399

IMPROVEMENT ON THE TOWER TESTING METHODOLOGY

Working Group
B2.08

December 2009

Improvement on the Tower Testing Methodology

CIGRÉ SC B2.08
Working Group

WG B2.08

IMPROVEMENT ON THE TOWER TESTING METHODOLOGY

Working Group

Members

Convenor: J.B.G.F. da Silva (BR)*****, **Secretary:** D. Hughes (GB)***,** L. Binette (CA), J. Fernandez (ES), A. Fuchs (DE)*****, R. Jansson (SE), L. Kempner (US)*****, D.I. Lee (KO), N. Masaoka (JP), G. Nesgard (NO), V. Numminen (FI), L. Pellet (FR)*****, J. Peralta (PO), R.C. Ramos de Menezes (BR)*****, J. Rogier (BE), J.D. Serrano (ZA), E. Thorsteins (IS), S. Villa (IT)*

Corresponding Members

C.G. Alamo (VE), G. Brown (AU), G. Gheorghita (RO)*, R. Guimarães (BR)***,** H Hawes (AU), C. Laub (CZ), F. Legeron (CA), T. Leskinen (FI), M. Ishac (CA), J.M. Menéndez (CU), F. Meza Rosso (BO), K. Nieminen (FI), R. Peixoto (BR), J. Prieto (ES), C. Thorn (GB), J. Toth (CA), K. Van Dam (Belgium), M. Vanner (UK), N. Lemieux (CA)*****

*Task Force Members

ISBN: 978-2-85873-086-5

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

ABSTRACT:

For a long time, new tower designs have been validated by loading tests. IEC 60652, "Loading Tests on Overhead Line Structures", was first published in 1979 to standardize and provide guidance for performing Transmission Tower Tests.

After some years of practical experience with that standard, the Working Group Cigré SCB2.08 decided to review its application.

During this period, it has been promoted significant changing in the philosophy for the design of transmission lines, evolving from the deterministic approach to the probabilistic based analysis. As far as the structures are concerned, the load tests have been performed in compliance with the IEC 60652 Standard which still does not fully include the principles of the probabilistic method (according to IEC 60826). Concepts such as the statistical distribution of tower strength, strength factor (ØR), 10% exclusion limit strength, etc, need to be taken into account due to their importance for the tests both philosophically and from the practical point of view.

As said above, to review the application of the standard, as well as to discuss the influence of the probabilistic concepts in the methodology for loading tests on towers, Cigré Working Group B2.08 established the Task Force 5 – Improvement on the Tower Testing Methodology.

With this objective, two Questionnaires were prepared and circulated among B2.08 Group members. The aim of that Task Force was to produce a technical brochure consolidating the opinions of the experts around the world which could be helpful for those directly involved with load tests on overhead line towers and/or to provide support for future revisions on standard documents.

INTRODUCTION

For a long time, new tower designs have been validated by tower loading tests. Clients, designers, tower manufacturers and the personnel of a testing facility meet in a test station area for the simulation of the extreme operational conditions during the life time of a tower. In order to make the different interests of all the participants compatible and to give a guide for such tests, the standard IEC 60652 was published in 1979.

After some years of practical experience with the standard IEC 60652, the Working Group Cigré SCB2.08 decided to review the application of the standard. A new Task Force was established investigating:

- The experience gained with the application of the standard,
- Uncertainties and shortcomings observed during application,
- Suitability of the clauses in the standard,
- Crucial conditions for validation of a new tower design by a load test,
- Potentials for improving the standard.

A questionnaire was prepared by the Task Force Leader, D. Hughes, and distributed in 1997. He added some explanations to all the questions or stated his own opinion in order to make answering easier.

The questionnaire followed the sequence of clauses in IEC 60652 and focused on:

- Restriction of scope,
- Necessity of tests,
- Classification of tests,
- Methods of erection,
- Necessity of destruction tests,
- Selection of tower heights,
- Sources of material,
- Selection of critical load cases,
- Accuracy, balancing, grouping, duration of load application in steps,
- Dynamic effects,
- Sequences of load cases,
- Acceptance criteria regarding deflection limits and hole deformations,
- Procedures in an event of failure,
- Material quality checks,
- Post test procedures,
- Test programs and test reports.

Eight experts from five (5) different countries responded the questionnaire. Due to the extended scope of the questionnaire and the different opinions in the responses, the answers could not be evaluated immediately. Consequently, a revision on the IEC 60652 was started and finalized in 2002 without using the results and recommendations of the questionnaire launched by the Cigré Working Group.

In the meantime, a second questionnaire was proposed in 2005 by L. Pellet, the French representative in the Working Group. The objective was to find out the practice regarding tower design validation: Validation by a full-scale loading test or numerical validation, and if the latter is practiced, under which conditions or restrictions.

This subject corresponds well with one of the questions of the first questionnaire regarding the object of tower testing: "Shall the standard state why testing is necessary." Responses were received from thirteen (13) countries. The evaluation of the answers revealed different practices in countries. Advantages of both numerical validation and full-scale test method were summarized. This comparison represents an excellent support for clients to take decisions whether new tower designs shall be tested or not.

Responses on the second questionnaire were quite successful. Those positive replies encouraged the Working Group to re-evaluate the answers given to the first questionnaire. The Working Group agreed that the Task Force scope should be expanded to review also the IEC 60652 last edition (of 2002) to provide support to IEC TC11, Maintenance Team MT 1, which deals with the necessity of upgrading IEC transmission line standards after a certain period of time.

An adhoc Group composed by A. Fuchs, G. Gheorghita, L. Kempner, L. Pellet, N. Lemieux and R. Guimarães, all members of WG08, was agreed to summarize the replies for each question and complete some points which have been considered to be substantial. Furthermore, the initial questionnaire was supplemented in the brochure's content by the corresponding clauses of the revised standard IEC 60652 (2002) – done by the Working Group member S. Villa. As the result, the following important items were recommended to be revised when IEC 60652 will be updated:

- Reasons for testing,
- Accuracy and precision of loading measuring device,
- Load cells location and rigging arrangement,
- Acceptance criteria.

Furthermore, the Working Group members pointed out that the design philosophy for transmission lines has changed towards probabilistic based analysis. The actual IEC 60562 (2002) does still not fully include the principles of the probabilistic method. Concepts such as the statistical distribution of tower strength, strength factors and 10% exclusion limit strength need to be taken into account due to their importance. The brochure provides information on the investigations and experience made in Brazil during the last years.

As some test stations still do not position the load measuring devices at the load application points, investigations were made to determine the friction losses in pulley systems and to analyze the behavior of sheaves under load. The results are added to the brochure.

Summarizing, this document presents consolidated opinions of the experts around the world regarding the practice of tower design validation and tower testing. The information given can be used for those directly involved with load tests on overhead line supports. Simultaneously, the document can provide support for future revisions of the standard IEC 60652, and can be used as a guideline for the work of the IEC TC11 Maintenance Group.

IMPROVEMENT OF TOWER TESTING METHODOLOGY

1. OBJECT

1.1. Target

Tower test methods of transmission line supports are codified in IEC 60652. After some years of application of the first edition of the standard IEC 60652 (1979) in practice, the experience of the experts involved in tower testing were surveyed by the members of the Task Force which was established by Cigré SCB2 Working Group 08 in 1997. Some findings have already been considered when the standard was revised in 2002. The responses to a new questionnaire launched in 2005 revealed, that there are still substantial issues that should be addressed to IEC TC11 for future revisions of IEC 60652 (2002).

Furthermore, the consequences for tower testing due to the change in design philosophies for transmission lines towards probabilistic based analysis should be investigated. The actual IEC 60562 (2002) does still not fully include the principles of the probabilistic method. Concepts such as the statistical distribution of the material properties, strength factors and exclusion limits need to be taken into account due to their importance.

Beside the critical review of the IEC 60652 (2002), the document presents consolidated opinions of the experts around the world regarding the practice of tower design validation and tower testing. Arguments are given for a numerical tower design validation as well as for validations by full-scale tower testing. The information given can be used by all those who are directly involved with load tests on overhead line supports.

1.2. Review of IEC 60652

To review the application of IEC 60652 (1979), the Task Force members thought that, the best way to start the works on the subjects, was to study item by item the existing standard currently used around the world as a basic document for carrying out the overhead line support tests. For this purpose, D. Hughes, the Task Force Leader, prepared and circulated a questionnaire for collecting WG members' responses. He added some explanations to all the questions or stated his own opinion in order to make answering easier.

Eight experts from five (5) different countries responded the questionnaire. Due to the extended scope of the questionnaire and the different opinions in the responses, the answers could not be evaluated immediately. Consequently, a revision on the IEC 60652 was started and finalized in 2002 without using the results and recommendations of the questionnaire launched by the Cigré Working Group.

After an adequate period of time for Group discussions, an adhoc Group composed by the members A. Fuchs, G. Gheorghita, L. Kempner, L. Pellet, N. Lemieux and R. Guimarães was agreed to summarize the replies for each question and complete some points which have been considered to be substantial. Furthermore, the initial questionnaire was supplemented by the corresponding clauses of the revised standard IEC 60652 (2002) – done by Working Group member S. Villa. As the result, the following important items were recommended to be revised when IEC 60652 is updated:

- Reasons for testing,
- Accuracy and precision of loading measuring device,

- Load cells location and rigging arrangement,
- Acceptance criteria.

A summary of the replies obtained from the first questionnaire, as well as the corresponding clauses of IEC 60652 (2002) are given in Chapter 2 of this brochure.

A second questionnaire was issued by L. Pellet (WG08 member) and addressed to the Working Group in 2005. The questionnaire was entitled “Lattice Tower Validation Practices” and its main purpose was to collect the responses of the group to the following two questions: “Would it be satisfactory to validate a lattice tower design by one or several numerical calculations rather than performing a mechanical test?” and “In which condition would it be acceptable and with which safety factors?”

This subject corresponds well with one question of the first questionnaire regarding the object of tower testing: “Shall the standard state why testing is necessary.” Responses were received from thirteen (13) countries. The evaluation of the answers revealed different practices in countries. Advantages of both numerical validation and full-scale test method were summarized. This comparison represents an excellent support for clients to take decisions whether new tower designs shall be tested or not.

1.3. Probabilistic Design

The design philosophy for transmission lines has changed towards probabilistic based analysis during the last years. The actual IEC 60562 (2002) does still not fully include the principles of the probabilistic method. Concepts such as the statistical distribution of the material properties, strength factors and exclusion limit need to be taken into account due to their importance. The basic concept for the potential use of the “Bayesian Approach” in the interpretation of tower test results is presented. Chapter 3 and Annexes A and B report about the investigations and experience made in Brazil and give recommendations for future revision of IEC 60652 (2002).

1.4. Test Equipment

Although many test stations in the world are equipped with modern load measuring instruments, some test stations still do not position the load measuring devices at the load application points. Investigations were made to determine the friction losses in pulley systems and to analyze the behavior of sheaves under load. The results are shown in Annexes C and D.

2. COMPARISON WITH IEC 60652

2.1 IEC 60652 definitions

The IEC Standard 60652 (2002) comprises the following definitions which are still not defined in IEC 60050(466) – “International Electrotechnical Vocabulary – Overhead Lines”:

2.1.1 Client
Organization which contracts with the testing station and provides the test specification.

2.1.2 Design load
Load for which the support has been designed.

2.1.3 Failure load
Point at which the support cannot carry any additional load.

Note: It is also known as the limit state failure load and is determined during a destruction test on the support.

2.1.4 Test report
Document summarizing all the relevant aspects of the tests.

Note: It is recommended that the definitions listed herebefore shall be supplemented in IEC 60050(466).

2.2 The First WG08 TF05 Questionnaire

2.2.1 General

After some years of application of the standard IEC 60652 in practice, the Working Group decided to review the application of the standard. A new Task Force was established investigating:

- The experience gained with the application of the standard,
- Uncertainties and shortcomings observed during application,
- Suitability of the clauses in the standard,
- Crucial conditions for validation of a new tower design by a load test,
- Potentials for improving the standard.

A questionnaire was prepared by the Task Force Leader D. Hughes and distributed in 1997. D. Hughes added some explanations to all the questions or stated his own opinion in order to make answering easier.

The questionnaire followed the sequence of clauses in IEC 652 and focused on:

- Restriction of scope,
- Necessity of tests,
- Classification of tests,

- Methods of erection,
- Necessity of destruction tests,
- Selection of tower heights,
- Sources of material,
- Selection of critical load cases,
- Accuracy, balancing, grouping, duration of load application in steps,
- Dynamic effects,
- Sequences of load cases,
- Acceptance criteria regarding deflection limits and hole deformations,
- Procedures in an event of failure,
- Material quality checks,
- Post test procedures,
- Test programs and test reports.

Eight respondants from five countries, Brazil, France, Slovakia, South Africa and United Kingdom, answered the first questionnaire.

The following chapters show the questions, a summary of their answers and the quotation of the relevant clause in the revised standard IEC 60652 (2002).

2.2.2 Scope

2.2.2.1 Voltage Limitation:

Is there any reason why the voltage should be limited to "above 45 kV"?

Summary of Responses:

According to most contributors, there is no reason why the voltage should be limited to above 45 kV. The only restriction is that it should not duplicate other standards.

Contents in IEC 60652 rev.02, 2002

Chapter 1 "**Scope**" says:

"…..
It is applicable to the testing of supports and structures of overhead lines for voltages above 45 kV; it can also serve as reference to the testing of lower voltage supports.
….."

2.2.2.2 Type of structure:

Should the standard's Scope positively embrace steel, concrete and wood poles and, perhaps other structures?

Summary of Responses:

The tower testing standard should not be restricted to one type of material and may include alloys, concrete, timber. But some contributors think that the testing method for very flexible structures, like poles, requires more attention than for rigid structures.

During the tests, the applied loads can vary depending on the structure movement and the rigging system used.

In addition, attention should be paid to the redundancy or contradiction between the different existing standards.

Contents in IEC 60652 rev.02, 2002

Chapter 1 “Scope” says:

“….. There is no restriction on the type of material used in the fabrication of the supports which may include, but not be limited to, metallic alloys, concrete, timber, laminated wood and composite materials. If required by the client, this standard may also be applied to the testing of telecommunication supports, railway/tramway overhead electrification supports, electrical substation gantries, street lighting columns, wind turbine towers, ski-lift supports, etc……”

2.2.3 Object

2.2.3.1 Has the standard "codified" tower testing?

The standard quotes the 'Object' is to "codify the methods of testing towers". Has the standard "codified" tower testing?

Summary of Responses:

Some contributors think that “codified” is not an appropriated word, and that the IEC document should be a recommendation; others think that it should be a standard that imposes a method.

Contents in IEC 60652 rev.02, 2002

Chapter 1 “Scope” says:

“This International Standard codifies the methods of testing supports for overhead lines.
……”

2.2.3.2 The standard should state why testing is necessary.

Summary of Responses:

Two different points are discussed.

- Should tower tests be performed for each fabricator?

  That proposition was rejected by the participants, because it is often desirable and imperative to have a range of fabricators to supply work. If it is acceptable that the methods for detailing and fabrication are the same from one manufacturer to another, and that quality control procedures are performed, there is no reason to consider that tower tests are specific to one fabricator.

- Should the standard state why testing is necessary?

  The reasons which can induce a designer to perform a tower test should be pointed out: tower tests are performed "to verify the design method (and inherent assumptions), the method of (member) detailing and the quality of fabrication, manufacture, and materials."

But there is no consensus about the necessity of tower testing.

The latter problem was taken up in 2005 by a separate questionnaire, considering that computer softwares have been improved during the last years. This second questionnaire wanted to get responses whether new tower design validation can be performed by numerical calculations or full-scale tower tests are still seen to be necessary.

Again there was no consensus in the answers received. But the quantity and quality of the answers received have been much higher and better compared with the first questionnaire. Therefore, the arguments given for tower testing could be inserted in a revised standard IEC 60652.

The results of the second questionnaire are summarized in Chapter 3.

Contents in IEC 60652 rev.02, 2002

Chapter 4"Categories of tests" says:

"With respect to the purpose of the test, the level of instrumentation and the method of execution, this standard refer to two categories of tests:

a) Design tests;
b) Sample tests.

4.1 Design tests

Design tests are normally carried out on prototype supports, with one or more of the following objectives:

a) as part of a research and/or development program in the design of an innovative support;
b) to verify compliance of the support design with the specifications (also known as type tests);
c) to develop and/or validate a new design standard or methodology;
d) to develop and/or validate new fabrication processes.

When tests are carried out to verify design parameters, the test support shall be identical as far as possible to the production supports (see clause 5, first paragraph). Tests on full scale sections or part of the support may also be undertaken.

Design tests shall be carried out to at least the design load or to failure, especially when testing according to 4.1b) and/or 4.1c).

4.2 Sample tests

These are intended for use either prior to or during the fabrication of the production of a batch of supports to act as a check on the quality of the fabrication, or on the materials being used.

The support may be taken at random from the production supports during manufacture.

Sample tests are taken to a specific percentage of the design load (usually 100 %), as stipulated in the test specification."

(WGB2.08 members' opinion is that, it is not a current industry practice to perform "sample loading test" on towers. They are not practical from the supply point of view and should be replaced by a quality assurance program that could guarantee that the towers being fabricated are as closer as possible to the tower that has been tested).

2.2.4 General Test Criteria

2.2.4.1 "Prototype" tests and "Acceptance" tests.

This clause refers to "prototype" tests and "acceptance" tests. These are required to be defined.

Summary of Responses:

All the contributors agreed that IEC 60652 should be revised in order to better clarify the "prototype" and "acceptance" definition.

Contents in IEC 60652 rev.02, 2002

In chapter 4 "Categories of tests" are defined:

Chap 4.1 "Design Tests" - Design tests are normally carried out on prototype supports, with one or more of the following objectives:

a) as part of a research and/or development program in the design of an innovative support;
b) to verify compliance of the support design with the specifications (also known as type tests);
c) to develop and/or validate a new design standard or methodology;
d) to develop and/or validate new fabrication processes.

Chap 4.2 "Sample Tests" - These are intended for use either prior to or during the fabrication of the production of a batch of supports to act as a check on the quality of the fabrication, or on the materials being used. The support may be taken at random from the production supports during manufacture…….

2.2.4.2 Method of Erection:

The method of erection of the test structure is significant for the results of the test and should be addressed.

Summary of Responses:

The contributors' opinions are different:

- The majority of the contributors agreed on the matter that theoretically the strength of a structure may be affected by the method of erection, even if it may be difficult to quantify its effects on the strength of the structure;
- On the other side the majority agreed that practically it is difficult to impose the erection method that will be utilized on the site (erection by crane, by derrick, by gin-pole, by helicopter etc.) to the testing stations; this could make erecting a test tower slow, dangerous and more expensive.

Figure 1 – Tower erection – 230 kV Double circuit guyed tower

Contents in IEC 60652 rev.02, 2002

The chapter 8 “Assembly of support” says:

- The test support shall be erected on a footing that simulates the design assumption;
- The testing station shall proceed with the assembly of the support in accordance with the instructions provided by the client;
- In the case where the testing station encounters a difficulty in the assembly or erection of the support, the client shall be informed and shall decide on the modifications required;
- If requested by the client, a report of assembly shall be provided by the testing station. This report may include a video of the different phases of the assembly and any particular difficulty encountered.

2.2.4.3 Destruction Tests

The standard should address the methodology to be employed for destruction tests

Figure 2 – Destructive test – 230 kV Double Circuit tower

Summary of Responses:

If a destruction test has to be carried out, the majority of the responders agreed to perform it in one of the normal cases increasing both the transverse and the vertical loads (or even longitudinal in case of “anti-cascade” loading hypothesis or dead-end tower) as required; this solution could allow to gain information on actual vs. predicted behaviour, and the failure load could then be related to an increase in span utilization. In cases when there is no ice involved, it is a current practice to increase only the transverse (or longitudinal) loads.

Figure 3 – Destructive test –230 kV TL Guyed tower

A contributor raised some doubt as to the relationship of the failure load to a wind speed and return period. In the contributor’s opinion a high wind failure load related back to a wind speed could produce a design wind speed in the 'hurricane' / 'tornado' range, and thus provide justification to use the tower in areas affected by high intensity winds, but the behaviour of these wind forces is far from that assumed by most designers.

Contents in IEC 60652 rev.02, 2002

There is no mention of the “Destruction Test”, but only a connection with it in chapter 9.3 “Loads Level” where it says:

“The test loads shall be applied in increments to 50 %, 75 %, 90 %, 95 % and 100 % of the specified loads.

If required by the client, additional load levels may be considered.”

2.2.4.4 Foundation Displacement

The possibility for simulating foundation displacement (differential settlement) should be included.

Summary of Responses:

Some contributors considered all the possible foundation displacements, coming from errors during foundations erections, from the elasticity of soil under the loads and from ground movements.

The majority of contributor’s opinions on the question are against the possibility to simulate foundation displacement during a prototype tower test for the following main reasons:

- There are a large number of different combinations of foundation displacements (horizontal, vertical, due to error in the stub setting or foundation erection, ground movement etc.);
- It would simply add another unpredictable factor into the testing, as it would be impossible to determine whether any failure was influenced by the alignment;
- The FOS (overload factor) already cover the matter.

In any case all the contributors agreed that to calculate the maximum foundation displacement accepted by the tower could be very helpful to define acceptance criteria for foundation erection errors or stress in the tower elements due to ground movements.

For these reasons some contributors suggest to perform a whole series of tests on similar towers with different foundation errors in order to study the sensitivity of the structures in relation to their methods of fixing. This proposal should, however, be more oriented toward a research programme and not be a part of an international standard.

<u>**Contents in IEC 60652 rev.02, 2002**</u>

There is no mention of foundation displacement simulation.

In chapter 6 “Test specification” says:

“The client shall prepare and transmit to the testing station, at an agreed time prior to the delivery of the support, the following appropriate information:

……
Foundation setting tolerances and verticality tolerances of the support.
……”

In chapter 8 “Assembly of support” says:

“The test support shall be erected on a footing that simulates the design assumption.
………”

Figure 4 – Test arrangements - 500 kV TL Guyed Tower

2.2.4.5 Structure heights

For structures that have the possibility of more than one height the standard should address the method by which the height of tower should be selected for the test.

Summary of Responses:

For the majority (3 of 5) the choice of tower to be tested should be left to the discretion of the designer.

On the tower test height, the following suggestions were provided:

- Body extension with short leg extension where the loads are higher;
- Long slender leg extensions with a small angle between the leg and bracing that are more vulnerable to failure;
- The most frequent combination of tower height in the line;
- The body extension with the highest stress levels;

- The tallest structure with the highest body and leg extension.
- The tallest structure with the highest body extension, higher leg extensions and, if possible, with one short leg (compression leg).

Contents in IEC 60652 rev.02, 2002

There is no mention.

2.2.4.6 Source of materials

As mentioned in Item 2.2.4.2 above it is considered the test should be specific to the manufacturer. Therefore the source of materials used should be pre-defined.

Summary of Responses:

All the contributors, with only one exception, agreed on that the materials for the tower test have to follow the same material standards and fabrication tolerances used in the production of all towers.

Providing these, the tests need not to be considered specific to one fabricator.

Contents in IEC 60652 rev.02, 2002

Chapter 5 "General test Criteria" says:

"For a design test the material(s) and the manufacturing processes used in the fabrication of the prototype support shall be to the same specifications as those used during the fabrication of the production supports. These specifications shall include the member sectional properties, connection details, e.g. bolt or weld sizes, material grades and fabrication processes.

Figure 5 – Buckling on tower leg extension

Figure 6 – Failure detail

Chapter 15 “Material Specification” says:

The selection of materials, manufacturing tolerances and engineering properties (i.e. geometrical and mechanical characteristics) for the support are the responsibility of the client.

The materials used for the fabrication of a prototype support shall be representative of the materials used in production structures and within the appropriate industry specification.

Figure 7 – Member fail by compression

2.2.4.7 Prototype Finishing (New)

Summary of Responses:

Only two contributors answered this question; they agreed that the prototype towers to be tested have to be galvanized since there is no "black tower" in the field. In case, for any reason, the supplied towers will be black ones, then, the prototype tower should also be tested without galvanization.

Contents in IEC 60652 rev.02, 2002

Chapter 5 "General test Criteria" says:

" …… Prior to the commencement of the prototype support fabrication, agreement (between the client and the testing station) shall be made with regard to the surface coating of the support. ….."

Figure 8 – Non galvanized prototype - 230 kV Double circuit tower

2.2.5 Load Application

2.2.5.1 Critical load cases

The standard should recommend how the 'critical' load cases to be tested should be selected from the 'design' cases.

Summary of Responses:

According to the most of the contributors, the standard should recommend how the critical load cases to be tested should be selected from the design cases. The standards should provide the principles but keeping the designer's responsibility for selecting the critical cases to client's approval.

That guidance should state, for instance, that at least one test from each of the following categories: normal service, failure containment and safety, should be chosen. Also the cases (possibly limited to a maximum number) should be selected from those conditions which give rise to the maximum number of members in the structure loaded over 80% of their design capacity. Consideration must also be given to load cases which produce the maximum compression or tension in main tower members, such as leg members and crossarm chords.

Contents in IEC 60652 rev.02, 2002

Chapter 6 "Test specification" says:

"The client shall prepare and transmit to the testing station, …., the following appropriate information:

- The exact position of the load application points for each loading case. *(WGB2.08 comment: "The right positions of the wind loads to be applied on the tower body should be discussed among the designer and the testing station)"*
- The design loads to be applied on the support for each loading case.

Chapter 11 "Sequence of test loading cases" says:

"The sequence of test loading cases shall be determined by the client and stated in the test specification. It is recommended to choose first those tests having the least influence on the results of the successive tests. If agreed by the client, the testing station may adjust the test sequence to simplify the test operations or to reduce the cost of the test."

2.2.5.2 Test tower - the most perfect of all

With the introduction of IEC 60826 (or other probability based method for deriving the structure design loads) the test loads should consider that the test tower is, in all probability, the most perfect of all towers to be constructed on the project.

Summary of Responses:

This issue is one of the most important and problematic points of this document. Some contributors questioned if the test tower could be really considered the most perfect tower from a batch of towers, others argued what would be the criteria to determine the most perfect tower.

The fact is that there are other questions related to that subject which have not been answered yet. Two of these questions are how to take into account the concept of "exclusion limit: and how to correlate it with the "strength factor" (according to IEC 60826) and the 100% ultimate load step? Unfortunately there is no consensus on these questions, but some discussions/suggestions are given in the annexes A and B.

Contents in IEC 60652 rev.02, 2002

Chapter 5 "General test criteria" says:

"For a design test (according to 4.1b or 4.1c), the material(s) and the manufacturing processes used in the fabrication of the prototype support shall be to the same specifications as those used during the fabrication of the production supports. These specifications shall include the member sectional properties, connection details, e.g. bolt or weld sizes, material grades and fabrication processes.

…….
If a sample test is required on a production support, the components may be chosen at random from the batch. ………"

2.2.5.3 Test Loads

The loads for which the tower is tested should be related to those for which the tower has been designed.

Summary of Responses:

All the responders agreed that the towers should be tested to their design loads, rather than the loads coming from a particular site application. One important objective of the test is to verify the design method so that it is possible to have confidence in those towers and extensions which are not tested.

Contents in IEC 60652 rev.02, 2002

Chapter 5 "General test criteria" says:

"Whether it is for the design test (according to 4.1b) or the sample test, the support shall successfully withstand the loads specified by the client. …."

Chapter 4.1 "Design tests" says:

"…..
Design tests shall be carried out to at least the design load or to failure, especially when testing according to 4.1b (to verify compliance of the support design with the specifications) and/or 4.1c (to develop and/or validate a new design standard or methodology)"

Chapter 4.2 "Sample tests" says:

"…….
Sample tests are taken to a specific percentage of the design load (usually 100 %), as stipulated in the test specification."

2.2.5.4 Uplift Loading Cases

The standard should give guidance for the method of testing structures designed for uplift.

Summary of Responses:

In general, most of the contributors agreed that uplift tests for the entire tower are not necessary. Besides that, the majority of the test stations do not have the facilities to apply uplift loads on the towers. On the other hand, uplift tests on individual members such as crossarms are desirable and not difficult to be conducted.

Contents in IEC 60652 rev.02, 2002

The Standard does not mention Uplift Loading cases.

Chapter 5 "General test criteria" says:

"Whether it is for the design test (according to 4.1b) or the sample test, the support shall successfully withstand the loads specified by the client. …."

Chapter 4.1 "Design tests" says:
"…..
Tests on full scale sections or part of the support may also be undertaken. …."

2.2.5.5 Load application

The rigging arrangement and method of attachment to the structure should simulate the design assumptions.

Summary of Responses:

Contributors agreed that the rigging arrangement and method of attachment to the structures should simulate design assumptions. Moreover they recommended that the fittings used to apply the loads during the tests should be the same used in the line, reflecting the site conditions.

Contents in IEC 60652 rev.02, 2002

Chapter 7 "Test Programme" says:

The test programme shall include but not be limited to the following information:

- The method of load application.
- A drawing of the test rigging arrangement and attachment details.
- The position of the dynamometers and/or load cells and the position of angle transducers in the case of resultant load applications.

Chapter 9.1 "Combined loads" says:

"If, for practical purposes, certain loads (e.g. due to wind on the support) have to be combined, the value of the resultant, its direction, and its application point shall be shown in the test programme."

Chapter 9.2 "Precaution for loads application" says:

"The dynamometer/load cells shall be located in the test rigging as close as practical to the load application point on the support.

Similarly, it is recommended that the test rigging should be arranged so as to minimize any load eccentricity.

The testing station shall minimize the influence of any contact between the test rigging and the support; where this is not practical, this shall be drawn to the client's attention.

2.2.5.6 Accuracy of applied loads

The standard should identify an acceptable tolerance for the measurement of applied loads.

Summary of Responses:

Most of the contributors recommended that the standard should state that each separate load (tension) in respect of the application on the structures should not exceed a tolerance varying from ±1% to ±2% of the maximum load.

Regarding the accuracy of the applied loading when the load cell is remote from the load application point, some responders also expressed their worries about the losses due the friction through the rigging. They suggested that the standard should address that issue and a possible wording to this matter could be "where the load cell is not directly connected in line with the load attachment point and there are multi-sheave rigging blocks between the load cell and the load attachment point, due allowance shall be made for the frictional resistance in the rigging ropes and blocks." Unless the Test Station can provide different values supported by actual test measurements, those contributors suggested to use the friction values taken from British Rope hand-book supported by BS MA48-1976, which are 2% for sheaves with roller bearings and 6% for plain bearings and these values are accumulative. Another relevant point concerning the friction factor is that a contact with British Ropes (Bridon) indicates that the actual friction is dependent on the ratio of the sheave and pin diameter.

Contents in IEC 60652 rev.02, 2002

Chapter 9.2 "Precaution for loads application" says:

"The dynamometer/load cells shall be located in the test rigging as close as practical to the load application point on the support.

Chapter 10.1 "Load and angle measurements" says:

"The accuracy of the dynamometers and/or load cells and/or angle transducers shall be such that errors in measurement are not greater than 1 % at full scale (including the effect of the test rigging). The accuracy specified assumes a standard deviation of 3 σ.

2.2.5.7 Grouping of Loads

2.2.5.7.1. Method of load application

The standard should address the different methods by which the test loads may be applied; hydraulic rams, winches, scale (dead weight) pans and suggest the advantages of one method to another.

Summary of Responses:

There is a general agreement that the standard should present the advantages and disadvantages of methods by which the test loads may be applied. However, these methods should not be imposed or specified. One respondent proposed to include a list of the different traction methods as a reminder.

Contents in IEC 60652 rev.02, 2002

There is no mention of it.

2.2.5.7.2. Wind Direction

The significance of the direction of the wind during the test should be highlighted.

Summary of Responses:

There is a general agreement around the importance of the local wind during test (direction and intensity). Test stations should measured meteorological data during tower test. However, there is no agreement on the wind speed and direction value from which the test should be suspended.

Contents in IEC 60652 rev.02, 2002

In chapter 16 "Test report" says:

"The testing station shall document all relevant test information and data.

The test report shall include the following data:

………

t) Local meteorological data during the tests series (e.g. wind speed and direction, temperature, etc.). …………..."

2.2.5.8 Application of Load in steps

2.2.5.8.1. Importance of 100% step to the tower test

The standard should identify that only the 100% step is of any importance to the outcome of the tower test

Summary of Responses;

There is a general agreement that only the 100% step is important for the tower acceptance. Intermediate load steps are perceived useful only for balancing the loads prior to the 100% step. See 2.2.5.10.1 for additional comments on intermediate load steps.

However WG-08 members have additional comments on this issue:

- Intermediate steps are useful for comparing measured displacements and stresses to theoretical values and possibly for rapidly identifying an abnormal structural behaviour;
- They could be essential to ensure proper rigging settings (load orientation and rigging interference);
- They could prevent a premature collapse of the whole tower.

Contents in IEC 60652 rev.02, 2002

Chapter 9.3 “Load levels” says:

“The test loads shall be applied in increments to 50 %, 75 %, 90 %, 95 % and 100 % of the specified loads.

If required by the client, additional load levels may be considered.”

Chapter 9.5 “Loading rate and holding period” says:
“ ……..
For the final 100 % level, the loads shall be maintained for a minimum of 1 min and for a maximum of 5 min. The holding period chosen for the final level shall be included in the test programme.
……..”

Chapter 13 “Acceptance Criteria” says:

“The performance of the support shall be considered acceptable if it resists the specified design loads (at 100 %) for 1 min without failure of any components or assemblies even though a longer holding period may have been specified.

2.2.5.8.2. Loading steps

The loading steps should be re-defined to provide a more realistic representation of the in-situ loading.

Summary of Responses:

There is a general agreement that loading a tower with 100% of vertical dead load prior to the application of the transverse or longitudinal load might be a more realistic procedure. Nevertheless this may represent a meanless procedure since only the 100% step is really important for the tower acceptance (also see 2.2.5.8.1).

Contents in IEC 60652 rev.02, 2002

There is no mention of it.

2.2.5.9 Dynamic Effects

The present standard precludes dynamic loads. This should be reconsidered.

Summary of Responses:

The opinion of the responders is when a dynamic load from a broken conductor case is specified by the designer it should be applied statically during a full-scale tower test. Dynamic loads from wind and broken conductors on a transmission line tower are a reality, but the industry has addressed these cases using a static load philosophy. An attempt to simulate a broken conductor dynamic load would be easier than a dynamic wind load. Proposals have been developed to simulate this loading using a drop-weight concept. Because the dynamic frequency of a broken conductor load is significantly higher than that of most transmission line towers, this load would only be felt on the tower is an impulse load. After the dynamic event is over, the tower would then be loaded with the conductor static residual load.

Therefore, utilities have used two different approaches to address this type of loading event. For towers to resist the full impulse load a dynamic impact factor is applied to the conductor tension and this load is applied as a static load during a tower test. Utilities who accept potential tower failure adjacent to the broken conductor span use the static residual load during the tower test. In a transmission line system the behaviour of an individual tower to a broken conductor event can be influenced by the unbroken conductor phases, the overhead ground-line, and the deflection of the adjacent towers. These parameters would be difficult to simulate on a tower test station.

Contents in IEC 60652 rev.02, 2002

There is no mention of it. (WGB2.08 comment: *"Any how, if real dynamic loadings due to wind or broken conductor is to be simulated, a complete revision on the Tower Testing Standard should be performed)"*

2.2.5.10 Adjustment of loads per step

2.2.5.10.1. Range of loadings

The permissible range of loadings has little relevance and should be removed / adjusted.

Summary of Responses:

The responders agreed that the 100% load step is the most important stage of the full-scale tower test. At this load step a tolerance should be applied, such as +/- 2% of the individual load components (transverse, longitudinal, and vertical) and/or +/-5% on the average of all the loads. There was a difference of opinion concerning the intermediate load step stages. One respondent clarified the purpose of the intermediate loads. The purpose of these load stages are for characterizing the tower behaviour as the loads approach the 100% level. These load stages would identify any non-linear behaviour and would allow further calibration between the full-scale test and the structural analysis software. At these lower load stages a higher tolerance maybe acceptable, such as +/-5% – 10% of the individual load components.

Another important point concerning the intermediate load stages is that the tower can be checked for premature failure of individual members. This could prevent the total loss of the tower at a lower load stage and the resulting delay in delivery of the tower steel for transmission line construction.

Contents in IEC 60652 rev.02, 2002

Chapter 9.4 “Tolerances on applied loads” says:

“For each load level, the applied load measurements shall be considered acceptable if they are within the limits shown in Table 1:

Table 1 – Load tolerances

Load level (%)	Acceptable range (%)
50	49 to 51
75	74 to 76
90	89 to 91
95	94 to 96
100	100 to102

2.2.5.10.2. Balancing of loads

At all load stages the loads must be maintained, i.e. they should be 'balanced' in respect to each other and, especially at 100% kept at or above the 100% load.

Summary of Responses:

The responders agreed that balancing of the test loads can be problematic. It was recommended that the 100% hold not start until after the loads show some level of balance. It was also pointed out that at the 100% level, and load balancing appeared to be stable, there is typically little load shifting, unless the tower is experiencing an initial large displacement failure mechanism.

Contents in IEC 60652 rev.02, 2002

There is no mention on the balancing of loads; for the acceptable range see previous comment to question 2.2.5.10.1.

2.2.5.11 Duration of load application

Summary of Responses:

There was only one respondent and they had no comments. The duration of load, particularly at the 100% load stage has been a point of issue within the tower testing industry. The commonly recommended levels are 5 – 10 minutes. It is this reviewer's opinion that a 5 minute hold period is acceptable.

Contents in IEC 60652 rev.02, 2002

Chapter 9.5 "Loading rate and holding period" says:

" ……..
For the final 100 % level, the loads shall be maintained for a minimum of 1 min and for a maximum of 5 min. The holding period chosen for the final level shall be included in the test programme. …….."

Chapter 13 "Acceptance Criteria" says:
"The performance of the support shall be considered acceptable if it resists the specified design loads (at 100 %) for 1 min without failure of any components or assemblies even though a longer holding period may have been specified.

2.2.6 Sequence of test loading cases

The sequence of the test cases should be determined by the designer, not the client

Summary of Responses:

The majority of the responders agreed that the order of testing should be determined by the designer. Some responders added that the designer's decision should be in agreement with the test station and/ or approved by the client. Only one responder stated that the customer of the test station chooses the order of tests.

However, whoever makes the decision; he should be aware that international practice and publications about tower tests differ in their recommendation regarding the sequence of test load cases. Some responders recommend starting with the most severe case, but others advise the contrary.

Contents in IEC 60652 rev.02, 2002

Chapter 6 "Test Specification" says:

"The client shall prepare and transmit to the testing station, at an agreed time prior to the delivery of the support, the following appropriate information:

- The design loads to be applied on the support for each loading case.
- If the support is to be realigned between individual tests.

Chapter 11 “Sequence of test loading cases” says:

“The sequence of test loading cases shall be determined by the client and stated in the test specification. It is recommended to choose first those tests having the least influence on the results of the successive tests. If agreed by the client, the testing station may adjust the test sequence to simplify the test operations or to reduce the cost of the test.”

2.2.7 Check of tower mechanical strength

2.2.7.1 Deflections

The standard should be modified to address deflection limits for all structure types (acceptance and serviceability limits).

Summary of Responses:

The majority of the responders say that no serviceability limits shall be addressed. Moreover, a test standard shall neither discuss the purpose/ application of the tower nor the specification of the final customer. The reviewer fully agrees to that and adds that the standard shall give the approach only how to measure the tower deflections. Deflection limits depending on the purpose/ application of the tower cannot be regulated by a test standard but have to be considered in the specification and design. More importance shall be attached to residual deflections when the tower has passed one test successfully as the subsequent test will be effected. Two responders highlighted this effect of residual deflections and recommend to specify limits.

Other responders proposed to list some acceptable deflection limits for steel poles (if they are included in the test standard) and urban transmission line towers at every day conditions.

Contents in IEC 60652 rev.02, 2002

Deflection limits are no indicated.

Chapter 10.2 “Deflection measurements” says:

“…… The accuracy of measurements shall be 25 mm. The accuracy specified assumes a standard deviation of 3 σ.”

2.2.7.2 Ovalization of holes

Acceptance of hole ovalization and bolt deformation should be subject to an upper limit of the deformed shape.

Summary of Responses:

The opinion of the responders is divided into two groups: 50% says no limits of acceptance shall be defined as it would be not worthwhile, not practicable and the load case which caused deformations cannot be identified. The question was also raised who shall evaluate all holes after tower dismantling.

The other 50% says yes to define acceptance limits and propose some criteria in case of deformed hole shapes. Criteria for acceptable deformations could be functions of grade of steel, grade of bolts and bolt diameter or simply no tears shall be apparent at the hole edges.

Contents in IEC 60652 rev.02, 2002

Chapter 13 "Acceptance criteria" says:

"…… Ovalization of holes and permanent deformation of bolts shall be accepted. ……"

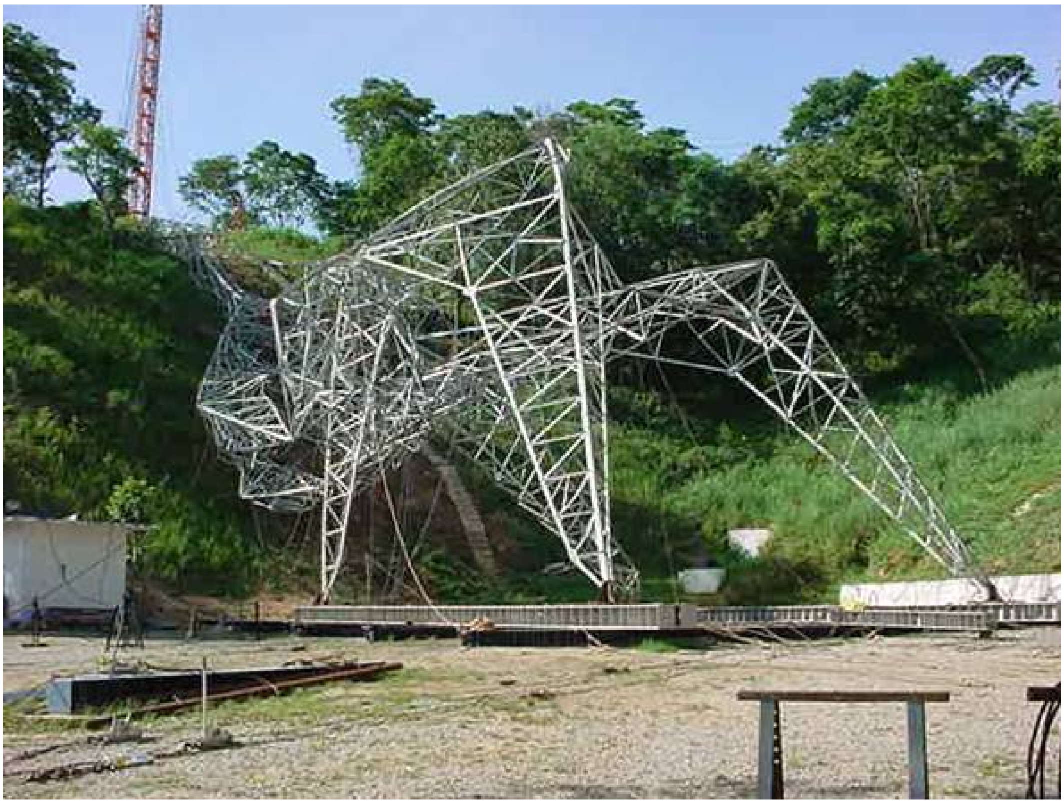


Figure 9 – Destructive test - 500 kV TL Tower

2.2.8 Procedure in the event of a premature collapse

During a tower test if a tower passes one or more proving tests but suffers damage during another such that it is necessary for the tower to be rebuilt (with or without modification) is it necessary for the tests which have already been successfully completed to be repeated?

Summary of Responses:

The general opinion of the responders is that tests which have been performed successfully shall not be repeated.

Only if the tower had been modified in a substantial way (complete new tower with significantly modified details) as consequence of a failure, all tests shall be repeated.

Figure 10 – Failure at 75 % loading

Failure at 75% of expected loading: Detailing error. One bolt diagonal missing. Calculations specified 2 bolts, drawings detailed just one.
Conclusion: Shear on the diagonal bolt.
Remedial works: Diagonal connection redetailed with 2 bolts, test continued.

Contents in IEC 60652 rev.02, 2002

Chapter 14 “Premature failure” says:

“14.1 Design tests:

In the event of failure at less than 95 % of the specified design load, the failed component(s) may be replaced by other component(s). The modified structure shall be retested to resist 100 % of the specified design loads.

In the event of failure between 95 % and less than 100 % of the specified design loads, with the exception of the final load case (frequently the destruction load case), the support shall be modified and retested. If failure occurs in the final load case, the client may elect not to retest the modified support.

In the event of failure at 100 % of the specified design loads but at less than 1 min into the holding period, the client may accept the support without modification.

14.2 Sample tests:

In the event of a failure at less than 100 % of the specified design load, the failed component(s) shall be replaced by identical components and the support retested. In the event of a subsequent failure, the client may reject the batch of supports from which the test support has been drawn.

Figure 11 – Failure at 75 % loading

Failure at 75 % of expected loading: No evidence as design error.

Conclusion: Premature failure identified as eccentricities/partial fixing moment loads.

Remedial works: Thickness of the connection plate increased and inferior section of the shield wire support redetailed.

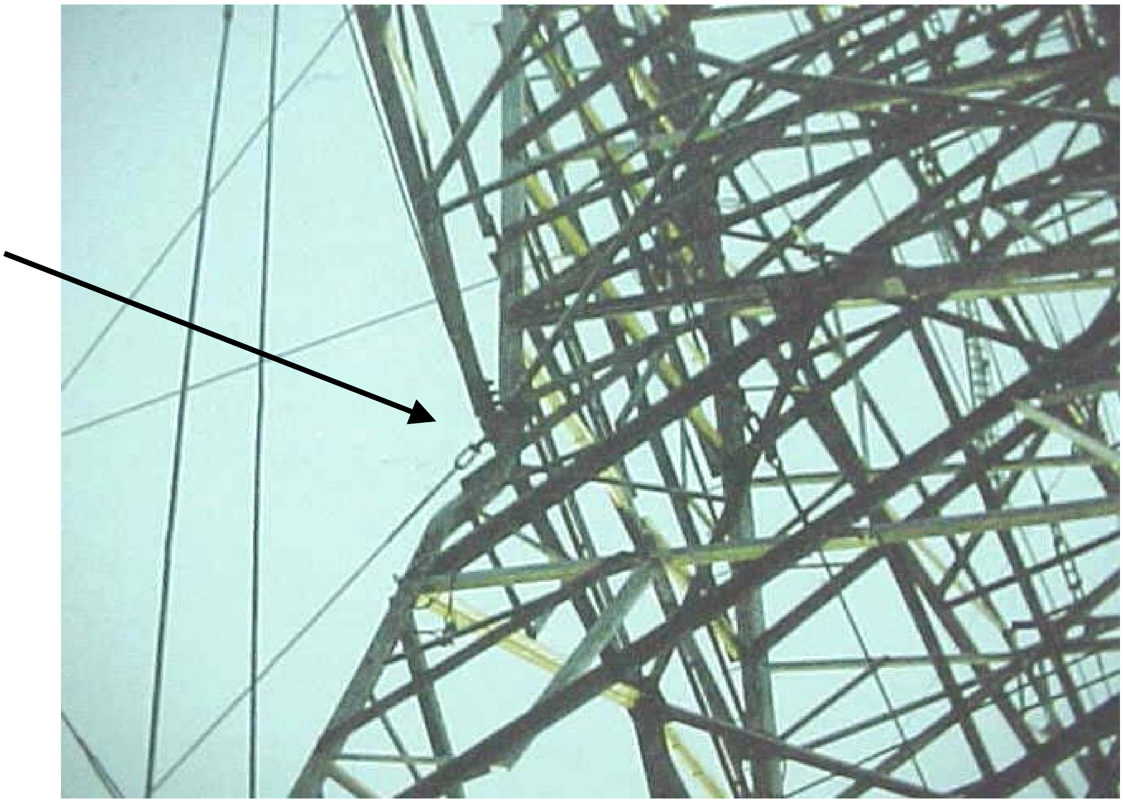


Figure 12 – Failure at 90 % loading

Failure at 90% of expected Loading: No evidence as design error.

Conclusion: Premature failure identified as eccentricities/partial fixing moment loads.

Remedial works: Crossarm connection redetailed and leg member fabricated again without increasing sections. Test continued.

Figure 13 – Double TL 230 kV – 90 % stage

Failure at 90% of expected loading: Failure due to eccentricities

Conclusion: Partial fixing moment loads

Remedial works: To increase members, strengthening the detail. Test continued.

In the event of a failure at 100 % of the specified design load but at less than 1 min into the holding period, the client may accept the batch of supports from which the test support has been drawn."

Figure 14 – Failure at 100 % loading

Failure at 100% of expected loading while waiting 5 minutes holding time. No evidence of design error. Failure identified as eccentricity on detailing.

Conclusion: Partial fixing moment loads

Remedial works: Modification on the joint detailing to avoid eccentricity, and tower retested.

Figure 15 – Failure at 100 % loading

Failure when completing 100% of expected Loading: No evidence of design error.

Conclusion: Failure due to eccentricities.

Remedial works: Reinforce the buckled element, and to retest the tower.

2.2.9 Check of quality of materials used for prototype test

2.2.9.1 Materials employed for the test tower

The standard should address acceptance criteria for the dimensional (physical) properties of the steel as well as the mechanical properties.

Summary of Responses:

All the responses agreed that the acceptance criteria for the physical and mechanical properties of the steel (material) to be used are those specified on the relevant international inspection standards, *e. g.* EN ISO 9001:2000, sub-chapter 7.4.3 Verification of Purchased Product, ASTM A6, ASTM A36, ASTM A572, etc.

Contents in IEC 60652 rev.02 2002

Chapter 5 "General test criteria" says:

"For a design test (according to 4.1b or 4.1c), the material(s) and the manufacturing processes used in the fabrication of the prototype support shall be to the same specifications as those used during the fabrication of the production supports. These specifications shall include the member sectional properties, connection details, e.g. bolt or weld sizes, material grades and fabrication processes. ……..

If a sample test is required on a production support, the components may be chosen at random from the batch.…..".

Chapter 15 "Material specification" says:

"The selection of materials, manufacturing tolerances and engineering properties (i.e. geometrical and mechanical characteristics) for the support are the responsibility of the client.

The materials used for the fabrication of a prototype support shall be representative of the materials used in production structures and within the appropriate industry specification.

On completion of the test series, it is recommended to take samples from the prototype support in order to verify the compliance of the material with the specifications.

The number and location of samples are the responsibility of the client.

If the components of the support do not fulfill the requirements of the applicable industry standards, the client may declare the test invalid and reject the support."

2.2.9.2 Post test check of material yield points

The test specimens should be taken randomly from the structure.

Summary of Responses:

All responses conclude that member material tests should be performed.

Related to the number of samples, five to eight samples are normally checked after an successful test.

Related to the definition, South Africa definition “most highly stressed” could be used.

Contents in IEC 60652 rev.02, 2002

Chapter 15 “Material specification” says:

“……. On completion of the test series, it is recommended to take samples from the prototype support in order to verify the compliance of the material with the specifications.
The number and location of samples are the responsibility of the client.………..”

2.2.9.3 Redundants

The statement that redundants have little influence on the collapse of structures should be removed as, for heavy structures, it is not correct.

Figure 16 – Failure of redundant member

Failure when completing 100% of expected Loading

Remedial works: Reinforce the buckled element, and to retest the tower.

Summary of Responses:

UK 3 and Brazil agree with the suggestion.

France agree that the problems of static redundancy have a great influence on the mechanical strength of the supports, but they are related to design, and have no justification in being in a test Standard.

Contents in IEC 60652 rev.02, 2002

There is no mention on the redundant.

2.2.9.4 Verification of design principles

If it is accepted that one of the purposes of a (prototype) tower test is to verify the design and detailing then a method is required for verifying the design of those portions of the tower that are not subject to test.

Summary of Responses:

All responses conclude that "not all tower types and individual heights can be subject to test."

UK3 considers that parts not tested must be designed / detailed / fabricated in a similar manner to the test tower, and subject to independent check, both of design and detailing.

The Engineer may require a higher material factor for untested structures, i.e. higher minimum reserve factor.

UK4 considers that the scope of test is verification of Design Principles. Test on individual towers or portions of the tower have to be considered to be representative of the design and detailing practice adopted by the tower designer.

France considers the purpose of Standard IEC 652 is to define the test procedure.

Brazil commented about the difficulty or impracticability to cover all structural combinations. It could be said that the test results could be accepted as a way to verify the adequacy of the basis of design and detailing (calculation assumptions) as well as the technical tools

South Africa considers that Maximum design parameters should be tested not maximum project utilization parameters.

A suggestion, for the same structure using equal and/or unequal leg extensions a computer simulation could be used as a method for structure evaluation.

Contents in IEC 60652 rev.02, 2002

Chapter 5 "General test criteria" says:

"For a design test (according to 4.1b or 4.1c), the material(s) and the manufacturing processes used in the fabrication of the prototype support shall be to the same specifications as those used during the fabrication of the production supports. These specifications shall include the member sectional properties, connection details, e.g. bolt or weld sizes, material grades and fabrication processes. …..”.

Figure 17 – Guy cross arm fail by tension

Failure when completing 120% on a destructive test

2.2.10 Presentation of test results

Summary of Responses:

The test report shall conform to the Standard, IEC 60652:2002, requirements.

Contents in IEC 60652 rev.02, 2002

Chapter 16 “Test report” says:

“The testing station shall document all relevant test information and data.

The test report shall include the following data:

a) Indication of the applicable standard for testing supports (IEC 60652),

b) Designation, type, and description of the support,

c) Name of the support manufacturer,

d) Name of the support designer,

e) Name of the client,

f) Dates and location of testing,

g) Names of the persons present during the tests,

h) List of workshop and/or erection drawings of the test support, including any modifications,

i) Methods and measurements of the joints assembly,.

j) Description of all anomalies and difficulties met during the assembly as well as corrective measures adopted by the client,

k) Rigging drawing used to apply the test loads,

l) Brief description of the test facility including the number, location, range and calibration charts or tables of every load and angle transducer or other load measuring devices, as well as the accuracy of the equipment used to measure the test loads,

m) Loads required at the various points on the support and at each load level,

n) Holding period for the final level,

o) Calibration records,

p) Deflection measurements,

q) Strain gauge measurements if appropriate,

r) In case of failure:
  - Maximum loads applied to the support prior to failure;
  - A description of the failure;
  - When required by the client, engineering properties of the failed component(s);
  - If required by the client, a video film of the failure,

s) Photographs showing the whole support before, during and after tests and, where appropriate, details of any failure,

t) Local meteorological data during the tests series (e.g. wind speed and direction, temperature, etc.),

u) If required by the client, observations of noticeable permanent deformations during the dismantling,

v) When applicable, the number of the certificate of quality assurance of the station according to ISO/IEC 17025,

w) If required by the client, the engineering properties of component samples taken from the support."

2.2.11 Acceptability of test station

The test station itself must be suitable and fit-for-purpose. Criteria for the acceptability of the test station should be established.

The test station should be able to demonstrate that:

- ***Its rigging equipment is well maintained (pulley blocks greased, etc.)***
- ***The load application devices (winches, hydraulic rams, etc.) should not impart dynamic effects when operated - i.e. should be smooth running.***
- ***The load measuring devices are calibrated against an instrument that itself is calibrated by a recognized independent calibration organization.***
- ***The equipment employed for the mechanical testing of the steel is calibrated.***
- ***The layout of the station is safe - if the structure should collapse the control building is not located dangerous***
- ***The station pad is clear of loose material during the test (collapse of the structure can cause loose material to be projected into the air resulting in possible danger to the witnessing personnel)***
- ***All erection personnel are provided with adequate safety equipment to perform their function and is certified.***
- ***All equipment employed for lifting personnel has been regularly tested***
- ***The station has adequate provision to limit the collapse of the tower in the event of a failure, i.e. crane, back-stays or other.***
- ***If the tower is allowed to collapse completely the failed member(s) can be very difficult to identify.***

Summary of Responses;

All criteria defined in the question, together with Slovakia, France and South Africa remarks, shall be applied as conditions for the acceptability of the test station.

Contents in IEC 60652 rev.02, 2002

Chapter 5 "General test criteria" says:

"……. If required by the client, the testing station shall be accredited by an external organization to perform this type of test according to the procedures of quality assurance defined by ISO/IEC 17025."

2.2.12 Test Program

The standard should identify the minimum requirements for the test program under the following headings:

- ***Required design loads,***
- ***Detailed rigging arrangement suitable for checking load corrections,***
- ***Load corrections due to the rigging self weight, arrangement (pulley reduction gear) and inclinations,***
- ***Required loads to be applied and recorded on the load measuring devices during the test at 100% (and other loading stages as appropriate),***
- ***Location of deflection readings.***

Summary of Responses:

There is a general agreement on this point. Notice that IEC 60652, 2th edition already includes most of these minimum requirements

Contents in IEC 60652 rev.02, 2002

Chapter 7 "Test programme" include all the requirements above mentioned, together with other information as indicated here below:

"The test programme shall include but not be limited to the following information:

- The expected test date.
- A description of the proposed foundations for the test support.
- The method of load application.
- A drawing of the test rigging arrangement and attachment details.
- The position of the dynamometers and/or load cells and the position of angle transducers in the case of resultant load applications.
- The case of resultant load applications.
- The position of deflection measurement points.
- The position and orientation of strain gauges if appropriate.
- The tolerances (loads, resultant angles, deflections, strain gauges).
- Details of applied loads for each test load case, load increment and holding period.
- Holding period for the final level.
- Loading rate for elastic-plastic materials and creep-sensitive materials.
- The category of the test (design or sample)."

2.2.13 Post Test procedure

The standard should require a random re-test of the load cells

Summary of Responses:

There is a general agreement on a minimum of 3 load cells re-test. However, accuracy of ±1% is not considered realistic by many respondents.

WG-08 members believed that re-tested load cells should be selected by the client.

Contents in IEC 60652 rev.02, 2002

Chapter 10.1 “Load and angle measurements” says:

“The accuracy of the dynamometers and/or load cells and/or angle transducers shall be such that errors in measurement are not greater than 1 % at full scale (including the effect of the test rigging). The accuracy specified assumes a standard deviation of 3 σ.

All dynamometers and/or load cells and/or angle transducers shall be calibrated before and after every test series. The calibration instruments shall be certified at least once a year.

2.2.14 Check Assembly

The check assembly of a tower is an important part of the process to verify the adequacy of a tower and its subsequent production. The title should be changed to "Tests on overhead line structures" and address, in detail, the minimum requirements for assembly tests.

Summary of Responses:

There is a general agreement on the importance of the assembly test and that minimum requirements should be added to the standard.

However, WG-08 members do not believe that the IEC 60652 title should be changed.

Contents in IEC 60652 rev.02 2002

In general there is no mention on the minimum requirements of assembly test.

Only chapter 8 “Assembly of support” says:

“……. The testing station shall proceed with the assembly of the support in accordance with the instructions provided by the client.

In the case where the testing station encounters a difficulty in the assembly or erection of the support, the client shall be informed and shall decide on the modifications required.

If requested by the client, a report of assembly shall be provided by the testing station. This report may include a video of the different phases of the assembly and any particular difficulty encountered.”

The title has been changed into "Loading tests on overhead line structures”

3. The Second WG08 TF5 Questionnaire

“Lattice tower validation practices”

Prepared by LAURE PELLET

As said in item 1.2, in 2005 a second Questionnaire was prepared and addressed to the Cigré Working Group. The Questionnaire was entitled “Lattice Tower Validation Practices” and its main objective was to collect the Group responses to the questions proposed as per item 3.1 – Premises, as follows:

3.1 Premises

In many countries the compliance of every new transmission line support family design with the specifications has to be verified by mechanical full-scale tests. The progress recently made on the numerical calculation of structures strength involves a questioning about the possibility of reviewing these tower validation practices: would it be satisfactory to validate a lattice tower by one or several numerical calculations rather than performing a mechanical test? In which conditions would it be acceptable and with which safety factors?

In order to enrich this thinking, it is interesting to have an overview of the international practices concerning the validation of tower design. The opinions of the Cigré SCB2.08 respondent members are hereafter summarized.

3.2 The questionnaire

In order to enrich this research, we would like to have an overview of the international practices concerning the validation of tower design. That’s why we invite you to answer this few questions.

Name:
Country:
Company:

1 - Which standards do you rely on for the design of lattice towers?

2 - Do you usually perform tests on new supports?

3 - Have you ever used a “numerical validation” without any mechanical test?

4 - Do you plan to investigate the possibility of a “numerical validation” of lattice towers? Why?

If the answer to question 3 is yes:

5 - In what cases do you consider that a numerical validation is acceptable?

6 - Was the tower computed by an independent company?

7 - Did you consider the manufacturing and erection uncertainties in the calculations? Did you use particular safety factors?

If the answer to question 3 is no:

8 - What is the main reason? (Numerical tools are not precise enough. A test is necessary anyway, for other reasons than validation. A numerical validation would be as expensive as a mechanical test. Etc…).

9 - What would be the progress to make so that you could rely on a numerical validation?

3.3 Participants

Seventeen respondants from thirteen countries, Australia, Belgium, Brazil, Canada, Finland, Germany, Iceland, Japan, New Zealand, South Africa, Spain, Venezuela and USA, answered the second questionnaire.

3.4 Summary of responses

The answers to the second questionnaire can be summarized as:

The points of view and the practices concerning new tower validations can be very different from a country to another. The arguments given by the different participants are summarized below:

Advantages of numerical validation:

- Sometimes mechanical full-scale tests are not possible (for very large towers…)
- Lower cost
- Some of the participants think that the we now have a great experience in the field and that if the tower is computed by experienced designers, with a correct computer program, and using standardised details the knowledge of the behaviour is sufficient to avoid testing.
- Similar scale structures aren't tested.
- The test is only representative of the tower being tested (particular height, material, erection…). In most cases only one tower variant is tested for a few load cases. Numerical validation allows to test much more load cases and every variant of towers.
- Towers may pass the mechanical full-scale test although not properly designed.

Advantages of full-scale testings:

- Long standing practice
- Some consider that for numerical validation, there is a need for very advanced numerical techniques (modelling of eccentricities, joint slip…)
- Some of the participants have a lack of confidence in numerical simulation. They think we need more successful comparisons with tests.
- Additional cost of the towers due to additional safety factors
- Legal aspect. Full scale testing is a good proof of structural adequacy and prevent from arguments about bad modelling in case of failure.
- Tests are a good way to identify defects due to detailing and erection
- Tests prevent from human mistakes and material quality problems
- Tests validate the numerical modelling of the tower family

4. PROBABILISTIC DESIGN

During the past years, the transmission design industry has been promoting significant changes in the philosophy for the design of transmission lines, evolving towards the probabilistic based analysis. As concerns to structures, the load tests have been performed in compliance to the IEC 60652 Standard which still does not fully include the principles of the probabilistic method (according to IEC 60826). Concepts such as the statistical distribution of the materials properties, strength factors ($Ø_R$), exclusion limits, etc, need to be taken into account due to their importance for the tests both philosophically and from the practical point of view.

Applying IEC 60826 as basic philosophy for the design of overhead lines, means in terms of structures to adopt the following general equation:

$$\gamma_u Q_T \leq R_{10\%}$$

Where:

Q_T = Design loading referred to a returned period T (or/with specific load factors);

$R_{10\%}$ = Design strength with a 10% exclusion limit

γ_u = Use factor coefficient

On the other side, the 10% exclusion limit strength should be obtained by:

$$R_{10\%} = \phi_R R_C$$

Where:

R_C = Characteristic strength assessed by calculations and/or calibrated by loading test or professional experience;

ϕR = Strength factor to be used in the design and evaluated as function of the statistical distribution of towers strengths.

So, as far as the OHL supports design and calculations are concerned, to use the IEC 60826, enables the designer to estimate the characteristic strengths of the towers applying realistic known “Strength factors”. Both, the characteristic strength and the strength factors, are concepts, parts of the same issue involving design and loading tests.

The statistical distribution of tower strength has been studied by Paschen *et al* (Report 22-13, “Probabilistic evaluation on test results of Transmission Line towers”, Cigré Session 1988) and Riera *et al* (Report 22-305, "Evaluation of the probability distribution of the strength of Transmission Line steel towers based on tower test results", Cigré Session 1990). Both studies have similar conclusions indicating a log-normal distribution as the best fitted curve for the population of results available, with mean values "little above" 100% and coefficient of variation below 10%.

From the second study, carried out in Brazil, the following design curve could be established:

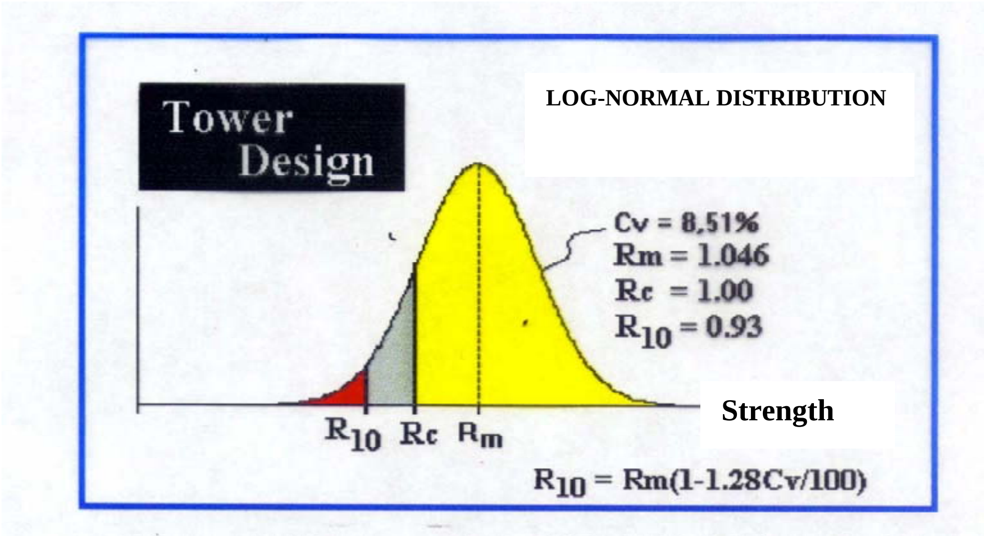


Figure 18 – Tower strength statistical distribution – Brazilian experience

Where Cv = Coefficient of Variation, Rm = Mean Strength, Rc = Design Strength, R_{10} = 10% Exclusion Limit Strength;

From that study, the 10% Exclusion limit Strength and the "Strength Factor" of "$\phi_R = 0.93$" could be calculated.

A corresponding loading test on a probabilistic based analysis criteria should has as targets to reach statistical distribution curves such as, for example, in the specific case of the Brazilian experience, as shown on Figure 16; where Q_T = Design Load.

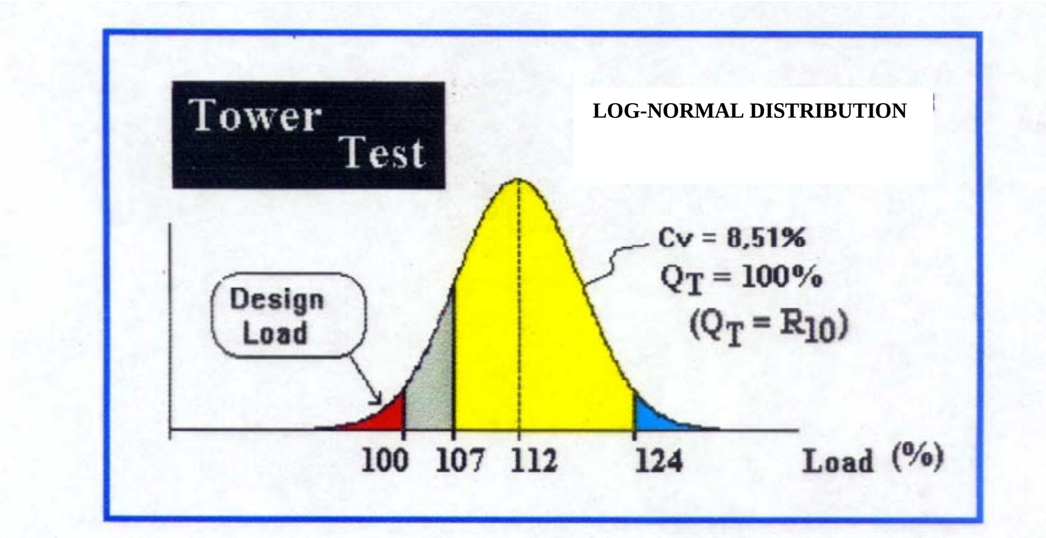


Figure 19 – Tower test strength statistical distribution – Brazilian experience

So, the results of tower loading tests on a probabilistic based philosophy should have the objective to confirm and/or calibrate both curves in terms of "Loading and Strength". Similar studies and calculations can be done (and should be encouraged) reflecting other experiences and local circumstances.

With the aim of having loading tests on towers on a probabilistic based approach level, the WG08 TF5 have discussed and agreed upon the following assumptions / proposals:

- Tower tested to withstand 100% specified Loading**.**
- The tower is designed for loads which already consider the possible loading, its application (use factor) and material variation factors.
- If the tower withstands 100% loading it has achieved the mean loading RC.
- The tested tower has withstood the required mean load of the population**.** This is proposed as the Withstand Test**.**
- The Characteristic Strength and standard deviation of the tower population has not been determined for a single tower that has passed the WITHSTAND TEST.
- The actual strength of a tower can only be determined from a test to failure, i.e. a Destruction Test.
- IEC 60826(1979) allows the destruction test to be at the option of the purchaser.
- For long lines, a destruction test on suspension tower(s) be required as part of the acceptance criteria for reasons of reliability and economy, and even for the increase of the industry knowledge bank.

- The Destruction test should be performed on a “probabilistic” loading case, i.e. normal conditions.
- The acceptance level be subject to the purchaser - but should be nominated at the time of the order.

Regarding guidelines for selection of a minimum failure load, the following recommendations are given:

- The failure load selected should be based on past knowledge of previous failure loads for towers designed and detailed:
- to the same standards;
- employing the same range of available section sizes and material sources;
- to the same level of quality control over material supply and fabrication;
- and differentiate between “economically” designed towers, e.g. suspension tower and others (tension towers).

5. PULLEY SYSTEM FRICTION LOSSES – ANALYSIS OF SHEAVE TESTS

Some test stations still do not apply the load measuring device at the load point (for economic or other reasons) or the loads are too small to justify load cells (the loads being applied by direct weights through pulley systems). Therefore, the problem of friction in pulley systems and angle sheaves is actual and cannot be neglected due to the measured friction values. Tests have shown that the friction for plain pin bearing pulleys (under static conditions) could reach up to 8% of the applied load - PER SHEAVE.

This is in contradiction with the actual standard IEC 60652 (2002) which has identified an accuracy of 2% for load and angle measurements. Obviously, this cannot be achieved by test stations which do not utilize direct reading of the load at the point of application.

The test stations should be committed to calibrate their load application rigging system in order to ensure the required 2% of load accuracy at the load application point. Otherwise, the load losses due to the pulley or rigging systems – in an extreme case 8% per sheave – have to be taken into consideration.

Annexes E and F indicate the test records for pulley systems. The objective of the performed tests was to identify the losses (amount of friction as percentage of the applied load) and to show how to determine them in practice.

6. CONCLUSIONS

From the responses of the two questionnaires circulated, as well as from the fruitful discussions carried out inside the group, important conclusions could be obtained. Among them, the following should be highlighted:

- The current practice adopted by the industry on testing OHL towers is correct and valid, but it seems that the test objectives should be reviewed.

- Especially for long new lines, at least the light suspension(s) tower(s) should be tested, preferably up to the destruction. It is always important to remark that, according to IEC 60826, those towers should be the “weakest link” of the transmission line system, being, therefore, the risky element.

- When it is not possible, for any reason, to test at least the most numerous suspension tower, the desirable reliability level should be evaluated and adequate “Strength factors $Ø_R$” should be adopted/proposed aiming to reach that target.

- If a “Probabilistic based approach” is used as the main design philosophy, it is recommended to perform the loading tower tests coherent with that philosophy. Using this concept, those tests should be carried out aiming to assess the tower strength:

    - To support expected “loading cases” as minimum;

    - To behave as estimated by the structural calculations, having a “failure strength” compatible with the strength factor ($Ø_R$) adopted.

    - Therefore, as better explained previously in Item 3 and in Annex C, the interpretation and approval of the test results should be based in two premises: the “loading support capability” and the “expected strength/behavior”.

- As far as the test confidence is concerned, as pointed out in Item 4, correct arrangements of rigging systems, accuracy and the right position of the measurement devices are essential to guarantee quality and reliability on tests results. Friction pulley losses on tests arrangements conducted by this Cigré Task Force reveled up to 12% of losses on the rigging system adopted.

- Tests acceptance criteria should be based on “Exclusion limit strength” (R10% according to IEC 60826) and “Strength factor” concepts, as explained in Item 3 “Probabilistic Design” and according to Annex C “Test Acceptance Criteria - Considerations & Proposals” and/or Annex D “The Bayesian Approach”.

Regarding the “Numerical simulation practices” aiming to avoid mechanical tests, according to the answers received from the second questionnaire, the following could be concluded:

- The points of view and the practices concerning new tower validations can be very different from a country to another.

- Advantages of numerical validation:

  - Sometimes mechanical full-scale tests are not possible (for very large towers).
  - Lower cost.
  - Some of the participants think that there is a great experience in the field and if the tower is computed by experienced designers, with correct computer software, and using standardized details, the knowledge of the behavior is sufficient to avoid testing.
  - Similar structures of the same “family” aren’t tested.
  - The test is only representative of the tower being tested (particular height, material, erection). In most cases only one tower variant (basic tower, body extension, leg extensions) is tested for a few load cases. Numerical validation allows for evaluation of more load cases and every combination of body and leg extensions.
  - Towers may be approved in a mechanical full-scale test although not properly designed.

- Advantages of full-scale testing:

  - Long standing practice.

- Numerical validations are valid only if very well advanced modeling techniques and softwares are used (e.g. those able to take into account joint eccentricities, bolts slippage, partial fixing moments, etc).

- Some of the participants have lack of confidence in numerical simulations. More successful comparisons with tests are still need.

- The relative cost of testing is a small percentage of the total line cost and nothing as compared with the cost of a failure in the line.

- Additional cost of the towers due to the use of additional safety factors.

- With respect to the legal aspect, full scale testing is a good proof of structural adequacy and prevents arguments about bad performance and mistakes on the modeling in case of failure.

- Tests are the best way to identify defects due to calculation, detailing, fabrication and erection.

- Tests identify human mistakes and material quality problems.

- Tests validate the numerical modeling of the tower family.

As final comment, the Cigré SCB2-08 believes that this Technical Brochure can be a helpful document for those directly involved with overhead line supports, both in design/calculation and tests. It is recommended, so, that this brochure should be taken into consideration for new revision works on Tower Testing Standards like IEC 60652.

7. ACKNOWLEDGMENTS

The group recognizes the support received from the contributors:

A. King, A. Wirski, B. Jubb, B. Rassineux, C. Thorn, F. Ritky, J. Salewski, J. Bissett, K. Välimaa, M. A. M Cadete, N. Sudo, P. Dindofer.

The WGB2.08 Convenor also thanks Elias Ghannoum and Robert Lake for their works of revision and comments.

8. REFERENCES

[1] IEC 60652-1979 – Loading tests on overhead line structures

[2] IEC 60652 – 2002/2006 – Loading tests on overhead line structures

[3] IEC 60826 - Loading Calculation of OHTL

[4] IEC 1773 – Foundation testing

[5] British Rope handbook

[6] BSI- Design and Operation of Ships' Derrick Rigs - BS MA 48;1976

[7] EN ISO 9001:2000 – Assurance Quality System

[8] ISO/IEC 17025:2005 - General requirements for the competence of testing and calibration laboratories

[9] EN 50341-1:2001 - Overhead electrical lines exceeding AC 45 kV.

[10] ASCE 10-97 - Design of Latticed Steel Transmission Structures. 1997.

[11] DIN VDE Standards

[12] Variability of the Mechanical Properties of Materials for Transmission Line Steel Towers. - Electra nº189.

[13] Statistical Analysis of Structural Data of Transmission Line Steel Towers - Electra nº208.

[14] The Effect of Fabrication and Erection Tolerances on the Strength of Lattice Steel Transmission Towers, Cigré SCB2-08 Technical Brochure.

[15] Report Cigré 1990 Session - nº 22-305 – Evaluation of the probability distribution of the strength of transmission line steel towers based on tower tests results

[16] Report Cigré 1988 Session - nº 22-13 - Probabilistic Evaluation on Test Results of Transmission Line Towers

[17] Diaphragms in Lattice Steel Towers - Electra nr. 199, December 2001.

[18] Recommendations for Angles in Lattice Transmission Towers. - ECCS TWG 8.1. 1985.

ANNEX A

Test Acceptance Criteria
Considerations & Proposals

Prepared by RUY C. R. MENEZES and JOÃO B. G. F. DA SILVA

A.1. PREMISES:

Since IEC 60826 is a "probabilistic based" recommendation for TL design, only a "probabilistic based" tower testing interpretation should make sense.

Therefore, to accept or to reject/reset a test result must be a "probabilistic based" approach.

A.2. DESIGN CRITERIA

According IEC 60826: Ultimate Limit State:

$$R_{10} \geq Q_T$$

Where,

Q_T : Design loading referring to T (return period or/with specific load factor),

$R_{10} = \phi_R R_C$ → design strength with a 10% exclusion limit,

ϕ_R : Strength factor (to be used in the design).

⇒ So, a tower test with a probabilistic approach should be able to check the "design loading (Q_T)" and the design strength ($\phi_{R,}$ R_{10}).

A.3. HOW TO EVALUATE ϕ_R, R_{10}

A.3.1. Cigré Experience

- Report Cigré session 1988, Nº 22-13
  "Probabilistic Evaluation on Test Results of Transmission Line Towers"

- Report Cigré session 1990, Nº 22-305
  "Evaluation of the Probability Distribution of the Strength of Transmission Line Steel Towers Based on Tower Test Results"

A.3.1.1. The designer/ the test station has its own experience: ϕ_R

They should be encouraged to evaluate their own values.

A.3.1.2. Data not available

To use the Cigré experience

BRAZILIAN EXPERIENCE
1990 Cigré Session Paper 22-305

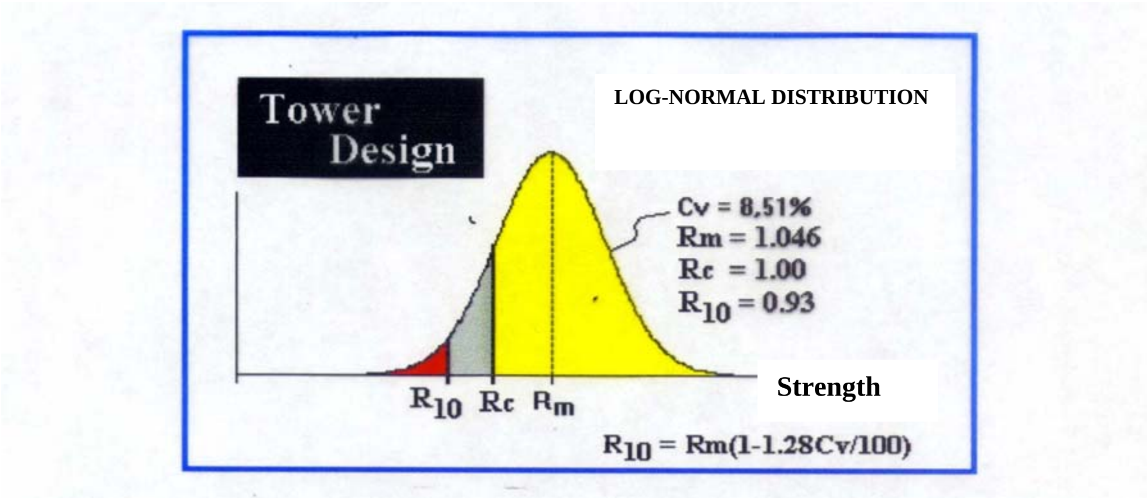


Figure 20 – Statistical tower design curve - Brazilian experience

A.4. ACCEPTANCE CRITERIA FOR SUSPENSION TOWERS

A.4.1. First step: verifying design loads

$$\mathbf{R_{10} \geq Q_T}$$

- Prototype fails under 100% ⇒ test not approved
- Prototype fails at 100% or above ⇒ test "could be" approved

A.4.2. Second step: verifying design strength

$$\mathbf{R_{10} \geq Q_L}$$

Where:

$Q_L = Q_T / \phi_R$
$\phi_R = 0{,}93$ (according to the Brazilian experience)

⇒ $Q_L = 107\%$

a) Prototype fails above 107% ⇒ test approved
b) Prototype fails above 100% and below 107% ⇒ tower design should be re-examined.

A.5. PROBABILITY BASED DECISIONS:

- To accept the test as valid
- To repeat the test without reinforcement
- To reinforce without another test
- To reinforce the tower and test again

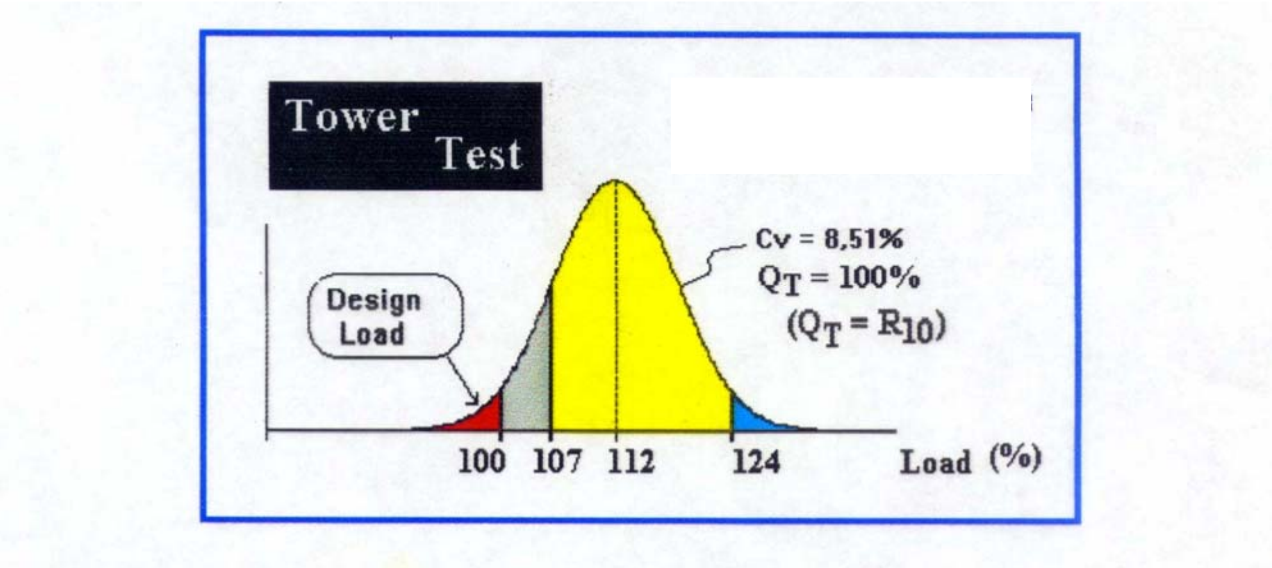


Figure 21 – Statistical tower test strength curve - Brazilian experience

A.6. RECOMMENDATIONS

A.6.1. Destructive tests on suspension towers (the weakest link) must be strongly encouraged in order to get data to update the knowledge about tower resistance under current design practice (Figure 22);

A.6.2. For design of angle, anchorage and terminal (special towers) smaller values of ϕ_R should be recommended;

A.6.3. For special towers, the tests, if possible, should be performed basically to “verifying design loads” (first step) since ϕ_R should be conservative.

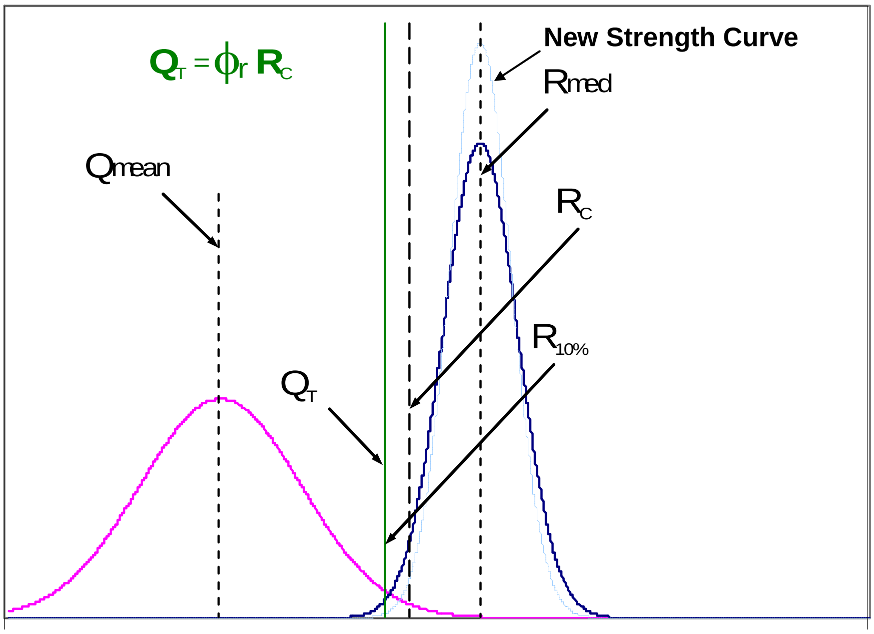


Figure 22 – Test target according IEC 60826

The light blue line, New Strength Curve, should be a permanent objective of the industry practice. The destructive tests are excellent measures for calibrating the tower's strength curves. The knowledge is improved permitting to reach better "coefficient of variations" of the strength curve that can lead to reduced values of ϕR (strength factors) in the future.

ANNEX B

The Bayesian Approach

Prepared by RUY C. R. MENEZES

ON THE USE OF "BAYESIAN APPROACH" FOR THE INTERPRETATION OF PROTOTYPE TEST RESULTS OF TRANSMISSION LINE TOWERS

This technical note presents basic concepts to the potential use of the "Bayesian Approach" in the interpretation of prototype test results, which should be a probabilistic based decision to be coherent to IEC 60826 design methodology.

The main recommendations for TL design, IEC 60826, assumes that the tower strength is a random variable and, as a consequence, it is completely described by a probability distribution. On the other hand, when testing towers, there is still a predominance of deterministic approaches that consider that the prototype must resist up to 100% of the design load as an acceptance criterion. Hence, there is a philosophical incoherence between design procedures and prototype tests.

It is well known that for an accurate estimation of the distribution parameters, a large amount of data is necessary. However, as usually happens in Engineering, the available data are limited and the statistical estimates need to be inferred (or even need to be substituted) by information previously obtained from similar designs. Under the concepts of the classic method of statistical estimation, there is no way to combine the prior information from other designs with real observed data to estimate distribution parameters. Indeed, the unknown parameter is seen as a defined constant to be determined only from the tests.

With the aim of gathering the information previously obtained (prior knowledge) with the current data, resulting in an updated and balanced estimate, there is the statistical estimation method known as the "Bayesian Approach" where the unknown parameters of the distribution are considered as random variables.

BAYESIAN APPROACH - Bayesian inference is a method of analysis that is very useful when comparing hypotheses. It assigns probabilities to all the possible outcomes of an experiment, combines this with all the knowledge once known, and then calculates the probability of each hypothesis occurs.

With respect to the current design practice in engineering, the Bayesian methodology offers a lot of advantages in comparison to the classic methodology, such as: it supplies the formal procedure to incorporate the engineer's experience, expressed in terms of probabilities, with the observed data; it systematically combines the uncertainties associated with randomness and those that arising from errors of estimation and prediction; and it still supplies a formal procedure for systematic updating the collected information.

It can be said that the updated distribution (the posterior) is proportional to the previous distribution (a prior) times a likelihood function, which is given by the new observations (or accomplished test). In case that the previous distribution and the likelihood function are Gaussian, the updated distribution, which will be a multiplication of two normal density functions, will also be Gaussian with mean and standard deviation of the mean given by:

$$\mu_p = \frac{\mu_0\sigma^2 + n\bar{x}\sigma_0^2}{\sigma^2 + n\sigma_0^2} \qquad (1)$$

$$\sigma_p = \sqrt{\frac{\sigma^2\sigma_0^2}{\sigma^2 + n\sigma_0^2}} \qquad (2)$$

Where:

μ_0 is the mean of the previous distribution;

σ_0 is the standard deviation of the mean of the previous distribution;

σ is the standard deviation of the population;

$\bar{x}$ is the mean of the new test;

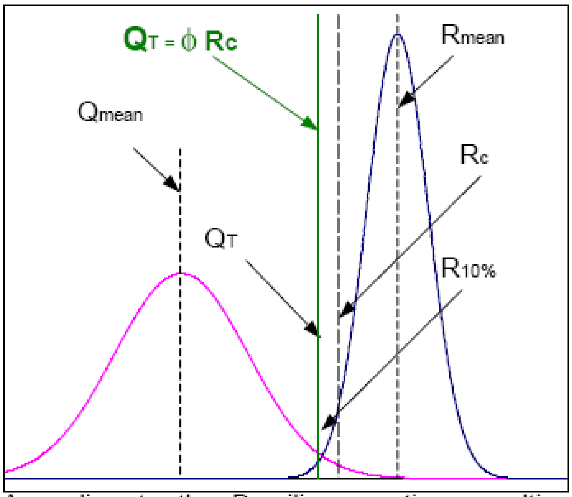
n is the sample size of new test data.

APPLICATION TO PROTOTYPE TESTS - The central idea of the methodology proposed here is that the most important information is contained in the updated distribution (corrected by the tests). Therefore, by using the Bayesian method of statistical estimation, it is intended to update the previous information with prototype test results. By this, a new updated distribution is determined and, as a consequence, new partial safety coefficients can be used to evaluat/interpret the prototype test. The updating of the previous knowledge about the distribution parameters is performed by simple expressions, as equations (1) and (2).

According to IEC 60826, the design equation is given for:

$$\tilde{a}_U Q_T < \ddot{O}_R R_C \qquad (3)$$

Where typical values, according to the Brazilian practice, are:
Q_T is the load effect associated to a return period of T years. For instance, T = 150 years;
R_C are values usually considered as resistance of components, calculated taking nominal values of yield stress (for instance, f_y = 250MPa), Young modulus, etc, into account.
The main idea may be illustrated by figure 1.



According to the Brazilian practice, resulting from an extensive tower test survey, the probability distribution for the tower resistance can be represented, for instance, by a normal distribution with mean of 104.6% and with a coefficient of variation of 8.51%. This yields to a resistance coefficient, Φ_R = 0.93, to be applied to the nominal values in order to have a 10% of exclusion limit. Therefore, if this previous knowledge is taking into account, the tower design is carried out considering such Φ_R = 0.93, which means that the distribution of the tower resistance will follow a similar pdf with similar parameters (IEC 60826 model).

Then, prototype test is carried out either up to 100% of the design loads or to the failure. Occurring the failure, the value of the collapsing load will be used to update the expectation of one of the parameters (mean or coefficient of variation) of the probability distribution for tower resistance by means of the Bayesian Approach.

In other words, herein it is proposed to calculate a new value of Φ_R.

By this approach, the tower design will be accepted or rejected depending on the new resistance coefficient Φ_R, or R_{10}, which is the design resistance representing an exclusion limit of 10%. In other words, it is proposed that the design will be verified again with the new design parameters. Hence, depending on the tower test result and on the adopted safety margin the tower will "pass" or "not pass" the test. By this approach, the tower test acceptance criterion would became a probabilistic based decision.

PRACTICAL EXAMPLE - Consider that from previous designs, an engineer knows that the resistance of transmission lines towers can be satisfactorily modeled by a normal distribution with mean, μ_o, equal to 104.6%, and with a standard deviation of that mean, σ_o, of 4.45 and a standard deviation of the population, σ, of 8.9.

Therefore, the design load of 100% has an exclusion limit of 30.26% and, as a consequence, to obtain an exclusion limit of 10%, Φ_R (that multiplies Rc) must be 0.93.

Now, considering that a new series of tower, designed in agreement with these assumptions, is tested.

Two prototype tests are performed and the following values for the collapse loading are observed: 98.0% and 99.0%, resulting in a mean, $\bar{x}$, equal to 98.5%.

It is then assumed that those new tests can be modeled by a normal distribution. The function of the tests is usually called as likelihood function and it allows updating the previous information.

Considering the result of the new tests and applying Bayesian Approach, it is possible to update the information on the tower strength distribution, which will have properties that result from a combination of the previous information with the result of the new tests. Then, being applied the equations (1) and (2) and being known that the updated distribution will be Gaussian (it results from a combination of two normal distributions) an updated mean, μ_p, of 102.57% and a standard deviation of this updated mean, σ_p, of 3.63 are obtained.

$$\grave{\imath}_p = \frac{\grave{\imath}_0 \acute{o}^2 + n\bar{x}\acute{o}_0^2}{\acute{o}^2 + n\acute{o}_0^2} = \frac{104.6 * 8.9^2 + 2 * 98.5 * 4.45^2}{8.9^2 + 2 * 4.45^2} = 102.57$$

$$\sigma_p = \sqrt{\frac{\sigma^2\sigma_0^2}{\sigma^2 + n\sigma_0^2}} = \sqrt{\frac{8.9^2 * 4.45^2}{8.9^2 + 2 * 4.45^2}} = 3.63$$

Therefore, the design load of 100% has an exclusion limit of 38.65% and, as a consequence, to obtain an exclusion limit of 10%, Φ_R should be 0.91. Hence, the tower should be verified again with this new Φ_R of 0.91, and only afterwards the decision the tower design has ‘passed” or “not passed” will be taken.

The graphs of the figure 2 shows the comparison between the previous distribution and the updated distribution of the mean resistance of the towers. Figure 2a shows the general aspect of de distribution of tower resistance and Figure 2b shows the detail of the exclusion limit.

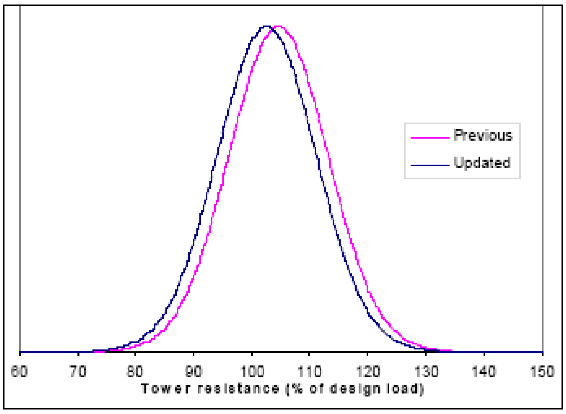


FIGURE 2a – Comparison between the previous and the updated distributions.

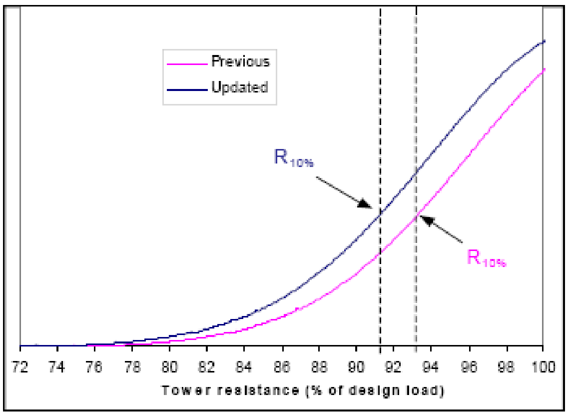


FIGURE 2b – Comparison between the previous and the updated distributions (detail of 10% of exclusion limit).

CONCLUSIONS - As it was discussed, there is currently a philosophical incoherence between the design procedures and the prototype tests. This results from the fact that the code for designing transmission line towers (IEC 60826) is a code based on the probabilistic theory while prototype tests are based on deterministic methods.

Taking this into account, this technical note suggests considering the Bayesian Approach as a framework for interpreting results of prototype tests of transmission lines towers. Using the Bayesian approach, the previous knowledge, which is used as base for the tower design, is combined with the result of prototype tests to result in an updated distribution of the towers resistance. This would allow determining a new coefficient Φ_R, by which the tower would be verified again, to decide the acceptance or rejection. The approach aims to reach coherence between design and prototype tests, considering both in a probabilistic based format.

Even though, it is necessary to carefully study the Bayesian theory, to compare with similar applications in other engineering areas, to perform additional simulations, in order to have a more complete understanding of this proposal.

REFERENCES

[1] Peter H. Madsen e Niels C. Lind, “Bayesian Approach to Prototype Testing”, Journal of the Structural Division, ASCE, Vol 108, Nº ST4, p 753-770, April 1982.

[2] Ang, A. H.-S., Tang, W.H.; 1984; Probability Concepts in Engineering Planning and Design; Basic Principles – Chapter 8: “Bayesian Approach”, New York, Hohn Wiley & Sons Inc.

[3] Grigoriu, M., Lind, N.C., “Probabilistic Models for Prototype Testing”, Journal of the Structural Division, ASCE, Vol 108, ST7, pages 1511-1525, July 1982.

[4] Madsen, P.H., Lind, N.C., “Bayesian Approach to Prototype Testing”, Journal of the Structural Division, ASCE, Vol 108, ST4, pages 753-770, April 1982.

ANNEX C

FRICTION LOSSES IN PULLEY SYSTEMS UNDER STATIC LOAD

Prepared by JOÃO B. G. F. DA SILVA

C.1. OBJECTIVE

The friction losses in a pulley system have been identified to be attributable to the following:

1 Diameter of rope sheave,

2 Diameter of bearing pin (bore),

3 Type of bearing pin (bore) - normally plain bore (greased),

4 Magnitude of Loading,

5 Angles of ropes,

6 Type of sheave, i.e. single, twin, more.

C.2. ARRANGEMENT

The arrangement used in the test was the one suggested below with a single pulley.

The test was conducted in the horizontal plane and the loads were maintained for a minimum of 1 minute before taking readings. The readings were made using load cells.

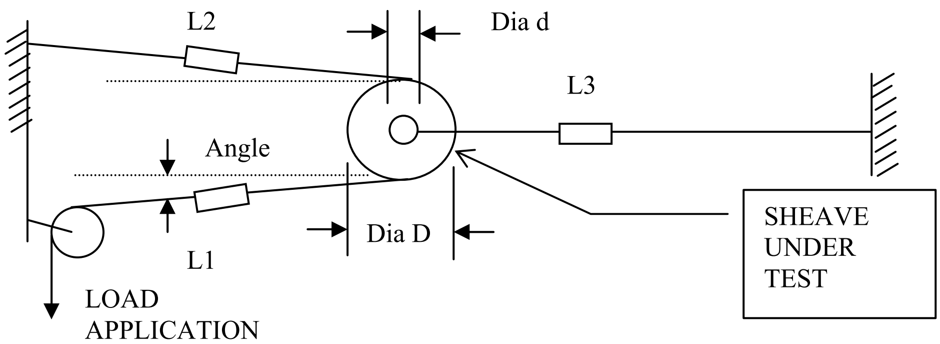


Figure 23 – Frictional pulley losses - Arrangement

C.3. LOAD RECORDING

C.3.1. Load Recording – Test 1

Type of sheave => single

Maximum capacity of sheave => 30.000 kg

Sheave Outside Diameter D => 300 mm

Sheave bore diameter d => 26,1 mm type => plain bore (bushing of bronze)

Angle of Rigging => 0º

Table 2 – Frictional pulley losses – Test 1

TEST RECORDS			
Load Stage	L1 (kg)	L2 (kg)	L3 (kg)
1	510	490	1000
2	1020	980	2000
3	1540	1470	3000
4	2050	1960	4000
5	2560	2440	5000
6	3070	2920	6000
7 (Rated strength)	3580	3410	7000

C.3.2. Load Recording – Test 2

Type of sheave => single

Maximum capacity of sheave => 30.000 kg

Sheave Outside Diameter D => 220 mm

Sheave bore diameter d => 25,6 mm type => plain bore (bushing of bronze)

Angle of Rigging => 0º

Table 3 – Frictional pulley losses – Test 2

TEST RECORDS			
Load Stage	L1 (kg)	L2 (kg)	L3 (kg)
1	540	480	1000
2	1070	950	2000
3	1590	1420	3000
4	2120	1900	4000
5	2640	2380	5000
6	3160	2850	6000
7 (Rated strength)	3680	3330	7000

C.3.3. Load Recording – Test 3

Type of sheave => single

Maximum capacity of sheave => 30.000 kg

Sheave Outside Diameter D => 220 mm

Sheave bore diameter d => 25,6 mm type => plain bore (bushing of bronze)

Angle of Rigging => 5º

Table 4 – Frictional pulley losses – Test 3

TEST RECORDS			
Load Stage	L1 (kg)	L2 (kg)	L3 (kg)
1	470	420	1000
2	930	840	2000
3	1400	1250	3000
4	1860	1670	4000
5	2310	2090	5000
6	2790	2500	6000
7 (Rated strength)	3230	2940	7000

C.3.4. Load Recording – Test 4

Type of sheave => single

Maximum capacity of sheave => 30.000 kg

Sheave Outside Diameter D => 300 mm

Sheave bore diameter d => 26,1 mm type => plain bore (bushing of bronze)

Angle of Rigging => 5º

Table 5 – Frictional pulley losses – Test 4

TEST RECORDS			
Load Stage	L1 (kg)	L2 (kg)	L3 (kg)
1	450	440	1000
2	900	860	2000
3	1350	1290	3000
4	1770	1740	4000
5	2250	2150	5000
6	2700	2580	6000
7 (Rated strength)	3150	3010	7000

C.3.5. Load Recording – Test 5

Type of sheave => single

Maximum capacity of sheave => 30.000 kg

Sheave Outside Diameter D => 300 mm

Sheave bore diameter d => 26,1 mm type => plain bore (bushing of bronze)

Angle of Rigging => 10º

Table 6 – Frictional pulley losses – Test 5

TEST RECORDS			
Load Stage	L1 (kg)	L2 (kg)	L3 (kg)
1	450	440	1000
2	910	870	2000
3	1360	1300	3000
4	1810	1740	4000
5	2260	2170	5000
6	2720	2600	6000
7 (Rated strength)	3130	3030	7000

C.3.6. Load Recording – Test 6

Type of sheave => single

Maximum capacity of sheave => 30.000 kg

Sheave Outside Diameter D => 220 mm

Sheave bore diameter d => 25,6 mm type => plain bore (bushing of bronze)

Angle of Rigging => 10º

Table 7 – Frictional pulley losses – Test 6

TEST RECORDS			
Load Stage	L1 (kg)	L2 (kg)	L3 (kg)
1	450	430	1000
2	930	850	2000
3	1390	1270	3000
4	1830	1710	4000
5	2310	2110	5000
6	2770	2530	6000
7 (Rated strength)	3230	2960	7000

C.3.7. Load Recording – Test 7

Type of sheave => single

Maximum capacity of sheave => 30.000 kg

Sheave Outside Diameter D => 220 mm

Sheave bore diameter d => 25,6 mm type => plain bore (bushing of bronze)

Angle of Rigging => 15º

Table 8 – Frictional pulley losses – Test 7

TEST RECORDS			
Load Stage	L1 (kg)	L2 (kg)	L3 (kg)
1	520	440	1000
2	1000	860	2000
3	1470	1290	3000
4	1940	1730	4000
5	2410	2170	5000
6	2890	2600	6000
7 (Rated strength)	3360	3030	7000

C.3.8. Load Recording – Test 8

Type of sheave => single

Maximum capacity of sheave => 30.000 kg

Sheave Outside Diameter D => 300 mm

Sheave bore diameter d => 26,1 mm type => plain bore (bushing of bronze)

Angle of Rigging => 15º

Table 9 – Frictional pulley losses – Test 8

TEST RECORDS			
Load Stage	L1 (kg)	L2 (kg)	L3 (kg)
1	460	450	1000
2	940	880	2000
3	1410	1320	3000
4	1880	1760	4000
5	2350	2190	5000
6	2810	2630	6000
7 (Rated strength)	3290	3060	7000

C.4. Analysis of Results

If the load L1 is assumed to be the “measured load under test” the actual load L3 will identify how much force is ‘lost’ through the rigging. Similarly, if the Load L2 or L3 are the main loads to be measured.

ANNEX D

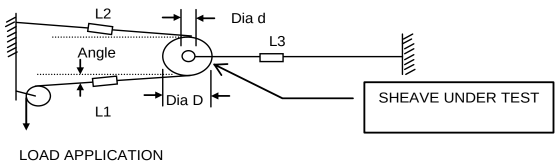
Sheave Tests Analysis

Prepared by DAVID HUGHES

2003-WG08-10

Data Source : 22-01(WG08)11 - Source da Silva

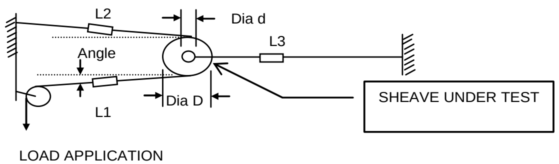
Test Arrangement



Test ID	**Brazil # 1**	
Test by :		**Perda de carga na Roldana**
Type of sheave	Single	
Type of Bore	plain	(bronze bushing)
Max Sheave capacity	30,000	kg
Sheave Diameter D	300	mm
Bore dia d	26.1	mm
Angle of Rigging	0	Deg
Control Leg	L2	(anchored leg)

Test results for Brazil # 1						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	3%	510	490	1,000	0	510	490	1,000	0	0.00%	980	20	2.04%	-20	-4.08%	
2	7%	1,020	980	2,000	0	1,020	980	2,000	0	0.00%	1,960	40	2.04%	-40	-4.08%	
3	10%	1,540	1,470	3,000	0	1,540	1,470	3,010	-10	-0.33%	2,940	60	2.04%	-70	-4.76%	
4	13%	2,050	1,960	4,000	0	2,050	1,960	4,010	-10	-0.25%	3,920	80	2.04%	-90	-4.59%	
5	17%	2,560	2,440	5,000	0	2,560	2,440	5,000	0	0.00%	4,880	120	2.46%	-120	-4.92%	
6	20%	3,070	2,920	6,000	0	3,070	2,920	5,990	10	0.17%	5,840	160	2.74%	-150	-5.14%	
7	23%	3,580	3,410	7,000	0	3,580	3,410	6,990	10	0.14%	6,820	180	2.64%	-170	-4.99%	Rated strength
									Average	-0.04%		Average	2.29%	Average	-4.65%	

Data Source : 22-01(WG08)11 - Source da Silva



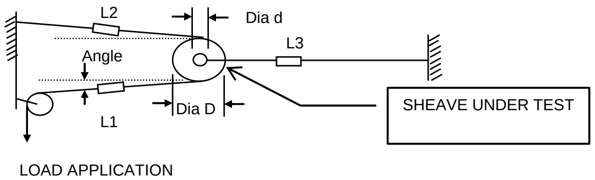
Test ID	**Brazil # 2**	
Test by :		**Perda de carga na Roldana**
Type of sheave	Single	
Type of Bore	plain	(bronze bushing)
Max Sheave capacity	30,000	kg
Sheave Diameter D	220	mm
Bore dia d	25.6	mm
Angle of Rigging	0	Deg
Control Leg	L2	(anchored leg)

Test results for Brazil # 2						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	3%	540	480	1,000	0	540	480	1,020	-20	-1.96%	960	40	4.17%	-60	-12.50%	
2	7%	1,070	950	2,000	0	1,070	950	2,020	-20	-0.99%	1,900	100	5.26%	-120	-12.63%	
3	10%	1,590	1,420	3,000	0	1,590	1,420	3,010	-10	-0.33%	2,840	160	5.63%	-170	-11.97%	
4	13%	2,120	1,900	4,000	0	2,120	1,900	4,020	-20	-0.50%	3,800	200	5.26%	-220	-11.58%	
5	17%	2,640	2,380	5,000	0	2,640	2,380	5,020	-20	-0.40%	4,760	240	5.04%	-260	-10.92%	
6	20%	3,160	2,850	6,000	0	3,160	2,850	6,010	-10	-0.17%	5,700	300	5.26%	-310	-10.88%	
7	23%	3,680	3,330	7,000	0	3,680	3,330	7,010	-10	-0.14%	6,660	340	5.11%	-350	-10.51%	
									Average	-0.64%		Average	5.11%	Average	-11.57%	

Data Source : 22-01(WG08)11 - Source da Silva

Test ID **Brazil # 3**

Test by :	**Perda de carga na Roldana**	
Type of sheave	Single	
Type of Bore	plain	(bronze bushing)
Max Sheave capacity	30,000	kg
Sheave Diameter D	220	mm
Bore dia d	25.6	mm
Angle of Rigging	5	Deg
Control Leg	L2	(anchored leg)

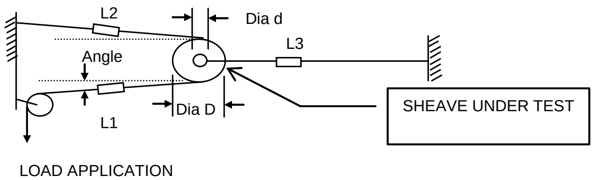


Test results for Brazil # 3						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	3%	470	420	1,000	5	472	422	893	107	11.93%	843	157	18.59%	-50	-11.95%	
2	7%	930	840	2,000	5	934	843	1,777	223	12.56%	1,686	314	18.59%	-90	-10.76%	
3	10%	1,400	1,250	3,000	5	1,405	1,255	2,660	340	12.78%	2,510	490	19.54%	-151	-12.05%	
4	13%	1,860	1,670	4,000	5	1,867	1,676	3,543	457	12.88%	3,353	647	19.30%	-191	-11.42%	
5	17%	2,310	2,090	5,000	5	2,319	2,098	4,417	583	13.20%	4,196	804	19.16%	-221	-10.57%	
6	20%	2,790	2,500	6,000	5	2,801	2,510	5,310	690	12.99%	5,019	981	19.54%	-291	-11.64%	
7	23%	3,230	2,940	7,000	5	3,242	2,951	6,194	806	13.02%	5,902	1,098	18.59%	-291	-9.90%	Rated strength
									Average	12.77%		Average	19.05%	Average	-11.18%	

Data Source : 22-01(WG08)11 - Source da Silva

Test ID **Brazil # 4**

Test by :	**Perda de carga na Roldana**	
Type of sheave	Single	
Type of Bore	plain	(bronze bushing)
Max Sheave capacity	30,000	kg
Sheave Diameter D	300	mm
Bore dia d	26.1	mm
Angle of Rigging	5	Deg
Control Leg	L2	(anchored leg)

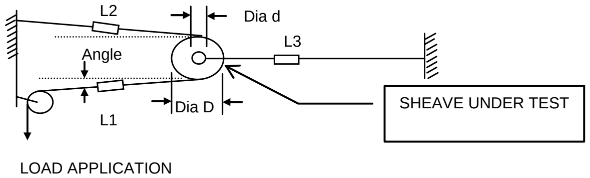


Test results for Brazil # 4						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	3%	450	440	1,000	5	452	442	893	107	11.93%	883	117	13.20%	-10	-2.28%	
2	7%	900	860	2,000	5	903	863	1,767	233	13.20%	1,727	273	15.84%	-40	-4.67%	
3	10%	1,350	1,290	3,000	5	1,355	1,295	2,650	350	13.20%	2,590	410	15.84%	-60	-4.67%	
4	13%	1,770	1,740	4,000	5	1,777	1,747	3,523	477	13.53%	3,493	507	14.51%	-30	-1.73%	
5	17%	2,250	2,150	5,000	5	2,259	2,158	4,417	583	13.20%	4,316	684	15.84%	-100	-4.67%	
6	20%	2,700	2,580	6,000	5	2,710	2,590	5,300	700	13.20%	5,180	820	15.84%	-120	-4.67%	
7	23%	3,150	3,010	7,000	5	3,162	3,021	6,184	816	13.20%	6,043	957	15.84%	-141	-4.67%	
									Average	13.07%		Average	15.27%	Average	-3.91%	

Data Source : 22-01(WG08)11 - Source da Silva

Test ID **Brazil # 5**

Test by :		**Perda de carga na Roldana**
Type of sheave	Single	
Type of Bore	plain	(bronze bushing)
Max Sheave capacity	30,000	kg
Sheave Diameter D	300	mm
Bore dia d	26.1	mm
Angle of Rigging	10	Deg
Control Leg	L2	(anchored leg)

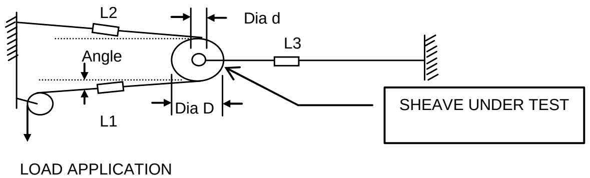


Test results for Brazil # 5						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	3%	450	440	1,000	10	457	447	904	96	10.65%	894	106	11.91%	-10	-2.31%	
2	7%	910	870	2,000	10	924	883	1,807	193	10.65%	1,767	233	13.20%	-41	-4.67%	
3	10%	1,360	1,300	3,000	10	1,381	1,320	2,701	299	11.07%	2,640	360	13.63%	-61	-4.69%	
4	13%	1,810	1,740	4,000	10	1,838	1,767	3,605	395	10.96%	3,534	466	13.20%	-71	-4.09%	
5	17%	2,260	2,170	5,000	10	2,295	2,203	4,498	502	11.15%	4,407	593	13.46%	-91	-4.21%	
6	20%	2,720	2,600	6,000	10	2,762	2,640	5,402	598	11.07%	5,280	720	13.63%	-122	-4.69%	
7	23%	3,130	3,030	7,000	10	3,178	3,077	6,255	745	11.91%	6,153	847	13.76%	-102	-3.35%	
									Average	11.07%		Average	13.25%	Average	-4.00%	

Data Source : 22-01(WG08)11 - Source da Silva

Test ID **Brazil # 6**

Test by :		**Perda de carga na Roldana**
Type of sheave	Single	
Type of Bore	plain	(bronze bushing)
Max Sheave capacity	30,000	kg
Sheave Diameter D	220	mm
Bore dia d	25.6	mm
Angle of Rigging	10	Deg
Control Leg	L2	(anchored leg)

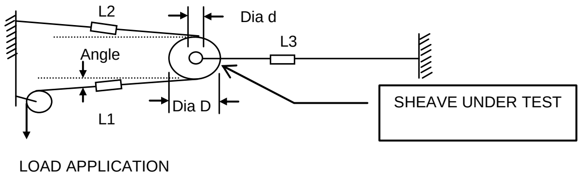


Test results for Brazil # 6						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	3%	450	430	1,000	10	457	437	894	106	11.91%	873	127	14.51%	-20	-4.72%	
2	7%	930	850	2,000	10	944	863	1,807	193	10.65%	1,726	274	15.86%	-81	-9.56%	
3	10%	1,390	1,270	3,000	10	1,411	1,290	2,701	299	11.07%	2,579	421	16.32%	-122	-9.59%	
4	13%	1,830	1,710	4,000	10	1,858	1,736	3,595	405	11.28%	3,473	527	15.18%	-122	-7.13%	
5	17%	2,310	2,110	5,000	10	2,346	2,143	4,488	512	11.40%	4,285	715	16.68%	-203	-9.62%	
6	20%	2,770	2,530	6,000	10	2,813	2,569	5,382	618	11.49%	5,138	862	16.78%	-244	-9.63%	
7	23%	3,230	2,960	7,000	10	3,280	3,006	6,285	715	11.37%	6,011	989	16.45%	-274	-9.26%	
									Average	11.31%		Average	15.97%	Average	-8.50%	

Data Source : 22-01(WG08)11 - Source da Silva

Test ID **Brazil # 7**

Test by :		**Perda de carga na Roldana**
Type of sheave	Single	
Type of Bore	plain	(bronze bushing)
Max Sheave capacity	30,000	kg
Sheave Diameter D	220	mm
Bore dia d	25.6	mm
Angle of Rigging	15	Deg
Control Leg	L2	(anchored leg)

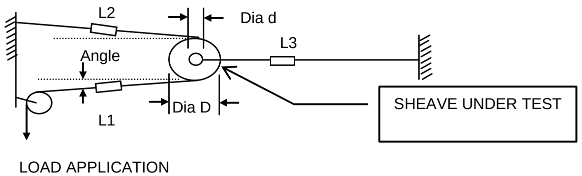


Test results for Brazil # 7						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	3%	450	430	1,000	15	466	445	911	89	9.76%	890	110	12.32%	-21	-4.82%	
2	7%	930	850	2,000	15	963	880	1,843	157	8.53%	1,760	240	13.64%	-83	-9.74%	
3	10%	1,390	1,270	3,000	15	1,439	1,315	2,754	246	8.94%	2,630	370	14.09%	-124	-9.78%	
4	13%	1,830	1,710	4,000	15	1,895	1,770	3,665	335	9.14%	3,541	459	12.97%	-124	-7.27%	
5	17%	2,310	2,110	5,000	15	2,391	2,184	4,576	424	9.27%	4,369	631	14.45%	-207	-9.81%	
6	20%	2,770	2,530	6,000	15	2,868	2,619	5,487	513	9.35%	5,238	762	14.54%	-248	-9.82%	
7	23%	3,230	2,960	7,000	15	3,344	3,064	6,408	592	9.23%	6,129	871	14.21%	-280	-9.44%	
									Average	9.18%		Average	13.74%	Average	-8.67%	

Data Source : 22-01(WG08)11 - Source da Silva

Test ID **Brazil # 8**

Test by :		**Perda de carga na Roldana**
Type of sheave	Single	
Type of Bore	plain	(bronze bushing)
Max Sheave capacity	30,000	kg
Sheave Diameter D	300	mm
Bore dia d	26.1	mm
Angle of Rigging	15	Deg
Control Leg	L2	(anchored leg)

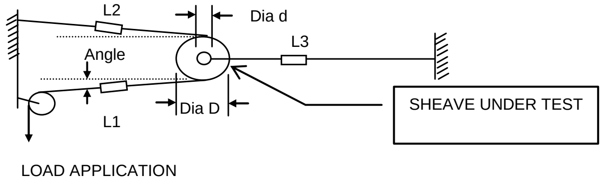


Test results for Brazil # 8						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	3%	460	450	1,000	15	476	466	942	58	6.15%	932	68	7.33%	-10	-2.30%	
2	7%	940	880	2,000	15	973	911	1,884	116	6.15%	1,822	178	9.76%	-62	-7.06%	
3	10%	1,410	1,320	3,000	15	1,460	1,367	2,826	174	6.15%	2,733	267	9.76%	-93	-7.06%	
4	13%	1,880	1,760	4,000	15	1,946	1,822	3,768	232	6.15%	3,644	356	9.76%	-124	-7.06%	
5	17%	2,350	2,190	5,000	15	2,433	2,267	4,700	300	6.38%	4,535	465	10.27%	-166	-7.56%	
6	20%	2,810	2,630	6,000	15	2,909	2,723	5,632	368	6.54%	5,446	554	10.18%	-186	-7.09%	
7	23%	3,290	3,060	7,000	15	3,406	3,168	6,574	426	6.48%	6,336	664	10.48%	-238	-7.78%	
									Average	6.28%		Average	9.65%	Average	-6.56%	

Data Source : 22-01(WG08)26 - Source da Silva

Test ID **Brazil # 9**

Test by :	**ABB Brazil**	
Type of sheave	Single	
Type of Bore	plain	??
Max Sheave capacity	??	kg NOT QUOTED - ASSUMED
Sheave Diameter D	160	mm
Bore dia d	??	mm
Angle of Rigging	0	Deg
Control Leg	L2	(anchored leg)

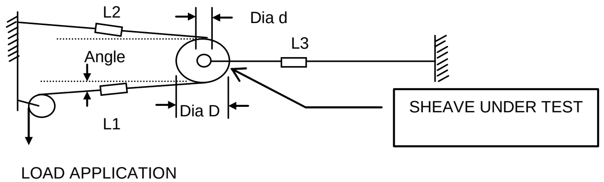


Test results for Brazil # 9						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	#VALOR!	1,000	980	2,000	0	1,000	980	1,980	20	1.01%	1,960	40	2.04%	-20	-2.04%	
2	#VALOR!	2,100	2,000	4,000	0	2,100	2,000	4,100	-100	-2.44%	4,000	0	0.00%	-100	-5.00%	
3	#VALOR!	3,100	2,900	6,000	0	3,100	2,900	6,000	0	0.00%	5,800	200	3.45%	-200	-6.90%	
4	#VALOR!	4,250	4,000	8,000	0	4,250	4,000	8,250	-250	-3.03%	8,000	0	0.00%	-250	-6.25%	
5	#VALOR!	5,300	5,100	10,000	0	5,300	5,100	10,400	-400	-3.85%	10,200	-200	-1.96%	-200	-3.92%	
									Average	-1.66%		Average	0.71%	Average	-4.82%	

Data Source : 22-01(WG08)26 - Source da Silva

Test ID **Brazil # 10**

Test by :	**ABB Brazil**	
Type of sheave	Single	
Type of Bore	Ball bearing	
Max Sheave capacity	??	kg NOT QUOTED - ASSUMED
Sheave Diameter D	390	mm
Bore dia d	??	mm
Angle of Rigging	0	Deg
Control Leg	L2	(anchored leg)



Test results for Brazil # 10						**Analysis**										
			Control			Results Corrected for angle			Results Error		If L2 employed as Test control			Sheave Friction Loss		Comments
Load Stage	Load % of sheave capacity	L1	L2	L3	Angle	L1'	L2'	(L1'+L2')	Diff between L3 and (L1'+L2')	%Diff	Assumed Load on L3 = L2' x 2	Diff with actual load (L3)	%Diff	L2' - L1'	% of original Load	
1	#VALOR!	1,000	1,000	2,000	0	1,000	1,000	2,000	0	0.00%	2,000	0	0.00%	0	0.00%	
2	#VALOR!	2,060	2,020	4,000	0	2,060	2,020	4,080	-80	-1.96%	4,040	-40	-0.99%	-40	-1.98%	
3	#VALOR!	3,060	3,030	6,000	0	3,060	3,030	6,090	-90	-1.48%	6,060	-60	-0.99%	-30	-0.99%	
4	#VALOR!	4,160	4,150	8,000	0	4,160	4,150	8,310	-310	-3.73%	8,300	-300	-3.61%	-10	-0.24%	
5	#VALOR!	5,200	5,180	10,000	0	5,200	5,180	10,380	-380	-3.66%	10,360	-360	-3.47%	-20	-0.39%	
									Average	-2.17%		Average	-1.81%	Average	-0.72%	

Load stage 4 data error L1 and L2 transposed