Performance of Edge Drains in Concrete Pavements in California

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ABSTRACT

The California Department of Transportation (Caltrans) recently completed a study to evaluate the performance of edge drain systems placed along portland cement concrete (PCC) pavements. To date, a variety of edge drain designs, backfill materials, and placement methods have been used and have resulted in varying degrees of success when measured against overall pavement performance. This study investigated several different types of edge drain systems that have been used by Caltrans. Their performance was evaluated, and it was observed that more than 70 percent of the surveyed edge drains were not performing efficiently or as designed. This poor overall result can be attributed to design flaws, improper construction practices, and lack of maintenance. Generally, the performance of originally constructed edge drains was better than retrofit projects, since originally constructed edge drains are generally equipped with larger diameter drain pipes, deeper trenches, and treated permeable bases. Edge drain trenches in retrofit projects are generally not deep enough to effectively collect all infiltrated water from the PCC and base layers. The geotextile filter fabric materials found in excavated projects are not soil-specific, which can cause clogging and eventually reduce the ability of these edge drains to allow free flow of water. Improper construction practices, such as high percentages of cement in cement-treated permeable base backfill material and improper placement of geo-fabric material were observed in a few of the surveyed edge drain projects. Among surveyed projects, more than 50 percent of the edge drain outlet pipes were either buried or clogged, which can be attributed to lack of maintenance.

INTRODUCTION

Excess free water in a portland cement concrete (PCC) pavement section can cause erosion in these sections, eventually leading to loss of slab support, joint faulting, and slab cracking. This process reduces ride quality and results in early maintenance and rehabilitation needs. The most typical problem is that many concrete pavements are essentially a built-in “bathtub without a drain,” and once water gets into the bathtub, it can stay there for a long period of time. If

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certain design features are not addressed regarding free water intrusion, serious problems can develop. These problems became quite apparent in the 1970s in California and other States as truck traffic increased (see Figure 1).

![Figure 1. Typical pumping and erosion of jointed plain concrete pavement with no dowels.](image)

At that time, States, including California, took action to reduce damage occurring in existing concrete pavements, which included keeping out water by sealing joints and cracks and draining water from the structural section by installing retrofit edge drain systems. In the 1980s and 1990s, at the strong encouragement of the Federal Highway Administration (FHWA), many States adopted full subdrainage systems consisting of a permeable drainage layer directly beneath the concrete surface, with edge drains and lateral outlets on the sides to remove water from the pavement section.

A wide array of subdrainage designs were constructed in California. The retrofit drains showed early promise in reducing pumping and joint faulting in PCC pavements. However, after a few years, these benefits virtually disappeared, and erosion and joint faulting continued, along with premature slab cracking. These problems were investigated, and it was determined that many of the retrofit edge drains, and even the full subdrainage systems, became ineffective due to design inadequacies, construction problems, and (especially) lack of maintenance. Many joints and cracks were not sealed regularly to reduce the inflow of water. Many of the retrofit edge drains were in areas with nondoweled joints that had large differential deflections as heavy wheel loads rolled over the joints. This action caused large water pressures that eroded the weakened base, subbase, and shoulder materials, causing further loss of support beneath pavement panels.

Full subdrainage systems also experienced a wide range of performance and effectiveness deficiencies. Many of these problems were related to design, materials used, and construction errors. Others were related to the failure to maintain otherwise functioning edge drains and outlets. Outlet pipes eventually clogged and stopped draining moisture from the subbase and subgrade.
OBJECTIVES

The objectives of this study were as follows:

1. Determine the effectiveness of edge drains placed in PCC pavement systems throughout California.

2. Investigate the different types of edge drain systems used in California to ascertain any changes that could be implemented to improve their performance.

EFFECTS OF DAMAGE DUE TO EXCESS MOISTURE IN PAVEMENTS

Damage caused by excess moisture in pavement structures depends on several key design features and material properties, as well as subdrainage capabilities. PCC pavements constructed in California with undoweled joints, erodable base materials, or erodable materials in the shoulder are all susceptible to moisture damage. In fact, the placement of edge drains along the pavement edge cannot prevent continuing erosion due to the high differential deflections at slab corners, as heavy axle loads roll over these joints. Pumping is inevitable and is often followed by joint faulting. Doweling of the joints is required to reduce differential deflections at the joints and corners. The addition of a tied PCC shoulder significantly reduces deflections and, with sealed joints, reduces the amount of water entering the longitudinal joint. Some State agencies, such as the Georgia Department of Transportation (GDOT), have elected not to place edge drains, but rather to intensify the sealing of joints to reduce moisture ingress as much as possible.

As noted in the preceding, many conventional pavement sections are built in a de facto “bathtub,” which results in water infiltrating into the roadbed structure beneath the concrete surface course. When combined with heavy truck traffic and the presence of moisture-susceptible materials, the service life of a PCC pavement is bound to be reduced.

Moisture can come from many different sources—the subgrade, the surrounding terrain, and directly through the pavement structure via surface penetration (see Figure 2). Moisture may seep upward from a high groundwater table due to capillary action, vapor movement or pumping; it can drain into the pavement substrate from the surrounding hills and drainage basin; it can infiltrate through unsealed cracks and joints on the pavement surface; or it may flow laterally from the pavement edges and side ditches (1).

Figure 2. Sources of moisture in pavement systems (1).
Problems caused by prolonged exposure to excess moisture fall into three broad categories:

- Softening of pavement layers and the subgrade as they become saturated, and remain saturated, for lengthy periods of time.
- Degradation of moisture susceptible materials.
- Loss of bond between pavement layers due to saturation.

**Erosion Process**

- Water infiltrates and accumulates at the bottom of slabs and stabilized base courses. Up to 80 percent of ongoing precipitation can enter through longitudinal lane or asphalt shoulder joints.
- Heavy repeated loads cause differential deflections at slab edges and corners, especially when no load transfer devices (dowel bars) are used at the transverse joint, or when the PCC shoulders are not tied to the lane.
- Differential deflections force water at a high velocity and pressure over and beneath the stabilized underlying materials, thus causing erosion of the base, subbase, and shoulder materials.
- The buildup of materials under the approach slab results in joint faulting and increases roughness over time.
- The resulting loss of support beneath the leave slab causes higher slab stresses, which eventually lead to corner, transverse, and longitudinal cracks.
- The pavement fails prematurely due to lack of structural support, repeated loadings, inadequate maintenance, and increased roughness.

**SITE SELECTION**

Selection of project sites was based on the presence of drainage systems, variability of geographical locations, and range of traffic. A number of sites were selected from the previous Caltrans edge drain evaluation study (2). In addition, consideration was given to ease of access at the site (without traffic control) to conduct a preliminary survey. The investigation included both retrofit and original construction edge drain projects.

After reviewing project information, numerous project sites throughout the State were short-listed, representing various traffic mixes and geographical locations. From the short list, specific projects were then selected. A visual pavement condition survey, along with a detailed drainage evaluation, was conducted at each project site. Any distresses observed in the survey were rated and recorded for all identified sites. Various distress types that were recorded in accordance with severity level are presented in Table 1.
### Table 1
Jointed Concrete Pavement Distress Types and Severity Levels (3)

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Severity Level</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corner breaks</td>
<td>Low</td>
<td>No measurable faulting</td>
<td>Faulting: &lt; 13 mm</td>
<td>Faulting: 13 mm and up, corner piece is broken into two or more pieces</td>
</tr>
<tr>
<td>Longitudinal cracking</td>
<td>Medium</td>
<td>Crack widths: &lt; 3 mm, no spalling or faulting</td>
<td>Crack widths: 3 to &lt;13 mm; or spalling: &lt; 75 mm or faulting: &lt; 13 mm</td>
<td>Crack widths: ≥ 13 mm; or spalling: ≥ 75 mm or faulting: ≥ 13 mm</td>
</tr>
<tr>
<td>Transverse cracking</td>
<td>High</td>
<td>Crack widths &lt; 3 mm, no spalling or faulting</td>
<td>Crack widths: 3 to &lt; 6 mm; or spalling: &lt; 75 mm or faulting: &lt; 6 mm</td>
<td>Crack widths: ≥ 6 mm; or spalling: ≥ 75 mm or faulting: ≥ 6 mm</td>
</tr>
<tr>
<td>Spalling of longitudinal joints</td>
<td>Medium</td>
<td>Spalls: &lt; 75 mm wide</td>
<td>Spalls: 75 to 150 mm wide</td>
<td>Spalls: &gt; 150 mm wide; broken into two or more pieces</td>
</tr>
<tr>
<td>Spalling of transverse joints</td>
<td>Low</td>
<td>Spalls: &lt; 75 mm wide</td>
<td>Spalls: 75 to 150 mm wide</td>
<td>Spalls: &gt; 150 mm wide; broken into two or more pieces</td>
</tr>
<tr>
<td>Faulting of transverse joints and cracks</td>
<td>Medium</td>
<td>Faulting: &lt; 6 mm</td>
<td>Faulting: 6 to 13 mm</td>
<td>Faulting: &gt; 13 mm</td>
</tr>
<tr>
<td>Lane / Shoulder dropoff or separation</td>
<td>Low</td>
<td>Severity level not applicable; a complete record of the measurements taken is much more desirable, however, because it is more accurate and repeatable than severity level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patch deterioration</td>
<td>Medium</td>
<td>No faulting; no pumping</td>
<td>Faulting: ≤ 6 mm; no pumping</td>
<td>Faulting: ≥ 6 mm; pumping</td>
</tr>
<tr>
<td>Pumping</td>
<td>High</td>
<td>Severity level not applicable because the amount and degree of water bleeding and pumping changes with varying moisture condition</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 mm = 0.039 in.

A total of 30 projects in 20 counties throughout California, representing seven Caltrans districts, were identified for the preliminary surveys (4). Among these projects, six had been overlaid with AC; hence, no drainage evaluations were conducted on these projects. Therefore, as shown in Figure 3, 24 projects were surveyed in 15 different counties, and 9 were selected for further evaluation by excavating the shoulder (see Table 2). The selection for shoulder excavation was based on information collected from the field survey and the availability of traffic control. A brief description of the performance of edge drains is presented in the following section.
Figure 3. Locations of edge drain projects (4).
## Table 2
### Field Investigation Sites (4)

<table>
<thead>
<tr>
<th>Sl. No./Route/District/County</th>
<th>Post Mile</th>
<th>Permeable Material</th>
<th>Field Survey/Shoulder Excavation</th>
<th>Edge Drain Observation</th>
<th>Observed Distresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 / I-5 (NB) / 2 / Siskiyou</td>
<td>51–58</td>
<td>UTPM</td>
<td>Survey</td>
<td>Flowing water through outlets</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>2 / I-5 (NB) / 2 / Siskiyou</td>
<td>11.17–18.30</td>
<td>UTPM</td>
<td>Survey</td>
<td>Clogged outlets</td>
<td>About 1-in. of joint faulting</td>
</tr>
<tr>
<td>3 / I-5 (NB) / 2 / Shasta</td>
<td>14–18</td>
<td>UTPM</td>
<td>Survey</td>
<td>Clogged outlets</td>
<td>About 0.5-in. of joint faulting</td>
</tr>
<tr>
<td>4 / I-5 (NB) / 2 / Tehama</td>
<td>41–42</td>
<td>CTPM</td>
<td>Excavation</td>
<td>70% clogged drainage pipe</td>
<td>Medium severity transverse cracking</td>
</tr>
<tr>
<td>5 / I-5 (NB) / 2 / Tehama</td>
<td>23.05–25.65</td>
<td>UTPM</td>
<td>Survey</td>
<td>Buried outlets</td>
<td>High severity corner breaks &amp; patch deterioration</td>
</tr>
<tr>
<td>6 / I-5 (NB) / 3 / Sacramento</td>
<td>4.70–12</td>
<td>-</td>
<td>Survey</td>
<td>Buried outlets</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>7 / I-80 (EB&amp;WB) / 3 / Nevada</td>
<td>2.80–7</td>
<td>-</td>
<td>Survey</td>
<td>Clean outlets</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>8 / US-101 (NB&amp;SB) / 4 / Sonoma</td>
<td>44.95–46.85</td>
<td>-</td>
<td>Survey</td>
<td>Buried outlets</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>9 / I-280 (SB) / 4 / San Mateo</td>
<td>15–16</td>
<td>CTPM</td>
<td>Excavation</td>
<td>90% clogged drainage pipe</td>
<td>No notable distresses—ground pavement</td>
</tr>
<tr>
<td>10 / US-101 (NB) / 4 / Santa Clara</td>
<td>16–17</td>
<td>UTPM</td>
<td>Excavation</td>
<td>No edge drains Found</td>
<td>High severity corner breaks, transverse and longitudinal cracks</td>
</tr>
<tr>
<td>11 / US-101 (NB) / 5 / Monterey</td>
<td>27.50–30</td>
<td>-</td>
<td>Survey</td>
<td>Clogged outlets</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>12 / US-101 (NB) / 5 / San Luis–Obispo</td>
<td>37.70–42.50</td>
<td>-</td>
<td>Survey</td>
<td>Clean outlets</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>13 / I-5 (NB) / 6 / Kern</td>
<td>0–3.50</td>
<td>-</td>
<td>Survey</td>
<td>Buried outlets</td>
<td>High severity faulting, transverse and longitudinal cracking; pumping</td>
</tr>
<tr>
<td>14 / SR-99 (NB) / 6 / Kern</td>
<td>31.50–34.43</td>
<td>-</td>
<td>Survey</td>
<td>Buried outlets</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>15 / SR-120 (WB) / 10 / San Joaquin</td>
<td>1.60–6.40</td>
<td>-</td>
<td>Survey</td>
<td>Flowing water through outlets</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>16 / I-205 (EB) / 10 / San Joaquin</td>
<td>3–15</td>
<td>UTPM</td>
<td>Survey</td>
<td>Clogged outlets</td>
<td>Medium severity transverse cracking and joint faulting</td>
</tr>
<tr>
<td>17 / SR-99 (NB) / 10 / Stanislaus</td>
<td>18.90–24.60</td>
<td>CTPM</td>
<td>Survey</td>
<td>Buried outlets</td>
<td>Medium severity faulting</td>
</tr>
<tr>
<td>18 / SR-99 (NB) / 10 / Stanislaus</td>
<td>10.20–14.90</td>
<td>CTPM</td>
<td>Survey</td>
<td>Buried outlets</td>
<td>Medium severity faulting</td>
</tr>
<tr>
<td>19 / SR-99 (NB) / 10 / Merced</td>
<td>36–37</td>
<td>CTPM</td>
<td>Excavation</td>
<td>100% clogged drainage pipe</td>
<td>High severity corner breaks, transverse and longitudinal cracking, and faulting—slab replacement in progress</td>
</tr>
<tr>
<td>20 / SR-99 (NB) / 10 / Merced</td>
<td>21–2</td>
<td>CTPM</td>
<td>Excavation</td>
<td>100% clogged drainage pipe</td>
<td>High severity corner breaks, transverse and longitudinal cracking, and faulting—slab replacement in progress</td>
</tr>
<tr>
<td>21 / I-15 (SB) / 11 / San Diego</td>
<td>46–47</td>
<td>CTPM</td>
<td>Excavation</td>
<td>Clear drainage pipe</td>
<td>High severity corner breaks, transverse and longitudinal cracking, and faulting</td>
</tr>
<tr>
<td>22 / I-5 (NB) / 11 / San Diego</td>
<td>35–36</td>
<td>CTPM</td>
<td>Excavation</td>
<td>No Edge Drains Found</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>23 / I-8 (EB) / 11 / San Diego</td>
<td>40–41</td>
<td>CTPM</td>
<td>Excavation</td>
<td>Clear drainage pipe</td>
<td>No notable distresses</td>
</tr>
<tr>
<td>24 / I-8 (WB) / 11 / San Diego</td>
<td>52–53</td>
<td>CTPM</td>
<td>Excavation</td>
<td>40% clogged drainage pipe</td>
<td>High severity lane/shoulder patch deterioration</td>
</tr>
</tbody>
</table>

UTPM = untreated permeable material; CTPM = cement treated permeable material
PERFORMANCE OF EDGE DRAINS IN CALIFORNIA

Only a few (< 30 percent) of the edge drains investigated were operating in an acceptable manner (see, for example, Figure 4). The properly operating edge drains were generally in areas of higher rainfall, especially in the upper foothill and mountainous areas, where the natural materials were coarser and noncohesive in nature. Considering this fact, it can be assumed that the volume and velocity of water drained from these pavement sections prevent the fines from settling and clogging the drainage pipes.

Figure 4. Flowing water from edge drain outlets on northbound I-5 in Siskiyou County.

The majority of the remaining sites investigated appear to have had little or no maintenance. These sites revealed drain pipes clogged with soil from both roadbed drainage and the shoulder area, and a majority of outlets were completely covered with dirt or were overgrown with vegetation (see for example Figures 5 and 6). These existing conditions would not allow the systems to drain properly, thus trapping the water beneath the concrete pavement and adversely affecting the base and subgrade and causing premature pavement failure. However, other factors such as traffic, age of the pavement, materials, design, construction, and climate also contribute to pavement failure. In addition, generally due to recent pavement rehabilitation, a few pavement sections did not show any visible distresses although the edge drains were clogged. Accordingly, the correlation between observed pavement distresses and clogged edge drains was not found to be significant (see Table 2).

Many of the pavement sections investigated with retrofit edge drains were more than 30 years old. Maintenance is badly needed to preserve the structural integrity of the edge drain structure and prevent further accumulation of fines in the drain pipes. Also, a majority of the outlet pipes have no end wall protection, which can cause clogging. The use of end walls reduces (but does not eliminate) the need for maintenance.
Figure 5. Clogged edge drain outlet pipe on northbound I-5 in Sacramento County.

Figure 6. Clogged and buried edge drain outlet pipe on northbound I-5 in Tehama County.
Apart from lack of maintenance, design flaws and improper construction practices were also observed in a majority of the excavated edge drain projects. A summary of observed edge drain discrepancies are as follows:

- The lane/shoulder interface becomes critical when it comes to water infiltration into the base section. In the section of the roadway on I-15 in San Diego County, water runs through the interface and accumulates on the cement-treated base extension along with water trapped under the PCC slabs (see Figure 7), thus, allowing base erosion through slab action and resulting in loss of slab support.

- On I-5 in Tehama County, the nonwoven filter fabric, which has a high permeability, was double layered around the circumference of the permeable material (see Figure 8). Complete encapsulation of the permeable material with nonwoven filter fabric caused fines to infiltrate—and eventually clog—the edge drain.

- In the same section, no outlets were found within the project limits. The outlets were probably buried under the soil, not allowing the water to drain. The fines from the shoulder area might be entering through outlets and clogging the drainage pipe (see Figure 9).

- As per the Standard Plans (see Figure 10) for SR-99 in Merced County, slotted drain pipes were placed at the same level as the slab/base interface. This design feature does not provide enough depth for the drain pipe to collect all infiltrated water from the PCC and base layers.

- On SR-99 in Merced County, due to the low rainfall in the region, there was a tendency for fine particles to settle at the bottom of the drainage pipe, resulting in an inadequate velocity to drain the fine particles which were mixed with infiltrated water. This often causes sedimentation, eventually resulting in clogged drain pipes (see Figure 11).

![Figure 7. Edge drain design on southbound I-15 in San Diego County (5).](image-url)
Figure 8. Double-lined woven filter fabric on northbound I-5 in Tehama County.

Figure 9. Clogged edge drain pipe on northbound I-5 in Tehama County.
Figure 10. Edge drain design for northbound SR-99 in Merced County (6).

Figure 11. Fully clogged edge drain pipe on northbound SR-99 in Merced County.
CONCLUSIONS

Based on a literature review, engineering knowledge, and an extensive survey of existing edge drain sites in California, the following conclusions can be drawn:

- Among the nine excavated projects, 71 percent of the edge drain pipes were clogged. Of the 24 surveyed projects, 77 percent of the outlets were clogged.

- The performance of originally construction edge drains is relatively better than retrofit projects, as original construction edge drains generally have larger diameter drain pipes, deep trenches, and treated permeable bases.

- The performance of edge drains in high rainfall areas is better than those at relatively lower rainfall areas.

- One hundred percent of the retrofit edge drains with slotted pipes 2 in. (51 mm) in diameter were totally clogged, while 50 percent of the retrofit edge drains with slotted pipes 3 in. (76 mm) in diameter were partially clogged.

- The edge drain trenches in retrofit projects are, generally speaking, not deep enough to effectively collect all infiltrated water from PCC and base layers.

- The geo-textile filter fabric materials found in excavated projects are not soil-specific, which can cause clogging and eventually reduce the ability of the edge drain system to function properly.

- As a result of improper construction procedures, several edge drains were installed in the higher side of cross slope, which prevents the water flowing to the drain pipe.

- Also, improper construction practices, such as high percentages of cement in cement-treated permeable base backfill material and improper placement of geo-fabric, were observed in few edge drain projects.

- Among the 24 surveyed projects, 73 percent of the edge drain pipes were not draining water properly, which can be attributed to lack of maintenance.

RECOMMENDATIONS

- Edge drain systems should not be installed if there is no long-term commitment to maintain such a system.

- The amount of recent and historical rainfall that has occurred in the project area as well as the permeability of the natural soil in the area should be investigated prior to designing an edge drain system.

- When edge drains are selected for a given project, they may not be required throughout the entire project, but rather only in critical drainage areas.
• Soil investigation should be conducted and findings should be used to determine the appropriate geo-fabric required for edge drain design.

• Filter fabric should be placed along the shoulder side and bottom of the trench to prevent migration of aggregate base fines into the drainage medium.

• Slotted pipes 4 in. (102 mm)—instead of 2 or 3 in. (51 or 76 mm)—in diameter should be used, because the larger diameter will allow video inspections for maintenance purposes.

• Dual outlet features should be included in the design for easier maintenance.

• Retrofitted edge drain pipes should be placed at the bottom of the base so that all infiltrated water from the PCC and base can be effectively collected by the drain pipe.

• Construction inspection will ensure that the trench configuration, geo-fabric installation, drain pipe placement, and permeable backfill placement all meet the project design and specifications.

• Local maintenance personnel must be trained to conduct timely maintenance of edge drain systems in their districts.

• With the introduction of load transfer devices (dowel and tie bars), daylighted permeable base sections and asphalt concrete interlayers, edge drain systems may not be as beneficial in the long run and may not considerably improve the performance of PCC pavements.

REFERENCES


