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AIR FORCE SOIL STABILIZATION RESEARCH

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ABSTRACT

The Air Force Weapons Laboratory (AFWL) formulated a research program directed toward satisfying Air Force requirements in soil stabilization. Current research includes the establishment of an index system for effective use of soil stabilization methods currently available, development of techniques to better use commonly available additives and techniques to satisfy the rapid construction requirement of advanced mobility concepts. A brief discussion of the current research being conducted by the AFWL is presented.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION I
INTRODUCTION

The US Air Force is required to conduct sustained air operations on a worldwide basis in support of national policy. It must be capable of operating in all geographical areas and climates and can be employed from temporary bases. These bases must permit extended all-weather operations with minimum preparation and minimum reliance on fixed permanent facilities. Present-day, conventional soil stabilization systems do not satisfactorily meet these support requirements for planned mobility posture. Present methods of stabilizing soils are time-consuming and logistically burdensome, rarely compatible with air transport, and not suitable or effective for the wide range of soil conditions anticipated in short or sustained worldwide operations. An improved soil stabilization system must be developed to support the rapid mobility requirement of the Air Force.

A soil stabilizing system capable of satisfying the following requirements is required.

a. The system should be suitable for controlling soils ranging from OH (organic clays of medium-to-high plasticity or organic silts) to GP (poorly graded gravels or gravel-sand mixtures with little-to-no fines). A single pass capability is preferred, but is not required.

b. Equipment and techniques must be developed for applying the stabilization control system quickly and easily.

c. Equipment must incorporate standardized components to the maximum extent, capitalizing on modular replacement of assemblies and subassemblies; have improved reliability through the simplification of components and techniques; and permit rapid repairs to be made in the field by normally trained technicians with a minimum requirement for complex tools.

d. Only simple preparation of soil and any required materials should be incorporated in a stabilization system using additive materials.

e. Any system requiring soil additive materials should be effective when applied in quantities weighing not in excess of 4 psy (as an objective).

f. Stabilized areas should be trafficable within minimum time after control application, preferably within 2 hours.

g. The system should be air transportable in C-130 type aircraft and adaptable to other acceptable aerial delivery systems.

h. It must be noncorrosive and otherwise non-injurious to aircraft and personnel.

i. It must be resistant to jet blast and propeller wash.

j. It must maintain effectiveness for at least 30 days with only minor maintenance required.

k. It must be suitable for soil control application in a wide range of temperatures from -25°F to +125°F and must resist freezing, thawing, and high or low-temperature deterioration.

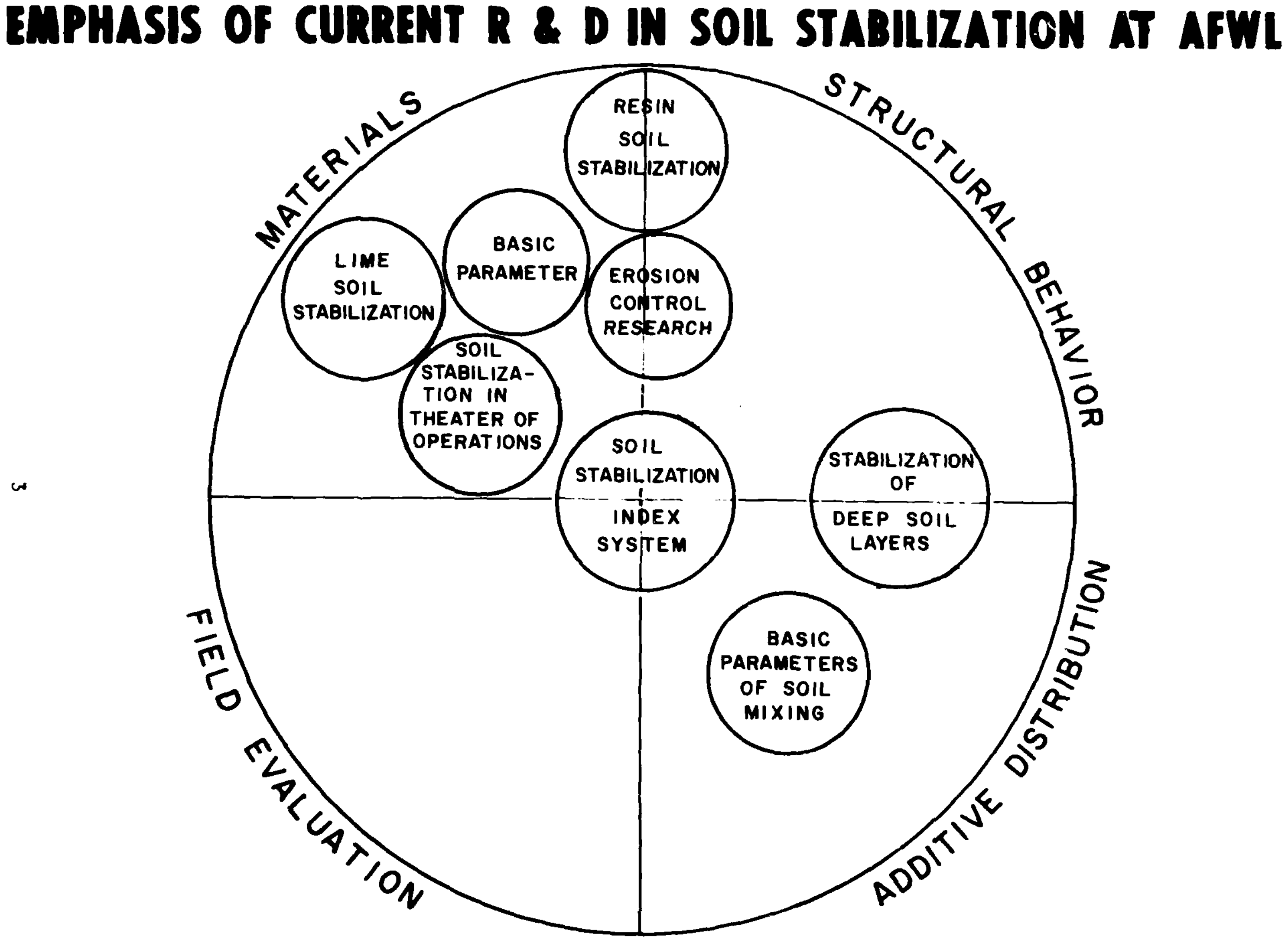
l. Required soil additive materials for a system using such materials must be suitable for storage at temperatures of -25°F to +160°F with a shelf life of 10 years.

m. The system should increase and maintain the load-bearing capacity of the soil to sufficiently support the aircraft and vehicle loads normally experienced at operational air bases.

n. The new system will reduce requirements for matting, membrane surfacing, and construction equipment, which in turn, will create savings in material, manpower, shipping, and logistic support.

o. Materials, techniques, and equipment must be compatible with user requirements and capabilities.

During the past several years, the Air Force Weapons Laboratory (AFWL) has been working toward meeting these requirements. As recommended in the 1968 *Soil Stabilization Review* (summarized in Section II), a well-rounded research program addressing materials, structural behavior, additive distribution and field evaluation must be completed to develop a satisfactory soil stabilization system. Figure 1 shows current research emphasis. As can be seen, work is heavily oriented toward materials and construction. Field evaluation and structural behavior are research gaps which must be closed in the future.



Emphasis of Current R&D in Soil Stabilization at AFWL
Figure 1

SECTION II
1968 AIR FORCE SOIL STABILIZATION REVIEW*

In 1968, a review was held at Kirtland AFB, New Mexico, under the direction of the Eric H. Wang Civil Engineering Research Facility (CERF). The objective of the seminar was to review Air Force operational requirements in soil stabilization, to assess current research sponsored by the Department of Defense in soil stabilization, to identify those areas in which the technology is not available to satisfy Air Force operational requirements, and to make recommendations as appropriate.

The operational requirements of the various services were found to be very similar. The Air Force stated requirements were for a soil stabilizing system capable of stabilizing all soils, under adverse environmental conditions, capable of supporting both vehicular and aircraft traffic using a minimum amount of simplified equipment, in a short period of time, with minimum logistical requirements. Present systems were defined as being time consuming, logistically burdensome, rarely practical for air transport, and not suitable or effective for the wide range of soil conditions encountered during Air Force operations.

Air Force research and development activities were found to be heavily oriented toward materials with little coordination with structural behavior. Also, only limited activity exists in the areas of construction and field evaluation. Future R&D programming appeared broader and more comprehensive. A systematic approach was recommended to formalize and integrate current and future research needs and objectives.

The use of the systematic approach would simplify R&D planning, programming, and coordination; provide continuous review and updating of current and proposed R&D; facilitate information collection, storage and retrieval. Thus, application of R&D findings would be accelerated, unintentional R&D duplication would be eliminated, and more accurate and specific delineation of R&D needs would result.

Figure 2 shows a flow diagram for the proposed systematic approach. The various subdivisions are identified in Table 1. The approach is utilized by proceeding through the diagram until the flow in interrupted. At this point, an evaluation check is performed on a major research area preceding in accordance with Figure 3.

Results of the evaluation check would be incorporated into Figure 2 and the procedure repeated. This would be continued until an acceptable solution

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* For a more detailed discussion, see AFWL-TR-69-128, "Proceedings Soil Stabilization Seminar" dated November 1969. A brief summary of the seminar is provided therein. In preparing this summary, information has been freely extracted from the above reference.

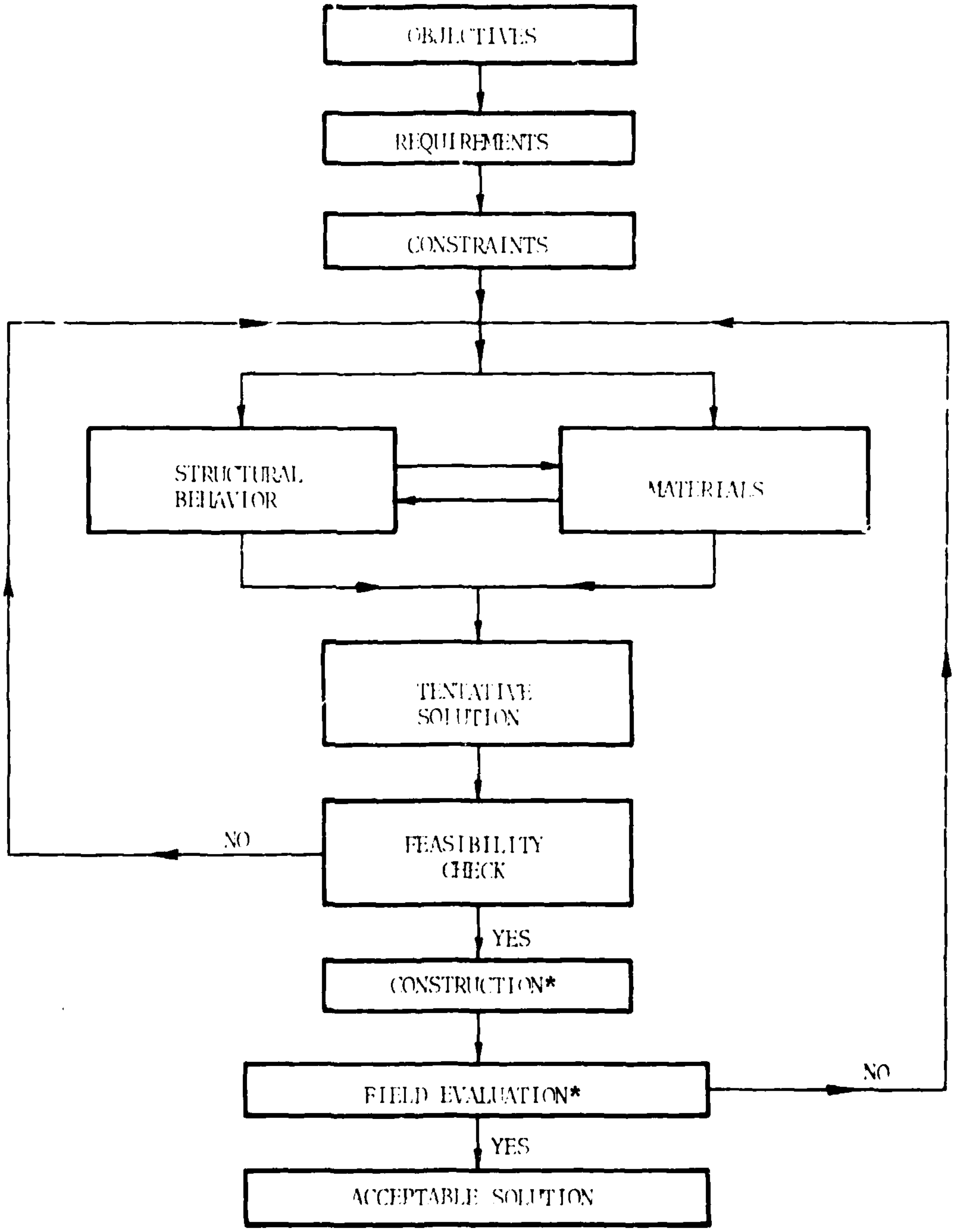


Figure 2. Systematic Approach to Soil Stabilization

Table 1
TYPICAL SUBDIVISIONS OF SYSTEM COMPONENTS

OBJECTIVES

1. Erosion Control
2. Dust Control
3. Structural Improvement
4. Other

REQUIREMENTS

1. Design Life
2. Traffic
3. Environmental Conditions
4. Other

CONSTRAINTS

1. Logistics
2. Time (Construction and Curing)
3. Construction Capabilities
4. Economics
5. Other

STRUCTURAL BEHAVIOR (Includes pavements, thin surface membranes, and landing mats)

1. Pavement Behavior
2. Loading Considerations
3. Environmental Influences
4. Pavement Design - Design Criteria
5. Other

MATERIALS

1. Soils: site evaluation; classification and identification (mineralogy, physicochemical, etc.); distribution and occurrence; engineering properties; other
2. Stabilizers: classification (waterproofers, dust proofing, cementing, etc.); composition; pertinent characteristics (toxicity, pot life, powder-liquid, etc.); engineering properties; other
3. Soil-stabilizer system: soil-stabilizer interaction (type of stabilizer, secondary additives, curing conditions, etc.); engineering properties of stabilized materials (strength-elasticity, durability, dimensional stability, etc.); construction-associated problems (incorporation of stabilizer, blending, mixing, compaction, etc.)
4. Mixture Design: testing procedures, quality criteria; other

CONSTRUCTION

1. Equipment Development (mixing, compaction, etc.)
2. Techniques and Procedures
3. Critical Construction Factors
4. Specifications - Quality control
5. Environmental Influences
6. Other

FIELD EVALUATION

1. Testing Techniques, Procedures, and Measurements
2. Analysis and Interpretation
3. Performance
4. Other

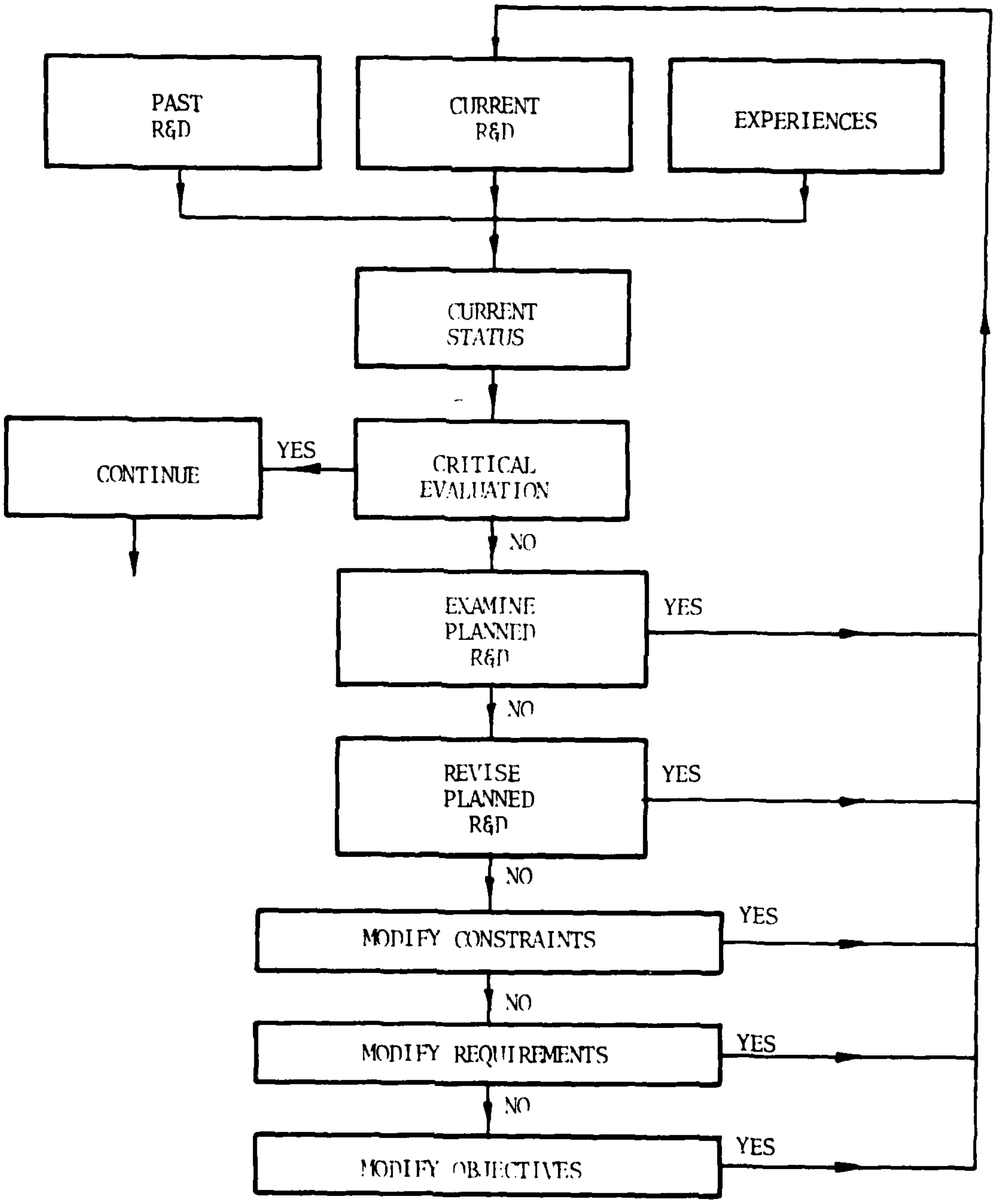


Figure 3. Systematic Approach Evaluation Check

is obtained based upon criteria. Improvement in the solution can be accomplished by making the criteria more severe.

In summary, the various operational requirements and R&D objectives of the various military services are similar. A joint requirements document endorsed by all service branches is required. The requirements stated in the Air Force TAC ROC summarized in Section I are valid technical requirements and are not beyond attainment. Areas in which immediate research is required are mixing equipment, structural behavior of stabilized materials and construction and field evaluation. A systematic approach is needed to identify research requirements and to integrate the research efforts of the various services.

SECTION III
BASIC PARAMETERS OF SOIL STABILIZATION

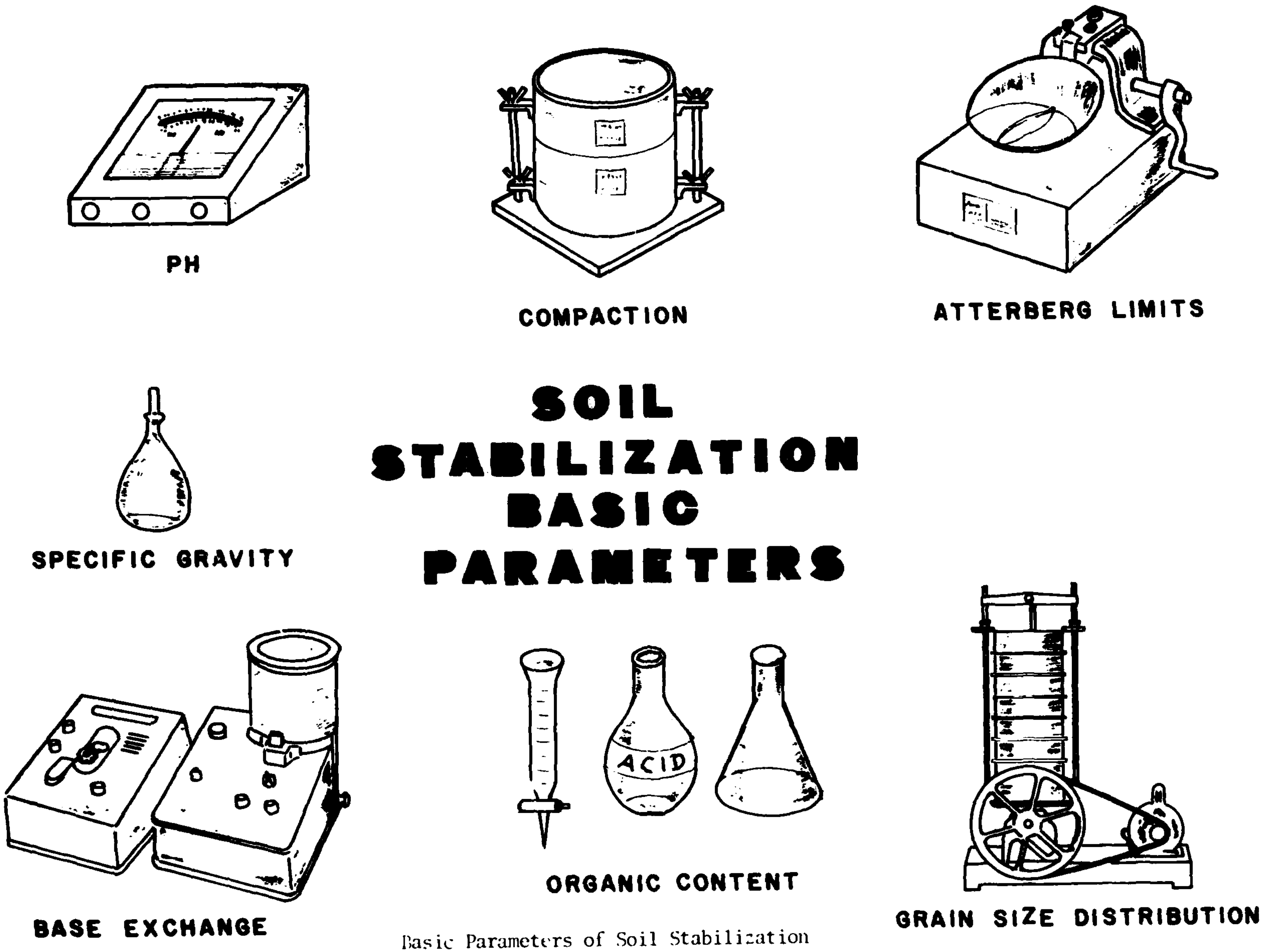
Before any method of soil stabilization can be utilized, the nature of those basic physio-chemical parameters active in soil stabilization must be ascertained. Also, in order for a military engineer to utilize a certain soil stabilization technique, that person must first be able to define the problem, and then utilizing the basic physio-chemical parameters and others such as time, equipment, and material available, select the correct stabilization technique to use.

Considerable conventional soil stabilization work has been performed by various DoD agencies, industry, and universities; however, if soil stabilization technology is to be significantly advanced, more basic investigations into the physical, chemical, and mineralogical properties of soils are required. Figure 4 gives a partial listing of these parameters.

Thus, the purpose of this project is to define and investigate the basic physio-chemical parameters that influence the stabilization and strengthening of natural soils when various admixtures are incorporated. Once these parameters are defined, they can be utilized as a basis for developing new and improved stabilizers and stabilization techniques that will provide more effective and economical methods for the stabilization and strengthening of natural soils.

In the initial phase of this research, a survey and analysis was made of previous soil stabilization work which attempted to define basic parameters. From this summary, the apparent basic parameters which influence the improvement in soil properties were identified. Areas where more basic soil stabilization research was needed were also identified. In the second phase of research, a theoretical analysis was made of the problem areas. This theoretical analysis hopefully would tell us why certain soils were difficult to stabilize with certain additives. Those parameters which were determinant were identifed. Along with the theoretical analysis, a laboratory verification program was carried out to actually determine if indeed certain factors were controlling the behavior of the soil stabilization system.

Laboratory investigations were accomplished on five soil types; a kaolin, a lateritic clay from Panama, an expansive clay from Texas, an organic clay from New York, and a fine, well-graded sand. Five types of stabilizing agents were employed in this study. They were aniline-furfural, cement, asphalt lime, and lime-cement mixture. To determine material behavior, standard tests such as freeze-thaw cycles, wet-dry cycles, and unconfined compression were utilized. Laboratory tests were conducted to determine the influence of parameters such as pH, base exchange capacity, organic matter content, gradation, compaction, specific gravity, liquid and plastic limits, etc. At present, this program is nearly complete, with only a small amount of the laboratory verification tests to be done.



Basic Parameters of Soil Stabilization
Figure 4

This research will provide the basis for establishment of an Index System for soil stabilization. The establishment of basic parameters which govern the behavior of stabilized materials is essential to the success of such a system. This system is discussed in Section IV.

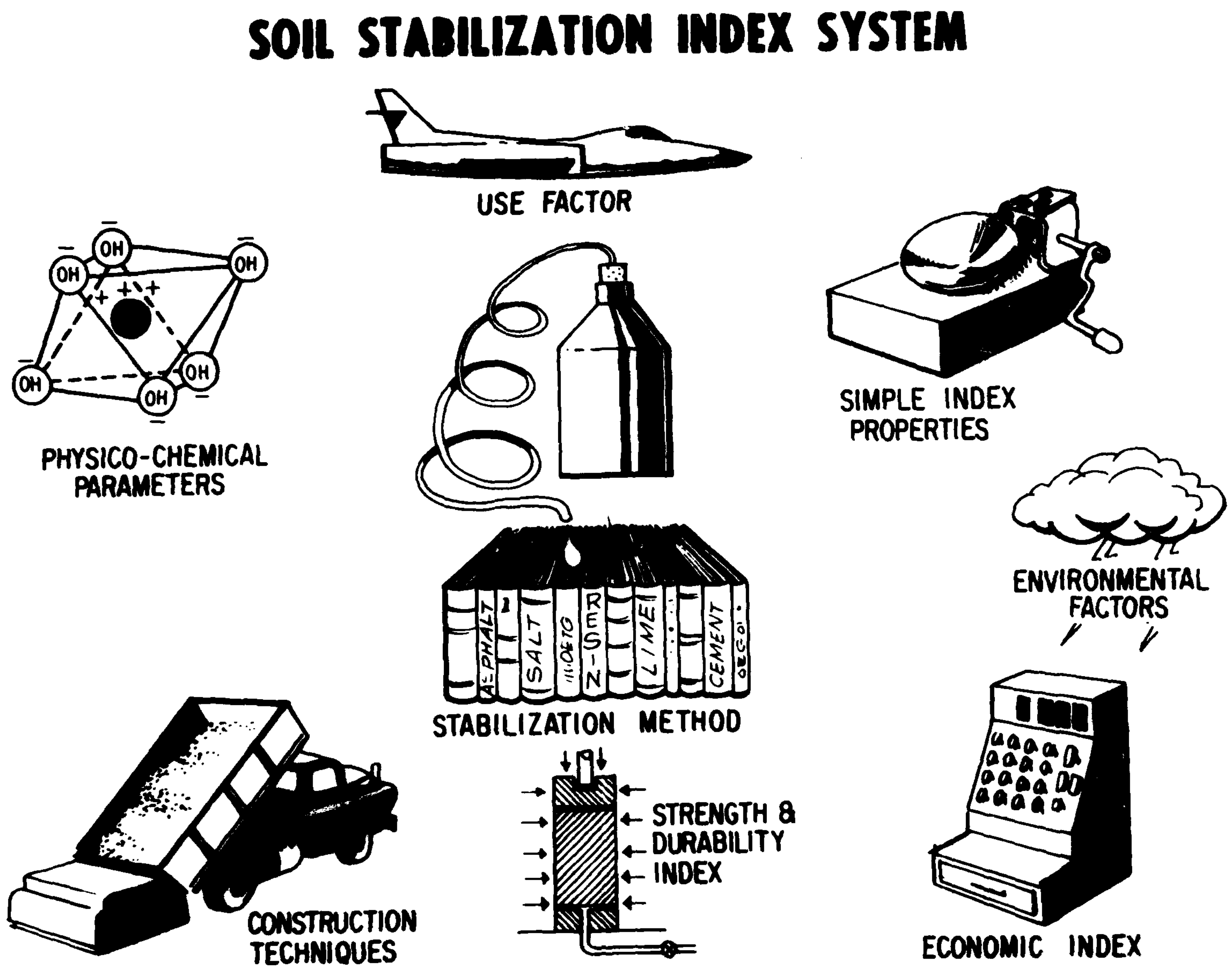
SECTION IV
SOIL STABILIZATION INDEX SYSTEM

There exists today a wealth of information on soil stabilized materials, the structural behavior of stabilized soils, construction of stabilized pavement layers, and field evaluation of the behavior of these layers. The establishment of this data was prompted by the attractive benefits to be gained in using this powerful engineering tool. Although this raft of information is available, it is often difficult to locate and use adequately. Attempts have been made to correlate this data into a meaningful system. The attempts which have been made specify the soils in very general terms with no mention of their physio-chemical properties. Also, the majority of the research to date has been on commonly occurring soils; thus, engineers very often have no basis for predicting the gross benefits to be gained from soil stabilization when dealing with uncommon soils. The mobility concept of the Air Force does not allow an extensive evaluation of each soil it contacts throughout the world before the soil can be used for supporting a pavement for aircraft and vehicular traffic.

An index system is required which the military engineer can use in evaluating the benefits of stabilization techniques in a rapid manner. The engineer will enter the system with soil properties, use factors, and environment factors (see Figure 5). The system will consider construction potential and economic considerations in the process of arriving at a recommendation of the best stabilizer to use and possible alternatives. In essence, the system will contain all useful knowledge in soil stabilization in such a form that it can be effectively used by the military engineer who normally does not have extensive training in soil stabilization techniques.

The first stage in this effort to establish an index system will be to develop use and environmental factors. Concurrently, the critical basic soil parameters of soil stabilization will be defined using the results of Princeton University's contract in which the basic parameters were identified. It is not intended to restrict the soil parameters to those being identified by Princeton University or to ones easily determined and familiar to the civil engineer. Otherwise, it is possible that significant parameters may be omitted. It is always easier to eliminate parameters which are not significant, or even to develop special test equipment to determine important parameters, than it is to develop the index system with insufficient or insignificant parameters which would surely result in failure of the system in the initial phases.

The next stage will be to collect the information regarding soil parameters, use factors, environmental factors, and construction procedures. The information collected will be limited to asphalt, cement, lime, and mechanical stabilization. In addition to the available published literature, personal visits are being made to knowledgeable personnel in the producer, consumer, contractor, and special interest (universities, and research institutes) groups. The producer group will include such organizations as the Asphalt Institute, Portland Cement Association, and National Lime Association.



Soil Stabilization Index System
Figure 5

The consumer group largely consists of highway departments, divisions of the Federal government, and private industry. Information will also be collected on foreign soils in order that the resulting index system can be used on a worldwide basis. The information shall be coded and computerized.

Soils will then be divided into groups based on their basic parameters, and the most suitable stabilizer(s) for each group determined. The suitability will be based on both use and environmental factors. A statistical approach will be used in treating the data collected. Construction techniques and economics will enter the picture after consideration of the use and environmental factors has been made.

The final result of the first stage will be a chart or graph into which the selected soil parameters, use factors and environmental factors can be entered to determine the most favorable types of stabilizers. Gaps in the index system and incomplete information required to finalize the index system will be identified.

In stage two, at least one typical soil from each group will be tested in the laboratory to perform final validation of the system. The basic soil parameters needed to enter the system will be determined, followed by the physical testing. The more or less typical tests, such as freeze-thaw, wet-dry, etc. will be performed.

A repetitive load test on specimens in which the environment is varied is considered to be a more realistic test. While being subjected to repetitive loading, a specimen can be alternately frozen and thawed, or wetted and dried, to closely simulate field conditions. The feasibility of using such a test shall be investigated.

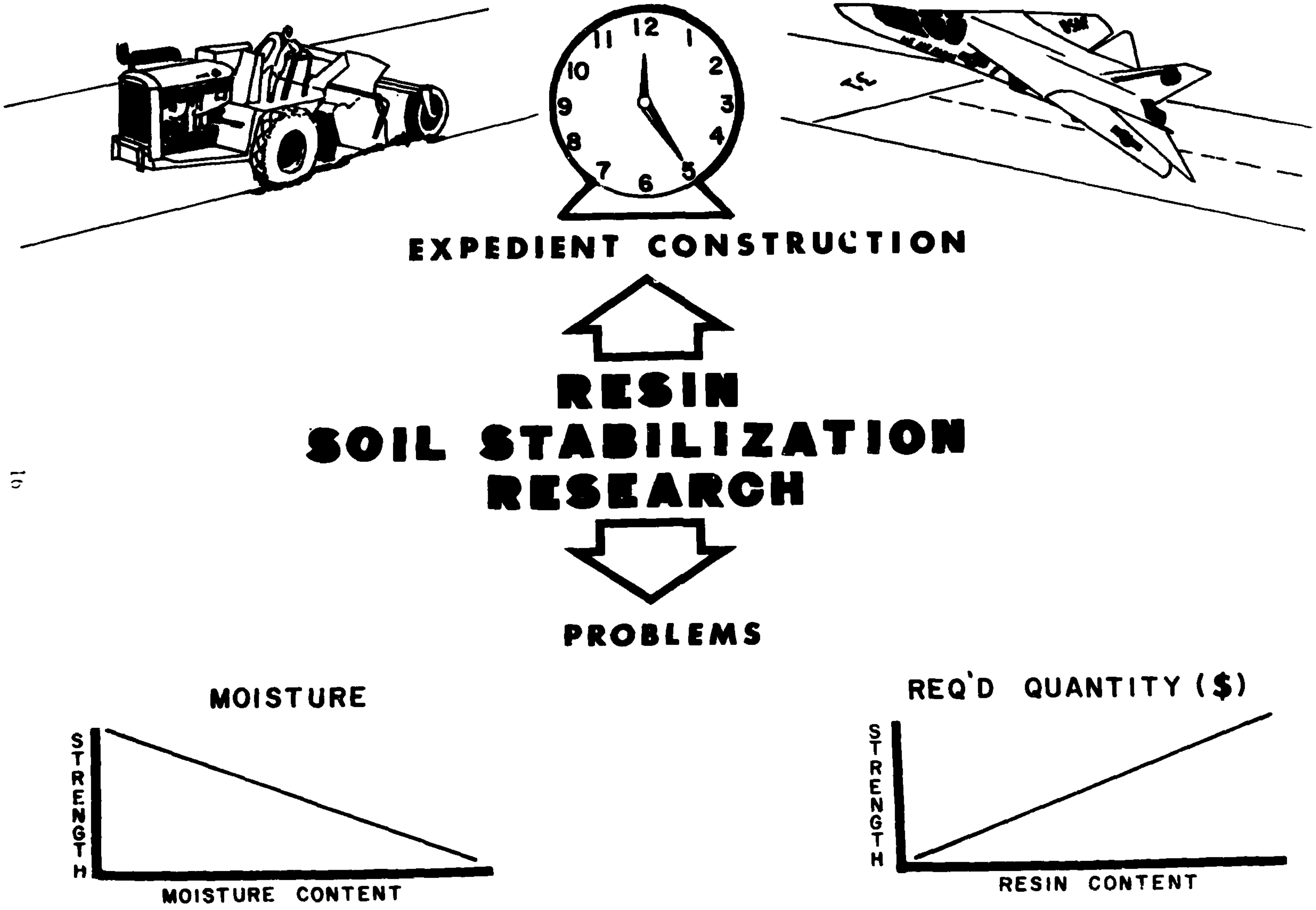
SECTION V
RESIN SOIL STABILIZATION

The need for an improved and rapid soil stabilization system has been greatly increased by new concepts of ground and air mobility. Soil stabilizers must be developed which will rapidly stabilize most types of soils, increase soil traffic capability, and improve waterproofing and dust control. Present mobility concepts require operational capability only days after deployment of a tactical force and all supporting facilities to a bare base. The only surfacings in being in the bare base are runway, taxiways, and aircraft parking areas. Other surfacing requirements include roads, logistical storage areas, building floors, etc. Thus, the requirement for a rapid, air transportable soil stabilization system is paramount.

Commonly used additives such as cement, asphalt, and lime gain strength only after reasonably long periods of time. There is some immediate strength increase in lime treated clays; however, this is applicable only to soils having plasticity. Thus, a new material must be sought to meet the requirement of air mobility application. Based upon the 1968 Soil Stabilization Review summarized in Section II, knowledge to design new additives and processes lies in the field of clay mineralogy, soil physics, physical, organic and inorganic chemistry as well as soil mechanics. The resins offer some promise in meeting these requirements. Under certain conditions, they gain significant strength in a very short period of time. However, they have serious shortcomings which must be eliminated to afford feasibility (see Figure 6).

Early research indicated that soil moisture degraded the strength of the cured resin-soil mixtures and the addition of resin to a wet soil caused the soil to become an unmanageable liquid. New material formulations have been studied including water extendable resins, in an attempt to find materials that will not present the problems with soil moisture that were previously encountered. In addition, other additives to the resin-soil mixture to improve the efficiency and utility of resins in soil stabilization have been investigated. The results of the study indicate that there are a number of resin materials that show promise for soil stabilization use.

Research is now being conducted on the most promising resins in order to better determine the performance of the resin materials and the soil-resin mixtures under a wide range of environmental conditions that simulate probable field conditions. This work includes screening of the resins with a clay soil rather than the sand soil previously used, study of the effect of prolonged water submersion on the cured resin-soil mixes, effect of water submersion on the curing and setting characteristics of the resin-soil mixes, effect of temperature variations on the initial curing of resin-soil mixes, effect of extreme high and low temperatures on the cured resin-soil mixes, effect of freezing and thawing on the resin-soil mixes, and the effect of very high clay soil moisture contents on the workability and strengths of clay-resin mixtures.



Resin Soil Stabilization
Figure 6

SECTION VI
STABILIZATION OF DEEP SOIL LAYERS

The majority of the airfields supporting Air Force operations today were designed and built during World War II. These airfields are approaching the end of their design life requiring increased maintenance and repair. To complicate matters even further, these airfield pavements will soom be required to carry the loads of the very heavy, many-wheeled transport aircraft such as the C-5A. These large aircraft with gross weight approaching one million pounds and landing gears with upward of 30 tires spread over a large area are inducing stresses in the pavement systems which have never been experienced before. These stress levels are no more severe in the upper pavement layers than the stress levels resulting from loads of the manned bombers such as the B-52 and large transport aircraft such as the C-141; however, at greater depths they are significantly greater (see Figure 7). This can be attributed to the fact that the load is distributed over a much larger area and the pressure influence areas of the tires overlap in the subbase and subgrade layers. This results in increased stresses, pore pressure and consolidation which will eventually lead to failure and consequently an unusable airfield.

Techniques have been advocated in the civil engineering profession for increasing the strength of inaccessible zones using techniques such as electroosmosis, grout injection, pile formation, etc. Unfortunately, the success realized to date using these techniques has been very limited. The majority of the applications reported have been in the coarser grain soils (sands) with very limited success in the finer grained soils (silts and clays). The majority of the Air Force pavement systems which will pose subgrade problems when subjected to the very heavy loads of future generation aircraft are suspected to be of fine grain materials.

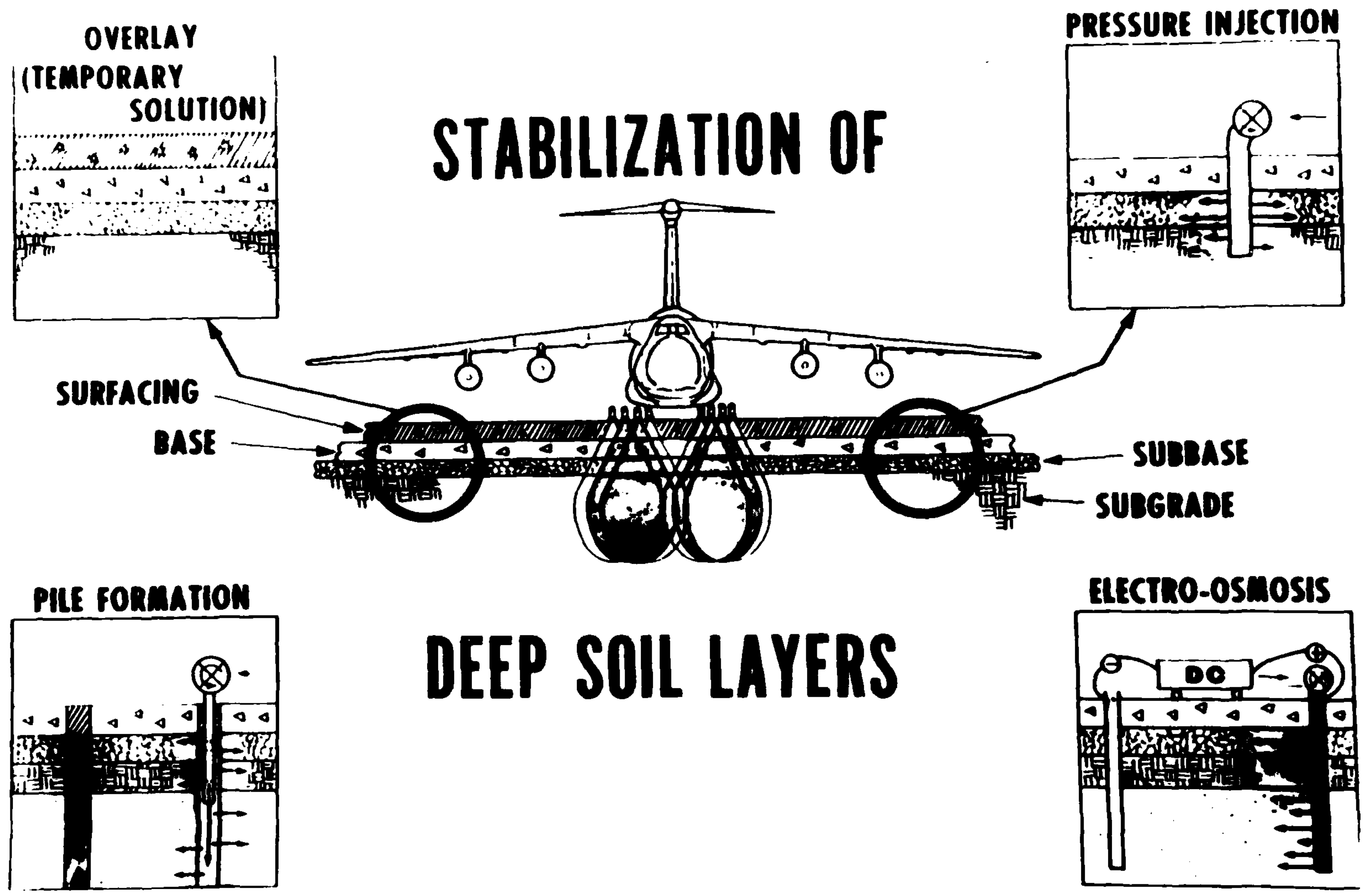
Techniques for stabilization of deep layers have been developed in some areas of industry. For instance, petroleum engineers often utilize grout injection to reduce water flow or increase oil flow while drilling and operating wells. In other areas, electroosmosis, electro-chemical and other methods have been utilized. However, the application of all of these techniques seem to be an art rather than science and in most cases are rather expensive and may be impractical for effective field application in stabilization of subbase and subgrade layers under airfield pavements.

In an attempt to rectify the problem of weak subbase and subgrade pavement layers, the "Soil Stabilization of Deep Layers" project was initiated. Under this project, a technique or techniques will be developed or adapted for increasing the strength of deep foundation layers under airfield pavement systems. These techniques could be an adaptation of one of the aforementioned, electroosmosis, grout injection, or pile formation, or it may be a totally new and novel technique (see Figure 7). Three major limitations will be imposed upon the technique or techniques to be utilized. First, the techniques must result in a system which is stable with a significant strength increase and reduced compressibility. Secondly, the application of this technique must not damage the pavement surfacing or upper layers significantly during construction and thirdly, this technique must be cost competitive with the construction of an 8 inch unreinforced concrete overlay.

In the initial phase of research, a technical data base is to be established, which will be concerned with that soil stabilization technology having direct application to stabilization of deep soil layers under pavements without disturbing the pavement surfacing and base courses. Both existing techniques and novel approaches will be evaluated. For each technique studied, a sound theoretical approach, as well as the problems which would be encountered in field application will be evaluated.

During the second phase, a laboratory investigation will be conducted to provide the necessary information for a successful field application of each technique which seems feasible. The minimum number of techniques necessary to stabilize all soil types except organic soils will be studied.

At present, the program is approximately half-way through the initial phase. Techniques such as electroosmosis and electro-chemical stabilization, cement and chemical pressure injection and pile formation have been investigated. Of these methods, the technique of pile formation seems the most feasible. This technique consists of drilling a hole through the pavement surfacing and deeper layers to a depth of approximately 15 feet and then utilizing pressure injection to introduce some form of stabilizer into the pavement layers and drill hole to form a stabilized soil pile.



Stabilization of Deep Soil Layers
Figure 7

SECTION VII
KOREAN SOIL STABILIZATION

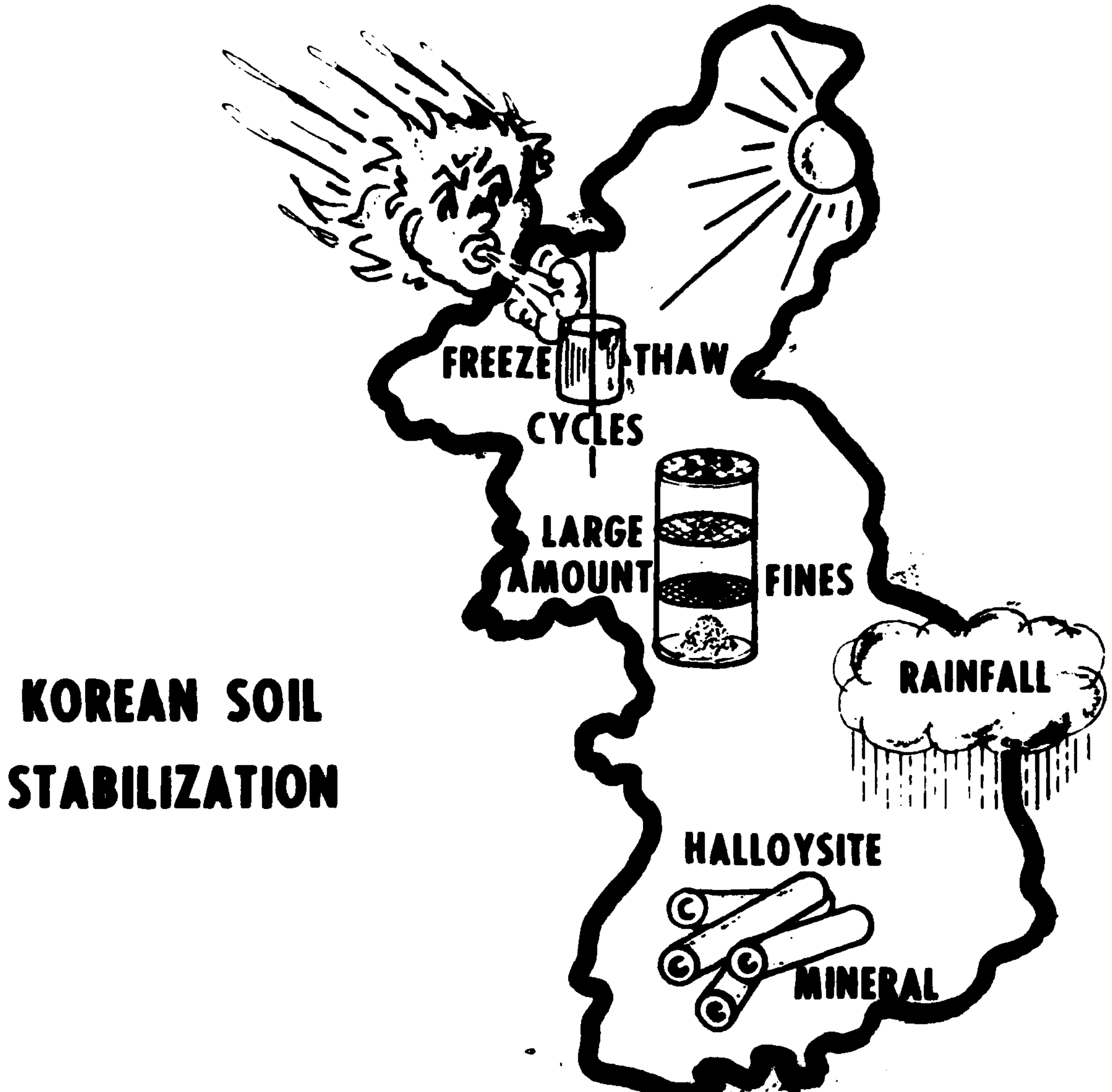
Military build-up is often required in remote countries in which there is a severe shortage of useful soil stabilization data. To insure that the most economical pavement structure is constructed in these situations, soil stabilization studies must be conducted. Numerous studies of this nature have been conducted for soils in Vietnam, Thailand, Korea, Turkey, Pakistan, Panama, and elsewhere. These studies normally consist of a soil survey and sample collection; laboratory tests to determine physical, chemical, and mineralogical properties, as well as strength and durability of various stabilizing schemes.

In the Korean Soil Stabilization Study, samples were collected from five bases spread over the peninsula. The initial laboratory investigation included classification tests, chemical tests and mineralogical analysis. Soil cement stabilization was first tried on these soils. In addition, sodium hydroxide, sodium sulfate, magnesium carbonate, and octylamine additives to the Portland cement were investigated. The unconfined compressive strength of the samples cured under varying conditions was determined.

Preliminary conclusions indicated an increase in strength with Portland cement stabilization; however, the sodium hydroxide, sodium sulfate, magnesium carbonate, and octylamine additives caused no strength increase. There was a strength decrease due to freeze-thaw, wet-dry, soaking, and freeze-soak tests. This strength loss was thought to have been caused by the presence of Halloysite, a soil mineral with a hollow tubular structure. Due to the large reduction in strength of these soils with the addition of water, a stabilizer is required which will prevent water from entering the soil structure. Therefore, bituminous stabilization is now being considered. These soils meet all grain size and plasticity criteria except for the quantity of material smaller than 2μ. The percent of material smaller than 2μ ranges from 4 to 81 percent in the Korean samples collected (see Figure 8).

Bituminous stabilization of soils having large quantities of material smaller than 2μ is not clearly defined in the literature and very little data is available. This has been identified as one of the serious gaps in soil stabilization technology and must be resolved in order that the objectives of this effort can be met as well as those for the establishment of an index system for soil stabilization discussed in Section IV.

The laboratory analysis to be accomplished will investigate the effect of varying quantities of fine fraction on the asphalt stabilized soil system. Lime will be used as a pretreatment to reduce the plasticity of the soil and facilitate the coating of the fine grained particles with asphalt. An emulsified asphalt will be used to increase the cohesive strength and provide the waterproofing required. Wet-dry and freeze-thaw tests shall be conducted to evaluate the stability of the stabilized material under adverse weather conditions.



Korean Soil Stabilization
Figure 8

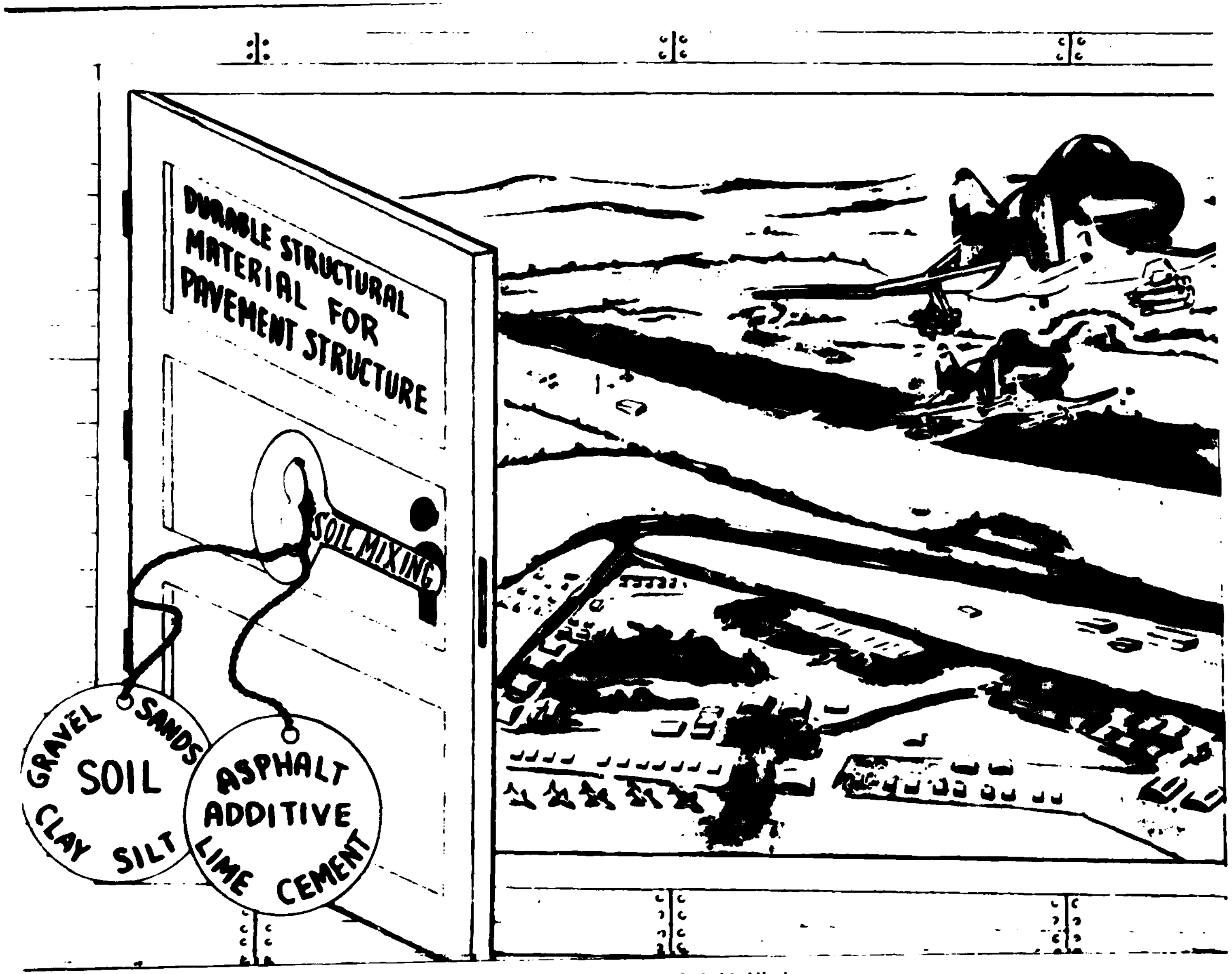
SECTION VIII
BASIC PARAMETERS OF SOIL MIXING

Stabilized soils have been successfully utilized as base courses, subbase layers and modified subgrades in pavement construction. Construction operations typically included in conventional mixed in-place stabilization are: (1) initial scarification and pulverization, (2) stabilizer distribution, (3) final pulverization and mixing, (4) grading, (5) compaction, (6) and curing. In general, the most difficulty in construction is encountered in steps 1 and 3, the major difficulty being pulverization and mixing (see Figure 9). Final mixing and pulverization requirements typically call for uniform homogenous mixtures of soil and stabilizer and approximately 50-80 percent material passing the No. 4 sieve. With coarse textured soils, satisfactory pulverization and mixing are generally obtained. However, the medium to fine textured soils, due to their higher plasticity and clay content, generally are much more difficult to adequately pulverize and mix. If a high degree of homogenous mixing can be effected in these medium to fine textured soils, it would seem that a smaller quantity of stabilizer than presently required would create the same strength. This would reduce logistical support requirements for soil stabilization proportionately.

Since complete pulverization and mixing is more difficult to obtain in heavy soils, this project will be concerned mainly with soils with textures ranging from coarse silts to heavy clays. An effort will be initiated to define those basic soil properties which are active in soil pulverization and soil-stabilizer mixing. The degree of pulverization and mixing required to give an optimum durability increase will be determined for each soil texture in conjunction with each of the three major stabilizers; lime, cement, and asphalt. In this study both standard and novel pulverization and mixing techniques will be considered.

Initially, a technical data base will be established to provide a firm foundation for accomplishment of follow-on work. This technical data base will be concerned with that soil stabilization technology which has direct application to soil pulverization and soil stabilizer mixing. A review and evaluation will be made of the present day knowledge pertaining to pulverization and mixing. A theoretical explanation will be made concerning all of the techniques and their relationship to those basic soil properties active in pulverization and mixing. New and novel techniques of soil pulverization and soil-stabilizer mixing will be explored both from a theoretical and practical approach.

Follow-on work will consist of a laboratory study to verify which of those soil properties active in pulverization and mixing are most important. This study will also determine the effectiveness of various pulverization and mixing techniques. The degree of pulverization and mixing required to yield an optimum durability increase in a stabilized soil will be determined for various soil textures and stabilizer additives. Soil textures will range from coarse silts to heavy clays and the various stabilizers to be tested with each soil will consist of lime, cement, and asphalt as well as any combinations deemed beneficial.



Basic Parameters of Soil Mixing
Figure 9

SECTION IX
LIME-SOIL STABILIZATION

There are many instances when lime soil stabilization of soils on a worldwide basis can be beneficially and economically utilized as a construction expedient as well as a more permanent construction material. In most cases, however, sufficient knowledge is not yet available for evaluating the probable lime reactivity of a natural soil, without extensive testing of the individual soil. This situation is particularly prevalent in tropical and sub-tropical regions, where soil research has been quite limited.

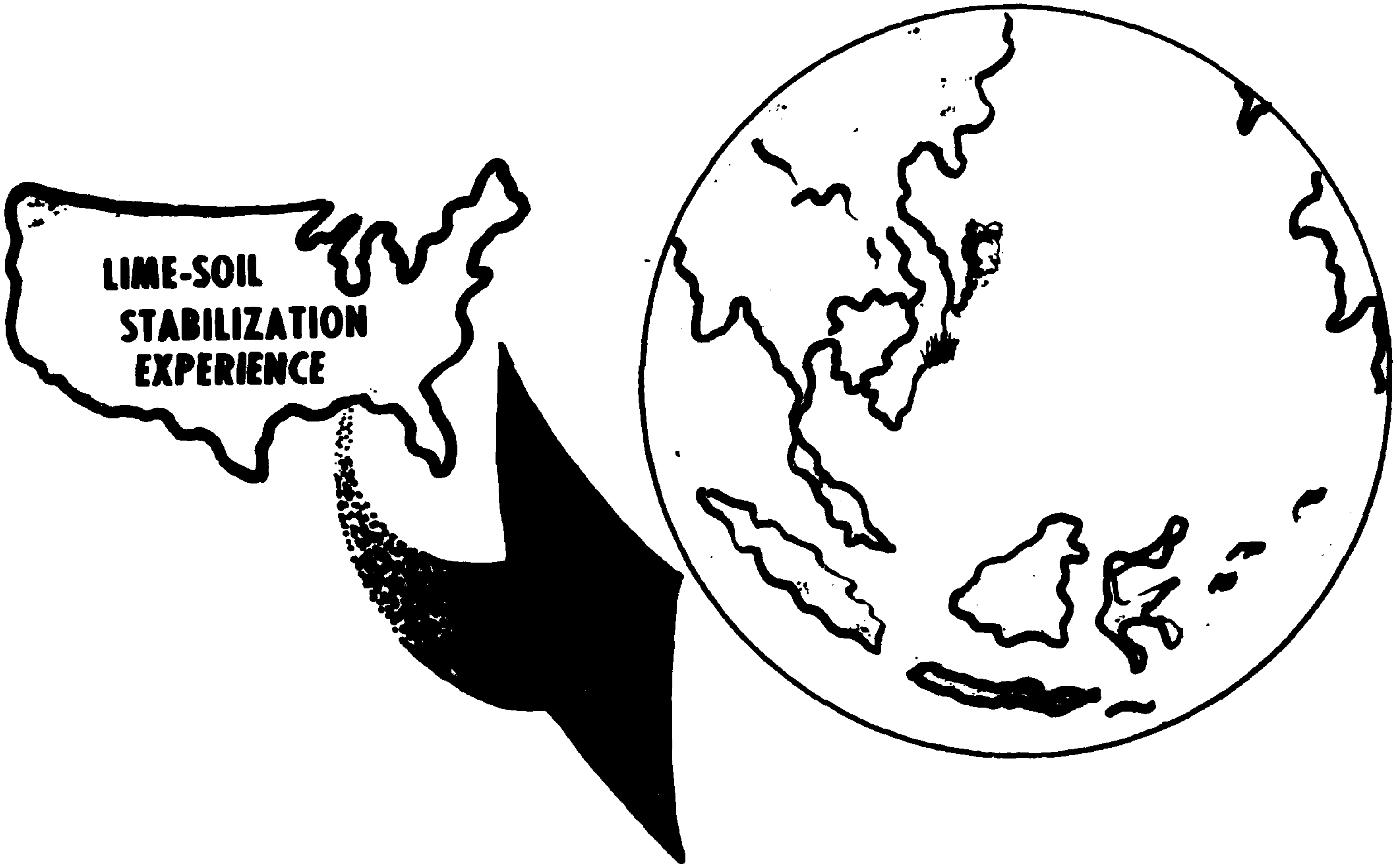
In the past six years, extensive research in the mechanisms of lime-soil stabilization, and significant factors influencing the lime-soil reactivity has been accomplished in the United States. Significant factors have been found to include type of lime, percent of lime added, length and temperature of curing, density of compacted material, and natural soil properties. Natural soil properties found to be significantly correlated to lime reactivity in relatively unweathered soils include soil pH, percent organic carbon, clay mineralogy, natural soil drainage, horizon effects, and to some extent, the amount of <2μ clay. Based on this research, it is possible to qualitatively forecast the lime reactivity to certain classes of surficial soils on a worldwide basis. However, to date this type of research and correlation has been restricted to the relatively unweathered tills and loesses of the central United States, although some correlating data on similar soils in Europe has also been published.

Although the research findings regarding significant factors influencing lime reactivity of central United States soils shows definite correlation with several natural soil properties, it is not feasible to extend these conclusions to other soil types without additional investigation and study. In fact, completed research on central United States soils indicated limited pozzolanic reaction in soils having a natural pH less than about 5.5; yet work in Australia indicates strong pozzolanic reactions in soils with pH's significantly less than 5.5.

This investigation is required for effective worldwide utilization of lime soil stabilization in the index system discussed in Section IV (see Figure 10). Soil samples shall be collected to represent typical soils in the tropics, subtropics, and humid temperature areas of the world covering the weathered soil spectrum.

A laboratory testing program will be conducted. The investigation will include the determination of the properties of the natural soils and also the evaluation of their lime-reactivity. Conventional and proven testing procedures will be utilized to determine the following chemical, mineralogical, and engineering properties of the samples. Soil lime reactivity will be evaluated using the procedure developed by Thompson and satisfactorily used in a study of Illinois soils. The evaluation consists of determining the compressive strengths of the natural and the lime treated soils. Factors such as lime type, compaction, curing time and temperature, etc., are controlled.

LIME-SOIL STABILIZATION



Lime-Soil Stabilization
Figure 10

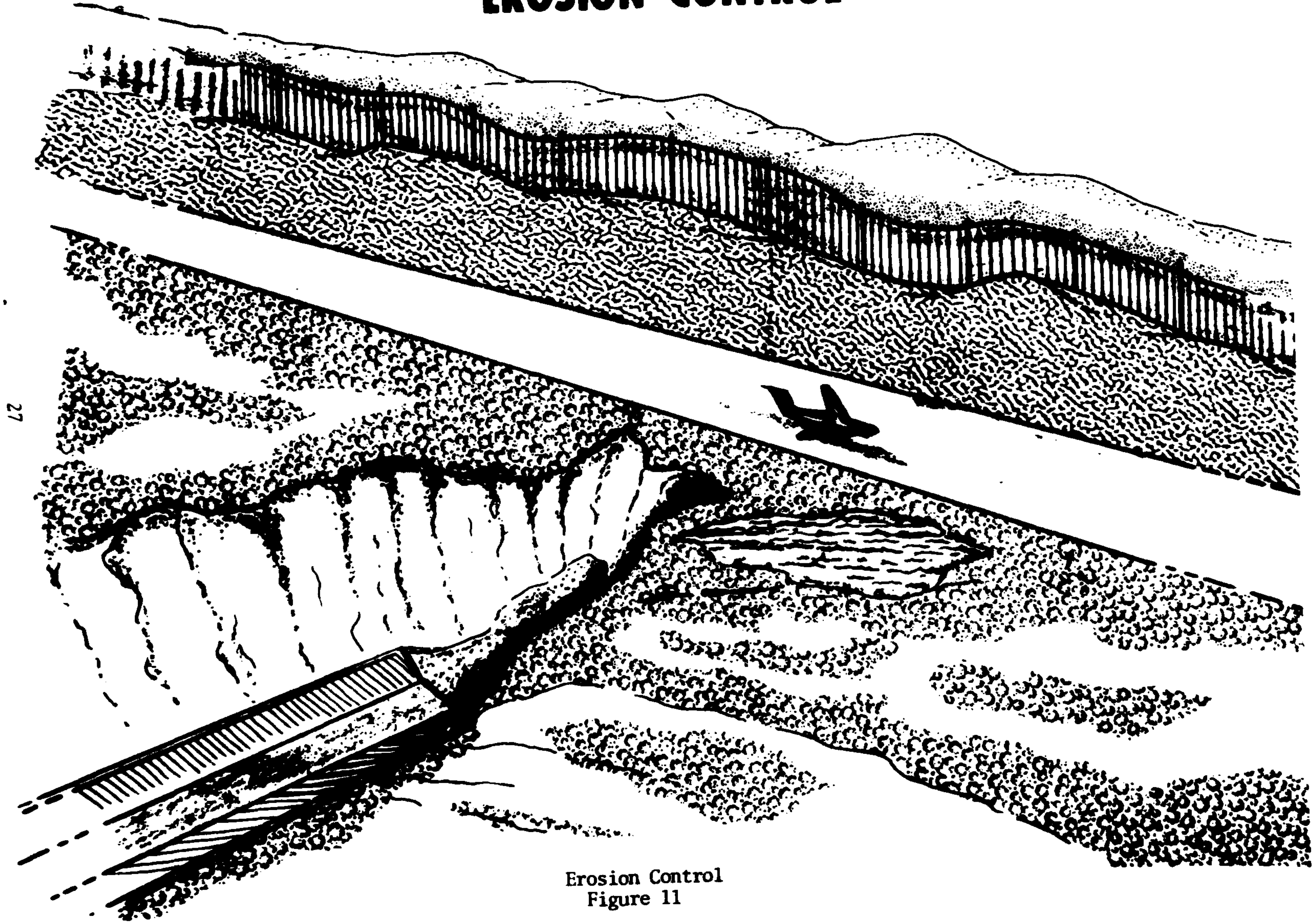
SECTION X
EROSION CONTROL

Erosion control is one of the most challenging and troublesome problems of Air Force Base Civil Engineers, particularly at new bases or in areas of construction where existing vegetation has been stripped away. Road cuts, ditches, and unprotected earth revetments are susceptible to severe erosion when subjected to moderate to heavy rains, strong winds, and jet blasts. Erosion effects are unsightly, damaging to the facility and its operational effectiveness, destructive to drainage systems, and causes increased maintenance and management costs. Bases in Southeast Asia and elsewhere have experienced very serious erosion problems which have seriously hampered operations (see Figure 11). The Base Civil Engineer at these bases have not been able to solve these problems without special consultation with erosion control experts. Existing manuals were not adequate to solve the problems faced. These problems were similar to those which occur in developing any urban region as a result of construction activities which expose unprotected soils to the detaching and transporting forces generated by wind and water. Thus, it was apparent that the Base Civil Engineer needs a more useful, complete, and lucid handbook for erosion control which can be used on a worldwide basis.

An assessment of the state-of-the-art of erosion control as it is represented by both current research literature and available manuals of operations experience was first conducted. The relationship between selected soil and environmental properties and soil erodibility was then established.

Methodology will be established for the evaluation of on-site environmental and soil conditions which describe the type and magnitude of both existing and potential erosion problems. A technical data base will be established for the selection and design of effective erosion control and prevention measures based on the evaluation of existing and expected erosion hazards. This base will utilize the most recent survey and planning techniques for applying these measures. This research will provide the information required for the development of a manual for use by Base Civil Engineers to control effectively erosion throughout the world.

EROSION CONTROL



Erosion Control
Figure 11

SECTION XI
SUMMARY

A critical need exists for an improved soil stabilization system capable of supporting advanced air mobility concepts presently being pursued by the Air Force. A research program has been established at the AFWL in response to this requirement. The current research program is addressing materials, structural behavior, field evaluation and construction problems involved in upgrading the strength of construction materials.

The hub of the ongoing research is the establishment of an index system for soil stabilization to be used by military engineers on a worldwide basis. In support of this research effort, the basic parameters involved in stabilizing soils are being identified. An investigation is being conducted to establish the feasibility of using resins as soil stabilizers in support of rapid construction of airfield and secondary pavement systems. Techniques are being investigated for upgrading inservice airfields using deep layer stabilization schemes which does not require destruction of the in situ pavement surfacing structure. New stabilization methods are being adapted to soils which heretofore have been considered unusable as high quality construction materials. The very critical mixing problem which is considered the key to successful application of existing additives is being researched. Commonly used additives are being studied more thoroughly for use on a worldwide basis. Erosion control techniques are being studied and categorized into a manual for use by base civil engineers. No exploratory or advanced development is being pursued in erosion control.

Future work will concentrate on the structural behavior of stabilized soils under varying environmental and loading conditions. The mixing problem will be continually researched. The gaps identified in the index system will be closed and the system evaluated in the field. New additives and stabilization schemes will be sought to satisfy Air Force mobility rapid construction requirements.