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FAILURE ANALYSIS OF REINFORCED CONCRETE CROSSARMS IN OVERHEAD DISTRIBUTION LINES: A CASE STUDY

ANÁLISE DE FALHAS DE CRUZETAS DE CONCRETO ARMADO EM LINHAS AÉREAS DE DISTRIBUIÇÃO: UM ESTUDO DE CASO

ANÁLISIS DE FALLAS DE BARRAS TRANSVERSALES DE HORMIGÓN ARMADO EN LÍNEAS AÉREAS DE DISTRIBUCIÓN: UN ESTUDIO DE CASO

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ABSTRACT
Given that most electric power distribution in Brazil relies on overhead transmission lines, any disruption in the power supply can have significant societal implications. This paper provides a qualitative assessment of material creep, which can result in sudden breakage of transmission line structures. A specific case study is presented, focusing on the rupture of a reinforced concrete crossarm in União dos Palmares, Alagoas, Brazil, which belongs to Equatorial Energia's distribution line. The crossarm failure led to a complete power outage in the entire city. This instance emphasizes the importance of further research on creep in concrete structures, particularly those utilized in transmission lines.

KEYWORDS: Cement-based material. Concrete creep. Transmission line structures.

RESUMO
Considerando que a maior parte da distribuição de energia elétrica no Brasil depende de linhas aéreas de transmissão, qualquer interrupção no fornecimento de energia pode acarretar implicações sociais significativas. Nesse sentido, este artigo propõe uma avaliação qualitativa da fluência do material, que pode resultar na ruptura súbita das estruturas das linhas de transmissão. É apresentado um estudo de caso específico, com ênfase na ruptura de uma cruzeta de concreto armado em União dos Palmares, Alagoas, Brasil, que faz parte da linha de distribuição da empresa Equatorial Energia. A falha da cruzeta ocasionou a interrupção total do fornecimento de energia elétrica em toda a cidade. Esse caso ressalta a importância de pesquisas adicionais sobre a fluência em estruturas de concreto, especialmente aquelas utilizadas em linhas de transmissão.

PALAVRAS-CHAVE: Materiais à base de cimento. Fluência do concreto. Estrutura de linhas de transmissão.

RESUMEN
Teniendo en cuenta que la mayor parte de la distribución de electricidad en Brasil depende de las líneas aéreas de transmisión, cualquier interrupción en el suministro de energía puede tener implicaciones sociales significativas. En este sentido, este artículo propone una evaluación cualitativa de la fluencia del material, que puede resultar en la ruptura repentina de las estructuras de las líneas de transmisión. Se presenta un estudio de caso específico, con énfasis en la ruptura de una cruz de hormigón armado en União dos Palmares, Alagoas, Brasil, que forma parte de la línea de distribución de la empresa Equatorial Energia. La falla del travesaño causó la interrupción total del suministro eléctrico en toda la ciudad. Este caso subraya la importancia de una mayor investigación sobre la fluencia en estructuras de hormigón, especialmente las utilizadas en líneas de transmisión.

PALABRAS CLAVE: Materiales a base de cemento. Fluidez concreta. Estructura de líneas de transmisión.

[1] Equatorial Energia.
[2] Companhia Siderúrgica Nacional.
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INTRODUCTION

Power distribution networks play a crucial role in developing and operating a modern country. They are responsible for bringing electrical power safely and reliably to homes, businesses, industry, and essential infrastructure such as hospitals and schools. These grids provide the power to run vital equipment and systems, boosting the economy, facilitating communication, transportation, and improving people's quality of life. In addition, power distribution networks also play an essential role in implementing sustainable solutions, such as integrating renewable energy sources and reducing carbon emissions, contributing to a country's energy transition and environmental sustainability.

The substantial electricity requirements in a geographically vast country such as Brazil highlight the necessity of employing overhead transmission line networks, consisting of conductor wires, ground wires, insulator chains, and supporting structures, for effective power distribution (ABRADEE, 2021).

In this context, the security of transmission line structures is gaining increasing attention from the technical and scientific community, primarily due to accidents in these structures, which can result in consequences surpassing the reconstruction costs. The disruption of power supply can lead to issues in specific sectors of society, as outlined by Carvalho (2010): the cessation of critical hospital equipment, deactivation of alarms and absence of city lighting, inoperable traffic signals, sudden elevator stoppages between floors, cessation of industrial electrical equipment, as well as expenses incurred in repairing damage to the transmission line and the costs associated with procuring temporary energy supply from alternative distributors.

The primary causes of structural collapse typically stem from loads induced by meteorological events, particularly those associated with high-intensity winds (REIS, 2020). However, there are rare instances in transmission lines where failure may be attributed to material creep, a phenomenon characterized by the permanent deformation of materials when subjected to constant loads or stresses over time (MADUREIRA et al., 2013). Concrete creep leads to progressive strains in structural members under sustained loads, resulting in reduced stress on the concrete and increased stress on steel within reinforced concrete elements (MADUREIRA; FONTES, 2020).

While high temperatures usually drive creep in ceramic materials, cement-based materials such as mortars and concretes exhibit significant deformation over time, even at ambient temperatures. In transmission lines, one critical structural component responsible for supporting cables is the reinforced concrete crossarm, whose design requirements in Brazil adhere to the NBR 8453-1 standard (ABNT, 2012).

In light of this context, this study aims to qualitatively explore material creep in structural elements used in transmission lines, a phenomenon currently overlooked by the abovementioned standard. To accomplish this, a case study concerning the rupture of a reinforced concrete crossarm is presented. This case occurred at a transmission line structure in União dos Palmares, Alagoas, Brazil, leading to a complete disruption in power supply for the entire city.

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THE STATE OF THE ART

To the best of the author's knowledge, no existing literature establishes a connection between accidents involving transmission lines and the phenomenon of material creep, particularly concerning concrete. Therefore, the following studies examined these two subjects separately.

In a study conducted by Liu et al., (2019), they investigated an incident of rupture in a 220 kV overhead ground wire caused by a significant lightning strike (475.9 kA) in Qingyuan, Guangdong Province, China. The authors examined this case through fractography analysis of the broken ground wire samples and a three-dimensional thermoelectric coupling simulation model. The results demonstrated a method for analyzing the mechanism of overhead ground wire breakage resulting from lightning strikes, offering valuable references and suggestions for analyzing and resolving similar accidents.

Karpov et al., (2022) presented simulation-based studies on 110 kV substations located in the Euro-Arctic region of Russia. The authors investigated longitudinal and transversal disturbances in the high-voltage grid and highlighted the impact of harsh climatic conditions on the frequency of accidents. Using a numerical model of the 110 kV section of the Kola power system, they conducted simulations that considered the influence of combined overvoltage on the electrical equipment of substations. The simulation results revealed that overvoltages in power grids with one-way power supply could pose a significant threat to the insulation of substation equipment.

Approaching the subject differently, Su et al., (2017) focused on concrete, one of the most widely used materials in modern civil engineering construction. They proposed a novel method for testing the short-term creep of concrete and assessing the deformation state after the unloading process. The findings indicated that long-term creep primarily arises from irrecoverable deformation, as recoverable deformation gradually transforms into irrecoverable deformation through micro-damage accumulation. Furthermore, the authors discovered hysteresis recovery and time-dependent behaviors, revealing the viscoelastic nature of concrete creep.

Continuing within this context, Madureira et al., (2017) conducted a numerical simulation to evaluate the mechanical performance of reinforced concrete beams, with particular attention to creep, following relevant parameters from the NBR 6118 standard (ABNT, 2014). Their analysis focused on the effects of temperature. The authors concluded that temperature accelerates the deformation process associated with creep, thereby advancing the attainment of asymptotic stress levels in the reinforcement steel bars.

In conclusion, these studies provide valuable insights into transmission line accidents, emphasizing the need to consider material creep, especially in the case of concrete structures. The investigations shed light on the mechanisms and influential factors behind such accidents, offering references, suggestions, and potential avenues for further analysis and resolution.

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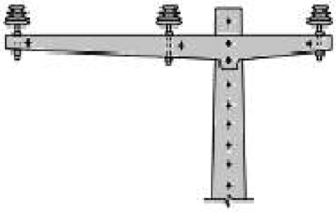
CASE STUDY

This study focused on a section of a distribution line in the primary network of Equatorial Energia, which authorized the reproduction of the following images and information, operating at a voltage level of 13.8 kV. The line consists of three bare aluminum wires with a steel core, specifically 4/0 AWG type, supported by reinforced concrete crossarms of the Normal type, as illustrated in Figure 1.

Figure 1 – Normal-type reinforced concrete crossarm.



In February 2022, within the city of União dos Palmares, Alagoas, Brazil, a crossarm supporting the three cables of the system ruptured at the structure located at coordinates 9°07'24.4"S and 36°02'33.0"W, resulting in a complete power outage for the entire city. Figure 2 depicts the type of suspension structure and highlights the specific point of crossarm failure.

Figure 2 – Suspension structure with broken crossarm.

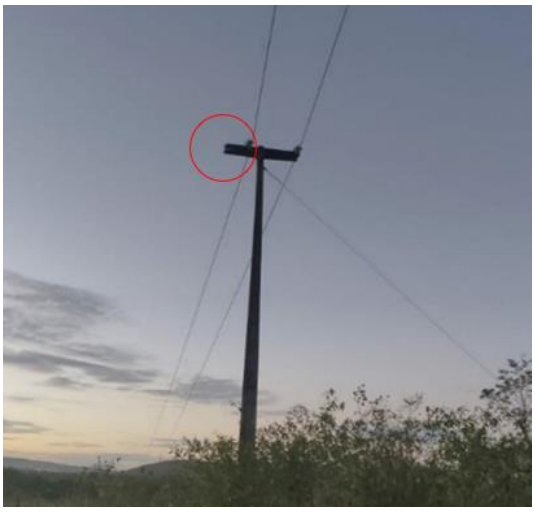
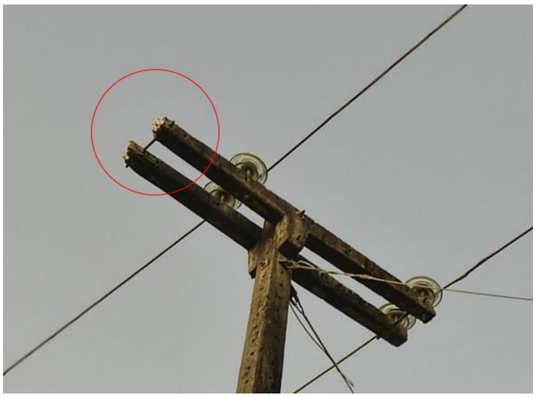


Figure 2 illustrates a cable-stayed pole structure with cables present on one side only. As the transmission line changes direction, there is an angular deviation between the underlying spans. In the studied stretch, the subjacent spans of 207 and 91 meters form a 5º angle. Although minor, this directional deviation causes resultant forces to pull the suspension structure towards the formed side, necessitating the installation of tension rods on the opposite side to maintain mechanical balance.

Figure 3, in turn, emphasizes the type of crossarm utilized in the system and precisely locates the point of material failure, which occurred at the bearing point of an end cable.

Figure 3 – Broken crossarm at the bearing point of an end cable.



Initially, cable breakage was considered the primary cause of the incident. However, upon on-site inspection, it was discovered that the cables only broke after making contact with the ground due to the formation of arcing, as depicted in Figures 4 and 5.

Figure 4 – Evidence of the arc formed when the cable touched the ground.

Figure 5 – Broken aluminum conductor wire.

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Based on this evidence, it was determined that the accident resulted from the rupture of the reinforced concrete crossarm, as seen in Figure 7, which displays samples of the fractured crossarm. Figure 6, in turn, reveals that the concrete aggregate mixture is well-dispersed around the steel reinforcement bars and that there is no accumulation of dirt or organic matter on the inner surface of the component, indicating the sudden rupture of the crossarm. Additionally, it highlights the preferred failure direction, associated with shear in the gravitational direction. It appears that the steel reinforcement was not adequately designed, as one of the four required steel bars for the crossarm is practically absent from the failure surface displayed in Figure 6 and also in Figure 7, which focuses on the broken crossarm end. However, it is evident that this was not the primary cause of the accident, as crossarms are typically designed to have a service life exceeding 30 years, suggesting that the rupture should have occurred earlier.

Figure 5 – Broken aluminum conductor wire.

Figure 6 – Broken aluminum conductor wire.

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Further analysis of this situation reveals that the abrupt rupture of the crossarm was caused by concrete creep. Due to the system's nearly constant loads and stresses, gradual increases in permanent deformations occurred over time, even if these stresses were below the material's strength limit. In the case of concrete, these deformations manifest as micro-cracks that propagate towards the external surface, leading to the sudden rupture of this structural component.

CONCLUSIONS

The case study presented in this research demonstrates that concrete creep played a significant role in the unforeseen failure of the crossarm. It underscores the importance of comprehending the long-term consequences of sustained loads and stresses to prevent similar incidents in the future effectively. It is imperative to prioritize the meticulous design and maintenance of concrete structures, considering the potential for creep-induced failure, as this is essential for ensuring the safety and reliability of transmission line systems. Furthermore, this study emphasizes the pressing need for further investigations concerning creep in concrete structures, particularly those utilized in transmission lines. Despite proper specifications within standards, the rupture associated with this phenomenon can jeopardize numerous vital societal activities. Consequently, additional research is warranted to advance our understanding and address the risks posed by creep, ultimately leading to improved safety and resilience in the field of transmission line infrastructure.

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