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FALL PREVENTION SUPPLEMENTARY DEVICES FOR BRIDGE CONSTRUCTION WORKERS: A LIFE CYCLE COST ANALYSIS

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Abstract: Construction workers along bridge decks or overpasses have experienced a considerable number of fatal and non-fatal injuries in the United States. An investigation of fall prevention along the bridge decks reveals the existing guardrails do not meet the required height to provide adequate fall protection. Therefore, fall protection supplementary devices (FPSDs) must be provided to minimize falls from bridge decks. This study conducts a life cycle cost analysis (LCCA) comparing the two opposing options of FPSDs. These options, once installed, could be utilized to extend the existing guardrails' height and provide adequate fall protection along the bridge deck. These two options are: (1) installing temporary barrier protection along the existing guardrails to increase their height to an acceptable level, and (2) installing fixed anchor point(s), a cable between two anchor points along or near the existing bridge deck guardrail. Accordingly, both options of fall protection have been compared on a similar basis to effectively compare the LCCA. The two options were equated to a total cost per 100 linear feet (LF) of installation. Accordingly, all associated costs were included in the estimation such as material costs, installation/dismantling labor costs, yearly inspection, repair costs. The LCCA reveals that the options that have been investigated in the study have a slight difference in life cost. Finally, further investigation should be conducted to determine the design compatibility of the suggested option and its associated alternatives, with the practices and conditions of the workplace.

1 INTRODUCTION

Bridge deck maintenance and repair are performed by construction crews. As these tasks are performed, crews are solely dependent on the existing bridge deck barrier as a means of fall protection. The typical height of the concrete New Jersey barrier rail is 32 inches (ASTM 2011). However, the Occupational Safety and Health Administration (OSHA) requirement to provide adequate fall protection is 39-45 inches. Nearly 88% of all existing bridge deck guardrails in North Carolina do not meet (OSHA) barrier height protection requirements (Zuluaga, et al. 2018). As a result, over 82% of fall fatal injuries among roads construction workers were the result of a fall along bridge decks or overpasses (USDOL 2013). Thus, providing additional means of fall protection is a necessity to prevent fatal and non-fatal falls. Accordingly, the temporary installation of Fall Protection Supplementary Devices (FPSD) should be used. These devices once installed provide adequate fall protection that meets OSHA's requirements. This study conducts a LCCA of two options of FPSDs that can be utilized. The first option is temporary and is typically installed only when the work is being performed. This option has recently been suggested by Zuluaga et al. (2018)

and involves installing a temporary C-Clamp system, see Figure 1. According to Zuluaga et al. (2018), this option is compatible with over 80% of all existing bridge deck guardrails found in North Carolina.

Figure 1.The CC 120 C-Clamp System (Safety Systems and Signs Hawaii, 2018)

The second option is permanent and has been suggested by this study's authors. This option involves installing a permanent fall protection system on or near the bridge deck railing. This alternative is like the rooftop anchor devices, see Figure 2. This second option requires the construction worker to wear a full body harness and self-retractable lanyard. In addition, it involves a continuous cable system which is attached between two or more appropriately spaced anchors. This alternative allows up to three workers to attach.

Figure 2. Permanent Anchors System (Engineered Fall Protection, 2018)

2 METHODOLOGY

Comparing the two identified options is the core of this study. Thus, each suggested option has been equated and compared on a similar basis which is the total cost per 100 linear feet (LF). The quantified LCCA of these two options included: initial product costs, installation costs, inspection costs, and mobilization costs. Also, the costs associated with the individual full body harness and the self-retracting lanyard device when needed have been included. Accordingly, the components of each option that are needed to provide adequate fall protection along a 100 LF section were identified. Following this, the present value of each option was calculated. It was also assumed that both options required to be maintained and used over the routine inspection time frame. The discount rate was taken as 3%. The cost information was gathered from the manufactures and/or distributors of both options and RSMeans 2018. The manufactures and/or distributors were contacted by either phone, email, or manufacturers' and/or distributors' websites. Finally, the LCCA calculation was based on a 10-year time period. For simplicity, it has been assumed that neither option had residual value (salvage value) following the study period

3 FINDINGS

The costs of the two identified options were compiled and equated to a total cost per 100 LF. Thus, the following costs have been acquired.

3.1 Option 1: Temporary FPSD

This section investigates the first option of FPSD that includes C-clamp and wood boards, assuming an 8-foot spacing constraint. The divisions of costs compiled were the product cost, mobilization and installation costs, and inspection cost.

- Product Costs: The unit cost for each C-clamp CC120 was $120. The spacing requirement for each C-clamp is 8 LF. Thus, the total material cost to install 100 LF of fall protection for this option was determined to be approximately $1,560 (i.e., 13 units). It has been assumed that there is a need to replace the C-clamps after five years. In addition, the cost of 2"X4" wood board is $6.27 per LF. The wood board is required to erect the top and mid rail. Thus, the total cost was determined to be $1254. The assumption is that there is a need to purchase new wood boards every two years. Therefore, the total initial cost is $2814.
- Mobilization and Installation Costs: Mobilization of FPSD requires roughly two hours of travel time to bridge location (two-ways). In addition, the total time for installing/ dismantling the 13 FPSD unites was estimated to be three hours, and the work was to be completed by two workers and a supervisor. Therefore, the total estimated labor cost to install/dismantle 100 LF of this option was calculated as $300. It was also assumed that the system will be used at least twice a year on the same bridge for inspection and maintenance purposes. Accordingly, the total mobilization and installation cost of temporary FPSD for a bridge is calculated as $6,000 for the 10-year period. After completing the installation, an inspection by a competent individual will be needed, the estimated cost to perform the required inspections is $100 per year.
- Inspection Costs: The inspection costs associated with the requirement to routinely check all installed temporary fall protection was analyzed in this cost division. This cost was equated to half of the installation time when performed by a competent person. Hence, the time was estimated to be approximately 15 minutes per device. Thus, the total cost to inspect and potentially repair 100 LF of installed FPSD on a bridge is estimated to be $100 per year.

Accordingly, the life cycle cost for 100 LF of the temporary FPSD, was determined to be $12,222.8, see Table 1.

3.2 Option 2: Permanent FPSD

This section investigates the second option of FPSD that includes permanent anchors and cable system, assuming 40 feet section. The divisions of costs compiled were only the product costs, installation costs, inspection costs, and safety equipment costs (i.e., full body harness and retractable lanyard cable costs).

- Product Costs: The product costs required for every 100 LF of fall protection using anchors and cable System was determined to be $4000
- Installation Costs: The manufacturer's installation costs for the system was determined to be $5,000.
- Inspection Cost: The manufacturer's inspection cost is required for checking the bolts of the fall protection system every year. The time was estimated to be approximately 1 man-hour per inspection. Therefore, the inspection cost was calculated as $200 per year.
- Full Body Harness and Retractable Lanyard Cable Costs: The number of workers assumed to be attached to the system was estimated at three workers. The cost for the full body harness and retractable lanyard cable was estimated at $600.

Accordingly, the LCCA of the permanent FPSD was determined to be approximately $11,415.5, Table 2.

Table 1. The LCCA of the Temporary FPSD

Year	Initial Cost	Installation Cost	Inspection Cost	Total Cost
0	2,814.0	300.0		3,114.0
1		291.3	97.1	388.3
2	1,182.0	282.8	94.3	1,573.8
3		274.5	91.5	366.1
4	1,114.2	266.5	88.8	1,469.6
5	1,345.7	258.8	86.3	1,690.7
6	1,050.2	251.2	83.7	1,385.2
7		243.9	81.3	325.2
8	989.9	236.8	78.9	1,305.7
9		229.9	76.6	306.6
10		223.2	74.4	297.6
Total	8,710.3	2,559.1	953.0	12,222.8

Table 2. The LCCA of the Permanent FPSD

Year	Product Cost	Installation Cost	Inspection Cost	PFAS*	Total Cost
0	4,000.0	5,000.0	200.0	600.0	9,800.0
1			194.2		194.2
2			188.5		188.5
3			183.0		183.0
4			177.7		177.7
5			172.5		172.5
6			77.0		77.0
7			162.6		162.6
8			157.9		157.9
9			153.3		153.3
10			148.8		148.8
TOTAL	4,000.0	5,000.0	1,815.5	600.0	$11,415.5

*Personal Fall Arrest System

4 DISCUSSION

The LCCA analysis indicates that the permanent option payback period is around 7.5 years compared to the temporary option, see Figure 3. Even if the initial cost of the temporary option is much cheaper than the permanent option at Year 0, the costs for replacement, mobilization, and inspection increase the overall life-cycle cost of the temporary option in a ten-year period. On the other hand, the permanent option lasts for ten years, whereas CC-120 needs C-clamps replacement every five years and wood board replacement every two years. The permanent option needs inspection once a year, where CC-120 needs to be inspected every time which is assumed to be two times a year in this study. In addition to this, there are no mobilization cost for the permanent option, while CC-120 needs to be transported from storage to the bridge location every time. Overall, both options can be utilized to mitigate fall hazards on bridges based on the decision-makers' choice and budget.

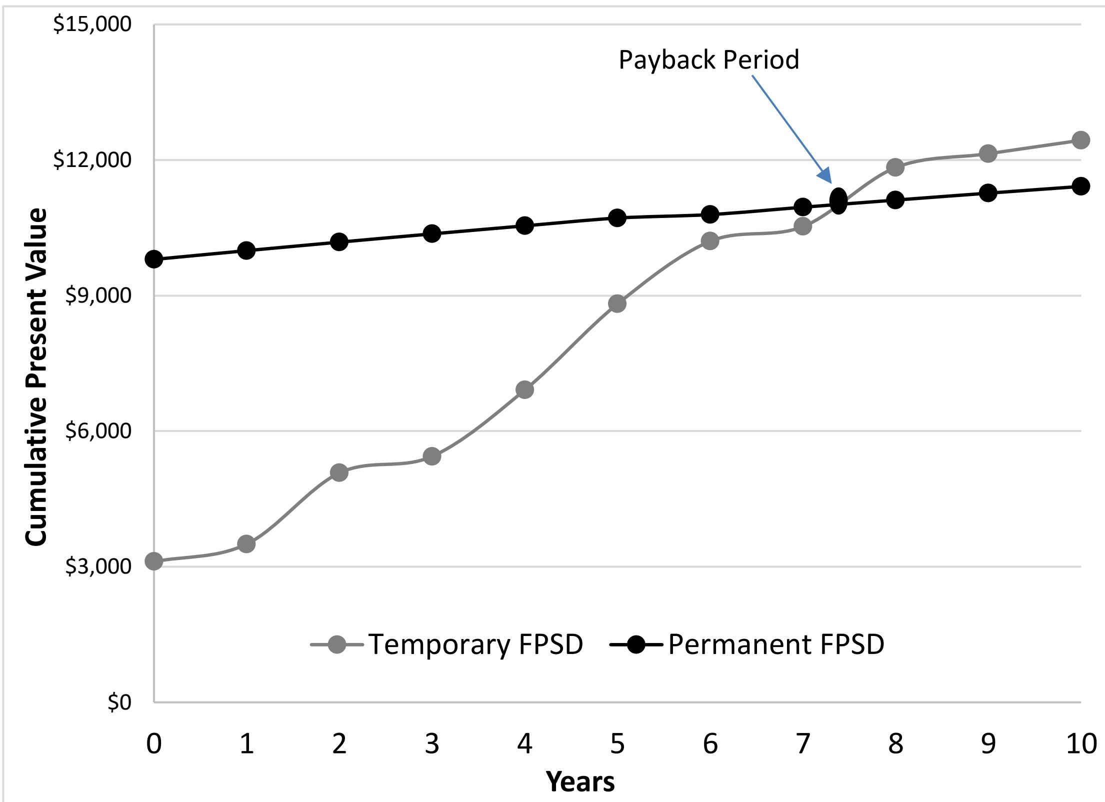

Figure 3. The present values of the FPSD options

As a result, further investigation is needed to incorporate other characteristics of these two options to obtain a more structured comparison. Overall, there are three main points that should be considered for further investigation:

- A more in-depth structural analysis must be conducted to establish the compatibility of the permanent system when installed on or near bridge deck guardrails. Tipping, sliding, and structural failure of the permanent system must be analyzed, and deemed safe before proceeding with installing the permanent systems. On the other hand, utilizing temporary option exposes construction workers to fall hazard while installing and dismantling the system. Furthermore, transferring the system from the storage area to the work area exposes the construction workers to struck by hazards.
- The permanent FPSD will be visible for the general public to view. Thus, the system should be installed out of general view or below grade. One example of a below-grade fitting is that similar to

fire hydrant water value. To access and use the fire hydrant during emergency conditions, a first responder must first remove the valve cover, insert a valve key and turn the water valve to the “on” position. Once performed, the fire hydrant is usable. The individual fixed anchor point can be installed below grade within a below-grade casing.

- It is also important to gauge the desirability of bridge deck construction workers to use these means and methods as fall protection. Therefore, two case studies must be conducted to investigate the desirability and practicality of each system.

5 CONCLUSION

The threshold for fall protection in construction workplaces is 6 feet. Fall protection systems acceptable at construction workplaces include guardrail system, personal fall arrest system, and safety net. According to OSHA, the top rail of a compliance guardrail system should at least reach 39 inches. However, the typical height of bridges’ guardrail systems is roughly 32 inches. Therefore, fall protection supplementary devices (FPSD) have been suggested to protect construction crew members. This study conducted a Life Cycle Cost Analysis for two options of FPSD, with the first option being temporary, and the second option permanent. In addition, the first option works thorough increases the height of bridge guardrails to the acceptable height as determined by OSHA, while the second option utilizes the personal fall arrest system. The result indicates that there is no significant difference in overall cost between the two investigated options. Therefore, other factors such as constructability and desirability should be investigated to help to determine the optimal option.

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