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EVALUATION OF LIQUID BINDERS FOR AIRFIELD BOMB DAMAGE REPAIR

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EVALUATION OF LIQUID BINDERS FOR AIRFIELD BOMB DAMAGE REPAIR

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A laboratory and a field study were conducted to evaluate the use of an epoxy binder to stabilize a gravel layer for the repair of bomb craters in airfield pavements. The particular repair system investigated consisted of backfilling the crater with ejected debris, sand to within 12 in of the top of the pavement, and a 3/4-in uniform gravel to the surface. The gravel was stabilized by a liquid epoxy resin which had a cure time of 10 to 15 min. The field test section successfully withstood 100 passes of an F-4 tire loaded to 30,500 lb without any measurable elastic or permanent deflection.

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FOREWORD

This report was prepared by the Civil Engineering Research Facility, University of New Mexico, Kirtland AFB NM under contract F29601-74-C-0030, job order 21044B09 with the Air Force Civil Engineering Center, Tyndall AFB FL. This report summarizes work done between March 1974 and August 1975. This project originated with the Air Force Weapons Laboratory and was transferred to AFCEC when elements of the AFWL Civil Engineering Research Division were reorganized and transferred to AFCEC. Lt Raymond S. Rollings was the project officer.

The following products referenced in this report are registered trade names and should be treated as such.

a. DER 321, DER 331, DER 732, DEH 39 - DOW Chemical Company

b. Eccobild RP-10 - Emerson and Cuming, Inc.

c. Petroset RB - Phillips Petroleum

d. Epon 820 - Shell Oil Company

e. Epocast 530 - Furane Plastics

f. XB-2391 - 3M Company

This report has been reviewed by the Information Officer (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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INTRODUCTION

BACKGROUND

Air base runways, taxiways, and parking aprons are potential targets for enemy air attack. If an airfield pavement is extensively damaged, and no alternative runways exist, aircraft can easily be rendered useless. Rapid runway bomb-damage repair techniques are used to insure the operational capability of an air base after enemy attack.

The present USAF bomb-damage repair technique was developed through testing at Eglin AFB, Florida (1962-1965). The USAF required that three 750-lb bomb craters be repaired within 4 hr. The present technique has been tested under simulated conditions, and with revisions it is now adequate; however, under actual wartime conditions a faster repair technique would be necessary.

A suggested faster repair technique consists of backfilling the bomb crater to a certain depth with crater ejecta, filling the rest of the crater with aggregate, and spraying a liquid binder over the surface. The success of this technique depends on the properties of the binder, which would have to penetrate deep enough into the aggregate to form a strong, durable, impact-resistant surface for aircraft operation. This repair technique is of particular interest to the Air Force because a large number of small craters can be repaired rapidly. Presently, aluminum mats are used to repair craters; however, this technique (AFR-93-2) is not useful for repairing many small craters because: (1) the intermittent spacing of mats effects a very severe roughness profile for the aircraft, and (2) the time, manpower, and material requirements to simply put together and anchor a large number of mat groups are excessive when compared to the type of bomb-damage repair suggested here.

OBJECTIVE

This study was conducted for the Air Force Weapons Laboratory (AFWL) by the Eric H. Wang Civil Engineering Research Facility (CERF). The objective was to evaluate the feasibility of using liquid binders to stabilize an aggregate layer which would serve as a temporary surface (cap) for the repair of bomb-damaged airfield pavements. This surfacing was envisioned as a repair which could be made quickly and easily. It would provide rapid rehabilitation of the pavement but would have limited durability; thus, a permanent repair would be required at a later date.

The specific goals were as follows:

(1) To perform a structural analysis of the proposed cap to determine the stabilized cap thickness required to support a 50,000-lb load on an F-4 aircraft tire.

(2) Based on the structural analysis, to suggest the minimum laboratory tensile strength required in a 6-by 6-by 20-in beam loaded at the third points to support the 50,000-lb load on a prototype field cap.

(3) To determine the optimum gradation of sand and aggregate for proper penetration of the liquid binder through the gravel and into the sand.

(4) To evaluate four liquid binders suggested by AFWL. The optimum percentage of each binder was to be determined as the minimum binder needed to provide the required tensile strength in the beam tests. Gel and cure times of the neat binder at room temperature were also to be determined.

(5) To construct and load test a 10-by-10-ft prototype repair cap using a subgrade with a low California Bearing Ratio (CBR).

The particular repair technique investigated consisted of backfilling the crater with crater ejecta, placing sand over the ejecta backfill, and then placing a graded-gravel layer over the layer of sand. The gravel layer was 10 in thick[*] and level with the surface of the undamaged pavement. The aggregates were stabilized by spraying the gravel with sufficient liquid binder to penetrate several inches into the sand layer.

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[*] The 10-in depth of gravel was determined from the structural analysis in which the stabilized cap was modeled as an unrestrained plate.

Binders which would easily and rapidly penetrate the gravel but would be retarded by the sand layer were selected. Thus, the sand layer would be saturated to a depth of several inches while the aggregates would only be coated with the binder. Depending on the viscosity and gel time of the binder, the lowermost portion of the gravel layer might also be saturated with the liquid binder. Thus, once the binder hardened, the structural system would support the surface load in bending with the lower binder-saturated layers providing the tensile strength. The upper portion of the gravel layer would be in compression with a sufficient amount of binder to prevent shear displacement in the compression zone.

SCOPE

This study was limited to an investigation concerned with examining the feasibility of using available liquid binders to effect the repair method suggested above. The investigation consisted of a limited laboratory investigation of binder strength, percent binder and aggregate gradation, a limited structural analysis of the repair cap, and the construction and load testing of a small-scale field repair cap.

SECTION 2
STRUCTURAL ANALYSIS

THEORETICAL APPROACH

A brief analytical study was made to verify the mathematical model used for the repair cap and to identify the strength requirements for the cap. The cap is, in effect, a structural system which must support a 54,000-lb F-4 aircraft having a single wheel main gear load of 26,000 lb and a tire contact area of 110 in^2. The following structural systems are possible:

(1) A rigid cap (plate) system.

(2) A flexible system in which the load is distributed to the substructure in flexure through a series of layers of decreasing rigidity.

A flexible cap is inappropriate because ejecta are used to backfill the crater, and this material cannot be compacted because of the limited construction time. The sand and gravel layers are only slightly compacted; thus, the entire system is weak and cannot develop the load-distribution characteristics required of flexible layered systems. Hence, a rigid plate is required to distribute the load to the subgrade. Such a system can be modeled as a plate on an elastic foundation.

The differential equation for a circular plate on an elastic (linear) foundation with symmetrical loading (fig. 1) is

$$\left(\frac{d^2}{dr^2} + \frac{1}{r}\frac{d}{dr}\right)\left(\frac{d^2w}{dr^2} + \frac{1}{r}\frac{dw}{dr}\right) = \frac{q - kw}{D} \text{ (ref. 1)} \qquad (1)$$

where

q = normal unit loading
k = foundation modulus
w = deflection
D = flexural rigidity of the plate defined by

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[1] Timoshenko, S., *Plates and Shells*, McGraw-Hill, New York, N.Y., 1959.

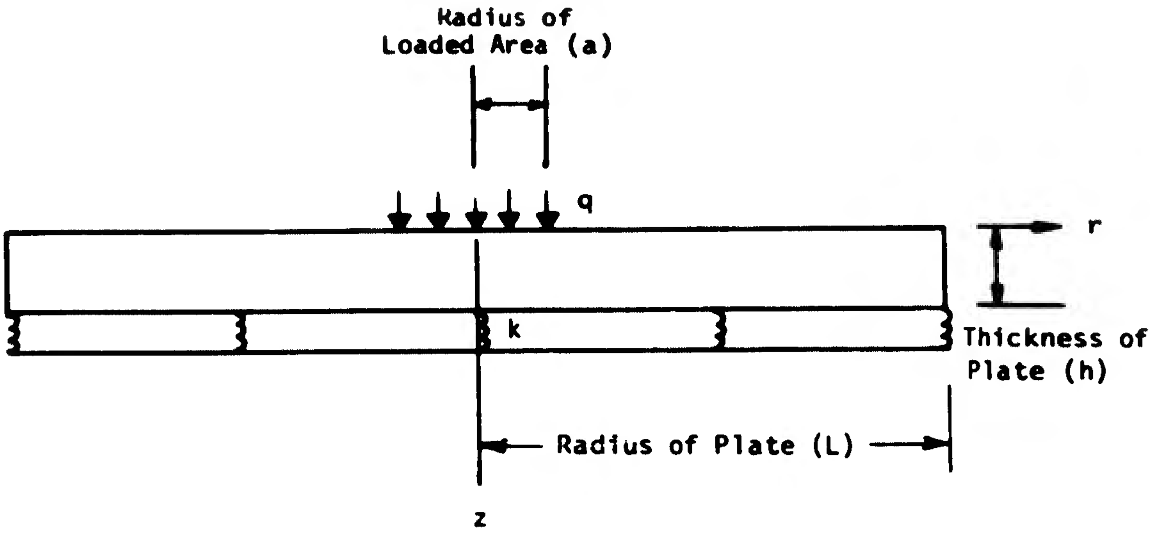

Figure 1. Structural Model of Repair System

$$D = \frac{Eh^3}{12(1 - \nu^2)}$$

Using the Laplacian operator

$$\nabla^2 = \frac{d}{dr^2} + \frac{1}{r}\frac{d}{dr} + \frac{1}{r^2}\frac{d^2}{d\theta^2} + \frac{d^2}{dz^2} \text{ (ref. 2)}$$

one can write eq. (1) in cylindrical polar coordinates (r, z, θ) as

$$\nabla^2 w = \frac{q - kw}{D} \qquad (2)$$

where

$$\nabla^2 \equiv \nabla(\nabla) \equiv \left(\frac{d}{dr^2} + \frac{1}{r}\frac{d}{dr}\right)\left(\frac{d^2}{dr^2} + \frac{1}{r}\frac{d}{dr}\right)$$

---

2. Fung, Y. C., *Foundations of Solid Mechanics*, Prentice-Hall, Englewood Cliffs, New Jersey, 1965.

with the operation being independent of θ because the problem is axisymmetric and independent of z because it is assumed that $|w| \ll h$; thus, all derivatives of w with respect to z vanish. This requires that the model be considered either a plate of infinite length or a shorter plate of finite length. An infinite-plate assumption implies that the load is far enough away from the edges of the plate so that the boundary conditions develop strictly local stresses which have no significant influence on the stresses in the neighborhood of the load. In the solution for a finite plate both the interaction of the boundary and load-induced stresses are considered; i.e., the boundary stresses are significant and must be considered in the solution. The mathematical solution of the differential equation for plates on an elastic foundation is greatly simplified if the boundary conditions can be neglected and the problem modeled as an infinite plate.

In practice it is often assumed that a finite plate is an infinite plate, especially when the loaded area is small compared with the radius of the plate. In this study, the F-4 tire imprint was modeled as a circular bearing area having a radius of 5.9 in, even though the actual tire imprint is oval. The symmetry achieved through this assumption and the large radius (60 in) of the field-tested repair cap seem to justify the use of an infinite-plate model. Nevertheless, this assumption was verified as part of the analytical study. Before any numerical studies are presented, the general theory of this problem is briefly outlined.

The solution to eq. (2) for the deflection, w, under a point load is

$$w = -\frac{P\ell^2}{2\pi D} \operatorname{kei} \rho \quad \text{(ref. 1)} \tag{3}$$

where

P = total load

$\ell = \sqrt[4]{\frac{D}{k}}$

ρ = argument of kei

kei = real part of the Bessel function of the third kind of order zero (Hankel function)

Timoshenko (ref. 1) gives the solution to eq. (3) for the case in which the radius of the loaded area, a, is small compared with the plate radius, L (infinite plate) as

$$w_{center} = \frac{P\ell^2}{8D} \tag{4}$$

and

$$M_{center} = \frac{(1 + \nu)P}{4\pi} \left[\ln \frac{\ell}{a} + 0.616\right] \tag{5}$$

where M is moment and ν is Poisson's ratio.

With eqs. (3) and (4), it is possible to investigate the assumption made earlier regarding the modeling of the repair cap as an infinite plate. To do this it is necessary to introduce the concept of attenuation length. *Attenuation length*, χ, is a term used in structural analysis to describe the decay of moment, shear, or deflection induced in a structure due to isolated loads, with respect to distance from the load. In this problem, if it can be shown that the plate deflection along a radius of the plate decays so rapidly that the deflection reaches a small value at a radius less than the plate radius, then the boundary stresses due to any restraint which develops between the repair cap and the undamaged pavement can be overlooked and the repair cap can be represented as an infinite plate.

The concept of attenuation length is derived from a general theory of cylindrical shells in which the general solution for deflection is written in terms of $e^{\pm\lambda r}$, for the case of cylindrical coordinates, where

e = Napierian base

$$\lambda = \frac{1}{\ell} = \sqrt[4]{\frac{k}{D}}$$

This concept is fully applicable here since the repair cap is a special case of a cylindrical shell--one with a very large radius of curvature. The λ term includes the flexural rigidity of the cap as well as the elasticity of the supporting subgrade, and it is an important term in influencing the shape of the deflected plate. Thus, the factor λ is often called the *characteristic of the system*, and since it has the dimension of length^{-1}, $1/\lambda$ is often referred to as the *characteristic length*. Thus, λr is an absolute number and it is defined here as *attenuation length*.

$$\chi = \lambda r \tag{6}$$

To check the boundary assumption (i.e., infinite plate ~ finite plate), the effects of attenuation length, λ, and plate thickness, h, on deflection, w, were plotted as shown in figure 2. This figure was constructed using $P = 50{,}000$ lb, $k = 200$ psi/in, $E = 2 \times 10^6$ psi, $\nu = 0.15$, and plate thicknesses of 4, 6, and 8 in. Points for zero attenuation length correspond to the deflection under the center of the load and the ordinate values indicated were calculated with eq. (4). The numerical values of the variables in eq. (4) were as follows:

h, in	D, in^4	ℓ, in	w_{max}, in
4	1.09×10^7	15.28	13.37×10^{-2}
6	3.68×10^7	20.70	7.28×10^{-2}
8	8.73×10^7	25.70	4.72×10^{-2}

Deflection values for attenuation lengths greater than zero were calculated with eq. (3). To use this equation, values of kei β were calculated with the equations given by Timoshenko (ref. 1). For values of $\lambda \leq 1$

$$\text{kei}\ \lambda = -(\lambda^2/4)\ln\lambda - \pi/4 + 1.11593\lambda^2/4 \tag{7}$$

For values of $\lambda > 1$

$$\text{kei}\ \lambda \sim -\frac{e^{-\sigma}}{\sqrt{2\lambda/\pi}}\sin(\sigma + \frac{\pi}{8}) \tag{8}$$

where

$\sigma = \lambda/\sqrt{2}$

Values of kei β are tabulated below for selected values of λ.

λ	kei β
0.5	-0.6723
1.0	-0.5064
1.5	-0.3519
2.0	-0.2095
3.0	-0.0508
4.0	+0.0029
5.0	+0.0116
6.0	-0.0038

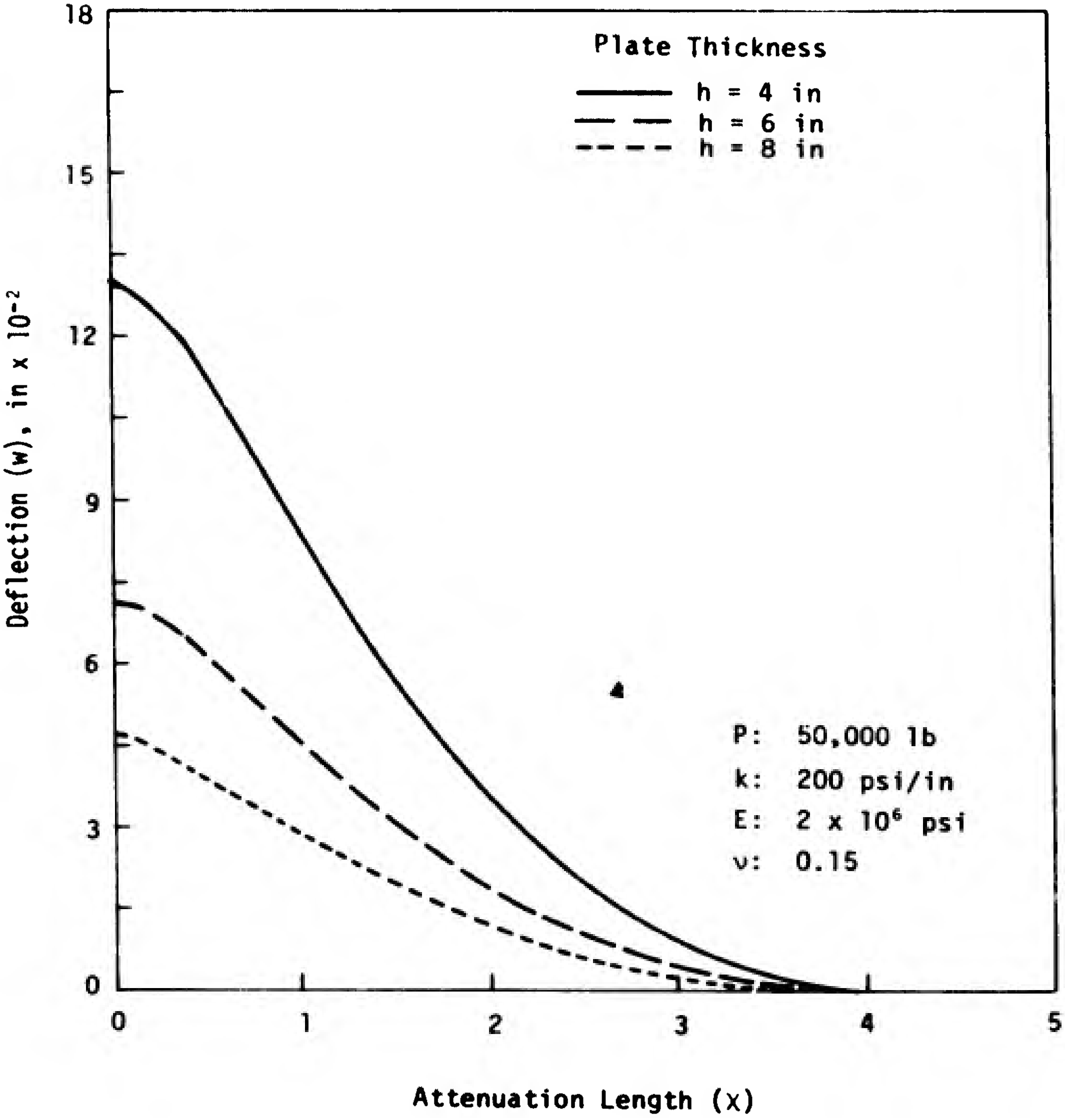

Figure 2. Deflection versus Attenuation Length and Plate Thickness

The oscillatory nature of the kei function is indicated by the sign change shown for kei β. The kei function is a monotonically decreasing function so that the maximum value of kei β for $x > 6$ will not exceed ± 0.0116. For an 8-in-thick plate, this corresponds to a deflection of 0.0007 in. Certainly any stresses set up by such a low deflection will be insignificant compared with the stresses in the neighborhood of the applied load.

At a radius of 60 in (that of the repair cap), x will be 2.33 for an 8-in-thick plate; i.e., $\lambda = 1/\ell = 0.0389$ so that $x = \lambda r = 60 \times 0.0389 = 2.33$. From figure 2 this corresponds to a plate deflection of 0.007 in. This is 15 pct of the maximum deflection (0.0472 in); thus, some influence of the edge boundary conditions will be reflected in the field deflection measurements. Since the repair cap is restrained by the undamaged concrete and the bonding of the resin to this concrete, the field deflections can be expected to be less than those predicted in this analysis. However, even with this edge influence, the model of the infinite plate appears acceptable for the field test and most certainly for larger bomb craters.

PARAMETRIC STUDY

Equations (4) and (5) were used in a parametric study conducted to suggest repair cap thicknesses and resin strengths required for the field test. The values of the variables used in this study were selected more or less arbitrarily so as to suggest parameters and to give an indication of the probable performance of the repair cap. Although the repair cap is a two-layered composite, it was necessary to model it as a homogeneous plate. A more detailed analysis would have required material properties which were not available during the initial stages of this project. Although these could have been obtained, emphasis in the program was placed on demonstrating the usefulness of the repair cap proposed, and thus approximate methods of analyses were considered appropriate.

The first effect studied was that of variations in plate thickness on the maximum flexural stress in the repair cap. The reported stresses were calculated with eq. (5) used to determine the maximum bending moment under the centerline of the load. Equation (5) yields the moment per unit width of the plate, so that the bending stress is obtained by dividing the moment by the modulus of the repair cap ($h^2/6$). A foundation modulus of 200 psi/in was selected to represent the ejecta backfill, and a Young's modulus of 2×10^6 psi was arbitrarily judged to be representative of the repair cap. The result of plate thickness variation is shown in figure 3. The flexural stress varied approximately as the inverse of the thickness cubed.

The second effect studied was that of variations in Young's modulus on the flexural stress. The assumed plate thickness was 12 in and the assumed foundation modulus was 200 psi/in. The result is shown in figure 4. It may be noted that flexural stress is not very sensitive to variations in Young's modulus.

The third effect studied was that of variations in foundation modulus on the flexural stress. The assumed Young's modulus was 2×10^6 psi and the plate thickness was 12 in. The result is shown in figure 5. It is interesting to note that the flexural stress does not vary much with changes in foundation modulus.

Finally, centerline deflection [eq. (4)] versus foundation modulus was studied. A plate thickness of 4 in and a Young's modulus of 2×10^6 psi were used. The result is shown in figure 6.

These preliminary analyses were based on assumed material properties. However, preliminary laboratory test results suggested that an ultimate flexural strength of 1200 psi could be expected for aggregate beams stabilized with epoxy resin. Thus, with a safety factor of 1.5, a plate thickness of 8.75 in would be adequate to support an F-4 aircraft (fig. 3). However, this thickness was increased to 10 in for the field repair cap because the subgrade in the field would probably be softer than that used in figure 3.

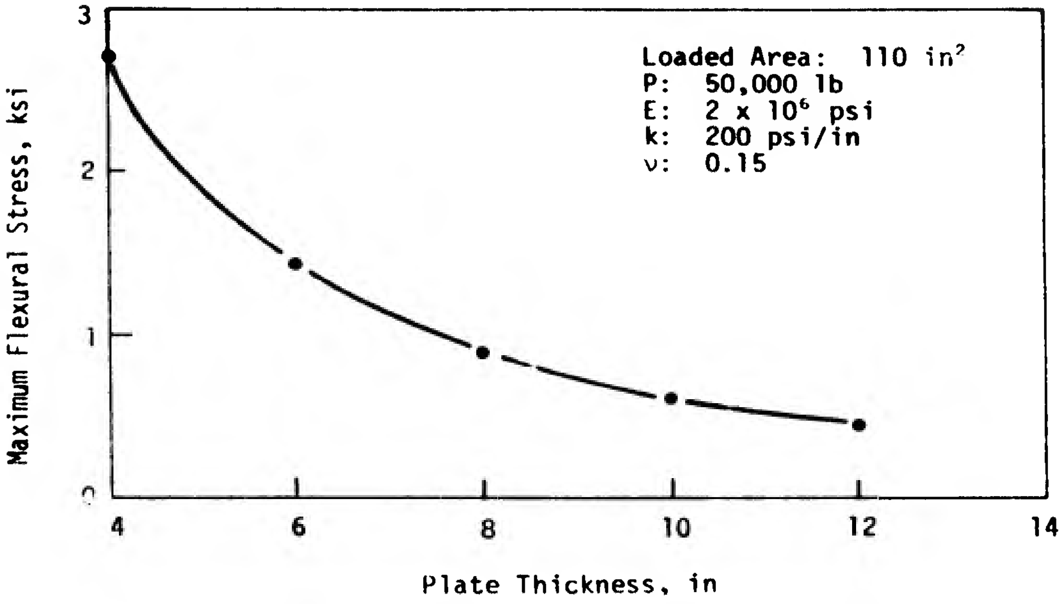

Figure 3. Flexural Stress versus Plate Thickness

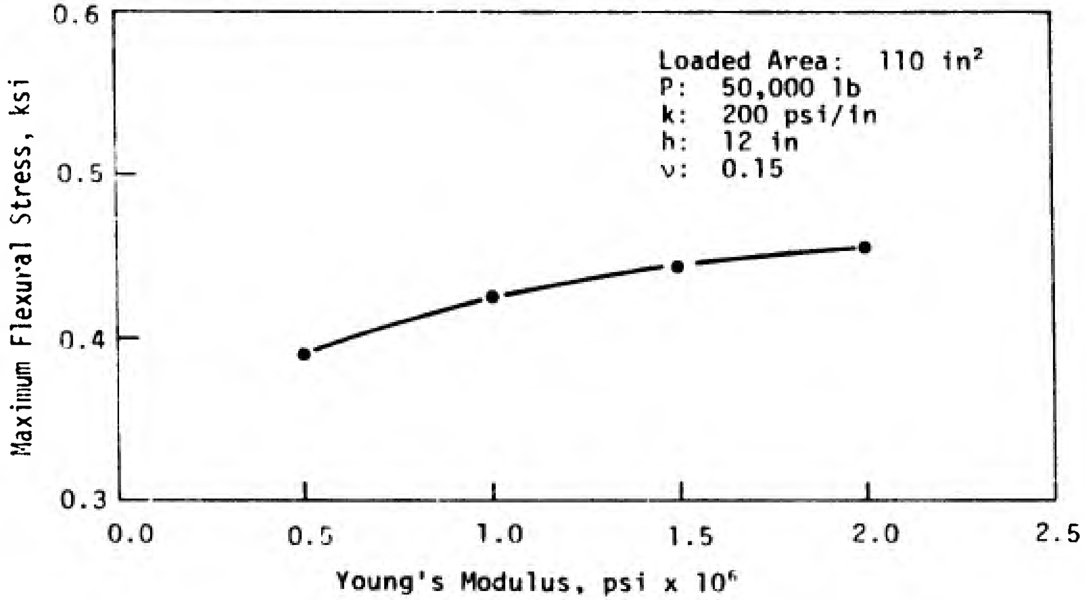

Figure 4. Flexural Stress versus Young's Modulus

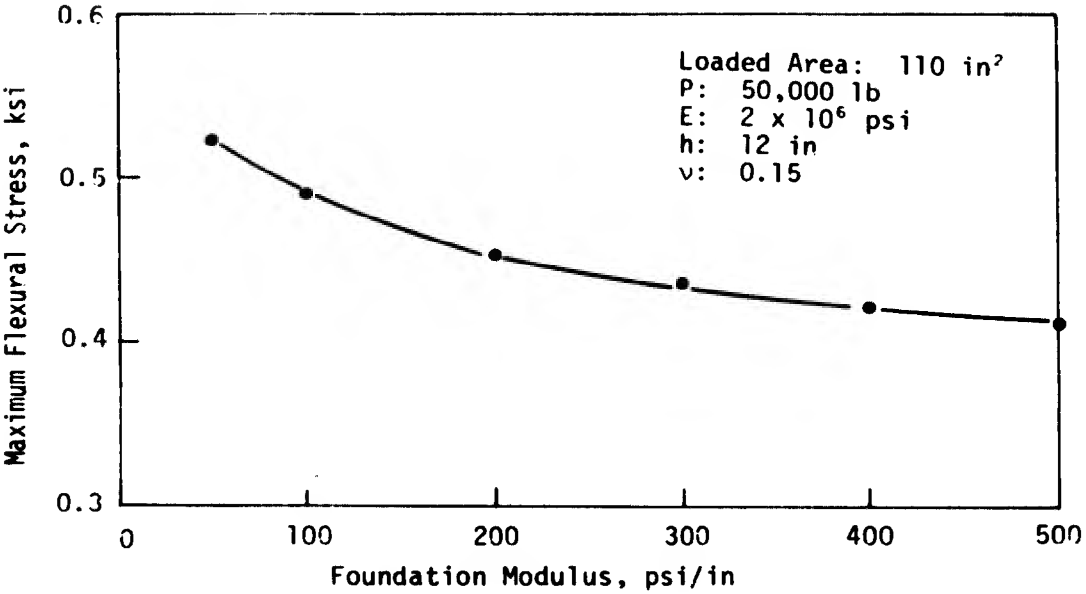

Figure 5. Flexural Stress versus Foundation Modulus

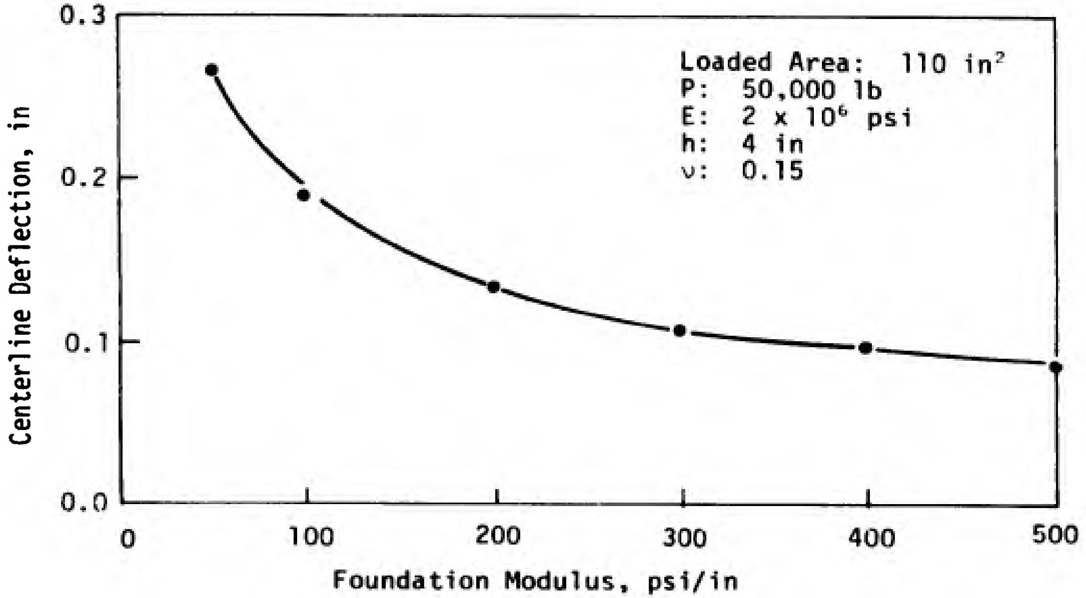

Figure 6. Centerline Deflection versus Foundation Modulus

SECTION 3
LABORATORY TEST PROGRAM

AGGREGATES

Initial laboratory studies using Furane Plastics Epocast 530 were undertaken to establish the aggregate gradation. Three aggregate gradations were investigated in selecting an aggregate blend for the beam tests: a well-graded base material, a uniform fine aggregate, and a uniform coarse aggregate (fig. 7).

The well-graded base material contained about 20 pct fine sand. This fine sand did not allow sufficient or uniform penetration of the liquid binder. The uniform fine aggregate was a washed roofing gravel of 3/8 in maximum size. This gradation contained small particles which also prevented uniform and sufficient penetration. The uniform coarse aggregate allowed uniform and sufficient binder penetration, and thus it was selected for the beam tests. However, any sound, coarse aggregate having a coefficient of uniformity of 6 or less, a maximum diameter of 38.1 mm (1.5 in), and a minimum diameter of 6.35 mm (0.25 in) could be used. Larger aggregates cause excessive surface roughness and grading problems.

Although the uniform coarse aggregate was adequate, much of the liquid binder completely penetrated the aggregate and drained out the bottom. Thus, a cushion was needed on the bottom to prevent the loss of the liquid binder. Three methods were tested. First, a mat of roven woven fiberglass was placed 1/2 in from the bottom. This mat was not soaked uniformly and weak points developed in the plane causing failure at low loads. Second, a filler of Cab-O-Sil was mixed with the Epocast 530 to give high viscosity and fill the voids. This, however, weakened the physical strength of the binder and caused erratic penetration. Third, a sand layer was placed beneath the aggregate. The liquid binder flowed uniformly over the surface of the sand and penetrated the entire layer. Thus, not only was the loss of liquid binder prevented, but flexure strength was developed in this layer.

Because of surface abrasion and shear stresses, the aggregates should be sound and have good abrasion resistance. Thus, to insure that high-quality aggregates

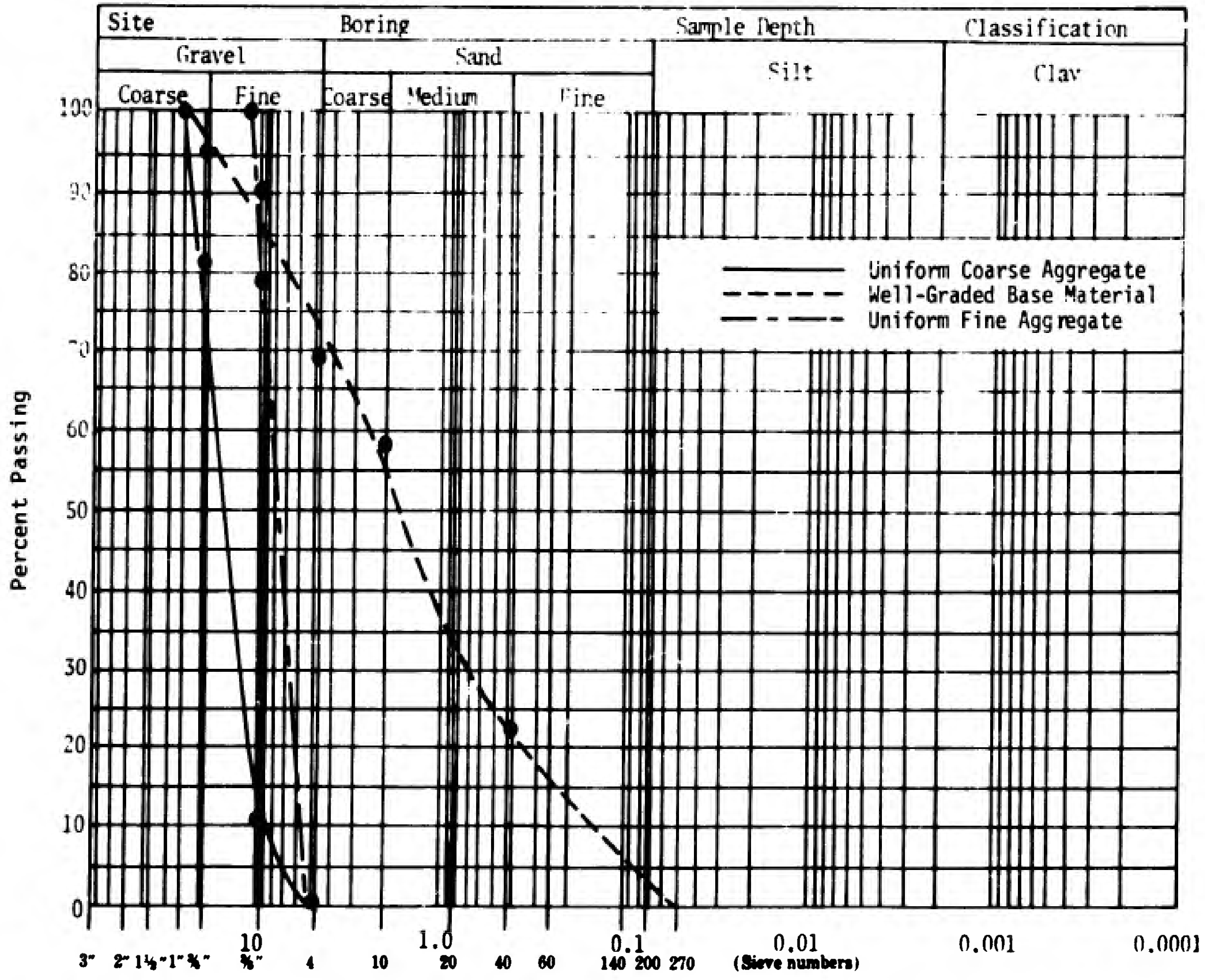

Figure 7. Aggregate Gradations Investigated

are used in field repair situations, it is recommended that the aggregates be . tested for abrasion and soundness. Aggregates should have a weight loss of not more than 40 pct by the Los Angeles Abrasion Test (ASTM C-13). The soundness test (ASTM C-88) should show a weight loss of not more than 12 pct when sodium sulfate is used and not more than 18 pct when magnesium sulfate is used. Any clean, inorganic sand meeting acceptable gradations for a concrete sand (ASTM C-33) is suitable for the sand layer. The gradation of the sand used in this study is shown in figure 8.

LIQUID BINDERS

Four AFWL-proposed liquid binders were to be evaluated as part of this study. These binders and their suppliers are as follows:

(1) Dow Chemical Company
Midland, Michigan
Material: DER 321 or 331 with DER 732 using DEH 39 as catalyst

(2) Emerson and Cuming, Inc.
Canton, Massachusetts
Material: Eccobild RP-10

(3) Phillips Petroleum
Bartlesville, Oklahoma
Material: Petroset RB

(4) Shell Oil Company
Woodbury, New Jersey
Material: Epon 820

The following additional materials were also evaluated in this study:

(1) On-Fast System (polyester resin) developed by Boeing for the United States Marine Corps using PPG Industries, Inc., polyester resin No. RS50214.

(2) Epocast 530--Furane Plastics, Los Angeles, California

(3) XB-2391--3M Company, St. Paul, Minnesota

Of the four liquid binders suggested by AFWL only Eccobild RP-10 and Petroset RB were available for test and evaluation; the products from Dow Chemical and

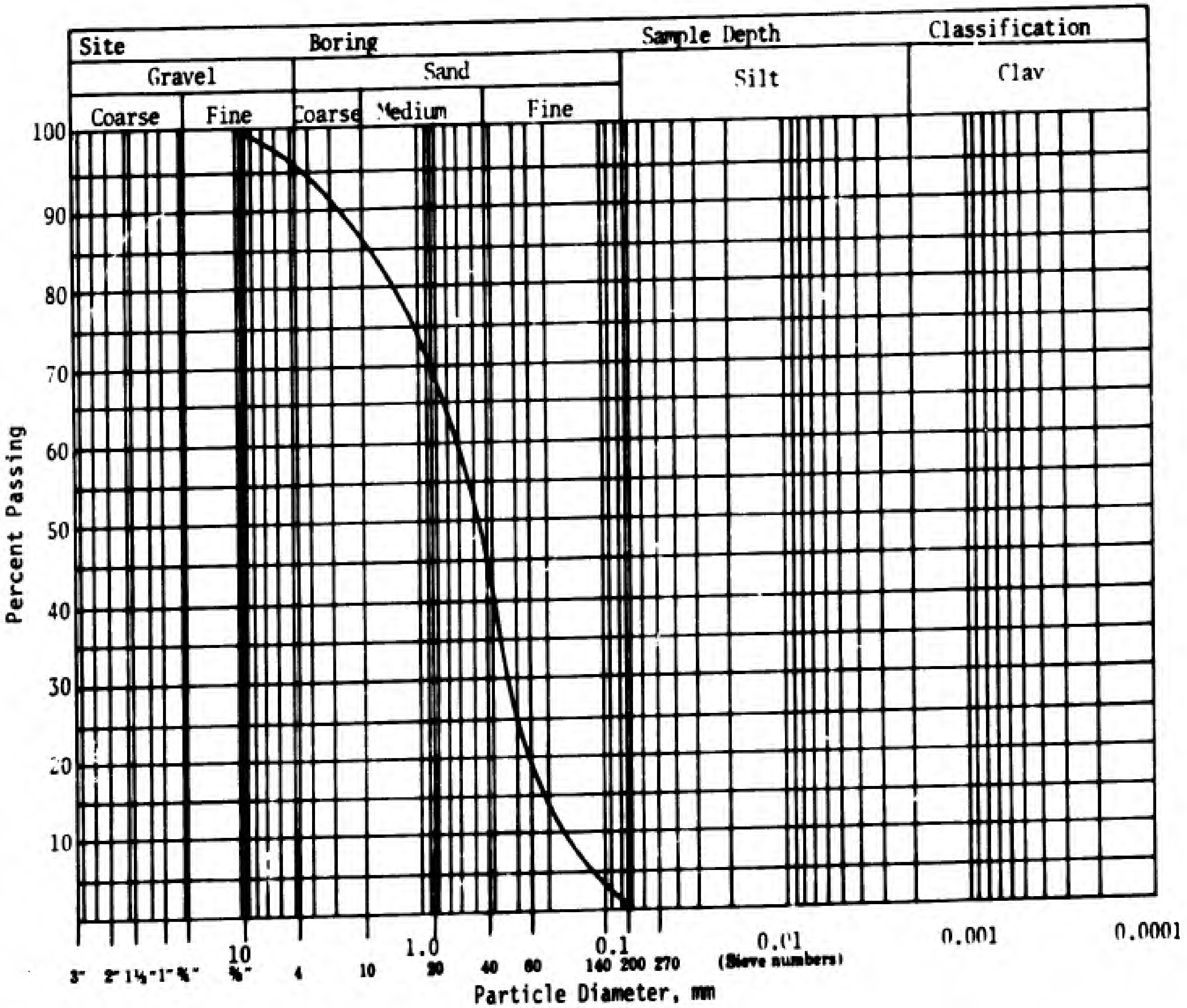

Figure 8. Grain-Size Gradation of Sand Layer

Shell Oil could not be obtained. However, three additional products, XB-2391 manufactured by 3M Company, Epocast 530 manufactured by Furane Plastics, and On-Fast were available and were also used in the test program.

Eccobild RP-10 is a concrete repair kit containing an epoxy resin, a catalyst, and dried graded aggregate. This system compares with Epocast 530 in that both use epoxy resins and obtain adequate flexure strengths. Petroset RB is an emulsified-rubber system which has inadequate flexure strength, and there is no way to increase the strength. XB-2391 is a liquid reactive polymer solution which when applied to soil or rock reacts with soil or air moisture to form a unified, load-bearing surface. However, from laboratory tests, the flexure strength proved to be inadequate. Epocast 530 with 9816 hardener met the criteria for strength and penetration. A brief summary of these four liquid binders is given in table 1. The strengths generated by On-Fast when used as a soil-surfacing agent were thought to be adequate for bomb damage repair (ref. 3) and since the materials needed for a field repair cap were readily available, On-Fast was utilized in the beam tests. On-Fast is a three-part system consisting of a polyester resin (with styrene monomer), benzoyl peroxide catalyst, and dimethyl anailine promoter. When On-Fast is sprayed onto chopped fiberglass, the hardened mat provides a suitable temporary roadway to support amphibious landing operations.

BEAM TESTS

Beam tests are summarized in table 2, and a typical test beam is shown in figure 9. All beams were 6 by 6 by 20 in with 4 in of 3/4-in gravel over 2 in of concrete sand and were tested 20 to 24 hr after fabrication.

Beams used in tests 1, 2, and 3 were fabricated using 1 pct catalyst and 0.25 pct promoter. The binder penetrated the sand 1 in. These beams had flexural strengths of 333, 458, and 405 psi, respectively, and the binder was tacky at

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3. Griffin, Donald F., "Synthetic Surfacing Systems for Soils." *The Military Engineer*, Vol. 65, No. 424, March-April 1973, pp. 79-81.

Table 1. Liquid Binder Test Results

Binder	Description	Penetration	Flexure Strength,* psi	Gel Time, hr	Cure Time, hr	Brookfield Viscosity,** cps	Remarks
Petroset RB	Emulsified rubber solution reacts with previously sprayed-on aqueous ammonia.	Erratic 1 to 3 in	0	12	72	470-570	Emulsified rubber forms fingers in aggregate.
Eccobild RP-10	Two-part epoxy resin with catalyst.	Less than 1 in	1399	2	4		Concrete repair kits. Two gallons epoxy, 100 lb blasting sand.
XB-2391	Liquid reactive polymer reacts with moisture in air and soil to form a urethane bonding material.	Full 4 in thoroughly	250	8-12	24	35 ± 20	Manufacturer provided 5-gallon sample.
Epocast 530 with 9816 Hardener	Two-part epoxy resin with catalyst.	Full 4 in thoroughly	1300	1	2	200-300	The experimental binder used in aggregate gradation selection.

Note: Liquid binder was 10 pct by weight of aggregate, poured using garden type sprinkler can. All specimens were poured at room temperature with aggregates having less than 1-pct moisture content. Specimens consisted of 3 in of 3/4-in maximum size aggregate, except Petroset RB which had 3/8-in maximum size aggregate. All had 1-in-thick sand base with a sheet of polyethylene beneath the sand.

*ASTM C-78.

**ASTM 2669.

Table 2. Beam Test Results (1 of 2)

Test	Binder, % of Total Mix	Catalyst, % of Binder	Promoter, % of Binder	3/4 in Aggregate, kg	Sand		Flexure Strength, psi	Gel Time, min	Cure Time, min	Sand Penetration, in	Remarks
					Type	Weight, kg					
1	10.00	1.00	0.25	13	Concrete	5	333	15	30	1	No aggregate failures; matrix failed in bond.
2	10.00	1.00	0.25	13	Concrete	5	458	15	30	1	
3	10.00	1.00	0.25	13	Concrete	5	405	15	30	1	PML strain gage.
4	13.00	1.00	0.50	13	Concrete	5	375	15	30	1/2	Strength did not increase with 3% increase in binder.
5	13.00	1.00	0.50	13	Concrete	5	360	15	30	1/2	
6	13.00	1.00	0.50	13	Concrete	5	371	15	30	1/2	
7	10.00	1.00	1.00	18			281	10	15	--	1-1/4-in bound rock; thermal cracks.
8	13.00	1.00	2.00	13	Concrete	6	173	5	15	1/4	Thermal cracks developed.
9	13.00	1.00	2.00	13			142	5	15	--	Thermal cracks; 1 in binder.

Table 2. Beam Test Results (2 of 2)

Test	Binder, % of Total Mix	Catalyst, % of Binder	Promoter, % of Binder	3/4-in Aggregate, kg	Sand		Flexure Strength, psi	Gel Time, min	Cure Time, min	Sand Penetration, in	Remarks
					Type	Weight, kg					
10	13.00	1.33	0.25	13	Ottawa	6	489	10	20	1-3/8	
11	13.00	1.33	0.25	13	Ottawa	6	502	10	20	1-3/4	Rock crushed-rock not bonded with fiberglass on top of sand.
12	13.00	1.33	0.25	13	Ottawa	6	--	10	20	1-1/2	Not broken; PML strain gage.
13	13.00	1.50	0.25	13	Ottawa	6	313	10	20	1-1/4	
14	13.00	1.67	0.25	13	Ottawa	6	614	10	20	1	
15	13.00	2.00	0.25	13	Ottawa	6	464	10	20	3/4	
16	13.00	1.67	0.25	13	Ottawa	6	208	1	2	1/2	Bad break; rock heated to 212°F.
17	13.00	1.75	0.25	13	Ottawa	6	269	10	20	1/2	Rock heated to 212°F.
18	13.00	1.00	0.50	13	Ottawa	6	507	15	25	1	
19	13.00	1.00	0.50	32	Ottawa	9	591	15	30	1	5 x 9.5 x 30 in beams.
20	11.43*	1.00	0.50	20	Ottawa	15	412	15	30	2-1/2	5 x 9 x 30 in beams.

*Poured in two batches: 13.3 pct on sand - 10 pct on 3/4-in aggregate - laminated between layers.

Figure 9. Typical Test Beam

the time of the tests. After several days of air drying, the binder fully cured.

To accelerate the cure, the promoter was increased to 0.50 pct for tests 4, 5, and 6. In these beams binder penetration into the sand layer was reduced to 0.5 in. This increase in promoter reduced the gel time and thus penetration into the sand was reduced. This resulted in lower flexural strengths of 375, 360, and 371 psi, respectively. However, the binder was also tacky at test time.

The beam used in test 7 consisted of 6 in of aggregate, no sand, and a binder of 1 pct promoter. This beam had 1-1/4 in of aggregates in a resin matrix, was tacky at test time, and developed a low flexural strength of 281 psi. Extensive thermal cracks appeared in the beam, presumably due to the high percentage of promoter.

Tests 8 and 9 were the final tests in the series. The beams used in these tests had 1 pct catalyst and were fabricated using 2 pct promoter with the standard

4 in of gravel over 2 in of sand. The binder gel time was about 5 min. This resulted in only 0.25 in of penetration into the sand and low flexure strengths of 281 and 173 psi, respectively.

In these nine tests the percentage of promoter was systematically increased in an attempt to accelerate the cure time so as to eliminate tacky binder and increase flexure strength. However, as the percentage of promoter was increased, the gel time decreased so that the binder did not fully penetrate the 2-in sand layer. Thus, the beam strength did not increase as anticipated. Also, at the higher percentages of promoter (1 pct and above) thermal cracks occurred in the hardened binder, and these undoubtedly contributed to the lower flexure strengths, and the tacky feeling of the beams prevailed.

Before continuing the test program, the above results were discussed with personnel at PPG Industries, Inc. They indicated that 0.25 to 0.50 pct promoter is optimum and that the catalyst should be increased. Tests 10 through 16 were thus conducted on beams with 0.25 pct promoter and increasing percentages of catalyst. Because Ottawa sand is more uniform than concrete sand, it was used to permit the binder to penetrate the sand more effectively. As seen in table 2, the flexure strengths and penetration in this test series increased somewhat. However, these strengths were well below the required 1200 psi. Also, all of these beams were tacky at test time but were fully cured after several days of air drying. Other experts advise that polyester resins (On-Fast) are naturally tacky and that complete cure can take several days. It was noted that the styrene monomer in On-Fast (35 pct) is very volatile and causes rapid cooling. This, coupled with the heat-sink characteristics of the aggregates, contributes to the slow curing of the binder. Test 16 was conducted with aggregates heated to 212°F. Note that this beam cured quickly and that only 0.5 in of sand was penetrated. The resin, however, was fully cured but the beam did not fail properly and the test was repeated. This test (test 17) showed only a minor increase in strength. Beams with less catalyst and more promoter were used in tests 18, 19, and 20. This resulted in increased flexure strengths; however, these values were still well below the required 1200 psi.

The extensive testing of the On-Fast system (polyester resin) indicates that polyester resins apparently do not have engineering properties which render the resin useful in this particular application, and that epoxy resins must be used as a liquid binder to meet the strength and cure time required for bomb-damage repair as proposed herein. Polyester resins are reported to be naturally tacky and have relatively poor adhesion to aggregates. The problem of tackiness when the resin comes in contact with aggregates is aggravated because the rock acts as a heat sink and retards the curing of the resin. Increasing the percentage of promoter does not improve this problem because thermal cracking occurs when the promoter approaches the 2-pct level. These cracks greatly reduce the flexure capacity of the resin/sand matrix and thus have a negative effect in terms of improving the engineering properties of the stabilized cap.

SECTION 4
FIELD TEST PROGRAM

CONSTRUCTION OF STABILIZED REPAIR CAP

A prototype repair cap was evaluated in the field. An 8-in-thick Portland cement concrete pavement which was formerly used in a weapons penetration study (ref. 4) was repaired. This pavement, located at the CERF facility, had been subjected to a blast created by 15 lb of C-4 explosive placed 84 in below the surface of the concrete. This blast destroyed the pavement and created a shallow crater with a surface area of about 100 ft^2 (fig. 10).

The crater was excavated to a depth of 5.5 ft to simulate a bomb crater. The walls of the crater were naturally deposited silty sand with an in-situ density of 123 pcf at an average moisture content of 8 pct. The crater was backfilled with a local material known as *McCormick Ranch silt* (fig. 11). This silt has the following properties:

Sand	40%	Liquid Limit	22%
Silt	37%	Plastic Limit	14%
Clay	23%	Specific Gravity	2.72

The silt was dumped into the crater in 12-in lifts, which were spread and lightly compacted to within 16 in of the top of the concrete rim. The in-situ CBR of the silt was estimated using the airfield penetrometer. The average in-situ CBR, determined from 120 readings, was 6 (values ranged from 1 to 10). Four inches of concrete sand was placed on top of the silt, and 12 in of 3/4-in gravel was placed over the sand to the top of the concrete rim. Before placing the gravel layer in the crater, polyester-embedded strain gages were placed just below the surface of the sand layer. The gage layout is shown in figure 12. The three gages shown in vertical alignment were directly under the center

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4. Cassino, Vincent, and Chavez, David J., *Effect of Pavement Design on Cratering Damage from Penetrating Weapons*, AFWL-TR-74-197, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico (to be published).

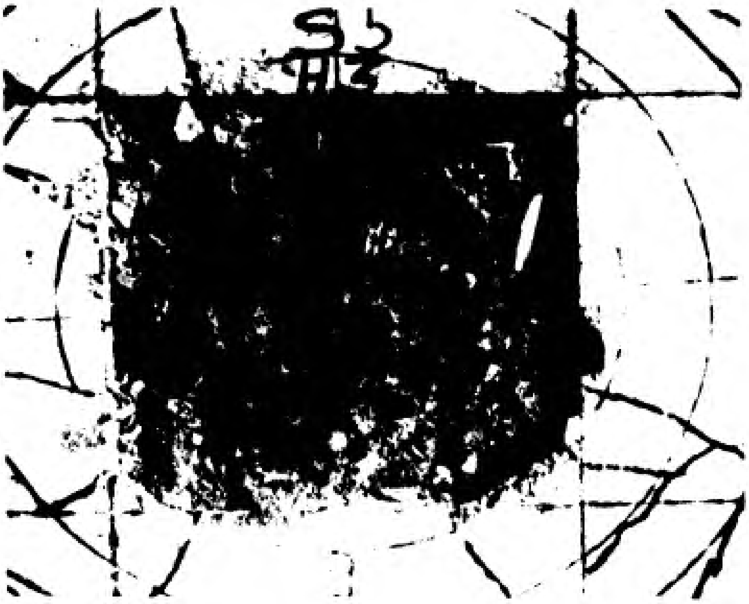

Figure 10. Crater to be Repaired

of the load path. Both sand and gravel were simply dumped into the crater and spread to a uniform thickness. Compaction consisted only of the foot traffic of the field personnel in spreading the materials. Figure 13 shows the backfilling application and figure 14 shows the completed backfilled crater before application of the liquid binder.

Furane Plastics Epocast 530 with 946 hardener* was used as the liquid binder. This binder was hand mixed in steel barrels in 4:1 proportions (epoxy to hardener) and then transferred into 5-gallon pails and poured onto the gravel surface which was sectioned into quadrants. Each quadrant was treated sequentially with its full predetermined weight of liquid binder (10 pct by weight) by simply pouring the liquid uniformly over the surface. Weather conditions on the day of placement were sunny with an 84°-F maximum temperature and a slight wind.

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*This is a modified 9816 hardener designed for faster cure time (10 to 15 min).

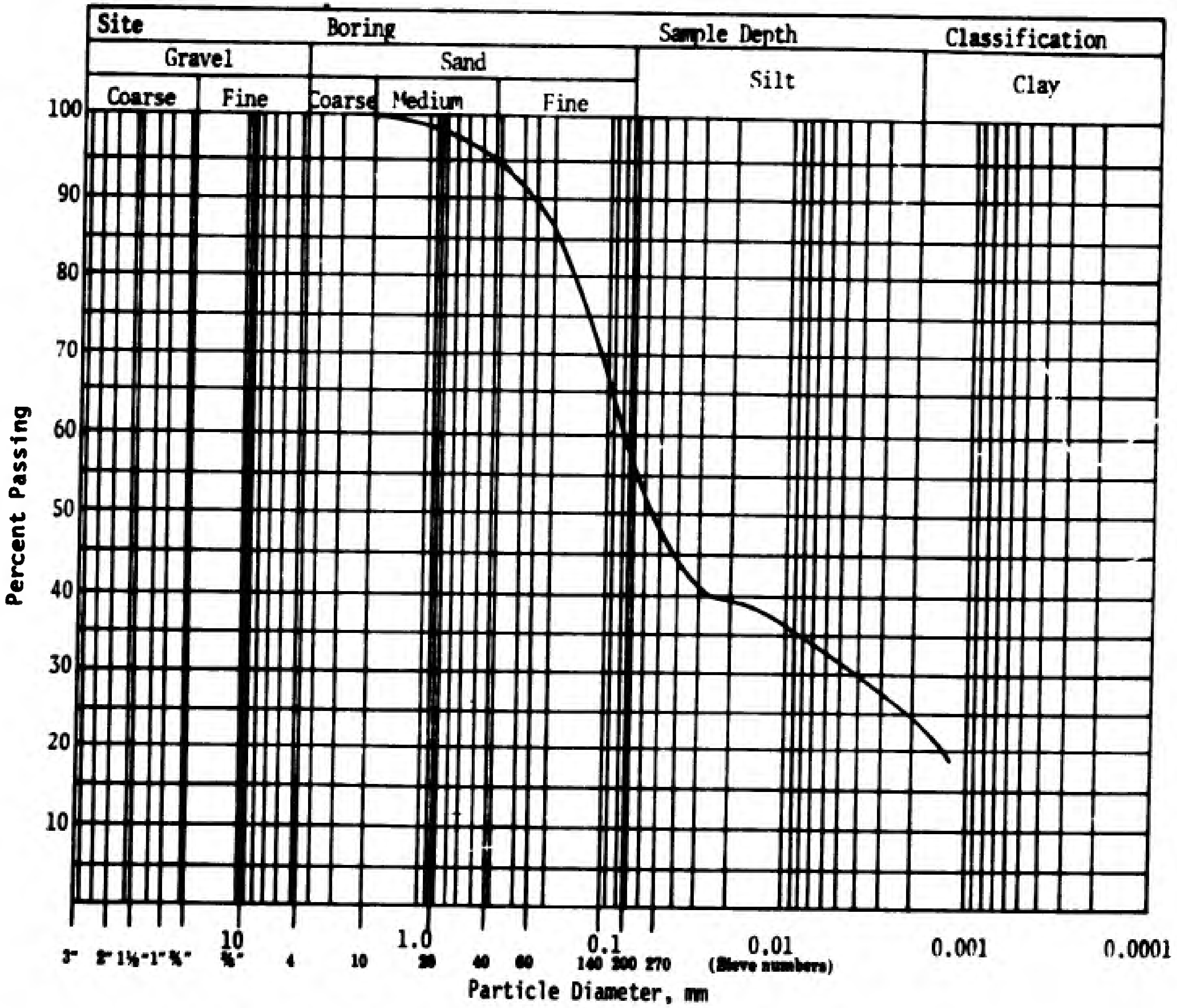

Figure 11. Grain-Size Gradation of McCormick Ranch Silt

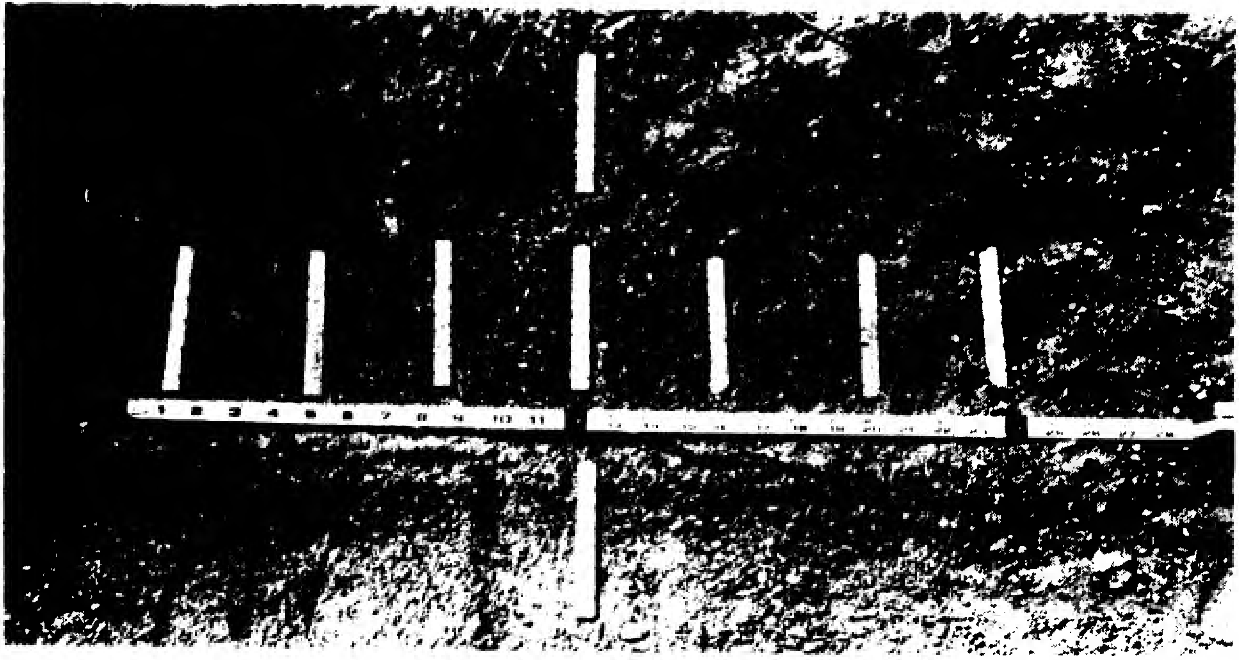

Figure 12. Strain Gage Layout in Repair Cap

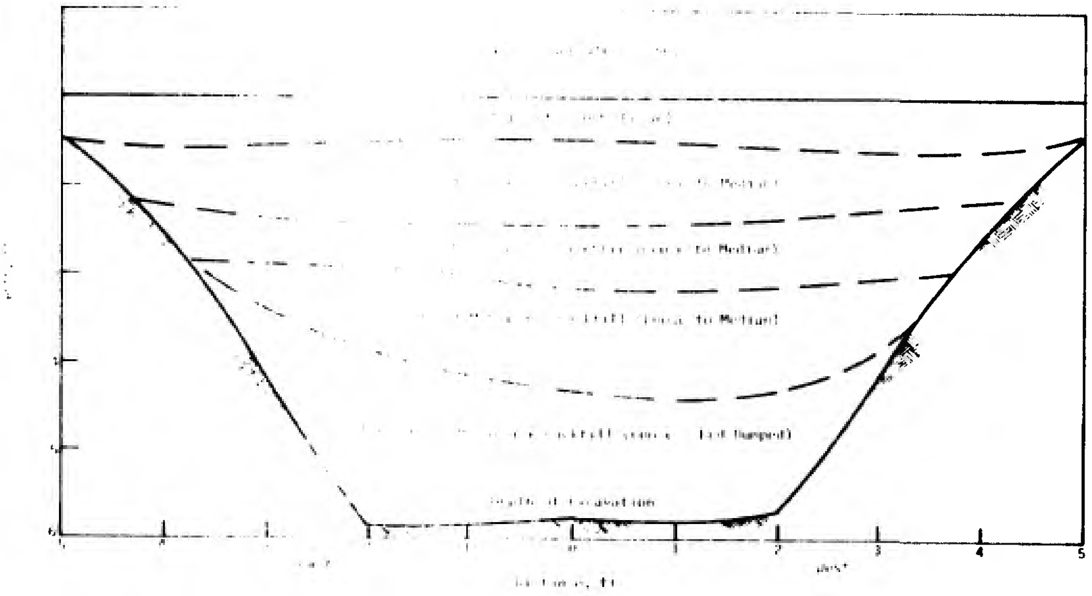

Figure 13. Crater Backfilling Technique

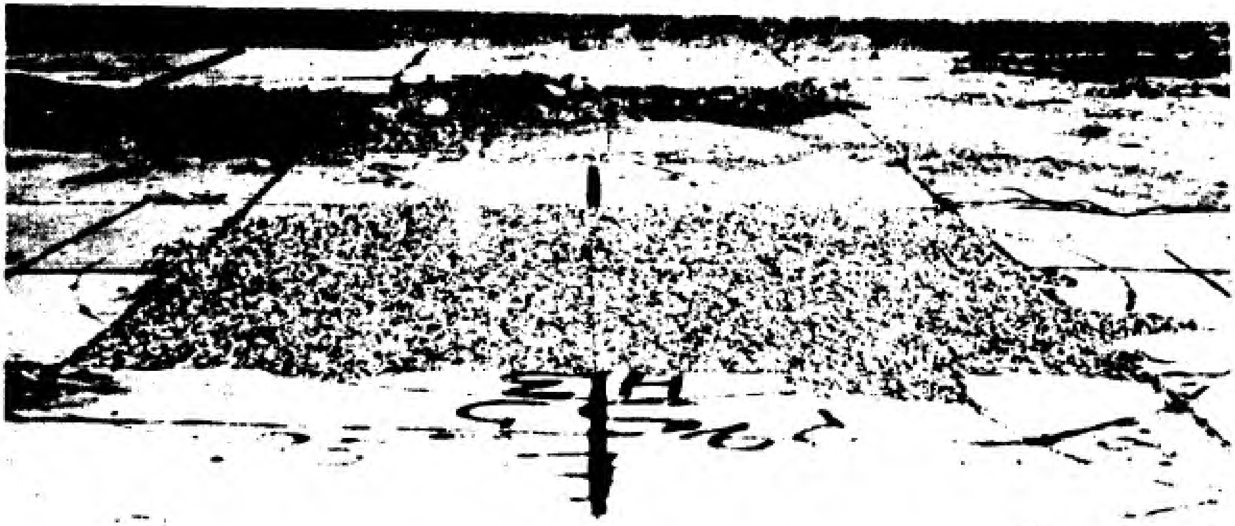

Figure 14. Completed Backfilled Crater

Cores taken from the cap after it had been trafficked (fig. 15) revealed that the binder penetrated the sand layer about 1 in and that the bottom 3 in of gravel were fully saturated with the binder. Thus, the gages were essentially fixed to the lower surface of the stabilized cap, and the strain measurements taken would indicate the extreme bending strains (tension) in the gravel. Field test specimens taken during the pouring operations indicated a 10- to 15-min cure time for the neat resin. However, cure time for the aggregate/resin system can be expected to be somewhat longer than for the neat specimens because the aggregates serve as a heat sink and thus retard the curing. Two test beams fabricated during the pouring operations were ready for testing on the afternoon of the same day they were formed. These beams failed, one at a flexure strength of 1440 psi and one at 1375 psi.

LOAD EVALUATION

The stabilized repair cap was trafficked with an F-4 tire mounted on the CERF load cart (fig. 16) on the day after the binder had been poured. The tire

Figure 15. Core Sample from Repair Cap

pressure was 280 psi and the total load supported by the single wheel was 30,500 lb (cart capacity). Surface deflection measurements under this load were taken along the traffic path and along a line perpendicular to the path of the tire. Surface deflections were also measured at the same points with the load removed from the cap so as to evaluate any permanent displacement of the repair cap. Surface deflection measurements were made with a rod and

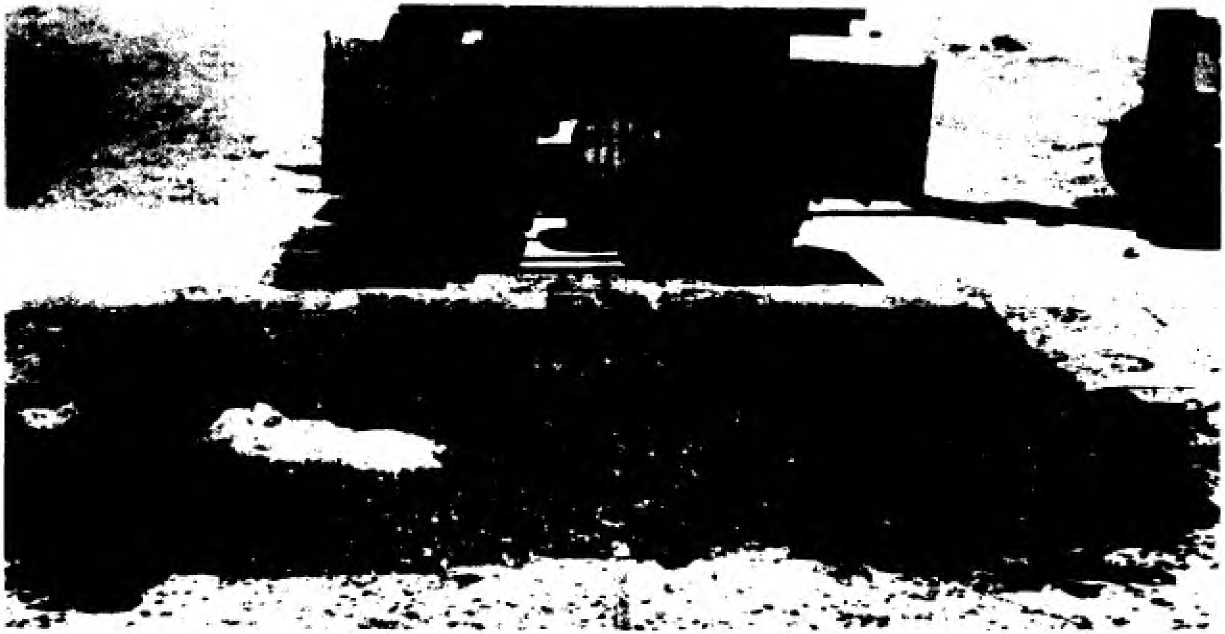

Figure 16. Load Cart Trafficking Repair Cap

level, reading to the nearest 0.01 ft. The cap successfully withstood 100 passes of the load cart without any visible or measurable signs of distress, and no measurable deflections, either under load or permanent, were revealed. The surface of the cap raveled somewhat, but the effect was beneficial in that the traffic path was smoothed; surface aggregates were either crushed or split and poorly bonded surface aggregates were broken away.

An attempt was made to determine the load capacity of the repair cap by performing a plate-bearing test. A 12-in-diameter plate was loaded to 43,000 lb. This resulted in a deflection of 0.125 in. A second load cycle of 50,000 lb produced a slightly larger deflection. No visible distress was observed at these load levels. No further testing on the 12-in-diameter plate was performed since the limit of the equipment had been reached. A similar test on a 3-in-diameter plate showed a deflection of 0.14 in with no distress when the reaction capacity of the cart (54,000 lb) was reached.

Recorded strains were consistent with the deflection data in that the strains did not significantly increase as the number of load cycles approached 100.

The maximum strain recorded by the center gage was 191 μin/in on the 75th pass. The minimum strain recorded by this same gage was 144 μin/in on the 3rd pass. Most of the variation in strain was attributed to the location of the surface load rather than to material fatigue.

SECTION 5
CONCLUSIONS AND RECOMMENDATIONS

The engineering development documented in this report demonstrates the feasibility of using a liquid binder and gravel to temporarily repair the surface of airfield pavements which have been subjected to enemy air attack. The advantages offered by this repair method are as follows:

(1) roughness problems of current AM-2 mats are eliminated,
(2) the repair develops the necessary strength to support aircraft loads,
(3) the repair is easily performed with locally available sand and gravel,
(4) the liquid binder can be applied by spraying or pouring by hand in emergency situations, and
(5) the system is very useful for the repair of small craters.

Potential problem areas include the cost and shelf life of the resin and surface ravelling of the cap.

The particular repair cap field tested (12 in thick) was thicker than that suggested by the structural analysis. However, this was done in an attempt to successfully demonstrate the feasibility of the repair technique proposed. Therefore, the following efforts are recommended in order to design thinner and more economical repair caps:

(1) A laboratory study to determine the elastic modulii, compression, tension, and strain characteristics of sands and gravels stabilized with Epocast 530.
(2) Limited structural analyses to determine required thicknesses of repair caps to support mission aircraft and an optimization study to select the most efficient cross section. Such a study should cover weak subgrades, ejecta backfill, and the position of the load on the repair cap. This latter consideration is important in order to evaluate the assumptions made in this study (section 2) relative to attenuation length.

(3) Field testing and trafficking of the optimum cross sections determined in the above study in order to validate the design procedure.

(4) A laboratory study to determine the fatigue life and impact resistance of binder-stabilized materials in order to predict the useful service period of a repair cap.

(5) A search for less costly binders and an evaluation of these in the laboratory.

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

CBR	California bearing ratio
D	Flexural rigidity of homogeneous plate
E	Young's modulus
L	Radius of plate
M	Moment
P	Total load
a	Radius of loaded area
e	Napierian base
h	Thickness of plate
k	Foundation modulus
kei	Real part of Bessel function of the third kind of order zero (Hankel function)
ℓ	$\sqrt[4]{D/k}$
q	Normal unit loading
r	Spatial coordinate
w	Deflection
β	Argument of kei
λ	$1/\ell$
ν	Poisson's ratio
σ	$\chi/\sqrt{2}$
χ	Attenuation length