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CONSTRUCTION OF A SECTOR SHOCK TUBE

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ABSTRACT

This report presents (1) the desirability of the construction of a tube in which shocks can be studied; (2) a chronological account of the construction of the tube, including a description of materials used and methods employed; and (3) plans for future investigation.

OBJECTIVE

The purpose of this project is to investigate shock waves and their interactions with other shock waves and various models. A tube whose cross section is 2 x 7 in. throughout, which produces plane shock waves, and a sector shock tube, described in detail in this report, and which produces cylindrical shock waves, are the basic equipment.

INTRODUCTION

The desirability of the construction of a tube in which nonplanar shocks could be studied occurred to the author sometime in 1951. The standard shock tube for plane normal shocks, with attenuation due solely to viscosity, heat conduction, or radiation, is indeed a most useful scientific instrument, but does not help in the understanding of actual blast effects. The investigation of spherical shocks is possible either through the study of real detonations in the field or by model experiments such as the bursting of a glass sphere through overpressure. However, the former experiments do not lend themselves to photographic observation while the latter type has always been on such a small scale as to make the "three-dimensional shock tube" more a toy than a scientific instrument.

The investigation of cylindrical shock waves constitutes, therefore, an interesting link between the study of plane shocks and the difficult study of spherical shocks. A further reason for the desirability of studies on cylindrical waves is the fact that an air burst will always form a Mach stem on the ground; due to the cylindrical symmetry of an air-burst phenomenon, such a Mach stem will actually be a cylindrical shock. Thus actual damage at intermediate distances from the epicenter is produced by neither plane nor spherical shocks, but by cylindrical ones. It is clear that, because one deals with a two-dimensional phenomenon, the gas flow can be confined between two parallel planes and that portions of cylindrical shock waves can be produced by having the two other walls at some angle to each other, such as, for example, 30°, 45°, or 90°.

In the autumn of 1951, these ideas were presented to Colonel Blunda and Dr. Perkins of AFSWP, who showed interest in the proposal. Dr. Perkins made the interesting point that the flow behind cylindrical shock waves would be an especially interesting study because it would exhibit the peaked character attributed to curved shocks. It was thought desirable to have a shock tube built up of several concentric sections so that compression chambers of various radii could be employed.

The following design is the one that was ultimately decided upon: the sector shock tube is made of 1-in. aluminum plate; the interior distance between the two parallel sectors is 4 in.; the sector angle is 30°; there are 4 sections with large breech radii of 2, 4, 6, and 8 ft; the 5th section terminates in a straight edge at a distance of 10 ft from the apex (see Fig. 1). Each section except the smallest has a window with a diameter of 9-in. Aluminum rather than steel was used to avoid excessive weight and to simplify the machining. The tube is of bolted construction throughout; the joints are vacuum-sealed with Permatex.

CHRONOLOGICAL REPORT

The first difficulty to be overcome was the cutting of the aluminum plates along circular arcs of such large radii. A vertical boring mill appeared to be the only machine capable of doing this job. The entire autumn of 1951 was spent in attempting to persuade various institutions to undertake this job, the Naval Gun Factory having flatly refused it at the outset. In June, 1952, General Electric agreed to perform the cutting, and the plates were returned in September, 1952.

Since it was contemplated to operate the expansion sections of the tube at a pressure less than atmospheric, the rather considerable force on the two large vertical plates had to be reckoned with. A set of braces for these plates was therefore thought advisable; the services of Harry B. Benford, Professor of Marine Engineering and an expert in submarine construction, were secured as a consultant for the design of these braces.

Many model experiments were carried out to determine the best method for mounting the diaphragm. It was realized at an early stage that the bulging of a cylindrically shaped diaphragm, because of overpressure, might give rise to shocks not perfectly cylindrical but having more complicated curvature.

The last three months of 1952 and the first half of 1953 were devoted to the design of braces, to their manufacturer, to the assembling of the various sections, and to the mounting. Professor Benford designed a system of braces made up of welded sections of angle irons as shown in Fig. 2. Bolting the braces of contiguous sections together is the means whereby the sections are clamped together. The tube is mounted on U-shaped cradles (Fig. 3) which can roll on two steel rails (Figs. 4 and 5). Each two-foot section can be moved independently. Locating pins take care of the proper alignment (Figs. 6 and 7). During the second half of 1953, construction of schlieren stations and of the ancillary electronic equipment was begun. In November, with three sections in place, the first shadowgraph pictures of the cylindrical shocks progressing into air at atmospheric pressure were obtained. It was anticipated that the entire expansion section would have to be partially evacuated to be able to produce and to observe sufficiently strong shocks, so a Kinney vacuum pump (type VSD 8811) was purchased. For the installation of the last rather heavy sections, it was necessary to equip the laboratory with an overhead hoist. Until April, 1954, the work was concentrated on the vacuum system and on the perfection of the electronics. A 1.8-Mc Potter counter-chronograph was purchased.

During the summer and fall of 1954, work continued on a reduced scale because increased emphasis was being placed on diffraction studies in the 2 x 7-in. shock tube. This work actually continued until January, 1956, although work on the sector shock tube was resumed in October, 1954.

From October, 1954, until the spring of 1955, progress was severely hampered due to vacuum trouble. To be able to fire reasonably strong shocks, it is essential that the expansion chamber have a very low leak rate. It was therefore decided to disassemble all the sections and to seal the joints with Permatex. Also at that time the supporting cradles were reinforced and strengthened with gussets. By June, 1955, a good vacuum and proper alignment of the entire tube were achieved. In October, 1955, manometers were installed and the tube was pumped down to 0.1 mm of Hg. A vacuum better by two orders of magnitude was achieved by substituting an extra large hose for the smaller one between the shock tube and the Kinney pump.

The rest of 1955 saw the construction of gate circuits, control units, a vacuum thermocouple gauge, and a spark source. Since December, 1955, work has been done on new techniques for breaking the very large diaphragms that are needed in the sector tube. Various methods, such as burning the diaphragm by means of stretching a wire alongside it and sending a current pulse through the wire, or by sending a strong current pulse through an aluminum-coated mylar diaphragm, have been and are continuing to be tested. For large diaphragms a prod which initiates a small spherical shock at the point of contact seems to be inappropriate for initiating shocks.

In April, 1956, a series of shadowgraph pictures was taken which indicated that the equipment is in proper working condition.

FUTURE PLANS

The first task is clearly a detailed investigation of shock speed as a function of distances from the apex for various initial pressure ratios. This can be done with the equipment now available. The next very promising idea is to investigate pressure behind the shock, since these flow quantities will now exhibit marked variations. This can best be done with commercially available pressure gauges. Measurement of density behind the shock, using the absorption of light or x-rays is also feasible. Although a compression chamber of zero length, i.e., a line source, was not contemplated originally, it has since been considered favorably. For this purpose shocks would have to be produced by means of an explosive line source. Finally, it is our desire to study convergent shocks by inserting a large diaphragm between the last two sections and observing the shock near the apex. This might furnish interesting information on the stability, or lack of stability, of convergent shocks and on the possibility of obtaining high temperatures in this manner.

ACKNOWLEDGEMENTS

Much of the early design work of the sector tube was done by Dr. R. N. Hollyer, Jr., now with the Research Laboratory of General Motors. The following workers were responsible for the assembly and alignment: Mr. J. Green, Mr. W. Johnson, Dr. A. Kolb, Mr. A. LaRocca, Dr. R. E. Slattery, and Mr. D. L. Upham. The electronic equipment was constructed by the junior author (A. L. Cole) of this report, who is also slated to carry out the first measurements. Much general advice and help from Dr. E. B. Turner, now with Ramo-Wooldridge Corporation, is gratefully acknowledged. On the technical side, the assistance of Mr. Herman R. Roemer, supervisor of the physics instrument shop, and of Mr. A. O. Buchholz was of great value.

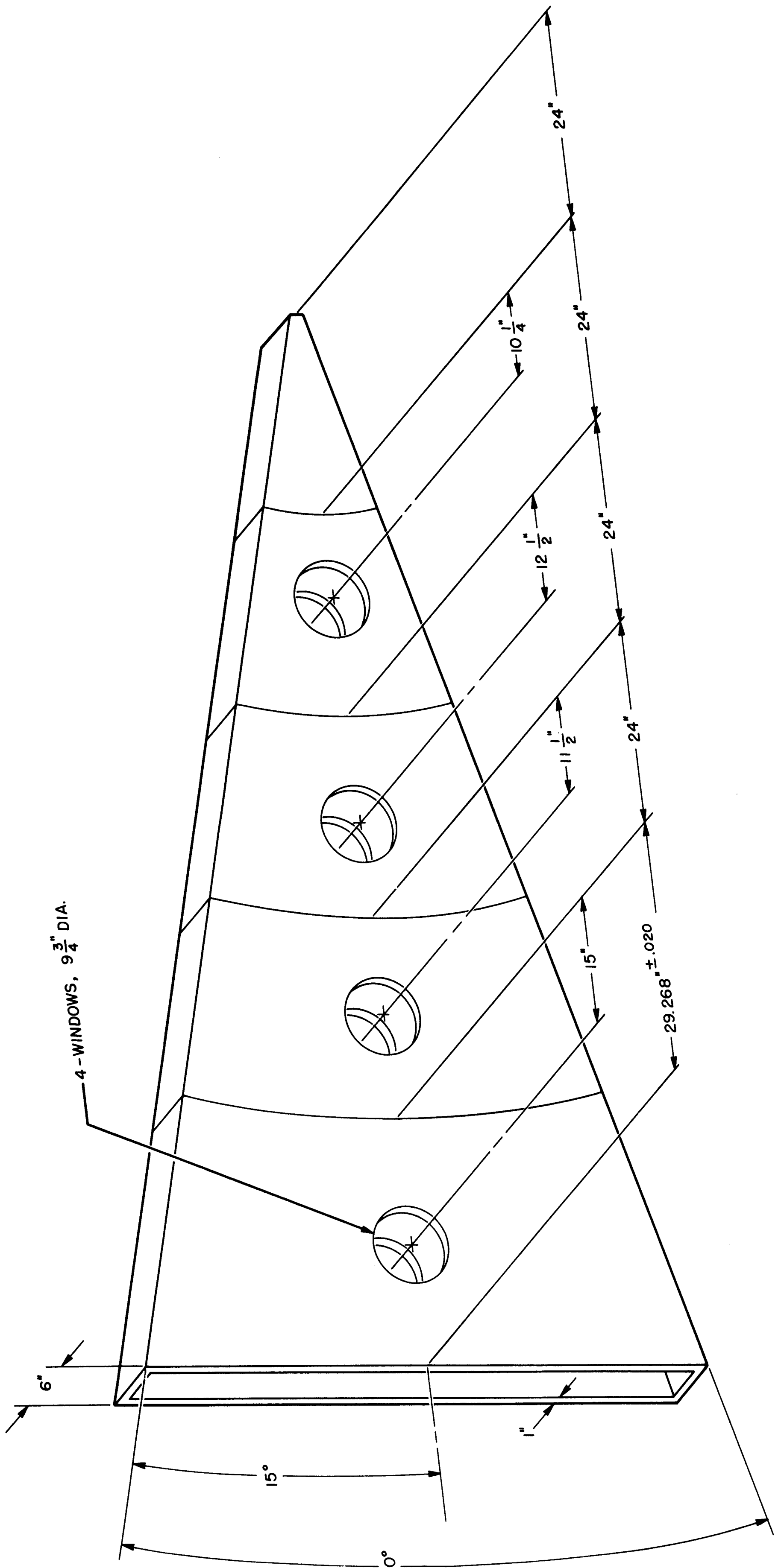

Fig. 1. Trimetric drawing of sector tube.
Design and assembly of sector shock tube.

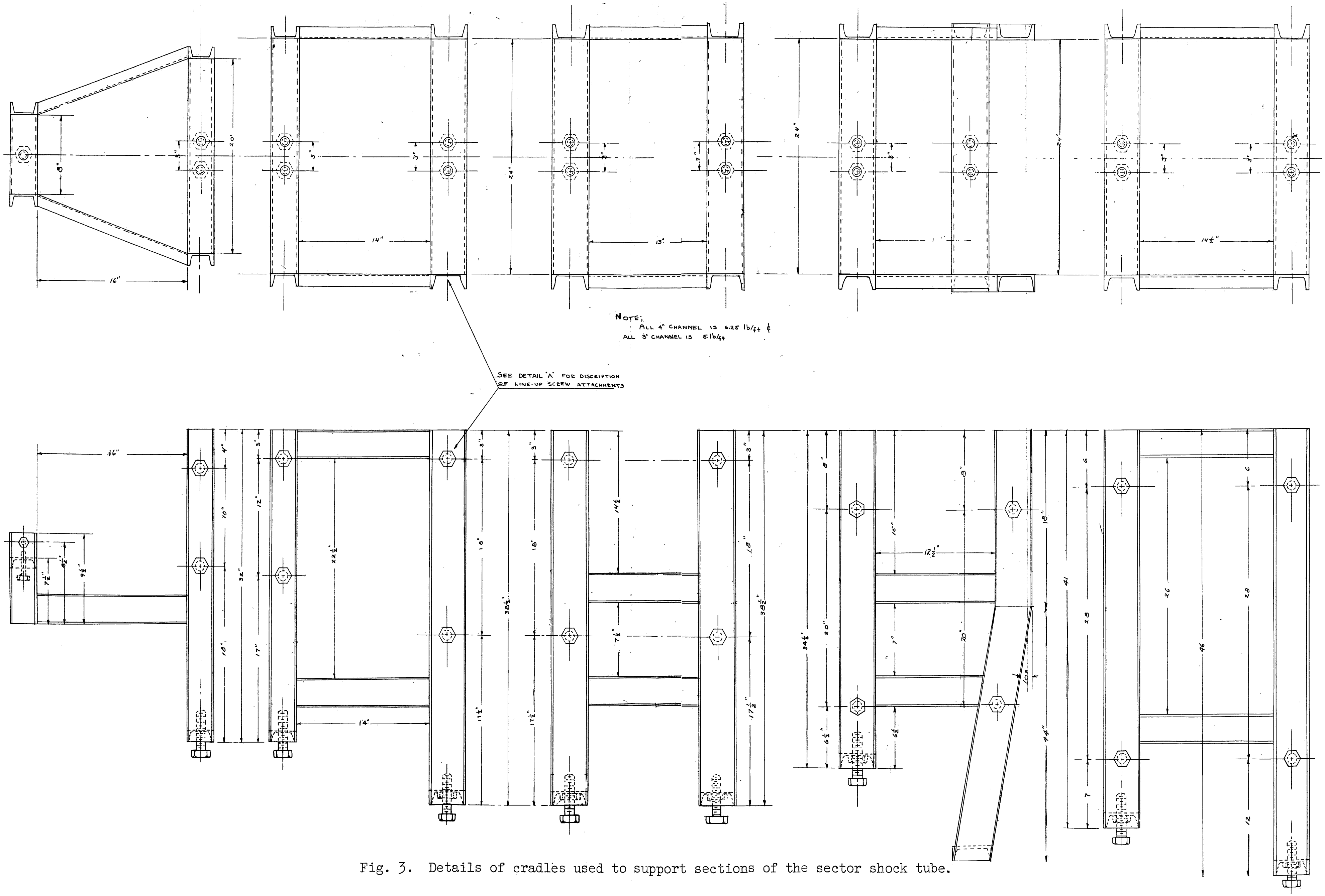

Fig. 3. Details of cradles used to support sections of the sector shock tube.

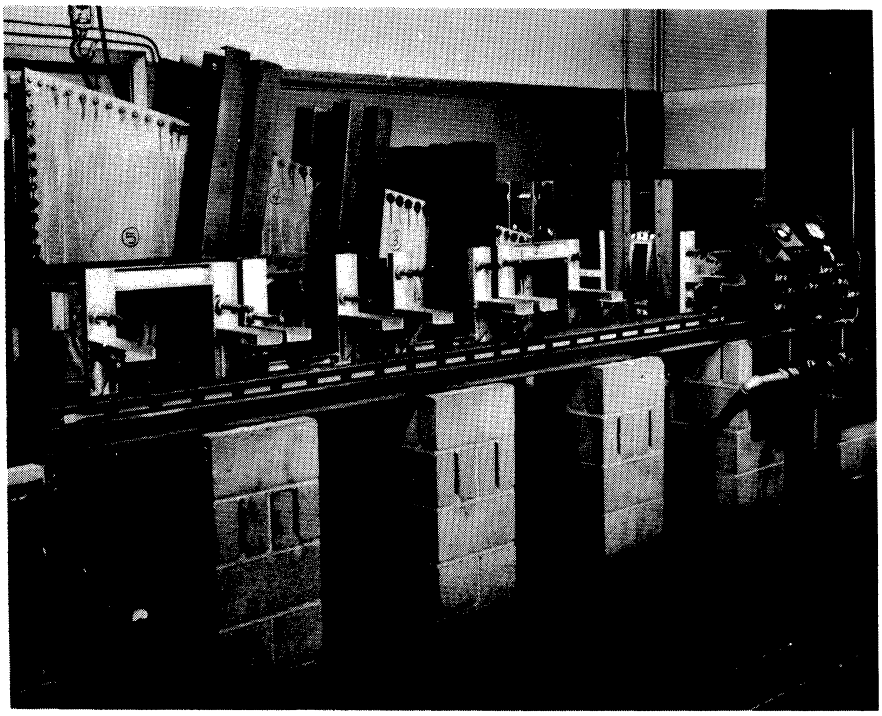

Fig. 4. The assembled sector shock tube with the vacuum and pressure control system.

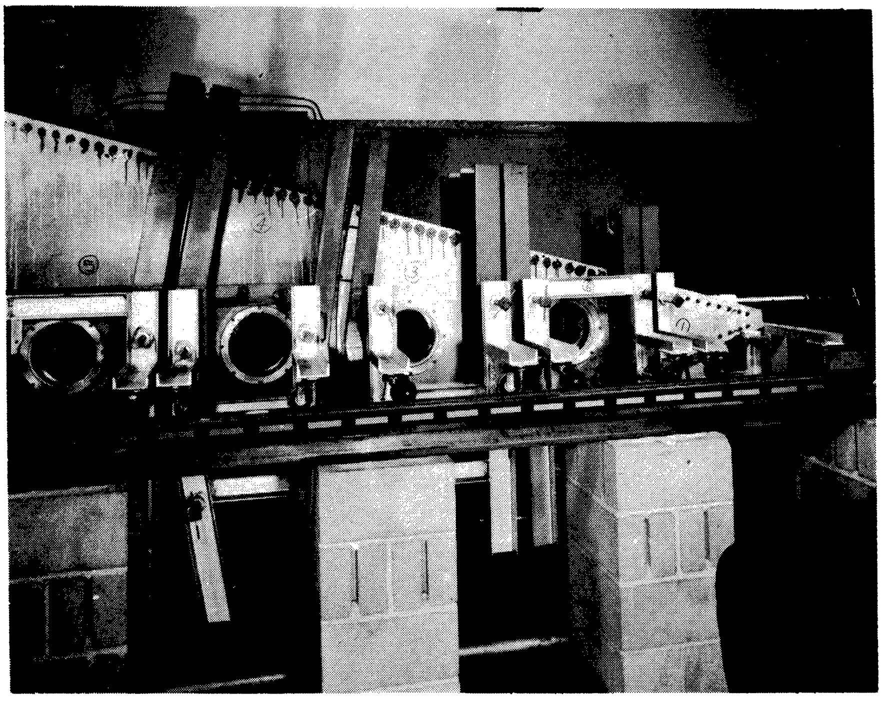

Fig. 5. The sector shock tube assembled with braces, mounting cradles, rails, and pillars.

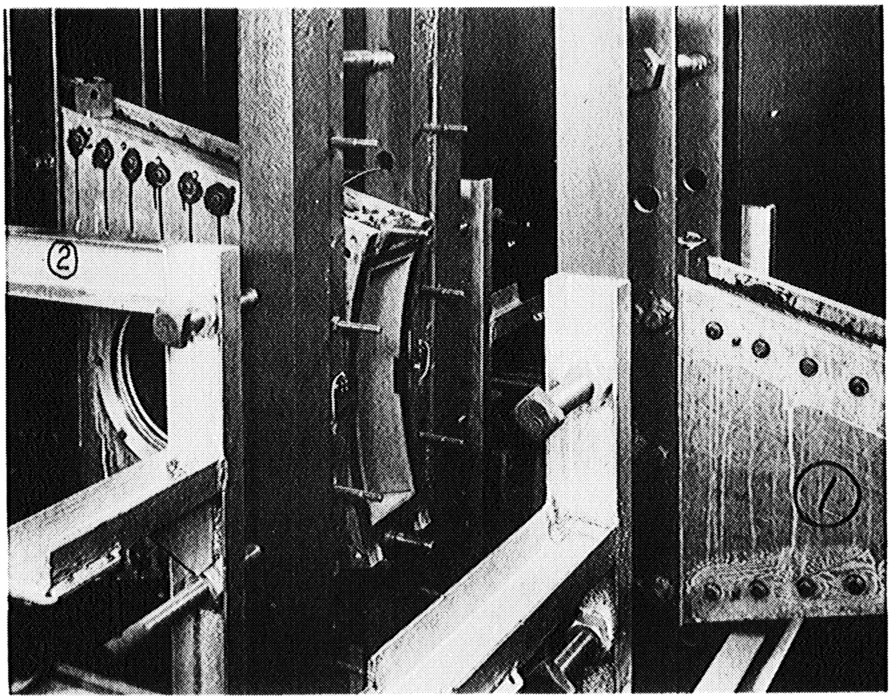

Fig. 6. Details of the diaphragm breech showing the locating pins and clamping bolts.

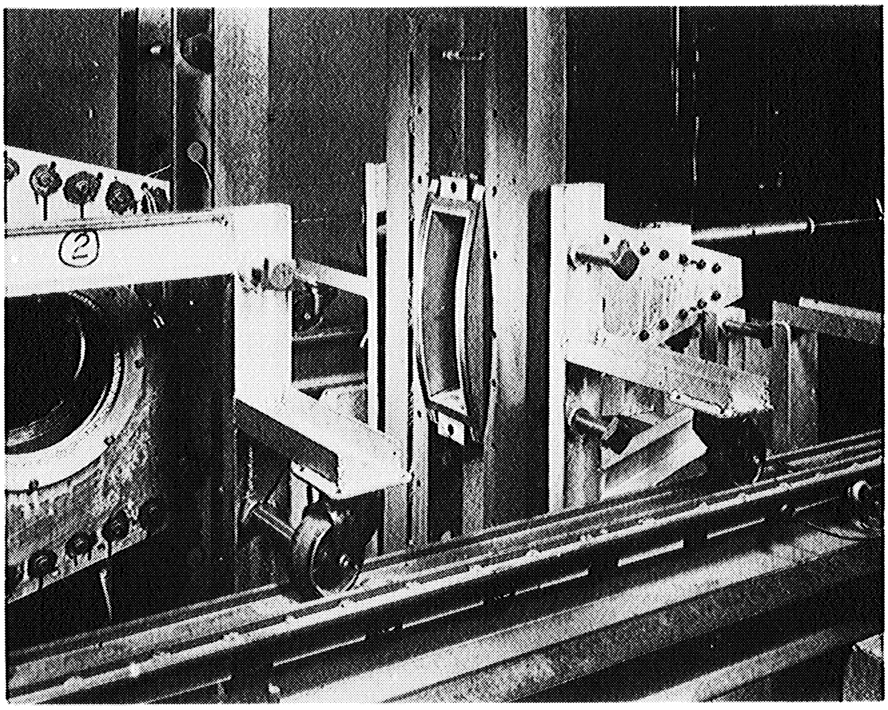

Fig. 7. Details of the diaphragm breech showing the holes for the locating pins.