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Michael David Drury
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THE EFFECT OF PRESTRESSING ON THE INELASTIC (CREEP) BEHAVIOUR OF
AUSTRALIAN MADE BARE OVERHEAD CONDUCTORS

A thesis submitted in fulfilment of the requirements for the award of the degree

MASTERS OF ENGINEERING (HONOURS)

from

UNIVERSITY OF WOLLONGONG

by

MICHAEL DAVID DRURY, B. Met (HONS)

DEPARTMENT OF MATERIALS ENGINEERING
1993

I hereby declare that I have not submitted this material either in whole or in part, for a degree at this or any other institution. Whilst this thesis has been prepared with the proper care, the information advice, opinion and recommendations contained herein are offered, I accept no responsibility for the use of the information in any particular application.

MICHAEL DRURY
July 24, 1993

ABSTRACT

The creep behaviour of Australian manufactured bare overhead conductors was examined. The CIGRE proposed relationship for prestressing behaviour was assessed. A comprehensive literature survey yielded alternative experimental models and extensive amounts of creep constants for many conductor constructions.

19, 37 and 61 strand ACSR and AAAC/1120 conductors were tested. 1000 hour creep tests were performed at tensile loads of 20, 30 and 40% of the NBL of the conductor at 20°C. Prestressing overloads of either 10 or 20% NBL were applied for periods of 1,2 or 7 days.

It was found that prestressing removed a considerable portion of the total predicted creep of a conductor in a relatively short time, i.e. has the effect on creep, of "overaging" a conductor. Analysis of the tests revealed that prestressing will stabilise creep strains for a period of time after load reduction. The stabilised period is adequately described by the CIGRE equivalent time relationship.

$$t_{eq} = \left(\frac{\sigma_1}{\sigma_2} \right)^{\frac{\alpha}{\mu}} t_1$$

Creep constants determined by this work and revealed by the literature survey for Australian conductors, were compared with those published for comparable conductors manufactured overseas. It was shown that there are significant differences between the creep constants of Australian and overseas conductors. Creep constants therefore, for overseas conductors, are not applicable to Australian conductors.

ACKNOWLEDGMENTS

The author wishes to thank the Department of Materials Engineering, and the Department of Mechanical Engineering, from the University of Wollongong, MM Cables and the Australian Electrical Supply Industry Research Board for providing the opportunity to contribute to this area of research, establishing a work place where it was a pleasure to work, and providing the on going funding and availability of research facilities essential to successfully carry out the work.

My thanks are directed to Mr. G. Brennan, Mr. A.C.G. Secrett, Dr. A. Basu and Dr. T. Chandra for their interest in the project and supervision.

I am indebted to Mr. F. Van Eimeren for many hours of discussions and the years of accumulated knowledge passed on to me so freely and cheerfully. For assistance in sample preparation and testing the author wishes to thank Dr. M. Apperley, Mr M. Boyle, Mr. J. Capri, Mr. R. Solanki, Mr L. Wallace and Ms. J. Wines. The wishes to thank Mr. F. Pedersen, and M. I. Fishburn for engineering support in modifying and constructing the test rig.

Lastly, I owe a very special debt of gratitude and thanks for the endless support, cheerful smiles, forbearance, encouragement and understanding during the course of these studies by my wife Belinda. To Sean my son many thanks for his smiles and happy face in trying times.

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CONDUCTOR TERMINOLOGY

AAAC

Abbreviation for all aluminium alloy conductor. A stranded conductor in which all the strands of wire are of aluminium alloy D6201-T81 or 1120.

AAC

Abbreviation for all aluminium conductor. A stranded conductor in which all the strands of wire are of aluminium alloy 1350 (D1045).

AC

Aluminium clad steel wire.

ACAR

Abbreviation for aluminium conductor aluminium alloy re-enforced. A stranded conductor with a core of aluminium alloy 6201 (D6201-T81) wires surrounded by one or more layers of high conductivity aluminium wires 1350 (D1045).

ACSR

Abbreviation for aluminium conductor steel re-enforced. A stranded conductor with a core of steel wires surrounded by one or more layers of high conductivity aluminium wires 1350 (D1045). Sometimes referred to as S.C.A. i.e. steel cored aluminium conductors.

ALDREY

An Al-Mg-Si heat treatable alloy similar in properties to 6201 or 6101A originating in Switzerland.

ALMELAC

An Al-Mg-Si heat treatable alloy similar in properties to 6201 or 6101A originating in France.

ALUMINIUM-CLAD STEEL WIRE (AC)

A wire used as an electrical conductor which is composed of a steel cored coated with a uniform continuous coating of aluminium. The coating is anodic to the core so they protect exposed areas of the core electrolytically during exposure to corrosive environments. Trade names are Natalum, Alumoweld and A.S. wire.

ALUMINISED STEEL WIRE (AZ)

A steel wire with a thin aluminium coating applied by a hot dipping process. Used as steel core wires for ACSR conductors.

ARVIDAL

An Al-Mg-Si heat treatable alloy similar in properties to 6201 OR 6101A.

AS

Abbreviation for Australian Standard. Used as a prefix to a standard specification number i.e. AS 3607.

ASC

Aluminium Stranded Conductor (USA and Canada)

ASTM

Abbreviation for American Society for Testing and Materials. Used as a prefix to Standard specifications i.e. ASTM B232.

AWG

Abbreviation for American Wire Gauge. A system of gauge numbers widely used in the United States for designating the diameter of wire or thickness of sheet. Each successive number is a constant multiple of the preceding number. Also referred to as B. & S. (Brown and Sharpe) gauge.

BIRD CAGING

A term used to describe an open lay in a stranded conductor, i.e. when the outer strands bulge outwards from the inner core wires.

BREAKING LOAD

The maximum tensile load for either an individual wire or stranded conductor on the tensile testing machine.

BSWG

See SWG.

BS

Abbreviation for British Standard. Used as a prefix to standard specifications prepared by the British Standards Association i.e. BS 125.

B. & S.Gauge

Brown and Sharpe Gauge - see AWG.

CALCULATED EQUIVALENT ALUMINIUM AREA

This term denotes the area of solid aluminium rod which would have the same resistance as the conductor.

CATENARY

The curve assumed by a conductor when strung between two towers or poles.

C.B.L.

See M.C.B.L.

CERL

Central Electricity Research Laboratory, of the Central Electricity Generating Board, England.

CIRCULAR MILS

A unit of area used for electrical conductors. One circular mil is the area of a wire 1 mil in diameter (1 mil = 0.001 inches)

COEFFICIENT OF THERMAL EXPANSION

A number measuring the of change in dimensions per unit dimension, here length of a conductor caused by a change in temperature.

COMPOSITE CONDUCTOR

A conductor consisting of two or more strands of different metals, such as aluminium and steel or copper and steel, assembled and operated in parallel.

COMPRESSION FITTING

A metal sleeve which is compressed onto a conductor either for joining the ends of two conductors or connecting a conductor to a terminal.

CONDUCTOR

A term generally applied to a material designed to carry electric current.

CREEP

The permanent deformation of metals held for long periods of time at stresses lower than the normal yield stress. Creep is dependent on the material, conductor construction, applied stress, the time and the temperature.

DEAD_END FITTINGS

A compression fitting used to terminate a length of overhead conductor at a tension tower.

DIAMETER

The mean of two measurements of a conductor at right angles at a single cross section.

DIRECTION OF LAY

The direction of lay is defined as right-hand or left-hand. With right-hand lay the slope of the wires is in the direction of the central part of the letter Z when the conductor is held vertically. With left-hand lay, the slope of the wires is in the direction of the central part of the letter S when the conductor is held vertically.

DUCTILITY

The property that permits permanent deformation before fracture by stress in tension.

EARTH WIRE

Any conductor which carries current to earth.

E.C. ALUMINIUM

Electrical grade aluminium 1350

EDS

Abbreviation for Every Day Stress. The normal operation stress in an overhead conductor and is usually 20-25% of the rated tensile strength.

ELONGATION

Is the increase in gauge length of a tension test specimen, usually expressed as a percentage of the original gauge length. (The increase in gauge length maybe measured either at or after fracture.)

EXTENSOMETER

A device usually mechanical, for indicating the deformation of metal while the metal is subjected to stress.

FEEDER

An overhead or underground cable of large current carrying capacity.

GALLING

The damaging of one or both metallic surfaces by removal of particles from localised areas during sliding friction.

GALVANISING

A zinc coating applied to steel or iron generally by immersion in a bath of molten zinc. Steel core wires in ACSR are usually galvanised to improve corrosion resistance.

GAUGE LENGTH

The original length of that portion of the specimen over which strain or change of length is determined.

GZ

Steel wire with a zinc coating.

IACS

Abbreviation for International Annealed Copper Standard. A comparative scale the relative conductivity of a material in relation to the conductivity of a fully annealed copper sample. Usually expressed as a percentage. i.e. 61% IACS.

INITIAL CREEP

The early part of the time-elongation curve for creep, in which extension increases at a rapid rate.

IWG

See SWG.

JOINTING SLEEVES

Oval-shaped tubes used for joining together the ends of electrical conductors.

KING WIRE

Is a larger central wire (king wire) in the finished conductor. The size of this wire in general is approximately 5% greater in diameter than that of the surrounding wires.

KINK LENGTH

See Lay Length.

LAY RATIO

The ratio of the axial length of a complete turn of the helix formed by an individual wire in a stranded conductor, to the external diameter of the helix.

LENGTH OF LAY

The axial length of one turn of the helix formed by a strand of the conductor.

MCBL

Abbreviation for Minimum Calculated Breaking Load.

AAC/AAAC

For a conductor containing not more than 37 wires, 95 % of the sum of the strength of the individual wires calculated from the minimum breaking load of each wire as set out in the standard.

For a conductor containing more than 37 wires, 90 % of the sum of the strength of the individual wires calculated from the minimum breaking load of each wire as set out in the standard.

ACSR

For a conductor 95 % of the sum of the strength of the individual wires calculated from the minimum breaking load of each wire as set out in the standard.

EARTHWIRES**AC**

For a conductor containing not more than 3 wires, 95 % of the sum of the strength of the individual wires calculated from the minimum breaking load of each wire as set out in the standard.

For a conductor containing 7 or 19 wires, 90 % of the sum of the strength of the individual wires calculated from the minimum breaking load of each wire as set out in the standard.

GZ

For a conductor 95 % of the sum of the strength of the individual wires calculated from the minimum breaking load of each wire as set out in the standard.

MCM

Abbreviation for Milli-Circular mils. $\text{MCM} = 10^{-3} \times \text{circular mils}$.

See Circular Mils.

MECHANICAL PROPERTIES

Those properties of a material that reveal the elastic and inelastic reaction when force is applied, or that involve the relationship between stress and strain; eg. the modulus of elasticity, tensile strength and fatigue limit.

MICRON

A linear distance of 0.001 mm.

MIDSPAN JOINT

A compression joint joining the two ends of lengths of overhead conductor between poles or towers.

MODULUS OF ELASTICITY

The slope of the elastic portion of the stress-strain curve in mechanical testing (ratio of stress to strain within the elastic range). The stress is divided by the unit elongation. The tensile elastic modulus is called "Young's Modulus"

NATALUM

Aluminium Clad Steel wire used as an electrical conductor. Trade name of National Standards Company.

NECKING DOWN

Reduction in area concentrated at the subsequent fracture when a ductile metal is tested in tension.

PHYSICAL TESTING

Those properties familiarly discussed in physics. eg density, electrical conductivity, co-efficient of thermal expansion.

PLASTIC DEFORMATION

Permanent distortion of a material under the action of applied stresses.

PLASTICITY

The ability of a metal to be deformed extensively without rupture.

PREFORMING

A process in which each strand of a cable is correctly bent before stranding so as to produce a tight uniform lay which resists unravelling.

PROOF STRESS

In a test stress that will cause a specified permanent deformation in a material, usually 0.01 or less.

REDUCTION IN AREA

The difference between the original cross-sectional area and that of the smallest area at the point of rupture, usually stated as a percentage of the original area.

RTS

Abbreviation for rated tensile strength. Term is often used as an alternative for U.T.S. in overhead conductor terminology.

RULING SPAN

The length of a span which most nearly represents the behaviour of all spans in a section of an overhead transmission line. $\text{Ruling span} = \text{average span} + \frac{2}{3}(\text{max. span} - \text{min. span})$.

SAG

The vertical distance from the lowest point in the span from the line joining the supports at the ends of the span.

SAG TENSION CHART

A series of graphs which show the relationship between sag, tension and ruling span for a given conductor reacting under a given set of conditions.

SDC

Abbreviation for self damping conductor. A conductor which by virtue of its construction is able to prevent harmful vibrations being induced by steady cross winds.

SECONDARY CREEP

The second portion of the creep curve following the initial creep stage and in which the rate of creep has reached a rather constant value.

SHAVED ROD

Rod which has the rolled surface removed prior to drawing.

SILMALEC

An Al-Mg-Si heat treatable alloy similar in properties to 6201 or 6101A originating in Britain.

SPAN

The horizontal distance between supports of an overhead conductor.

SMOOTH BODIED STRAND

A stranded conductor in which the wires of the outer layer are shaped so as to produce a smooth outer surface.

SSAC

Abbreviation for Steel Supported Aluminium Conductor. Similar to ACSR. Annealed (0 Temper) 1350 alloy aluminium wires surrounding a steel core.

STRAIN

Deformation expressed as a pure number or ratio. Ordinarily expressed as ϵ , equivalent to the change in length divided by the original length.

STRAND

One of the wires, or groups of wires, of any stranded conductor.

STRANDED CONDUCTOR

A term applied to wires stranded together to form a flexible larger capacity conductor.

STRANDED STRAND

A conductor produced by stranding together several previously stranded conductors. These conductors are very flexible.

STRESS- CONDUCTOR

The load per unit cross-sectional area, of a conductor.

STRESS STRAIN GRAPH

A graph showing the extensions produced in a material with increasing and decreasing stress. Stress-Strain graphs are used to construct sag-tension charts for overhead conductors.

SUSPENSION CLAMP

A fitting for attaching a conductor to a supporting structure.

SWG

Abbreviation for Standard Wire Gauge. A system of gauge numbers widely used for representing wire sizes or sheet thicknesses. Also called British Standard Wire Gauge and Imperial Wire Gauge.

TENSILE STRENGTH- OF A CONDUCTOR

The value obtained by dividing the maximum load observed during tensile straining by the specimen cross-sectional area before straining.

UPRATING

A term used to describe an increase in the rating of a power transmission line.

UTS

Abbreviation for Ultimate Tensile Strength. Defined as the maximum load divided by the original cross sectional area.

YIELD STRENGTH

The stress at which a material exhibits a specified limiting deviation from proportionality of stress to strain. An offset of 0.2% is used for many metals such as Aluminium-base alloys, while a 0.5% total elongation under load is frequently used for copper alloys.

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LIST OF SYMBOLS

n	= regression constant, is a fundamental property of the material at the test temperature considered.
t	= elapsed time at load
ϵ_{tot}	= total permanent elongation
τ	= average temperature of conductor °C
T_{max}	= maximum mechanical tension.
T	= mechanical tension of the conductor.
$H(x)$	= is a co-efficient that generally depends on the formation of the conductor.
γ	= a co-efficient that depends upon the internal factors.
σ	= average conductor stress (kg/mm ²).
$f(\tau)$	= function increasing with temperature
$\alpha, \mu(\sigma)$	= mechanical tension of the conductor.
ϵ_{creep}	= creep strain
ϵ_p	= creep strain $\mu\epsilon$.
H	= regression constant.
k	= regression constant in mm/km.
T	= Tension kg.
β	= regression constant.
δ	= regression constant.
$1/n$	= regression constant- slope of line.
k_1	= regression constant- y intercept.

k_2 = stress exponent

h_1, h_2, h_3 = temperature co-efficients

ϵ_{Kr} = creep strain

k_1 = regression constant- y intercept in h^{-1} .

t_0 = 1 hour (time unit)

n_1 = regression constant- slope of line.

$$0 < n_1 < 1$$

ϵ_{Kr} = creep strain rate

$k_2(\Theta)$ = regression constant in h^{-1} .

σ_N = nominal stress

$\sigma_{N0}(\Theta)$ = stress that causes an almost constant creep rate.

$n_2(\Theta)$ = regression constant- slope of line.

$$0 < n_2$$

e = creep strain $\mu\epsilon$

W = Steel in percent of total weight.

T = Temperature $^{\circ}C$.

P = Tension in % Nominal Breaking Load (Rated Strength).

A = cross sectional area mm^2 .

β = regression constant.

ϕ = regression constant, experimentally shown to be load independent.

Θ = Temperature $^{\circ}C$.

UTS = Nominal Breaking Load.

ϵ_c = metallurgical creep strain $\mu\epsilon$ mm/km

- K = regression constant dependent on the material in mm/km.
- σ = is the average stress on the conductor (kg/mm^2)
- β = is the average of the angles of the tangent at a point of the wires with the axis of the conductor.
- ϕ = experimentally determined regression co-efficient.
- α = experimentally determined regression co-efficient.
- μ = experimentally determined regression co-efficient.
- E_a = elasticity modulus of aluminium or alloy (kg/mm)
- E_{st} = elasticity modulus of steel (kg/mm)
- ϵ_s = geometrical settlement creep strain $\mu\epsilon$ mm/km
- σ_{ult} = is the ultimate tensile strength (kg/mm^2).
- d = is the average diameter of aluminium or alloy wires (mm).
- m = the ratio of aluminium or alloy cross section to steel cross section.
- $\sigma_{ult a}$ = is the ultimate tensile strength of the aluminium or alloy (kg/mm^2).
- $\sigma_{ult st}$ = is the ultimate tensile strength of the steel (kg/mm^2).
- ϵ = creep strain $\mu\epsilon$ mm/km
- k_2, k_3 = regression constant dependent on the material in mm/km.
- c_1, c_2, c_3, c_4, c_5 = experimentally determined regression co-efficient.
- x_{cr} = creep strain
- s = stress MPa
- σ, Δ, β = regression constants
- x_{cra} = aluminium creep strain

- T_a = aluminium temperature in °C
- s_a = aluminium stress MPa
- κ_{crs} = steel creep strain
- T_s = steel temperature in °C
- s_s = steel stress MPa
- UTS = Ultimate Tensile Strength of the steel