Exploring Methods for Fast, Sustainable Partial-Depth Concrete Bridge Deck Repair

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In 2025, the United States had over 4 billion ft^2 of in-service bridge deck, and 5% of that bridge deck was rated as being in poor condition.[1] That means approximately 200 million ft^2 of bridge deck needed either repair or replacement. One commonly used method for the repair of concrete bridge decks is partial-depth concrete repair, a technique in which small, partial-depth patches of deteriorated concrete bridge deck are removed and replaced with new cementitious material. By removing the deteriorated patches, the spread of the concrete degradation is limited, thus extending the service life of the bridge deck. While significant advances have been made in the development of rapid-setting cementitious materials for partial-depth bridge deck repair,[2] the concrete removal and patch preparation process is still laborious and time consuming.

Sustainability Study

In recent research,[3,4] the authors investigated methods to reduce the preparation time for concrete patching through automation. The goal was to improve the efficiency of partial-depth deck repair while simultaneously reducing air-pollutant emissions. A review of the existing literature showed that four common concrete removal methods are used in partial-depth repairs: saw and patch, chip and patch, mill and patch, and water blast and patch. Using a Utah bridge deck repair project as a case study,[2] investigators estimated five air-pollutant quantities (CO_2, CO, NO_x, SO_2, and PM_{10}) for each of the four removal methods by employing the MOVES2014b model[5] and GREET model.[6]

MOVES (MOtor Vehicle Emission Simulator) is an emissions modeling system that calculates air pollutants while adjusting for conditions such as speed, temperature, and vehicle age. GREET (Greenhouse gases, Regulated Emissions, and Energy use in Technologies) is a full life-cycle assessment model that evaluates the environmental impacts of technologies, fuels, and vehicle combinations across their entire life. These two complementary models were used to calculate emission quantities: MOVES2014b for vehicle activity and GREET for life-cycle analysis of fuel and vehicle production (see **Table 1**).

Comparing the equipment use time, investigators also estimated the traffic delays for each method (**Table 2**). The results show that the methods that produce the most pollutants (mill and patch, and water blast and patch) require less time, whereas those that produce smaller amounts of pollutants (saw and patch, and chip and patch) require more time. This relationship demonstrates the difficulty in balancing sustainability with efficiency in construction practices. However, increased traffic delays may also increase the amount of emitted pollutants. This topic is discussed in a previous article by the authors.[3]

Reduced Preparation Time Study

After completing the sustainability portion of the study, the authors investigated whether the methods with lower levels of pollutant emissions could be automated to reduce the amount of time needed to prepare the patches. With this outcome in mind, the saw and patch method was chosen for additional study due to its popularity

Table 1. Estimated air-pollutant emissions associated with the method of removing 31 m^3 of concrete (based on a Utah bridge deck repair project case study)[2]

Method	CO_2, kg	CO, kg	NO_x, kg	SO_2, kg	PM_{10}, kg	Total emissions, kg	Total emissions, kg/m^3
Saw and patch	720.371	3.792	2.019	0.0824	0.300	726.565	23.7
Chip and patch	649.231	2.602	1.911	0.0819	0.293	654.119	21.2
Mill and patch	5756.444	3.934	9.998	0.101	0.531	5771.008	187.5
Water blast and patch	3317.890	4.671	13.874	0.142	0.921	3337.497	108.4

Table 2. Estimated traffic delays for case study based on average lane capacity of 560 vehicles per hour[2]

Method	Required time, hours	No. of vehicles delayed
Saw and patch	92.24	51,654
Chip and patch	88.49	49,554
Mill and patch	57.61	32,262
Water blast and patch	33.66	18,850

among contractors and its potential for automation.

Four unreinforced concrete slabs measuring 5 ft wide, 5 ft long, and 10 in. deep were cast, each with different concrete mixture proportions and different compressive strengths. The target compressive strengths for all specimens were between 5000 and 7000 psi. Each concrete slab was then marked into four equal areas measuring 2 ft by 2 ft (**Fig. 1**), and the concrete was removed to a target removal depth of 3 in. following four different discretized sawing patterns. The concrete saw used was a gas-powered model with a 14-in.-diameter blade, and the jackhammer model produced a triaxial vibration of 5.9 m/s^2 for chiseling into concrete. For each method, the removal and equipment usage times for each of the slab sections were measured. The differences between each method are the number of saw-cut lines (from 4 to 10) and the quantity of subpieces required to be removed. Figure 1 shows the discretization, with each drawn line representing a saw-cut line.

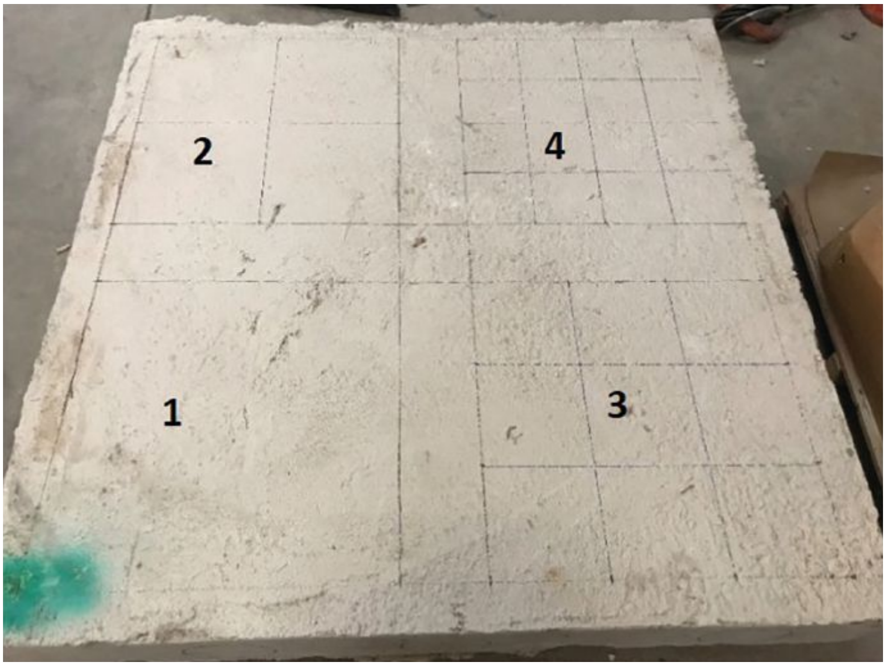

Figure 1. Saw-cutting patterns on the slab specimens help establish the relationship between time and air-pollutant emissions during partial-depth concrete deck repair methods. All Figures: Courtesy of Israi Abu Shanab.

Figure 2. Concrete removal method 4 uses the most saw cutting of the four tested methods to reduce the jackhammering time. The concrete removal time, equipment usage, and labor required for partial-depth concrete deck repairs were compared for each method.

Investigators found that as the number of saw-cut lines increased, the removal time, which includes both saw cutting and jackhammering, decreased.[4] The explanation for this finding stemmed from discussion with the operator who removed the concrete patches. The operator, a semiskilled laborer with previous experience using both the concrete saw and jackhammer, noted that using the saw required much less physical exertion than using the jackhammer. Furthermore, because the concrete pieces for the more-discretized patches were smaller in size, the operator could simply "pop off" the concrete with the jackhammer (as shown in **Fig. 2**). As such, the removal of the concrete was easier and the physical toll on the laborers was less; therefore, the workers could be more efficient and work for longer intervals. The results also show the potential for future automation as saw cutting seems to be more easily automated than jackhammering. Subsequent studies in this area are currently underway.

Finally, the results of the secondary study were applied to the original case study of the Utah bridge deck to demonstrate the removal time for each method. The results show a dramatic decrease in removal time and a corresponding decrease in overall construction time as the number of saw-cut lines increases in a given surface area of bridge deck (**Table 3**).

Conclusion

This study showed that, of the most widely used repair preparation methods, saw and patch produces the least amount of pollutants. Additionally, by increasing the number of saw cuts, the removal time can be decreased dramatically.

Table 3. Required time for concrete removal using the four methods for the case study bridge deck

Method	Total predicted removal time, hours
1 (4 saw-cut lines)	656.71
2 (6 saw-cut lines)	610.07
3 (8 saw-cut lines)	598.02
4 (10 saw-cut lines)	426.05

Note: Time was predicted based on extrapolation of time for each method in the laboratory setting.

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