

R-352

LIGHTNING DAMAGE TO CONCRETE PAVEMENT
US 10 Bypass, Midland (Project 56044, C9)

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Michigan State Highway Department
John C. Mackie, Commissioner
Lansing, March 1961

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US 10 Bypass, Midland (Project 56044, C9)

On the night of August 2, 1960, an extremely severe electrical storm passed over Midland. The following day, R. H. Fosdick, project engineer on the US 10 Bypass north of Midland (Project 56044, C9), discovered unusual damage on the westbound roadway pavement of this divided highway, which was not yet open to traffic. Basically, this damage consisted of an irregular pattern of spalling and burnt mortar. One spall was notably broader and deeper than the others.

On the assumption that the damage was associated with lightning discharges, Fosdick reported the incident to the Saginaw construction office.

The Road Construction Division requested an investigation of the spall-burn damage and with the approval of W. W. McLaughlin, Testing and Research Engineer, personnel of the Research Laboratory Division visited the project on August 9, to inspect and photograph the pavement.

The damaged pavement included two distinct zones of spalling (Fig. 1). At the west, 23 shallow spalls and burns, none more than 4 in. in diameter, were broadly distributed over 169 lineal feet poured in October 1959 (Figs. 2 and 3). Nineteen of these points were concentrated within 25 ft of a single transverse joint.

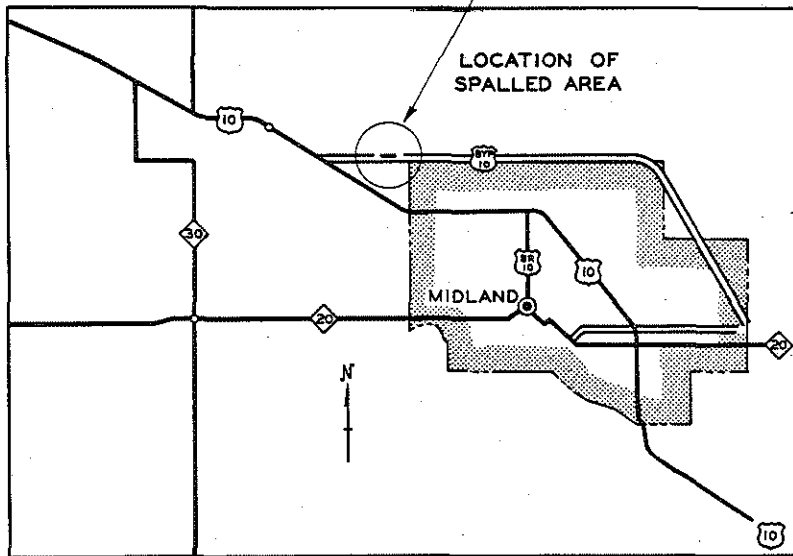
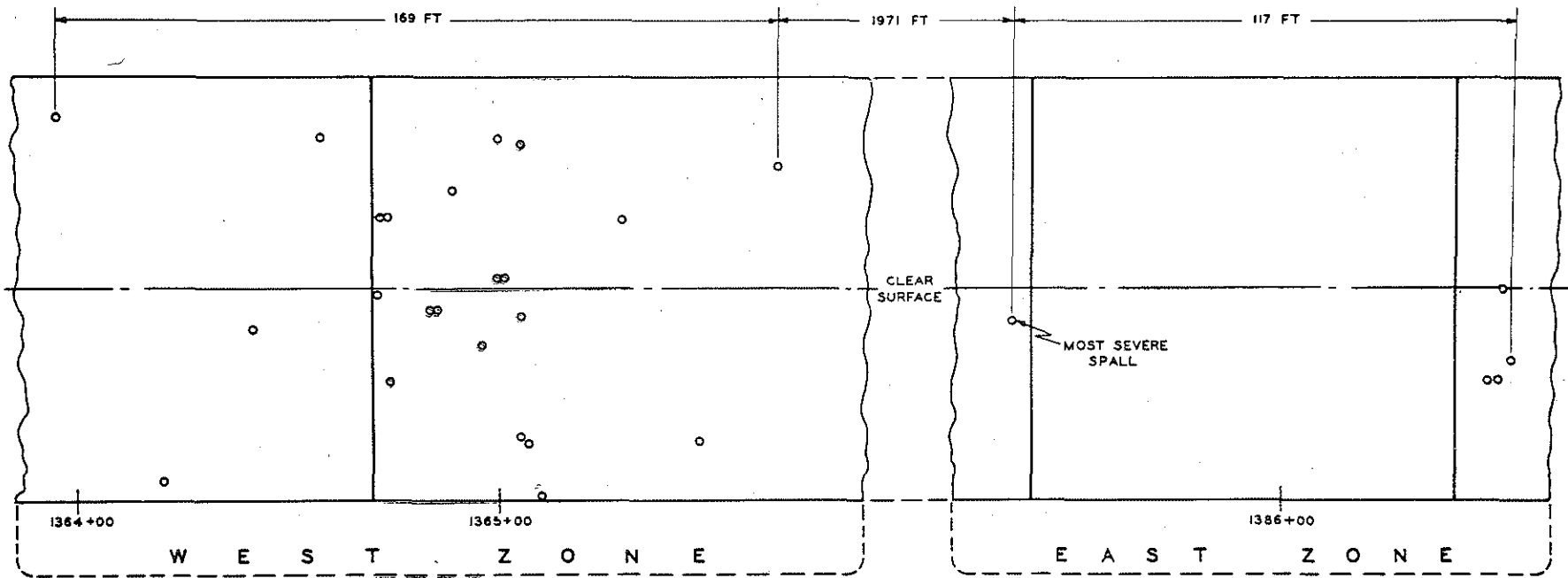
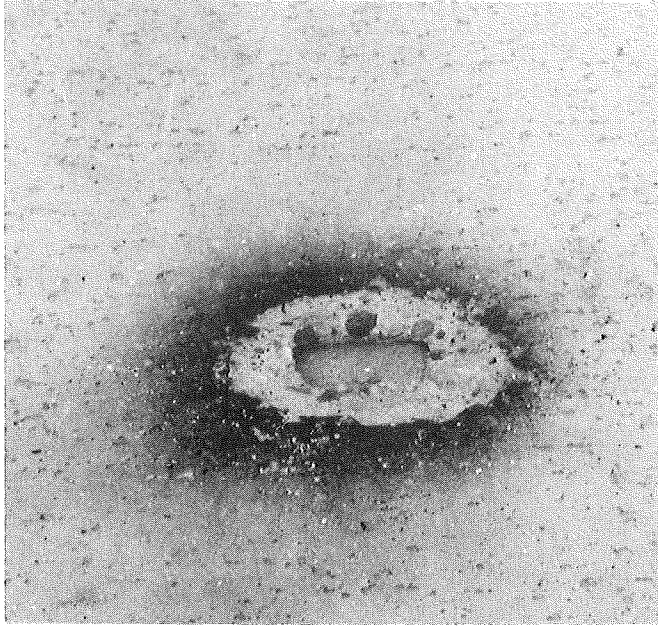
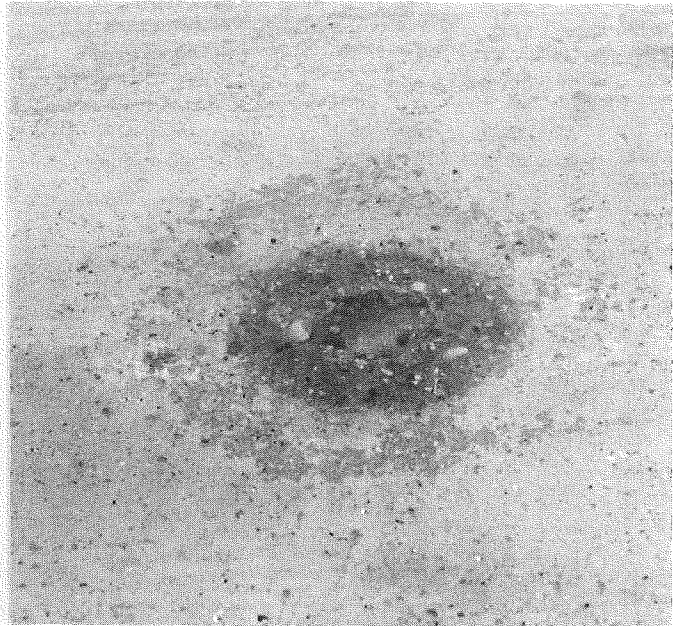


Figure 1. Schematic drawing of the damaged pavement, showing distribution of spalls. Western spalls were small and shallow, eastern were wide and deep.



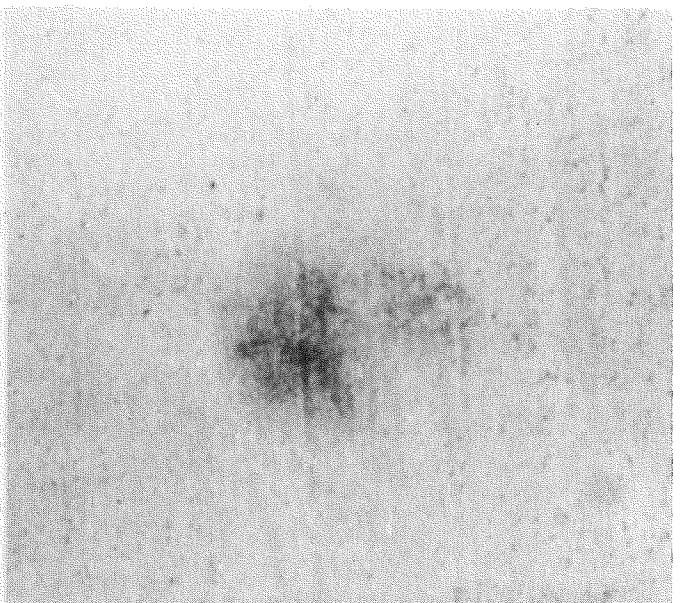
A popout fringed at the surface with scorched mortar and membrane, suggesting heating effects of electrical energy (popout: 4-in. diam).



A popout showing a ring of mortar and membrane damaged by heat of current flow (popout: 4 in. diam).



A popout with clear breakaway of overlying mortar due to pressure associated with heating effects just below the surface (popout: 3-1/2 in. diam).



Discoloration of curing membrane without spalling, due to heat at or just below the surface (scorched area: 2 to 3 in. diam.)

Figure 2. Typical appearance of spalls found in the western zone of damage, an area of small, shallow, closely spaced popouts. Note widespread minute pits and stains on the pavement surface, probably resulting from the heat of current flow.

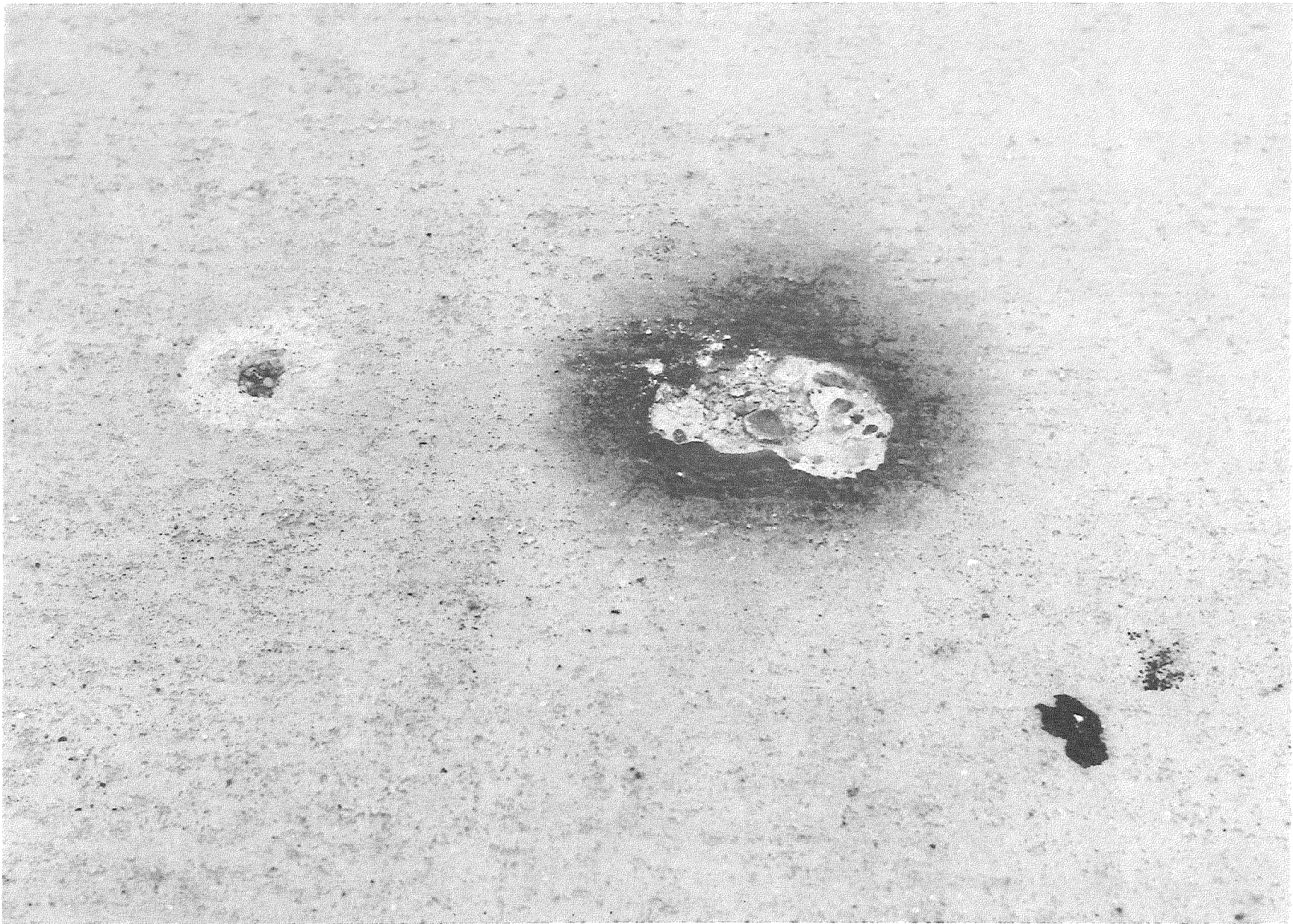


Figure 3. In the western zone of damage, adjacent spalls occasionally exhibited different types of damage, suggesting varying reactions of aggregates of different conductivity, chemical composition, and moisture absorption properties.

At the east, in pavement poured in May 1960, the single point of most severe damage, roughly a foot in diameter and 4 in. deep at its extreme depth, was about 4 ft on the right side of a construction joint (Figs. 4 and 5). Four more spalls, all broader and deeper than those in the west zone, were found 117 ft farther east of the largest spall. These four spalls were also near a transverse joint (Fig. 6).

Between these two zones--169 ft on the west and 117 ft on the east--was 1971 ft of clear, undamaged pavement.

In 1954, the Research Laboratory Division conducted an extensive search of the literature dealing with lightning damaged concrete, which was abstracted and presented in Research Report 208, a discussion of presumed lightning damage on US 41 in Baraga County. At that time the following criteria were developed as typical of lightning damaged pavement:

1. Occurrence of spalling incident during a thunderstorm.
2. Location of pavement on likely terrain for development of high electrical potential during an electrical storm.
3. Scattering of concrete for several feet at spalled points, as distinguished from spalling associated with freezing and thawing or slow thermal changes found under normal weather conditions.
4. Spalling confined to definite areas, rather than being general throughout the project as might be expected under normal service conditions.

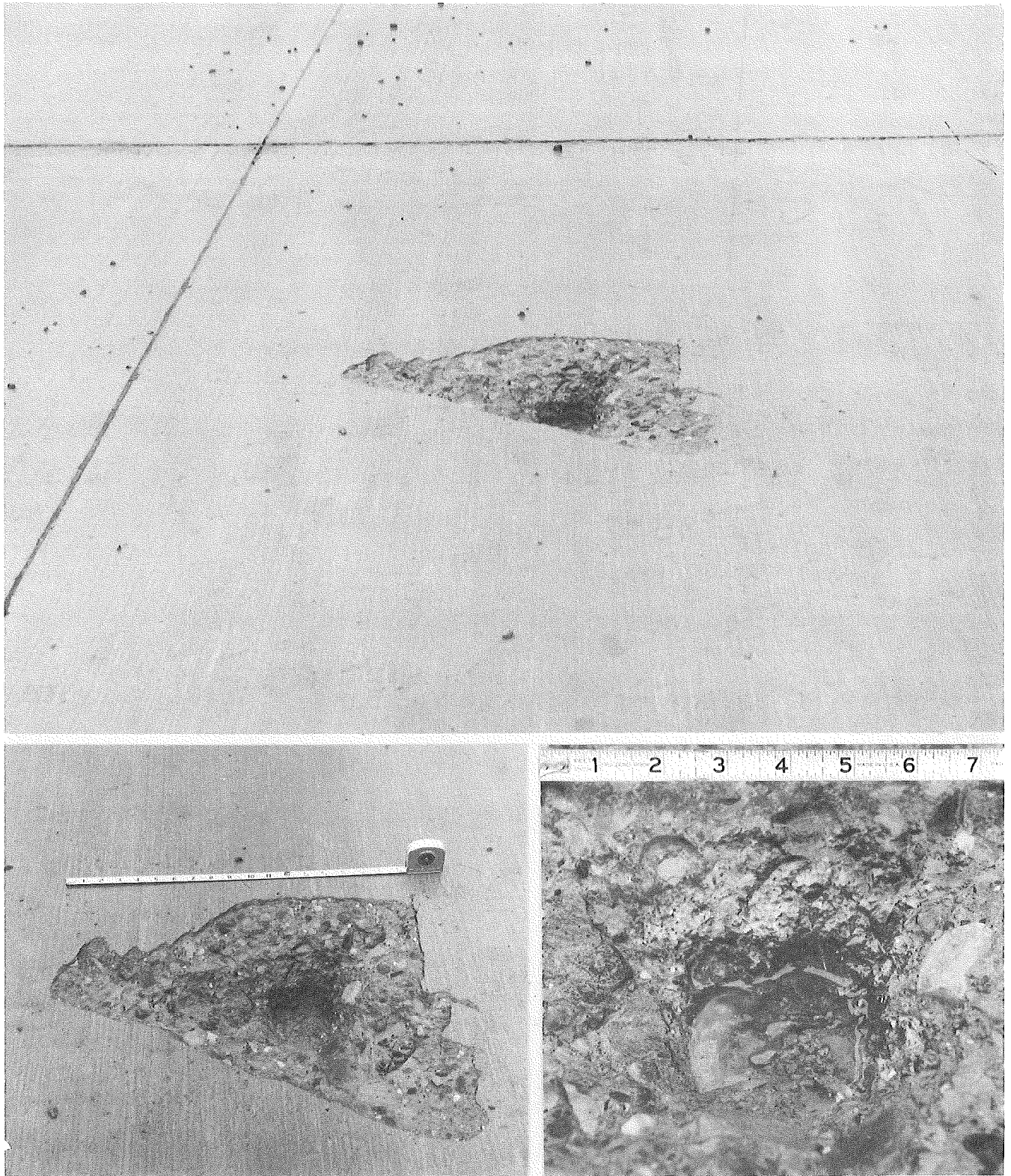


Figure 4. Three views of the point of greatest spall damage. Note burned concrete at center of hole--material was shattered and charred to a depth below the reinforcing steel. Surface dimensions: 18 by 10 by 14 in.

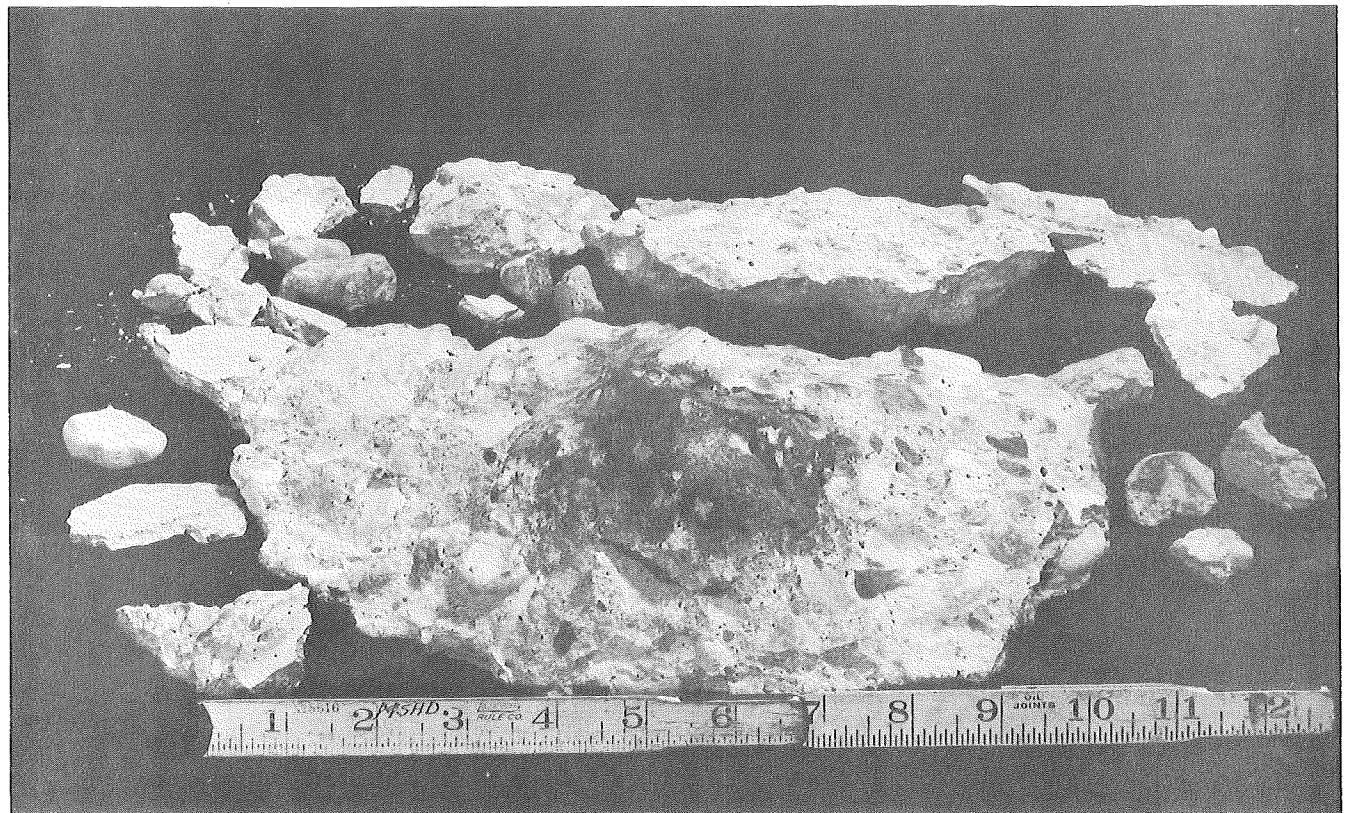
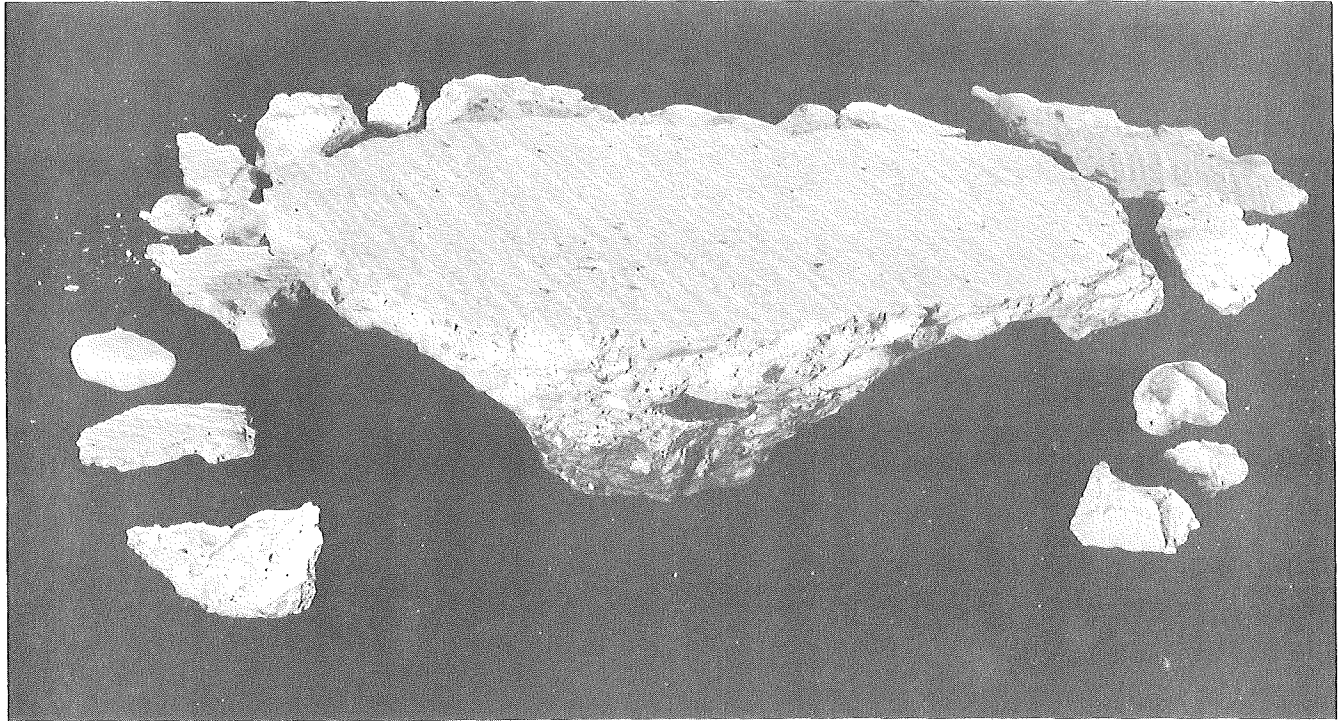


Figure 5. Displaced material from the point of greatest spall damage, showing intact mortar and curing membrane at the top surface and the burnt tip, suggesting generation of high gas pressures in association with extreme heating effects at the reinforcement level.

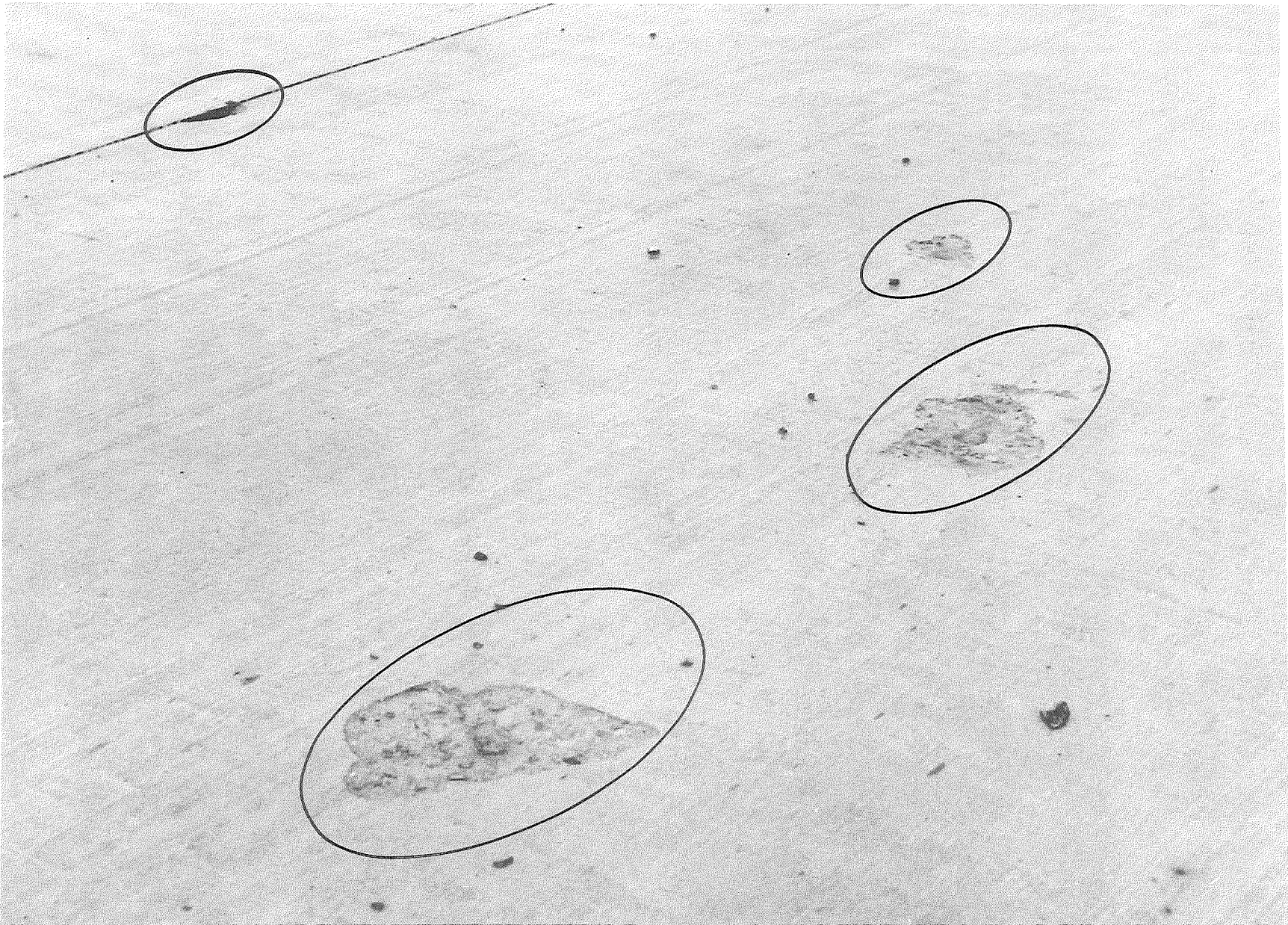


Figure 6. General view of spalling in eastern zone of damage, an area of broader, deeper and fewer spalls than at the west. Note scattering of ejected pavement material.

In addition, the spalling may occur at any point on the slab surface, but typically concentrates at joints or at the pavement edge--at the periphery of the reinforcing steel. Also, resistance to the flow of electrical energy through the pavement may cause temporary heating effects of great intensity.

This description clearly applies to the Midland pavement. The thunderstorm was accompanied by relatively light rain--probably enough to wet the pavement but not to penetrate the shoulder or foundation soils. This pavement was constructed on a fill which raised the slab approximately 5 ft above the surrounding original ground level. In addition, concrete fragments were scattered several feet at many spalled points, and most spalls were relatively close to transverse joints.

In the last 20 years, intensified research in the mechanics of lightning, primarily to solve problems in military and civil aviation, has resulted in rejection or revision of much traditional theory in this subject area.* Without a first-hand account of the Midland lightning incident, it is possible to state certainly only that the numerous shallow, small spalls in the west zone of damage probably resulted from diffuse or "low-order" lightning. However, the large, deep, isolated spalls in the eastern zone of damage probably involved concentrated or "high-order" lightning discharge. Further, the damage in the two areas may have occurred either simul-

*Byers, Horace R. (ed), Thunderstorm Electricity. Chicago: Univ. of Chicago Press (1956), 344 pp.

taneously, or, since the two zones were separated by nearly 2000 ft of undamaged pavement, in separate discharges.

A low-order lightning discharge would cause small spalls, with minor burning or charring of mortar and curing membrane at the margin of the spalls. On the other hand, a high-order discharge would involve greater current and internal arcing within the pavement, producing sufficient heat to vaporize internal moisture and pavement material and to cause destructive gas pressures.

The big, roughly conical section of concrete from the largest spall was taken to the laboratory for chemical analysis of its blackened apex. This analysis was limited to establishing the presence of iron.

A blackened stone was removed from the concrete and submerged in hydrochloric acid until the blackened area dissolved. The stone was then submerged in another hydrochloric acid bath for an equivalent time.

Colorimetric results obtained on the two fractions indicated that iron was present in the blackened area. The concentration of iron found in that fraction was approximately ten times greater than the iron content of the stone. A high iron content was also found in darkened portions of the mortar. The iron was assumed to be present in the blackoxide form, presumably produced by a high energy electrical discharge from the pavement reinforcing wire.

On August 15, a follow-up condition survey of the spalled area revealed no further deterioration. Early in September, the contractor filled the spalls with a fine-mix bonding cement which has held well since then. The project was opened to traffic November 4, 1960.

Another condition survey was performed on February 27, 1961, more than six months after the lightning incident, and nearly six months after the patching of the spalls. All patches were still firmly bonded to the pavement and there was no evidence of any further deterioration in the zones of lightning damage.