Experimental study of towers for high tension lines

Autor(en): **Borges, Ferry / Lima, Arga E.**

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Experimental study of towers for high tension lines

Versuche über Hochspannungsleitungsmaste

Estudo experimental de postes para linhas de alta tensão

Etude experimentale de pylônes pour lignes à haute tension

FERRY BORGES
Research Engineer

ARGA E LIMA
Assistant Engineer

Laboratório Nacional de Engenharia Civil
Lisbon

INTRODUCTION

The fact that the supporting structures for the high tension electric lines represent a large proportion of their total installation costs justifies a thorough study of these structures. Furthermore as large numbers of identical structures are employed, it follows that a small economy achieved in individual elements represents a very large total economy.

This is one of the problems for which it will be possible to obtain important economies through the discussion of the fundamental problem of safety, especially on a statistical basis. The fact that great numbers of structures are being dealt with gives a large volume of information relative to the behaviour of these structures and makes it possible to handle this information on statistical and economic bases. These statistical studies, which have only just been initiated, are not presented here.

The principal difficulties of the application of analytical methods derive from structures in question not being isostatic and their strength being influenced by buckling. The rigorous treatment of buckling is particularly difficult due to the large number of elements and to the difficulty in defining the rigidity of joints.

The experimental methods, especially tests on prototypes, are particularly fruitful in this case, and their drawbacks, principally that of causing the destruction of the structure, in failure tests, are minimized by the fact of having to construct numerous identical structures.

The analytical methods are very useful for a preliminary design, but it is only by experimental tests that convenient information can be obtained of the overall behaviour of a structure and its joints. Experimental tests thus allow a more exact design and they moreover supply information for improving analytical studies.

This paper presents the methods followed at the Laboratório Nacional de Engenharia Civil in carrying out tests on models and prototypes and gives a summary of some of the conclusions derived from the tests [1].

2. *Model tests.*

Towers for two high tension lines (both 150 Kv) were studied by by means of models. For one of the lines two types of towers were studied. Only one type was studied for the other line.

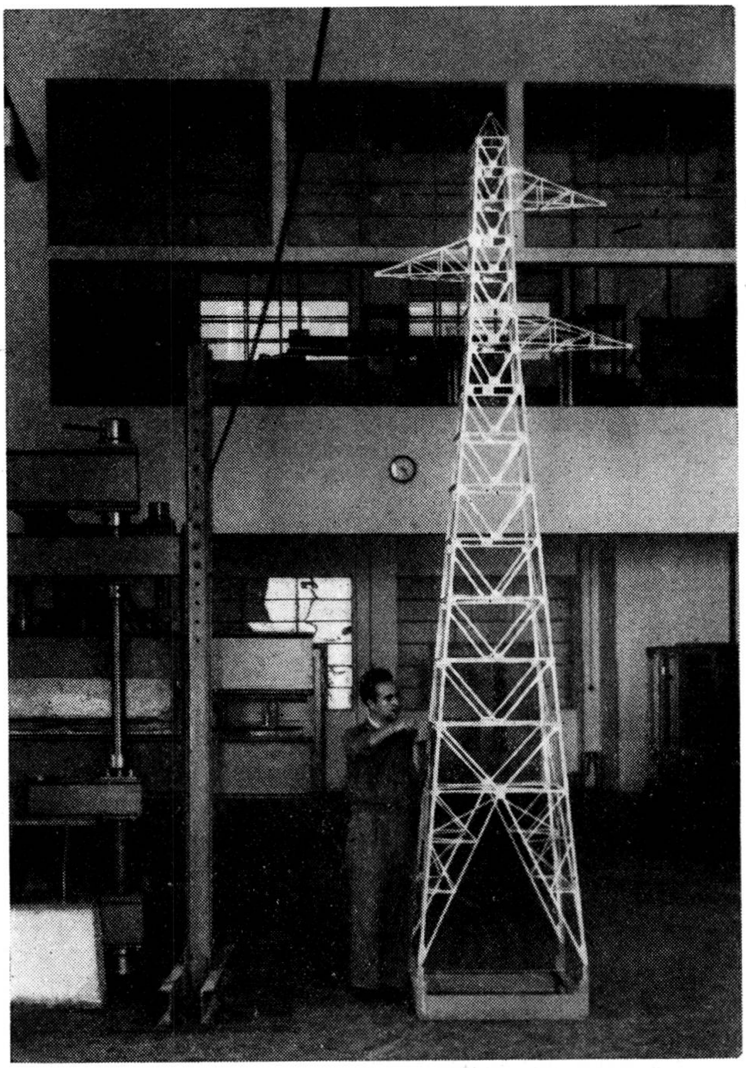

FIG. 1. Model to a scale of 1/6

Three models were built in which perfect geometric similarity in relation to the prototypes was maintained; the two first ones to a scale

[1] The tests were sponsored by the Companhia Nacional de Electricidade that is in charge of high power distribution in the country. The analytical studies and design of the towers was also undertaken by this company.

of 1/6 and the third to a scale of 1/7. Fig. 1 and 2 show two of the models. The model in fig 2 was photographed near by a prototype.

The angle shapes of the models were obtained by bending steel sheets and the joints, made by means of screws, were also reproduced faithfully to scale.

The test method consisted in applying loads and measure the displacements and strains. Fig. 3 shows one of the models during test.

The loads were applied by means of weights, the loading hypotheses considered in the analytical calculation being reproduced. Thus vertical

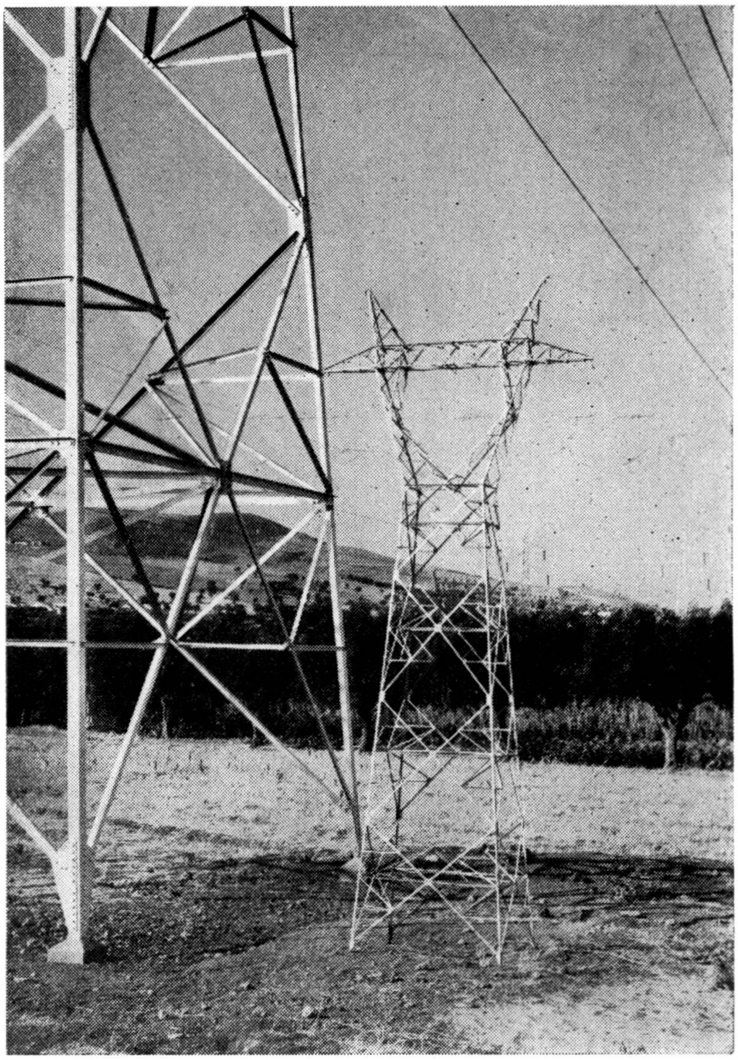

FIG. 2. Model to a scale of 1/7

loads were applied corresponding to the weight of the various elements and horizontal loads which reproduced the loadings due to wind and breakage of cables. The scale of forces was chosen such that the stress limit of proportionality was not exceeded.

The measurement of strains was carried out by Huggenberger strain-meters with an 8 cm base length, three strain-meters being placed at each section, at the vertex and at the edges of the legs. By this means it was possible to determine the strains at the centre of gravity of the sections with perfectly satisfactory accuracy. For the model in which the greatest number of measurements were taken the strains were measured at 48 sections.

For the measurement of displacements deflectometers graduated in 0.1 and 0.01 mm were employed. They were connected to the structure by steel wires.

Taking into consideration the scale of the models and forces, the values determined in the tests were transferred to the actual structure.

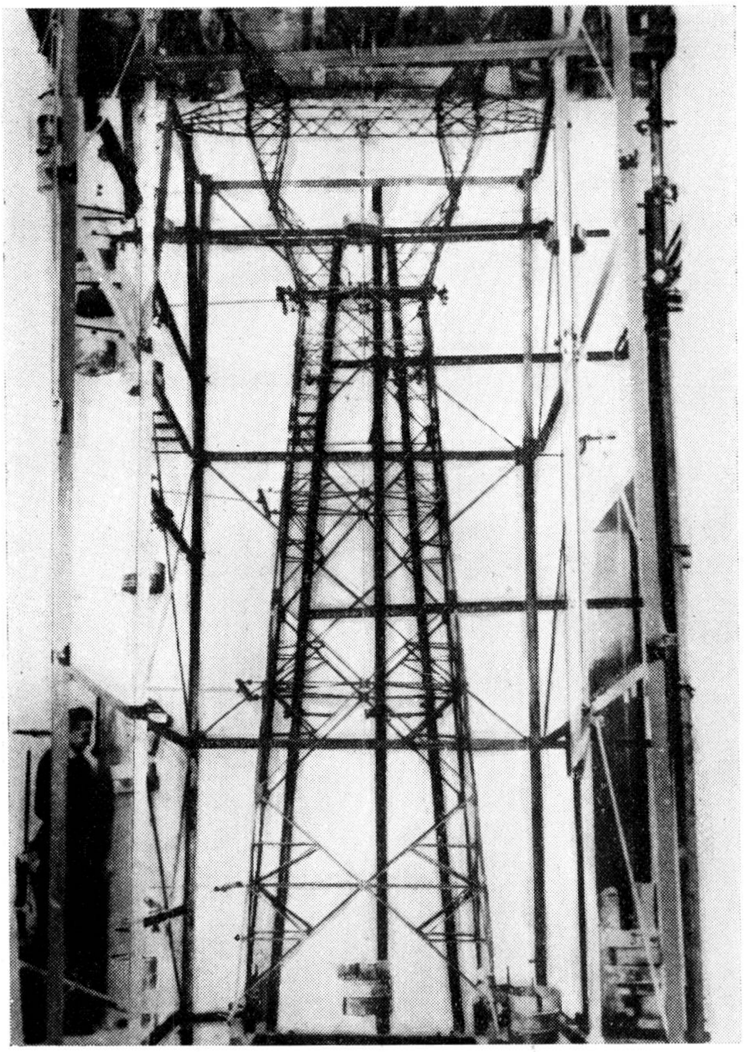

FIG. 3. Model during test

In order to calculate the stresses from the strains measured, accurate determinations of Young's modulus were made on the actual members used in the construction of the models.

From the comparison of the stresses determined analytically and experimentally, fig. 4, it was possible to conclude the following.

For the hypothesis in which the loading was symetrical in relation to the axis of the towers, there was, as was to be expected, relative agreement between the results of the tests and the analytical calculations.

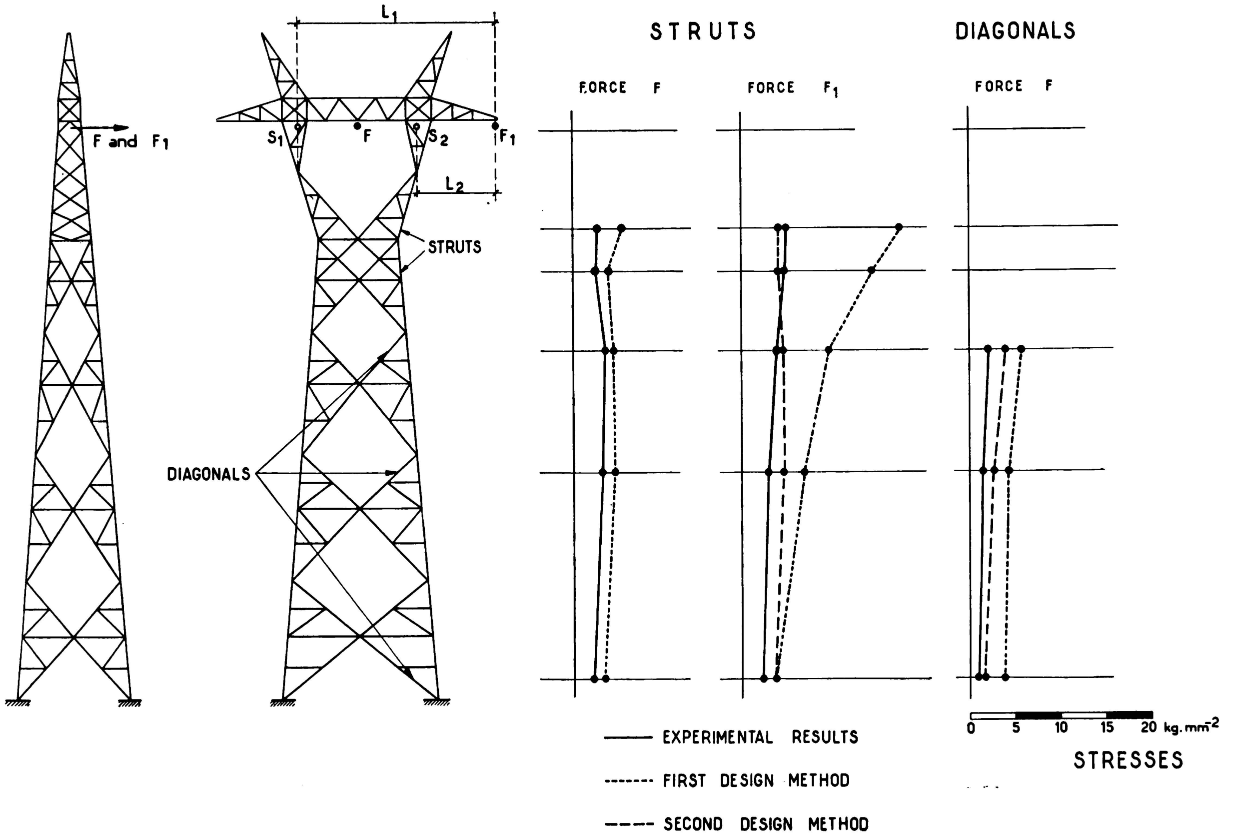

FIG. 4. Results of model test

For the hypothesis in which the loading is not symmetrical and which corresponds to rupture of a lateral cable the stresses determined experimentally differ considerably from the analytical ones. This fact results from the analytical method first adopted being based on unsuitable hypotheses.

In fact, in this first method, to calculate the stresses due to cable rupture the hyperstatic reactions of the frame, which constitutes the upper part of the tower shown in fig. 4, were determined by the current method. The stresses in the members of the tower body were calculated by resolving in an arbitrary way these reactions along the supporting arms of the frame and transmitting the forces thus obtained to the triangular beams which constitute the four sides of the tower body. By this process large stresses were obtained, principally in the struts, whilst, on the other hand, the experimental results showed that the stresses in the struts due to torsion forces were practically negligible.

This led to the adoption of a second calculation method which simply consists in resolving the torsion moment at a given level into forces acting on the sides of the tower, forces which are inversely proportional to the distance between the sides.

The results of this second method are very much closer the experimental results than those of the first method.

For the calculation of the supporting arms of the frame, the application of the force due to rupture of a lateral cable corresponds to the application to each arm of forces S_1 and S_2 (fig. 4). Considering the isostatic system it is clear that $S_1/S_2 = L_2/L_1$. The torsion rigidity of the arms can however lead to values of S_1/S_2 less than the above. For the tower of fig. 4, isostatically, S_1/S_2 is equal to 1/2.5, whilst experimentally S_1/S_2 was equal to 1/3.5.

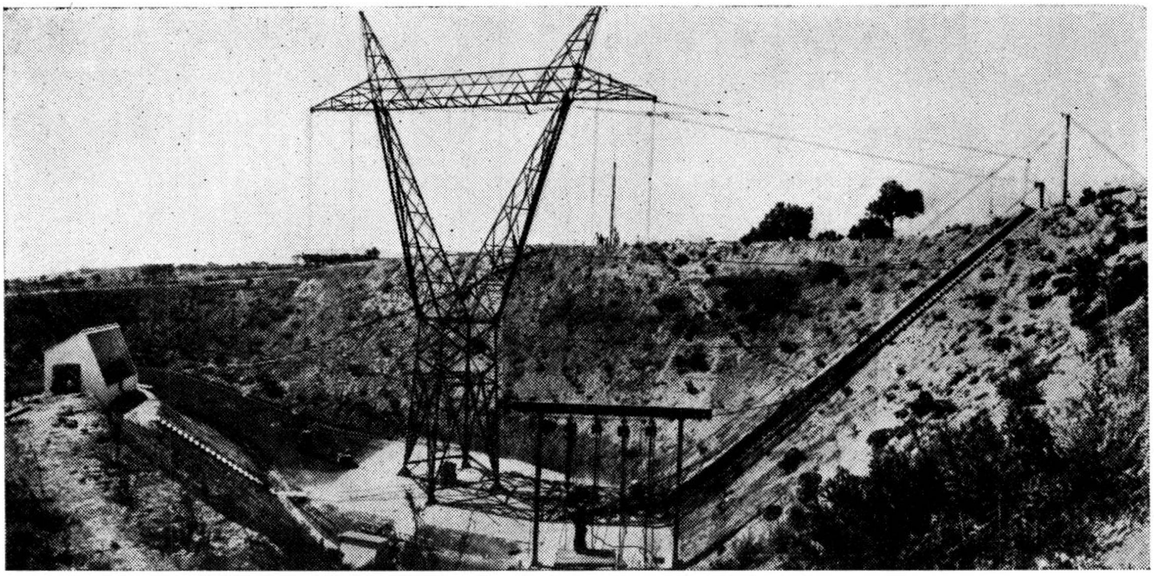

FIG. 5. Installation for the test of prototypes

3. *Prototype tests.*

In order carry out tests on prototypes a special installation was built on the grounds of the Laboratório Nacional de Engenharia Civil, fig. 5, 6 and 7.

The installation consists of a reinforced concrete slab in which steel beams were embedded. The connection of the bases that receive the struts is made through bars that are welded to the upper face of the beams.

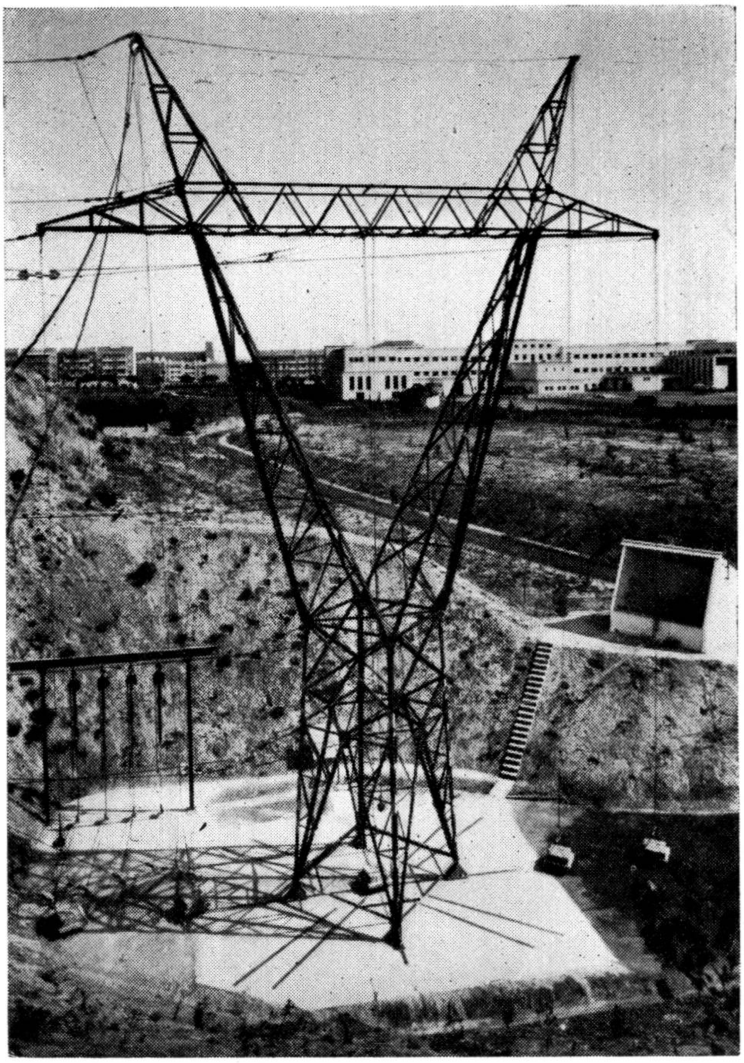

FIG. 6. Installation for the test of prototypes

The application of the loads is made by means of cables and pulleys. The cables are pulled by chain hoists suspended from a frame.

As horizontal forces had to be applied at a distance of about 20 m from the tower base advantage was taken of the natural configuration of the ground. So it was not necessary to construct large structures to absorb the cable reactions. Use was made of small metallic towers and of a reinforced concrete beam that goes up the side of a slope.

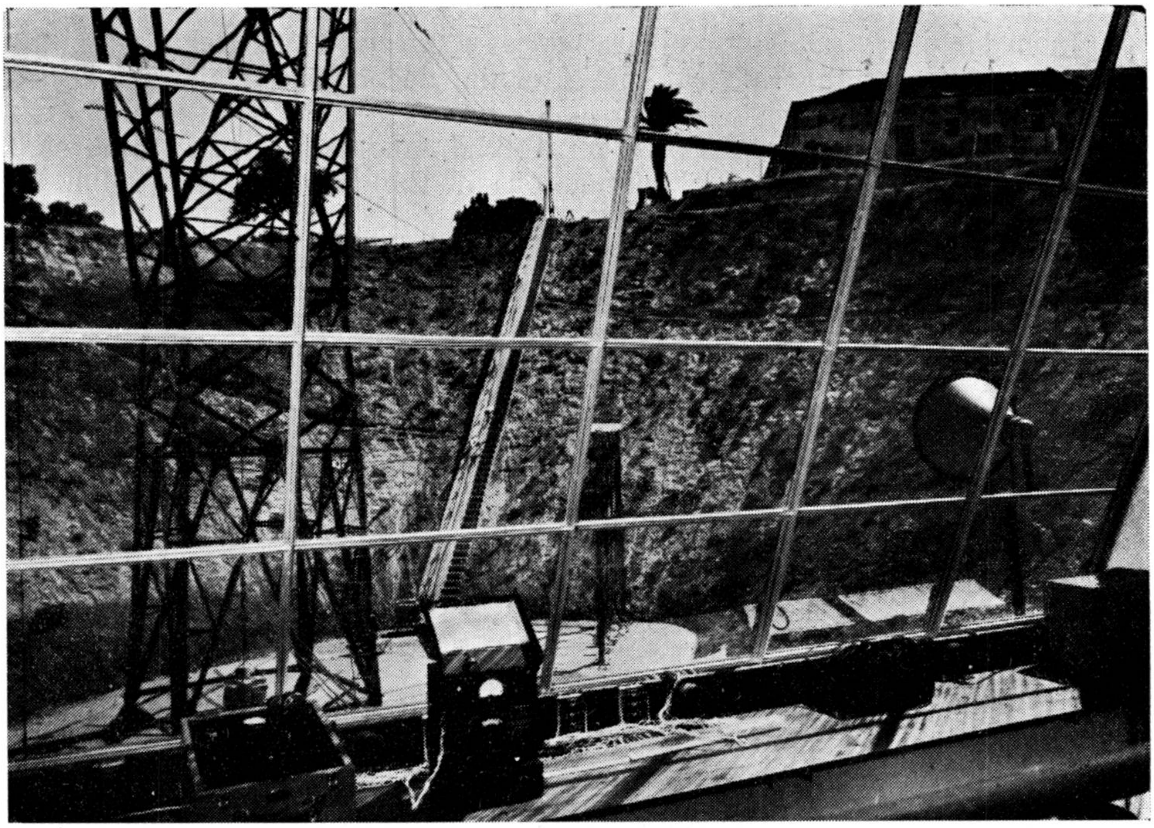

FIG. 7. Observation post

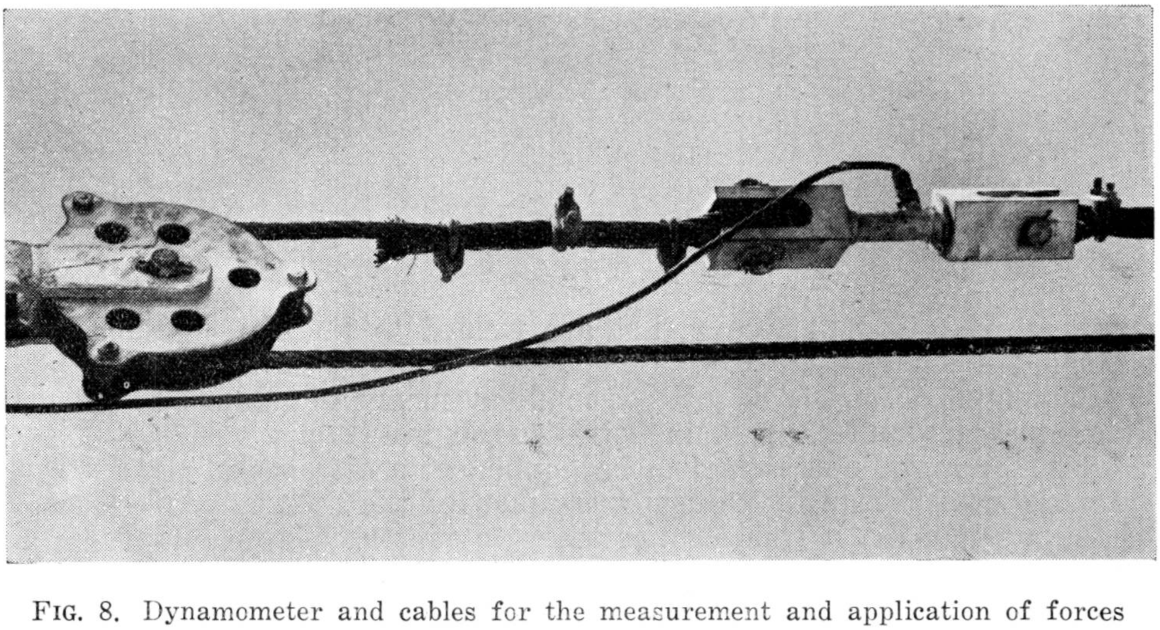

FIG. 8. Dynamometer and cables for the measurement and application of forces

For measurement of the forces specially built dynamometers, fig. 8, are introduced in the cables near the tower under test. The dynamometers have acoustic strain meters inside them. They have capacities from 1.5 to 10 tons and measure the forces with errors of less than 0.5 % of their capacity.

For measurement of displacements simple systems of rules and cursors are employed, the rule being fixed to the ground and the cursor

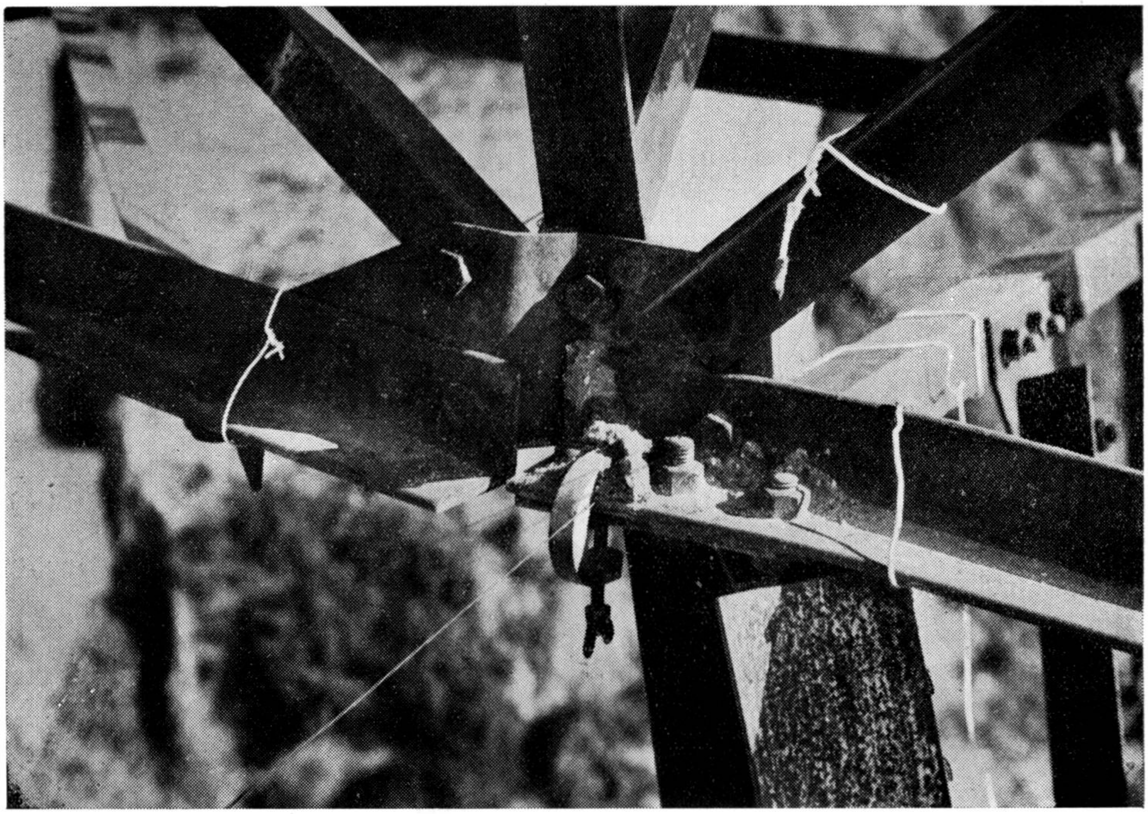

FIG. 9. Rupture of a gusset plate

to a wire connected to the structure under test. To maintain the wire under constant stress, springs having suitable deformability are employed. Optical levelling is used to measure the displacements of the tower base.

Strains are measured by electrical resistance strain gauges protected from hygrometric variations by the method developed by Philips.

A small observation post was built, for the control of the tests, fig. 7. The simple system of manual regulation of the forces by chain hoists proved to be perfectly satisfactory. Instructions to the operators are given by loud-speakers from the observation post.

The first tower tested in this installation was for the 220 KV lines at present being constructed in the country. The base of this tower is rotated through 45° in relation to the direction of the line.

These tests revealed the defficiency of certain types of joints fig. 9, which were thus replaced by more suitable ones.

In these tests the relation between the forces S_1 and S_2 acting on the upper arms was 1/3 whilst isostatically it should be 1/3.3, values which are not very different.

At present tests are being carried out on a type of tower similar to the one above but designed for another type of cable.

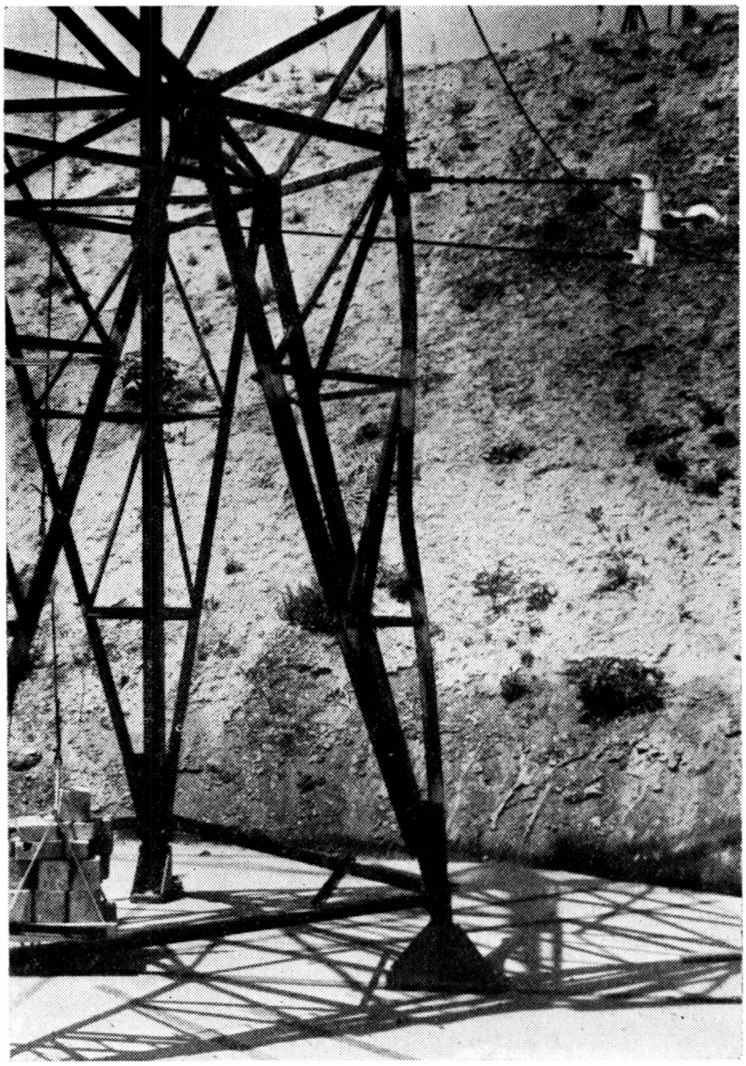

FIG. 10. Buckling of a strut

The failure load for the transverse forces, experimentally determined, was 1.5 times the working load. Failure occurred through the buckling of the strut near the base, fig. 10.

SUMMARY

This paper presents the methods followed at the Laboratório Nacional de Engenharia Civil in carrying out tests on models and prototypes of towers for electric lines of 150 and 220 KV. Some conclusions obtained from the tests are also given briefly.

ZUSAMMENFASSUNG

In der vorliegenden Arbeit werden die Methoden beschrieben, die vom Laboratório Nacional de Engenharia Civil in Lissabon für Versuche mit Modellen und Prototypen zur Prüfung von Leitungsmasten für 150 und 220 KV verwendet wurden. Einige Ergebnisse dieser Untersuchungen sind kurz dargestellt.

RESUMO

Nesta comunicação apresentam-se os métodos seguidos pelo Laboratório Nacional de Engenharia Civil na realização de ensaios sobre modelos e sobre prototipos de postes metálicos para linhas eléctricas de 150 e 220 KV. Referem-se também alguns resultados obtidos nestes ensaios.

RÉSUMÉ

Dans ce rapport sont presentées les méthodes suivies au Laboratório Nacional de Engenharia Civil pour la réalisation d'essais sur modèles et sur prototypes de pylônes métalliques pour lignes électriques de 150 et 220 KV. On y donne aussi quelques résultats obtenus au cours de ces essais.

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