Selecting Rubblization for Rehabilitation of Concrete Pavements: 
Case Studies in Texas 

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ABSTRACT
Rubblization is a unique means of rehabilitating concrete pavements by in-place conversion of the old concrete pavement into a useable base. Rubblization employs machinery that will break the concrete in place and leave pieces small enough that reflective cracking problems are significantly reduced or ideally eliminated. This paper presents overviews of three topics relevant to rubblization. First, an overview of slab fracturing techniques, including rubblization, for concrete pavement rehabilitation is given. While construction specifications for rubblization exist within many agencies, detailed site investigation plans to evaluate whether a project can be rubblized are generally lacking. Therefore, a comprehensive plan for evaluating the suitability of a project for rubblization is presented next. This plan involves project history, visual site inspection, and ground-penetrating radar, falling weight deflectometer, and dynamic cone penetrometer surveys. Finally, case studies of pavements in Texas illustrate the application of the investigative methods described.

INTRODUCTION
Rehabilitation of concrete pavements is a major issue within Departments of Transportation (DOTs). In the Texas Department of Transportation (TxDOT), many miles of old jointed and continuously reinforced concrete pavement exist which are approaching the end of their service life. Black topping and white topping can be used to gain additional life, but these treatments are often impacted by reflection cracking. In some instances the existing concrete pavement is structurally deteriorated so simple overlays will not provide adequate performance, and reconstruction requires significant funding. TxDOT needs good alternatives for rehabilitating these concrete pavements. Several states have substantially invested in rubblization for concrete pavement rehabilitation. With minimal experience using rubblization, TxDOT is actively seeking to develop guidelines for evaluating Texas pavements that may be candidates for rubblization. This paper provides a brief background on the development of concrete pavement slab fracturing techniques followed by a presentation of the current project analysis procedures used in Texas to evaluate if a project is suitable for rubblization. Three case studies wrap up the discussion illustrating use of the analysis procedures to evaluate concrete pavements needing rehabilitation.

BACKGROUND
For several decades DOTs have investigated various options for rehabilitating concrete pavements. The high costs of reconstruction, and the typical poor cracking performance of overlays over jointed concrete, led to the development of concrete slab fracturing techniques for rehabilitation. These techniques include crack and seat, break and seat, and rubblization (1). The term “crack and seat” applies to unreinforced concrete pavements where the objective is to develop closely spaced tight cracks which permit load transfer through aggregate interlock with little loss of structural value. Cracking through the entire layer is the goal. The term break and seat applies to reinforced slabs where the goal is to physically fracture the distributed steel or completely debond the steel from the concrete to reduce the effective slab length. These two techniques typically employ large guillotine breakers to fracture the concrete.

Rubblization is the most recent development in concrete fracturing techniques for pavement rehabilitation. Unlike the other two fracturing approaches which essentially seek to significantly reduce the slab length, rubblization typically destroys slab action (1). This means that, compared to the other two fracturing techniques, rubblization results in a lower probability
of reflective cracking and a lower layer modulus since the resultant concrete fragment sizes will be smaller \((I)\).

Witczak and Rada \((2)\) evaluated all three major types of slab fracturing techniques and determined that rubblization resulted in a lower variability in the fractured slab modulus than the other two fracturing methods. Additionally, field performance indicate rubblizing is the most economical and successful technique \((I, 3)\). With the status as the most successful slab fracturing method, rubblization has been used and reported on in many DOTs such as Arkansas, Illinois, Michigan, Alabama, Pennsylvania, and Colorado. Significant areas identified as crucial to rubblization success are: adequate pavement drainage \((4)\), adequate subgrade support \((5)\), and adequate stiffness of pavement layers beneath the concrete \((6)\).

Two primary providers for rubblization exist. The resonant breaker used by Resonant Machines, Inc. (RMI) employs a high-frequency, low-amplitude tamper to fracture the pavement \((7)\). The multi-head breaker (MHB) used by Antigo Construction, Inc., uses 12 drop hammers that impact the pavement to accomplish rubblization \((8)\). The Illinois DOT (IDOT) developed a chart to select whether rubblization is feasible, and which rubblization method to use. This chart uses the pavement thickness plotted versus the bearing value of the subgrade, illustrated in Figure 1. Rubblization methods used by IDOT include:

- Method I: MHB.
- Method II: RMI high flotation (HF) tires with tire pressures less than 60 psi.
- Method III: RMI with no restriction on tire pressures.
- Method IV: MHB or RMI.

![FIGURE 1 IDOT Rubblization Selection Chart (5).](image)

TxDOT possesses few experiences with rubblization and therefore in 2004 began research work investigating the use of rubblization for Texas pavements. While the Illinois and Michigan DOTs present frameworks for evaluating potential rubblization projects \((5, 6)\), in Texas many concrete pavements in need of rehabilitation are several decades old and have little to no base beneath them. Therefore, current efforts in Texas seek to build upon existing
practices while also incorporating methods and adjustments as appropriate for Texas pavement conditions.

PAVEMENT EVALUATION METHODOLOGY
Based upon a review of factors influential on the success of rubblization, and a review of other DOT procedures, a forensic investigation plan for use on Texas projects was drafted. This plan collects information on pavement structure, pavement condition (distress and structural properties), and subgrade condition (bearing capacity and moisture condition). For a thorough analysis of the project, this plan includes reviews of plans, a visual site assessment, and surveys with ground-penetrating radar (GPR), falling weight deflectometer (FWD), and dynamic cone penetrometer (DCP). The GPR survey can be used to estimate pavement layer thicknesses, identify changes in the pavement structure, and detect locations of wet subgrade (9). The FWD provides data to evaluate the structural condition of the pavement layers. For jointed concrete pavements, the FWD also provides data to evaluate joint transfer efficiency. The DCP data serves for validation of the subgrade conditions. Highlights of the plan used in Texas are as follows:

- Plans: Collect and review plan sheets from the project to identify the existing pavement structure. Identify important parameters such as: existence of any treated subgrade layers, presence and thickness of base (if any), thickness of concrete pavement, thickness of any overlays, and presence of any pavement widening with non-uniform construction.
- Visual Condition Survey: Review the project for the overall level of and type of distresses present. Examine and note the location of any maintenance treatments where the structure may be different. Look for low-lying areas or areas with poor drainage where subgrade conditions may be poor.
- GPR: perform a GPR survey over the entire project, collecting data at 1 foot (0.305 m) intervals. Use Colormap (9) to analyze the GPR data to estimate pavement layer thicknesses, locate limits of potential section breaks in the pavement structure, and identify locations where the subgrade may be excessively wet.
- FWD: Collect FWD data on the project at 0.2 mile (0.32 km) intervals, or at intervals sufficient to obtain at least 30 drops on the project, whichever is less. Collect the drops in the center of the concrete slabs. If the project is jointed concrete, randomly collect joint transfer tests to aid in evaluating the joint transfer efficiency. Process the FWD data with Modulus 6.0 (10).
- DCP: From the FWD data identify the locations with the highest and lowest deflections at the outermost deflection sensor. Perform DCP tests at these locations. Test a minimum of two locations of high outer sensor deflection with the DCP. Test at least one location with low outer sensor deflection with the DCP. Estimate the thickness of the base layer from the DCP data, and use the Corps of Engineers equation to convert the DCP penetration rate to California Bearing Ratio (CBR) (11). Determine the CBR and thickness of the base layer. If the DCP data do not clearly detect a base layer, then the CBR of the first 6 inches (152 mm) beneath the concrete is used as a “dummy” base layer (many older concrete pavements in Texas do not have a base beneath them). Determine the CBR of the first 6 inches (152 mm) of subgrade.
**Decision Criteria for Selecting Whether to Rubblize**

The collection of the pavement evaluation data allows the project to be analyzed for its suitability for rubblization. Performing the following steps enables making this determination:

- The DCP data are evaluated using an adaptation of the IDOT rubblization selection chart as follows:
  - Plot the concrete thickness versus the CBR of the base. These data are used to gauge whether the concrete will rubblize, since sufficient support beneath the slab is crucial for satisfactory breakage.
  - Plot the combined thickness of the concrete and base versus the CBR of the subgrade. Use a “dummy” base layer of 6 inches (152 mm) if the DCP data do not distinguish a base layer. These data are used to evaluate whether the subgrade can support construction traffic after rubblization.
- If all the data points fall in the zones that indicate rubblization is feasible, the project should be suitable for rubblization.
- If all the data points fall in the “Do Not Rubblize” zone of the chart, rehabilitation options other than rubblization should be considered.
- If some, but not all, of the data points fall in the “Do Not Rubblize” zone, certain portions of the project may not be suitable for rubblization. More analysis, interpretation, and judgment are required. Typically in Texas these instances are encountered on the older (pre-1960) concrete pavements with little to no identifiable base present. Perform additional analysis as follows:
  - Determine the average CBR of the first 12 inches (305 mm) beneath the concrete.
  - From the rubblization selection chart, determine the minimum CBR necessary to support rubblization for the known concrete thickness at the project. Do this by starting on the Y-axis at the known concrete thickness, then project horizontally until intersecting the boundary where rubblization is feasible. At this intersection project down to the X-axis and read the minimum subgrade CBR required.
  - Form a relationship between the subgrade modulus and CBR by graphing the average CBR of the first 12 inches (305 mm) beneath the concrete versus the subgrade modulus. Input the minimum CBR necessary into this relationship to determine the anticipated minimum subgrade modulus needed.
  - Graph the subgrade modulus with distance for the project. Where the modulus does not exceed the minimum subgrade modulus needed, a risk exists that the project may not rubblize. At this point the data must be reviewed on a case-by-case basis and a judgment made as to where, if at all, rubblization should be attempted.

**CASE STUDIES**

Currently nine pavements have been investigated in Texas using the described methodology. Recommendations were presented to the appropriate TxDOT offices for each of the projects. The three case studies presented below represent a cross section of the types of projects encountered in Texas. The first two projects described below, US 83 and FM 1155, are old 9-6-9 JCP projects. The final project presented here, Loop 288, is a concrete pavement contraction design (CPCD) project constructed in 1987.
This project is an old 9-6-9 JCP pavement overlaid with approximately 3 inches (76 mm) of HMA. The section proposed for rehabilitation is in Cottle County from the King County line to approximately 6.57 miles (10.57 km) north of the county line. Figure 2 illustrates the GPR data collected. The GPR data did not reveal any locations of excessively wet subgrade. The GPR data did reveal an apparent layer of select fill beneath the slabs, and the data also detected two section breaks where the pavement structure changes. One of these section changes is illustrated by the data to the right of the section break noted in Figure 2.

The FWD survey confirmed the existence of the two different sections in the project. Figure 3 shows backcalculated layer two modulus values with distance through the project. Two sections noted in Figure 3 exist where these modulus values are less than 100 ksi (689 MPa). The location of these sections corresponds with the location of different pavement structures identified in the GPR data; therefore, the GPR data together with the FWD analysis indicate that most likely the concrete pavement has been removed within these two sections.

**FIGURE 2 Example GPR From US 83.**
Table 1 presents the data collected for use in the rubblization selection chart, which is presented as Figure 4. The data show the project is suitable for rubblization since all data points fall within the zone in Figure 4 indicating rubblization is feasible. Adequate support exists for breakage of the concrete since at all three test locations the base CBR was greater than 10. The only concern exists at the location of test 1, where based upon the current guidelines and analysis methods, the data indicate that subgrade conditions are at the borderline for being able to support construction traffic after rubblization.

**TABLE 1 DCP Data from US 83.**

<table>
<thead>
<tr>
<th>DCP Test Location</th>
<th>Concrete Thickness (inches)</th>
<th>Base Thickness (inches)</th>
<th>Base CBR</th>
<th>CBR Values</th>
<th>Subgrade CBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.5</td>
<td>2</td>
<td>15.5</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>5</td>
<td>29.3</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>2.5</td>
<td>49.3</td>
<td>8.3</td>
<td></td>
</tr>
</tbody>
</table>

1 inch = 25.4 mm
Rubblization is being performed on US 83 with the resonant breaker. Completion of the project will serve as feedback to validate the analysis procedures used.

**FM 1155**

This project, in Washington County from FM 912 to Park Road 12, was constructed pre-1940 and exhibits significant transverse cracking in the concrete slabs. The typical joint spacing is 40 feet (12.2 m), and the typical transverse crack spacing is approximately seven feet (2.1 m). Figure 5 shows the site. Figure 6 shows an excerpt of the GPR survey. In Figure 6, the data to the left of the annotation marked “End ACP” is a section with a thick HMA surface patch.
FIGURE 5 FM 1155 Project Site.

FIGURE 6 Example GPR Data from FM 1155.
Table 2 presents the data collected for use in the rubblization selection chart, which is presented as Figure 7. The data show two borderline cases (at DCP locations 1 and 5) where rubblization may not be feasible due to poor support immediately beneath the slab. Additionally, due to the poor subgrade bearing capacity, the Illinois criteria recommend the MHB equipment would be more appropriate to accomplish rubblization.

**TABLE 2 DCP Data from FM 1155 with Corresponding Subgrade Modulus.**

<table>
<thead>
<tr>
<th>DCP Test Location</th>
<th>Concrete Thickness (in)</th>
<th>Base Thickness (in)</th>
<th>CBR Values</th>
<th>Subgrade Modulus from FWD (ksi)</th>
<th>Location (feet North from RM 631 on FM 912)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.5</td>
<td>6*</td>
<td>5.5</td>
<td>3.8</td>
<td>8.2</td>
</tr>
<tr>
<td>2</td>
<td>8.5</td>
<td>6*</td>
<td>66</td>
<td>133.0</td>
<td>12.7</td>
</tr>
<tr>
<td>3</td>
<td>7.4</td>
<td>4.3</td>
<td>15.5</td>
<td>7.5</td>
<td>10.1</td>
</tr>
<tr>
<td>4</td>
<td>7.0</td>
<td>6*</td>
<td>15.8</td>
<td>12.6</td>
<td>5.3</td>
</tr>
<tr>
<td>5</td>
<td>7.0</td>
<td>6*</td>
<td>3</td>
<td>2.6</td>
<td>7.1</td>
</tr>
<tr>
<td>6</td>
<td>7.1</td>
<td>5.9</td>
<td>9.0</td>
<td>2.2</td>
<td>8.9</td>
</tr>
<tr>
<td>7</td>
<td>7.4</td>
<td>4.1</td>
<td>8.5</td>
<td>2.4</td>
<td>7.7</td>
</tr>
</tbody>
</table>

*Assigned to 6 inches because no clear base layer boundary observed in DCP data
1 inch = 25.4 mm; 1 ksi = 6.89 MPa

**FIGURE 7 Rubblization Selection Chart for FM 1155.**
1 inch = 25.4 mm
Due to the two borderline cases for rubblization and the fact that DCP testing coverage is limited, efforts were made to use the FWD data to better partition the project into sections where rubblization may be an option. To accomplish this segmenting, the minimum recommended subgrade CBR that would enable the concrete to be broken was read from Figure 7. For the concrete thickness on FM 1155 (~7.5 inches [190 mm]), a minimum subgrade CBR of approximately 6 would be required. Next, a relationship between the FWD and average CBR of the first 12 inches (305 mm) beneath the concrete was evaluated. With all the data, a poor fit exists. When the two outliers (at test locations 2 and 4) are trimmed, as shown in Figure 8, a much better fit exists. The trimmed data in Figure 8 indicate a backcalculated subgrade modulus of approximately 8.4 ksi (57.9 MPa) is necessary. With the outliers included, data indicate a minimum backcalculated modulus of approximately 7.3 ksi (50.3 MPa) is needed. The two analyses reasonably agree; therefore, it seems reasonable to estimate the minimum required backcalculated subgrade modulus as approximately 8 ksi (55.2 MPa).

![FIGURE 8 Subgrade CBR vs. Backcalculated Subgrade Modulus for FM 1155 (outliers trimmed).](image)

With the minimum acceptable subgrade modulus estimated as 8 ksi (55.2 MPa) in order for rubblization to be considered viable, Figure 9 illustrates the backcalculated subgrade modulus with distance on the project. Segments are identified according to whether the risk of encountering problems is low, medium or high. Using the FWD data in conjunction with the DCP data, Figure 9 shows the limits of the segments identified for this project. With this information, TxDOT can decide where to plan for rubblization, and where other options should be considered.
As part of a pavement safety program to add shoulders to narrow pavements, TxDOT selected to rubblize sections of FM 1155. This work is still in the planning stage; however, TxDOT plans to rubblize both the low and medium risk sections. Construction of this project will provide a unique opportunity to validate the analysis methodology employed and if necessary modify the rubblization selection criteria currently being used.

**Loop 288**

This project, constructed in 1987, exhibits substantial longitudinal cracking as Figure 10 illustrates. The structure consists of 9 inches (229 mm) CPCD concrete pavement over 4 inches (102 mm) of asphalt stabilized base (ASB) with 8 inches (203 mm) of lime treated subgrade (LTS). The ASB clearly provides sufficient support for breakage immediately beneath the slab. According to the IDOT guidelines, the combined 13 inch (330 mm) thickness of the concrete and ASB indicate the minimum recommended subgrade CBR is 4 to rubblize without any restrictions on equipment. Currently the LTS remains in excellent condition (Figure 11 shows how the LTS came out as a solid core), and the minimum observed CBR of the LTS was 42. Subgrade support should not pose a problem on this project if TxDOT uses rubblization for rehabilitating the pavement.
In the course of evaluating this project’s suitability for rubblization, data revealed the longitudinal cracking in the pavement was confined to the concrete layer, and the pavement did not crack at the longitudinal saw cuts as intended. Figure 11 shows a core collected over a longitudinal saw cut, illustrating the lack of cracking at the cut. Figure 12 shows the core hole and core collected over a longitudinal crack, revealing that the crack stops at the ASB layer. Based upon this information, shrinkage cracks did not occur at the saw cuts as designed to relieve shrinkage stress, resulting in the occurrence of longitudinal cracking in the concrete layer. The TxDOT office in charge of this project currently is reviewing rehabilitation alternatives for the pavement.
a. Coring Hole over Longitudinal Crack.

b. Core Collected over Longitudinal Crack.

![Coring Hole and Core over Crack on Loop 288](image)

**FIGURE 12** Coring Hole and Core over Crack on Loop 288
Scale in inches; 1 inch = 25.4 mm

**CONCLUSIONS**

Using a pavement investigation plan similar to that described in this paper provides a wealth of information to allow practitioners to make well-informed decisions about whether a concrete pavement is suitable for rubblization. The plan presented provides a framework where section breaks can be identified through GPR, the structural condition of the pavement can be evaluated with the FWD, and subgrade conditions can be evaluated to gauge whether rubblization is feasible by using the DCP and the rubblization selection chart. Since performing many tests with the DCP can become labor and time intensive, correlating the FWD to the DCP can provide a means to gain a more comprehensive view of the project conditions. A key benefit of using such a comprehensive approach is that sections can be identified according to their risk level of experiencing problems. Sections at risk of not rubblizing can be identified in the planning stage, which allows for other options to be specified up front and therefore reduces the likelihood of needing costly change orders during construction.

Projects are currently underway in Texas using both the RMI and MHB. Monitoring of these projects before, during, and after construction will provide inputs for validation of the analysis methods and criteria used. These methods and criteria should be modified as appropriate as more field project information in Texas becomes available.
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REFERENCES