic field and applicable to AC are available.

It was decided in CIGRE 22.03 to proceed with a comparative study of electric field calculation and measurement methods known to members of the working group. A first questionnaire was circulated requesting information on methods used or known to members to calculate and/or measure electric fields and potentials [1]. The replies were given in [2] and showed that nearly all the members had access to field calculation software. However potential and field measurements were less generally available. It was then decided to compare the different electric field calculation programs on a simple model with the possibility of making field and potential measurements on a full scale object. This report summarizes the results of the comparative electric field calculations and the results of the field and potential measurements.

1 THE MODEL.

The model used for the calculations is shown in <u>**Figure 1**</u>. This model is based on one already used for comparative calculations by BEASLY, PICKLES et Al [3].

2. ELECTRIC FIELD CALCULATIONS.

2.1 First round calculations.

Firstly, a round of 13 calculations was carried out using the five following methods :

- FDM Finite Difference Method [4]
- FEM Finite Elements Method [5-7]
- BEM Boundary Element Method [6]
- BIM Boundary Integration Method [8]
- CSM Charge Simulation Method [9]

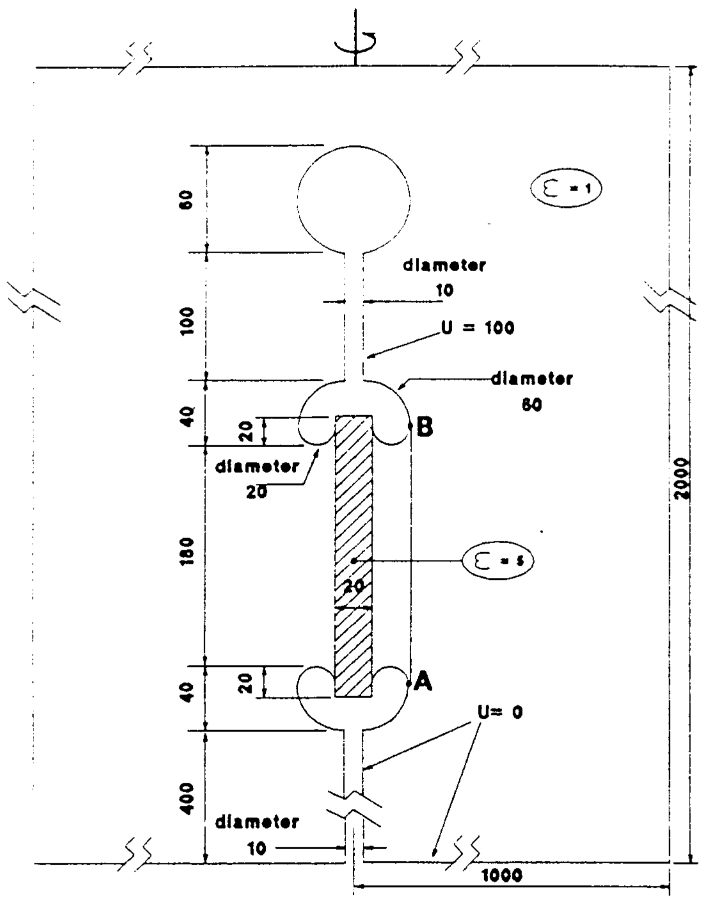

Figure 1. Model for comparative calculations (dimensions in mm)

TABLEAU. METHODES ET PRODUITS UTILISES POUR LE COMPARAISON
TABLE. METHODS AND PRODUCTS USED FOR THE COMPARISON

Reference	Program	Method	Remarks
A	ROTASYM	CSM [9]	High resolution output
B	I.E.S./ELECTRO V.2.2.	BEM [6]	Finer mesh (123 elements)
C	I.E.S./ELECTRO V.3.0.	BEM [6]	Very fine mesh (459 elements)
D	Flux 2d	FEM [5]	High resolution output
E	BICAMP	BEM [6]	Only field supplied Mesh not improved
F	ANSYS	FEM [7]	Using heat transfer model
G	MAGNA/FIM	FEM [5]	High resolution output potential only
H (reference)	HSSSM	BIM [8]	{ Taken arbitrarily as the { reference as in the first { round { High resolution output

All the calculations were carried out in 2 ½ dimensions (2D axi-symetric).

Times reported to prepare and enter the model's geometry varied from 20 minutes to 8 hours with a mean of 2.5 hours.

Times to solve the problem and produce the values of potential and field every 2 mm along the reference field strength line A-B (figure 1) varied from 2 minutes to 3 hours and 80 % of the calculations took under 10 minutes.

The field strength and the potential were noted along the line A-B on figure 1 for each calculation, in some cases this was done graphically.

To compare the results, one calculation was taken arbitrarily as a reference. The absolute difference of potential and field strength as well as the percent diffrence of field strength with respect to the reference calculation were then calculated for each set of results. This was found to be the optimum method of comparison, as plotting absolute values masked significant differences at lower values.

At this stage it became evident that the programs gave very varying results with differences in field of ± 30 % at certain points along the reference line taken on the model (A-B on figure 1). As far as potential is concerned the results were much closer, giving differences of the order of ± 2.5 %. In both cases the differences were highest near the electrodes.

These differences were attributed to :

- Digitizing errors on the curves supplied by each participant

- Different abilities and methods of the programs to deal with boundaries

- Insufficiently fine, or not exactly designed mesh construction of the mathematical model, especially for the finite difference methods.

2.2 Second round calculations.

In order to remove or reduce the effect of the above parameters, it was decided to ask the participants to carry out a second round of calculations using an "improved" mesh and supplying a printout or disk file of absolute field and potential values every 2 mm along the reference line A - B.

The second round was carried out in 1990. The participants in the table supplied data in the requested format following four of the five methods indicated above, methods FEM [5-7], BEM [6], BIM [8], CSM [9].

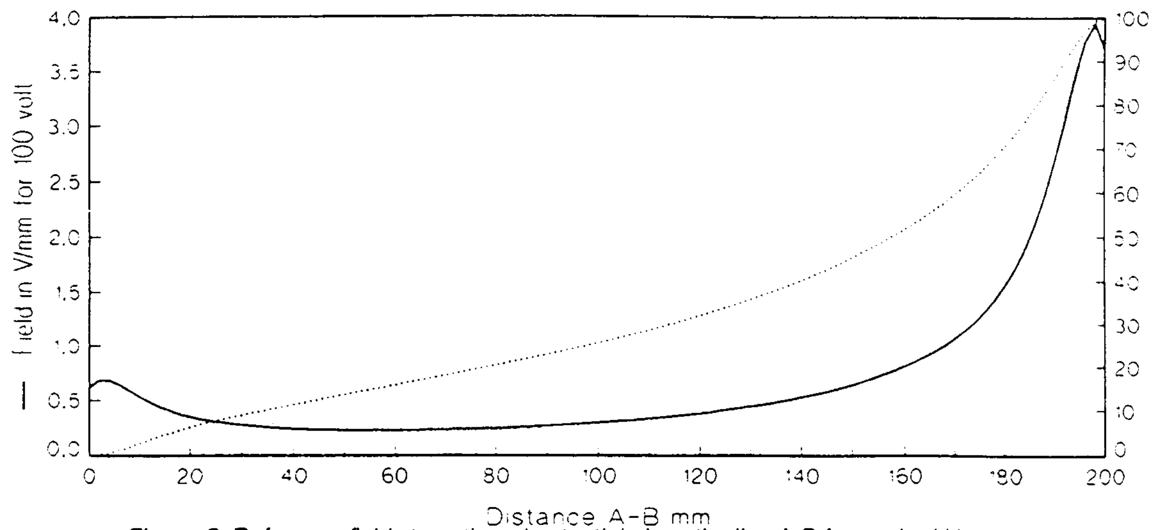

Figure 2. Reference field strength and potential along the line A-B for method H

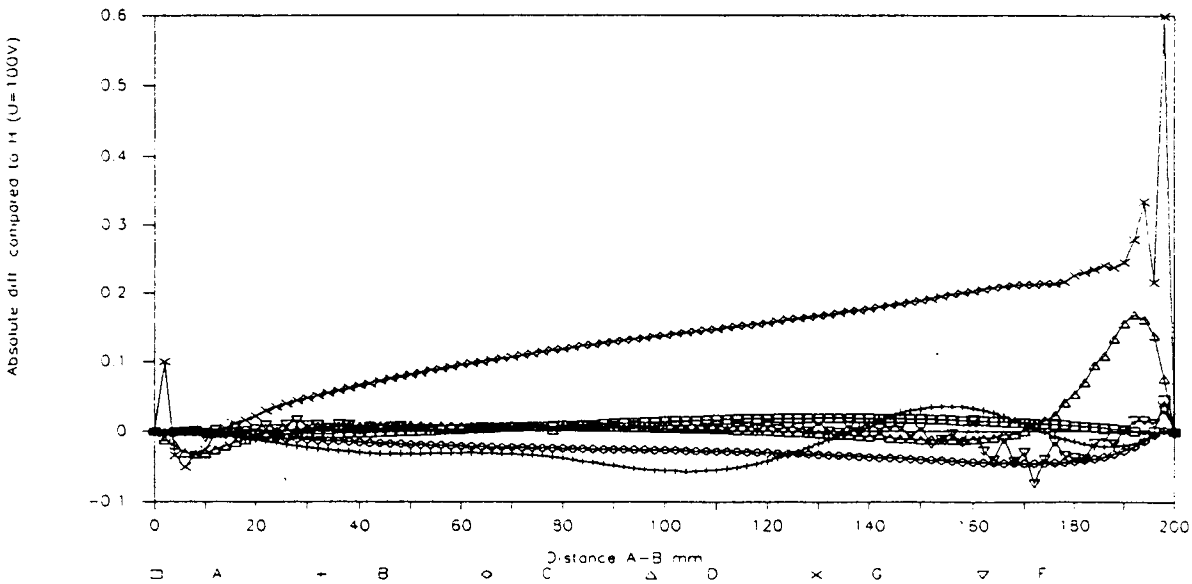

Figure 3. Absolute potential difference (U_{ref} - U_{calc}) for each calculation for 100 V applied (H - reference Calc) along the line A-B.

Since not all the participants supplied entry and calculation times, these are not given, but typically values were as for the first round. The finite difference methods could not be greatly improved, so were not considered in the second round.

2.3 Comparisons of second round calculations.

As in the first round, the calculation by H was taken as the reference. The results show that this calculation is still a good reference as no systematic positive or negative difference are found among the compared calculations. The reference field strength and potential plots along the line A - B are shown in **Figure 2**.

2.3.1 Calculation of potential.

Figure 3 shows the absolute potential difference (U_{ref} - U_{calc}) for each calculation for 100 V applied.

These results show a good agreement amongst themselves and with the reference (H). The maximum difference being less than 0.2 volt (for 100 V applied). It can be noticed that the differences are still generally greatest near the electrodes as was found in the first round calculation. The curve F shows a "saw tooth" effect which is no doubt due to a lack of fine mesh at critical points of the calculation domain.

The "sawtooth" effect was found in the first round on all the FEM calculations.

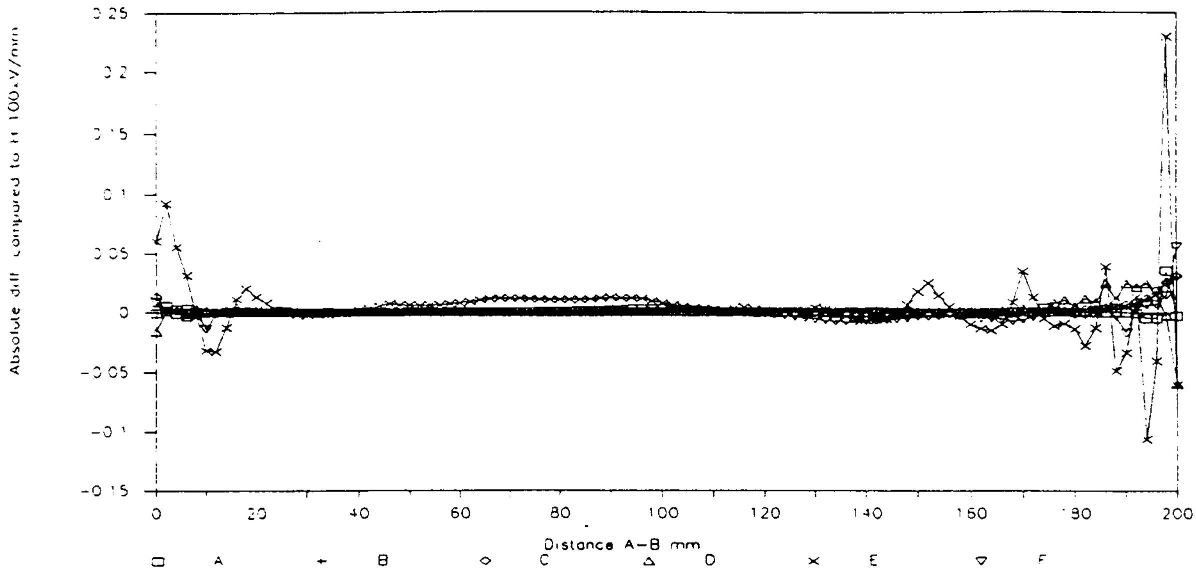

Figure 4. Absolute field strength difference along the line A-B.

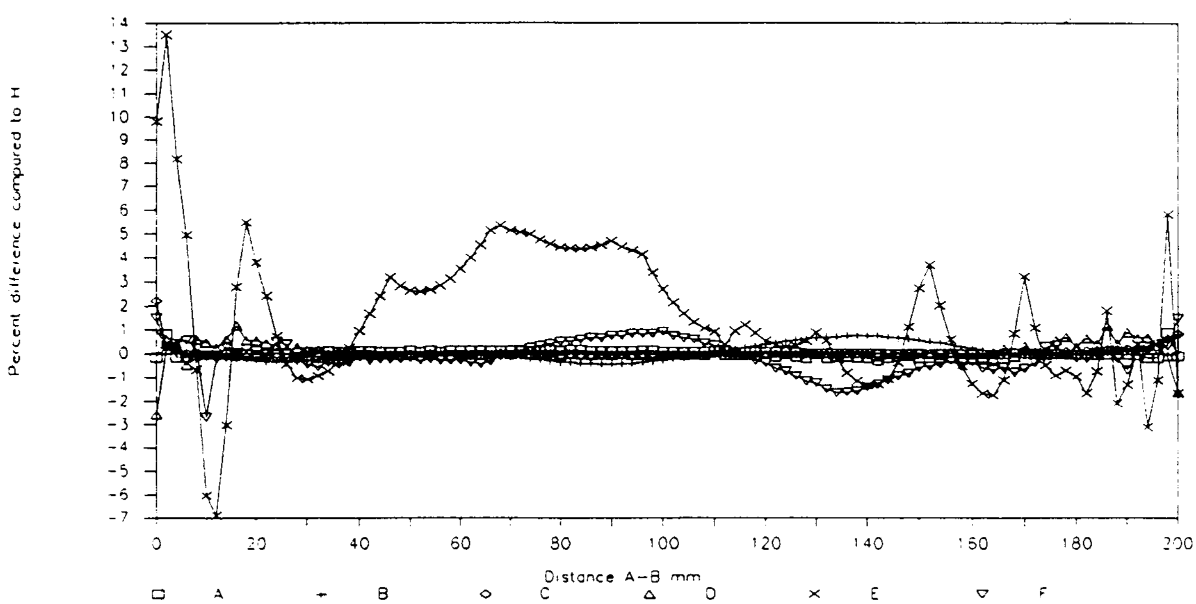

Figure 5. Field strength difference in percentage along the line A - B.

2.3.2 Calculation of field strength.

Figure 4 shows the absolute field strength difference (E_{ref} - E_{calc}) for 100 V applied. The results shows a good agreement between themselves and with the reference, being in general within 0.1 V/mm. Here the differences are noticeable at both the earth and H.V. electrodes.

Figure 5 shows the same comparison but expressed in percent difference :

$$\left[\frac{Eref - Ecalc}{Eref} \times 100 \right] \%$$

It can be seen that for the majority of calculations the apparently large absolute differences near the H.V. electrode are relatively small when expressed as a percentage.

This figure is zoomed to ± 3 % in **Figure 6** where the "sawtooth" effect of FEM methods becomes apparent.

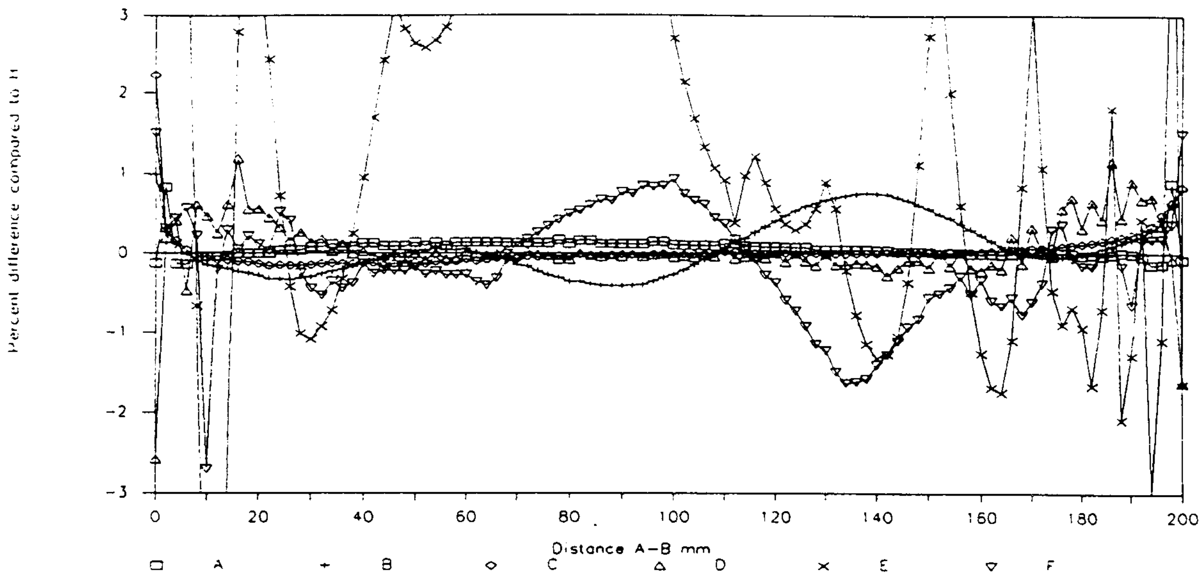

Figure 6. Zoomed field strength difference in percentage along the reference line A - B.

Here it is interesting to note that the two BIM methods using different numbers of elements show similar results at the electrodes, but the improvement in the number of elements reduces the difference only between the electrodes. A maximum difference in the field strength of ± 2 % at the electrodes was found for most methods used when the mesh is appropriately constructed.

2.4 Discussion.

When compared to the first round calculation, the results of the second round tests show the importance of the effect of the construction of the mesh or element definition on the potential and field strength calculation.

The potentials in the first round differed in general from the reference by up to ± 2.5 %, with greater differences near the electrodes. The second round results showed a reduction to ± 0.5 % except near the earth electrode.

For the field strengths, differences of up to 30 % at or near the electrodes and of 10 % between the electrodes were current for the majority of the first round calculations, whereas ± 5 % and ± 2 % are easily attainable with care as shown by the second round results.

As noted in § 2.2. above, entry and calculation times for the improved mesh structure calculations of the second round calculation were very similar to those of the first round. Increasing of number of nodes or elements at critical points of the model is thus demonstrated to have a positive effect on the accuracy of calculation without a significant penalty of increased operator or machine time.

3. FIELD STRENGTH AND POTENTIAL MEASUREMENTS.

3.1 Participants and methods.

Three participants carried out measurements on a full scale object reproducing the model chosen for the comparative calculations : one measured potential and two measured field strength.

The methods used were :

Reference	Method
Em *Potential*	Mechanical résonance type AC potentio-meter. Applied voltage 20-40kV [10].
Em *Field Strength*	Electro-optical method with quartz cubic sensor. Applied voltage 10-20kV.
Am *Field Strength*	Potential free spherical sensor [11].

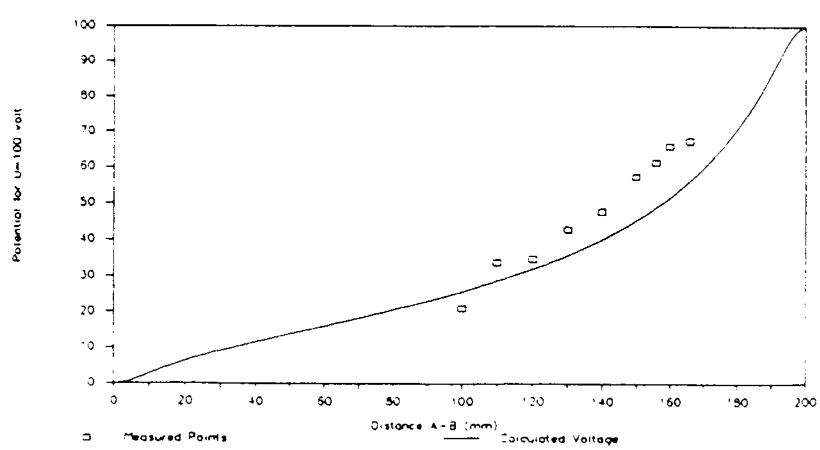

Figure 7. Measured and calculated potential along the reference line A-B compared with the H reference potential calculation.

It was not possible to make measurement close to the electrodes of the object along the reference line A-B, and in the case **Am** they were made at 110 mm from the axis of the object.

3.2 Results.

3.2.1 Measurement of potential.

Figure 7 shows the potential measurements along the reference line A-B for method **Gm** compared with the calculated values from H (taken as reference in the field strength calculation comparisons).

3.2.2 Measurement of field strength.

Figure 8 shows the field strength measurements for method **Em** along the reference line A-B compared with the calculated values from H reference calculation.

Figure 9 shows the field measurements made at 110 mm from the axis with method **Am** on the model compared with field values calculated using the method **A** charge simulation program (which gave good results in the field calculation comparison and for which results were available at this distance from the axis).

3.3 Discussion.

3.3.1 Measurements of potential.

Reference to Figure 7 reveals the difference between the measured and calculated values of potential.

The measured potential points fall within ± 10 % of the calculated values.

The results are within the expected accuracy of measurement due to the influence of the measuring probe on the potential distribution.

3.3.2 Measurements of the field strength.

The field strength measurements along the reference line A-B (**Em**, Figure 8) show a good correlation in the region between the electrodes. However there is a significant deviation near the electrodes which can be attributed to disturbance of the field by the measuring probe.

The field measurements at 110 mm from the axis of the object (**Am**, Figure 9) show a similar effect with a more pronounced difference near the ground end of the object.

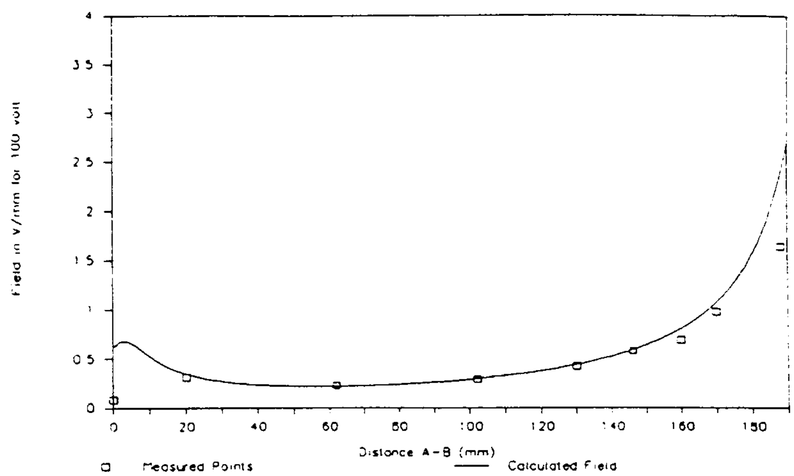

Figure 8. Method **Em** - Measured and calculated field strength along the reference line A-B compared with the reference field strength calculation.

4 CONCLUSION.

The first and second round of electric field strength calculations have shown that differing methods (finite elements, boundary methods, charge simulation methods ...) can give comparable results. The accuracy of these results is highly dependent on the mesh or element structure used. The reduction in field strength differences from 30 % to 2 % by refining mesh structure is a good illustration of this and underlines the importance of using a correct mesh definition.

The laboratory tests to measure field strength and potential on a full scale model provide an interesting comparison with the calculations obtained from a very fine mesh. They show that it is possible to measure field strength and potential with reasonable to good accuracy compared to calculated values. However, measurement proved difficult near the electrodes where the study of the effect of the field on materials is of most interest.

It would seem that for most cases (no corona, objects with a high degree of rotational symmetry) the calculation of field strength and potential by currently available software can be a very useful and accurate tool which can be used with confidence.

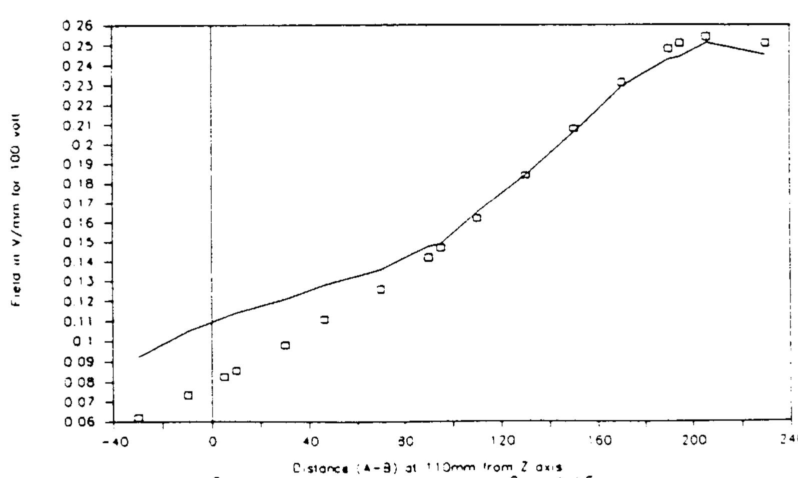

Figure 9. Method **Am** - Measured and calculated field strength along the line located at 110 mm from the axis of the model.

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