The Corrosion Effect of Gusset Plates on the Steel Joint Structure of Bridges: A literature review based on VOS viewer

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Abstract. Bridges have an essential role in a sustainable land transportation infrastructure. One of the challenges today is the nature of corrosion on the bridge structure. Corrosion due to reaction with the environment can damage the integrity of the bridge structure and reduce safety. This study aims to determine the map of the research development on the effects of corrosion on gusset plates with the VOS viewer bibliometric study and literature review. The research was conducted over 24 years, from 2000 to 2023, by searching through the Crossref and Scopus databases with the keywords corrosion, bridge structure, and gusset plates. The selected article data was obtained from 285 research articles. The search result articles were then analyzed descriptively, inputted, and analyzed with VOS viewer and a literature review to visualize mapping the development of topics and research subjects on corrosion on gusset plates. The results showed that the number of publications on gusset plate corrosion had increased significantly yearly. Then, based on the results of the mapping visualization using VOS viewer, the study was divided into 5 clusters. Meanwhile, based on the literature review results, the collaboration between authors is quite well spread. In addition, this paper shows ten primary papers with research topics with the highest citations.

Keywords: Corrosion, Gusset Plates, Steel Joint.

1 Introduction

The community knows that the road connects infrastructure from one place to another. This understanding often needs to remember the importance of bridges. Providing a resilient transport infrastructure system is essential to increase rural and urban areas' economic, social, and environmental feasibility. In addition to population growth and increasingly rapid urbanization flows, coupled with aging infrastructure, many regions face complex challenges due to the increasingly disruptive nature of human activities and extreme climate intensity, which tend to be difficult to predict. Transport infrastructure does not only cover operations but also the physical components of systems that are interrelated and capable of being essential service providers for the possibility

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of defense, improving the quality of life, and improving people's living conditions. Bridge inspection and assessment is a bridge maintenance effort to maintain the bridge's age and prevent damage to the bridge structure that is sustainable.

Bridges worldwide play an important role in road infrastructure by facilitating efficient and safe transportation over natural obstacles such as rivers, valleys, and ravines. However, they often encounter significant problems such as corrosion or rust. Dealing with rusty bridges poses significant challenges in maintaining strength, safety, and longevity. In the United States and Mexico, many bridges built in the early 20th century have exceeded their intended service life and require repair due to prolonged exposure to harsh environmental conditions that can accelerate the corrosion process. Corrosion is a significant problem in the field of materials and has a destructive impact; this can reduce the ability of a construction to withstand loads and reduce the life of construction buildings from what was previously planned [1].

The effects of bridge corrosion can be very significant, as it can compromise the structural integrity of bridges and pose a public safety risk. In Indonesia, bridge corrosion is a severe problem that needs to be resolved because it has a tropical climate with high humidity, and this condition can accelerate the corrosion process in bridge infrastructure. Steel plate corrosion in Indonesia often occurs in various steel plates, including shoulder plates. Gush plates are commonly used to connect the various steel components of bridges, and corrosion can weaken these joints over time, leading to potential bridge failure. Corrosion effects on gusset plates can vary depending on several factors, such as the severity and type of corrosion, plate material and thickness, and the bridge's load capacity. The coating is the primary protocol to improve the anti-corrosion performance of steel bridges [2]. The sealing method has been widely applied to prevent crevice corrosion, one of the main types of corrosion on steel bridges [3].

Corrosion of gusset plates in the steel connection structures of bridges can cause significant social and economic impacts. Corrosion affects equipment and structures' safety, reliability, and efficiency much more than metal mass loss [4]. Bridges are critical infrastructures that connect people and communities, enabling the efficient movement of people, goods, and services. If a bridge fails due to corrosion, it can cause significant disruption to the transportation network, resulting in economic losses [5]. Reduced access to essential services and increased travel time for road users.

Bridge failure due to corrosion of gusset plates can have a significant impact on public safety. These social impacts can be long-lasting, affecting affected communities' confidence in the security of their infrastructure. People's social security is not only a matter of human development, political stability of society, and affirmation of national interests but also a primary issue of all the fields mentioned above, namely economic growth [6]. In addition, repairing or replacing a bridge due to corrosion of the gusset plates can be costly and time-consuming, putting a strain on public finances and resources.

This article aims to explain the dangers of corrosion on gusset plates that can affect potential disasters, minimize economic and social impacts, and ensure the safety and welfare of the people who depend on bridge infrastructure. Infrastructure accidents include loss of life, material losses, moral losses, and negative environmental impacts; these accidents also impact people's productivity and welfare [1]. By understanding the

importance of maintaining the quality and safety of bridge infrastructure, we can encourage stakeholders to take the necessary actions to ensure bridges remain safe and can be used effectively in the long term.

2 Literature Review

2.1 Bridge Structure Corrosion

Bridge structure corrosion is a significant and severe problem in the field of infrastructure. Corrosion, the process of destroying metal due to a reaction with the environment, can damage bridges' structural integrity and threaten the infrastructure's safety and sustainability. Bridges play an essential role in facilitating efficient and safe transportation for people. However, harsh environments, such as exposure to water, salt, atmospheric pollution, and other factors, can accelerate the corrosion process in bridge structures. The corrosion process is an electrochemical process in which air or electrolyte is reduced, causing almost all types of metal to be susceptible to corrosion [7]. Moreover, bridges are often subjected to constant heavy loads and stresses, which can exacerbate the damage caused by corrosion.

In general, the leading causes of damage to steel bridge structures are corrosion and fatigue, resulting in a decrease in the bearing capacity and performance of steel bridge structures. So, the level of damage becomes uncertain, and safety and comfort are not sufficient a condition for bridge infrastructure management. Therefore, it is necessary to make a bridge infrastructure management system practical, such as evaluating its performance and predicting damage to bridge elements and planning a repair methodology that refers to minimizing costs with maximum quality.

Corrosion damage to bridge structures can have serious consequences. Essential parts of the bridge, such as beams, columns, and supporting cables, can experience a decrease in strength, erosion, or even structural failure due to unchecked corrosion. In addition, damage to protective coatings such as anti-rust paint can also speed up the corrosion process in the metal underneath. Corrosion can cause the progressive weakening of steel bridges, decrease static capacity, and increase the dynamic vulnerability of bridges [8]. To overcome the problem of corrosion of bridge structures, proper preventive and maintenance measures are essential. The selection of corrosion-resistant construction materials, application of an effective protective layer, routine maintenance, and periodic inspections are crucial steps. In addition, it is also essential to continuously monitor the condition of the bridge structure and carry out the necessary repairs or replacements so that corrosion damage can be prevented early.

Awareness of the importance of handling corrosion in bridge structures must also be increased. Governments, relevant agencies, and infrastructure professionals should work together to develop effective maintenance strategies, including using innovative technologies to protect bridges from corrosion. Suppose development is carried out without careful planning, implementation, supervision, and proper maintenance. In that case, the resulting infrastructure can be vulnerable to disasters, causing significant loss of life and damage, leading to more comprehensive losses [9]. With proper preventive measures, regular maintenance, and awareness of the importance of handling corrosion

of bridge structures, we can maintain the sustainability and safety of bridge infrastructure and ensure safe and efficient transportation for the community.

2.2 Gusset Plate

A gusset plate is a steel plate used to connect two or more structural elements in a bridge or other steel structure. The gusset plates are usually triangular or rectangular and bolted to their joined parts. They are often located at the intersection of beams, trusses, and other structural components. Steel-reinforced frames with gusset plate joints are economical and easily configured to accommodate various functional and architectural requirements [10].

The primary role of gusset plates in bridge steel joints is to provide additional support and transfer loads between structural elements. This condition helps to distribute the forces and pressures created by the weight of vehicles and other loads crossing the bridge. A strain gauge is attached to the gusset plate to plot the stress distribution [11]. Without gusset plates, the structural members will not be connected appropriately, leading to structural instability and failure.

The gusset plates also help stiffen and strengthen the bridge's steel joint structure. Because of stress concentration, when the tensile stress reaches the ultimate tensile strength of the gusset and spreads to the gusset, it further increases the skeletal stress [12]. It provides additional rigidity and prevents excessive movement between structural members. This condition is critical on bridges subjected to heavy loads, strong winds, and other external forces that can cause movement and deformation.

2.3 Factors Affecting Corrosion

The environmental conditions of the bridge site and exposure to environmental factors such as humidity, temperature, wind, and rain can significantly impact the rate and degree of corrosion. Since the slab is in an exposed and environmentally exposed area, regular maintenance and repairs must be carried out to reduce the risk of the collapse of the bridge structure. The results showed that the environment most strongly influenced the corrosion rate of the initial atmospheric deposition of carbon steel [13].

The type and quality of steel used to make gusset plates must be more substantial, complex, and resistant to corrosion because both are resistant to scratches and cracks that can cause corrosion. The manufacturing process dramatically influences the corrosion behavior of steel; the higher the carbon content in the steel, the better its corrosion resistance [14]. By paying attention to the type and quality of the material used, the steel connection structure of the bridge can function properly and safely for its users.

Exposure to chemicals can affect the corrosion of bridge connection structures because some chemicals can cause corrosion and damage metal surfaces; examples of chemicals that can affect corrosion are acid compounds and salts, chlorine compounds, sulfur compounds, and other chemicals. The protective effect provided by the barrier layer is determined by the level of its resistance to penetration of corrosive materials and the extent to which the layer is resistant to diffusion and adhesion [15]. Therefore, it is crucial to pay attention to the surrounding environment of the structure and choose materials that are resistant to corrosion, conduct regular inspections, clean the plate

surface regularly, and apply suitable protective coatings to protect the plate surface from corrosion.

2.4 Corrosion Impact

The environmental impact is that if the bridge collapses, the waste from the ruins can contaminate the surrounding environment and threaten biodiversity; this can impact the surrounding area. Infiltration of mercury and heavy metals will infiltrate the soil, contaminate groundwater, then enter fish and plants, damage the environment, and indirectly threaten human health [16]. Maintaining and maintaining the condition of the bridge structure properly is very important to prevent damage that can harm the surrounding environment.

Severe corrosion in the steel connection structure of the bridge can cause structural failure and even bridge collapse. This condition can result in an accident for the safety of road users and can even cause death. The structure presented considers maintenance and replacement costs, cracking time due to corrosion, traffic delays, including queues, risk of accidents, and the environmental impact of maintenance actions [17]. If a bridge collapses, it can limit access to certain areas and force people to seek alternative routes, resulting in delays, significant time and cost savings, and congestion on existing roads.

Bridge failure due to corrosion can cause significant economic losses, depending on the extent of the damage. Corrosion of the bridge's steel connection structure can affect the load limit allowed to cross the bridge; this can affect the transportation and delivery of goods and require additional costs to find alternative routes or use additional vehicles to meet service needs. Corroded bridges cannot be used because repairs and replacements can disrupt economic activities in the vicinity, resulting in business losses. Huge restoration and repair costs due to bridge damage can put significant pressure on the budget, impacting the cost of bridge work [18].

3 Method

The research method used in this research is the literature review method, comparing the corrosion rate of test gusset plates on bridges that experience structural failure due to corrosion with those that do not. Case-control studies are suitable for this research question because they allow us to investigate the relationship between exposure to corrosion risk factors and structural failure outcomes by comparing bridge cases with structural failure to control bridges without structural failure by searching for the best literature from international journals using the Crossref and Scopus The journals used are journals published from 2000 to 2023. From the data obtained, the author will use these data as the basis for the content and discussion of the paper. Data is essential in compiling research and conducting scientific modeling [19].

The author will collect journals relevant to the topic to be discussed, draw conclusions from these journals, and then review them in more detail to get the desired result. In this article, VOSviewer can assist in bibliometric analysis to identify research trends related to bridge corrosion, identify keywords that appear most frequently in the literature, and identify collaborations between researchers or institutions active in this field.

By using VOSviewer, researchers can gain better insight into the development of research on bridge corrosion, identify research areas that have yet to be explored, and direct further research directions to understand and overcome corrosion problems related to bridges.

4 Results And Discussion

4.1 Growth and Output Publications

Over the period 2000 to 2023, there has been a significant increase in the growth and output of publications focused on bridge corrosion. This periode reflects the increasing interest and concern towards understanding and addressing the corrosion challenges in bridge structures. Researchers, engineers, and practitioners from various disciplines have conducted extensive studies and published many articles and research results on factors contributing to corrosion, preventive measures, and effective maintenance and repair techniques. These publications play an essential role in disseminating knowledge, sharing the latest findings, and driving innovation to maintain the sustainability and safety of bridge infrastructure. With the continued growth and publication output in this field, awareness and collaborative efforts will continue to increase, resulting in more effective strategies and solutions to address the corrosion problem in bridges.

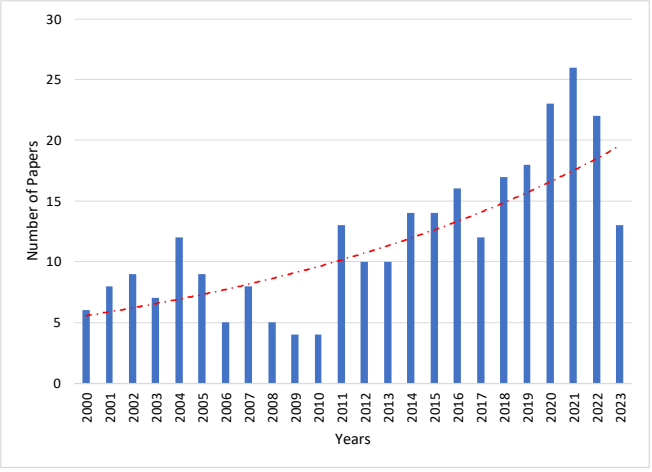

Fig. 1. Publication trend of bridge structures corrosion

4.2 Collaboration Network

A network of collaborations in bridge corrosion has grown, encouraging partnerships between researchers, engineers, and industry professionals worldwide. This collaborative network plays a critical role in addressing the complex challenges of bridge corrosion, facilitating the exchange of knowledge, expertise, and resources needed to

develop innovative solutions. Through this collaborative network, research collaborations, technological advances, and the application of best practices have emerged, aiming to ensure the bridge structure's integrity, strength, and longevity. The results of this collaboration also can influence industry standards and policies related to bridge corrosion, focusing on prevention, early detection, proper maintenance, and rehabilitation practices. Positive synergies are expected to emerge within this increasingly interconnected network of collaborations, enabling an effective and sustainable approach to combating bridge corrosion.

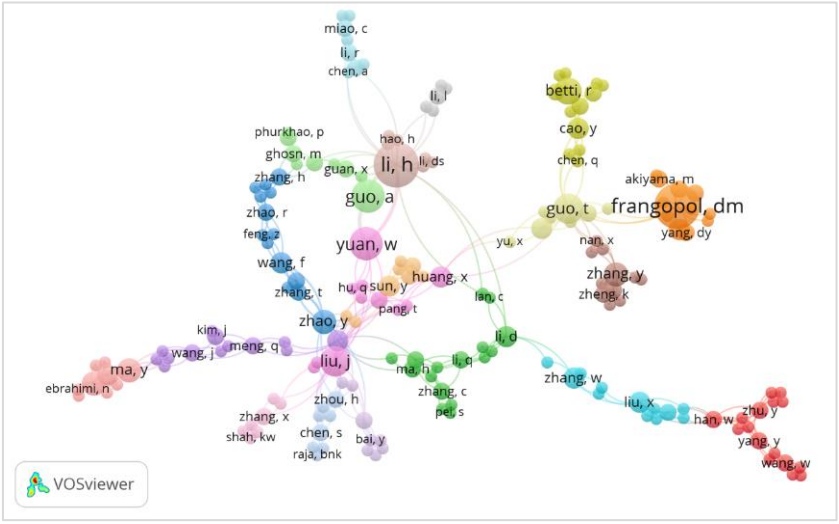

Fig. 2. Map of authors and collaboration networks

In this study, we analyzed to determine the authors who appear most often in publications on the corrosion of bridge structures. Our approach involves an analysis of the author's country and institution, the number of documents published, the average citations per publication, and the h-index. This information can provide valuable insight into the contributions of leading authors in understanding and addressing the problem of corrosion in bridges and provide a valuable reference for researchers and practitioners in this field. The results of our analysis can be found in Table 1, which displays the top 10 authors with the highest number of citations on corrosion of bridge structures. The mapping results show that Vu and Sterwart, with a paper entitled Structural reliability of concrete bridges, including improved chloride-induced corrosion models, have the highest citation of 1024. Meanwhile, Lau, Permeh, and Lasa are the latest authors with the title Corrosion of Prestress and post-tension reinforced concrete bridges, published in 2023 and has 39 citations.

Table 1. Top 10 authors with the highest number of citations on the corrosion of bridge structures

No	Author	Year	Title of paper	Citation
1.	Vu & Stewart	2000	Structural reliability of concrete bridges, including improved chloride-induced corrosion models [20]	1024
2.	Song & Saraswathy	2007	Corrosion Monitoring of Reinforced Concrete Structures - A Review [21]	703
3.	Coe, Gardoni, Rosowsky, & Haukaas	2009	Seismic fragility estimates for reinforced concrete bridges subject to corrosion [22]	264
4.	Shi, Fay, Yang, Nguyen, & Liu	2009	Corrosion of Deicers to Metals in Transportation Infrastructure: Introduction and Recent Developments [23]	158
5.	Cramer, et al	2002	Corrosion prevention and remediation strategies for reinforced concrete coastal bridges [24]	154
6.	Biondini, Camnasio, Palermo	2014	Lifetime seismic performance of concrete bridges exposed to corrosion [25]	150
7.	Kumar, Gardoni, & Sanchez-Silva	2009	Effect of Cumulative seismic damage and Corrosion on the life-cycle cost of reinforced concrete bridges [26]	149
8.	Deng, Yan, & Nie	2019	A simple corrosion fatigue design method for bridges considering the coupled corrosion-overloading effect [8]	87
9.	Lau, Permeh, & Lasa	2023	Corrosion of prestress and post-tension reinforced concrete bridges [27]	39
10.	Krolikowska, et al.	2021	Corrosion Assessment of a Weathering Steel Bridge Structure after 30 Years of Service [28]	6

4.3 Co-occurrence

Co-occurrence analysis in the field of bridge corrosion reveals patterns and significant relationships between various factors that affect the corrosion of bridge structures. By examining the co-occurrence of corrosion-related keywords, researchers have gained insight into the interrelationships of corrosion mechanisms, environmental factors,

material properties, and maintenance practices. This analysis enables a comprehensive understanding of the complex interactions that contribute to bridge corrosion and assists in identifying critical areas for research and intervention. Through joint event analysis, researchers can uncover hidden associations, spot emerging trends, and develop targeted strategies to reduce the impact of corrosion on bridge infrastructure. Ultimately, co-incidence analysis is valuable in advancing knowledge and effectively guiding efforts to combat bridge corrosion seen in Figure 3 for keywords that occur together.

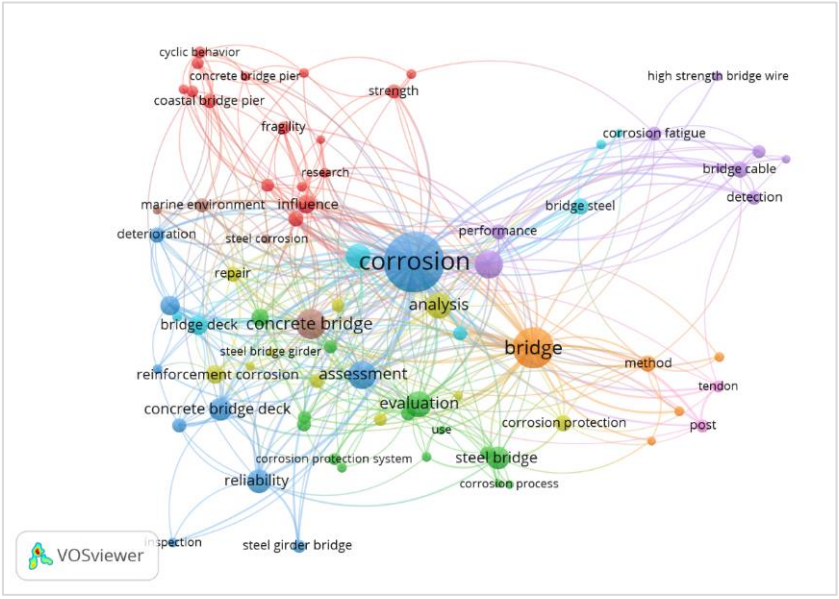

Fig. 3. Cluster visualization map for concurrent keywords

This study used the VOSviewer-generator overlay visualization network to describe research theme trends from the documents analyzed regarding the corrosion of bridge structures. This method allows us to present complex information visually, using a color key that reflects emerging theme trends. This network visualization provides a clearer understanding of the relationships between concepts related to corrosion structural bridges, allowing us to see the patterns and interrelationships that emerge in the scientific literature. Thus, this visualization can help researchers and practitioners understand the latest research trends and identify areas that need further attention to overcome bridge corrosion.

This scientific article has discussed the theme of corrosion of bridge structures using data from VOSviewer and the best-related journals. We conducted analyses involving overlay visualizations, author maps, and network collaborations to understand research trends, emerging topics, and interrelationships between authors in the scientific literature relating to bridge corrosion. Through our analysis, we found that the growth and output of publications focused on the crisis of bridge structures suffered tremendously from 2000 to 2023. Table 1 lists the top 10 authors who published the most articles in

this field, providing insight into their contributions. Understand and address the challenges of corrosion in bridges. This information can assist in determining the experts most closely related to this topic and exploring potential future collaborations.

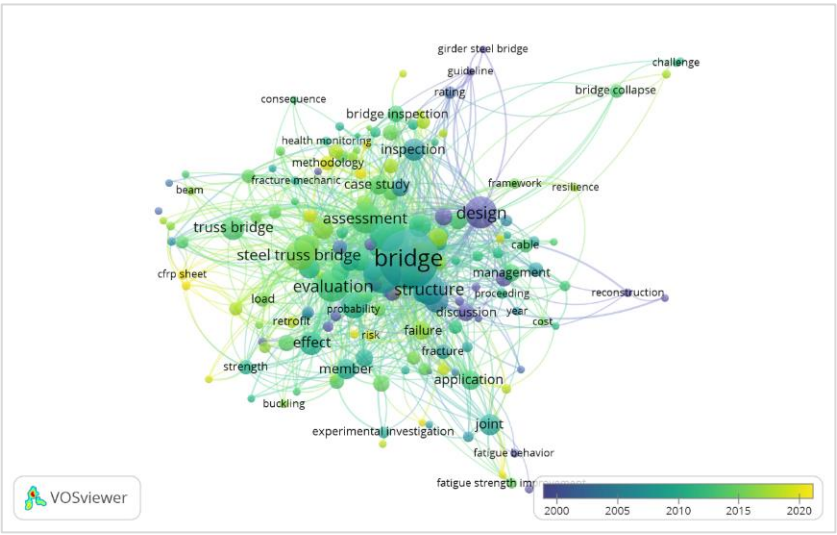

Fig. 4. Visualize the relationship between visually related topics.

The identified research theme trends from the documents were analyzed through overlay visualization. In this case, we use the color key to maximize the trend of the theme, providing a clearer understanding of the development of research topics in the corrosion domain structure bridge. In addition, we also apply author maps and network collaborations to visualize the relationships between authors and their collaborations in research on the corrosion of bridge structures. This condition allows us to see patterns of collaboration formed between authors and research institutions and gain insight into the involvement and role of the authors in this research.

5 CONCLUSION

The study provides a better understanding of developments and research trends related to corrosion structure bridges. Our findings show a high interest from researchers in various countries in understanding and addressing the corrosion problem in bridges. With a deeper understanding of emerging research themes and the interrelationships between authors, we can see the potential for further collaboration and innovation in efforts to maintain the sustainability and safety of bridge infrastructure in the future. The results showed that the number of publications on gusset plate corrosion had increased significantly yearly. Then, based on the results of the mapping visualization using VOSviewer, the study was divided into 5 clusters. Meanwhile, based on the literature review results, the collaboration between authors is quite well spread. In addition, this paper shows ten primary papers with research topics with the highest citations.

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