Analysis of Important Methods for Bridge Inspection and Maintenance

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Abstract. Bridges are considered an essential part of modern transportation systems and play a vital role in the economic growth and cultural exchange of the two regions they connect. However, loads from typhoons, overexposure to rain, sun or seawater, increased transportation loads, and even periodic deterioration of steel reinforcement can have serious negative effects on bridges. Inadequate preventive measures may lead to structural failure, which can result in injury, death and property damage. The awareness of the importance of bridge maintenance and preventive measures has now slightly increased, while many unhelpful, less than scientific and accurate questions have been raised. Therefore, this article concludes the factors that may lead to bridge damage, the significance of bridge maintenance, and five promising maintenance or construction approaches. The goal of better, safer, and more efficient design by engineers or workers through the above techniques and methods will hopefully be achieved. From the first two studies, it can be seen that if the newly introduced methods are scientifically proven, they may be more suitable to be adopted. This paper also analyzes and discusses three concepts that are extremely important for a probability estimation or a maintenance project construction.

Keywords: Vacuum grouting; CFFT; Damage equivalence factor; Intelligent detection; Concurrent maintenance.

1. Introduction

Bridges everywhere bear a heavy responsibility. Well-designed bridges can increase the sense of three-dimension and beautifies the city. Moreover, bridges can greatly reduce traffic pressure and improve the safety of urban transportation systems [1]. The material properties of bridges could be divided into wooden bridges, stone bridges, brick bridges, concrete bridges and steel bridges. The type of bridges could be classified by statics analysis into beam bridges, arched bridges, steel frame bridges and cable bridges [2]. To reach any one of them, there are specific correspondent approaches. The old methods have existed for a long time and usually have their reasons for retention. New methods are emerging, but many of them have not been tested enough to deter people from adopting them. This has allowed some of the more scientific or beneficial methods to exist in vain. This article concludes with five important methods to prove that these five methods are scientifically proven to be 100% safe. They were born in the minds of geniuses and are more likely to be adopted. It is well known that reinforced concrete, conventional grouting and damage equivalence factors are proven and have been used for decades. The claim that dikes reinforced with fibers have better resistance than RC beams is inconclusive. Is it possible that the damage equivalence factor can be divided into partial factors that will help make the results more accurate? These are not hypotheses, but facts proven through analytical studies and scientific experiments, each of which will be presented in this paper. Today's world is changing rapidly and the population is increasing at an even faster rate.

Population growth brings new challenges to bridge design and maintenance, and a rapidly changing society brings new technologies and scientific approaches. In the field of bridge construction today, traditional methods still exist, while advanced methods are being proposed. The authors found that some of all the methods in this paper are applicable to this case, while some were designed for another case. Some of the methods are traditional and have been used, but are not best utilized. The authors found it necessary to summarize their usefulness, classify them accordingly and merge them on the basis of analytical researches and scientific proofs.

2. Factors of bridge damage

2.1. Natural factors

Firstly, concrete expands with heat and contracts when exposed to low temperatures. Consequently, concrete has a tendency to expand in summer, but the stresses in the steel will tend to remain as they were, and cracks will form when the stresses exceed their maximum capacity. Secondly, prolonged exposure to rain or seawater could result in erosion of the concrete or the steel structure of the bridge. Thirdly, typhoons or floods could directly damage major parts of the bridge structure, or even the entire structure [3].

2.2. Human activities

In case of an automobile accident, it is likely to cause minor or major damage to the bridge structure. Even repair operations, just a little bit of faulty construction can negatively affect the life of a bridge. In addition, with the rapid growth of the global population, the corresponding rapid increase in load will put considerable pressure on bridges. When demand exceeds capacity, failures will occur. The probability of failure is crucial for expert calculations. Last but not least, if the survey is not done well enough there will be calculation errors, which may be very large [4].

3. Significance of Bridges Maintenance

3.1. Increasing the lifespan of the bridge and safety level for people

Professional engineers and designers design the bridge before construction and by the time being an age limit for the bridge would also cocome up with. When that limit is reached, the bridge possesses a very high probability of failure. After proper maintenance, the probability of failure is lowered again, safety is again guaranteed and lifespan is extended. In some cases where the bridge is overloaded, frozen or overly-heated, drained or overly-corroded, cracks resulting from car accidents or ship collisions, even natural causes could accelerate the aging of the bridge, thus, even age limits are not reached, professions are sent to regularly conduct structural analysis and probability analysis of the bridges to conduct correspondent maintenance. And regular paving could not only increase the safety level but also level the comfort level of the drivers. Therefore, regular maintenance reduces fatigue situations, guaranteeing safety factors and realizing most of the economic benefits of the bridge.

3.2. Leveling the management of the transportation system

Bridges are vital units of a transportation system, thus, their management of them is more than essential. With the development of society and the rapid growth of the population, tasks with higher standards are assigned to management engineers. Therefore, elements like the discipline of the workers, complete regulation for fixed positions and fixed number of workers, flawless process of defect checking, high quality of maintenance, and enough capital, are highly-valued for high standard management, only with that, could the safety be guaranteed and danger pre-neutralized [5].

4. Maintenance and preventive measures

4.1. The combining of the traditional grouting and the vacuum grouting

Strengthening the bridge by increasing the cross-sectional area, pre-stressed concrete with grouting can be commonly seen in most scenarios. But it is worth mentioning that in every bridge construction case, a clever combination can be very profitable. The pre-stressed concrete method is used in 70% of the bridges existing in today's world. It is a way to reduce the lack of difference between concrete and compression. High-strength steel wires are used to provide force at the ends to counteract some of the tension caused by the bending moment [6].

Table 1. Three Scheme comparing

Name	Charge	Ratio
Traditional grouting	Water: Cement	0.45: 1
Vacuum grouting	Water : Cement： expander: water-absorbent	0.37: 1: 0.1: 0.08

Table 2. Properties of Metal Bellow and Plastic Bellow

Name	Material	Corrosion resistance	Friction coefficient	Electric conductivity	Fatigue resistance
Metal bellow	Galvanize	impermanent	0.25	Excellent	Poor
PT-PLUS plastic bellow	HDPE	Perfect	0.14	Non	Excellent

In the traditional grouting method, the cement ratio is 0.4-0.45 and the grout is filled into the metal bellows from the hole at a pressure of 0.5 -1.0 MPa [7]. If the cement water is completely combined with the metal bellows for too long, the cement water may solidify and leave air behind, which may develop into cracks as a water storage place in the future. The water gathered might contains toxic material that would cause the concrete or metal bellows to rot. Water in northern areas may freeze due to low temperatures, which can cause concrete or metal bellows to expand. All the aforementioned possibilities could result in creating potential danger and increasing the probability of structural failure.

In vacuum grouting, the PT-PLUS plastic bellows are sucked to 80% vacuum density with a vacuum pump before grouting to create a pressure of 0.06-0.1 MPa. Advanced cement water is added to the bellows when a pressure of >0.7 MPa is applied at the other end of the bellows. Due to the difference in pressure at both ends, it is difficult for air to enter the bellows. In addition, advanced cement water is first added to a specific specimen by reducing the ratio of cement water, which all increases the flow of cement water and thus the density.

Comparison could be seen in table 1 and table 2.

But the newly invented method is too costly in terms of the time required to perform it, the human resources to operate it, and the cost of the advanced cement water and the PT-PLUS plastic bellows. Firstly, PT-PLUS plastic bellows are twice the price as metal bellows. Secondly, PT-PLUS plastic bellows are famous for their low fraction, and the traditional metal bellows' is higher but still fit in the international regulations. Thirdly, PT-PLUS plastic bellows are corrosion resistant. However, the grouting method of vacuum grouting actually minimizes the presence of an electrolyte, which means that the conditions for the formation of electrochemical reactions are eliminated. Combining these three reasons, it has been scientifically proven that the traditional bellows can be vacuum grouted with safe and favorable results.

4.2. CFFT instead of traditional reinforced concrete

After a period of fashion of the conventional reinforced concrete structures, CFFT (concrete-filled fiber-reinforced tube) was introduced. However, loads of tests and experiments have not yet been done for different case scenarios. CFFT was designed to minimize the probability of failure of the structure and reduce shrinkage and cracks, however, its defects are often concluded as follows as reasons to not adopt CFFT. Due to the addition of fiber, the weight of CFFT itself is heavier, thus increasing the axial loading from the beginning. Moreover, other than the higher cost problem, the fiber added would face the corrosion issue which is of vital significance for seashore bridges [8]. The study mentioned as follows, however, showcased experiments done on CFFT specifically concerning being exposed to a long-term marine environment. Beyond existing studies, energy-dispersive X-ray, differential scanning, microscopy and Fourier transform infrared spectroscopy tests have been conducted to test out the properties of the tube physically, chemically and thermally.

From the SEM image test, from the ×250 and ×2000 micro images, different extend of damage or debonding on the surfaces of the sample could be clearly shown. Cracks resulting from swelling stresses only occur at an extremely small scale and could be neglected while the longer the time immersed in the marine environment the sample is, the more severe the damage is. From the EDX test, the percentage of ions like Na+ could be tested. The chemical fact that OH– from NAOH would diffuse Na+ is used in this test since 0% Na+ was sensed in the samples, which further implies, seawater containing mordant ions is successfully blocked from getting in touch with the glass fiber. From the DSC test, throughout all four trials, the consistent temperature value of all implies that there was no hydrolysis reaction within the fibers. From the compression test, the longer the time immersed in the marine environment the sample is, the more the axial stress degraded; The higher the temperature is, the faster the absorption of water would be, which accelerated the damage in the sample.

Firstly, fibers are safe from chemical corrosion in the marine environment. Secondly, the maximum axial stress, the maximum shearing strength and the maximum hoop capacity decreased as time goes on and sharpener at the 10%-20% beginning of the total time. Thirdly, the higher temperature of the marine environment would result in a faster damage pace. Lastly, the energy released from the samples only varies due to the temperature of the environment and has no evident link with the time [9].

4.3. Improving the damage equivalence factor

The damage equivalence factor is closely related to the fatigue of bridges which is most important yet very complicated. Because the detailed calculation of the live loads would vary every second [1, 10]. The Eurocodes, together with the SIA codes introduced a predefined fatigue load model for the damage equivalence factors [2-5, 11-14]. However, disadvantages of one simple damage equivalence factor include the following: (1) the limited span length is defined for lines of influence, (2) continuous presence of irregular heavily- weighted items on bridges are impossible to capture and represent by the damage equivalence factor, and (3) the total bridge influence lines are not consistent with the safety margin. And the study proposed in this graph succeeded in improving the above-mentioned disadvantages by making small modifications and identifying effective partial damage equivalence factors and eventually using Monte Carlo Simulation to evaluate the results.

The essential elements required for computing damage equivalence factors are illustrated in Fig. 1. Elements required when computing damage accumulation are illustrated on the left side. The closer the model is to reality, the more accurate the result would be. s. The load history including

the kinematics amplification concerning the traffic model should be included in the load history which is designed for various bridge statics systems while lighter items like pedestrians or cycles should be excluded using the Rainflow Method [15].

The summation of damage = 1 could be derived by computing the S-N curve with the method of trial and error. The 2,000,000 cycles derived from the S–N curve correspondent to the equivalent force range. The range of the fatigue load model (ΔF_{FLM}） derived is shown at the right side model to obtain the force range, D F FLM, by placing the fatigue load model at the most severe positions. The equivalent force range (ΔF_{E2}) is taken into account in the damage summation. Modification of the value of ΔFFLM with the damage equivalence factor (λ). According to the [3], λ could be acquired from: $\Lambda=\lambda_1\times\lambda_2\times\lambda_3\times\lambda_4$; with $\lambda\leq\lambda_{max}$, where $\lambda=_1$ is the partial factor for the influence of the traffic; λ_2 is the partial

factor for the volume correction; λ_3 is the partial factor for age limit correction; λ_4 is the partial factor for the summation of influence due to the traffic, and λ_{max} is the maximum damage equivalence factor.

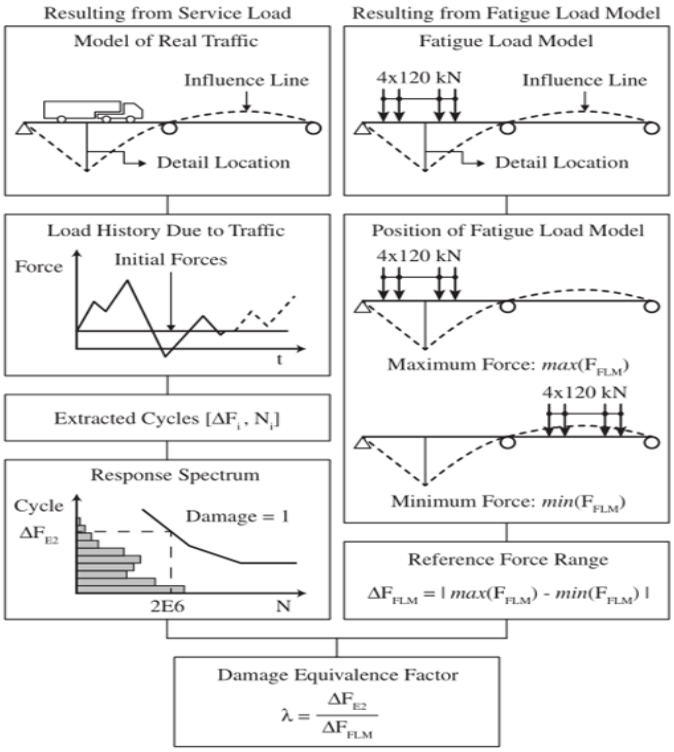


Fig. 1 Concept and main elements of damage equivalence factors

(Derived from Damage Factors Improvement)

Several approaches were used to help improve and simplify the task. From the application of imaginary lines of influence, six different imaginary cases are selected to be representatives for comparison, different case scenarios and conclusions. Case 1 has the shape of triangular. And case 2, having a shape of trapezoidal, could derive from the shape effect. While the Δsin could be derived from case 3. The repetition of the influence line could be represented by case 4 The value Δmax-Δmin is represented by case 5. Case 6 is representative of discontinuity.

For cases 1，2，3，4and 6, Δ_{max}-Δ_{min}=1 (Δinfl =1), which means that it remains constant when the unit length is increased.

When the value λ_2 represents the traffic volume the factor λ based on the Eurocode is not conservative in certain cases. By applying the continuous traffic model, the new partial damage equivalence factor (λ_5) is proposed and checked. It's scientifically acknowledged that the equivalent force range is based on the axial frequency of the status of the known traffic and repetitions of a given influence line for cases where span lengths are very short. While with λ_5, for span lengths that are long, the equivalence range could be derived by the sum of damage according to the vehicle weight of the given traffic [16].

4.4. New Intelligent Detection Technology

Cable-supported bridges are popular for their long lifespan and more attractive modern outlook. However, their short and thick concrete rods are more susceptible to impulse or corrosion. With the rapid development of technology, different types of methods and machines for different fields have been introduced to suit the modern world. Intelligent detection methods include a deep learning model (SqueezeNet) and micromagnetic sensors. The cables can first be inspected using a magnetic memory system and computer vision. Then, depending on the level of damage, it is classified into four alarm levels and provided with suggested remedial repairs. Different damage ranges of the cable will be classified as sunken, spalled, scratched and cracked. Where scratches and cracks will be classified according to the depth of the damage, longitudinal cracks and transverse cracks will also be distinguished according to the type of crack. Inevitably, electronic and noise interference will occur when deriving the image from the horizontal camera. After the analysis of the interference, an

algorithm with open-closed and closed-opened morphologies is generated during the image capturing to neutralize the interference.

In addition, the Squeeze-Net network is used to analyze the images and obtain the preferred accurate and precise results. This network can test the results in 0.51 seconds, while the other three commonly used networks take 1.85 seconds or longer. To further investigate the method, a real case study was implemented. Taking the Tianjin Haihe Bridge as an example, several bridges were selected and 1825 feature images were collected for the application. The results were satisfactory, with an accuracy rate of 97.18% [17].

4.5. Humanized Construction--Concurrent Maintenance

Engineers are suggested to work scientifically, and profitably, but also with a collective mind of looking out for the collective good. When a bridge needs maintenance, although only a part of it, in most cases the whole bridge is closed. As a result, traffic jams, high user costs, and a higher probability of accidents on other bridges. These costs are 20 times higher than the cost of the maintenance project itself [18]. Even if traffic impacts are the only variable, user costs are approximately 6 times the cost of the project [19]. Recently, researchers have also evaluated user costs when designing maintenance projects.CA4PRS software was utilized to simulate volumes of traffic for various pavement construction options and to compute the costs of the users to be a reference for stakeholders [20]. The impact of maintenance strategies was studied on user costs for the I-710 project [21]. However, another concept of parallel conservation is presented below.

The approach consists of A life-cycle cost analysis and B restrictive programming. The model formulation can be derived by substituting different element values in different bridges into the method. By knowing the values of the initial condition, deterioration rate and minimum acceptable condition range the earliest and latest time of the first repair could be computed. The approach aims to minimize the agency costs of bridges, the user costs and the negative impacts of bridge maintenance and to broaden the collective thinking of engineers or stakeholders [22].

5. Conclusion

This article sums up five promising and scientifically-proven maintenance approaches and preventive measures. It is stated clearly that bridge, as a significant role for people from places that it links, for the transportation system that it crosses and for the economic benefits of the society that it influences, should be taken seriously, with profitable and scientific care. This article concludes with five important approaches to help the goal above-mentioned be perfectly achieved.

During the application of pre-stressed concrete structures, it is proven that combining traditional grouting and vacuum grouting by applying vacuum grouting but using the metal below from traditional grouting, would be safer, less time-consuming and more profitable.

It is proven that the conventional reinforced concrete bars are less stable than the concrete-filled fiber-reinforced tube; It is also proven that the concrete-filled fiber-reinforced tube could be a hundred percent anti-corrosion even exposed to the marine environment for a long period, which clarifies doubts and concerns towards choosing which of them as construction material. However, the different temperatures applied in this research represent the marine environments of San Francisco and Miami, more correspondent temperatures are suggested to be tested to derive a more applicable result to other cases.

When using the value of the damage equivalence factor, the conventional factor λ has been proven to have such defects while the proposed partial factor $\lambda 5$ makes relations more direct and evident. This research, however, only used Monte Carlo Simulation. Therefore, other simulations are suggested to be applied to determine different traffic influences on the damage equivalence factor. When detecting damages in cable bridges, it is tested in a model that by applying intelligent image recognition and magnetic-memory technology helps make the accuracy of detection and repair upgraded to 97%. When deciding to have a maintenance construction operated and have the road

blocked, it is suggested to adopt the concurrent operation method by acquiring data on the bridges' car flow rate and deriving the best concurrent operation time, which satisfies the benefits of the drivers to the greatest extent.

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