MISCELLANEOUS PAPER N-69-1

TEST DEVICES
BLAST LOAD GENERATOR FACILITY

by

W. L. Huff

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U. S. Army Engineer Waterways Experiment Station
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FOREWORD

This paper was prepared by Mr. William L. Huff under the general supervision of Mr. W. J. Flathau, Chief, Protective Structures Branch, and Mr. G. L. Arbuthnot, Jr., Chief, Nuclear Weapons Effects Division, U. S. Army Engineer Waterways Experiment Station (WES).

Director of WES during the preparation of this paper was COL Levi A. Brown, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
kips	453.59237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter

SUMMARY

This paper presents a description of the various test devices of the Blast Load Generator Facility and their capabilities. The Large Blast Load Generator is capable of testing models of underground protective structures at pressure up to 500 psi dynamically and 1000 psi statically. The Small Blast Load Generator can be used to test small models at static pressures up to 2000 psi and dynamic pressures up to 250 psi. Higher static and dynamic pressures can be obtained using the 15,000-psi static loader and 1500-psi detonable-gas shock tube, respectively. For determination of the static and dynamic properties of materials, the 200- and 500-kip loaders are available.

TEST DEVICES, BLAST LOAD GENERATOR FACILITY

FUNCTION OF NUCLEAR WEAPONS EFFECTS DIVISION

Research concerned with nuclear weapons effects is conducted by the Nuclear Weapons Effects Division of the U. S. Army Engineer Waterways Experiment Station (WES) for the Army in cooperation with other Department of Defense (DOD) agencies utilizing theoretical, analytical, and experimental methods. The experimental work is carried out by means of small-scale high-explosive (HE) tests, special laboratory tests, and full-scale nuclear tests. Investigations are concerned chiefly with the design of protective structures to resist blast and with underwater shock effects. The Division also participates in the Plowshare program of the Atomic Energy Commission and provides consultant-type services to Office, Chief of Engineers (OCE), Office of Civil Defense (OCD), Defense Atomic Support Agency (DASA), and other Government agencies active in this field.

NUCLEAR WEAPONS EFFECTS RESEARCH FACILITIES

Development. Early in 1951, WES was selected to conduct an extensive research program in which high explosives were used to study the effects of explosions in shallow water. This represented the first effort by WES in the explosion-effects field. During this initial program, measurements of airblast, water shock, cratering, and water-surface waves were obtained. The experience gained by personnel and the instrumentation facilities acquired were subsequently used to accomplish explosion-effects research for several DOD organizations. In June 1955, WES was assigned an Army R&D Project with the main objectives of: (a) determining the effects of nuclear weapons on structures, terrain, and waterways so that planning data might be provided as needed for both offensive or defensive operations, and (b) developing criteria for use in designing underground structures for protection of personnel and equipment. Since 1955, the work has been expanded greatly to include weapons effects research studies for DASA, the Departments of the Navy and Air Force, and OCD. Theoretical and analytical studies, small-scale HE tests, and special laboratory tests are utilized to determine the basic effects of nuclear detonations, and to describe the damage that these effects will have on targets such as dams, airfields, harbors, terrain features, and underground structures. Supporting data and additional information are obtained by participating in full-scale weapons tests and in large-scale HE test programs. Through the various research programs, certain testing facilities have been acquired or developed which add to the WES capabilities in the nuclear weapons effects field.

Blast Load Generator (BLG) Facility. Before the ban on aboveground weapons tests, structures could be evaluated in full-scale tests. To do this required an extensive construction and instrumentation effort for a one-shot test. A more controllable and less expensive method of evaluating these structures would be laboratory tests that simulate the blast effects of a variety of nuclear devices. A contract was let in 1958 to study the feasibility of building a device that could simulate the airblast wave during a nuclear detonation. From this initial study, procedures and methods were developed for the design and subsequent construction of the Large Blast Load Generator (LBLG). In order to meet the demand of requirements for nuclear weapons effects research, other devices have also been constructed and still others are being planned. A summary of the capability of these devices located in the BLG follows.

Large Blast Load Generator (LBLG). The LBLG (Figure 1) is a three-dimensional device designed primarily to test underground protective structures subjected to pressure simulating those generated by both kiloton and megaton nuclear devices. Pressures from 10 to 450 psi having rise times of approximately 2 to 4 msec and durations approaching 2 sec can be produced in the generator. It will be possible to sustain static pressures up to 1000 psi when modifications on the test chamber are completed.

The LBLG consists of two basic components: the Central Firing Station (CFS) and the test chambers. The CFS is a massive, posttensioned prestressed concrete, reaction structure designed to resist the large dynamic or static loads generated in the test chamber. The two test chambers are cylindrical steel bins having a 23 ft OD and 22-ft 10-in. ID that contain the test media and test structures. A test chamber consists of three C rings that stack to a height of 10 ft, one B ring that contains 15 firing tubes, and one A ring that is a telescoping-type lid. The A and B rings are interchangeable with each set of C rings. The CFS and test chambers are housed in a large laboratory building equipped with overhead cranes, special handling equipment, instrumentation, and offices.

The explosives in the firing tubes (PETN in the form of Primacord) are fired electrically by a standard engineer cap connected to a leader strand of Primacord. The leader strand is connected to individual strands of Primacord that lead to each tube.

The device is used in various types of investigations. Studies are made in the design and analysis of the response of underground structures to dynamic loads to determine effects of the shape of the structure, the ratio of span length to depth of burial, the ratio of span length to overall length of the structure, structural flexibility, internal shock environment, and the ratio of the loading duration to the natural period of the structure.

Other studies are concerned with the response of various types of soils to dynamic loads, shock-isolation methods, stress-wave propagation in soils, blast-closure devices, and the design of entranceways and entrance-closure methods.

Small Blast Load Generator (SBLG). To design the LBLG, certain information was required which could be obtained only by direct experimentation. Consequently, a 4-ft-diam generator was constructed and used to obtain these data. The SBLG is now a companion to the LBLG and is located in the same building (Figure 2). It is used to evaluate designs and to verify design procedures for underground protective structures.

The SBLG can produce static pressures up to 2000 psi and dynamic pressures up to 250 psi having a rise time of 3 to 4 msec and durations in excess of 2 sec. The generator has a steel cylindrical shell and an elliptical dome top called the bonnet. The shell is composed of a series of stacked rings (46-3/4-in. ID) of various depths that are bolted together to allow the depth of a soil sample to be varied.

Two separate concrete foundations are available for anchorage of the generator. One foundation is 9-1/2 ft thick and has three anchorage locations, i.e. two rigid bottoms and one infinite bottom. A view of this foundation during construction is shown in Figure 3. This foundation is used for static pressure up to 500 psi and dynamic pressure up to

250 psi. One of the rigid bases has a flat concrete interface at the base and the other provides an anchorage for a cylindrical ring having a flat steel bottom plate 1 in. thick and heavily stiffened. In the center of the steel bottom a trapdoor can be mounted (maximum diameter 6 in.), and pressure transducers can be mounted at various locations on the plate. The infinite bottom is a 9.5-ft-deep, steel-lined hole in the base slab. The interface between soil specimen and base is the clay subsoil. With this base, a specimen up to 20 ft long, 46-3/4 in. in diameter, and with essentially no horizontal reflecting interface can be tested. The other foundation is 18 ft thick and also contains three anchorage locations, i.e. two rigid bottoms and one infinite bottom. A view of this foundation is shown in Figure 4. This foundation can be used for static pressure up to 2000 psi and has the capability of anchoring dynamic pressure up to 1500 psi. One of the rigid bases has a flat concrete interface at the base and the other has a flat steel 2-in.-thick base that is heavily reinforced and located at the bottom of a 12-ft-deep pit. The infinite bottom is an 18-ft-deep hole in the concrete base slab.

The dynamic bonnet houses two firing tubes surrounded by a baffle grid. the detonation of explosives (PETN in the form of Primacord) in the two firing tubes generates pressure which loads the soil surface.

The baffle grid breaks up the shock fronts and helps to form an essentially plane wave (within 8 to 10 percent) over the sample surface.

The SBLG is equipped with two quick-opening valves which can be timed to open automatically at 0.3, 0.9, 1.2, 1.5, or 1.8 sec after firing, or they can be operated manually. The body of the generator contains ports for the insertion or mounting of pressure transducers, accelerometers, and other instrumentation.

15,000-Psi Static Loader. Through the sponsorship of the Space and Missile Systems Organization (SAMSO), a 15,000-psi Static Loader was constructed and used initially in support of a program for SAMSO to test models of missile silos and their closures (Figure 5). The CFS is used as a reaction frame for this loader. The load from the static test fixture is developed through a cylinder-piston arrangement in which the piston is activated by water pressure supplied by an air-driven fluid pump. At the maximum operating pressure of 15,000 psi, the 32.25-in.-diam piston produces a force of 12,250,000 lb on the sample.

The component parts of the Static Loader starting at the floor of the CFS are (a) platen, (b) spacer blocks, (c) steel bearing plates with leveling plates, (d) space for test specimen, (e) cylinder and piston, and (f) upper bearing block.

The upper bearing block rests on four columns which are pinned to the platen. During a test the platen and the upper bearing block distribute the load to the bottom and top of the CFS, respectively.

The platen can be rolled in and out of the CFS for ease of sample placement. The spacer blocks can be added or removed, as needed, for various test-specimen heights.

The load is applied to the test specimen through a rubber pad confined at the edges by a T ring. Samples with diameters of 52, 32.25, 22, and 11.5 in. have been tested in the initial test series for deep closures.

1500-Psi Detonable-Gas Shock Tube. The design and fabrication of a 4-ft-diam, 40-ft-high detonable-gas shock tube are presently under contract and the device is scheduled to be installed in April 1969. Shown in Figure 6 is a model of the shock tube in place within the BLG facility. The shock tube will be capable of producing reflected pressures from 250 to 1500 psi with microsecond rise times. The pressure will decay to one half of the peak pressure in 2.0 msec.

To produce the desired pressure range, mixtures of oxygen-hydrogen, oxygen-methane, and oxygen-methane-hydrogen will be used. The gas mixture will be ignited at the top of the shock tube with a standard, automotive spark plug. The reflected peak pressure is controlled by varying the gas mixture ratios and the initial detonation pressure. It is predicted that the desired reflected pressure can be obtained repeatedly within 5 percent accuracy.

The shock tube is composed of five sections that are bolted together with flanges containing O-ring seals. The top section is 20 ft long with an elliptical bonnet bolted to the top. The three bottom sections are 16, 4, and 1 ft 9 in. long. By interchanging the 4- and 1-ft 9-in. sections, sample heights of 1 ft 9-in., 4-ft, and 5 ft 9 in. can be obtained.

Future Uses of 1500 Psi Shock Tube. To obtain deeper soil samples the top 20 ft section of the shock tube can be placed over the 18-ft-deep infinite bottom SBLG base. In this configuration a soil height of 18 ft could be obtained without having a rigid interface at the bottom of the soil column. A steel liner would have to be placed in the infinite bottom hole in order to conduct tests at pressures higher than 250 psi. To enable the section of the shock tube to be bolted to the SBLG base an adapter plate would be required. Both additions could be constructed for a total cost of approximately $6,000.

When the shock tube is moved to a remote outside location such as the WES Big Black Test Site, it is designed to produce 3000-psi reflected pressure with the top end of the tube open. To maintain the same decay characteristics as those in the indoor shots, an additional 20-ft section of the tube would have to be added. Some support system and foundation would have to be constructed and special handling equipment would be required for placing the sample.

To place the shock tube in operation in the field would cost approximately $40,000. In the field it would be possible to conduct tests not only for a 4-ft soil or rock column without a rigid bottom, but for specimens located below the foundation, thereby eliminating both rigid side and bottom boundary conditions.

Another possible field use for the detonable-gas shock tube would be in a horizontal position. In this position it may be possible to create a traveling wave across a test sample. The test sample would be held in a position normal to the direction of travel of the shock front. The test sample could be either inside or outside the shock tube. With the specimen in position outside the tube there would be a frangible diaphragm covering the end of the tube. When the detonation wave breaks the diaphragm the test specimen would be loaded. If this method did not work a special section of tube would have to be constructed to hold the test specimen inside the tube. With the shock tube in the field it would cost approximately $1000 to build a support to hold the tube in a horizontal position. An additional $10,000 would be required to construct a special section of tube to hold the test specimen.

6000-Psi Static Testing Device. Presently under contract is a 6000-psi static test chamber that will use the CFS as a reaction structure (Figure 7). The test chamber itself is a cylinder 46-3/4-in. ID and 40 in. high. It has a piston-type lid that seals the top and rests on a steel plate with an O ring to seal the bottom.

The testing device is composed of (a) platen, (b) spacer blocks, (c) test chamber, and (d) upper bearing block. When the test chamber is inside the CFS it is sandwiched between the upper bearing block and the spacer blocks. The entire assembly of bearing block, test chamber, and spacer blocks rests on the same platen used with the 15,000-psi device.

The platen can be rolled in and out of the CFS with the assembly on it.

An air-to-hydraulic multiplier is used to pressurize the test chamber. The pressure pushes the piston-type lid up until the upper bearing block makes full contact with the ceiling of the CFS. The upper bearing block and the platen distribute the load to the CFS. The test sample is then loaded by the water pressure supplied by an air-driven pump.

200-Kip Loader. The 200-Kip Loader (Figures 8 and 9) is a device capable of applying a concentrated load in short times over a maximum stroke of 6 in.

This loader is a companion to the 500-Kip Loader. Together they provide a capability for testing structural shapes with loading rates varying from slow static loads to those at which the maximum load is reached in a very few milliseconds.

The 200-Kip Loader is designed to apply forces varying from 10,000 to 200,000 lb in either tension or compression. The design of the device is such that loads as high as 400,000 lb may be possible; however, the maximum load capability of the device is dependent on the use to which it is subjected.

The minimum time required to develop a specific load is affected by many variables, including piston location, magnitude of load, response of resisting member, and characteristics of the control valves, etc.; therefore, the rise-time characteristics of the loader are a function of the test conditions. A minimum rise time of 1.3 msec for a load in excess of 200,000 lb with approximately 1/4-in. movement of the piston has been obtained with the device.

The types and sizes of specimens that can be tested include beams up to 24 in. deep, 18 in. wide, and 144 in. long; columns with a maximum height of 6 ft and cross-section diameter of 18-in.; circular specimens having a specimen diameter at the grips of 2-1/2 in. and length of approximately 36 in. under tensile loading; and members requiring 2-point loading with up to a maximum of 4 ft between points of load application.

500-Kip Loader. The 500-Kip Loader is a servo-controlled, hydraulic device capable of producing loads up to 700,000 lb. Shown in Figure 10 is an overall view of the loader located on the frame for conducting tensile tests. In Figure 11, a large tensile specimen is shown in position prior to application of load.

This loader provides the capability of reaching maximum load in times varying from 80 msec down to essentially a static load. The device may be located over the same 8-ft-deep, 5-ft-wide, and 25-ft-long pit used for the 200-Kip Loader, or it may be placed on a 12-ft-high test stand that is independent of the pit area. A minimum rise time of 80 msec for a load in excess of 350,000 lb with approximately 1/4-in. movement of the piston has been obtained with the device.

Primarily the loader is used to determine the effect of strain rate on the strength characteristics of various structural and engineering materials in both tension and compression under either transient or static loads.

Instrumentation. The instrumentation used in the BLG Facility (Figure 12) utilizes several systems which provide a capability to record phenomena on approximately 160 channels of data in the frequency band width of DC to 40 KHz. The recording systems along with response characteristics are listed in Table 1. Conditioning and amplifying systems used to transmit the original to the recorders are listed in Table 2.

A spin table, drop table, shaker, and high-accuracy pressure console are utilized to calibrate pressure transducers and accelerometers. Technically competent personnel are available for all types of precision strain-gage applications.

TABLE 1

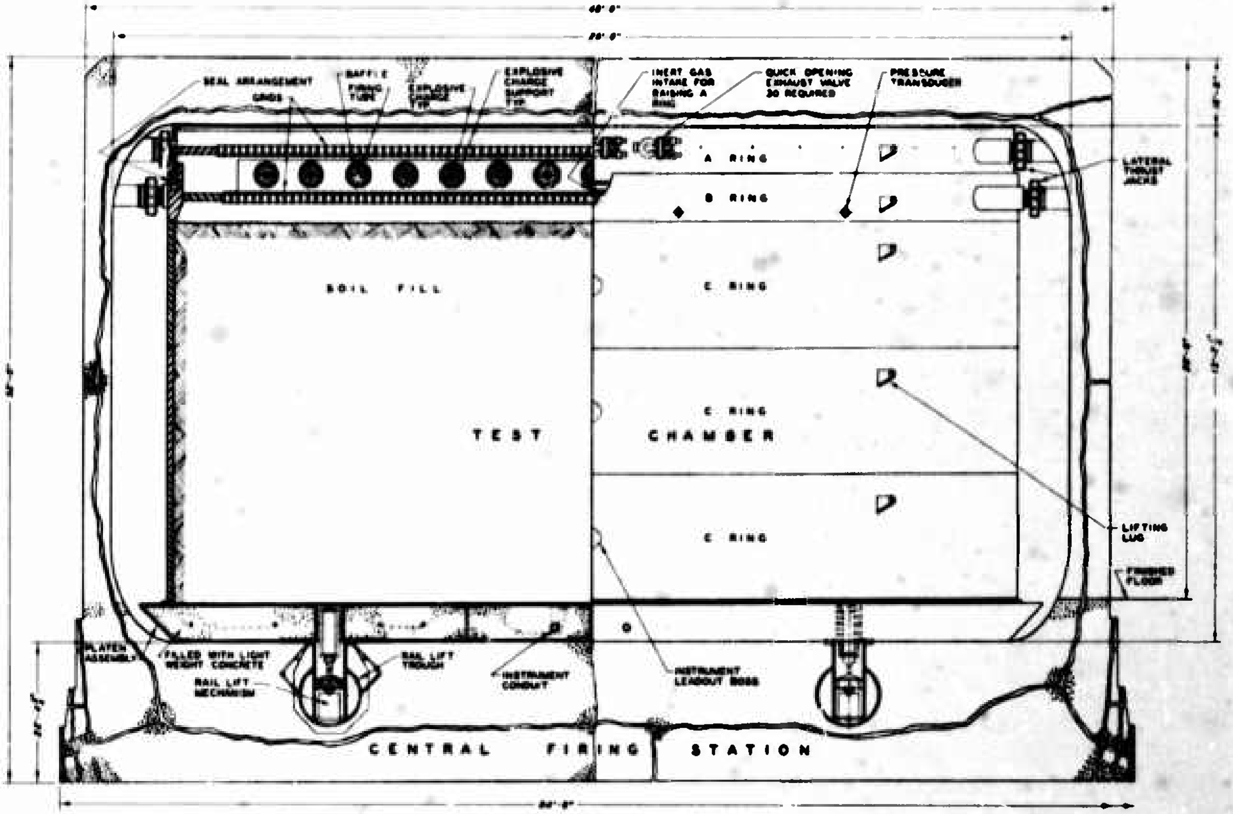
BLAST LOAD GENERATOR RECORDING SYSTEMS

Quantity	Systems	Data Band	Recording Speed in/sec
4	14-channel magnetic tape	DC-20 KCPS	60
5	14-channel magnetic tape	DC-40 KCPS	120
4	36-channel galvanometer Oscillographs	DC-2.5 KCPS (dep on galvo)	160
5	Oscillographs	DC-2.5 MCPS	-

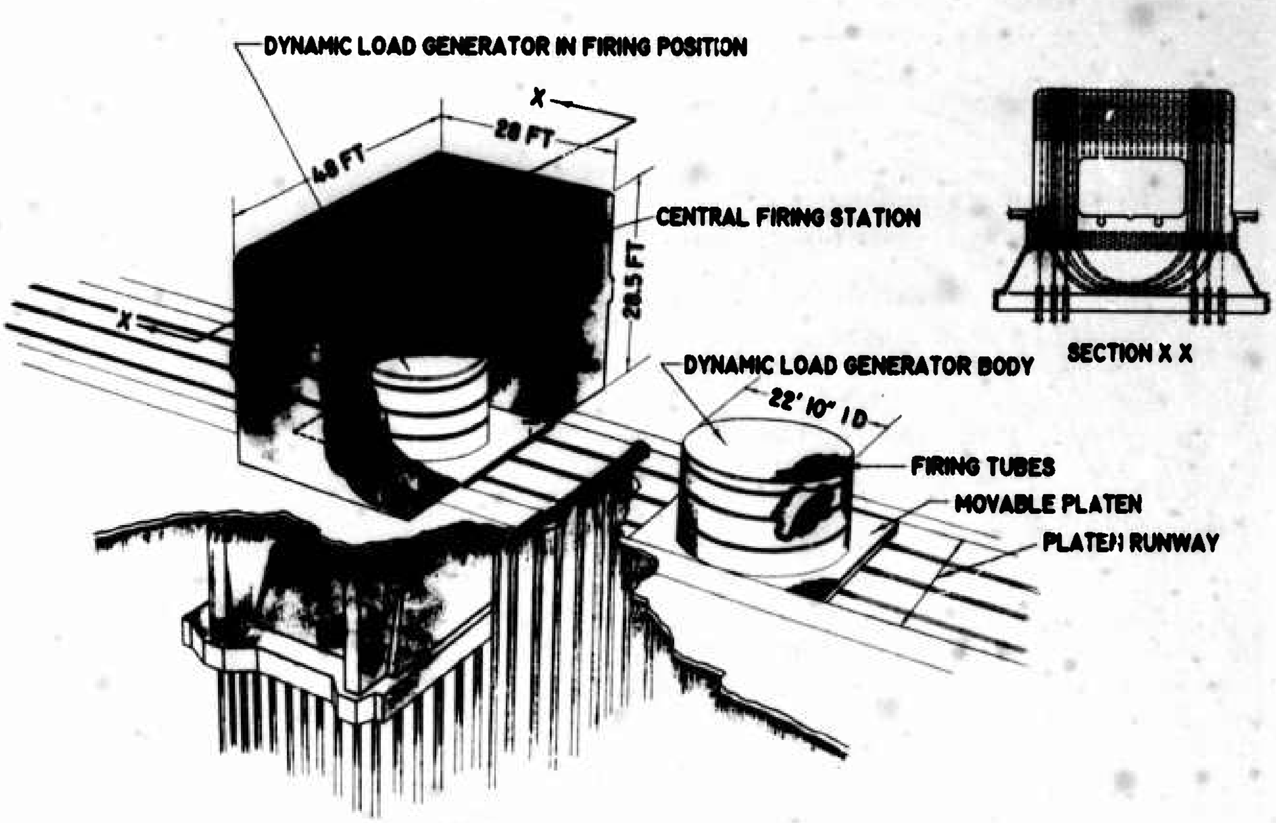
TABLE 2

AMPLIFYING AND SIGNAL CONDITIONING EQUIPMENT

Number of Channels	Equipment	Data Band
16	DC signal conditioning (for deflection gages)	0 - 600 CPS
48	WES-made operational ampli fiers with signal conditioner	0 - 20 KC
50	Commercial operational amplifier with signal conditioner separate	0 - 20 KC
48	Signal conditioner-amplifier module	0 - 20 KC

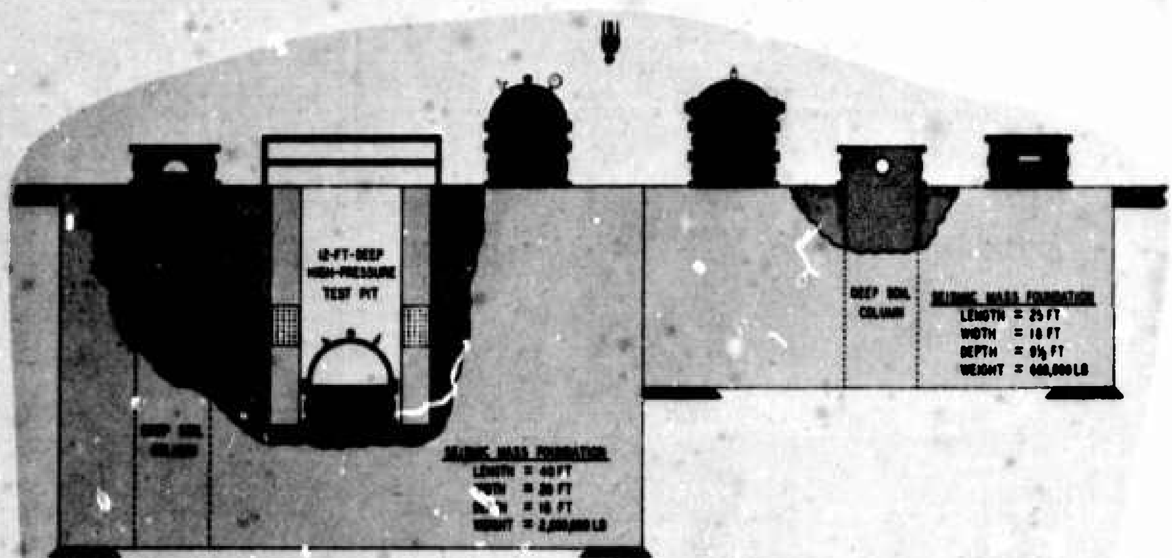


SECTION OF TEST CHAMBER



BLAST LOAD GENERATOR

Figure 1 Large Blast Load Generator.



SMALL BLAST LOAD GENERATOR FACILITY

CHARACTERISTICS

1. PEAK DYNAMIC PRESSURE: VARIABLE FROM 10 TO 250 PSI
2. MAXIMUM STATIC PRESSURE: 2000 PSI.
3. PRESSURE RISE TIME: 2 TO 5 MSEC.
4. DURATION OF PRESSURE: ≈ 1 SEC
5. INSIDE DIAMETER OF CHAMBER: 46 3/4 IN.
6. DEPTH OF SAMPLE: 2 IN. TO 38 FT.

APPLICATIONS

1. STUDIES IN THE DESIGN AND ANALYSIS OF THE RESPONSE OF UNDERGROUND STRUCTURES TO DYNAMIC AND STATIC LOADS:
   a. EFFECT OF THE SHAPE OF THE STRUCTURE.
   b. EFFECT OF THE RATIO OF SPAN LENGTH TO THE OVERALL LENGTH OF THE STRUCTURE.
   c. EFFECT OF STRUCTURAL FLEXIBILITY.
   d. EFFECT OF THE RATIO OF DURATION OF THE LOADING TO THE PERIOD OF THE STRUCTURE.
2. STUDIES IN THE RESPONSE OF VARIOUS TYPES OF SOILS TO DYNAMIC AND STATIC LOADS.
3. STUDIES IN METHODS OF SHOCK ISOLATION.
4. STUDIES OF STRESS-WAVE PROPAGATION IN SOILS.
5. STUDIES OF BLAST-CLOSURE DEVICES.
6. STUDIES IN THE DESIGN OF ENTRANCEWAYS AND ENTRANCE CLOSURE METHODS.

Figure 2 Small Blast Load Generator Facility.

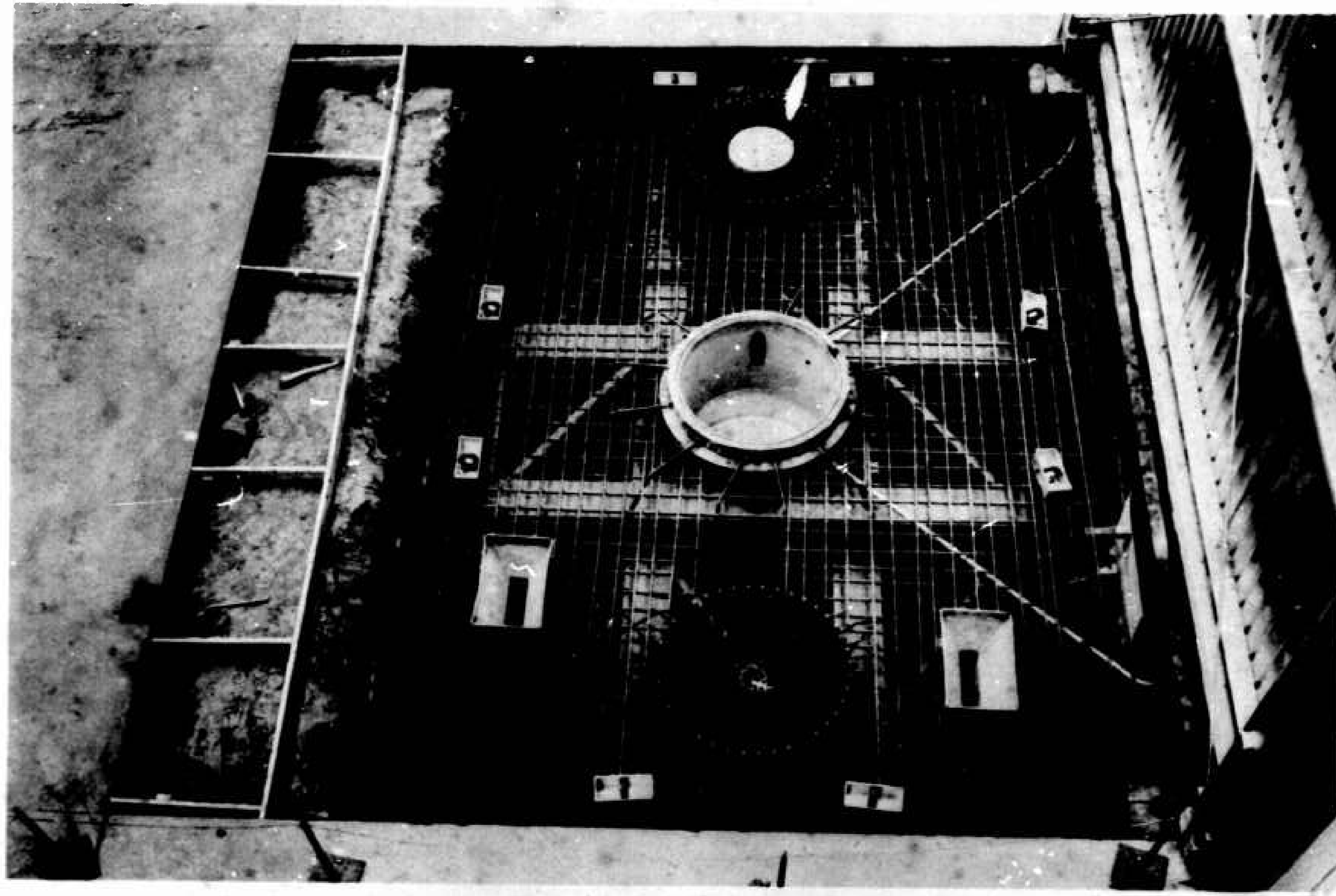


Figure 3 Construction view, 9-1/2-foot-thick foundation for SBLG.

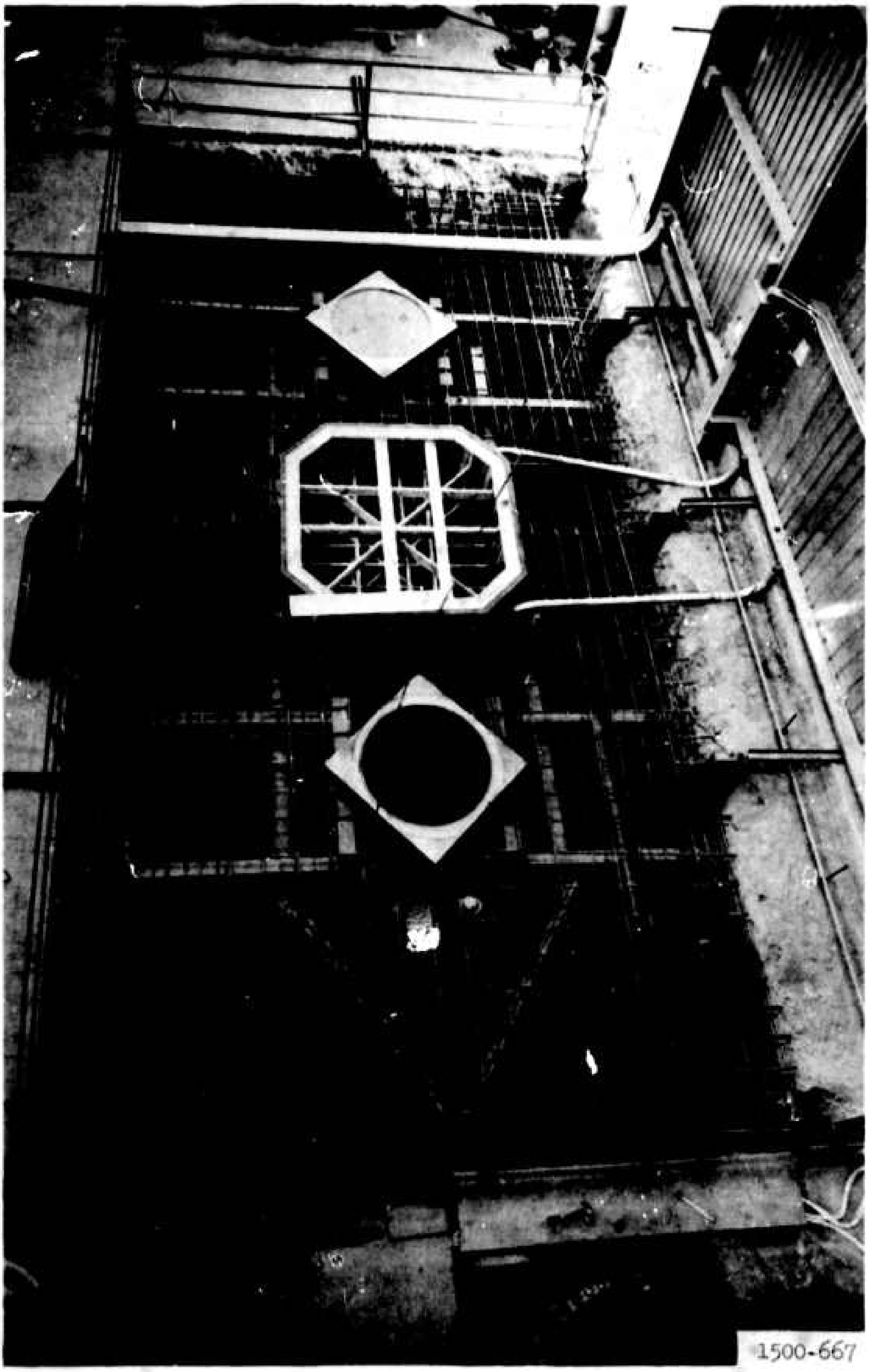


Figure 4 Construction view, 18-foot-thick foundation for SBLG.

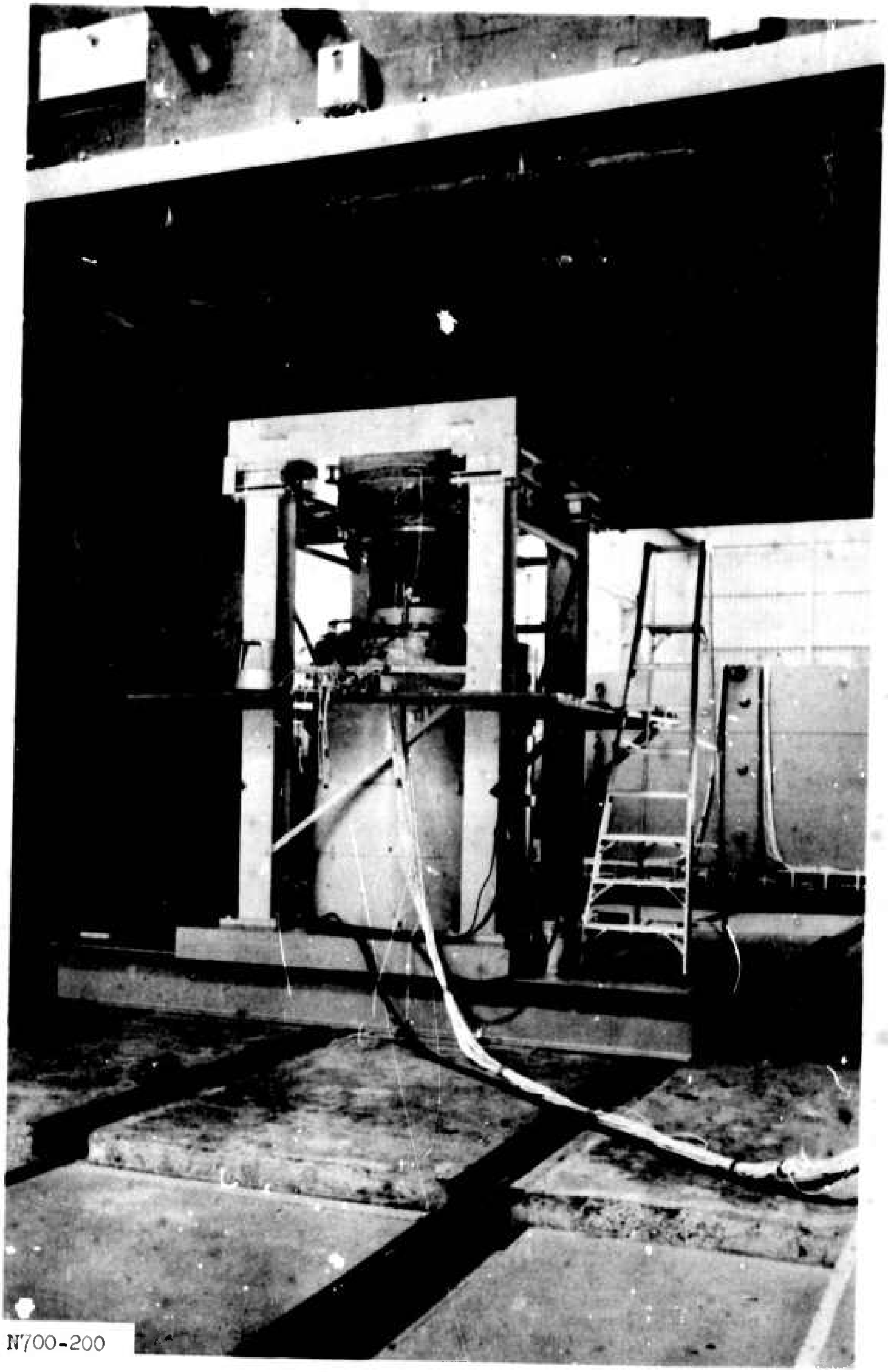


Figure 5 15,000-psi static loader.

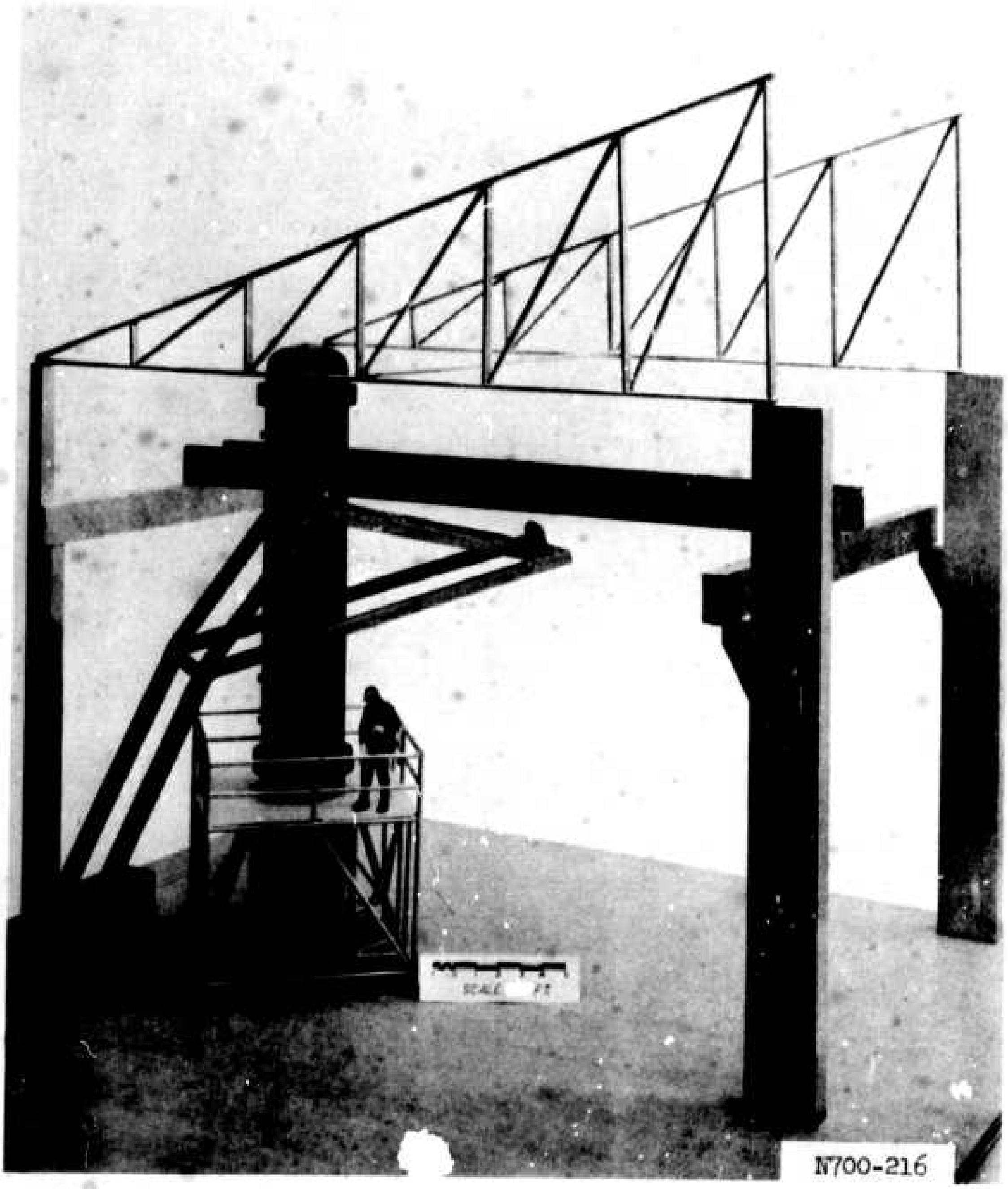


Figure 6 1500-psi detonable-gas shock tube.

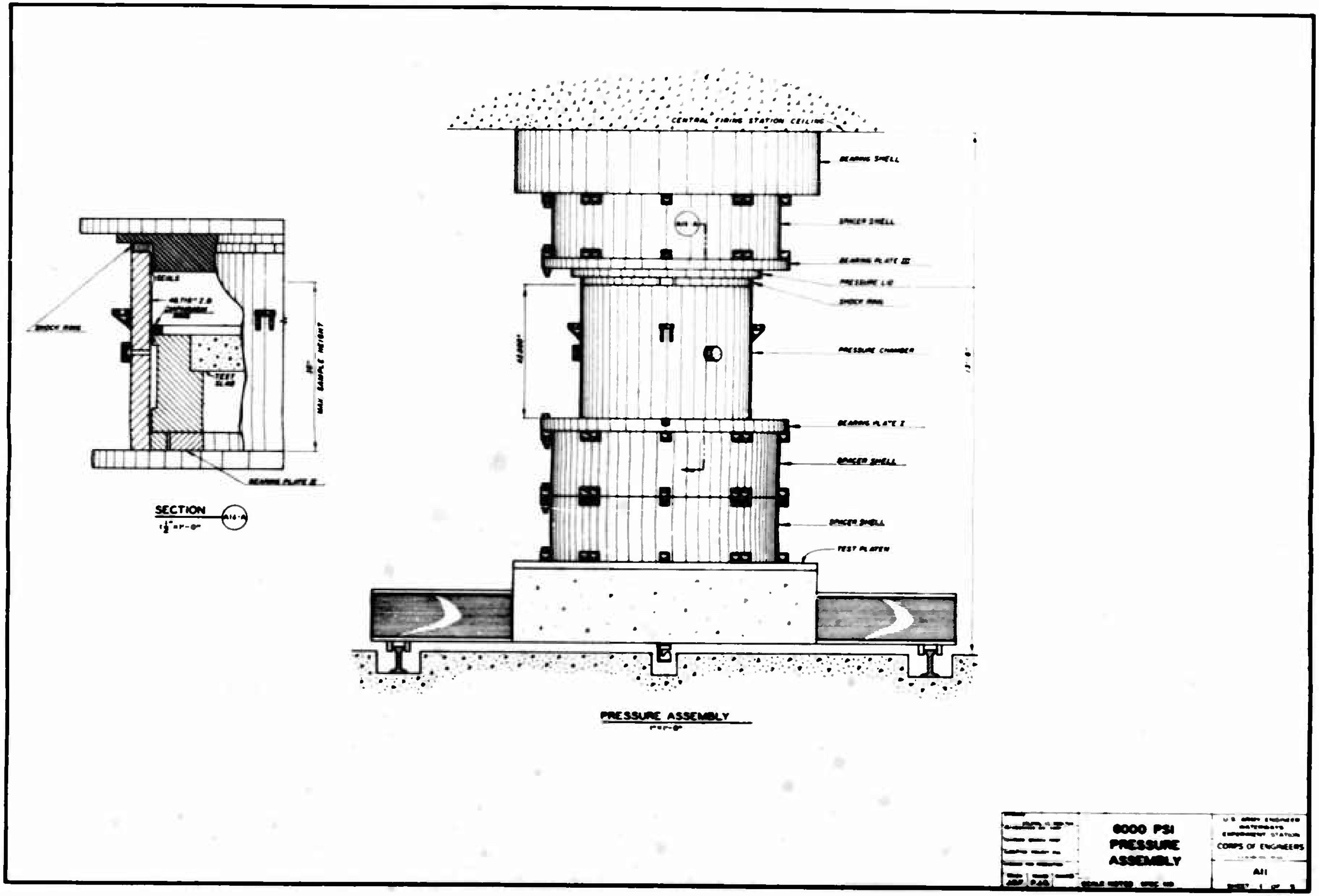
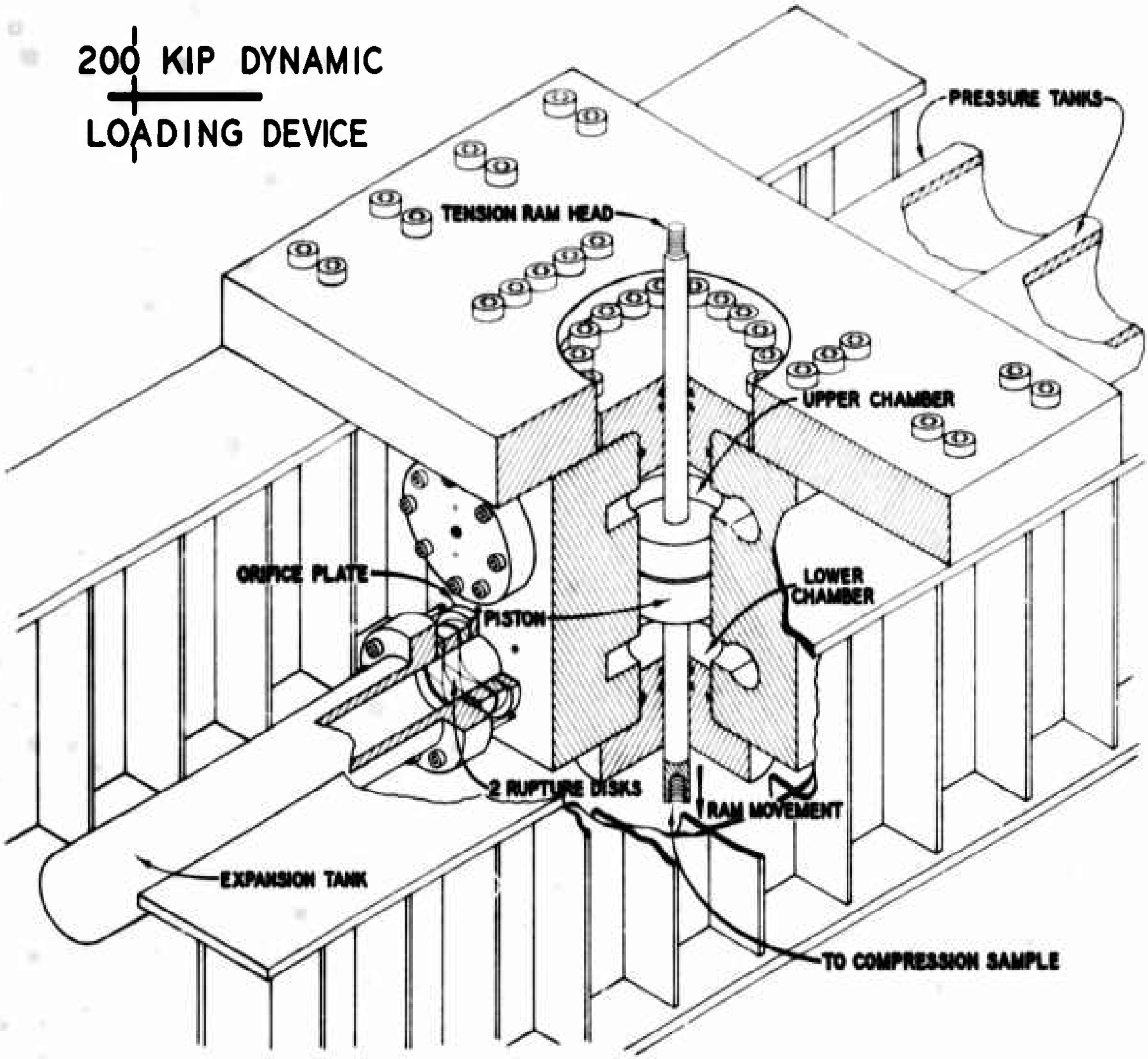


Figure 7 6000-psi static testing device.



CHARACTERISTICS

1. PEAK DYNAMIC LOAD: 200,000 LB IN LESS THAN 2 MSEC.
2. RISE TIME: 1 TO 200 MSEC.
3. HOLD TIME: 0 TO 200 MSEC.
4. DELAY TIME: 15 TO 500 MSEC.

APPLICATIONS

1. DETERMINATION OF DYNAMIC STRESS-STRAIN PROPERTIES OF CONSTRUCTION MATERIALS.
2. DYNAMIC TEST OF STRUCTURAL ELEMENTS:
   a. BEAMS UP TO 18 FEET IN LENGTH.
   b. COLUMNS UP TO 8 FEET IN LENGTH.
   c. TENSILE SPECIMENS UP TO 3 FEET IN LENGTH.
   d. STRUCTURAL CONNECTIONS AND FRAMES.

Figure 8 Characteristics of 200-Kip Loader.

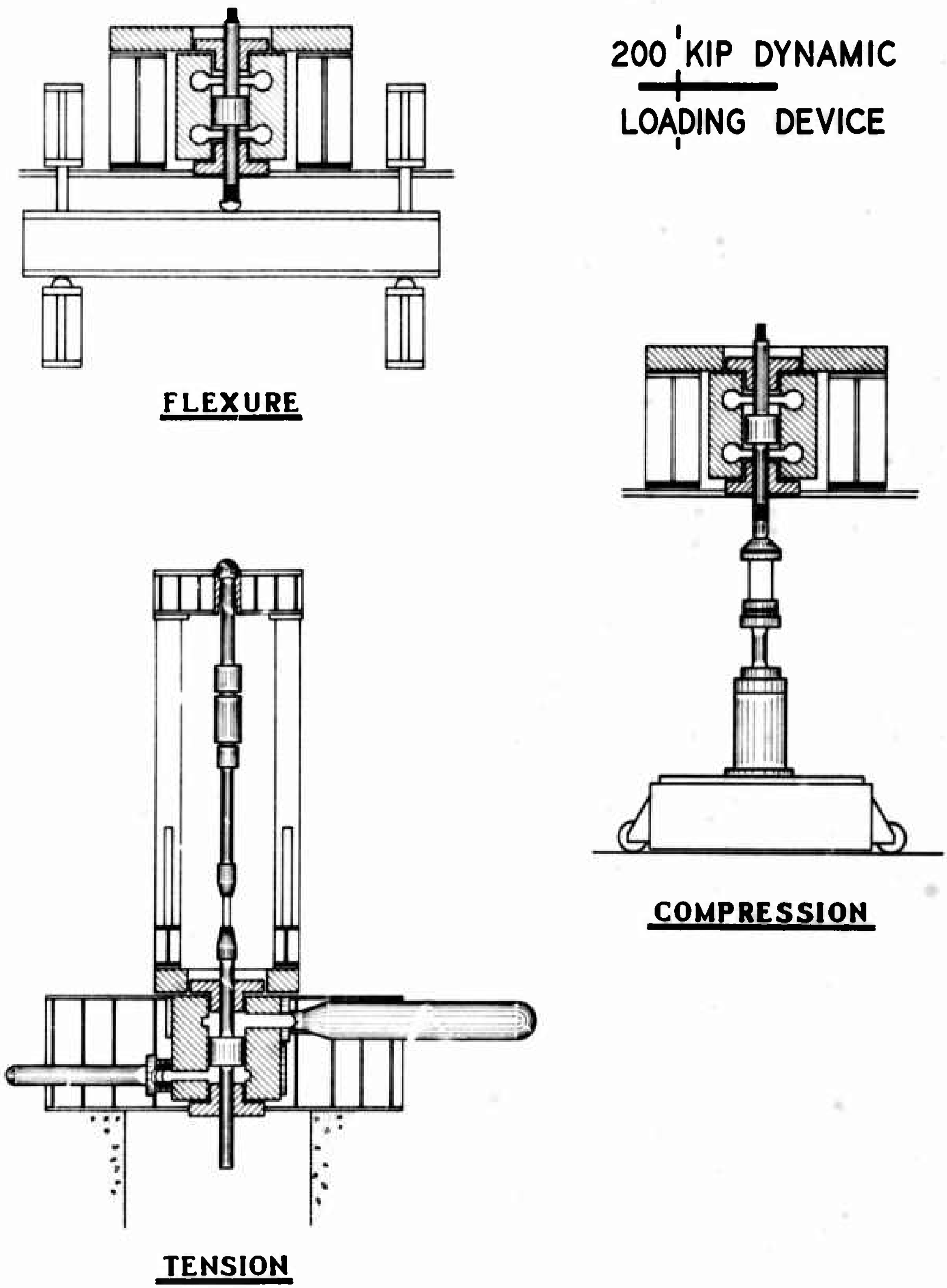


Figure 9 Loading modes for 200-Kip Loader.

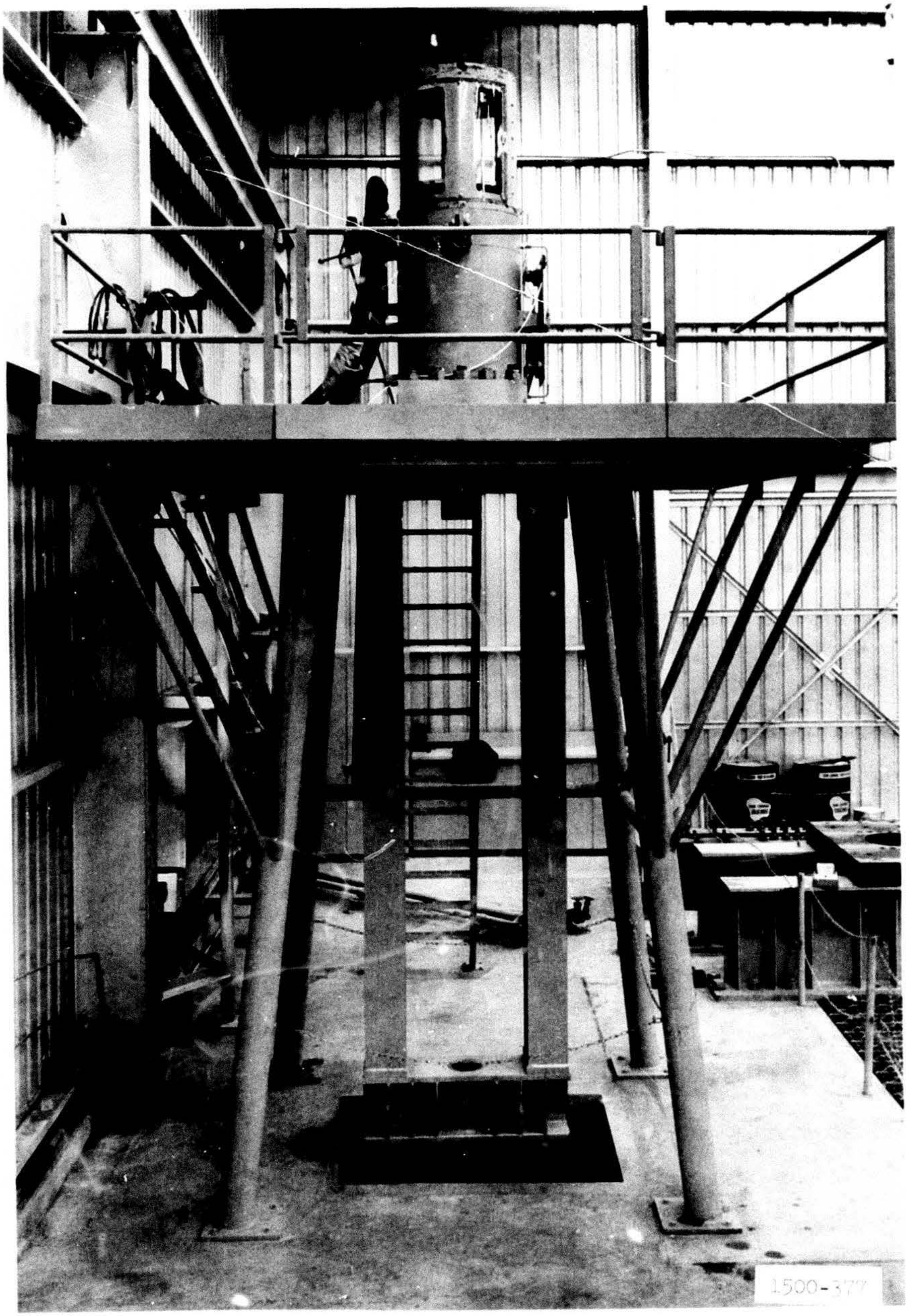


Figure 10 500-Kip Loader on tensile frame.

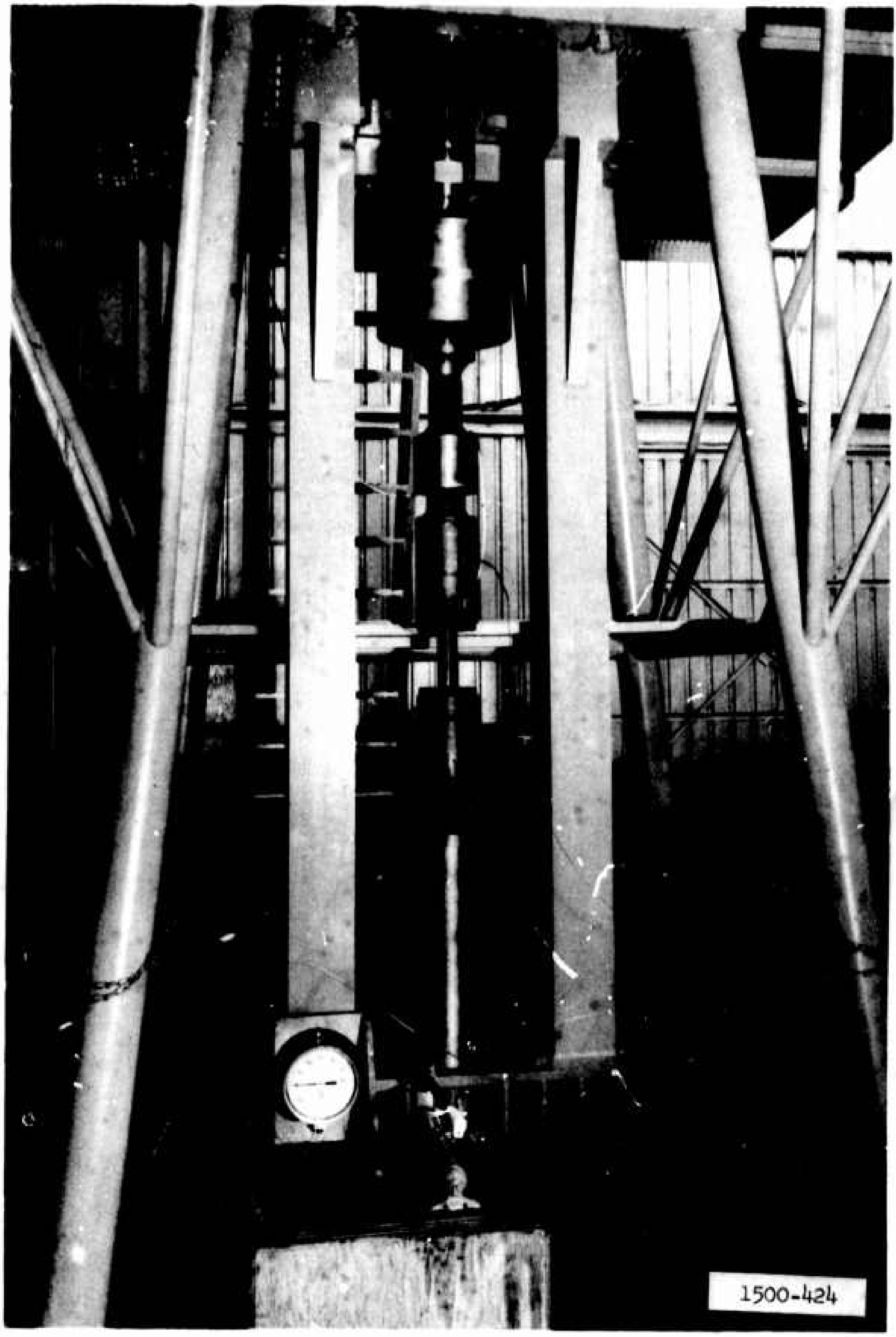


Figure 11 Tensile specimen in 500-Kip Loader.

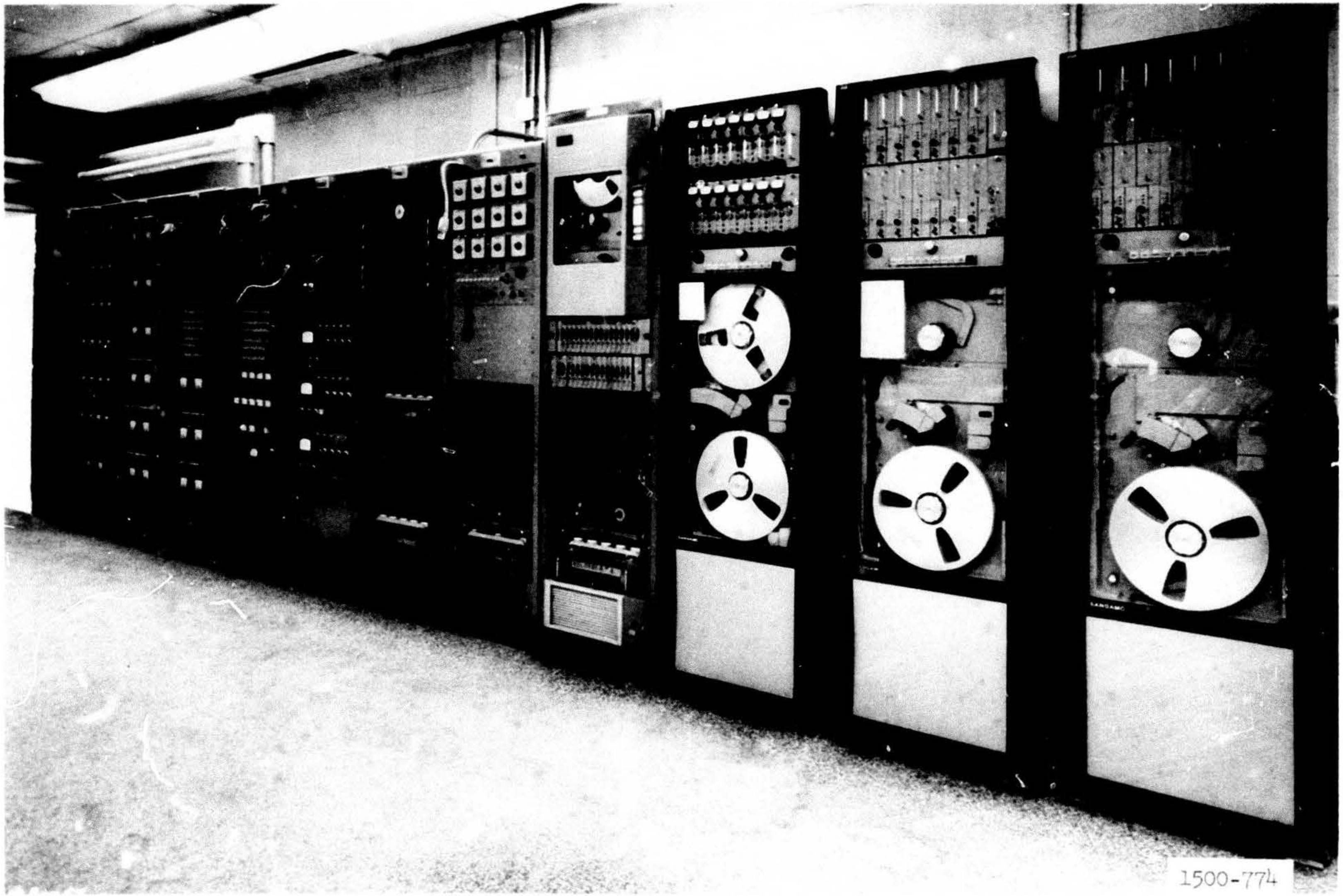


Figure 12 Primary instrumentation for Blast Load Generator Facility.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

~~This~~ The paper presents a description of the various test devices of the Blast Load Generator Facility and their capabilities. The Large Blast Load Generator is capable of testing models of underground protective structures at pressure up to 500 psi dynamically and 1000 psi statically. The Small Blast Load Generator can be used to test small models at static pressures up to 2000 psi and dynamic pressures up to 250 psi. Higher static and dynamic pressures can be obtained using the 15,000-psi static loader and 1500-psi detonable-gas shock tube, respectively. For determination of the static and dynamic properties of materials, the 200- and 500-kip loaders are available.

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	ROLE	WT	ROLE	WT	ROLE	WT
Blast load generators						
Models						
Subsurface structures						

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