Report No. FHWA-KS-96-2

FINAL REPORT

DETERMINATION OF BRIDGE DECK SUBSURFACE ANOMALIES BY INFRARED THERMOGRAPHY AND GROUND PENETRATING RADAR; POLK-QUINCY VIADUCT I-70, TOPEKA, KANSAS

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16 Abstract
The purpose of this study was to evaluate the use of infrared (IR) thermography and ground penetrating radar (GPR) to find subsurface anomalies, delaminations and de-bonding, on asphalt concrete overlaid concrete bridge decks. The traditional "chaining" method is a less effective option for finding subsurface defects after an overlay is in place.

An infrared thermographic and ground penetrating radar evaluation was conducted on the I-70 Polk-Quincy viaduct in 1993. The results were compared to other studies conducted to check for subsurface anomalies. These included a 1989 Geology bridge deck evaluation, completed before the membrane and overlay were in place, a 1992 membrane-pavement system electrical resistivity study, and a 1996 Research evaluation to check for de-bonding. The last two studies were completed after the asphalt concrete overlay was in place.

There were differences between the results of the IR/GPR study and those conducted using the more traditional methods. The IR/GPR survey did not find many of the de-bonded and delaminated areas found using the conventional methods. This is not to say that infrared thermography and ground penetrating radar are of little value and inaccurate. The fact that the Polk-Quincy viaduct has been overlaid with both concrete and asphalt, and it is in a general state of deterioration may have made it difficult to obtain good results. Another IR/GPR study will be conducted in 1998 and results will be compared to the 1993 study.

17 Key Words de-bonded, delamination, infrared thermography, ground penetrating radar, asphalt concrete overlay , geotextile membrane, resistivity, bridge deck, chaining, subsurface anomaly	**18 Distribution Statement** No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

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The 9-28-89 Geotechnical Unit report on the bridge deck condition of the Polk-Quincy viaduct, serial number 026, Shawnee County; Leo Teasley, Larry Cavender, and Wallace Taylor, was used as a basis for comparison of later studies. Interim report KS-91/4, "POLK-QUINCY VIADUCT I-70, TOPEKA, KANSAS, CONCRETE BOX GIRDER CONDITION SURVEY" by Dave Meggers, Ken Hurst, and Dan Scherschligt was used for reference. The 1993 report and bridge deck map of delaminations and area of subsurface de-bonding provided by EnTech Engineering, St. Louis, MO, were also used. We wish to thank Craig Rutherford, Engineering Technician Senior, who assisted in analyzing the data for comparison, John Wojakowski, Concrete Research Engineer, for his assistance interpreting resistivity data, and the others who assisted in the field work.

NOTICE

DISCLAIMER

INTRODUCTION

The purpose of this study was to evaluate the use of infrared (IR) thermography and ground penetrating radar (GPR) to find delaminations and de-bonding on concrete bridge decks with an asphalt concrete overlay and membrane.

Presently a common method to evaluate concrete bridge decks is by “chaining;” dragging a series of steel chains across the deck and using the human ear to detect sound differences between solid concrete and delaminated concrete. When an asphalt concrete overlay is placed on a concrete bridge deck, chaining is still used, but is much less effective in locating delaminations in the Portland cement concrete bridge deck. A process is needed that can accurately find and identify possible delaminations of the concrete bridge deck and de-bonding of the asphalt concrete overlay. As the asphalt concrete overlays become thicker, the need for a better process becomes greater.

A study conducted on the Polk-Quincy viaduct in 1993 used infrared thermography and ground penetrating radar to identify subsurface anomalies; de-bonded areas and delaminations. The results from this study will be compared to data from other surveys to determine how accurately infrared thermography and GPR find and identify subsurface anomalies.

WORK PLAN

The plan of study for this project called for three different surveys of the entire bridge deck, one standard survey by the geotechnical unit, one using an infrared (IR) thermographic unit and a third using ground-penetrating radar (GPR). The first survey was performed by the KDOT bridge deck survey crew previous to the placing of the asphalt concrete overlay. The second would use a vehicle mounted IR thermographic unit to locate de-bonded and delaminated locations. The IR survey was performed in two different manors. Initially the IR equipment was mounted on a minivan and two lanes were evaluated at one pass per lane. The evaluation of the other two lanes was performed by mounting the IR equipment on a lift truck that read two lanes per pass. The third survey used a GPR unit that read narrow strips of the bridge deck at two-foot intervals across the deck.

To determine the reproducibility of the test method, it is intended to have both the IR thermographic and GPR surveys conducted again in five years (1998). An attempt to compare the data from the two surveys will be made. The purpose of the comparison will be to determine the reproducibility of the surveys and determine if bridge deck deterioration can be tracked by use of this technology.

HISTORY

The Polk-Quincy I-70 viaduct, bridge number 70-89-361.33 (026), was constructed in 1963. The structure is 3,373 feet long and consists of 30 spans of reinforced concrete box girder and 9 spans of steel welded plate girder. The structure is separated into 12 units, with each unit being continuous construction.

A two-inch high-density concrete bridge deck overlay was applied in 1981. In September 1989, a Geology bridge deck survey was conducted, but only partially completed. This was due to I-70 pavement re-construction and the placement of a waterproof geotextile (petromat) membrane and 1.5 inch BM-1B asphalt concrete overlay on the bridge deck. About 65% of the deck surface area had been checked for delaminations prior to the asphalt concrete overlay placement. The north lane of the eastbound lanes was closed for construction of the overlay and could not be investigated. Approximately 30% of the area investigated was delaminated. Delaminations were found to be above, at and below the level of the top mat of reinforcing steel. Delaminations are hollow plane areas below the surface of the concrete. Fifty-eight, two inch diameter cores were extracted as part of the 1989 study.

The Research Unit conducted a limited evaluation of the electrical resistivity of the membrane-pavement system in 1992. Standard test method ASTM D 3633 was used. The purpose of the measurements was to evaluate the continuity of the waterproof geotextile membrane, which is bonded to the asphalt concrete overlay and the concrete bridge deck. Two measurements were taken at 10 foot intervals along the length of the south lane of the westbound lanes; one at 4 and one at 12 feet north of the bridge centerline.

In 1993, EnTech Engineering, St. Louis, MO, conducted an infrared thermographic and ground penetrating radar study of 100% of the bridge deck surface area for subsurface anomalies. One subsurface anomaly is de-bonding, which is a separation of the asphalt concrete overlay material from the concrete deck. In a de-bonded area, one would expect to find a hole, tear, or other form of deterioration in the petromat membrane, which would allow water to accumulate between the membrane and the bridge deck. Another subsurface anomaly is delamination; this is a splitting of the concrete, which is a result of the forces exerted on the concrete by the expansion of the corrosion products when the reinforcing steel corrodes leaving a hollow plane in the concrete bridge deck. Entech defined delamination as partial depth and full depth. Partial depth was delamination occurring above the level of the top mat of reinforcing steel. Full depth was a delamination occurring at, or below the level of the top mat of reinforcing steel. A total of 20.7% of the area of the bridge deck was found to contain subsurface anomalies. Two percent of which was de-bonded, 4.8% was partial depth delaminations and 14.0% was full depth delaminations.

In 1996, the Polk-Quincy viaduct was closed to replace the expansion joints between the units, in addition, some minor patching, mostly near the joints, was performed. Both westbound lanes were closed first and then both eastbound lanes. After patching and repairs were completed a conventional seal using lightweight aggregate (CM-L) and a polymerized emulsion was applied to the surface. A Research Unit crew checked selected areas for de-bonding by sounding the pavement with hammers and using the human ear to detect sound differences. A hollow sound represented de-bonding between the asphalt concrete overlay and the concrete deck. While the entire bridge deck was not evaluated, the areas surveyed were based on de-bonded areas indicated by EnTech in 1993 and areas of low electrical resistivity of the membrane-pavement system from the 1992 Research Unit study.

METHODS OF DETECTING BRIDGE DECK SUBSURFACE ANOMALIES

The traditional method used to detect bridge deck delaminations, “chaining,” is described in ASTM D 4580. Note that this method works well on concrete bridge decks but has limited accuracy on bridge decks with asphalt concrete overlays, and the only type of subsurface anomaly it can detect is a delamination. The depth of the defect below the surface cannot be determined unless a core sample is removed. Delaminated areas are marked off on the bridge deck and then drawn on a form having the layout of the bridge deck surface. An approximate percentage of the total area delamination is then determined.

Infrared thermography is a non-destructive, non-contact way of converting the bridge deck's temperature related infrared heat energy into visible images. An IR scanner converts heat energy into an electric signal, which is then turned into a thermal picture by a microprocessor. The scanner can be person or vehicle mounted. The thermal image is displayed on a computer screen in either a gray scale, ranging from black to white, or a color scale. Each different shade represents a temperature range, which can be as wide or narrow as the user selects. Note that this method, unlike the chain dragging procedure, can be used on concrete bridge decks with an asphalt concrete overlay. A skilled infrared thermographer can interpret the pictures to detect subsurface anomalies. One limitation of this procedure is that the thermal image shows only a top view. The location of the subsurface anomaly can be described only on the two-dimensional surface of the pavement. The depth of the defect, the third dimension required to locate the exact position in three-dimensional space, is not known. A second limitation is that the climatic conditions must be such that the scanner can determine the differences in the bridge deck temperature. The structure must be warm enough to radiate heat in a wide enough band for the scanner to detect.

Ground penetrating radar provides the depth of the subsurface anomalies, and together with the infrared thermographic study, gives the exact location of pavement defects in three-dimensional space. The GPR utilizes an electromagnetic pulse of about one nanosecond sent through an antenna coupled to a transceiver. The pulse travels through the bridge deck and reflects off of surfaces representing discontinuities in electrical properties. These include the asphalt concrete/Portland cement concrete interface, top and bottom reinforcing steel, deck top and bottom, de-bonded areas, and delaminations. The GPR pulses are echoed back to the receiver, which manipulates the pulses. They are then recorded on a data tape and displayed in real-time on a color monitor. Subsurface conditions are determined by changes in the signal amplitude, which is related to each material's dielectric property, and the time elapsed between the signal transmission and return.

One limitation of GPR is that, in general, it can only detect one defect at any given location. As the electromagnetic pulse travels through the bridge deck and strikes an anomaly, most of the pulse's energy is reflected back to the receiver. Only a small amount of electromagnetic energy is transmitted through the defect. For example, if a pulse struck a de-bonded area, the amount of energy passing through the de-bonded area would be so small that a delamination directly below the de-bonded area would not likely be found. The energy reflected from the second defect, the delamination, would probably be too small to be detected or positively identified as coming from a delamination.

COMPARISON OF THE 1993 ENTECH INFRARED THERMOGRAPHIC AND GROUND PENETRATING RADAR STUDY TO THE 1989 GEOTECHNICAL UNIT SURVEY

Comparison of the results of the two studies is difficult. In an ideal situation, the EnTech infrared thermographic and ground penetrating radar study would have been conducted immediately after the 1989 overlay and Geotechnical Unit survey, and that study would have covered 100% of the bridge deck surface area. In reality, there was a four-year time span between the two surveys. The geotextile membrane and 1.5 inch asphalt concrete overlay were applied after the Geotechnical Unit survey and before the EnTech study.

There are, however, some valid comparisons that can be made. The most accurate would involve the cores extracted from the bridge deck. Fifty-eight, two inch diameter cores were removed as part of the 1989 Geotechnical study. Fifty-seven, or 98.3%, were consistent with the chained delamination map of the bridge deck. For example, where a core indicated a delamination, the 1989 delamination map reflected a delamination in the same area from which the core was extracted. The one core that did not agree with the map contained a delamination that was not found by the chaining method. These results show that the chaining method used to find delaminations is very accurate. One could extrapolate that the bridge deck delamination map is very accurate also.

One would expect that where the delaminated cores were removed as part of the 1989 Geotechnical study, the 1993 EnTech survey would find a delaminated area. The subsurface anomalies that were present at the time of the 1989 study would also be present when EnTech performed the evaluation. The group of 58 cores removed in 1989 contained 36 cores with delaminations. Of these 36, EnTech's infrared and radar study identified 10, or 27.8%, as containing subsurface anomalies.

Six cores were extracted as part of the 1993 EnTech IR/GPR study to calibrate and confirm the results of the infrared thermographic and GPR survey. The cores were removed from the westbound lanes, and were located within 225 feet of the west end of the structure. Four of the six cores confirmed the results of the IR/GPR study. Of the four, one contained no subsurface anomalies, and three indicated full depth delaminations in the concrete. The two core samples that did not agree completely with the survey contained both de-bonding and a full depth delamination in the concrete. The IR/GPR study found only the full depth delamination in the concrete in the areas where these cores were removed.

The bridge deck map of delaminations generated by EnTech's survey was compared to the delamination map from the 1989 Geotechnical Unit study. EnTech found 32.4% of the delaminated areas that the Geotechnical Unit discovered. The delaminations that were present at the time of the 1989 Geotechnical study would also be present when EnTech performed the evaluation. Delaminations were found in 1993 that were not found in 1989. These were likely due to further bridge deck deterioration that resulted from the four-year time difference between the studies.

ELECTRICAL RESISTIVITY OF THE MEMBRANE-PAVEMENT SYSTEM: 1992 RESEARCH SURVEY

Relating electrical resistivity measurements to de-bonding of the asphalt concrete overlay from the concrete bridge deck is difficult. Electrical resistivity is an indicator of how impermeable the membrane is to water. While ASTM D 3633 specifies how to take the measurements, it does not provide for a method to interpret the data. In fact, the evaluation is quite subjective. For example, criteria from Spellman and Stratfull uses the following resistivity values, R ($k\Omega/ft^2$), to classify the state of the membrane separating the Portland cement concrete from the asphalt concrete overlay: $0 < R \leq 100$ (poor), $100 < R \leq 500$ (questionable), and $R > 500$ (excellent). When 50% of the data readings are below 500 $k\Omega/ft^2$, the useful life of the membrane is considered to have been exceeded and the membrane and overlay should be replaced. Derived by different individuals, there are several methods of classifying the condition of the membrane based on resistivity values. The best way to use this information is to monitor, over time, the changing resistivity values on a given bridge deck. There is no direct correlation between resistivity and de-bonding, although one might expect low resistivity values in de-bonded areas.

As mentioned in the History section, the resistivity readings measured in 1992 by the Research Unit, a total of

702, were all taken in the south lane of the westbound lanes. They represented 25% of the bridge deck overlay surface area. Using Spellman and Stratfull criteria, the readings, as they relate to the integrity of the membrane, are classified as follows in Table 1.

Resistivity range, R (kW /ft^2)	**number of readings**	**percentage**	**category**
0 < R ≤ 100	463	66.0%	poor
100 < R ≤ 500	100	14.2%	questionable
R > 500	139	19.8%	excellent

Table 1. Classification of all Resistivity Values Using Spellman and Stratfull Criteria.

The de-bonded areas identified by EnTech in 1993 overlapped some of the 1992 resistivity readings. If the de-bonded areas identified by EnTech were evenly distributed across the asphalt concrete overlay of the entire bridge, then 25% of the total de-bonded area would fall in the area of the resistivity measurements. One of four lanes was measured for resistivity. There were 48 of 702 resistivity readings that overlapped with the EnTech de-bonded areas.

resistivity range, R (kW /ft^2)	**Number of readings**	**Percentage**	**category**
0 < R ≤ 100	29	60.4%	poor
100 < R ≤ 500	10	20.8%	questionable
R > 500	9	18.8%	excellent

Table 2. Classification of Resistivity Readings that Overlap with EnTech Identified De-bonded Areas.

This represented 762 ft^2, or 18.3% of the 4,167 ft^2 total de-bonded area of the entire bridge, which had a total surface area of 209,789 ft^2. Again using Spellman and Stratfull criteria, the readings, as they relate to the integrity of the membrane, are classified as shown in Table 2. The distribution of resistivity readings is nearly the same in the areas that EnTech identified as de-bonded as it is for all of the data.

COMPARISON OF THE 1993 ENTECH INFRARED THERMOGRAPHIC AND GROUND PENETRATING RADAR STUDY TO THE 1996 RESEARCH SURVEY

The 1996 Research study to check for de-bonded areas did not cover the entire bridge deck. It did, however, cover all of the areas where EnTech found de-bonding in 1993. When the two studies were compared, the 1996 Research Unit survey found 57.6% (by area) of the de-bonded areas identified by EnTech.

CONCLUSIONS

Whether or not the infrared thermography and GPR were accurate in finding and identifying subsurface anomalies is uncertain. Perhaps the infrared thermography and GPR are not finding all of the delaminated and de-bonded areas. When the results from the 1993 IR/GPR study are compared to those of previous surveys, there are discrepancies. The infrared thermographic and ground penetrating radar study did not find a significant amount of the subsurface anomalies identified using traditional methods. This is not to say that infrared thermography and GPR are of little value and inaccurate. IR/GPR are the only methods (except for cores) for finding subsurface anomalies that give the depth of the delamination or de-bond. The fact that the Polk-Quincy Viaduct has been overlaid with both concrete and asphalt, and is in a general state of deterioration may have made it difficult to obtain good results.

The reason why the results of this IR/GPR evaluation and the traditional methods of detecting subsurface anomalies do not have better correlation is unclear. There are many variables that make a direct comparison difficult. Before the two-inch concrete overlay in 1981, the concrete bridge deck was milled off to a level just above the reinforcing steel. The 1989 Geology survey was conducted four years before the IR/GPR study, and before the geotextile membrane and asphalt concrete overlay was in place. The 1992 resistivity readings were all taken in one lane. There is no direct correlation between resistivity and de-bonded areas, and the comparison is subjective. At this point, a determination of the accuracy and repeatability of infrared thermographic and ground penetrating radar cannot be made.

IMPLEMENTATION

Approximately five years after the 1993 IR/GPR study, another evaluation of the Polk-Quincy viaduct will be made using the same IR/GPR technique. Comparisons will be made to determine if the subsurface anomalies identified in 1993 are also found during the new study. The subsurface defects found in 1993 should be found when the new study is conducted. One would expect additional deterioration due to the five-year time lapse. If there is correlation between the two studies, this will show the test method is consistent and repeatable and could be expanded for use on other structures and possibly applied to a bridge management system.

References

Teasley, Leo E. and Larry Cavender, “Bridge Deck Condition Report 70-89-K 4016-01 Polk Quincy Viaduct Serial No. 026 Shawnee County.” Kansas Department of Transportation, Bureau of Materials and Research, September 28, 1989.

“Standard Test Method for Electrical Resistivity of Pavement Membrane Systems,” ASTM Designation D 3633-88. Annual Book of ASTM Standards. Vol. 04.03. Philadelphia, PA: American Society for Testing and Materials, 1991.

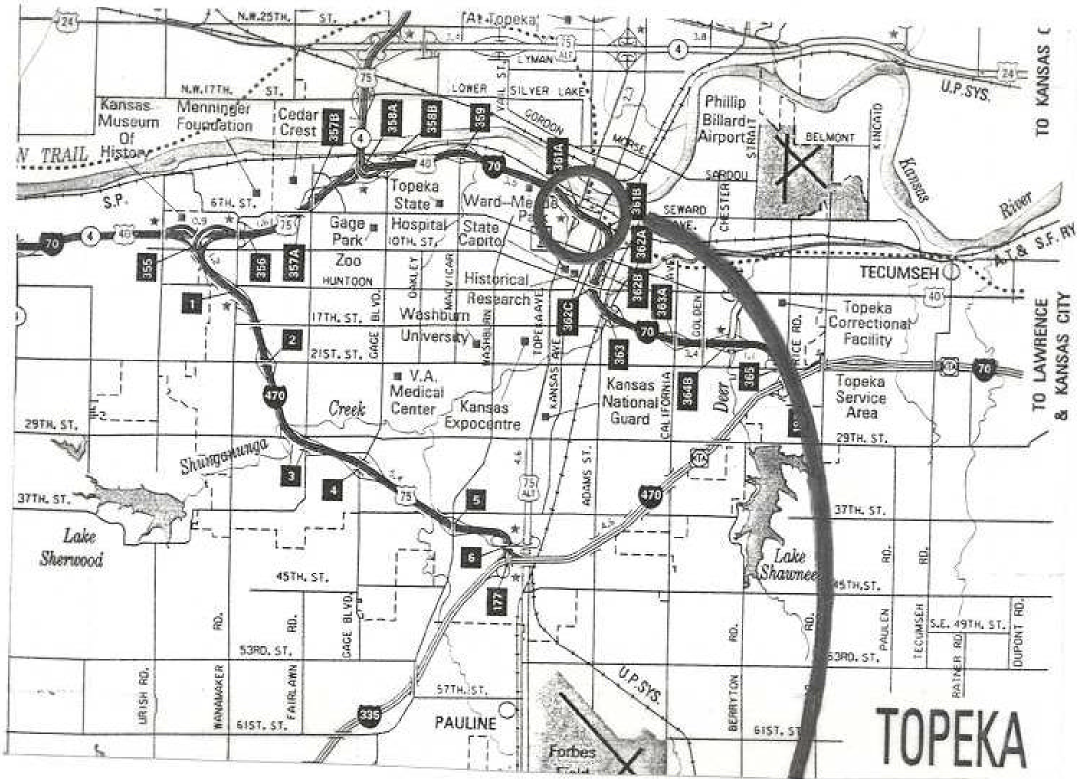
“Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding,” ASTM Designation D 4580-86. Annual Book of ASTM Standards. Vol. 04.03. Philadelphia, PA: American Society for Testing and Materials, 1986.

Meggers, D.A., K.F. Hurst, D. Scherschligt, “Polk-Quincy Viaduct I-70, Topeka, Kansas Concrete Box Girder Condition Survey.” Interim Report KS-91/4, Kansas Department of Transportation, December 1991.

Spellman, D.L. and R.F Stratfull, “An Electrical Method For Evaluating Bridge Deck Coatings,” Report No. M&R 635116-5, California Department of Transportation.

Appendix A:

Location of Polk-Quincy Viaduct


TOPEKA
Kansas Museum Of History
Menninger Foundation
Cedar Crest
Topeka State Hospital
Gage Park Zoo
Ward-Meade Park
State Capitol
Historical Research
Washburn University
V.A. Medical Center
Kansas Expocentre
Kansas National Guard
Phillip Billard Airport
TECUMSEH
Topeka Correctional Facility
Topeka Service Area
Lake Sherwood
Lake Shawnee
Shunganunga Creek
Deer Creek
Kansas River
PAULINE
Forbes Field
TO KANSAS CITY
TO LAWRENCE & KANSAS CITY
U.P.SYS.
A.T.& S.F.RY
N.W.25TH. ST.
N.W.17TH. ST.
6TH. ST.
10TH. ST.
HUNTOON
17TH. ST.
21ST. ST.
29TH. ST.
37TH. ST.
45TH. ST.
53RD. ST.
57TH. ST.
61ST. ST.
S.E. 49TH. ST.
GAGE BLVD.
KANSAS AVE
TOPEKA AVE
ADAMS ST.
CALIFORNIA
GOLDEN
BERRYTON RD.
URISH RD.
WANAMAKER RD.
FAIRLAWN RD.
SEWARD AVE.
BELMONT
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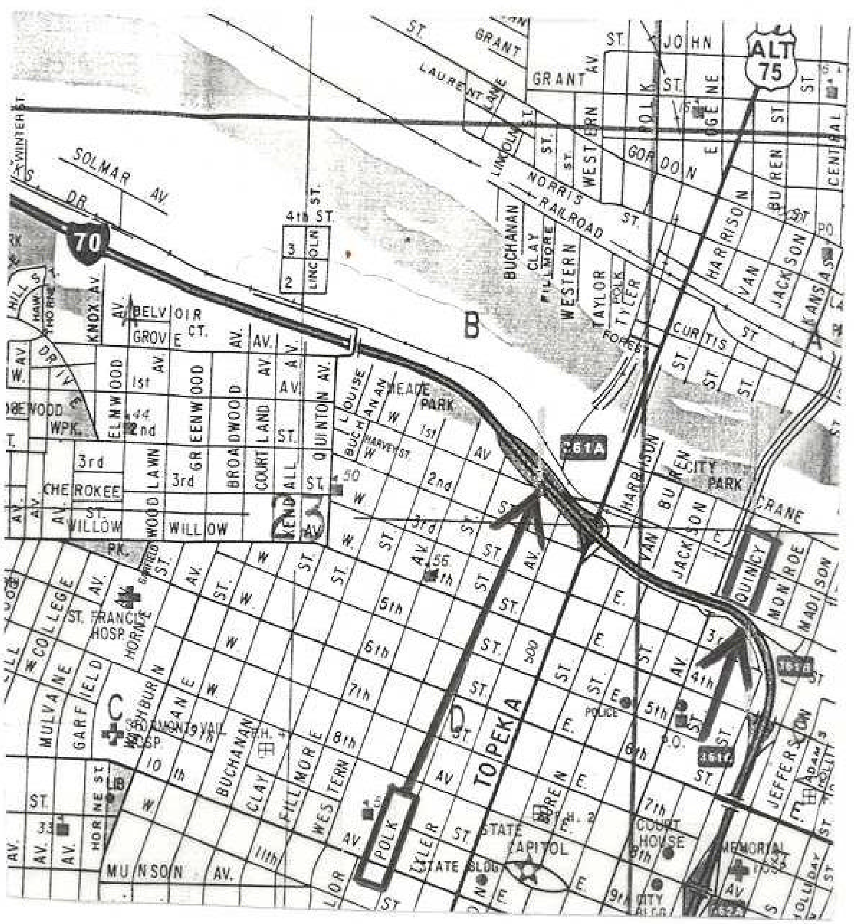
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70
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CITY PARK
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STORMONT-VAIL HOSP.
STATE CAPITOL
STATE BLDG.
COURT HOUSE
CITY BLDG.
MEMORIAL HOSP.
POLICE
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MUNSON AV.
MULVANE
GARFIELD
COLLEGE
WASHBURN
HORNE
KNOX AV.
ELMWOOD
WOODLAWN
GREENWOOD
BROADWOOD
COURTLAND
KENDALL
QUINTON AV.
LINCOLN