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Original Research Paper

Cost effectiveness of crack treatment methods: A field study

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HIGHLIGHTS

- The initial cost of crack sealing is on an average approximately 45% higher than crack filling treatment.
- Between crack sealing and filling treatment, crack sealing is more cost effective in a long run.
- The agency cost found to have reduced by 24% with crack sealing treatment over a 35 year analysis period.

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ABSTRACT

In the United States, more than 94% highways are paved with asphalt materials and placing crack sealant materials has been a common pavement maintenance for decades. Crack sealing treatment includes the use of a router to create a reservoir on the intended cracks whereas crack filling is given without doing any modification to the crack wall. Although the initial cost of crack sealing is higher, it is expected to have a longer service period compared to crack filling. There is little research on comparison of short and long term cost effectiveness between these two treatments using the real field cost data analysis. In this study four test sites in Texas were treated with crack filling and sealing using the same sealant material and finishing technique. Cost effectiveness of both treatments was measured in terms of initial, annual average and life cycle cost based on the cost inputs during construction. In general, the results of this study indicated that (1) on an average approximately 45% initial cost increase was estimated with the two routing configurations of crack sealing; (2) material and labor cost is found to have the most significant effect on the higher initial cost of crack sealing compared to other associated costs; (3) annual average and life cycle costs have shown that crack sealing is more cost effective pavement maintenance compared to crack filling over a long period of time; (4) agency cost is observed to be reduced by approximately 24% with crack sealing treatment based on the 35 year analysis period.

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1.   Introduction

Transportation infrastructure in the United States is worth a trillion dollars which includes approximately 2.5 million centerline miles of highways paved using asphalt materials (NAPA, 2018). Cracking is an inevitable phenomenon in asphalt concrete pavement and plays a vital role in pavement deterioration. There are two main concerns while designing the pavement: rutting and cracking. Cracking is considered as the primary mode of deterioration and main factor in determining time for the next scheduled rehabilitation in the pavement. The different types of crack formation are recognized as transverse, longitudinal, fatigue, block, reflective, edge and slippage. The main causes of these crack formations are traffic loading and vertical movement which exceeds the tensile or shear strength of pavement materials. Crack treatment is one of pavement maintenance methods performed by transportation agencies in order to delay pavement deterioration, extend service life and maximize the shrinking public funds. The main goal of these treatment is to minimize the penetration of moisture or water through crack openings into the under laying layers which can cause severe damage to the pavement. Among these crack treatments, crack sealing and crack filling are considered as the most common pavement maintenance performed by local transportation agencies for decades.

Crack sealing refers to routing cracks and placing material into the routed channel. On the other hand, crack filling refers to simply inserting sealant without cutting or performing any modification to the crack walls. Crack treatments can reduce the water infiltration, prevent pumping and avoid the need for premature base and pavement repair. These two types of treatment can be considered as the logical alternatives compared to other maintenance programs due to its economic benefits and vital role in extending the life of pavement (Eaton and Ashcraft, 1992). Eaton and Ashcraft (1992) stated that chip seal treatment cost 3–14 times more than crack sealing and an overlay cost 8–26 times as much as crack sealing. Several studies have been performed in the United States and abroad on different types of sealant materials and their performance evaluation criteria on these two types of crack treatments (FHWA, 1998; Masson and Lacasse, 1999; Smith et al., 1993; Smith and Romine, 1993). However, there is little or no comprehensive research on comparison of short and long term cost effectiveness between crack sealing and filling based on the real field cost data analysis.

Smith and Romine (1999) reported that the most cost effective treatment could be found with rubberized asphalt sealant materials that were placed in a shallow recessed band-aid configuration based on the seven-year performance monitoring of the various crack treatments.

Hand et al. (2000) conducted a literature review over 100 potential references regarding crack sealing. They found that only 18 of these references specifically address the cost effectiveness of crack sealing in terms of pavement performance and only four of the 18 consists of quantitative data. However, those studies were quite similar to each other and focused on the performance of material or technique combination rather than cost-effectiveness.

Masson et al. (2003) estimated the cost of installation and cost effectiveness for sealant materials with a hypothetical one to ten years of service life. They reported that crack filling would be more cost effective than crack sealing, if crack fillers were to show same durability. However, in their study they were assumed two different types of material for the two treatment types, the use of hot-pour material for crack sealing and cold-pour emulsion for crack filling. In another study, Cuelho and Freeman (2004) investigated the cost effectiveness of crack sealing materials and techniques for asphalt pavement. The study involved the use of eleven sealant materials with six sealing techniques in four experimental test sites. They have used the fourteen crack sealing bids over a six month period and eclectic forecasting model to estimate the cost of crack sealing. Also, the study did not consider the similar finishing technique for crack sealing and filling. They concluded that the use of Crafco 522 with a shallow reservoir and flush was the most cost-effective. They have also confirmed that after the fifth year evaluation, significant failures were observed for non-routed configurations (crack filling) compared to routed configurations (crack sealing).

Yildirim et al. (2006) investigated the field performance and compared the construction cost for hot and cold pour sealants. They have surveyed and studied thirty three different test sections in five districts using seven different sealant materials for four years. In their study they only consider crack filling treatment to treat the cracks. They concluded that hot pour sealants perform better than cold pour sealants and no significant difference in the construction cost.

As it is evident from the aforementioned studies that cost effectiveness of crack treatments only is analyzed based upon the field performance or prediction model rather than cost data analysis from the field. Results from the SHRP study showed that there is almost a 40 percent greater chance of sealant success if cracks are routed prior to sealing. The initial cost of crack sealing is higher due to the use of extra labor, material and equipment. However, this treatment can give a longer service period to the pavement life cycle before the next scheduled treatment (Cuelho and Freeman, 2004; Decker, 2014; Masson et al., 2003; Shuler, 2009). On the other hand, it is possible that higher initial cost treatment can be offset by the benefits of longer service period.

Since there is no comprehensive study to find out the initial and long term cost effectiveness in between crack sealing and filling using real field cost data, this research study attempted to achieve this objective. The main objective of this study is to compare the construction cost in terms of initial cost and life cycle cost. Four test sites were selected based upon several criteria, including location, average annual daily traffic (AADT), material and conditions (pavement condition, drainage, etc.) in Texas. Each potential cost factors (sealing time, labor, material, equipment, traffic, etc.) and all the cost inputs were identified and calculated in order to find out the best cost effectiveness treatment.

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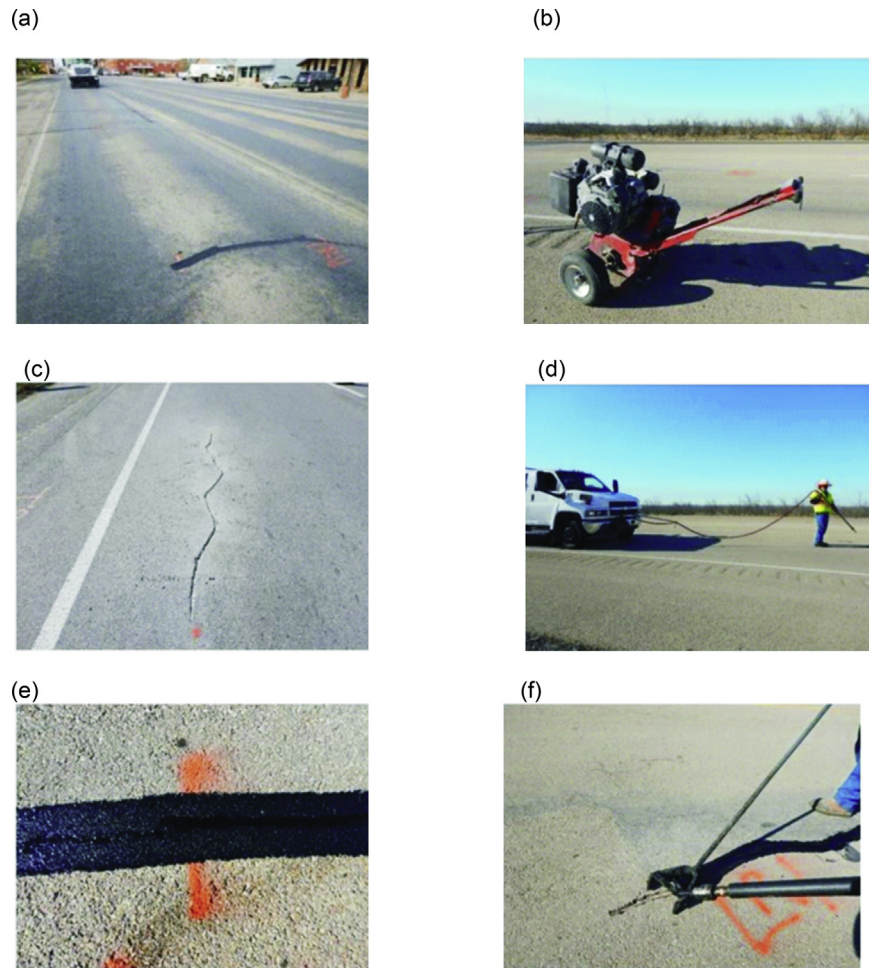**3**

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Fig. 1 – Crack filling and sealing installation process. (a) Longitudinal and transverse cracks. (b) Router. (c) Routing of cracks. (d) Cleaning of cracks. (e) Placing of sealant material. (f) Squeegeed flush to the surface of the road.

2. Crack sealing vs crack filling

Crack sealing is defined as using a router to create a reservoir or routed channel in a crack. After that the routed channel is filled with a sealant material. On the other hand, crack filling is defined as minor crack preparation, such as using an air gun to blow debris out of cracks, prior to installation of the sealant. There is no pavement removed with crack filling.

With crack sealing treatment, cracks are routed to a pre-defined geometry, cleaned and materials are placed into it in order to prevent the intrusion of water into the pavement surface through the upper surface. Routes are generally given with a width to depth ratio of one or greater than one that can enhance the sealant performance (Ketcham, 1996; Khuri and Tons, 1992; Wang and Weisgerber, 1993). Fig. 1 illustrates the different stages of the crack filling and sealing installation process.

Crack treatment can be more effective when applied to pavements which are in good condition with low to moderate crack density and where cracks show little or no branching (FHWA, 1998). Crack treatment is widely used as a component of pavement management systems (PMS), though is not a comprehensive treatment in and of itself (Hu et al., 2010).

Successful crack treatment implementation depends on the appropriate selection of pavement and material, crack preparation and crack sealant application.

3. Methodology

3.1. Selection of test sites and crack treatment

Installation took place at four test locations under a variety of conditions in Texas. Selected test sections present various environmental conditions (altitude and rainfall), average annual daily traffic (AADT) and pavement conditions. These test sites are Fort Worth, Abilene, Brownwood, and Corpus Christi.

Fig. 2 shows the location of the four selected test sites. In order to perform the installation effectively, initially the research team come up with proper plan and design for each site. Winter and spring months were selected to perform the installation. The same crew members of Crafco were awarded the contract for performing crack sealing and filling treatment in all test sites.

TxDOT was given the contract for traffic control. The research team visited all the sites prior to installation. For this
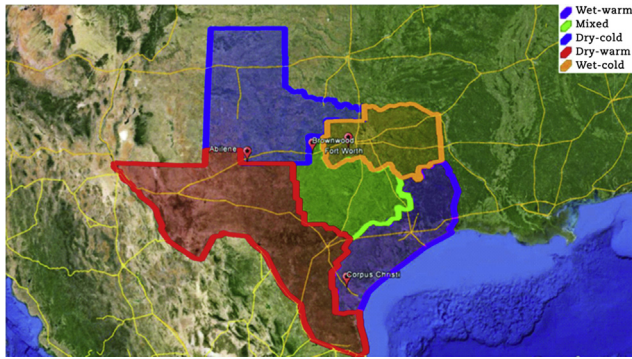
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Fig. 2 — Climate zones and potential test sites.

study, two types of cracks have been selected for the installation which are 3 mm or approximately 1/8″ in width. The first one is longitudinal crack which develops longitudinally along the pavement centerline. Another one is transverse crack which occurs perpendicularly to the center line of the pavement. Crack sealing treatment designated cracks were routed before putting the sealant material into the cracks. Routing incorporates the use of a router to open all the cracks up to a uniform width and depth. A router is a machine that operates using either carbide teeth or carbide tipped bits. Routing was done on a 1×1 profile (cutting as wide as deep) or $1/2″ \times 1/2″$ (W (inch) $\times$ D (inch)). Crack cleaning is the most important phase of a successful installation as it reduces the adhesion failures between the sealer material and the sidewall of the crack. High pressure air blasting is effective and efficient for removing dust, debris and some loosened AC fragments. For the proper cleaning of each crack at each location high pressure air blasting was used. After ensuring that pavement surface was free from moisture, hot pour sealants were applied into the cracks. The sealant material was squeegeed flush to the surface of the road so that it can provide a smooth drive to the drivers. The road was reopened to traffic after the sealant material gets cured.

3.2. Selection of configurations

The length and width of the designated cracks for crack filling were measured using slide calipers. Several cracks were measured and the research team calculated the average length and width of those cracks. The average configuration profile for crack filling was considered $1/8″ \times 1/4″$ (W (inch) $\times$ D (inch)). Routing was done on a 1×1 profile or $1/2″ \times 1/2″$. In order to observe the cost effectiveness with a small reservoir for crack sealing treatment, the research team also considered to add a $3/8″ \times 3/8″$ configuration. The cost effectiveness between these two types of configurations of crack sealing was also investigated.

3.3. Initial cost input

3.3.1. Identification of total time of sealing for both treatments
The total time of performing crack treatment depends on several criteria, which includes mobilization, travel to site, demobilization, rush hours, breaks, work assignments, food

Table 1 — Crack treatment practices within Texas.			
District	Does the district perform routing	If No — why not	Durability of crack sealant application
Beaumont	No	Costly practice	3 years using hot pour
Paris	No	No guidelines	No evaluation performed
Yoakum	No	Uncommon practice	2—5 years
Tyler	No	Blowing out the debris from cracks with air has seemed to get them clean enough to seal	1 year
Corpus Christi	No	Costly	No evaluation performed
Pharr	No	No guidelines	2 years
Bryan	No	Good success with current method	No evaluation performed
Dallas	No	Compressed air ensure the adhesion and effectiveness	Typically 4 years
Lubbock	No	Costly practice	No evaluation performed
Odessa	No	Uncommon practice	No evaluation performed
San Angelo	No	Contractors are not equipped to provide this service and as a result, it would be very costly	4—5 years
Childress	No	Blowing out the debris from cracks with air has seemed to get them clean enough to seal	Average 2—3 years, but sometimes cracks need refilling the next year
Laredo	No	Uncommon practice and have had good success with current method	No evaluation performed
Amarillo	No	They have routing practice in the past but leave it due to time consumption and equipment issue	3—5 years using hot pour
Waco	No	Blowing out the debris from cracks with air has seemed to get them clean enough to seal	No evaluation performed
Lufkin	No	Typically blow the debris from crack with air and fill the crack with sealant	1—2 years
Fort Worth	No	Hot pour crack seal has been used in the district to penetrate the crack width without routing	No evaluation performed
Austin	No	Not cost effective	3 years
Brownwood	No	Insufficient knowledge about benefits	5—10 years

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breaks, traffic control set up, traffic control removal, cleaning cracks, routing, and curing period. The research team identified the significant time variables which are traffic control set up and removal, waiting period for starting sealing before cleaning and curing period. Other time factors could reduce the sealing time, but those effects would be same for both treatment methods. Traffic control is one of the most important practices during the implementation of crack treatments; this practice ensures the safety of all workers. As mentioned earlier traffic control has been awarded to TxDOT. The time for traffic control setup was recorded in the field for all test sites. After the construction, traffic control removal time was measured. The research team recorded the same time period of 30 min for both traffic control set up in all test sites. As mentioned earlier during the construction of crack filling and sealing, selection of the appropriate cracks is considered as the first task. For crack filling, the next task is to clean the crack and then filling the cracks with sealant material. In the field all tasks has been done simultaneously. After designating the cracks, the cleaning crew started to clean the cracks and the sealant crew followed them after 10 min to put the sealant materials into the clean cracks. The reason behind putting 10 min interval period is to avoid the overlapping between these two tasks. As a result, both tasks can be done simultaneously and the sealant crew have sufficient cracks to seal before they reach at the point where cleaning crew were doing their work. On the other hand, for the construction of crack sealing the additional step was performing routing before cleaning the cracks. In that case, the waiting period before starting the sealing of cracks was given 20 min.

Curing time was given after sealing the cracks and measurement taken in the field. This duration presents the amount of time allowed for curing after completion of sealing until the road was opened to traffic. The amount of time to cure the sealant material was recorded 15 min. The total time for sealing the cracks was calculated by subtracting the times for traffic setup, traffic removal, waiting period before starting sealing and cure time from an 8 h working day for all test sites.

3.3.2. Length sealed per day

The length sealed per hour was calculated by the length of sealed cracks divided by the total sealing time at each test site. This result was multiplied by the prospective total sealing time performed in an 8 h working day.

3.3.3. Material cost per day

As mentioned earlier, the reservoir areas for crack filling and sealing are different and depending on the volume of reservoir the material application rate would be different for each treatment type. The volume of the reservoir was calculated in one linear feet of crack. The gross application rate of material in one linear feet of crack was calculated by multiplying the volume of reservoir by the unit weight of hot pour sealant materials. The net application rate of material was calculated by multiplying the gross application rate of material by 15% waste (Smith and Romine, 1993). The cost of the material per day was calculated by multiplying the length sealed per day by the actual amount of material used per linear foot for sealing at each test section and multiplying this by the material cost per unit.

3.3.4. Traffic control cost

Traffic control for the construction work was given by TxDOT. The cost for the overall traffic control equipment (arrow board, cone hauling truck, pickup truck, etc.) for that construction period was provided by TxDOT.

3.3.5. Crew cost

Four personnel were included for the crack filling operations: i) crack cleaning, ii) sealing of crack, iii) squeegeed flush to the surface of the road, and iv) hot pour sealant equipment driver. On the other hand, for crack sealing, one additional personnel is required for routing the crack. The crew cost per hour was provided by Crafco.

3.3.6. Air compressor, router and hot melt equipment

The cost per day for the air compressor, router and hot melt equipment was taken from the Crafco.

3.3.7. Total cost and unit cost

Total cost per day was calculated by adding together the material, traffic control, crew, equipment cost per day. The unit cost in dollars per linear foot was calculated by dividing the total cost per day by the total length of sealing work.

3.4. Average annual cost (AAC)

The AAC was calculated based on the explanations given in SHRP-H-348 "Materials and Procedures for Sealing and Filling Cracks in Asphalt Surfaced Pavements". The user delay cost and interest rate were considered while calculating the AAC. AAC values were calculated based on a 5 percent interest rate and user delay cost of $2000 per day. The calculated initial cost for this project was taken as an input for AAC.

3.5. Life cycle cost analysis (LCCA)

3.5.1. Survey

A survey of crack sealing and filling procedures was developed and distributed in Texas. The response was received and analyzed. Texas does not currently require routing, but decides on a case by case basis whether it is needed. Questionnaires were sent to 25 districts, responses were received from 19. In Texas, no district practice crack sealing however one of the responses (Amarillo) provided that they have routing practice in the past but leave it due to time consumption and equipment issue. Durability of crack sealant application varied from 3 to 5 years. However, 40 percent districts do not have field evaluation for measuring the crack treatment performance. All those districts that responded, six of them stated that blowing out the debris from cracks with air has seemed to get them clean enough to seal and ensured good success with current method. Five districts responded that crack sealing is a costly practice. Other districts mentioned that this practice is uncommon and do not have proper guidelines. Also, one district stated that they do not have any idea about its benefit. Responses to the questionnaire are provided in Table 1.

Decker (2014) conducted a survey on 157 individuals representing 28 state DOTs, 106 countries, 3 cities, 2 Federal Highway Administration (FHWA), 1 Canadian province, 2 US contractors and 1 contractor from New Zealand. They were

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asked to estimate the typical life span for crack sealing and crack filling on both major and minor roads. They concluded that majority of the respondents think crack sealing on both major and minor roads can perform for 5–10 years, but that crack filling will only last 1–4 years. Yildirim et al. (2006) reported that crack sealing without routing configuration using hot-pour sealant materials have a typical life cycle of 3–5 years. Rajagopal et al. (2003) reported that their prediction model indicated a life span of 3.6 years for crack filling treatment. According to literature review and survey from the Texas districts, the research team considered the pavement could stand with crack filling for 3 years and crack sealing for 5 years.

3.5.2. Strategy

The long term cost effectiveness between crack sealing and crack filling was based upon two categories, initial cost and durability of pavement after the two treatment type.

As it is obvious that the initial cost of crack sealing is more costly compared to crack filling. However, the service period is longer with crack sealing compared to crack filling. Initial cost per linear feet measured for crack sealing and crack filling is used as an input in LCCA for both treatment types. A 35 year analysis period was established to calculate the long term cost effectiveness in between these two treatment types (Walls and Smith, 1998). The research team considered that a new asphalt overlay would be placed after the service period of each treatment type. For example, the new overlay will be placed after three years and five years of service period for crack filling and crack sealing, respectively. The overlay cost of $27.38 (including all associated cost regarding freight and material) per linear feet considered for the input in LCCA. In order to make the calculation simple the research team neglect the interest rate, inflation rate and user delay cost. Also, depending upon the economic climate, the value may be very difficult to estimate for any time in the future over a 35 year analysis period.

4. Results and discussions

The key objective of this study is to determine the short term and long term cost effectiveness of crack sealing and crack filling. To determine the objective, the cost analysis was based on the comparison of all cost aspects regarding the implemented crack treatments on four highways in Texas. Each potential cost input for the construction of both treatments was recorded and analyzed to find out the initial, average annual and life cycle cost.

4.1. Initial cost analysis

The cost factors for each task during the construction of crack sealing and crack filling were determined and data used for analysis subdivided into six categories: total time of sealing, length of sealed cracks, material cost, traffic control, number of crew personnel, and sealing equipment. In order to show the method of calculating these costs, one sample calculation from crack filling and another from crack sealing (3/8″ × 3/8″) used to illustrate the calculation of costs.

Initial cost calculation (crack filling)
Total time of sealing:
Traffic control setup = 30 min/0.5 h.
Traffic control removal = 30 min/0.5 h.
Waiting period for starting sealing before cleaning = 10 min/0.17 h.
Curing period = 15 min/0.25 h.
Work day = 8 h.
Filling time = 8−0.5−0.5−0.17−0.25 = 6.58 h.
Length sealed per day:
Length of the sealed cracks at site = 978 linear feet.
Sealing time at site = 25 min.
Length sealed per day = (978/25) × 60 × 6.58 = 15,444.58 per day.
Material cost per day:
Length sealed per day = 15,444.58 lin ft.
Cross sectional area of reservoir = (0.12 in × 0.25 in) = 0.03 in^2.
Volume of reservoir (1 lin ft of crack) = 1 ft × (0.03/144 ft^2) = 0.000208 ft^3.
Gross application rate (no waste) = 73.31 lb/ft^3 × 0.000208 = 0.0152 lb/lin ft of crack.
Net application rate (15% waste) = 1.15 × 0.0152 = 0.01748 lb/lin ft of crack.
Material cost = $0.68/lb.
Material cost per day = 15,444.58 × 0.01748 × 0.68 = $183.6.
Traffic control cost per day = $1000.
Crew cost:
No. of personnel required = 4.
Cost per hour = $22.
Total crew cost = $88 × 8 = 704.
Truck + Compressor per day = $250.
Hot melt equipment per day = $380.
Total cost = 183.6 + 1000 + 704 + 250 + 380 = $2517.
Unit cost = $0.16 per foot.
Initial cost calculation (crack sealing: 3/8″ × 3/8″)
Traffic control setup = 30 min/0.5 h.
Traffic control removal = 30 min/0.5 h.
Waiting period for starting sealing before cleaning & routing = 20 min/0.33 h.
Curing period = 15 min/0.25 h.
Work day = 8 h.
Filling time = 8−0.5−0.5−0.33−0.25 = 6.42 h.
Length sealed per day:
Length of the sealed cracks at site = 978 lin ft.
Sealing time at site = 25 min.
Length sealed per day = (978/25) × 60 × 6.42 = 15,069.02 per day.
Material cost per day:
Length sealed per day = 15,069.02 lin ft.
Cross sectional area of reservoir = 0.375 in × 0.375 in = 0.140625 in^2.
Volume of reservoir (1 lin ft of crack) = 1 ft × (0.140625/144 ft^2) = 0.000977 ft^3.
Gross application rate (no waste) = 73.31 lb/ft^3 × 0.000977 = 0.0716 lb/lin ft of crack.
Net application rate (15% waste) = 1.15 × 0.0716 = 0.08234 lb/lin ft of crack.
Material cost = $0.68/lb.
Material cost per day = 15,069.02 × 0.08234 × 0.68 = $843.73.

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Fig. 3 — Initial cost for crack filling and sealing at each test site.

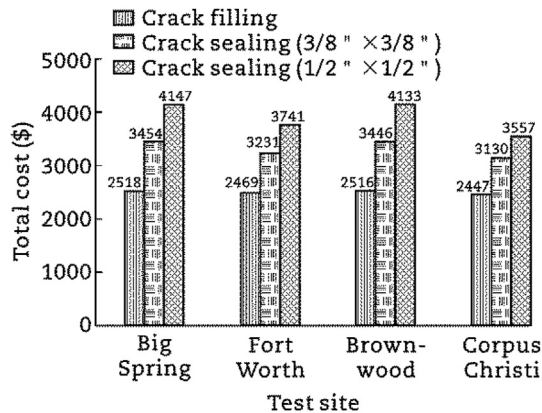Fig. 5 — Initial cost per linear feet for crack filling and sealing at each test site.

Traffic control cost per day = $1000.
Crew cost:
No. of personnel required = 5.
Cost per hour = $22.
Total crew cost = $110 × 8 = 880.
Truck + Compressor per day = $250.
Hot melt equipment per day = $380.
Router rent per day = $100.
Total cost = 843.73 + 1000 + 880 + 250 + 380 + 100 = $3453.
Unit cost = $0.23 per foot.
Percentage increasing with crack sealing = (3453 − 2517)/2517 × 100 = 37.18%.

Based on the aforementioned calculation procedure, the construction cost of crack sealing and crack filling for each test section was estimated. As expected the initial cost of crack sealing is higher compared to crack filling. In between
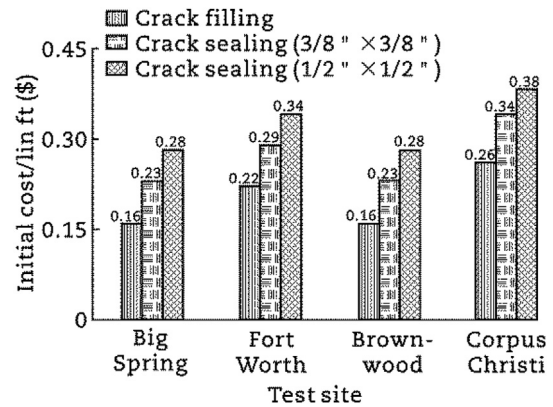
the two configurations of crack sealing, the small reservoir has less construction cost. Fig. 3 presents the total construction cost at each test section.

It is worth to note that the research team considered the different amount of treated crack length for each test site in order to observe the influential cost factors behind the construction of both treatment types. Table 2 presents the treated crack length at each test site.

It can be observed that the difference of total construction cost among the test sites was mainly due to the use of amount of materials and labor cost during construction which depends upon the sealing time spent at site by crew personnel and treated crack length per day. The total labor cost of crack filling and sealing treatment calculated $704 per day and $880 per day respectively. From the calculation, it is evident that the amount of material has the most significant effect on the

Table 2 — Total amount of treated crack length at each test site.

Test site	Big Spring	Fort Worth	Brownwood	Corpus Christi
Treated crack length (linear feet)	978	633	775	723

Fig. 6 — Cost increase with crack sealing at each test site.

Fig. 4 — Material cost for crack filling and sealing at each test site.

Table 3 — Initial cost reduction with small reservoir (3/8″ × 3/8″).

Site	Total cost ($)		Percentage reduction (%)
	3/8″ × 3/8″	1/2″ × 1/2″	
Big Spring	3453.73	4146.80	16.71
Fort Worth	3230.56	3740.49	13.63
Brownwood	3445.75	4132.51	16.62
Corpus Christi	3129.79	3556.90	12.01

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Table 4 – Sample calculation of costs for the analysis of AAC in big spring test site.

Cost parameter	Crack filling	Crack sealing (3/8″ × 3/8″)	Crack sealing (1/2″ × 1/2″)
A. Cost of purchasing and shipping material	0.68/lb	0.68/lb	0.68/lb
B. Net application rate	0.02 lb/lin ft	0.08 lb/lin ft	0.15 lb/lin ft
C. Placement cost	1718/day	1840/day	1840/day
D. Production rate	15,445 lin ft/day	15,069 lin ft/day	15,069 lin ft/day
E. User delay cost	2000/day	2000/day	2000/day
F. Total installation cost F = (A × B) + (C/D) + (E/D)	0.29/lin ft	0.36/lin ft	0.41/lin ft
G. Interest rate	5.0 percent	5.0 percent	5.0 percent
H. Estimated service life	3 years	5 years	5 years
I. Average annual cost	0.11/lin ft	0.08/lin ft	0.09/lin ft

high initial construction cost of crack sealing (1/2″ × 1/2″) because of its bigger cross-sectional area compared to crack filling. However, it is found that for crack filling and routing configuration of 3/8″ × 3/8″, labor cost is more significant cost factor compared to material cost. In general, for all test sites 4.5 and 8.4 times more material used compared to crack filling with the routing configuration of 3/8″ × 3/8″ and 1/2″ × 1/2″, respectively. Fig. 4 illustrates the material cost at each test site for two types of treatment.

The unit cost in dollars per linear feet was calculated by dividing the total cost per day by the length of sealing work. Fig. 5 illustrates the initial construction cost per linear feet for crack filling and sealing at each test site. As expected, the construction of crack sealing treatment is expensive due to the use of extra material, labor and equipment. Fig. 6 presents the percentage cost increase with the two routing configurations of crack sealing at each test site.

It has shown that the initial cost of agency could be approximately 27.9%−37.2% (on an average 33%) higher with 3/8″ × 3/8″ and 51.5%−64.7% (on an average 56%) higher with 1/2″ × 1/2″ routing configuration of crack sealing compared to crack filling depending upon the change of test site.

As a result, the agency can have less initial cost with small reservoir of crack sealing. Table 3 illustrates the initial cost reduction with 3/8″ × 3/8″ configuration compared to the 1/2″ × 1/2″ configuration of crack sealing. It is evident that the agency cost could be saved by approximately 12%−17% (on an average 15%) with 3/8″ × 3/8″ configuration compared to 1/2″ × 1/2″ routed channel.
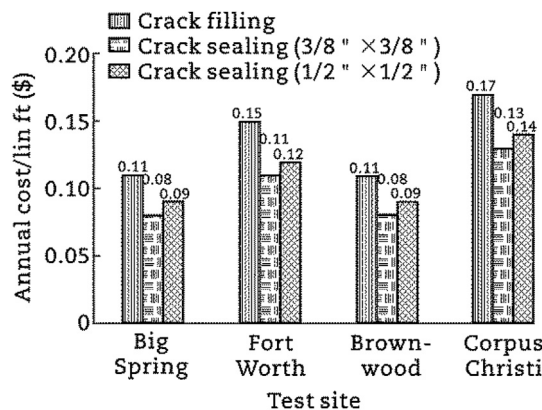
Fig. 7 – Annual average cost per linear feet for crack filling and sealing at each test site.

4.2. AAC analysis

As mentioned earlier AAC was calculated based on the instructions given in SHRP-H-348. The interest rate of 5% and user delay cost of $2000 were considered for the calculation of AAC. The cost factors obtained from this project were taken as an input for AAC. Table 4 presents the sample calculation of AAC based on the cost data calculated for Big Spring test site. Fig. 7 shows the calculated AAC of crack sealing and filling at each test site. It has shown that crack sealing is more cost effective than crack filling based on the calculated AAC.

4.3. LCCA analysis

In order to find out the long term cost effectiveness treatment between crack sealing and filling a 35 year analysis period was established. It was calculated based on the service life information collected from the TxDOT survey and existing literature review. For crack filling and sealing the research team considered a service period of 3 years and 5 years, respectively. To identify the long term costs between these two treatment types, all cost factors were calculated in an excel sheet using the initial construction and overlay cost per linear feet with no rounding. Fig. 8 illustrates the LCCA cost calculation sample for Big Spring test site. At the beginning a new asphalt mat has been placed. After two years, linear cracks appeared on the surface of the pavement. For those linear cracks, crack filling and crack sealing treatment has been given. Crack filling and crack sealing treatment will last for 3 years and 5 years, respectively. With crack filling treatment a new asphalt mat will be again placed after 5 years and with crack sealing after 7 years. This is the reason behind the consideration of a 35 year analysis period to analyze the long term cost effectiveness between these two treatments. In between 35 years, resealing with crack filling treatment will be performed 7 times and with crack sealing 5 times. Table 5 presents the long term cost per linear feet associated with these two types of treatment. It is evident from the calculation that in between these two treatments crack sealing is the most appropriate long term cost effective treatment. Based upon the calculated long term cost at different test site, it can be deduced that on an average with crack sealing treatment an agency can save approximately 24% more than crack filling treatment.

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Years	Crack Filling (Non-Routed) New Asphalt Mat $/LF	Crack Filling $/LF	Totals $	Running Total $ 220.16	Event Description	Crack Sealing (Routed) New Asphalt Mat $/LF	Crack Sealing $/LF	Totals $ 165.43	Running Total $	Event Description
0	$ 27.38		$ 27.38	$ 27.38	A new asphalt mat has been placed.	$ 27.38		$ 27.38	$ 27.38	A new asphalt mat has been placed.
1			$ -	$ 27.38				$ -	$ 27.38	
2		$ 0.16	$ 0.16	$ 27.54	A small crack appears and it is filled.		$ 0.23	$ 0.23	$ 27.61	A small crack appears and it is sealed.
3			$ -	$ 27.54				$ -	$ 27.61	
4			$ -	$ 27.54				$ -	$ 27.61	
5	$ 27.38		$ 27.38	$ 54.92	New overlay mat is placed.			$ -	$ 27.61	
6			$ -	$ 54.92				$ -	$ 27.61	
7		$ 0.16	$ 0.16	$ 55.08	A small crack appears and it is filled.	$ 27.38		$ 27.38	$ 54.99	New overlay mat is placed.
8			$ -	$ 55.08				$ -	$ 54.99	
9			$ -	$ 55.08			$ 0.23	$ 0.23	$ 55.22	A small crack appears and it is sealed.
10	$ 27.38		$ 27.38	$ 82.46	New overlay mat is placed.			$ -	$ 55.22	
11			$ -	$ 82.46				$ -	$ 55.22	
12		$ 0.16	$ 0.16	$ 82.62	A small crack appears and it is filled.			$ -	$ 55.22	
13			$ -	$ 82.62				$ -	$ 55.22	
14			$ -	$ 82.62		$ 27.38		$ 27.38	$ 82.60	New overlay mat is placed.
15	$ 27.38		$ 27.38	$ 110.00	New overlay mat is placed.			$ -	$ 82.60	
16			$ -	$ 110.00			$ 0.23	$ 0.23	$ 82.83	A small crack appears and it is sealed.
17		$ 0.16	$ 0.16	$ 110.16	A small crack appears and it is filled.			$ -	$ 82.83	
18			$ -	$ 110.16				$ -	$ 82.83	
19			$ -	$ 110.16				$ -	$ 82.83	
20	$ 27.38		$ 27.38	$ 137.54	New overlay mat is placed.			$ -	$ 82.83	
21			$ -	$ 137.54		$ 27.38		$ 27.38	$ 110.21	New overlay mat is placed.
22		$ 0.16	$ 0.16	$ 137.70	A small crack appears and it is filled.			$ -	$ 110.21	
23			$ -	$ 137.70			$ 0.23	$ 0.23	$ 110.44	A small crack appears and it is sealed.
24			$ -	$ 137.70				$ -	$ 110.44	
25	$ 27.38		$ 27.38	$ 165.08	New overlay mat is placed.			$ -	$ 110.44	
26			$ -	$ 165.08				$ -	$ 110.44	
27		$ 0.16	$ 0.16	$ 165.24	A small crack appears and it is filled.			$ -	$ 110.44	
28			$ -	$ 165.24		$ 27.38		$ 27.38	$ 137.82	New overlay mat is placed.
29			$ -	$ 165.24				$ -	$ 137.82	
30	$ 27.38		$ 27.38	$ 192.62	New overlay mat is placed.		$ 0.23	$ 0.23	$ 138.05	A small crack appears and it is sealed.
31			$ -	$ 192.62				$ -	$ 138.05	
32		$ 0.16	$ 0.16	$ 192.78	A small crack appears and it is filled.			$ -	$ 138.05	
33			$ -	$ 192.78				$ -	$ 138.05	
34			$ -	$ 192.78				$ -	$ 138.05	
35	$ 27.38		$ 27.38	$ 220.16	New overlay mat is placed.	$ 27.38		$ 27.38	$ 165.43	New overlay mat is placed.

Fig. 8 – LCCA cost calculation sample for Big Spring test site.

Table 5 – Long term cost effectiveness of crack filling and sealing.

Site	3/8″ × 3/8″ Crack filling (cost/lin ft)	Crack sealing (cost/lin ft)	Percentage reduction (%)	1/2″ × 1/2″ Crack filling (cost/lin ft)	Crack sealing (cost/lin ft)	Percentage reduction (%)
Big Spring	220.16	165.43	24.86	220.16	165.68	24.75
Fort Worth	220.58	165.73	24.87	220.58	165.98	24.75
Brownwood	220.16	165.43	24.86	220.16	165.68	24.75
Corpus Christi	220.86	165.98	24.85	220.86	166.18	24.76

5. Conclusions

This study is conducted to evaluate cost effectiveness between crack filling and crack sealing treatments. Potential cost factors were identified, recorded and analyzed for both treatments to find out the initial, average annual and life cycle cost upon the data obtained from the four test sites in Texas. Based on the results of the study, the following conclusions can be drawn.

1) According to the response of 20 Texas districts and extensive literature review a typical asphalt pavement could stand for three years and five years with crack filling and crack sealing treatment, respectively.
2) The initial construction cost of crack sealing is higher compared to crack filling. Based on the results of four test sites, this cost could be 27.9%–37.2% and 51.5%–64.7% higher with 3/8″ × 3/8″ and 1/2″ × 1/2″ routing configuration, respectively. It is recommended to implement the small reservoir for crack sealing, if it can ensure the adequate durability. It is evident that initial cost could be reduced by on an average 15% with 3/8″ × 3/8″ configuration of crack sealing compared to 1/2″ × 1/2″ routed channel.
3) Material and labor costs have the most significant effect on the difference of higher initial construction cost between crack sealing and crack filling compared to other associated costs.
4) AAC cost calculation has shown that crack sealing is more cost effective than crack filling.
5) Based on the 35 year analysis period, the agency cost can be reduced by approximately 24% compared to crack filling.

Conflict of interest

The authors do not have any conflict of interest with other entities or researchers.

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