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Root Cause Analysis of Jacket Cable of Aerobridge

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***Abstract* - Large moving facilities at airports, such as aerobridges, utilize a specific cable management system known as a cable chain, which houses power cables used to deliver electricity to the motors. These cables consist of multiple cores encased in a protective PVC jacket. However, after a relatively short period of operation, field observations revealed that the cable jackets had torn in many units. In most cases, the damage exposed the internal cable cores.**

Data collected from the field showed that 17 out of 33 aerobridge units experienced cable failures within just two years of operation. This study aims to investigate the mechanisms behind these failures and to identify their root causes. Understanding the root causes is essential for improving the design, manufacturing process, operational handling, and maintenance practices of the cable system.

The study applied a fishbone diagram and the Five Whys method as its analytical approach. The findings identified three primary root causes: the absence of a guiding system to secure the cable within the chain, the impact of high temperature exposure and the effect of ultraviolet (UV) radiation on the cable jacket.

Keywords: root cause; jacket cable; PVC; failure; fishbone.

I. INTRODUCTION

In today's moving equipment industry, flexible and dynamic cables are increasingly required. Unlike conventional installation cables—which are typically enclosed, protected, and fixed in place—certain applications demand cables that can move in sync with mechanical systems [1]. One such application is the aerobridge as shown in Figure 1.Aerobridge is a mechanical-structural system designed to serve aircraft during parking at airports. The aerobridge operates using telescopic movement, requiring cables that can endure repeated motion as the bridge extends and retracts to align with aircraft doors.

An aerobridge is a box-shaped, telescopically movable hallway that serves as a bridge between the airport terminal and the aircraft door, allowing passengers to board and disembark without exposure to the external environment [2]. As a key airport facility, the aerobridge enhances passenger comfort and safety by shielding them from extreme temperatures and other environmental hazards around the aircraft. To support its movement, the aerobridge is equipped with a flexible power cable system known as a cable chain, as illustrated in Figure 2.

A cable chain is a flexible wiring system in which cables are placed on a movable rack resembling a chain, typically made from polymer materials. Unlike conventional building wiring systems—where cables are installed on fixed racks or enclosed in metallic cable ducts—cable chains are designed to accommodate mechanical movement, including back-and-forth motion and limited rotation. The cables housed within the chain move in unison with the chain's motion, making this system ideal for dynamic applications such as in the aerobridge.

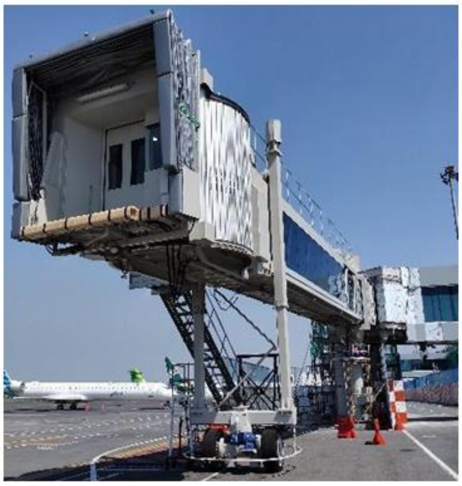

Figure 1: Aerobridge Indonesia

Figure 2: Chain cable

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This special chain is made of polymer that is insulating against electricity. This allows the power cable to be protected and its movement conditioned. Mechanically, the movement of this chain is limited to one direction; it looks like it is folded. Unlike chains in general which are mechanical elements that transmit power, this chain is not like that.

Several problems have been identified in cable chain systems, including twisted cables, damaged or injured cable jackets, broken or stretched cables, and even torn or broken chain links [3]. As illustrated in Figure 3, one common failure involves damage to the cable jacket, resulting in exposed internal cores—an undesirable and potentially hazardous condition. One significant issue is the twisting of the cable while housed inside the chain, which contributes to mechanical stress and eventual failure. This phenomenon presents an important subject for deeper technical investigation to understand its underlying causes and to develop effective engineering solutions.

Figure 3: The power cable was damaged

Cable chain issues were not isolated to a single aerobridge unit. As of May 2022, data showed that 17 out of 33 units had experienced cable chain failures. As illustrated in Figure 4, many units displayed recurring issues, such as twisted and torn cables, while others exhibited unique failure patterns. This widespread occurrence raises significant concerns that warrant further investigation—not only to address technical reliability but also to maintain customer satisfaction.

Notably, these failures occurred within just two years of installation. Units installed in 2020 began to exhibit twisted cable problems by 2021, which escalated to torn cables in 2022. In some cases, up to six cable strands per aerobridge unit were found to be damaged. This is particularly alarming given that each aerobridge is structurally designed for a 15-year service life.

This article investigates the underlying causes of cable damage in aerobridges. Identifying these factors is critical to support design improvements, enhance maintenance strategies, and ensure the long-term reliability of the system.

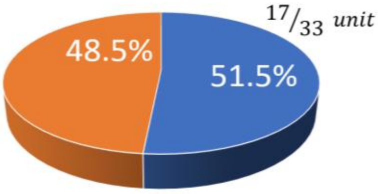

Figure 4: The comparison of problem units

II. METHOD

Data collection was carried out using the following methods:

1. **Visual Inspection** – A thorough visual inspection of the cables and cable chain system was performed to identify visible damage such as tears, cuts, or signs of wear. Particular attention was given to twisting and movement of the cables within the chain during operation.
2. **Photographic Documentation** – High-resolution photographs were taken of the damaged cables and associated components. These images were used to document the damage over time, assess the extent of wear, and compare failure patterns across multiple units.
3. **Interviews with Maintenance Personnel** – Interviews were conducted with aerobridge maintenance staff to gather firsthand insights into operational challenges, recurring issues, and any modifications made during maintenance. This provided valuable context regarding operational practices and failure trends.
4. **Review of Historical Data and Maintenance Logs** – A comprehensive review of past maintenance records, including incident reports and repair logs, helped identify patterns in cable damage, assess the frequency of failures, and evaluate the effectiveness of previous maintenance efforts.
5. **Environmental Assessment** – The environmental conditions surrounding the aerobridge system were evaluated, including temperature fluctuations, humidity, and exposure to UV rays. These factors were assessed to determine their potential impact on the cable's longevity and integrity.
6. **Cable Material Testing** – Laboratory tests were performed on the PVC material used in the cable jackets, assessing its durability under various conditions such as UV exposure and temperature extremes. These tests helped determine if material properties contributed to the cable failures.

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7. **Operational Monitoring** – Real-time observations of the aerobridge system during operation provided insights into the movement dynamics of the cables. These observations helped pinpoint areas where mechanical stress or friction could lead to damage.

By combining these methods, a comprehensive understanding of the factors contributing to cable damage was achieved, paving the way for informed recommendations on design improvements, operational practices, and preventive maintenance strategies.

III. RESULTS AND DISCUSSIONS

A cable is a stranded wire designed to transmit electrical power or signals between devices or locations [4]. The conductor inside the cable is sized to efficiently carry the electric current. Cables play a crucial role in connecting electrical systems for power distribution and signal transmission. Made from materials with excellent electrical conductivity, the conductor is insulated by a jacket, commonly made from polyvinyl chloride (PVC), which offers electrical isolation.

Table 1 compares the properties of PVC with steel and copper. While PVC has lower strength than these metals, it is more resistant to fatigue under normal conditions. However, PVC-jacketed cables are prone to aging and failures over time [5, 6, 7]. Identifying the root causes of these failures is essential for improving maintenance practices and ensuring reliable long-term operation. Addressing these issues can lead to reduced operating costs. For example, cable failures may result in the insulation breaking down and causing a flashover. One potential root cause could be poor installation practices, such as a contractor removing thermal conducting back-fill around ducts, which could lead to localized overheating and increased risk of failure.

Table 1: The comparison of PVC properties

Properties	Steel (1020)	Copper	PVC
Tensile (MPa)	380	200	21
Yield (MPa)	180	69	12
Ductility (%EL)	25	45	295
Modulus of elasticity	207 GPa	110 GPa	3.4 GPa
Hardness (HB)			84

The investigation revealed several important discrepancies between the actual conditions of the cable systems and the standard specifications intended to ensure proper functioning and longevity as shown in Table 2. These discrepancies were identified through a detailed examination of the cables' performance, both in terms of physical setup and environmental factors. Based on key findings and their implications [8], several factors were identified as the cause of the cable jacket failure:

1. **Improper Cable Securing:** One of the most significant issues found was that some cables were not properly secured within the cable chain. In an ideal installation, the cables should be fastened tightly enough to prevent any significant movement. However, the cables in some units were able to move freely within the chain, leading to excessive twisting and abrasion. This movement created friction points that wore down the cable jackets and, over time, compromised the insulation. This issue, if left unchecked, can quickly escalate, causing more severe damage, such as exposed conductors or even short circuits.
2. **Misalignment of Cable Pathways:** In several instances, the routing of the cables was found to be misaligned with the standard design. Cables were subjected to unnecessary bends or were routed through areas of the aerobridge where the movement caused excess strain on the cables. Standard guidelines typically require the cables to be installed in a way that ensures minimal tension and bending. These misalignments created points of stress that could easily lead to mechanical fatigue and premature failure.
3. **Environmental Stress Factors:** Another issue observed was the exposure of cables to extreme temperature variations and moisture. In some cases, cables were found in areas subject to direct sunlight or heat from nearby machinery, both of which can degrade PVC jackets over time. UV exposure and high temperatures cause the material to lose flexibility, increasing the likelihood of cracking or tearing. Additionally, moisture exposure—often from environmental humidity or condensation—can lead to insulation breakdown, further exacerbating the problem.
4. **Lack of Protection against Abrasive Forces:** In some instances, cables were found to be in close contact with other moving parts or sharp edges, leading to abrasion. Over time, this wear can lead to micro fractures in the PVC jacket, eventually allowing electrical components to be exposed and increasing the risk of short-circuiting or even electrical fires. The standard procedure typically includes the use of protective materials or buffers to ensure that cables are shielded from abrasive forces, but this step was not consistently followed in the field.

Table 2: The comparison of standard vs actual

Operation	Aspect	Actual (WAH)	Standard (WSBH)
chain cable movement	Material	**Twisted & bent**	Normal & straight
	Machine	Chain straight of chain direction	Chain straight of chain direction
	Milieu	**Affected by weathering**	Not affected by weathering
	Management	Manual operation was ready	Manual operation was ready
	Method	Cable move allow the chain	Cable move allow the chain
	Man	Operator in cabin	Operator in cabin

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The discrepancies identified are not merely minor installation oversights but represent significant design and operational failures. The fact that these issues were found in multiple aerobridge units points to a potential systemic problem in the initial design, installation practices, or both [9]. These findings also highlight a gap in the maintenance practices, where preventive checks may not have been conducted regularly to ensure cables were operating within the standards. The implications of these findings are far-reaching:

- **Increased risk of failure:** The continued use of cables in non-compliant conditions accelerates wear and tear, leading to increased maintenance costs and unexpected downtimes.
- **Safety hazards:** Exposed cables or short circuits create immediate safety risks, both to the passengers using the aerobridge and to the operational staff maintaining the equipment.
- **Higher operating costs:** The need for frequent repairs and replacements of damaged cables, coupled with potential operational halts, significantly raises the cost of maintaining the aerobridge systems.

To mitigate these issues, several design improvements and maintenance protocols are recommended:

1. Redesigning cable securing systems to prevent excessive movement within the chain and reduce twisting.
2. Ensuring proper alignment of cables to prevent unnecessary strain during operation.
3. Introducing environmental safeguards, such as temperature and moisture-resistant coatings, and UV-protective materials.
4. Regular inspection protocols to identify early signs of wear and tear, ensuring that damaged cables are addressed before they lead to critical failures.

The effects of both natural and accelerated artificial weathering on the physical, chemical, and mechanical properties of chlorinated polyvinyl chloride (CPVC) pipe material were studied. Natural outdoor exposures were conducted over periods ranging from 2 weeks to 18 months, while accelerated weathering involved subjecting samples to UV radiation for durations of 100 to 3000 hours. Tensile test results indicated that both natural and artificial weathering had limited effects on the material's strength and stiffness.

The second aspect pertains to external environmental effects on the cable system. Notably, discoloration observed on the cable jackets suggests aging-related degradation. In systems where cables are allowed to move freely along multiple axes (X-Y-X directions), unnecessary forces may be applied to the cable. This uncontrolled movement prevents the cable from returning to its original position, leading to distortion. This phenomenon is exacerbated by external factors such as UV radiation and temperature changes, which degrade the elasticity and integrity of the PVC jacket—compromising its ability to securely encase the cable core.

These findings highlight an opportunity for design improvements—specifically, incorporating protective enclosures to shield cables from environmental exposure and enhancing cable material elasticity. Improved elasticity would enable the cable to flex and return to its initial position without permanent deformation.

Future research should explore the influence of cable diameter reduction on movement flexibility, as well as the long-term fatigue behavior of PVC under UV exposure. These studies are essential for developing more resilient, long-lasting cable systems in outdoor or dynamic environments.

Focusing initially on the material aspect, a key indicator of failure was the occurrence of bent cables. Through the application of the Five Whys method and cause-and-effect analysis, it was determined that the bending resulted from the cable's inability to return to its original position after movement. This issue was traced to the cable's unrestricted movement within the cable chain. Further examination revealed that the cable was not secured to the chain—a direct consequence of a design that lacked provisions for cable ties. Additionally, no design guidelines or standards for cable tie implementation had been established at the time. Based on this root cause analysis, a fishbone diagram [10, 11] was developed to visualize the contributing factors, as shown in Figure 5.

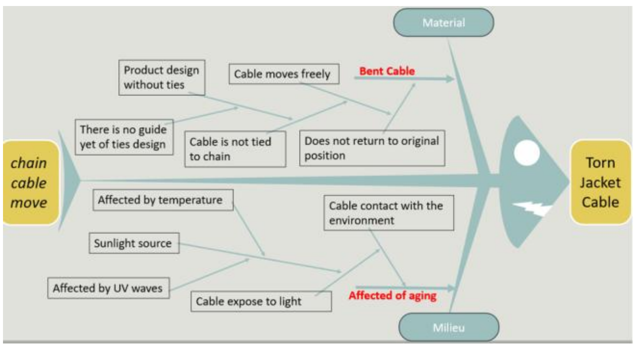

Figure 5

IV. CONCLUSION

The root cause identified was the degradation of the PVC jacket's ability to maintain the core cable's position, ultimately resulting in tearing. This failure is largely attributed to environmental exposure, mechanical stress, and insufficient support within the cable chain. To prevent recurrence, the study proposes several design improvements: (1) integrating secure cable tie mechanisms within the chain to restrict

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unnecessary movement, (2) applying protective outer sleeves or conduits to shield the cable from UV radiation and extreme temperatures, and (3) using more elastic or weather-resistant jacket materials to enhance durability and flexibility. The fishbone diagram has proven to be an effective tool in systematically identifying these root causes and guiding targeted design solutions.

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