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ENGINEERING MATERIALS FOR TOMORROW'S CONSTRUCTION

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U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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Foreword

This paper pertains to certain research tests concerned with the development of new and better materials, improvement of those that are currently available, and the impact of such developments on the design and operation of the machines of tomorrow. The work is sponsored chiefly by the Office, Chief of Engineers, Army Materiel Command, and the Defense Atomic Support Agency, and is conducted by the various technical divisions of the U. S. Army Engineer Waterways Experiment Station.

This paper was prepared for presentation at the meeting of the American Society of Civil Engineers held in Washington, D. C., on 25 May 1965; Colonel Alex G. Sutton, Jr. made the presentation.

ENGINEERING MATERIALS FOR TOMORROW'S CONSTRUCTION

by

Alex G. Sutton, Jr.,* and Frederick R. Brown**

Introduction

The design and the techniques for tomorrow's construction will depend, as in the past, upon the engineering materials available. To keep pace with other technological developments, the search for new and better materials is being carried forward at an ever-increasing rate. The success of these research efforts will not only govern future construction, but will control the design and operation of tomorrow's machines and equipment as well. In general, engineers, scientists, and metallurgists attempt initially to improve the materials of today by changing their properties through chemical additives or metallurgical processes. As necessary, emphasis is placed on the development of new materials and new combinations of existing ones; but to predict, today, their form and content only a few years hence is akin to sheer speculation.

The rate of technological change during the past 25 years staggers the imagination. In 1937, a comprehensive study at the National Government level attempted to analyze the impact of science and industry over the following 10- to 25-year period; it failed to foresee such important developments of only the subsequent 10-year period as atomic energy, radar, jet

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propulsion, and antibiotics. Prior to World War II, the construction demands to support heavy, manned aircraft were still not clearly evident; and missiles, space travel, and lunar environments were nebulous ideas in the minds of only a very few. Today, these are matters of immediate concern, and the demands for materials to satisfy the requirements they generate have either been met or are in the process of development.

President Johnson's recent announcement of a 2,000-mile-per-hour jet aircraft mentioned the breakthrough in metallurgical research and fabrication techniques for titanium which made such performance possible. Commercial jets of tomorrow, and perhaps other vehicles and structures as well, may make use of this metal, which is three to five times as strong as aluminum but less than twice as heavy. Loss of the submarine THRESHER has resulted in intensified efforts to develop metals which will permit very deep undersea operations with safety. An all-aluminum research submarine is currently being designed to operate at a depth of 15,000 ft. And a recent news release disclosed that scientists are now studying the feasibility of constructing submarine hulls of glass.

The space program has called for lightweight, high-strength materials which will withstand severe temperatures, dynamic and cyclic stressing, and unfamiliar environmental conditions. Nuclear reactors require high-temperature, high-pressure systems, with emphasis on safety. Domestic requirements for new and more efficient construction materials continue, and research in and more extensive use of alloys, plastics, glass, ceramics, and even paper have been the result.

Materials Research at the Waterways Experiment Station

The Waterways Experiment Station (Figure 1) is not concerned primarily with the development of structural materials, but is engaged in research in support of the Corps of Engineers' civil works responsibilities involving navigation and flood control and military projects including protective construction and mobility of the Army. As part of these programs of investigation, the limitations of available materials are determined, and the development and improvement of materials to support specialized construction are initiated. Current areas of research include special-purpose concrete, soil stabilization, flexible pavements, portable landing mats and membranes, and materials for protective construction.

Concrete Research

The extensive use of concrete as a construction material has caused many changes in design concepts. As recently as a decade ago, only two types of concrete were considered, plain and reinforced; today, designers think chiefly in terms of prestressed and posttensioned concrete, or of mass concrete in which additives are used to effect economies, improve workability, and increase resistance to freezing and thawing. Figures 2 and 3 show views of the Experiment Station's Concrete Laboratory which is engaged in the improvement of concrete mixes for many and varied uses. Research is now under way in the use of nonmetallic reinforcement, ultrastrength concrete, expanding concrete, and ultralightweight concrete. Some of this work is described in the following paragraphs.

Nonmetallic reinforcement for concrete

The Japanese have experimented with bamboo for reinforcement of concrete for purposes of economy, and designers in this country have considered it for like reasons. The press box at Clemson College Stadium, built about 1940, was reinforced with bamboo, and it served its purpose adequately without undue cracking. A noted inventor used bamboo successfully to reinforce a swimming pool on his estate in Florida. While admittedly bamboo will never replace steel for reinforcement, it can be used for light, emergency construction where steel is scarce.

A different sort of nonmetallic reinforcement under study is fiber glass-reinforced plastic. Reinforcing rods are made of glass fibers oriented longitudinally and bound together with a suitable plastic, usually an epoxy. In situations where electronic considerations are paramount, or in the presence of stray electric currents or environments which would cause corrosion of steel, such fiber glass reinforcement might have great potential. It is expensive at present, but in widespread use it should become much cheaper.

Ultrastrength concrete

The highest strength concrete known had a compressive strength of 40,000 psi. This was a stunt material made of pure cement formed under pressure. Today, in speaking of high-strength concrete, most engineers think in terms of about 5,000-psi compressive strength. Experiment Station research now is concerned with a practical structural concrete with a minimum strength of 10,000 psi, made with ordinary portland cement and ordinary, but good quality, aggregates. By use of an aggregate made from portland cement clinker, a strength of 15,000 psi at 28 days can be attained. These are materials which can be made and handled with conventional equipment. Higher strength reinforcement is also available, and coupled with high-strength concrete, will facilitate the design of protective structures or missile silos which can sustain extremely high pressure loads.

Expanding concrete

To combat shrinking and cracking as concrete dries, experiments are being conducted with expanding cements made by blending certain portland cements with expansive components made of calcium sulphoaluminates. By combining the expansive cement with portland cement, concrete can be made that will expand a controlled amount and will not undergo shrinkage on drying. Practical usage has included the self-prestressing of concrete pipe and slabs as well as other precast elements. Other applications might include special grouts for filling the annular space behind tunnel linings and for effecting tight repairs.

Ultralightweight concrete

Concrete ordinarily weighs about 140 lb per cu ft, but a lightweight concrete weighing from 10 to 50 lb per cu ft has been made for such purposes as thermal insulation for many years. An important use for such material from the military viewpoint is to encapsulate underground structures, missile silos, or command posts in order to isolate them from earth motion caused by nuclear detonations. Shock-absorbing concrete has been made at the Experiment Station with foam (Figure 4) generated from fish waste protein and cement paste, with cement paste plus expanded mica aggregate (vermiculite), and with other unusual aggregates such as expanded polystyrene beads. Concrete of this sort will crush under earth movement without transmitting the movement to the structure it surrounds, and may make a significant contribution to protective construction. While such foam concrete can provide protection against a single severe shock or a series of light shocks, it cannot, being friable, protect against multiple severe shocks. Accordingly, resilient foams are currently under active study.

Soil Stabilization

Research is also currently under way to improve methods of soil stabilization which will permit the utilization in highway and airfield construction of materials now considered inferior for such purposes. While soil as an engineering material is not as exotic as those required for space travel and lunar landings, the need for new techniques and new mixes in road and airfield construction is of utmost importance. High quality materials are becoming increasingly difficult and expensive to obtain. Logically, considerable effort is being expended in the improvement of readily available materials. This, in effect, is the creation of a new material.

A magic chemical has not yet been found which can be added to inferior materials in very small quantities to obtain a marked improvement in their engineering properties. Some such chemicals have enjoyed a short period of enthusiastic claims based on laboratory-scale results, but these glamour chemicals have not proved successful in full-scale operations. Currently, the soil stabilization program of the Experiment Station involves the use of readily available additives such as lime, portland cement, and bituminous products, each with a small amount of other chemicals added in order to improve its stabilizing characteristics. Progress is being made in this area.

Landing Mat Investigations

Since time and equipment are not always available to permit conventional road and airfield construction with equipment normally utilized for military operations, prefabricated surfacing materials must often be considered as the alternative. The design of such surfaces is a challenge as it involves, in addition to strength requirements, considerations of weight, bulk, packaging, air transportability, and rate of emplacement. Various designs of landing mat have been developed at the Experiment Station, and high-strength steel, magnesium, and aluminum have been used in efforts to reduce the weight. The most recent addition to the landing mat family is a sandwich panel consisting of two plastic facings with a plastic honeycomb core. Aluminum honeycomb core material has also been used in this research and development program.

One of the more promising mats developed to date is constructed of extruded aluminum panels. It employs improved placing methods, surfacing, and side and end connectors (Figure 5). Development of improved landing mat is an active program in which new materials, new fabrication techniques, new jointing methods, and the improvement of any characteristic that will produce a lighter and stronger product are continually being sought.

Materials for Protective Construction

The requirement that command echelons, retaliatory forces, and other elements survive a nuclear attack has led to expanded research in the field of protective construction. In order to develop design criteria for such construction, the Experiment Station is currently engaged in comprehensive studies of the dynamic properties of both soils and other materials. The Station's blast load generator (Figure 6) is designed to reproduce, in the laboratory, the blast effects of a spectrum of nuclear explosions. A test chamber 11 ft high by 22 ft in diameter contains the material or design under test, and permits studies of free-field blast phenomena, soil-structure interaction, and the response characteristics of the model structure itself.

Other extensive investigations of construction materials such as metals, concrete, plastics, fiber glass, or laminates thereof are currently planned, in order to determine how the composition of materials affects the response of a structure subjected to blast-type loading. Another device, a 200-kip dynamic loader (Figure 7), has been designed and fabricated to allow laboratory investigation of materials over a wide range of strain rates and at high levels of load. This device is designed to apply a load of 200 kips within a time frame of less than two milliseconds. An extensive test program will be conducted to determine the correlation between the composition of materials and the effects of strain-rate strength properties. This information will permit a more accurate prediction of the dynamic response of a structure and will result in improved design criteria.

Conjectures for the Future

As for the tomorrow of 10 to 25 years hence, we can only speculate on the new materials which will be in use. One scientist has stated that it is only possible to forecast future accomplishments in terms of what cannot be done, based on fundamental scientific principles; all else is possible. Yet even this negative type of prediction is suspect, unless it is assumed that no new scientific principles will be discovered in the future. When we consider the proposed use of such unconventional "materials" as the magnetic field with which scientists hope to contain controlled nuclear fusion, it seems safe only to say that some materials for tomorrow's construction will result from discoveries and developments which are unknown and undreamed of today.

It seems reasonable to assume, however, that some of the principles which will govern the military construction of the immediate tomorrow will continue to influence developments of the more distant future. These include the trends toward prefabricated, precast, premolded, prestressed, and pretreated materials and building blocks which minimize on-site construction effort as well as maintenance requirements; and they involve the ever-increasing considerations of environmental effects to insure successful performance in outer space or to withstand military attack. History indicates that this research will result in contributions to improved construction for specialized industrial and domestic use in everyday life as well.

From the military standpoint, these environmental considerations will continue to require an emphasis on protective construction. New developments in shielding and shock-absorbing materials will result, together with more effective use of the static and dynamic properties of the earth itself--soil and rock. In other applications, mixtures of soil and chemicals of various types will provide economical designs of hardened surfaces for roads and airfields.

Missiles and space vehicles will travel through space at incredible speeds, impervious to the heat generated by friction of the atmosphere or by the intense cold and heat of a lunar environment--due to the use of lightweight, high-strength metals yet to be developed. Whether these metals or alloys will be derivatives of steel, aluminum, or some yet unknown material is difficult to predict; but it is certain that the demand for them will be met.

Additional advances will be made in plastic materials which will provide still higher strengths and improved properties. Plastics will replace metals for such everyday use as plumbing and piping of all types. Plastics, which require no painting, will replace lumber and brick in the construction of homes, and will result in lower maintenance and construction costs. Concretes of the future will continue to meet any requirement placed upon them for domestic, industrial, and military usage; admixtures will provide additional desirable features which will influence the design of the structures of tomorrow. Paper, already in use as honeycombed cells to increase the structural strength of prefabricated panels, will be found in other novel roles.

The demands for tomorrow's materials to keep pace with other increasing technological developments will be met by today's research. And one of the basic considerations governing the research program at the Waterways Experiment Station today will continue to exert influence on all materials research efforts so long as either national security requirements or domestic competition exists for limited resources. This objective is to make the materials stronger, more durable, more effective, and at a lower cost.

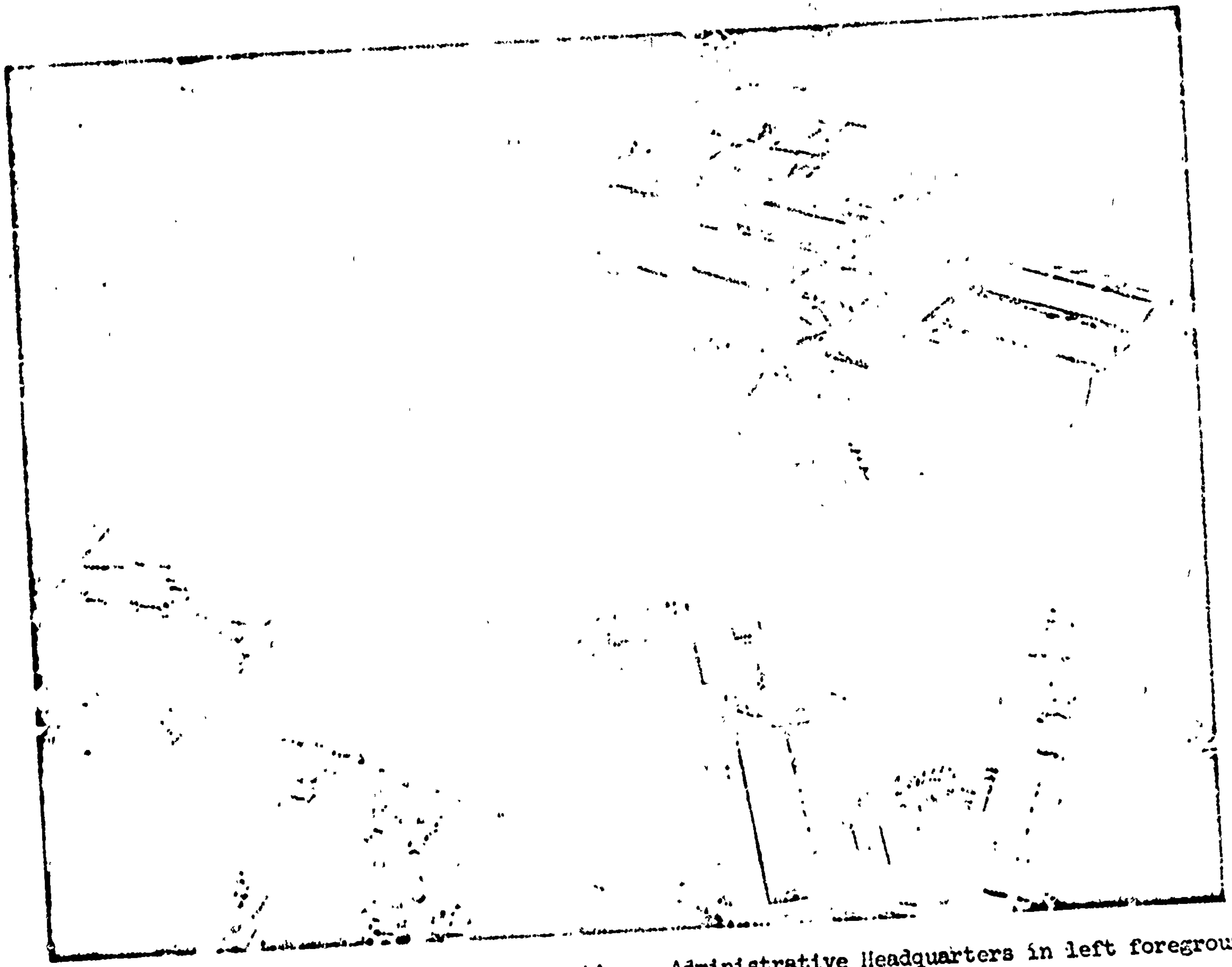

Figure 1. Aerial view of Vicksburg Reservation. Administrative Headquarters in left foreground

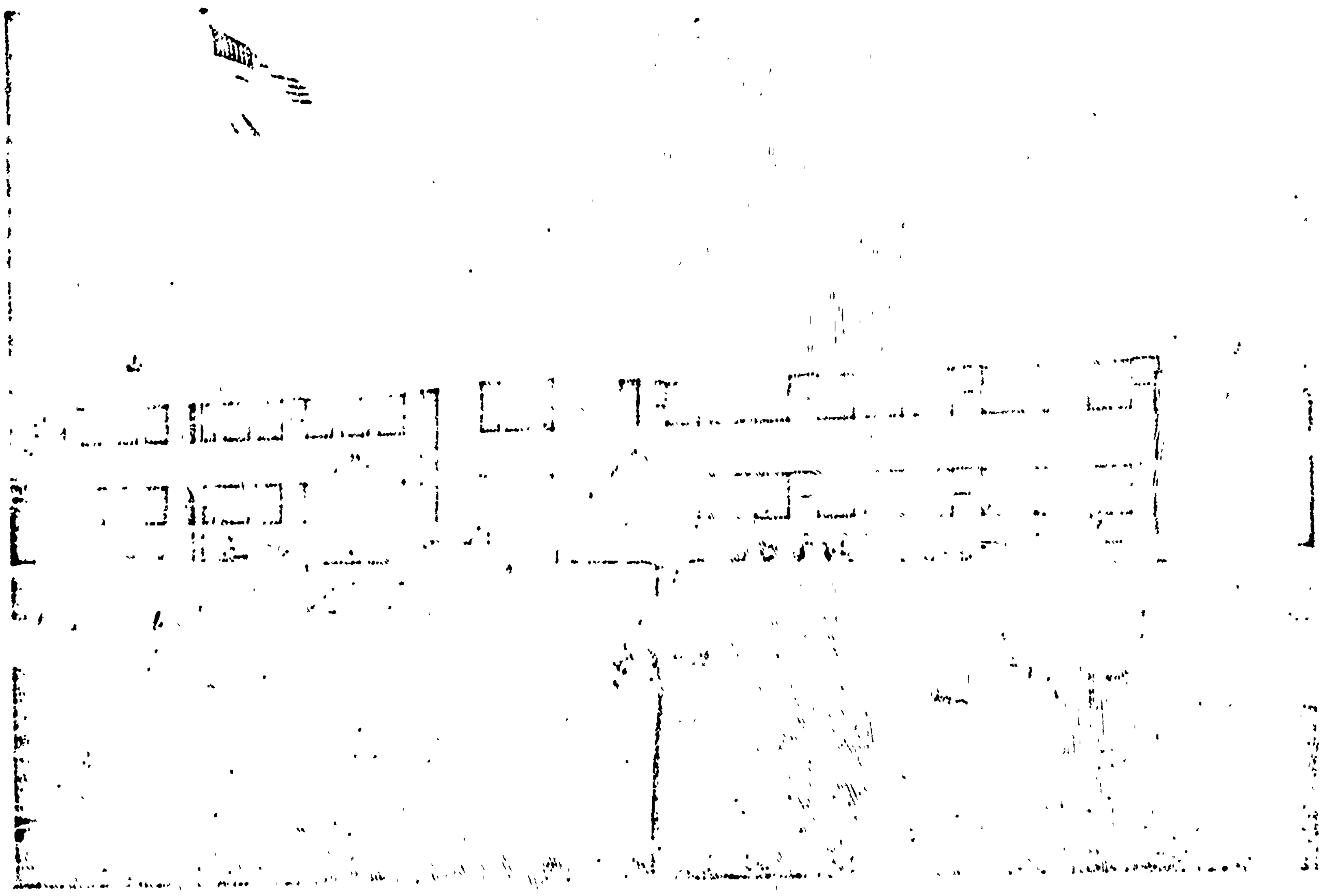

Figure 2. Concrete Laboratory

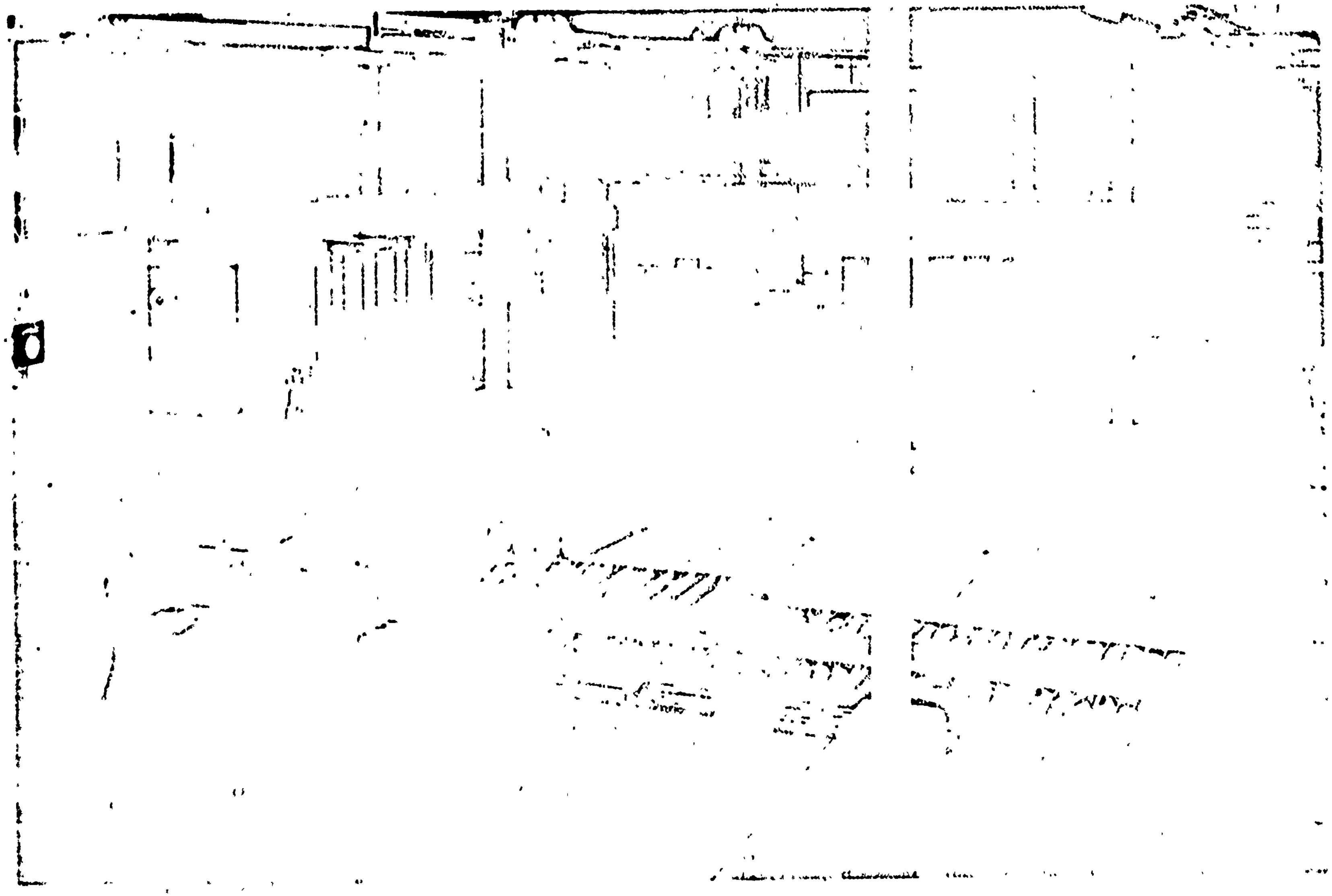

Figure 3. Strength testing area of Concrete Laboratory

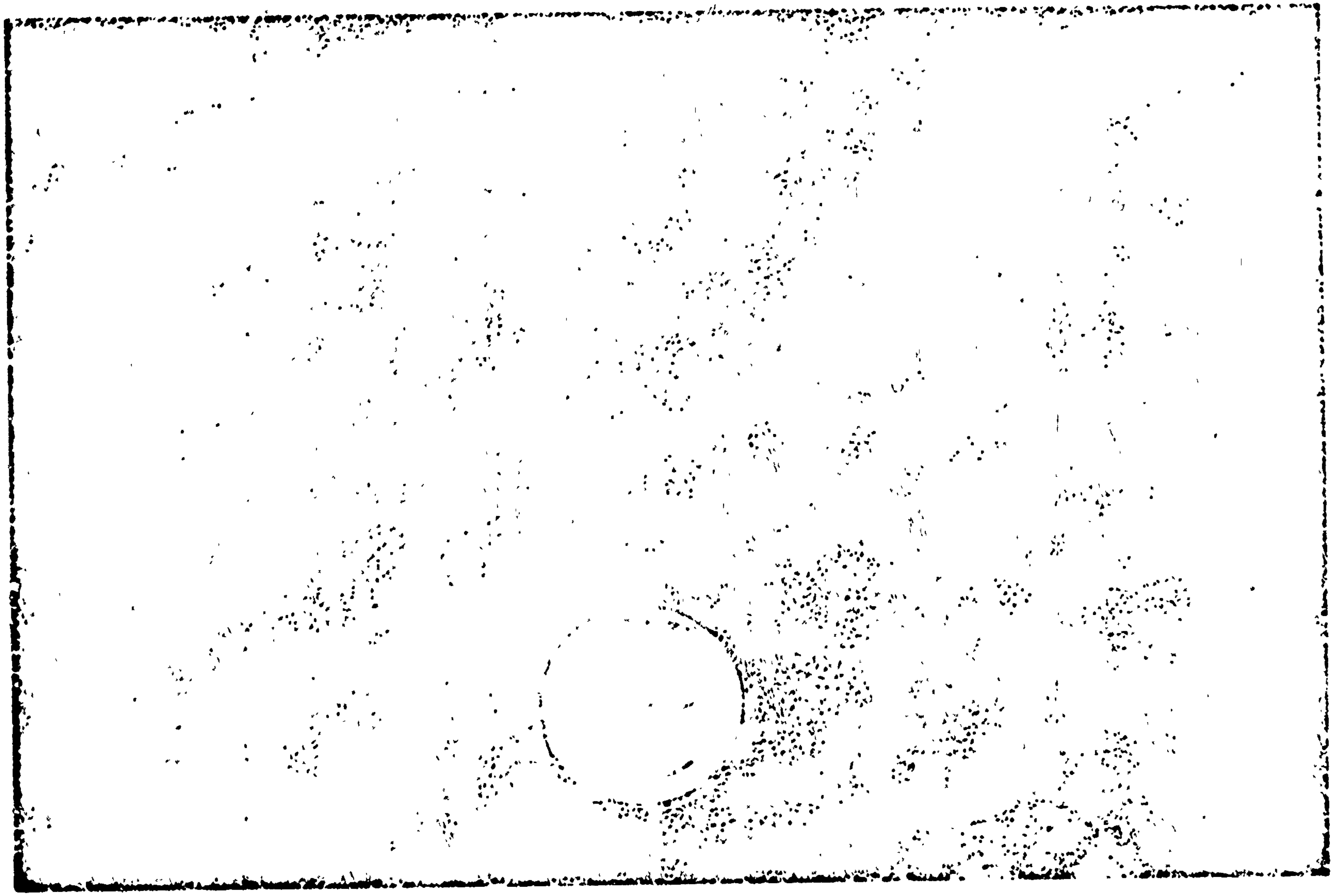

Figure 4. Surface of foamed concrete sample

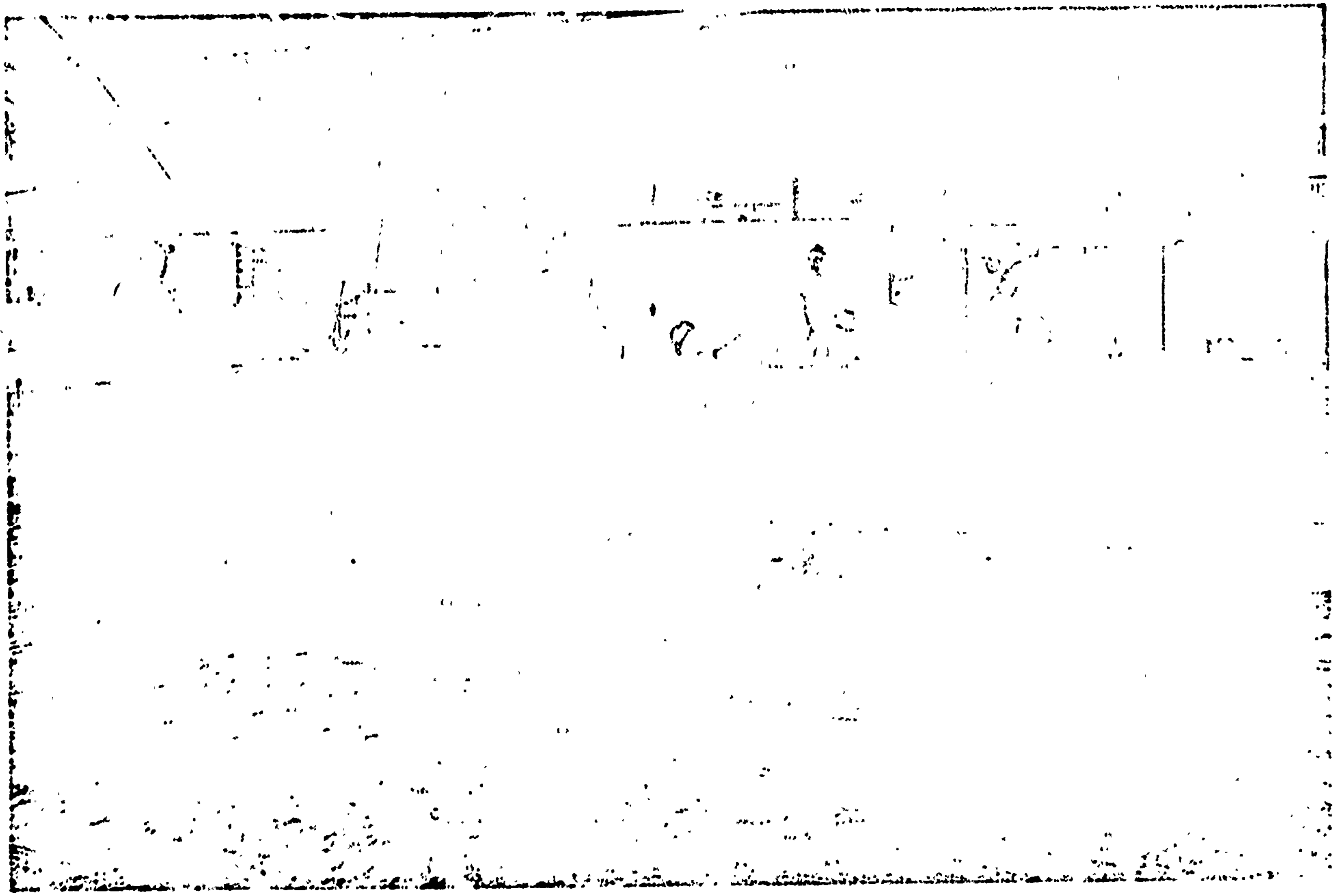

Figure 5. Placement of extruded aluminum landing mats

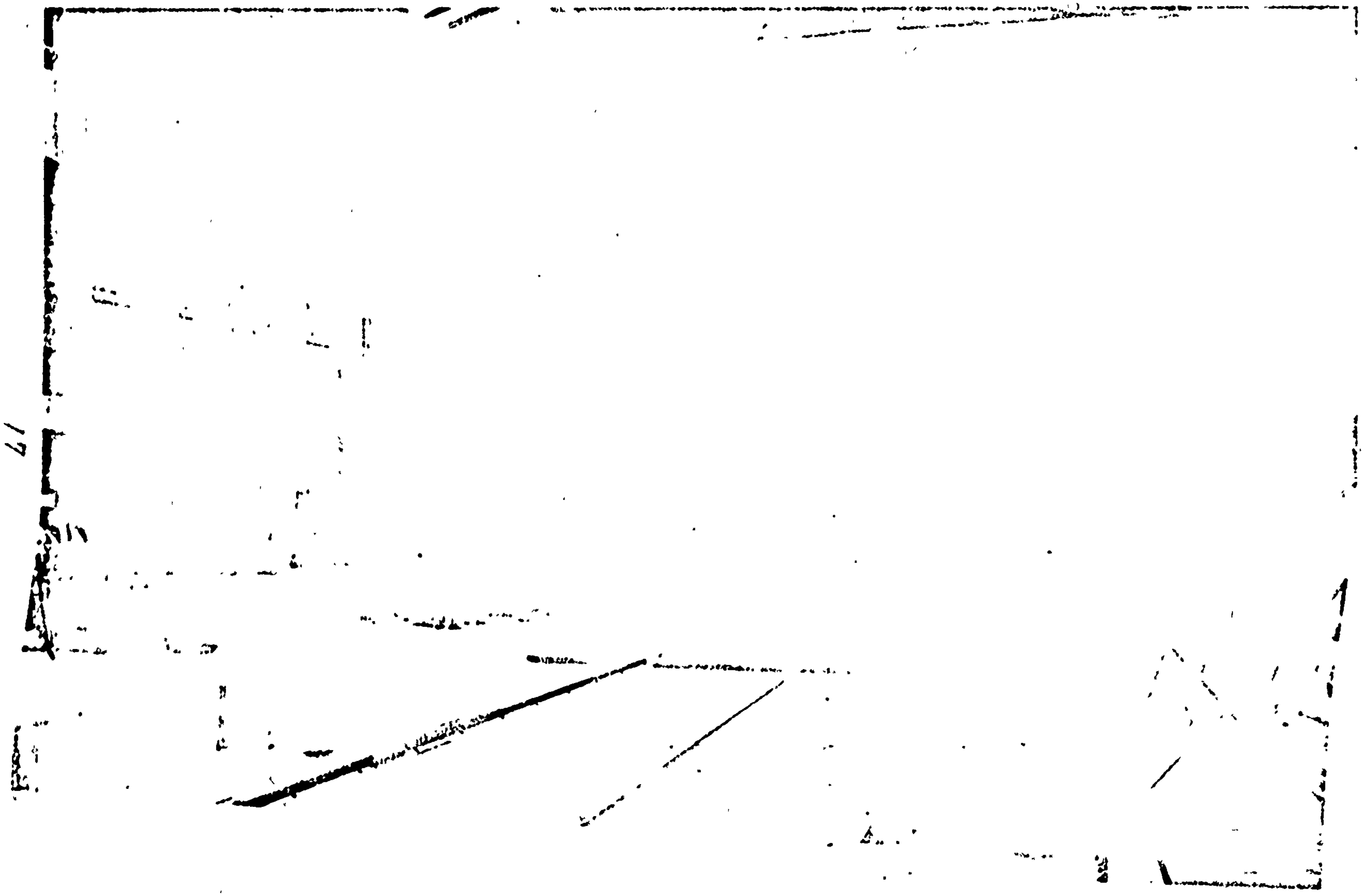

Figure 6. Blast load generator

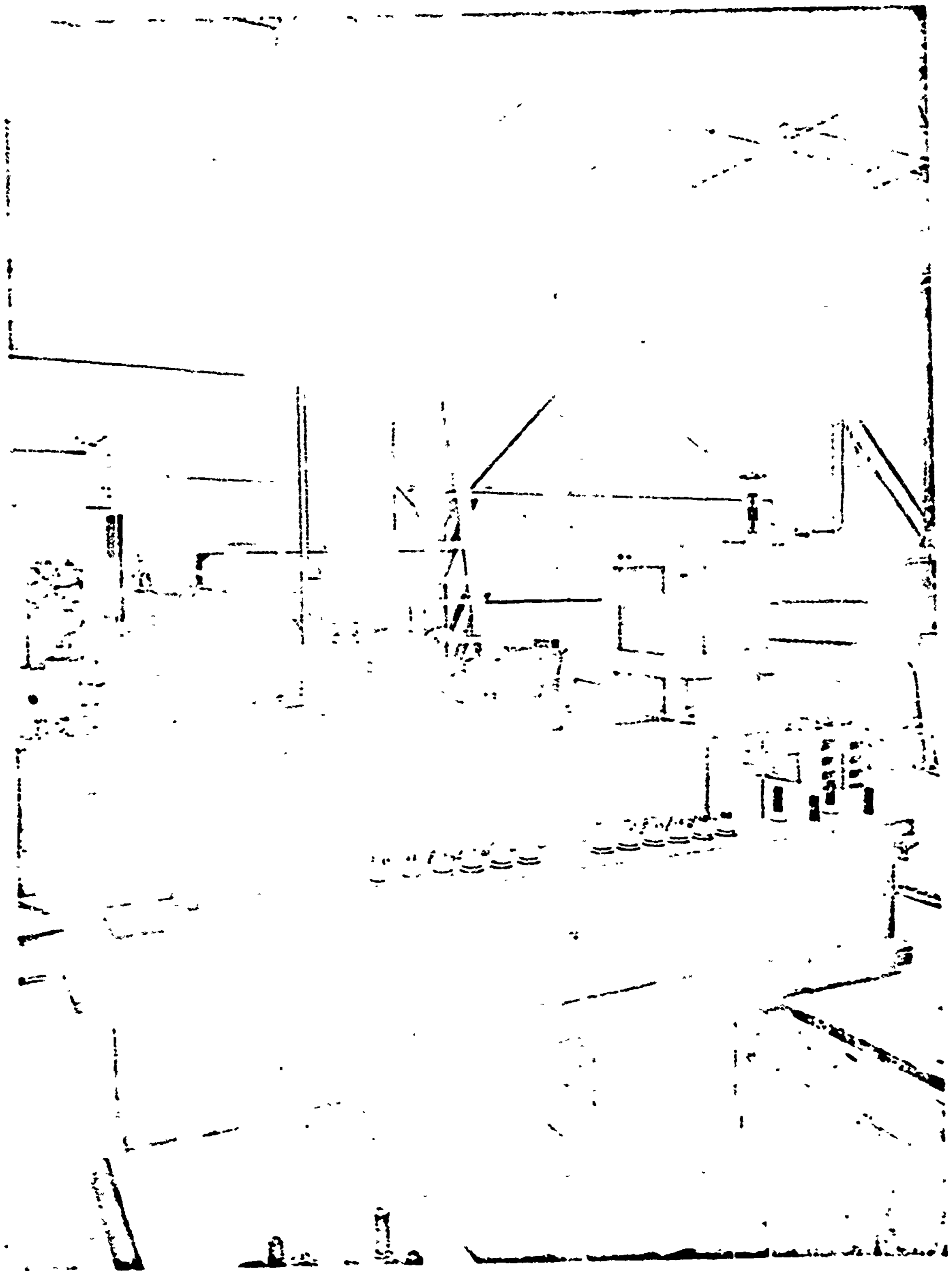

Figure 7. Dynamic loader (200 kips) for material testing