NRL Memorandum Report 4003

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Shock Performance of a Shipboard Electrical Switchgear

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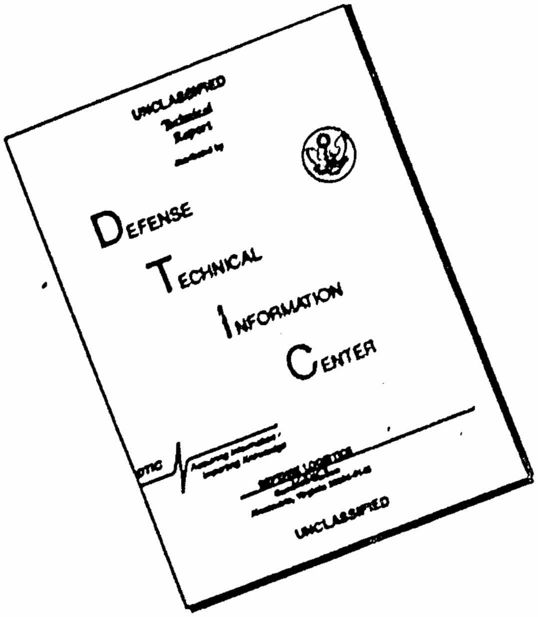
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Shipboard circuit breakers are required to be shock-certified on the Lightweight Shock Machine (LWSM). In spite of this, breakers sometimes malfunction during ship shock tests or shock tests of switchgear assemblies on the Mediumweight Shock Machine (MWSM). In the study described here, a total of 27 AQB circuit breakers were tested on the LWSM, their performance noted and the shock environments to which they were exposed measured. The same breakers were then installed in a typical shipboard switchgear which was tested on the MWSM, and again the

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20. Abstract (Continued)

performance of the breakers noted and their shock environments measured. Initially, almost all of the breakers malfunctioned on the LWSM, opening or tripping from the closed position. After some modification and adjustment, a majority of them passed the LWSM test, although some did not. None malfunctioned when installed in the switchgear or the MWSM. Comparison of shock environments in terms of peak acceleration indicated the LWSM environment to be several times as severe as the MWSM environment. It appears that the LWSM test is successful in its intended role as a screening test, so that breakers which pass can be relied on to operate properly during MWSM or ship shock tests. It also appears that breaker malfunction during LWSM tests can be substantially eliminated by proper setting of internal adjustments and/or minor modifications.

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SHOCK PERFORMANCE OF A SHIPBOARD ELECTRICAL SWITCHGEAR

BACKGROUND

Navy vessels, particularly combatants, must be able to operate at high speeds in rough seas for extended periods of time, possibly under enemy attack. Shipboard systems and equipments must operate reliably in spite of the severe mechanical shock and vibration environments which then prevail. To assure this reliability, the Navy has developed standard shock and vibration environments (Refs. 1, 2) to screen out system components and equipment items which would have a low probability of survival aboard ship. These standard environments are not intended to duplicate any particular shipboard environment (of which there are many) except in a general way, so are somewhat arbitrary. Their fundamental justification is the experience over a period of more than thirty years that things which survive the standard tests rarely give problems in service, while those which do not survive the tests almost always do. In addition, the Navy pursues an ongoing program of at sea ship shock tests, in which operating ships are exposed to underwater shock from nearby explosions. These tests provide measured data for maintaining a current shock data base, and serve as practical benchmarks as to how well the current design/test procedures and specifications are working. Several of these tests have indicated that circuit breakers are a potential problem, since a few may trip or open due to shock in the absence of electrical overload. While the percentage of those involved is low, only a few of the hundreds on board, the ramifications are serious. Failure of a small group of circuit breakers could result in the loss of propulsion for hours, for example. Further, ship tests are conducted at a level of severity well below that which the ship should be capable of surviving. It is reasonable to expect that at more severe levels a larger percentage of circuit breakers would fail. Similar failures have been found to occur in circuit breakers installed in switchgear assemblies exposed to the Navy standard shock tests, although the breakers themselves have passed similar tests previously.

PROBLEM STATEMENT

The Navy standard shock tests are performed on one of a group of specified machines according to the weight and size of the test item. These machines are considered completely equivalent for test purposes in all respects except payload capacity. They are the Navy Class HI Shock Machine for Lightweight Equipment (LWSM) (0-400 lb), ditto for Mediumweight Equipment (MWSM) (0-6,000 lb), and the Navy Floating Shock Platform (FSP) (0-60,000 lb). In the future they will be joined by

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the Navy Large Floating Shock Platform (LFSP) (0-450,000 lb) (Ref. 4). The governing Navy specification for circuit breakers (Ref. 5) requires that they be shock-certified on the LWSM, and that production units should be tested on a sample basis. The latter requirement could be waived on grounds of similarity to shock certified units. In recent years, breakers installed in switchgears have been found to fail in tests on the MWSM, the FSP and during ship shock trials. This immediately raises the question of whether these breakers could have passed the LWSM test.

The purpose of the study reported here was to subject the group of circuit breakers to the Navy standard shock and vibration tests, and to determine their failure rates and the critical parameters of the environments to which they were exposed; then, to install them in a typical electrical switchgear and expose it to the standard tests specified for it, and again determine failure rates and environmental parameters for the circuit breakers. Comparison of these sets of data would then reveal any serious discrepancies in the test environments and suggest methods to rectify the situation.

DESCRIPTION OF SWITCHGEAR

The switchgear (Fig. 4) used here was one assembled for the purpose by the Philadelphia Naval Shipyard. It was not an actual shipboard unit, but was of representative design and construction. The complete unit was 81 in. high, 92 in. wide and 43 in. deep, and was bolted to three 4 in. shipping channels (steel) at the base, making the total height 82-5/8 in. and weight 5650 lb. The basic structure was of welded dural angle, with steel and dural panels bolted or welded to it, and formed three bays. Primary feed connected to the right hand bay, which contained an ACB-2400 circuit breaker (middle compartment), a fuse compartment (bottom) and monitor instrumentation (upper compartment). The central bay contained two ACB-1600 breakers which were assigned identification numbers 1 (middle compartment) and 2 (bottom compartment). The upper compartment contained some monitoring circuitry and a pilot light. The left-hand bay contained eighteen AQB-LF101 breakers (upper section) and nine AQB-LF250's (lower section). These were numbered 1-18 and 1-9 from left to right and top to bottom. The ACB-2400 bay was 33 in. wide and the ACB-1600 27 in.; both were 43 in. deep. The AQB bay was 32 in. wide and 30 in. deep. To provide a foundation for attachment to the testing machines, the switchgear shipping channels were welded down to a 100 x 50 x 29/32 in. steel plate weighing 1320 lb.

TEST PROCEDURE

The basic test procedure was furnished by NAVSEC 6156 (Ref. 6), and required vibration tests of three AQB-LF101 and three AQB-LF250 breakers to the requirements of Ref. 2 modified by eliminating the endurance segment. All of the AQB breakers (27 total) were to be shock-tested on the LWSM using the fixtures and procedures of Ref. 5, each breaker being instrumented for the measurement of acceleration on the fuse block and at the back of the fixture panel to which the breaker was fastened. High speed movies were required for shock tests of the six breakers which had been vibration-tested. All of the above tests were to be conducted with the breakers carrying full rated current. The circuit breakers were then to be reinstalled in the switchgear, and the entire assembly subjected to the complete vibration test of Ref. 2. The switchgear was then to be mounted on the MWSM and subjected to shock test as described in Ref. 1, but of sub-standard test severity because of the excessive weight. The switchgear was instrumented extensively to measure acceleration histories at various points of its structure, on the three LF101 and three LF250 breakers which had been vibration tested, and on the three ACB breakers. The switchgear was to be tested twice, in effect. Each blow of the test specified by Ref. 1 was to be delivered with all breakers closed, then repeated with only the instrumented ones closed. For all shock and vibration tests of the switchgear, the six AQB breakers which had been vibration tested individually (and instrumented for the switchgear shock test) were to be energized at full rated current.

VIBRATION TESTS OF INDIVIDUAL CIRCUIT BREAKERS

Since the six AQB circuit breakers which were vibration tested were later to be instrumented for the switchgear shock test, they were selected to provide a survey of the shock environment as it might vary through the AQB bay. The LF101's were installed in three rows of six in the upper part of the bay: those chosen were No. 6 (last one in the top row, adjacent to the joint between the AQB and 1600 bays), No. 10 (fourth in the middle row) and No. 14 (second in the bottom row). Number 15 (third in the bottom row) was also selected for vibration test because it and No. 16 were rated at 50 amp, while all of the others were rated at 100 amp. It was not instrumented for the switchgear shock test, however. The LF250's were all 250 amp units, and were arranged in lower part of the bay in three rows of three. Those chosen for vibration test were No. 3 (last in the top row), No. 5 (middle of the middle row) and No. 7 (first in the bottom row). These seven breakers were removed from the switchgear together with one mounting base for each size. Test fixtures were fabricated following the drawings of Ref. 5 for test fixtures for shock testing LF101 and LF250 circuit breakers with fuse blocks. These were attached to a vertical fixture on the vibration machine using spacer channels slightly longer than those used on the LWSM, and after vibration tests were attached to the LWSM for shock tests. Vibration tests were conducted on the NRL 5000 lb. Reaction-Drive Vibration Machine in accordance with Ref. 2 over the frequency range 5-33 Hz, the endurance segments not being performed.

VIBRATION TESTS OF AQB-LF101 CIRCUIT BREAKERS

For vibration tests the LF101's were wired to a three-phase Y-connected resistive load and fed with 250v three-phase 60 Hz power. Current for No.'s 6, 10 and 14 was 90 amp, for No. 15, 50 amp. No mechanical or electrical activity could be detected for any of these breakers during or after the test. The test arrangement is shown in Figs. 1 and 2.

VIBRATION TESTS OF AQB-LF 250 CIRCUIT BREAKERS

The LF250's were wired with poles series-fed to a single-phase resistive load, and energized with 40v single-phase 60 Hz at 250 amp from a welding machine. As with the LF101's, no effect of vibration could be detected. The test arrangement is shown in Figs. 3 and 4.

SHOCK TESTS OF INDIVIDUAL CIRCUIT BREAKERS - INITIAL SERIES

After completion of the vibration tests, the test fixtures were attached to the LWSM and all twenty-seven of the AQB breakers tested to the requirements of Ref. 5, viz: one 5-ft Top blow and one 5-ft Back blow. Several breakers were given additional blows, as noted below. For shock tests, the breakers were energized with a commercial circuit breaker tester - although its duty cycle was limited, it was adequate for the few seconds required to deliver a blow. For convenience in operation, the LF101's were fed with poles in parallel and the LF250's in series. Power was about 30v, single-phase 60 Hz at full current rating. High speed movies were made of the tests of LF101 Nos. 6, 10 and 14 and LF250 Nos. 3, 5 and 7. The general test setup is shown in Fig. 5, details of the LF250 setup in Figs. 6 and 7 and of the LF101 setup in Figs. 8 and 9.

SHOCK TESTS OF AQB LF101 CIRCUIT BREAKERS

All of the circuit breakers furnished with the switchgear were taken from the Navy stock, and were supposedly shock-certified to the requirements of Ref. 5, which requires that they survive a 5-ft Top and 5-ft Back blow on the LWSM without malfunction. All of the LF101's were tested to this requirement, with the results shown in Table I. At this stage, no distinction was made between "Trip" (reset before closing) and "Open" (close directly) malfunctions; they are indicated as "Trips" because later observations were that this was the prevalent, perhaps exclusive, mode of malfunction. The significant aspect of these results is that only three of these eighteen shock-certified units passed the certification test, a situation which demanded investigation. First, some of the breakers were subjected to additional blows to determine the consistency of their behavior. The results are shown in Table II. Note that Breaker No. 10, which had previously passed, now failed, while No. 14, which had previously failed the 5-ft Top blow, now survived it. There appears to be a degree of inconsitency in that a breaker which has passed one test may not pass a second, although one which has failed will probably fail again. This sort of situation tends to indicate that the shock resistance of this type of breaker is marginal compared to requirements. There is also the possibility that malfunction is at least partially a result of the cumulative effects of preceding blows, although the prompt failure of most of the sample argues aginst this. Moreover, experience with a large variety of equipment items, as well as the predictions of most theories of damage accumulation, indicate that shock vulnerability has a threshold. When the shock severity is below threshold, the test item can withstand a number of blows, and when above, only a few. Thus, if it is the case that damage accumulates considerably from blow to blow, it is an indicator that the shock test is near threshold, meaning that the shock resistance of the item is marginal.

An additional series of tests were performed to estimate the threshold level of shock severity which would cause malfunction, with the results of Table III.

While Edge blows cause no problems, Back or Top blows of only one foot may cause malfunction.

It appeared that the problem was connected with the interlock mechanism. This was actuated by a spring-loaded finger protruding from the bottom of the circuit breaker which bore against the top of the fuse block, and tripped the breaker when the fuse block was removed. Hand actuation showed that very little travel of the finger was required to trip the breaker, and the high speed movies showed substantial relative motion between the fuse block and the breaker. It was also observed that it was possible to cuase the breaker to trip by prying between it and the fuse block with a screwdriver when mounted on the LSWM test fixture, but not when installed in the switchgear. This was presumably due to the larger rotational compliance of the test fixture in this direction because of its short vertical span, although its stiffness perpendicular to the mounting panel should be much higher than that of the switchgear because of the shorter vertical and horizontal spans and being made of steel, rather than dural like the switchgear. To verify that the interlock mechanism was indeed involved, the actuator of one of the breakers was permanently depressed by taping a piece of bakelite over its slot, and an additional series of blow delivered. The results are given in Table IV.

An additional stiffener bar (1 x 1/4 in. steel) (Fig. 9) was added to the back of fixture to see if a more rigid fixture would help. The breaker was then retested with the interlock actuator blocked and free, with the results of Table V.

It was concluded that the problem was mechanical rather than electrical, and connected with the interlock mechanism. Examination of the acceleration time traces measured on the fuse-block and panel back showed no significant change from the addition of the extra stiffener bar. It was agreed by NRL and NAVSEC representatives that future testing would be performed with the breakers cold, as their behavior was the same with and without power. It was also agreed that the breaker manufacturer should be requested to examine these breakers for possible defects.

SHOCK TESTS OF AQB-LF250 CIRCUIT BREAKERS

Like the LF101's, the nine LF250's provided with the switchgear were from Navy stock, and presumably shock-certified. The LWSM shock test setup is shown in Figs. 5, 6 and 7, and the results in Table VI. The breakers were energized at 250 amp in series feed.

As with the LF101's, the problem appears to be mechanical and associated with the interlock although the interlock mechanism is somewhat different from that of the LF101. The presence or absence of electrical load has no effect on the behavior. High-speed movies showed considerable of the fuse block relative to the body of the breaker, although they are structurally more intimate then is the case in the LF101. The LF250's have the fuse block embedded in the body of the breaker. The LF101's have it mounted on a separate base below the breaker, linked to it only by the current leads.

SHOCK TESTS OF INDIVIDUAL CIRCUIT BREAKERS - SECOND SERIES

Manufacturer personnel had inspected the breakers and witnessed many of the initial series of tests described above. Samples of both breaker types were returned to the factory for further examination and evaluation. Some discrepancies were identified in the settings and adjustments of the mechanisms involved in the interlock and trip functions. Manufacturer personnel returned to NRL and reworked the entire set of breakers to assure that adjustments were within tolerance. The interlocks of the LF101's were removed. All breakers were then retested except LF101 Nos. 10, 11, 12 and 14, and LF250 Nos. 3 and 5. All were tested cold, with the results of Table VII.

Of the LF101's not retested, No. 11 had its interlock removed but was not readjusted. No. 12 was not touched at all, and No. 13 had its interlock removed and was also readjusted, as noted. While considerable improvement can be seen, more than half of LF101's fail. Of those failed, all but No. 15 were again readjusted and retested, with the results of Table VIII.

Breaker No. 16 was found to be jammed closed (due to a defective spring in the shock latch). It was returned to the factory for repairs. This was later returned to NRL with two new LF101's which were assigned identification numbers 10A and 14A, and later installed in the switchgear in place of 10 and 14 respectively. None of the three had interlocks. Two new LF250's were also received, and were assigned numbers 3A and 5A and replaced 3 and 5 respectively. These were tested with the results of Table IX, which also includes a retest of LF250 No. 1. This was retested to investigate the possible influence of vibration-testing on shock performance and shock-testing on vibration performance. LF250 Nos. 3, 5 and 7 had been vibration-tested, then shock-tested, No. 1 was shock-tested, then vibration tested (without observable effect), then shock-tested again.

Thus, the final scorecard for the AQB circuit breakers as they were installed in the switchgear for its tests was as shown in Table X.

SHOCK ENVIRONMENT ON THE LWSM

The numerous acceleration-time waveforms recorded during this extensive series of tests were quite normal for the LWSM, and records for similar blow against similar configurations were essentially the same. A sample is shown in Figs. 10, 11, 12 and 13, which are the waveforms of, respectively, 5 ft Top Blow-LF101, 5 ft Back Blow-LF101, 5 ft Top Blow-LF250 and 5 ft Back Blow-LF250. There is a clear filtering action from the compliance of the fuse block assembly in all cases, but the same dominate frequency is discernible at the back of the panel. Peak accelerations are associated with the high-frequency components, and vary considerably with minor changes in the phasing of components: the precise value of the peaks is probably not too significant in terms of effects on the breaker. In the absence of any knowledge of the modal description of the circuit breakers, the acceleration waveforms shown were low-pass filtered at 1 KHz. The unfiltered records look substantially the same, indicating that most of the measured motion is in the 0-1 KHz range, which is not surprising in view of the flexibility of the test fixtures. The dominate frequencies, which are also the lowest detectable, are in the 70-80 Hz region, at the high end for the LF101's and low end for the LF250's. A sampling of typical peak accelerations and dominate frequencies is in Table XI. Note that for Top blows, the mounting-plate flexibility is not greatly exploited, while the rotational compliance of the fuse block is, and for Back blows, the mounting-plate flexibility becomes effective while the rotation of the fuse-block is decreased. This whows fairly clearly in the closer match of dominate frequencies of fuse-block and panel-back motions for Back blows compared to Top blows.

DAMAGE FROM LWSM TESTS

The circuit breakers sustained little structural damage, and that which occurred was of a nature such that it would cause nuisances in maintenance rather then threaten functional failure. A few of the breakers showed minor, localized cracking of the case, and the thread of one of the screws holding an LF101 fuse block to its mounting base stripped. The most serious damage was connected with the upper mounting base of the LF250's. Two of these were fractured just to the right of the middle, but not completely through, and two of the upper screws holding the breaker to the mounting base sheared at the surface of the threaded insert. In both cases it was the right hend (facing) screw, one of them being associated with a fractured base. The hold-down screws are small, 10-32 for LF101 and 1/4-20 for LF250, and while they are made of high-strength alloy, a great deal is being asked of them.

SWITCHGEAR VIBRATION TEST

Following the LWSM tests, the mounting bases and circuit breakers were replaced in the switchgear and it was fastened to the NRL 10,000 lb Reaction-Drive Vibration Machine, Figs. 14 and 15. The offset between the switchgear and the machine table is necessary to align the center-of-gravity of the switchgear with the center of reaction of the machine drive-force generator. All breakers were then closed, some difficulty being experienced with ACB-1600 No. 1. Vibration testing in accordance with Ref. 2 was then started, beginning with the Vertical direction. The switchgear was not energized for the vibration test, nor were any of the circuit breakers.

EXPLORATORY VIBRATION, VERTICAL

The exploratory vibration test was conducted over the range 8-33 Hz at a nominal table excursion of .20 in. (excursion = displacement peak-to-peak). Vibration amplitude was monitored at the table of the test machine and on the switchgear drip-pan over the angle structure at the rear-outboard corner of the AQB bay. The transmissibility ratio (TR, response amplitude divided by table amplitude, without regard to phase) was 1.1 at 8 Hz, rose to a peak of 1.3 at 24 Hz, and decreased to 0.9 at 33 Hz. Several component rasonances were located: ACB-1600 No. 1 showed visibly amplified motion at 16 Hz and above, finally isolating at 25 Hz; ACB-1600 No. 2 started at 22 Hz, and had not completely isolated at 33 Hz. Relative motion between the AQB-LF250 breakers and their cover panel could be seen starting at 21 Hz, and for the AQB-LF 101's starting at 23 Hz. Also starting at 23 Hz, a substantial motion of the LF101 horizontal bus bars was found, amounting to about 1/2 in. excursion at the free end at 24 Hz. Following the exploratory test, the horizontal bus bars for the middle (Nos. 4-6) and bottom (Nos. 7-9) rows of the LF250's were found to have loosened. There was a general loosening of the breaker ties from the bus bars to the AQB breakers. One of the nuts on LF101 No. 13 vibrated off completely. This was the top-most of three nuts on the post, and probably was not tightened initally.

VARIABLE FREQUENCY VIBRATION TEST, VERTICAL

The second segment of the vibration test procedure requires that table amplitude be maintained at a specified value for five minutes at each integral frequency through the test range (8-33Hz). The specified (displacement) amplitude is 0.030 ± 0.006 in. (0.060 in. excursion) up to 15 Hz, 0.020 ± 0.004 in (0.040 in. excursion) from 16-25 Hz, and 0.010 ± 0.202 in. (0.020 in excursion) from 26-33 Hz. With the higher drive amplitude, the behavior pattern was somewhat more involved than that found during the exploratory run. This is not uncommon with large, complex structures such as the switchgear, since relative motion of components can arise from other causes than true resonance conditions. The one responsible for most of the new features here was the motion allowed by intercomponent clearancs when the dynamic forces became great enough to overcome the restraining forces (friction, component weight, etc.). As before, the TR of the switchgear top to machine table started at 1.1, and peaked at 1.3 (21 Hz). Relative motion of ACB-1600 No. 1 was noted at 8 Hz, of No. 2 at 15 Hz, and of the ACB-2400 at 19 Hz.

The LF-250's showed motion relative to the cover plate at 21 Hz and above and the LF 101's starting at 22 Hz. Substantial deflections of the AQB horizontal bus structure were noted, the lower LF101 set (nos. 13-18) starting at 11 Hz, the central set (Nos. 7-12) at 15 Hz and the upper set (nos. 1-6) at 16 Hz. The lower and middle LF250 horizontal buses (Nos. 4-9) started at 21 Hz. During the run at 22 Hz, the LF101 buses were deflecting in excess of an inch peak-to-peak at the free(outboard) end, and the upper breaker ties began to fail from fatigue. Those for breakers 1,2,3,4,5,7,8,13 and 14 broke adjacent to the breaker connector post (Figs. 19-21). Large component motions were taking place, with substantial damage resulting, and the worst was yet to come. It was evident that the switchgear would not survive the vibration test without fairly extensive structural modifications. The principal purpose of the study was to evaluate shock environments seen by circuit breakers in a typical shipboard switchgear structure, represented by the switchgear as it stood, and to compare them with those seen on the LWSM. If the switchgear structure were to be modified, either by sustained damage or by intentional changes to avert damage, it would no longer be representative. Accordingly, it was agreed that vibration testing should be halted at this point, and resumed (time permitting) following the collection of the shock data.

Damage was thus limited to the broken breaker ties referred to above, which were replaced with steel strips of similar dimensions, and wear and abrasion to the ACB breakers and their door panels, Figs. 16-18.

SWITCHGEAR SHOCK TEST

The switchgear was next installed on the MWSM, arranged for vertical shock, as shown in Figs. 22 and 23. The off-center installation is necessary to align the center-of-gravity of the test arrangement over the center of percussion. It was expected that there would be problems with the switchgear due to poor construction in addition to those due to its design. Post-receipt inspection had found that only twenty-five of its forty-four hold-down bolts were actually installed, due to misaligment of holes in the switchgear base and the channels (Fig. 24). The bolts used throughout the assembly were a mixture of high-strength and ordinary bolts, rather than all high-strength. Welds of the aluminum frame members were uneven and porous. Five accelerometers of the instrumentation suite were assigned to the structure of the switchgear itself, fifteen to the circuit breakers, and one accelerometer and one velocity meter to the imput motion near the center of the mounting plate. All were oriented to sense motion in the vertical direction. The pickup locations are indicated in the sketches of Fig. 25, and listed in Table XII. High-speed movie coverage consisted of one camera concentrated on the AQB bay and one covering the switchgear overall.

SWITCHGEAR VERTICAL SHOCK TEST

As remarked above in the outline of the Test Procedure, Ref. 6, the shock test was intended to be of an exploratory nature, and would not be in compliance with the specification of Ref. 1 due to the excessive weight of the switchgear. With its mounting plate, the switchgear weighed 6970 lb, compared to the limit of 6,000 lb assigned to the MWSM Ref. 1, and the total weight on the anvil-table was 8028 lb compared to the assigned limit of 7,400 lbs. A further deviation from the requirements of Ref. 1 was in the mounting arrangement, where six car-building channels were used rather than the eleven indicated by extrapolating the tables of Ref. 1 up to a 6970 lb payload. The schedule of blows employed was that specified by Ref. 1 for the heaviest permissible test configuration, which represents the limit of capability of the MWSM. Each blow was repeated, so that the switchgear received identical blows with all circuit breakers closed and with only the instrumented ones closed. The effects of the deviations were to decrease the shock severity (from excess weight) and to increase the flexibility of the mounting system (from fewer channels).

Blow 1: 3 1/4 ft Drop, 3 in. Travel.

Instrumented breakers closed, uninstrumented open.

No change was found in the state of the circuit breakers. One of the screws in the lower latch of the base board sheared and the door panel for the six compartments in the two ACB bays tilted downward due to slippage of their hinges. The louvers in the door panels of the three ACB compartments sustained some additional bending and tearing.

Blow 2: 3 1/2 ft Drop, 3 in. Travel.

All breakers closed.

No change was noted in the state of the circuit breakers. One of the bolts holding the AQB and ACB-1600 bays together sheared. This was the lower bolt in the rear vertical member of the AQB bay frame. A possible crack was noted in the weld between the front outboard vertical member and the front bottom horizontal member of the AQB bay frame. Additional damage to the louvers in the ACB compartment door panels was noted.

Blow 3: 5 1/2 ft Drop, 3 in. Travel.

Instrumented breakers closed, uninstrumented open.

No change was found in the state of the circuit breakers. The switchgear sustained widespread general damage from broken welds, sheared bolts, bent frame members and deformed breaker components. This damage is discussed below and illustrated in Figs. 26-41. The shock test was suspended at this point for repairs to the switchgear.

DAMAGE TO SWITCHGEAR FROM BLOW 3

The following discussion of damage is keyed to the photographic coverage, hence the sequence is ordered by location rather than importance.

1. All six door-panels titled downward because of slippage of the hinges, and louvers were torn (Figs. 26, 32 and 33).

2. The door panel of ACB-1600 No. 2 was jammed closed due to damage of the lower lock (Fig. 32).

3. The horizontal frame members below the ACB breakers were bent downward from impact by the breakers (Figs. 26, 27, 28, 30, 32, 33 and 35).

4. The interlock mechanisms of the ACB breakers were damaged, those of ACB 1600 No. 2 and the ACB 2400 having their actuator pins bent and that of ACB 1600 No. 1 being knocked out completely (Figs. 28, 29, 32, 34 and 36).

5. There was some deformation of the sheetmetal parts of the ACB breakers with attendant changes in the relative location of parts mounted on them (Figs. 28 and 33).

6. One of the brackets holding the frame for the ACB 2400 breaker was broken off, and the upper guide and lock plate was bent. The bolts holding the melamine connector panel sheared, allowing the panel to slip down (Figs. 30, 37, 38, 39 and 40).

7. The hinge of the fuse panel slipped, allowing it to tip downwards (Fig. 31).

8. The frames of the ACB 1600 breakers were bent, and their support brackets slightly deformed (Figs. 35 and 37).

9. One of the switchgear hold-down bolts was stripped out. It was located at the outboard end of the central bottom frame member in the ACB 2400 bay (Fig. 40).

10. The welds attaching the bottom of the AQB mounting panel to the frame of the bay were broken (Fig. 41). Welds were of poor quality, with little penetration. Member edges had apparently been simply butted together without grooving.

Other damage, which was not photographed, were a slight outward bow in the outboard side of the frame of the ACB 2400 bay, and breaking three sensor sires attached to the B phase vertical main input bus (rear of the ACB 2400 bay).

Only the major damage was repaired - broken welds were gouged out and rewelded, broken bolts drilled out and replaced with high-strength bolts. The damage louvers on the ACB door-panels were stripped off entirely as they were a hazard to accelerometer cables. Bent frame members, slipped hinges, etc. were not repaired since similar damage could be predicted on the next blow with high confidence. When the test was resumed, ACB 1600 No. 1 was found to be inoperative. Attempts to close it in preparation for Blow 4 resulted in a 45° bend in a 3/4 in. diameter steel rod. This breaker remained open for the rest of the shock testing.

Blow 4: 5 1/2 ft Drop, 3 in. Travel.

All breakers closed except ACB 1600 No. 1.

No change was found in the state of the circuit breakers. The handles of LF101 Nos. 10A, 13, 14A and 15 moved down below their normal "closed" position but the breakers remained closed. Door-panels slipped slightly more.

Blow 5: 5 1/2 ft Drop, 1 1/2 in. Travel.

All breakers closed except ACB 1600 No. 1.

On this blow, LF250 No. 5A tripped, and while LF101 No. 17 remained closed, it would not operate consistantly after the blow.

Blow 6: 5 1/2 ft Drop, 1 1/2 in. Travel.

Instrumented breakers closed, uninstrumented and ACB 1600 No. 1 open.

No change was found in the state of the "closed" breakers, but LF 101 Nos. 7 and 13 shifted from "open" to "trip". Presumably this would not constitute a failure. Following the blow, LF101 No. 17 appeared to operate normally once more. The fuse panel slipped on its hinge a little further. Some tilting at the LF101 horizontal bus structure was noticeable.

DAMAGE TO SWITCHGEAR FROM BLOWS 4,5 and 6

Only minor damage such as slipping of door-panels and the fuse panel was noted as the test progressed. However, inspection after Blow 6 located fractures and deformation in the front bottom frame members at the bay junctions (Fig. 42) accompanied by loosening of the hold-down bolts in the vicinity. One hold-down bolt, in the corner of the ACB-1600 bay adjacent to the junction with the ACB-2400 bay, was stripped out. Replacing this bolt and tightening the loose ones drew the frame back down in contact with the channels. No other repairs were made.

SWITCHGEAR 30° INCLINED SHOCK TEST

The switchgear was arranged for 30° inclined test as shown in Fig. 43. All of the shock-motion pickups were rotated 30° with respect to the switchgear so that their sensitive axes remained vertical. Two additional accelerometers were added to LF101 No. 10A, one at the fuse block and the other at the back of the mounting panel, oriented to read motion normal to the mounting panel. The pair of mounting channels below the ACB 2400 bay was shifted 3 inches closer to the junction with the ACB 1600 bay to decrease the amount of counterweight (below the upper end of the mounting plate) needed for balance. A view of the underside of the mounting arrangement (Fig. 44) shows the spacer pads between the mounting plate and mounting channels. The same arrangement was used for the Vertical shock test. The total weight on the anvil-table for this test configuration was 9167 lb. This excessive weight, combined with the relatively small number of mounting channels, led to some slippage of the entire assembly along the mounting rails during the test, as noted below.

Blow 7: 3 1/4 ft Drop, 3 in. Travel.

Instrumented breakers closed, uninstrumented and ACB 1600 No. 1 open.

No change was found in the state of the breakers. No significant damage was noted. The entire assembly slipped down the angled mounting rails about 1/4 inch.

Blow 8: 3 1/4 ft Drop, 3 in. Travel.

All breakers closed except ACB 1600 No. 1.

No change was found in the state of the breakers. No damage was noted. The assembly slipped down an additional 1/2 inch impairing balance sufficiently to require repositioning.

Blow 9: 5 1/2 ft Drop, 3 in. Travel.

All breakers closed except ACB 1600 No. 1.

No change was found in the state of the circuit breakers. No damage was noted. The door-panel of the fuse compartment opened during the blow, and swung over to cover the ACB 1600 No. 2 compartment - evidently it had not been secured proper after inspection following the previous blow. The assembly slipped down the rails about 1/4 inch.

Blow 10: 5 1/2 ft Drop, 1 1/2 in. Travel.

All breakers closed except ACB 1600 No. 1.

No change was found in the state of the circuit breakers. Some cracking in the welds between the frame members of the AQB bay was observed. The assembly slipped an additional 1/2 in. requiring repositioning.

Blow 11: 5 1/2 ft Drop, 3 in. Travel.

Instrumented breakers closed, uninstrumented and ACB 1600 No. 1 open.

No change was found in the state of the circuit breakers. Cracking of the welds continued. The assembly slipped down the rails 1/4 inch.

Blow 12: 5 1/2 ft Drop, 1 1/2 in. Travel.

Instrumented breakers closed, uninstrumented and ACB 1600 No. 1 open.

No change was found in the state of the circuit breakers. Cracking in the welds and associated deformation of the AQB bay frame became extensive. The assembly slipped down 1/4 inch.

DAMAGE FROM 30° INCLINED SHOCK TEST

Like the vertical test, the 30° inclined shock test caused substantial damage to the switchgear structure, this time mostly in the AQB bay. As before the following description of damage is organized on the basis of location rather than significance.

1. The support pads of the AQB-LF250 cover panel were generally bent, with severe cracking of welds; one was broken off completely (Fig. 45).

2. Several LF250 hold-down screws were sheared off flush with the mounting base: both top screws for No. 3, the upper right of No. 6 and No. 9. The upper mounting base for No. 9 was also fractured (Fig. 46).

3. The weld between the front outboard vertical and front central horizontal frame members of the AQB bay was cracked (Fig. 47).

4. The outboard vertical frame members were broken loose from the bottom horizontal members. The outboard end of the AQB bay shifted 1/4 inch at the lower end (Fig. 48).

5. The inboard vertical frame members of the AQB bay were similarly broken loose from the horizontal bottom members (Fig. 49).

6. The frame and its supporting structure for ACB 1600 No. 1 was further damaged (Fig. 50), one of the guide pins being lost.

7. Door panels continued to tilt due to slippage of the hinges (Fig. 51).

8. The fuse panel slipped relative to its hinge, and its hinge relative to the switchgear frame (Fig. 52).

9. Deformation of the ACB 2400 sheet-metal components, its interlock mechanism, and the adjacent members of the swithgear frame continued (Fig. 53).

10. The melamine insulator panels for the horizontal bus between the ACB 2400 and ACB 1600 bays was torn and abraded (Fig. 54, ACB 2400

side, and Fig. 55, ACB 1600 side).

11. A small crack developed in the central horizontal member at the rear of the ACB 1600 bay frame, adjacent to the vertical member at the junction with the ACB 2400 frame. The crack apparently started in the weld and progressed into base metal (Fig. 56).

12. Bolts securing the mounting panel of ACB 1600 No. 2 were sheared off: these were the top left (Fig. 57) and lower right (Fig. 58).

13. Helicoil inserts in the top melamine support for the vertical bus in the AQB bay were loosened; one was stripped out entirely (Fig. 59).

14. The weld securing the rear central horizontal frame member of the AQB bay to the vertical member at the junction with the ACB 1600 bay was broken (Fig. 60).

15. Welds of the gusset plates at the bottom rear of the AQB bay were broken (Fig. 61).

16. The horizontal bus structure of the AQB bay was bent downward, particularly those of the LF101's (Fig. 62), with attendant deformation of the breaker ties.

17. Structural welds of the AQB bay frame front were broken (Fig. 63, inboard and Fig. 64, outboard).

The structurally significant damage was repaired, consisting of replacing damaged circuit breaker bases and hold-down screws, and relocating and rewelding the AQB bay frame members. The switchgear was then shipped to the West Coast Shock Facility for tests on the Floating Shock Platform.

SHOCK ENVIRONMENT OF CIRCUIT BREAKERS IN SWITCHGEAR, MWSM

As revealed by the high-speed movies, the motion of the circuit-breakers was lively, with frequent impact between the AQB breakers and their cover panels. These collisions are clearly indicated on the LF101 fuse block acceleration-time traces by characteristics spikes. These collison spikes are narrow (2-3ms) and high, having peak acceleration values several times, or even an order of magnitude higher than those associated with the basic motion of the breaker. Collison spikes are much less noticeable of the LF250 fuse blocks due to the difference in construction. In the LF101's, impact is directly on the fuse block; in the LF250's, impact is on the body of the circuit breaker, and the short, high acceleration pulse does not propagate through the material of the breaker and the bolted connection between the breaker and the fuse block. Occasionally, possible collison spikes could be found in the acceleration-time traces measured on the back of the mounting panel behind some of the LF250's. There seems to be little structure in this area which could explain such behavoir. Of mechanisms that might be conjectured, perhaps the most probable are a slight separation of part of the breaker body away from the mounting panel, with some slap resulting when the separation is taken up, or motion of the horizontal bus sufficient to drive one or more of the breaker ties into the channel member of the mounting panel. High speed movies are uninformative in this area as none were made behind the panel, and the cover panel effectively conceals the fine points of the motion from the front.

With regard to the tabulated readings, the peak accelerations are the highest observable readings, and represent collison spikes if present-these are indicated by asterisk. The acceleration associated with the basic motion of the fuse blocks are usually very substantially lower. This is done because the spikes do in fact represent the environment seen by components in the fuse block, and probably also by components around the periphery of the breaker, where impact with the cover panel is likely. However, because of the spiky nature of the environment, the frequency content of the basic motion is of less interest as an environmental description than it is as an indicator of mounting panel flexibility. The tabulated frequencies, then, are the lowest discernible in the acceleration-time trace, and may not be the dominate frequencies.* The intent of the tabulated values is that the peak accelerations of the fuse block describe environment for breaker components, the peak accelerations of the mounting panel and frequencies at both locations provide a basis for comparison with the environments on the LWSM test fixture. Peak acceleration and frequency values are given in Tables XIII, XIV and XV. For the ACB breakers, the values listed in the "Fuse Block" column are those measured on the operating panel.

Some typical acceleration-time records are shown in Figs. 65 (AQB-LF101 No. 10A) and 66 (AQB-LF250 NO. 5A on Blow 4 (5-1/2 3) (Vertical), and Figs. 67 and 68 for the same breakers on Blow 9 (5-1/2 3) (30° Inclined). Figure 69 shows the acceleration-time records in the direction normal to the mounting panel for AQB-LF101 No. 10A during Blow 9 (5-1/2 3) (30° Inclined).

COMPARISON OF LWSM AND MWSM CIRCUIT BREAKER ENVIRONMENTS

In Table XVI, the frequencies read from the acceleration-time records are averaged for all blows in each configuration. As before, the values shown for the ACB breakers in the "Fuse Block" column apply to the operating panel.

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*The collision spikes tend to run at a repetition rate of the dominate frequency, alternating sign as do the peaks of the dominate frequency.

Comparing the data of Table XI with those of Tables XIII, XIV, XV and XVI, it appears that the shock environment seen by circuit breakers on the LWSM is characterized by substantially higher accelerations and frequencies of motion than those of the environment seen in the switchgear on the MWSM. While some very high accelerations were observed on breakers in the switchgear, these were associated with impact between the breakers and (presumably) the cover panel, and were highly localized in time and space: i.e.; they were of short duration and would not propagate significantly through the breaker. It is reasonable to conclude that the environment in the MWSM tests is thus less severe than that during the LWSM tests, a conclusion supported by the observation that most of those breakers which failed the LWSM tests did not misbehave during the MWSM tests.

SHOCK RESPONSE OF SWITCHGEAR STRUCTURE

In addition to the accelerometers employed principally to measure the circuit breaker environments, a set of six accelerometers and one velocity meter were assigned for measurement of the motions of the switchgear structure. The locations of these pickups (shown in Fig. 25) were: one accelerometer and the velocity meter approximately at the centre of the mounting-plate; three accelerometers on the front vertical frame members at about mid-height, one each at the outboard end of the AQB bay, the outboard end of ACB 2400 bay, and the ACB 2400 bay at the junction with the ACB 1600 bay; two accelerometers on the drip-pan immediately above the front horizontal frame member, one each at the junction of the AQB and ACB 1600 bays, and at the outboard end of the ACB 2400 bay. All of these pickups were oriented to reed motion in the vertical direction. The peak accelerations and lowest discernible frequencies read from their output signal are listed in Table XVII. No good estimate of the mounting-frequency (i.e., the switchgear, etc. as a mass on the channels as a spring), which would be best seen at Location 1 (on the mounting plate), can be made. The accelerometer record is, of course, dominated by high frequency components, while the velocity meter trace has many reversals due to its own bottoming and anvil-table reversals.* It may be noted, however, that for dead-weight loads, the channel arrangements prescribed by MIL-S-901C yield mounting frequencies in the range of 60-70 Hz. Extrapolation of the tables in MIL-S-901C to the weight of the switchgear implies that ten or eleven car-building channels would be required, while six were used. Thus, it would be anticipated that the mounting frequency would be in the area of 45-55 Hz. It may be noted that the frequencies in Table XVII do average to this range for the Vertical shock test. For the 30° - Inclined shock test, the frequencies are somewhat lower; this is reasonable since in this orientation bending motions should be more prominent. Also of interest is the rather substantial difference in peak velocity between the two test orientations. While the total weight on the anvil-table was 14% greater for the 30° - Inclined test than for

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*See Appendix A for description of the instrumentation characteristics, and Appendix B for description of the MWSM.

the Vertical, the peak velocities are over 40% less. In the Vertical test, the peak velocity was associated with a high, intial spike some 5-10 ms long; following this, the waveform appeared to be a damped sinusoid about half as high as the initial spike. For the 30° - Inclined test , this initial spike did not appear, and the velocity waveform appeared substantially the same as that for the Vertical with the spike excluded. Note however, that the peak accelerations also indicate an approximately 40% decrease from the values for the Vertical test. There are two obvious factors which would tend to lead to such a decrease in peak acceleration and velocity. The first is that the switchgear in the 30°-Inclined orientation is more flexible with respect to motions along the shock axis, as bending of its structural members and the horizontal compliance of the mounting channels are exploited. The second, and probably more important, is that the switchgear and mounting plate constituted a fairly substantial overload for the mounting channels. As the mounting channels are bent upward, the clamping force holding them to the mounting rails is relaxed - with the overload existing here, the clamping force was not sufficient for friction to resist the authwartship component of the shock loading, so that the entire test assembly slid down the mounting rails with each blow.

CONCLUSIONS AND RECOMMENDATIONS

The following principal conclusions can be drawn:

(i) The shock environment provided to circuit breakers by the specified LWSM is substantially more severe, in terms of peak acceleration, than that seen by the breakers in the switchgear on the MWSM. Breakers which pass on the LWSM pass on the MWSM - in fact, some breakers which fail on the LWSM pass on the MWSM. This is how a proof test should operate.

(ii) Breakers which fail on the LWSM can be made to pass by careful setting of internal adjustments and/or elimination of apparently non-essential features (e.g., LF101 interlocks). This would tend to indicate a problem of quality control rather than design defects.

(iii) The structural performance of the switchgear itself from a shock and vibration standpoint was poor. Since the switchgear was not powered for these tests, it is not known whether its failures would interfere with its electrical functions, but the failures of bolts supporting the main bus structure and the large motions of the distribution bus are not encouraging in this regard.

(iv) Most of the structural problems with regard to shock were due to poor workmanship: poor welds, missing bolts, low-strength bolts, etc.

(v) Some improvement could be made by use of steel structural members rather than dural. This would provide greater rigidity and would be easier to weld properly.

(vi) Substantial extra buttressing and support would be required in order to allow the switchgear to pass the vibration test. Additional support for the distribution bus system is a particular need.

Note, however, that improvements in the structural strength of the switchgear would increase the severity of the shock environment seen by breakers mounted in it on the MWSM, as energy now absorbed in breaking welds and bolts would be available to increase structural motions. It is improbable, however, that such an increase would be large enough to render the LWSM test unconservative.

REFERENCES

1. MIL-S-901C, "Military Specification Shock Tests, H.I. (High Impact); Shipboard Machinery, Equipment and Systems, Requirements for" 15 January 1963.

2. MIL-STD-167-1 (SHIPS), "Military Standard Mechanical Vibrations of Shipboard Equipment (Type I-Environmental and Type II-Internally Excited)" 1 May 1974.

3. Clements, E.W., "Shipboard Shock and Navy Devices for its Simulation," NRL Report 7396, July 14, 1972.

4. Clements, E.W., "Characteristics of the Navy Large Floating Shock Platform," NRL Report 7761, July 15, 1974.

5. MIL-C-17361C (SHIPS), "Military Specification Circuit Breakers, Air, Electric, Insulated Enclosure (Shipboard Use)," June 25, 1973.

6. Forkois, Harold M., "Test Procedure for Vibration Testing and Shock Testing AQB Circuit Breakers and One Switchgear Assembly," September 12, 1977.

APPENDIX
CHARACTERISTICS OF SHOCK INSTRUMENTATION

The shock motion transducers employed for measurements on the switchgear consisted of one velocity meter and three accelerometers (see Table XII). The velocity meter is a cylindrical device 11 in. high and 2-1/4 in. diameter weighing 1 lb. 13 oz. It consists of a solenoid with a seismically-suspended internal magnet having a suspension frequency of about 2-3 Hz. The frequency spectrum of the shock motions lies substantially above this region; in this region the magnet remains at rest while the solenoid moves about it with the structure to which it is attached. The relative displacement between the solenoid and the magnet is thus the same as the absolute motion of the test structure at the location of the solenoid. The sensor mechanism is the cutting of the magnet's field by the turns of the solenoid--the output signal is a current proportional to the time derivative of the relative displacement, hence to the velocity of motion of the test structure. When used for shock measurements, the velocity meter's transient response is also excited. This consists of the 2-3 Hz motion of the magnet on its suspension springs and leads to error in the absolute velocity indicated after a time, although changes in velocity are indicated accurately. The error reaches 10% in about 40 ms, an ample time to capture the velocity maximum in practical applications. The frequency band of reliable shock velocity measurements has a low end set at 8-10 Hz by the suspension frequency, and an upper limit of about 1 kHz due to resonances in the structure of the velocity meter itself, principally in the coil form on which the solenoid is wound. Another limitation lies in total displacement. The clearance between the magnet in its rest position and the stops at the end of the solenoid is ± 2.5 in., so that when the motion of the test structure gets much beyond this value, the magnet bottoms out, introducing a reversal step in the output signal. Since the travel of the MWSM anvil table is 3 in., this happens regularly on the MWSM. However, computational routines have been developed which allow corrections to be made for bottoming, as well as for the transient response errors. but it is very rarely necessary to employ these if only a measure of peak velocity is required.

The accelerometer is similar to the velocity meter in that it may be regarded as a simple single-degree-of-freedom system for most purposes. It differs in that its sprung mass is suspended by a very stiff spring, so that the spectrum of input motion is always very much below its natural frequency. In this regime, the displacement of the spring mass relative to the base is proportional to the acceleration of the base, which is the same as that of the test structure at the point of attachment. The sensor mechanism is one which produces an electrical signal proportional to the relative displacement of the sprung mass, and must be highly sensitive since this displacement will be small when the natural frequency is high. Two types of accelerometers were used for the measurements on the switchgear shock test. Most were the type designated "SC", which were cylinders about 1 in. high and 1 in. diameter, fitted with a mounting flange 1 in. square and weighing about 3 oz. The sensor mechanism is an unbonded wire strain gage bridge. These units are "ranged", in that the stiffness of the suspension spring is adjusted so that a chosen range value of static acceleration produces the full relative displacement of the mass permissible. This also means that the natural frequency of the accelerometer varies as the square root of the range value. These units are damped at about .7 critical to extend the usable frequency range and to prevent their transient response from contaminating the output signal. The useful frequency range of these units was 0 to about 1 kHz for the 100g range, and up to about 2kHz for the 500g. The other type of accelerometer, "PR", is a cylinder 1 in. high and about 5/8 in. diameter weighing 1 oz. The sensor mechanism is a bonded piezoresistive strain gage bridge. These units are also damped at about .7 critical, and have a useful frequency range of 0-4 kHz.

The accelerometers were connected to electronics packages designed and built at NRL which provided excitation power and amplified the output signals to a level suitable for recording. Recording was on 1 in., 14 track magnetic tape at 60 ips in IRIG Low-Band FM. The velocity meter output signal was recorded without intervening electronics.

TABLE I

AQB-LF101 Proof Test, LWSM

Bkr No.	5-ft Top	5-ft Back	Evaluation
1	Trip	OK	Fail
2	OK	OK	Pass
3	Trip	Trip	Fail
4	OK	OK	Pass
5	Trip	Trip	Fail
6	Trip	OK	Fail
7	Trip	Trip	Fail
8	Trip	Trip	Fail
9	Trip	Trip	Fail
10	OK	OK	Pass
11	Trip	Trip	Fail
12	Trip	Trip	Fail
13	Trip	OK	Fail
14	Trip	Trip	Fail
15	Trip	Trip	Fail
16	Trip	Trip	Fail
17	Trip	Trip	Fail
18	Trip	Trip	Fail

TABLE II

AQB-LF101: Extra Blows on LWSM-Consistency

Bkr No.	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect
3	5-ft	Back	Trip						
5	5-ft	Back	Trip						
6	5-ft	Top	Trip	5-ft	Back	Trip	5-ft	Top	Trip
	5-ft	Back	Trip	5-ft	Top	Trip			
10	5-ft	Top	Trip	5-ft	Back	Trip			
14	5-ft	Top	OK	5-ft	Back	Trip			

TABLE III

AQB-LF101: Extra Blows on LWSM-Threshold

Bkr No.	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect
6	1-ft	Top	Trip	3-ft	Top	Trip	5-ft	Top	Trip
14	1-ft	Top	OK	3-ft	Top	Trip			
	1-ft	Back	Trip	3-ft	Back	OK			
	1-ft	Edge	OK	3-ft	Edge	OK	5-ft	Edge	OK

TABLE IV

AQB-LF101: Extra Blows on LWSM-Interlock

Bkr No.	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect
6							5-ft	Top	OK
6	1-ft	Back	OK	3-ft	Back	OK	5-ft	Back	OK
* 6	1-ft	Back	OK	3-ft	Back	OK	5-ft	Back	OK

*Breaker unenergized

TABLE V

AQB-LF101: Extra Blows on LWSM-Interlock

Bkr No.	Interlock	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect
* 6	Taped	5-ft	Top	OK	5-ft	Back	OK
* 6	Free	5-ft	Top	Trip	5-ft	Back	Trip

*Breaker unenergized

TABLE V1

AQB-LF250 Proof Test, LWSM

Bkr No.	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect
* 1	1-ft	Back	OK	3-ft	Back	OK	5-ft	Back	OK
*	1-ft	Top	OK	1-ft	Top	OK	5-ft	Top	OK
*	1-ft	Back	OK						
* 3	1-ft	Top	Trip	1-ft	Back	Trip			
5	1-ft	Top	OK	3-ft	Top	OK	5-ft	Top	Trip
	1-ft	Back	OK	3-ft	Back	OK	5-ft	Back	Trip
*	1-ft	Top	Trip	1-ft	Back	Trip			
7	5-ft	Top	Trip	5-ft	Back	Trip			

*Breaker unenergized

TABLE VII

AQB Circuit Breaker Retest, LWSM

Bkr Type/No.		Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect	Blow	Ht/Dir	Effect	Evaluation
LF101	1	1-ft	Top	OK	3-ft	Top	OK	5-ft	Top	OK	
		1-ft	Back	OK	3-ft	Back	OK	5-ft	Back	OK	Pass
	2	5-ft	Top	Open	5-ft	Back	OK				Fail
	3	5-ft	Top	Open	5-ft	Back	OK				Fail
	4	5-ft	Top	OK	5-ft	Back	OK				Pass
	5	5-ft	Top	Open	5-ft	Back	OK				Fail
	6	5-ft	Top	OK	5-ft	Back	OK				Pass
	7	5-ft	Top	OK	5-ft	Back	OK				Pass
	8	5-ft	Top	Open	5-ft	Back	OK				Fail
	9	5-ft	Top	OK	5-ft	Back	OK				Pass
	13	5-ft	Top	OK	5-ft	Back	OK				Pass
	15	5-ft	Top	Open	5-ft	Back	Open				Fail
	16	5-ft	Top	Open	5-ft	Back	Open				Fail
	17	5-ft	Top	Trip	5-ft	Back	Trip				Fail
	18	5-ft	Top	Open	5-ft	Back	OK				Fail
LF250	1	5-ft	Top	OK	5-ft	Back	OK				Pass
	2	5-ft	Top	OK	5-ft	Back	OK				Pass
	4	5-ft	Top	OK	5-ft	Back	OK				Pass
	6	5-ft	Top	OK	5-ft	Back	OK				Pass
	7	1-ft	Top	OK	3-ft	Top	OK	5-ft	Top	OK	
		1-ft	Back	OK	3-ft	Back	OK	5-ft	Back	OK	Pass
	8	5-ft	Top	OK	5-ft	Back	Trip				Fail
		1-ft	Back	OK	3-ft	Back	OK	5-ft	Back	Trip	
	9	5-ft	Top	OK	5-ft	Back	OK				Pass

TABLE VIII

AQB-LF101 Second Retest LWSM

Bkr No.	5-ft Top	5-ft Back	Evaluation
2	OK	OK	Pass
3	OK		Pass
5	OK		Pass
8	OK	OK	Pass
16			
17	Trip	Trip	Fail
18	OK		Pass

TABLE IX

AQB Circuit Breaker Retest, LWSM

Bkr Type/No.		5-ft Top	5-ft Back	Evaluation
LF101	10A	OK	OK	Pass
	14A	OK	OK	Pass
	16	OK	OK	Pass
LF250	1	OK	OK	Pass
	3A	OK	OK	Pass
	5A	Trip	Trip	Fail

TABLE X

LWSM Shock Performance of AQB Circuit Breakers as Installed for Switchgear Tests

Bkr Type/No.		5-ft Top	5-ft Back	Evaluation	Interlock	Readjusted
LF101	1	OK	OK	Pass	No	Yes
	2	OK	OK	Pass	No	Yes
	3	OK	OK	Pass	No	Yes
	4	OK	OK	Pass	No	Yes
	5	OK	OK	Pass	No	Yes
	6	OK	OK	Pass	No	Yes
	7	OK	OK	Pass	No	Yes
	8	OK	OK	Pass	No	Yes
	9	OK	OK	Pass	No	Yes
	10A	OK	OK	Pass	No	Yes
	11	Trip	Trip	Fail	No	No
	12	Trip	Trip	Fail	Yes	No
	13	OK	OK	Pass	No	Yes
	14A	OK	OK	Pass	No	Yes
	15	Open	Open	Fail	No	Yes
	16	OK	OK	Pass	No	Yes
	17	Trip	Trip	Fail	No	Yes
	18	OK	OK	Pass	No	Yes
LF250	1	OK	OK	Pass	Yes	Yes
	2	OK	OK	Pass	Yes	Yes
	3A	OK	OK	Pass	Yes	Yes
	4	OK	OK	Pass	Yes	Yes
	5A	Trip	Trip	Fail	Yes	Yes
	6	OK	OK	Pass	Yes	Yes
	7	OK	OK	Pass	Yes	Yes
	8	OK	Trip	Fail	Yes	Yes
	9	OK	OK	Pass	Yes	Yes

TABLE XI

Peak Accelerations and Dominate Frequencies, LWSM

Bkr Type/No.		Blow	Ht/Dir	Panel		Fuse Block	
				Acc/g	Freq/Hz	Acc/g	Freq/Hz
LF101	1	1-ft	Top	400	107	275	75
		3-ft	Top	570	75	410	78
		5-ft	Top	795	86	420	91
		Av			81		89
		1-ft	Back	550	80	230	77
		3-ft	Back	685		425	86
		5-ft	Back	700	83	480	67
		AV			82		77
LF250	7	1-ft	Top	295	67	250	100
		3-ft	Top	420	83	370	77
		5-ft	Top	750	75	540	111
		AV			75		96
		1-ft	Back	400	73	165	71
		3-ft	Back	710	71	315	70
		5-ft	Back	775	70	415	65
		AV			71		69

TABLE XII

Pickup Types and Locations, Switchgear Shock Test on MWSM

Gage No.	Type	Range, ±	Location
V1V	VM	2.5 in.*	Mounting plate, left rear corner of fuse compartment
A1V	PR	2000g	Fuse block, AQB-LF250 No. 7
A2V	SG	500g	Fuse block, AQB-LF250 No. 5A
A3V	SG	500g	Fuse block, AQB-LF250 No. 3A
A4V	SG	250g	Front outboard vertical frame member AQB bay at midpoint
A5V	SG	500g	Fuse block, AQB-LF101 No. 14A
A6V	SG	500g	Fuse block, AQB-LF101 No. 10A
A7V	SG	500g	Fuse block, AQB-LF101 No. 6
ABV	SG	250g	Front top frame member above AQB/ACB-1600 bay junction
A9V	SG	500g	Operation panel, ACB-1600 No. 2
A10V	SG	500g	Operation panel, AGB-1600 No. 1
A11V	SG	500g	Front vertical frame member AGB-2400 bay adjacent AGB-1600 bay at midpoint
A12V	SG	500g	Operation panel, AGB-2400
A13V	SG	250g	Front outboard vertical frame member ACB-2400 bay at midpoint
A14V	SG	250g	Top front outboard frame corner, ACB-2400 bay
A15V	SG	500g	Back of mounting panel, AQB-LF101 No. 6
A16V	SG	500g	Back of mounting panel, AQB-LF101 No. 10A
A17V	SG	500g	Back of mounting panel, AQB-LF101 No. 14A
A1BV	SG	500g	Back of mounting panel, AQB-LF250 No. 3A
A19V	SG	500g	Back of mounting panel, AQB-LF250 No. 5A
A20V	SG	500g	Back of mounting panel, AQB-LF250 No. 7
A21V	PR	2000g	Mounting plate near center
†A22F	SG	100g	Fuse block, AQB-LF101 No. 10A
†A23F	SG	100g	Back of mounting panel, AQB-LF101 No. 10A

*Total displacement

†Added for 30° inclined shock test only, reading motion normal to plane of mounting panel.

TABLE XIII

Switchgear, Vertical Shock Test, MWSH
Circuit Breaker Peak Vertical Accelerations

Blow No.	Drop ft	Travel in	Breaker Type	Ser	Fuse Block g	Freq Hz	Mount Panel g	Freq Hz
1	3-1/4	3	AQB-LF101	6	267*	53	151	
				10A	400*	47	128	53
				14A	116*	50	93	51
			AQB-LF250	3A	174	56	174	63
				5A	116	50	116	48
				7	165	36	148	50
			ACB-1600	1	70	53		
				2	64	40		
			ACB-2400		70	36		
2	3-1/4	3	AQB-LF101	6	496*	54	142	50
				10A	458*	50	99	53
				14A	273*	38	87	33
			AQB-LF250	3A	232	57	200	
				5A	133*	53	171	48
				7	244	63	122	45
			ACB-1600	1	55	37		
				2	67	33		
			ACB-2400		90			
3	5-1/2	3	AQB-LF101	6	632*	63	223	67
				10A	731*	30	139*	71
				14A	244*	36		
			AQB-LF250	3A	305	51	244*	
				5A	168	40	209*	63
				7	278*	50	145	50
			ACB-1600	1	87	33		
				2	116	33		
			ACB-2400		116	48		

TABLE XIII (Con't)

Blow No.	Drop ft	Travel in	Breaker Type	Ser	Fuse Block g	Freq Hz	Mount Panel g	Freq Hz
4	5-1/2	3	AQB-LF101	6	509*	44	235	56
				10A	749*	35	183	
				14A	209*	43	114	77
			AQB-LF250	3A			217	40
				5A	217*	33	166	
				7	286*	65	172	63
			ACB-1600	1	57	38		
				2	86	36		
			ACB-2400		114	45		
5	5-1/2	1-1/2	AQB-LF101	6	704*	68	223	
				10A	681*	53	112	48
				14A	335	29	112	48
			AQB-LF250	3A	292	42	240	49
				5A	200*	38	163	50
				7	389*	51	154	48
			ACB-1600	1	97	33		
				2	72	47		
			ACB-2400		166*	33		
6	5-1/2	1-1/2	AQB-LF101	6	704*	67	260	53
				10A	704*	32	194	43
				14A	406*	43	120	40
			AQB-LF250	3A	323	40	269	36
				5A	209*	44	212	54
				7	295	48	212	33
			ACB-1600	1	143*	45		
				2	80	48		
			ACB-2400		134*	53		

*Possible collision spikes visible.

TABLE XIV

Switchgear, 30° Inclined Shock Test, MWSM
Circuit Breaker Peak Vertical Accelerations

Blow No.	Drop ft	Travel in	Breaker Type	Ser	Fuse Block g	Freq Hz	Mount Panel g	Freq Hz
7	3-1/4	3	AQB-LF101	6	316*	74	220	45
				10A	280*	50	94	36
				14A	250*	59	106	50
			AQB-LF250	3A	245*	67	112	45
				5A	230	34	132	45
				7	120	50	170	37
			ACB-1600	1	64	50		
				2	78	63		
			ACB-2400		36	40		
8	3-1/4	3	AQB-LF101	6	436*	32	148	45
				10A	280*	43	94	63
				14A	360*	54	74	36
			AQB-LF250	3A	114	38	112	40
				5A	144	21	116	38
				7	100	29	116	45
			ACB-1600	1	74	44		
				2	32	40		
			ACB-2400		32	43		
9	5-1/2	3	AQB-LF101	6	496*	29	180	40
				10A	356*	40	114	40
				14A	524*	42	92	33
			AQB-LF250	3A	270	47	114	40
				5A	132	36	140	45
				7	148	68	146	29
			ACB-1600	1	70	48		
				2	84	51		
			ACB-2400		52	50		

TABLE XIV (Con't)

Blow No.	Drop ft	Travel in	Breaker Type	Ser	Fuse Block g	Freq Hz	Mount Panel g	Freq Hz
10	5-1/2	1-1/2	AQB-LF101	6	534*	33	170	34
				10A	406*	33	112*	48
				14A	336*	33	86	38
			AQB-LF250	3A	230*	50	94	40
				5A	160*	22	110	34
				7	100	50	146	37
			ACB-1600	1	68	31		
				2	68	56		
			ACB-2400		80	33		
11	5-1/2	3	AQB-LF101	6	468*	69	220	36
				10A	398*	42	108	38
				14A	256*	33	126	36
			AQB-LF250	3A	218*	40	154	36
				5A	114	33	166	40
				7	126	43	146	40
			ACB-1600	1	76	36		
				2	56	42		
			ACB-2400		84	38		
12	5-1/2	1-1/2	AQB-LF101	6	406*	40	178	50
				10A	348*	33	116	50
				14A	308*	59	76	45
			AQB-LF250	3A	258*	36	136	
				5A	134*	29	106	40
				7	112*	37	120	42
			ACB-1600	1	70	31		
				2	58	33		
			ACB-2400		64	42		

*Possible collision spikes visible

TABLE XV

Switchgear, 30° Inclined Shock Test, MWSM

Peak Accelerations Normal to Mounting Panel, AQB-LF101 No. 10A

Blow No.	Drop Travel		Fuse Block Frequency		Mounting Panel Frequency	
	ft	in	g	Hz	g	Hz
7	3-1/4	3	53	25	52	22
8	3-1/4	3	55	20	57	22
9	5-1/2	3	65	24	89	22
10	5-1/2	1-1/2	196*	24	166*	20
11	5-1/2	3	112	33	86*	40
12	5-1/2	1-1/2	100*	20	80	19

*Possible collision spikes visible

TABLE XVI

Average Frequencies from Circuit Breaker Vertical Accelerations

Vertical Shock Test

Breaker Type	Ser	Fuse Block Hz	Mounting Panel Hz
AQB-LF101	6	58	57
	10A	41	54
	14A	40	50
AQB-LF250	3A	49	47
	5A	43	53
	7	52	48
ACB-1600	1	40	
	2	40	
ACB-2400		43	

30° Inclined Shock Test

Breaker Type	Ser	Fuse Block	Mounting Panel	Normal to	
				Fuse Block	Mounting Panel
		Hz	Hz	Hz	Hz
AQB-LF101	6	46	42		
	10A	40	46	24	24
	14A	47	40		
AQB-LF250	3A	46	40		
	5A	29	40		
	7	46	38		
ACB-1600	1	40			
	2	48			
ACB-2400		41			

TABLE XVII

VERTICAL ACCELERATIONS IN SWITCHGEAR STRUCTURE

Vertical Shock Test

Blow No.	Ht ft	Tr in	Pos 1 Vel F/S	Pos 1 F/S	Pos 1 Accg	Pos 1 V/S	Pos 2A Accg	Pos 2A V/S	Pos 2B Accg	Pos 2B V/S	Poa 2C Accg	Poa 2C V/S	Pos 3A Accg	Pos 3A V/S	Pos 3B Accg	Pos 3B V/S
1	3-1/4	3	8.7	-	545	-	145	50	128	50	142	50	162	-	-	-
2	3-1/4	3	9.7	-	725	-	128	45	244	45	142	42	-	-	-	-
3	5-1/2	3	12.0	-	777	-	305	42	397	100	186	63	232*	-	-	-
4	5-1/2	3	11.8	-	618	-	192	38	472*	33	194	50	257*	-	664*	45
5	5-1/2	1-1/2	11.7	-	606	-	235	40	418	45	206?	53?	269	43	343*	42
6	5-1/2	1-1/2	12.7	-	755	-	326	56	335	50	266	56	297	53	349	50
AV								45		54		52		48		46

30° Inclined Shock Test

Blow No.	Ht ft	Tr in	Pos 1 Vel F/S	Pos 1 F/S	Pos 1 Accg	Pos 1 V/S	Pos 2A Accg	Pos 2A V/S	Pos 2B Accg	Pos 2B V/S	Poa 2C Accg	Poa 2C V/S	Pos 3A Accg	Pos 3A V/S	Pos 3B Accg	Pos 3B V/S
7	3-1/4	3	5.2	-	284	-	200	38	130	51	84	50	256	43	66	43
8	3-1/4	3	5.0	-	276	-	198*	42	136	61	72	38	180	43	66	38
9	5-1/2	3	5.7	-	444	-	178	42	212	34	94	31	180	31	104	40
10	5-1/2	1-1/2	5.6	-	320	-	198	25	212	50	98	33	230	-	110	-
11	5-1/2	3	7.0	-	492	-	204	38	128	36	100	33	236	57	120	33
12	5-1/2	1-1/2	7.2	-	572	-	174	48	152	25	88	40	210	38	104	23
AV								39		43		38		42		35

*Possible Collison Spikes

?Poor Record

Position 1: Base plate, approximate center.
2A: Front angle outboard end AQB bay at section separation.
2B: Front angle at 1600/2400 bay junction, same height as A.
2C: Front angle outboard end 2400 bay, same height as A&B.
3A: Drip-pan above Front angle at AQB/1600 bay junction.
3B: Drip-pan above Front angle at outboard end 2400 bay.

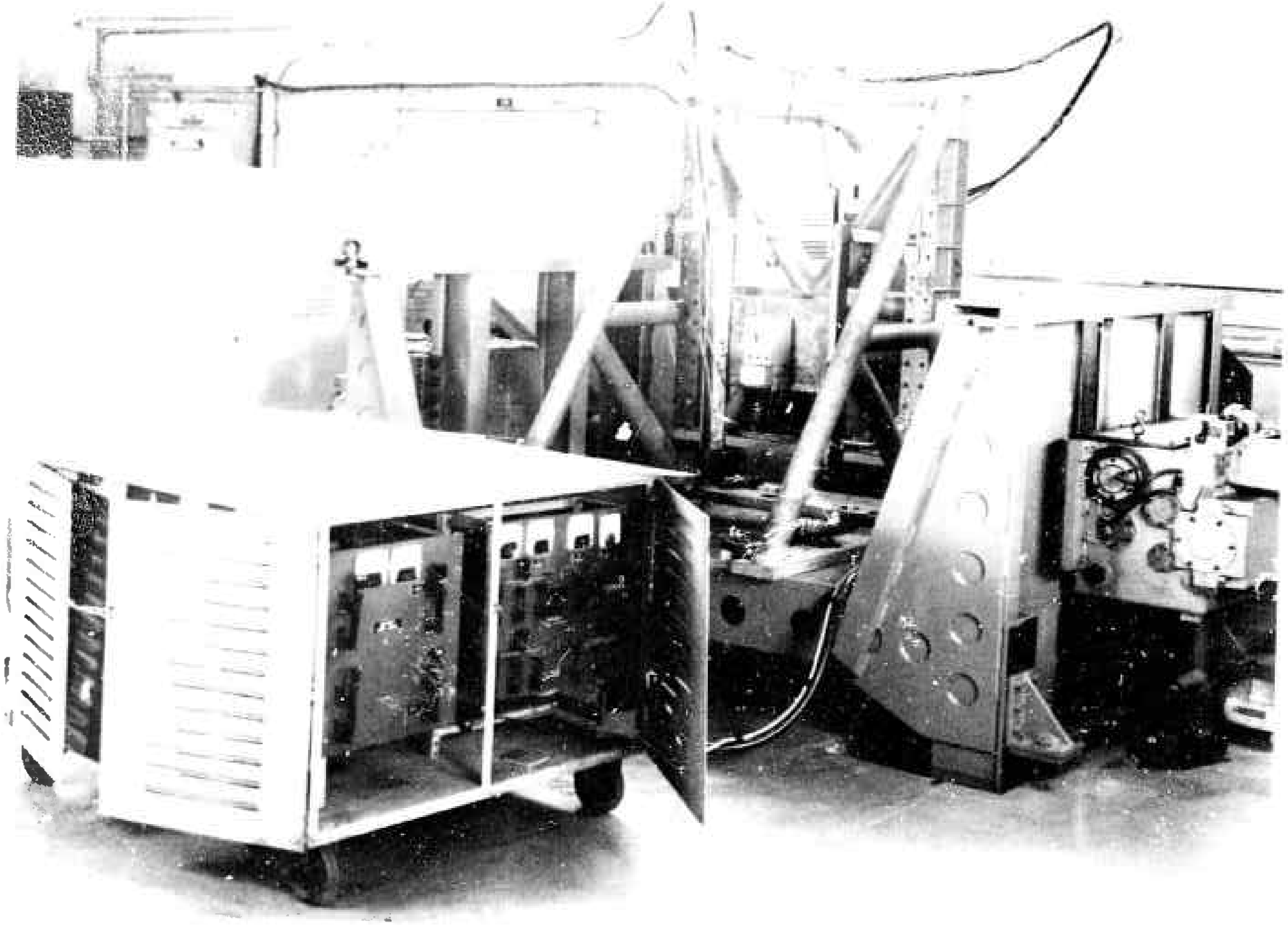


Fig. 1 - Vibration Test Setup. An AQB-LF101 circuit breaker is shown on the NRL 5000 lb Reaction-Drive Vibration Machine, arranged for vibration in the Horizontal-Parallel-to-Front plane. The Breaker is fed with 250 v̲ 3φ at 90 amp. The resistive load is in the foreground.

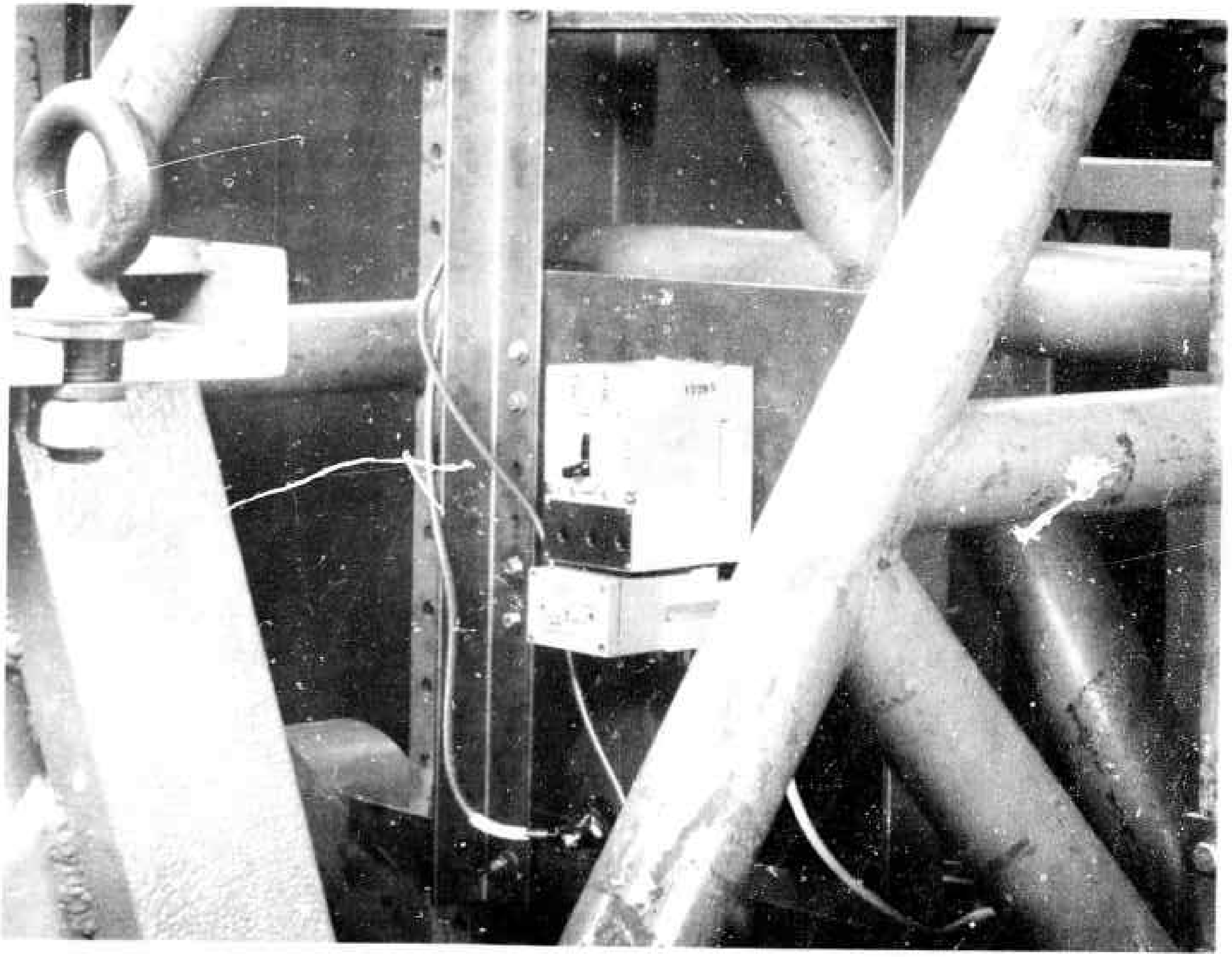


Fig. 2 - Closeup of the LF101 vibration test setup. The breaker is oriented for test in the Horizontal-Perpendicular-to-Front plane.

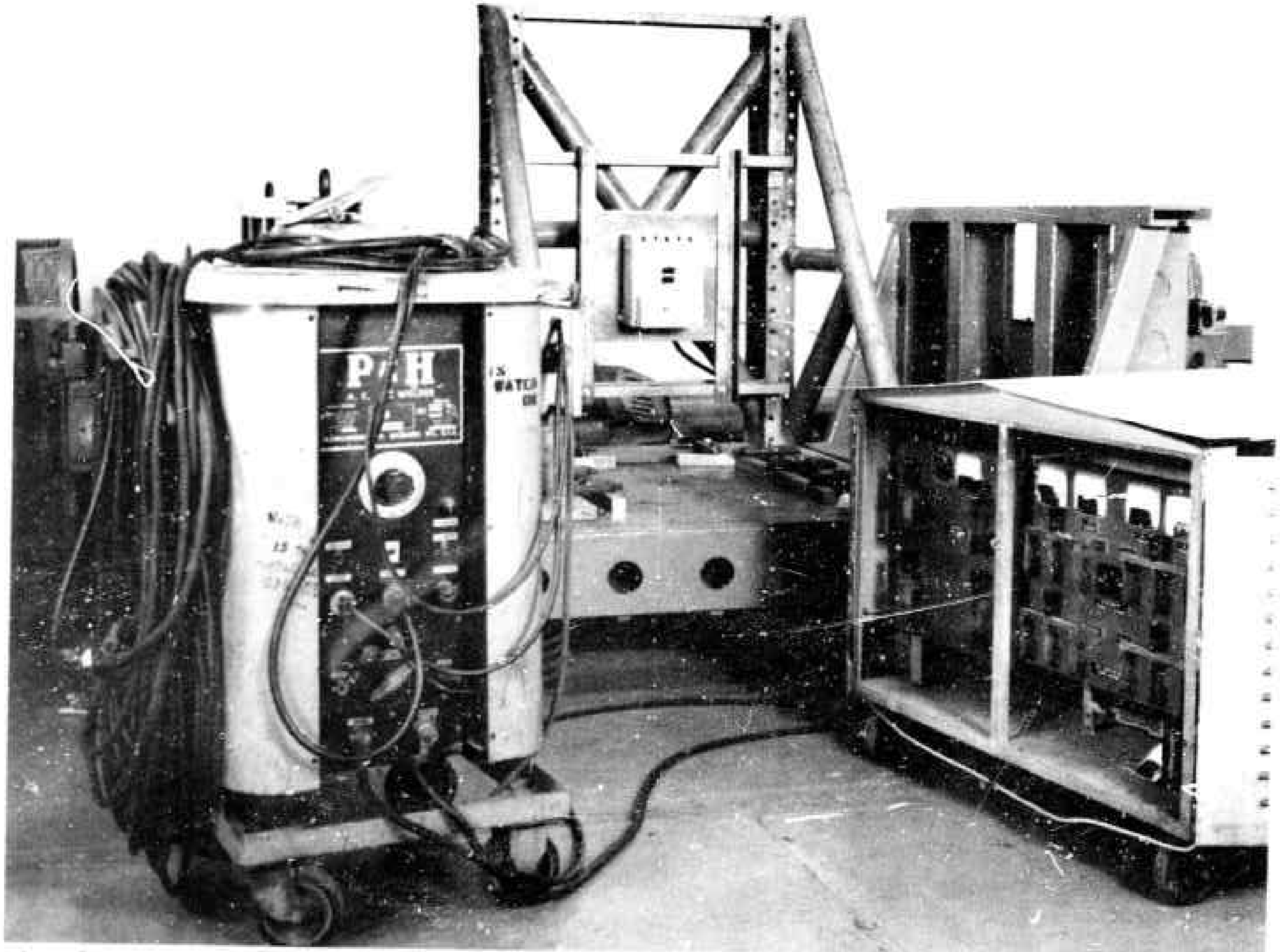


Fig. 3 - Vibration Test Setup for an AQB-LF250 circuit breaker. The breaker is powered with 40 v 1φ at 250 amp from the welding machine in left foreground.

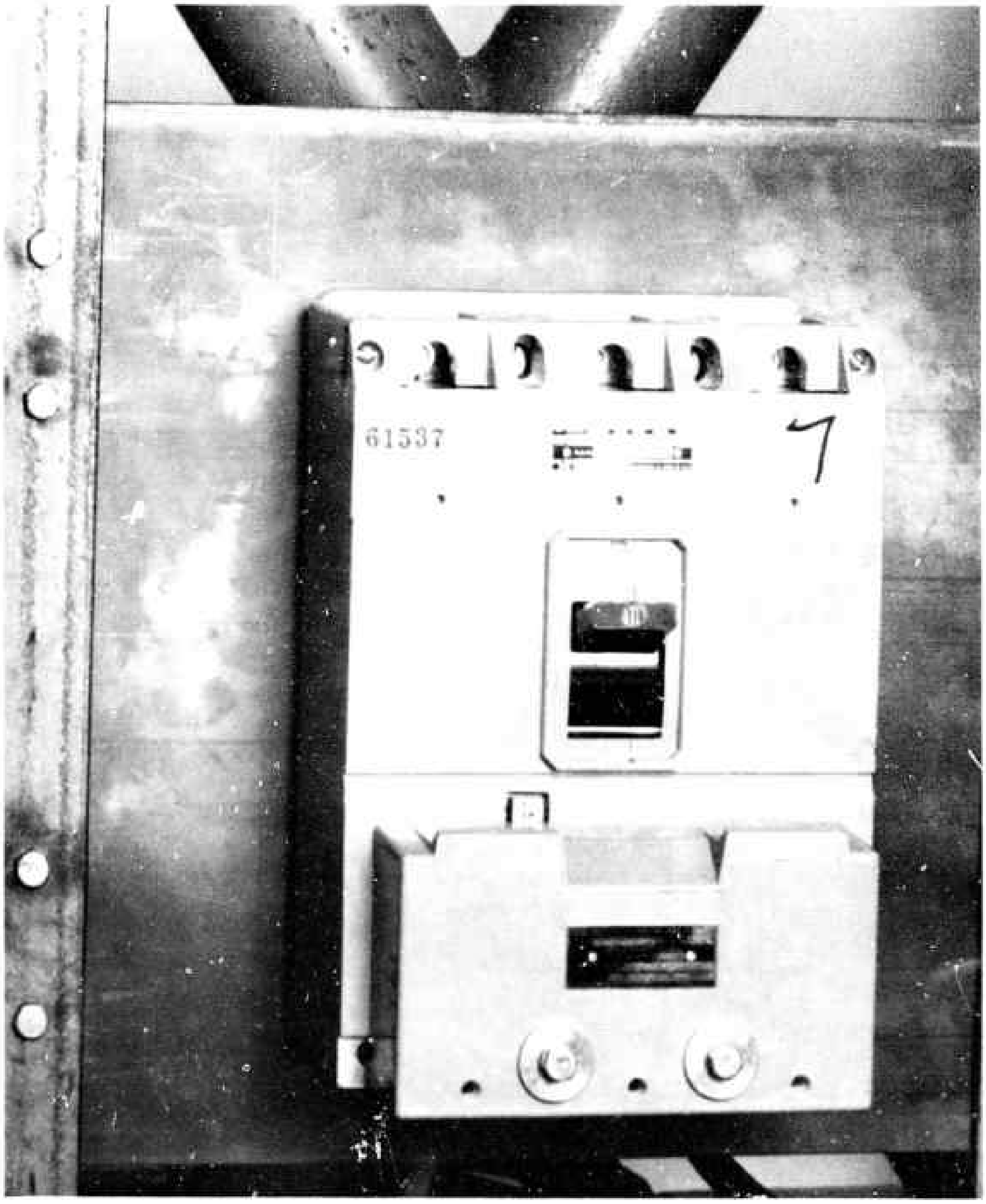


Fig. 4 - Closeup of the LF250 vibration test setup.

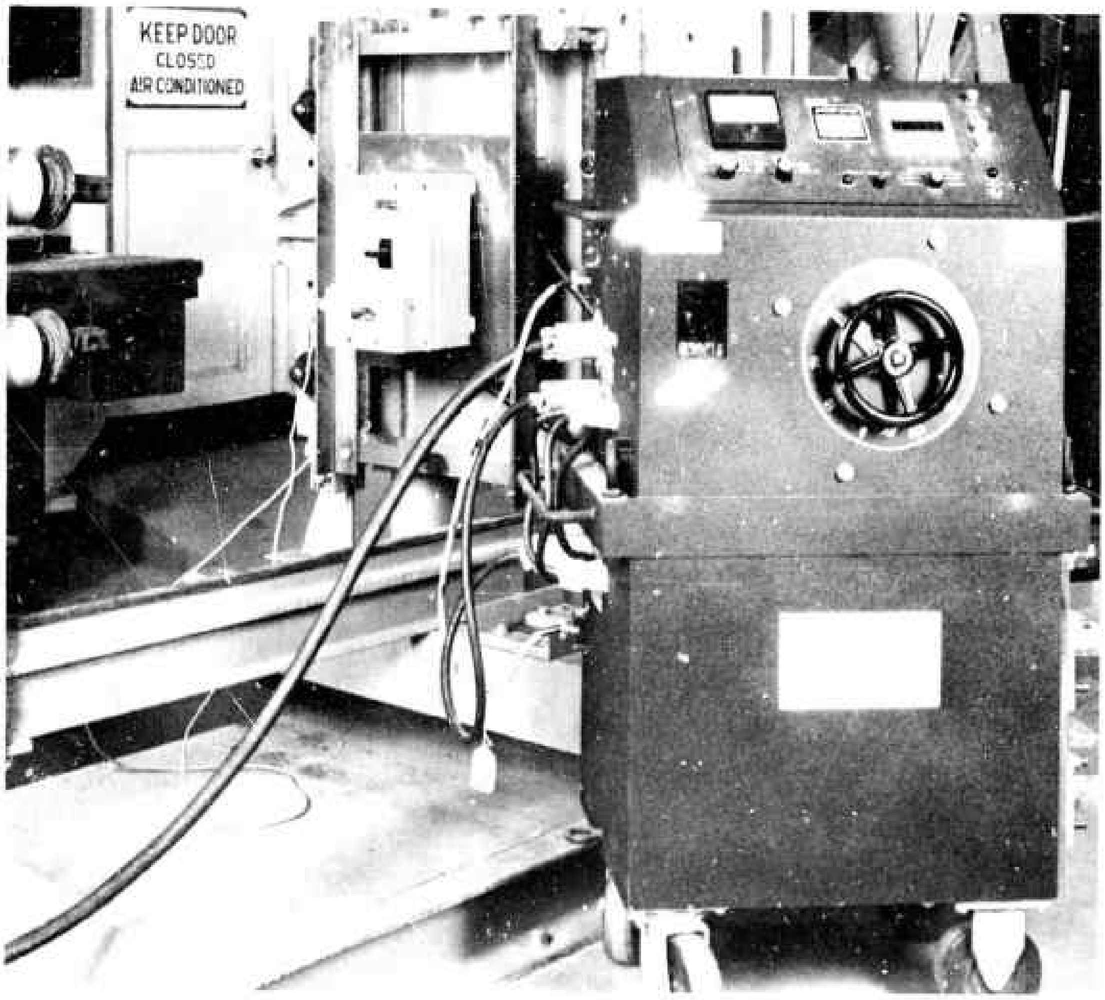


Fig. 5 - Setup for shock test of an AQB-LF250 on the Navy Class-HI Shock Machine for Lightweight Equipments (LWSM). The orientation shown is for Back and Top blows. The breaker was powered at 250 amp per pole by the circuit breaker test machine in the foreground.

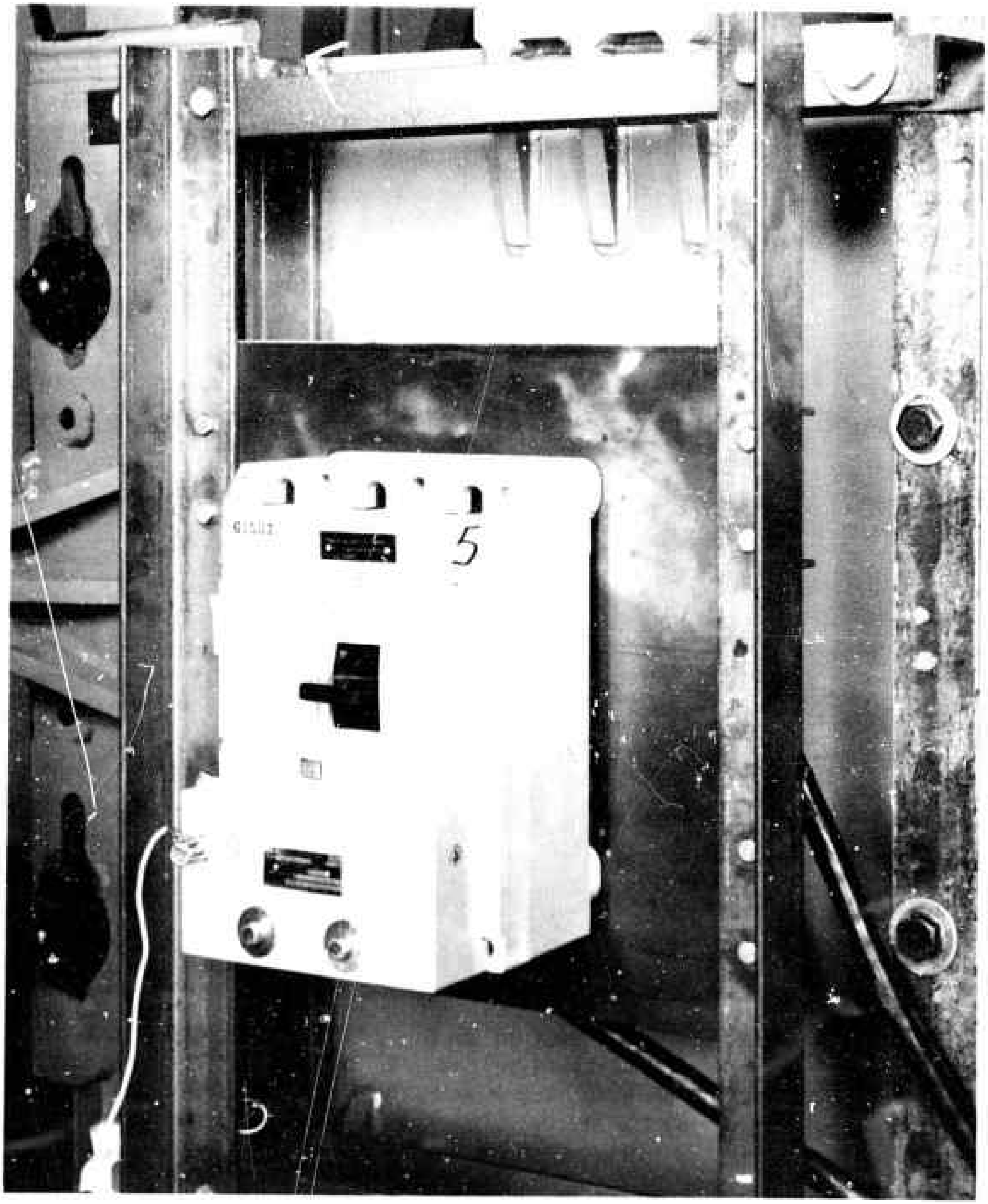


Fig. 6 - Closeup of the LF250 test setup on the LWSM.

Fig. 7 - Back view of the LF250 test fixture.

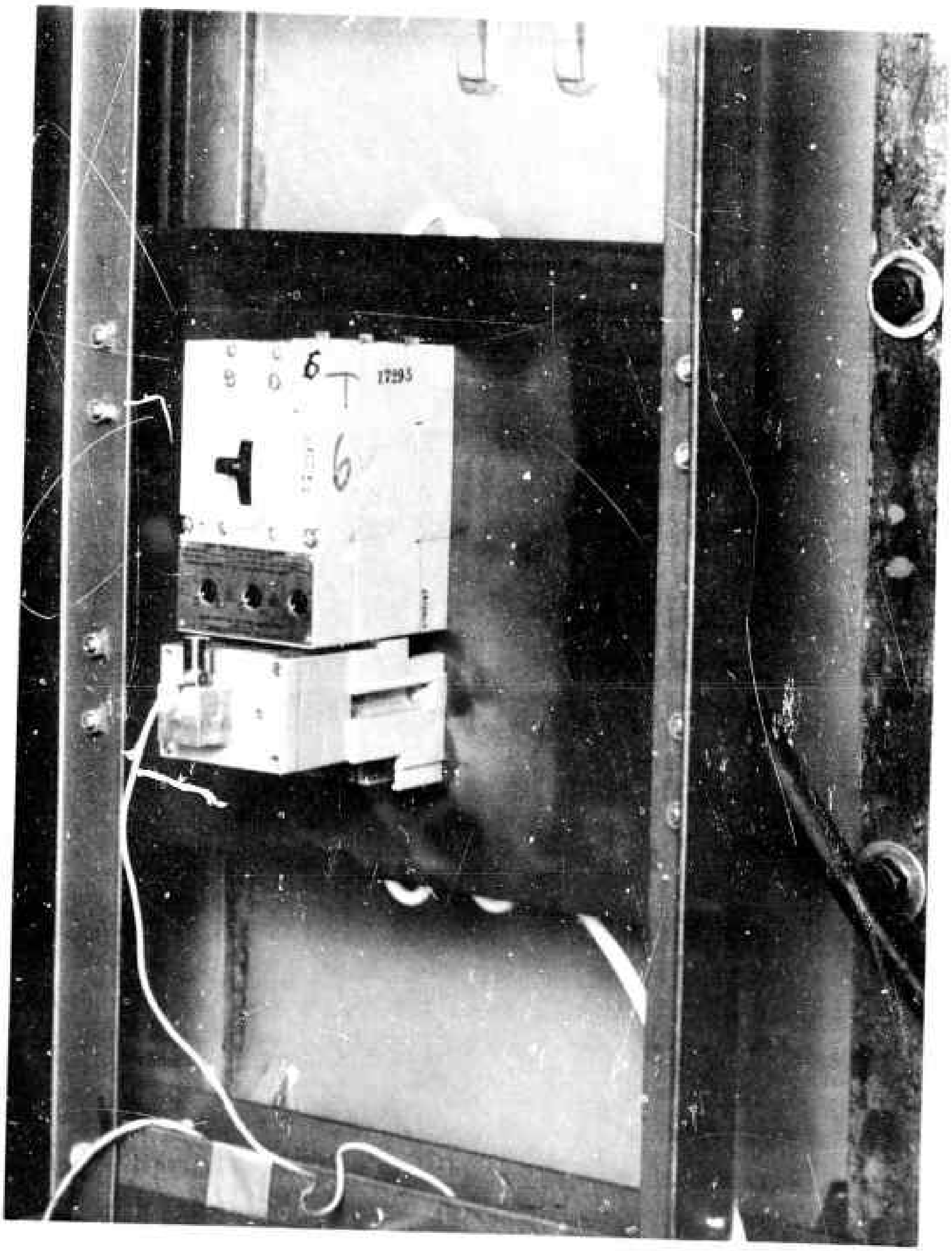


Fig. 8 - Closeup of the LF101 test setup on the LWSM.

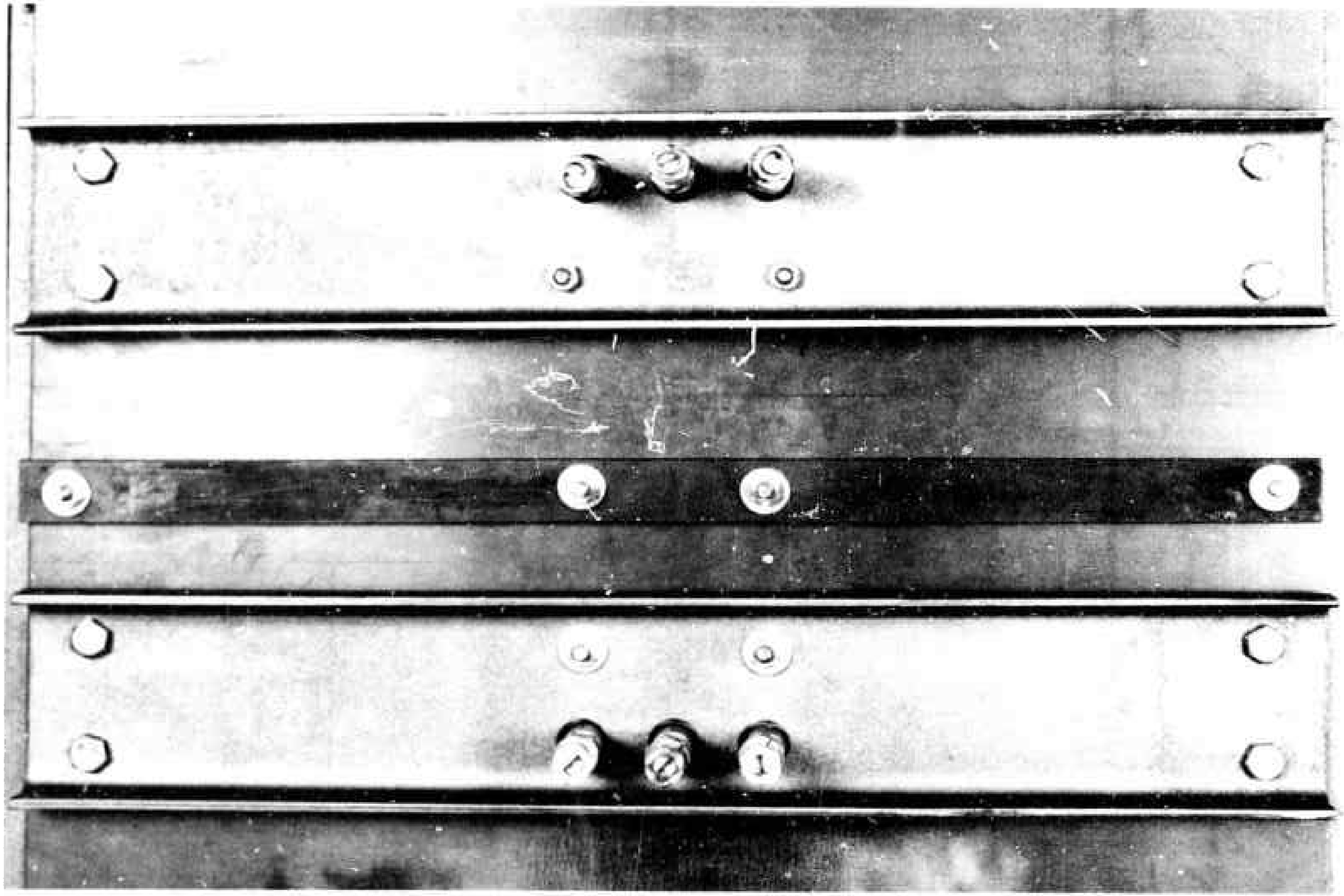


Fig. 9 - Back view of the LF101 test fixture, showing the extra 1" x 1/4" stiffening bar added at center.

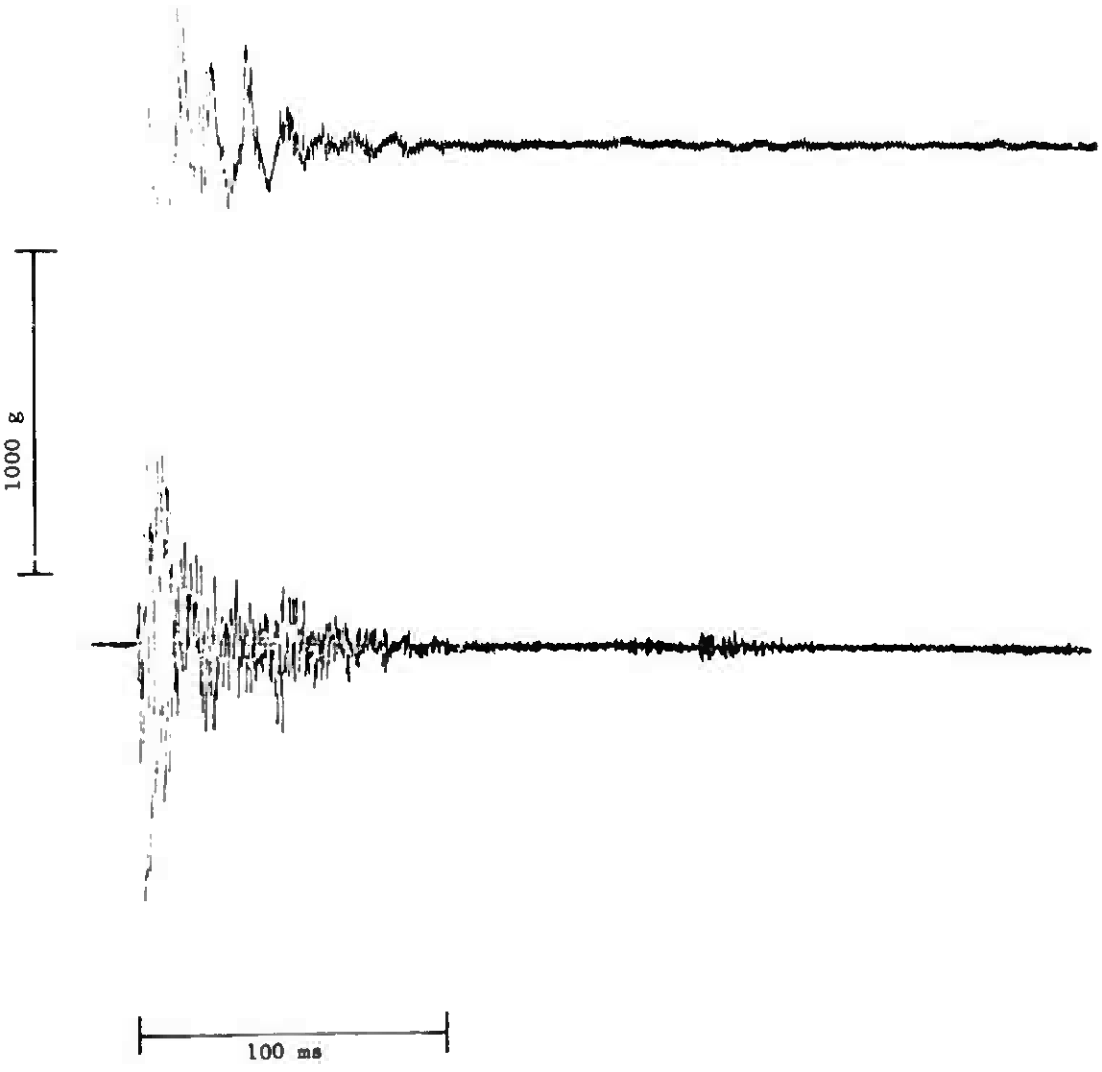


Fig. 10 - Acceleration-time waveform for 5 ft. Top blow, LF101. Bottom-Mounting Panel, Top - Fuse Block.

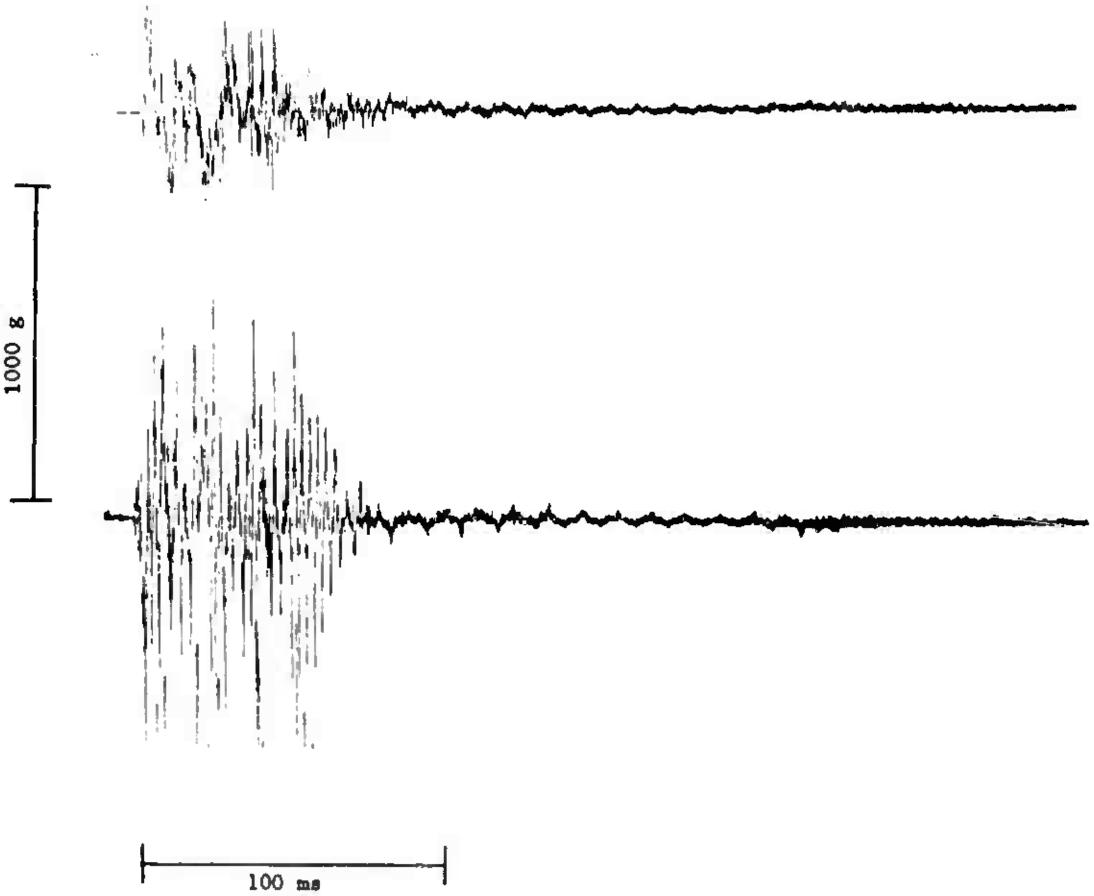


Fig. 11 - Acceleration-time waveform for 5 ft. Back blow, LF101. Bottom-Mounting Panel, Top - Fuse Block.

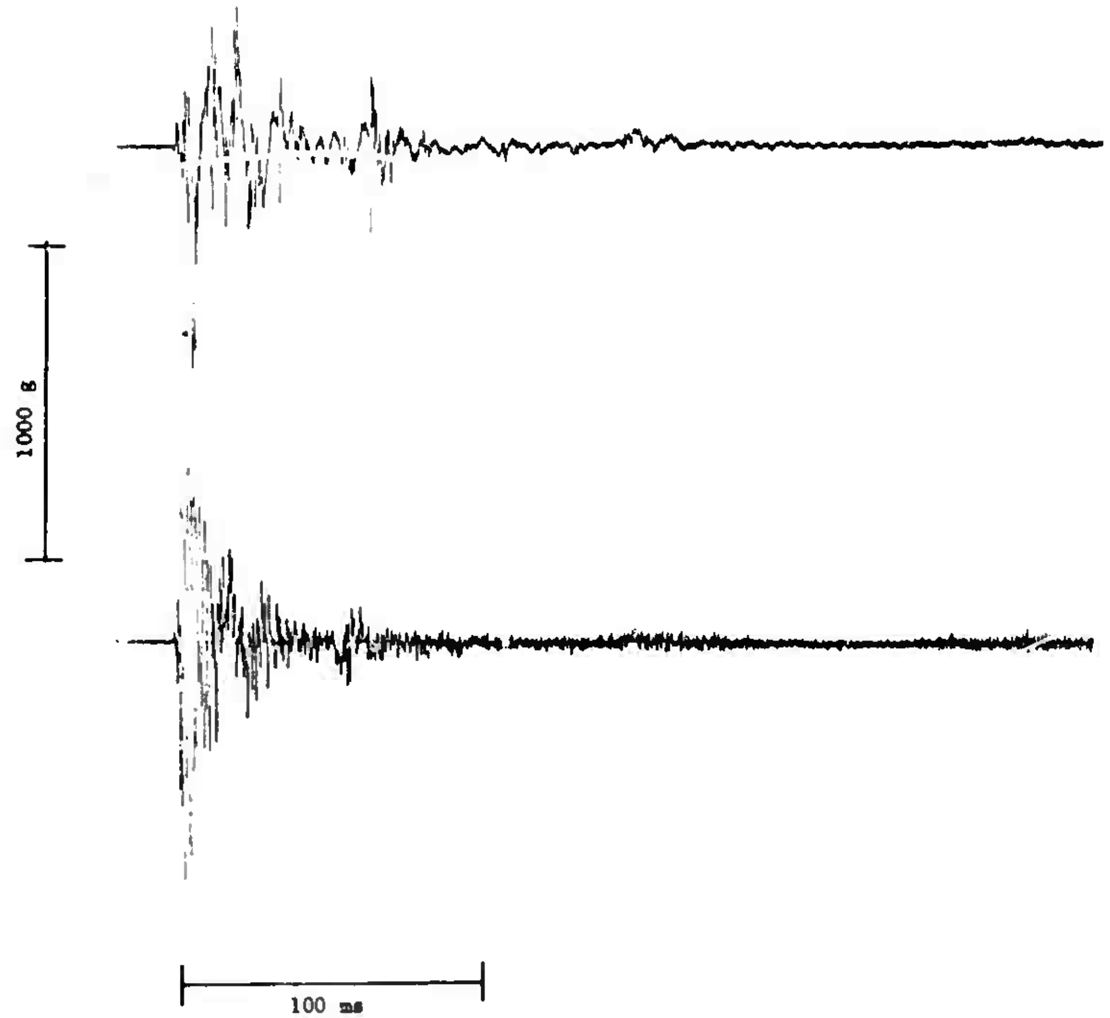


Fig. 12 - Acceleration-time waveform for 5 ft. Top blow, LF250. Bottom-Mounting Panel, Top - Fuse Block.

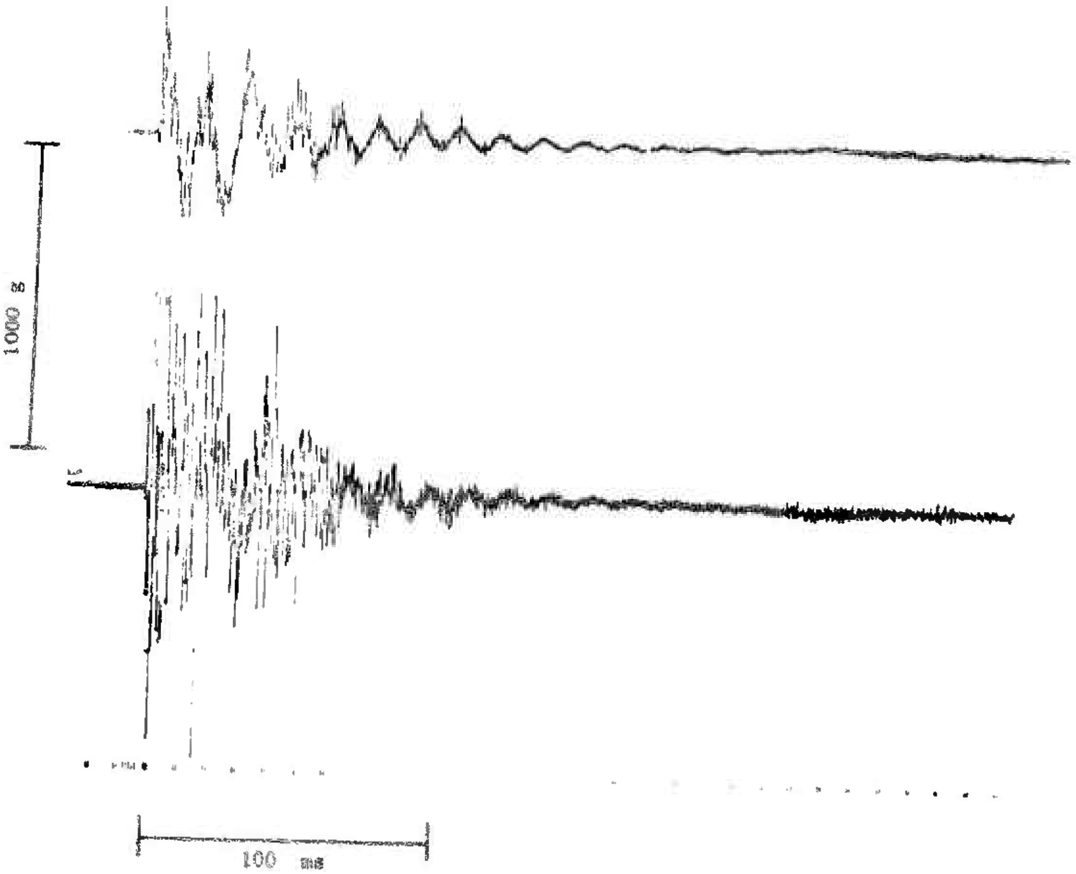


Fig. 13 - Acceleration-time waveform for 5 ft. Back blow, LF250. Bottom-Mounting Panel, Top - Fuse Block.

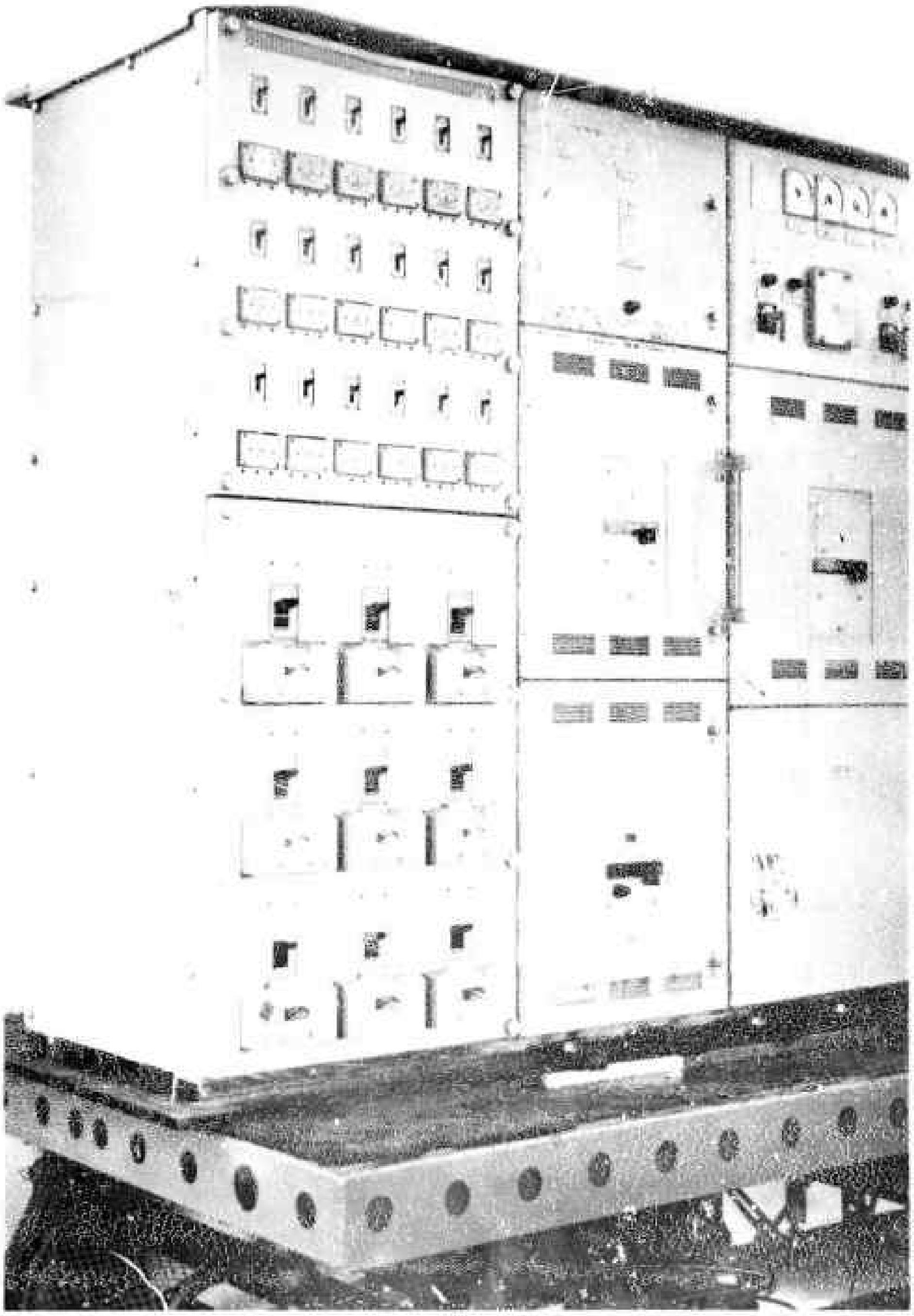


Fig. 14 - The Switchgear mounted on the NRL 10,000 lb Reaction-Drive Vibration Machine. The offset mounting orients the center-of-gravity of the switchgear directly above that of test machine. The orientation shown in that for testing in the Vertical and Horizontal-Parallel-to-Front plane.

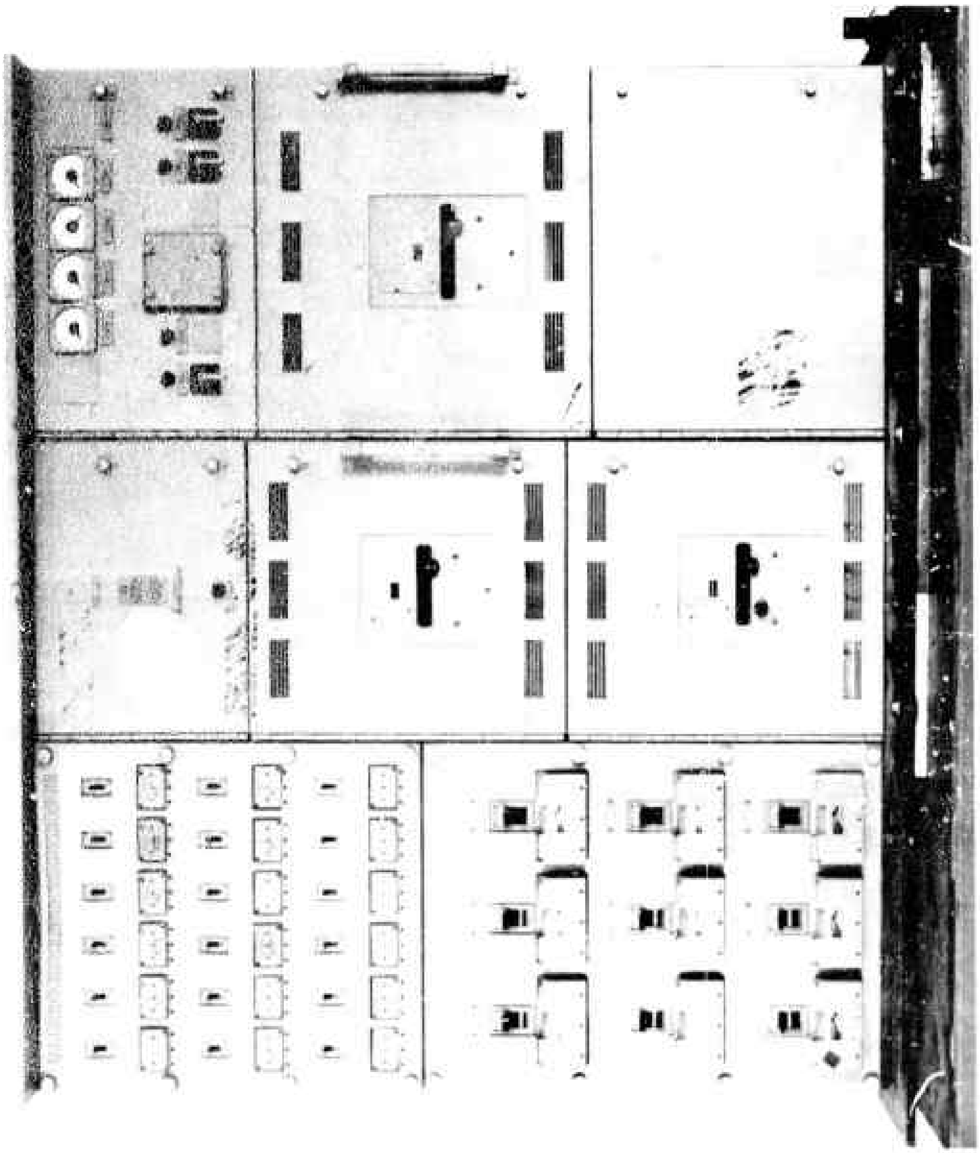


Fig. 15 - Another view of the vibration test setup.

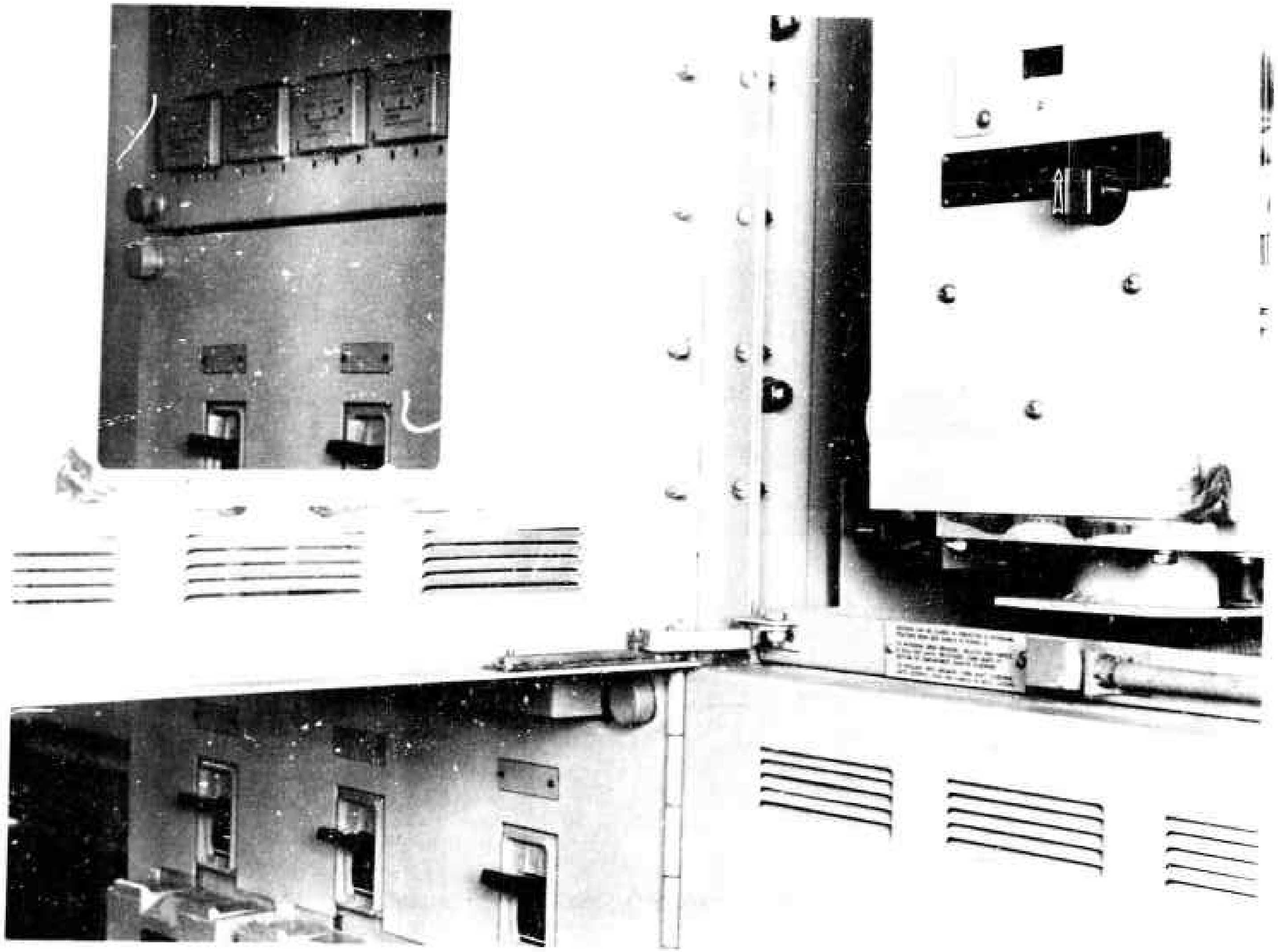


Fig. 16 - Damage from vibration test - upper ACB-1600. Note abrasion of breaker and door, and bending of louvers.

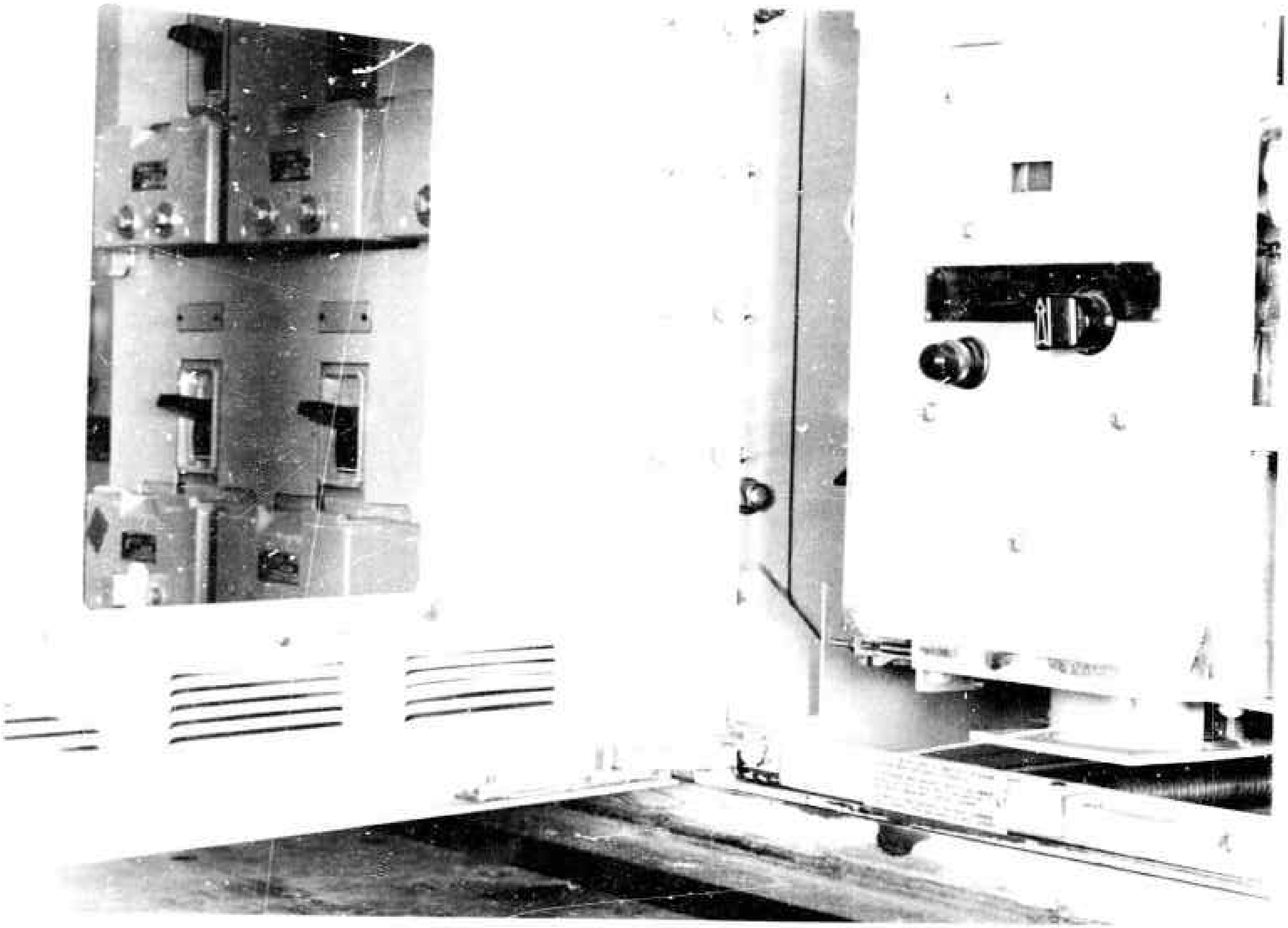


Fig. 17 - Damage from vibration test - lower ACB-1600. Note abrasion of breaker and door, and bending of louvers.

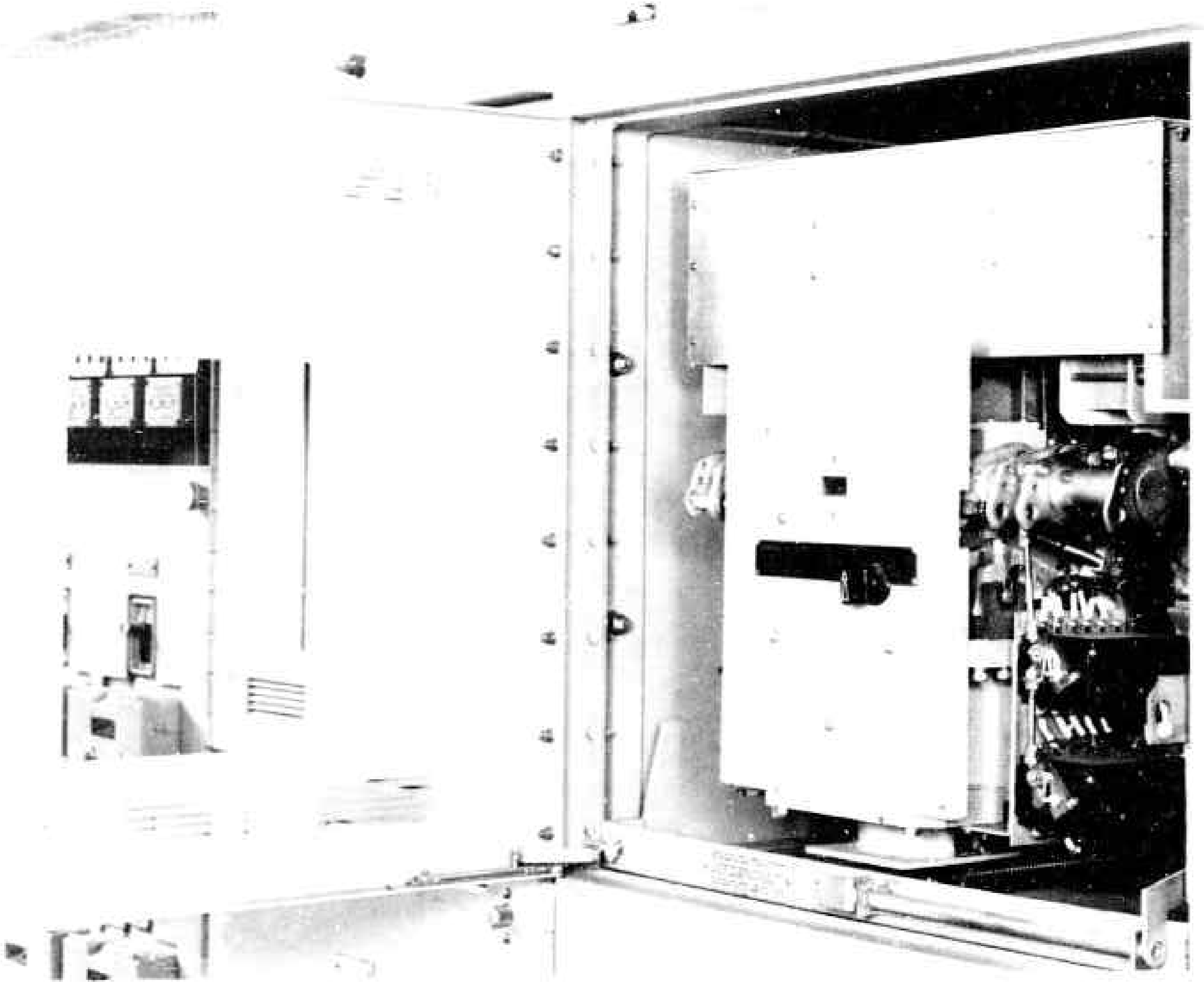


Fig. 18 - Damage from vibration test - ACB-2400. Note abrasion of breaker and door, and bending of louvers.

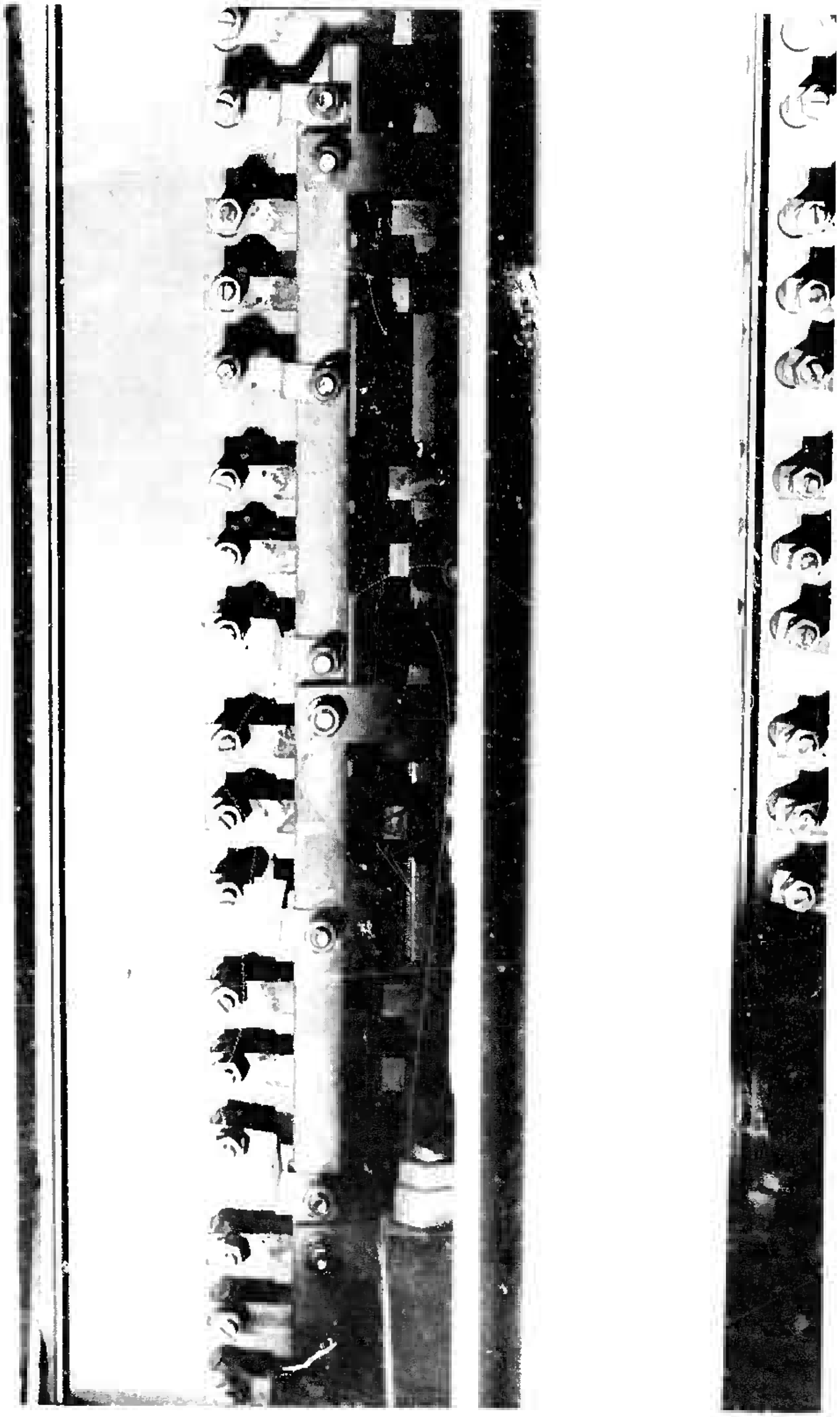


Fig. 19 - Damage from vibration test - upper horizontal bus (LF101). Note broken feeds from bus to breakers.

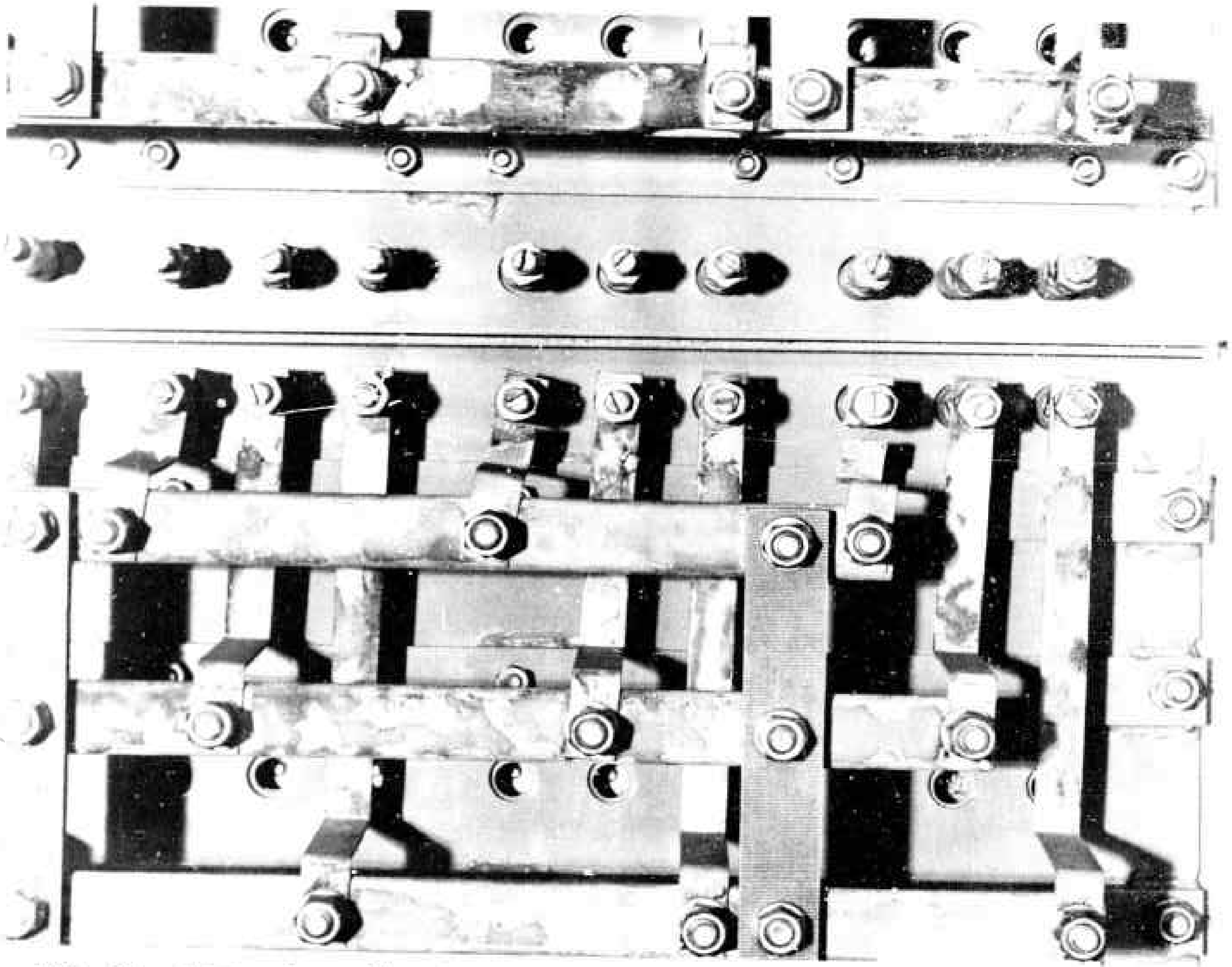


Fig. 20 - Damage from vibration test - middle horizontal bus (LF101). Note broken feeds from bus to breakers.

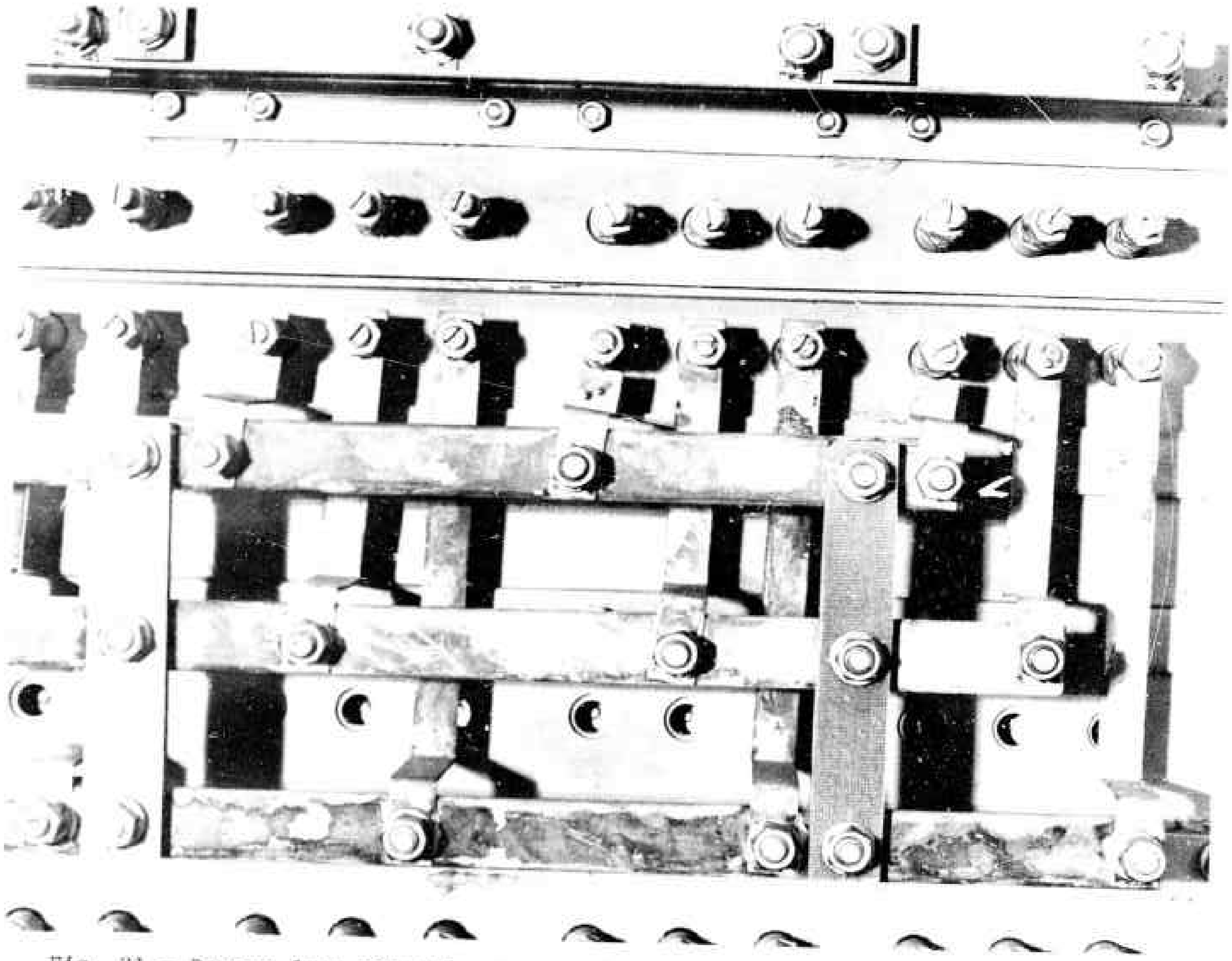


Fig. 21 - Damage from vibration test - lower horizontal bus (LF101). Note broken feeds from bus to breakers.

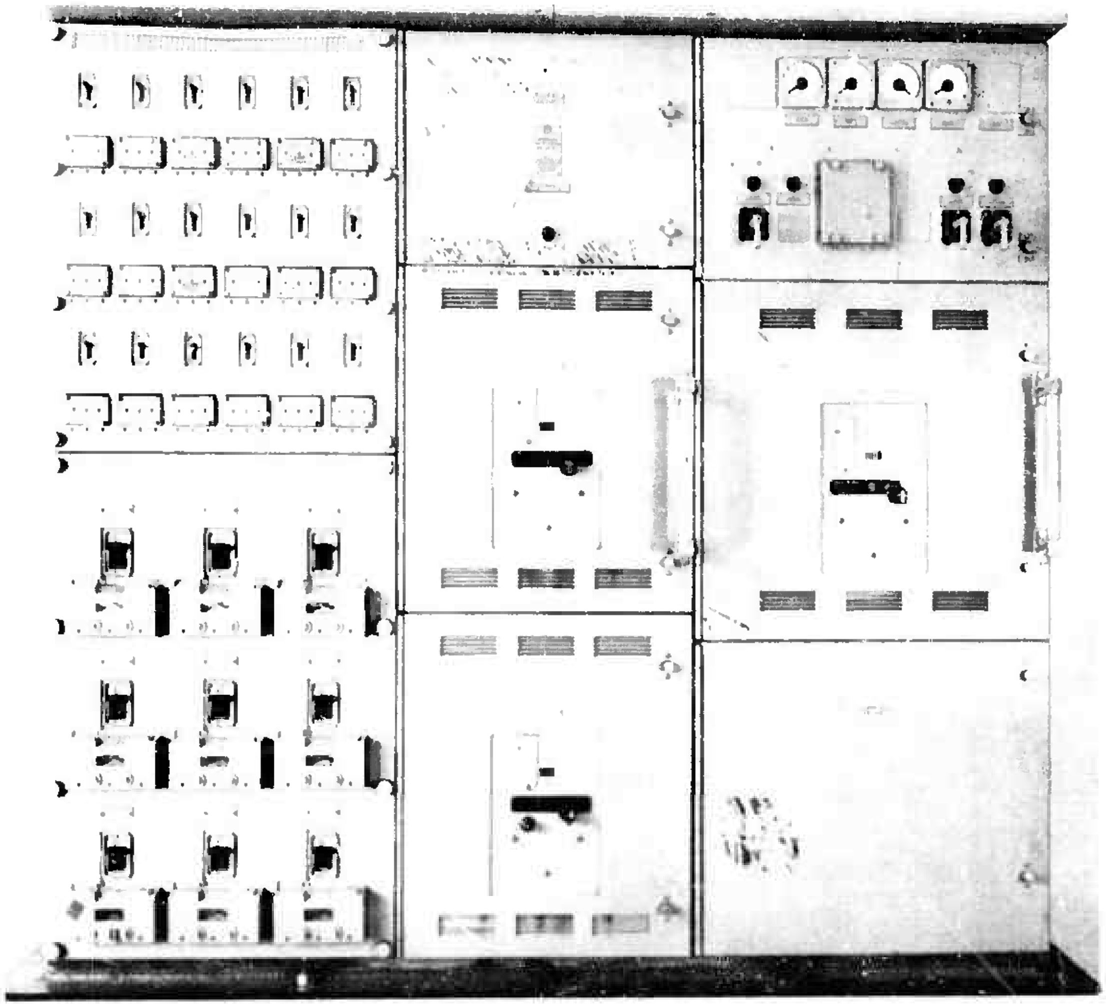


Fig. 22 - Shock Test Setup. The switchgear is mounted on the Navy Class-HI Shock Machine for Mediumweight Equipments (MWSM). The arrangement shown is for Vertical blows.

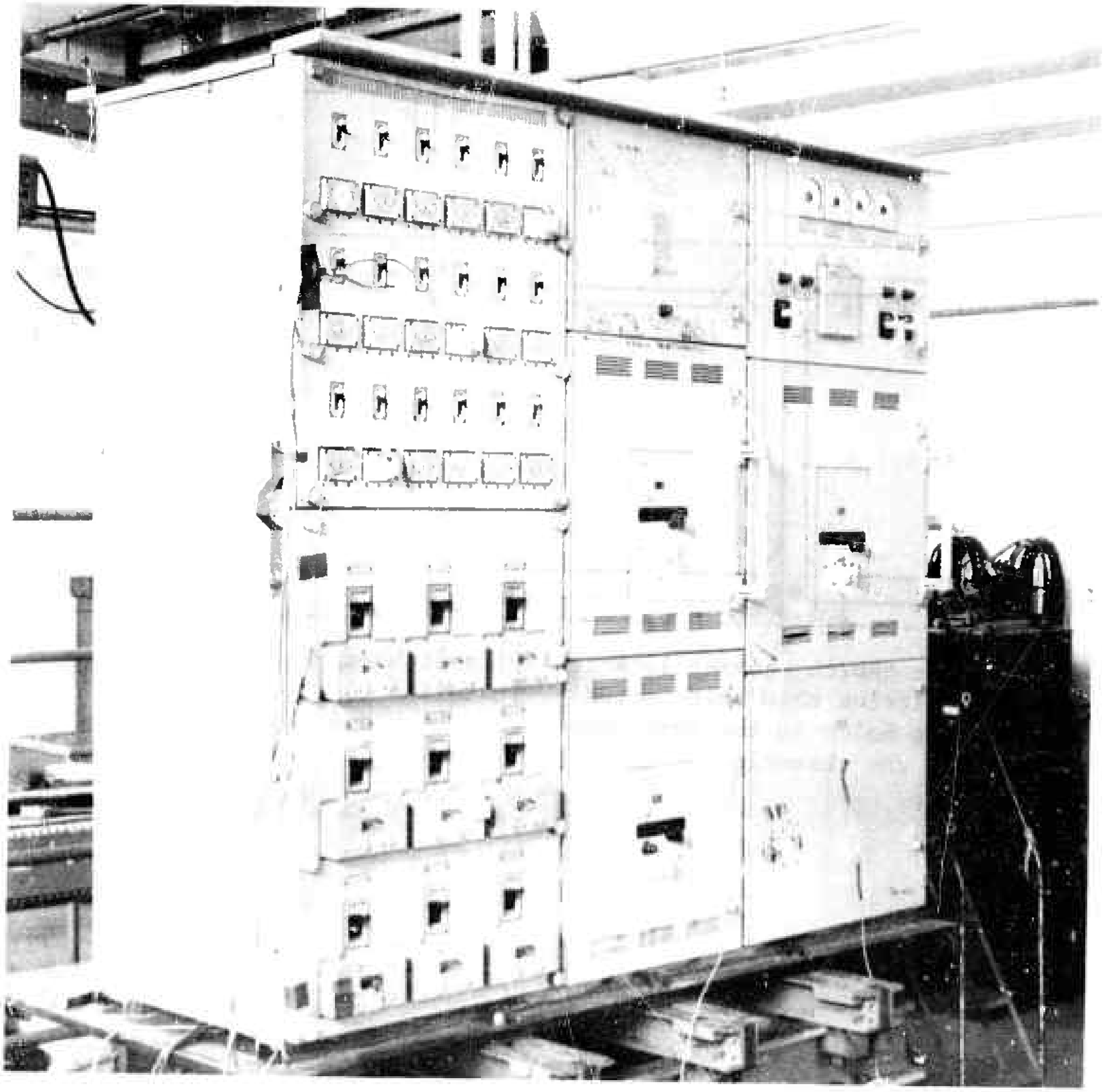


Fig. 23 - Shock Test Setup. The switchgear is shown during instrumentation installation. The offset in the mounting arrangement is in order to align the center-of-gravity of the switchgear plus anvil table, etc., on the axis of percussion.

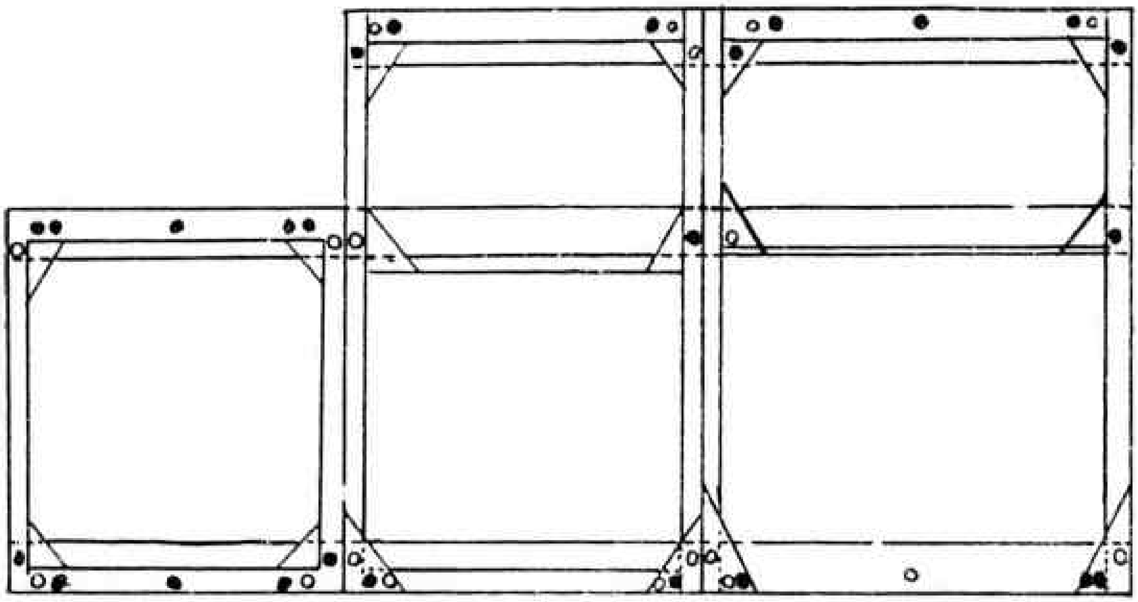
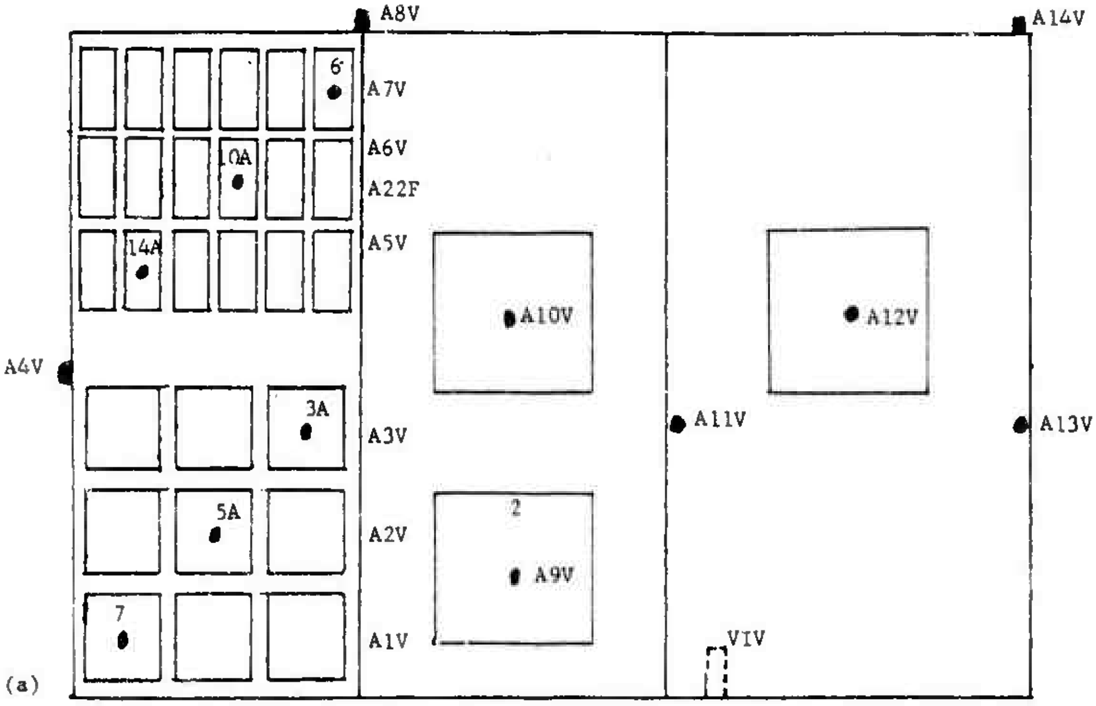
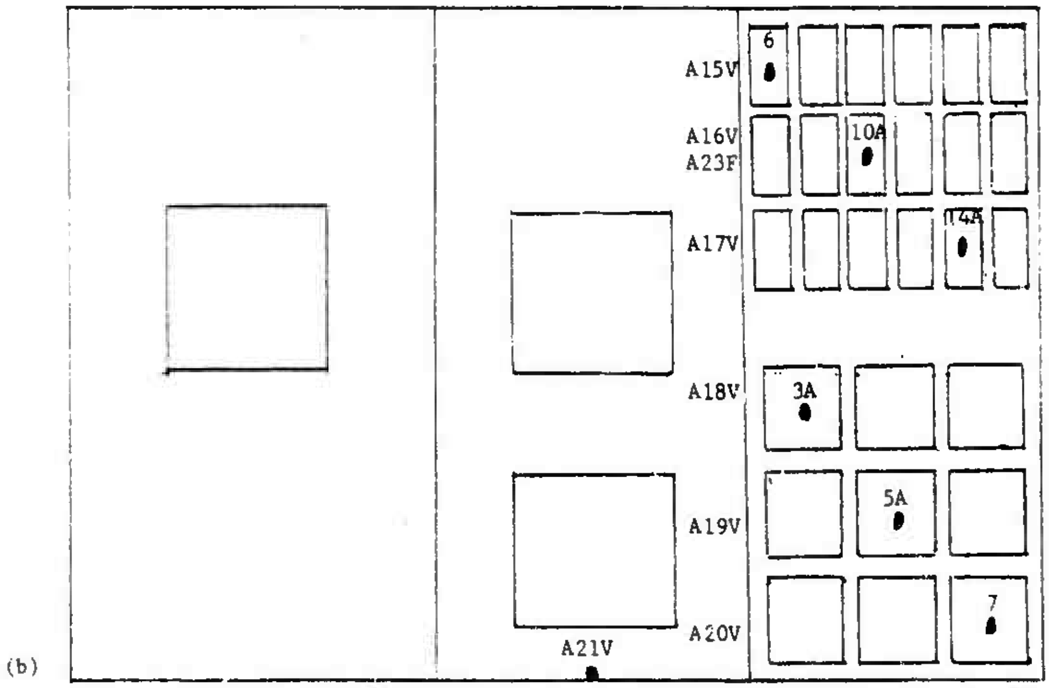


Fig. 24 - Sketch showing locations of switchgear hold-down bolts. Closed circles show bolts actually installed, open circles represent holes in the switchgear base which did not align with those in the channels.

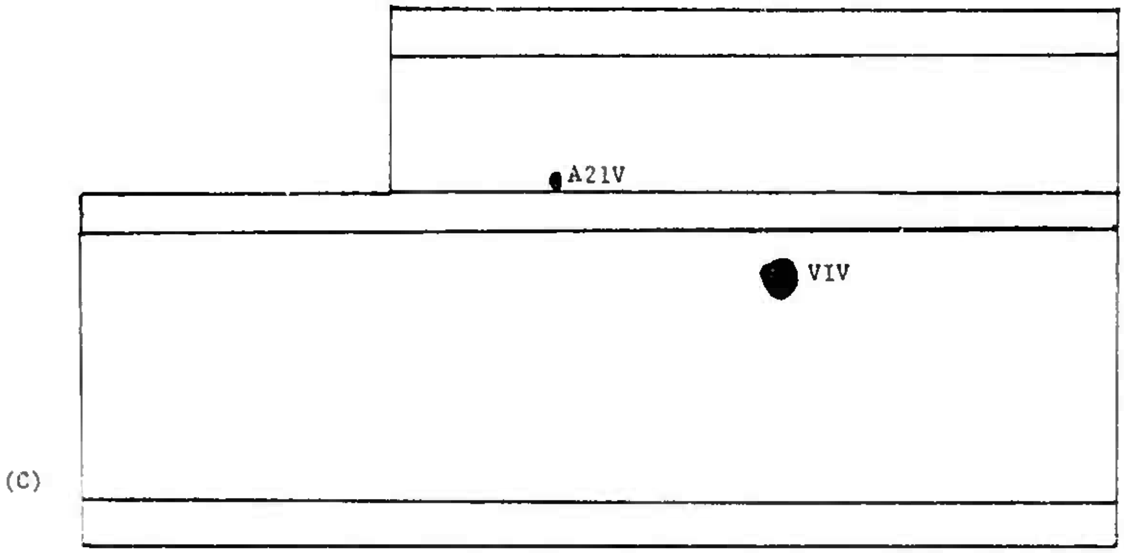


(a) Switchgear front

Fig. 25 - Locations of pickups for measurement of shock motions. Prefix "A" indicates an accelerometer, "V" a velocity meter. All were oriented to read vertical motion. For the 30°-inclined shock test, the same locations were instrumented, and the pickups were rotated 30° with respect to the switchgear so as to still read vertical motion. Also, two accelerometers were added to the fuse-block and the back of the mounting panel at LF101 No. 10A, oriented to read motion normal to the mounting-panel plane.



(b) AQB Mounting panel rear



(c) Plan view

Fig. 25 - Locations of pickups for measurement of shock motions. Prefix "A" indicates an accelerometer, "V" a velocity meter. All were oriented to read vertical motion. For the 30° - inclined shock test, the same locations were instrumented, and the pickups were rotated 30° with respect to the switchgear so as to still read vertical motion. Also, two accelerometers were added to the fuse-block and the back of the mounting panel at LF101 No. 10A, oriented to read motion normal to the mounting-panel plane.

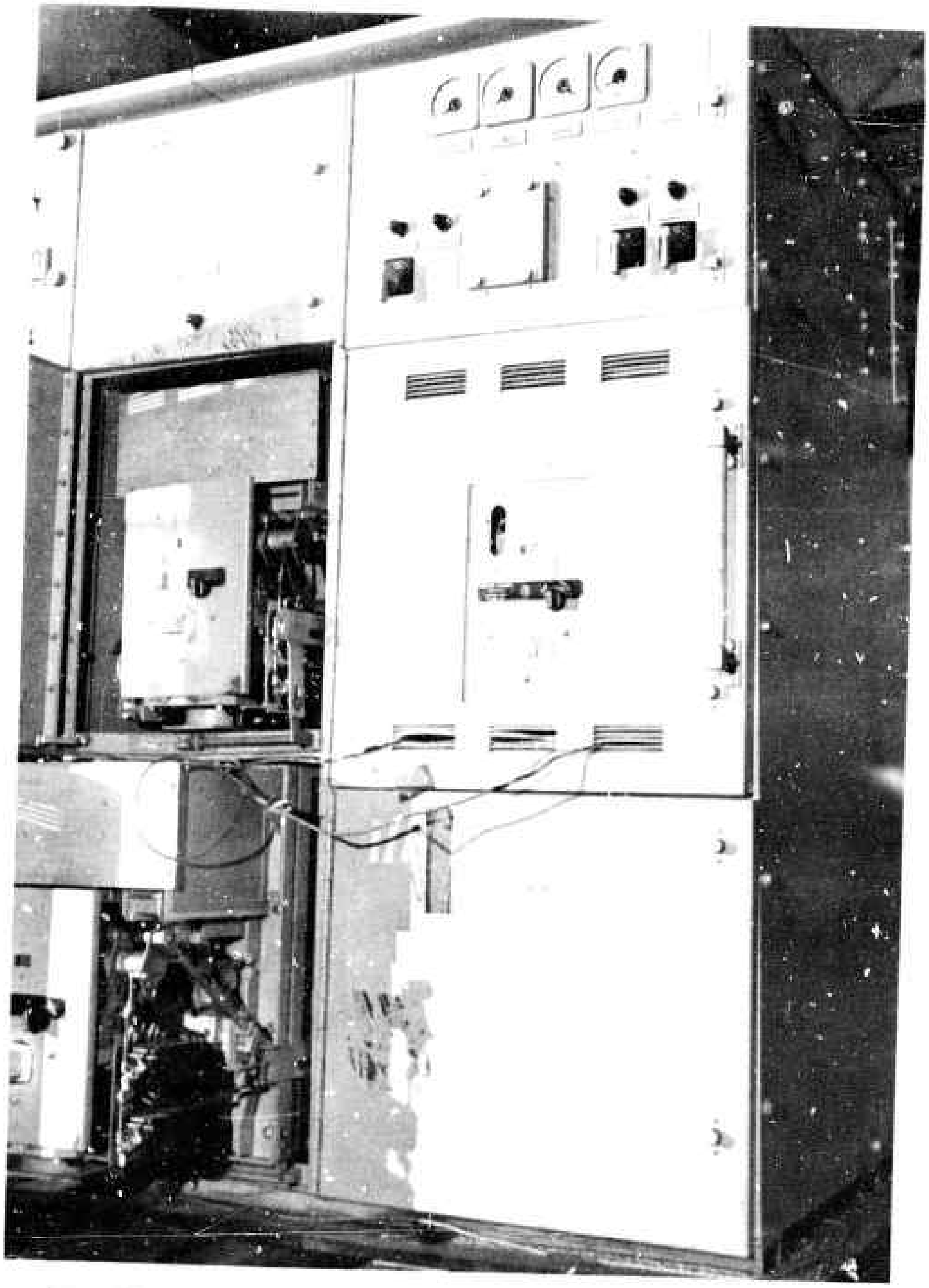


Fig. 26 - Damage from Vertical Shock. Note tilting of panel doors due to slippage of the hinges on the switchgear frame, and bending of the horizontal frame member below the upper 1600 A breaker. Photographed after Blow 3 (5-1/2 ft. Drop, 3 in 2 panel), but similar damage was noted for the preceding 3-1/4 ft. Drop blows.

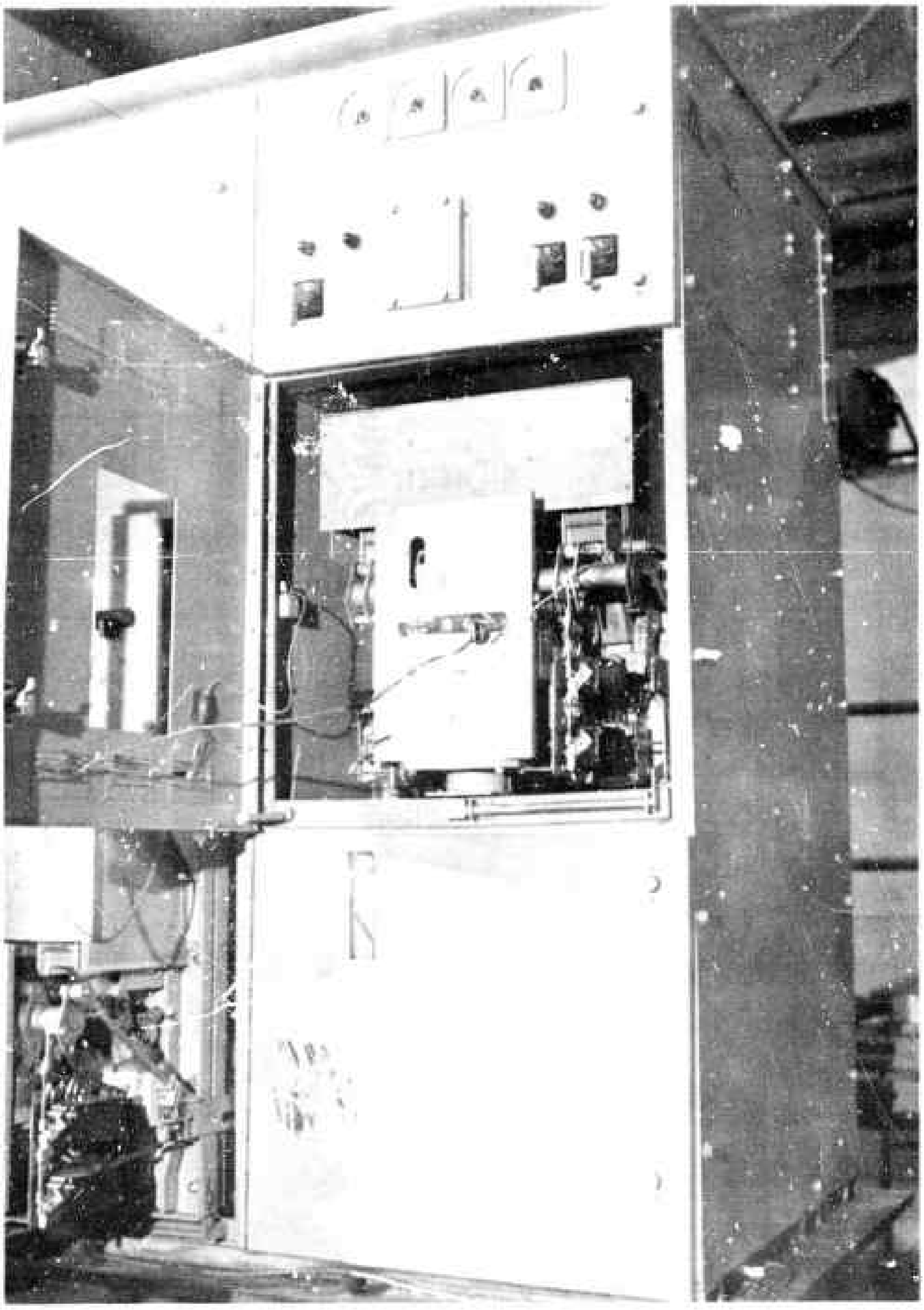


Fig. 27 - Damage from Vertical Shock. Note deformation of horizontal frame member below the 2400 A breaker, and misalignment of panel door hinge. (After Blow 3).

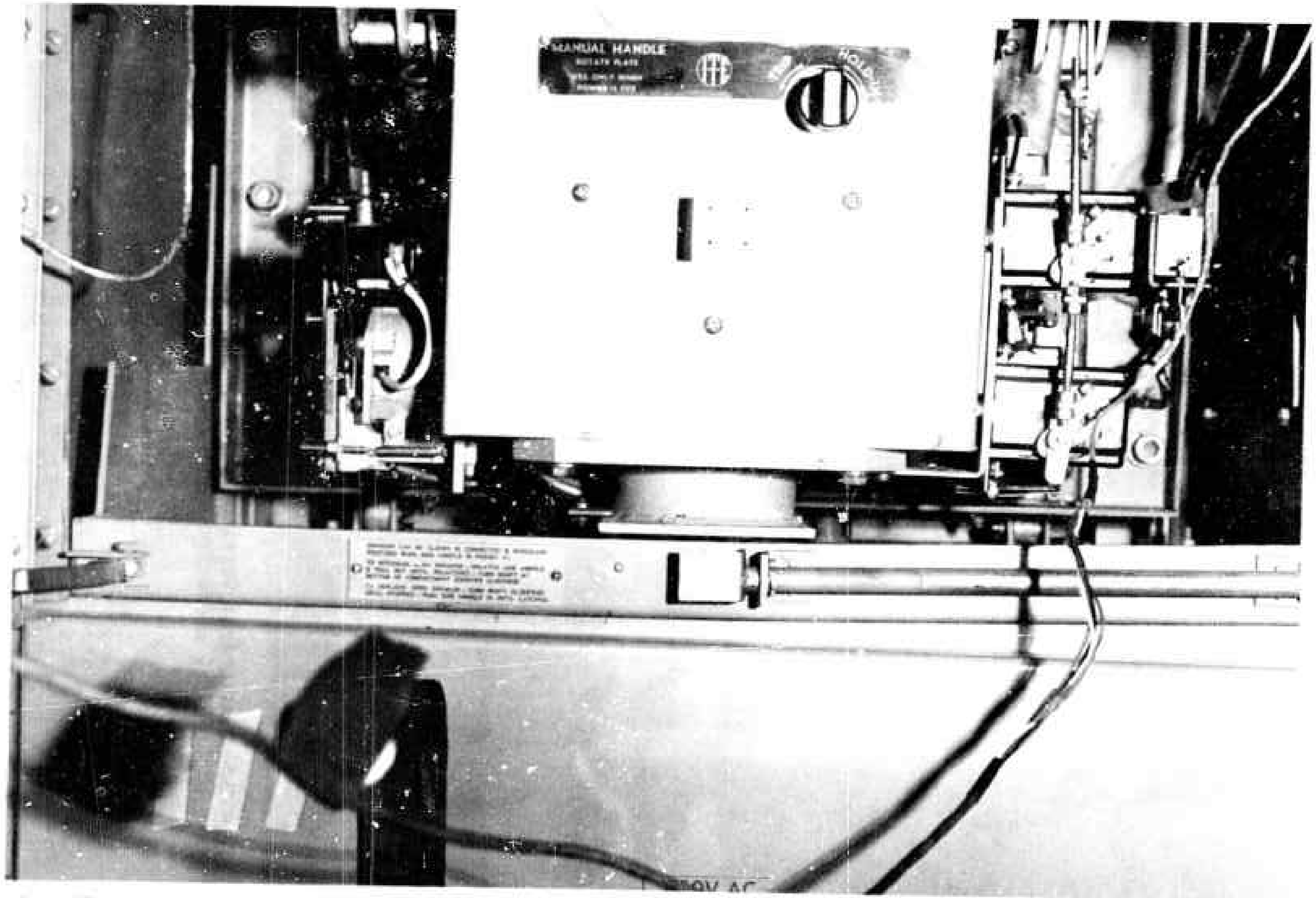


Fig. 28 - Damage from Vertical Shock - 2400 A Breaker Compartment. Note deformation of interlock mechanism (far right), breaker support, horizontal frame member; and slippage of panel-door hinge. (After Blow 3).

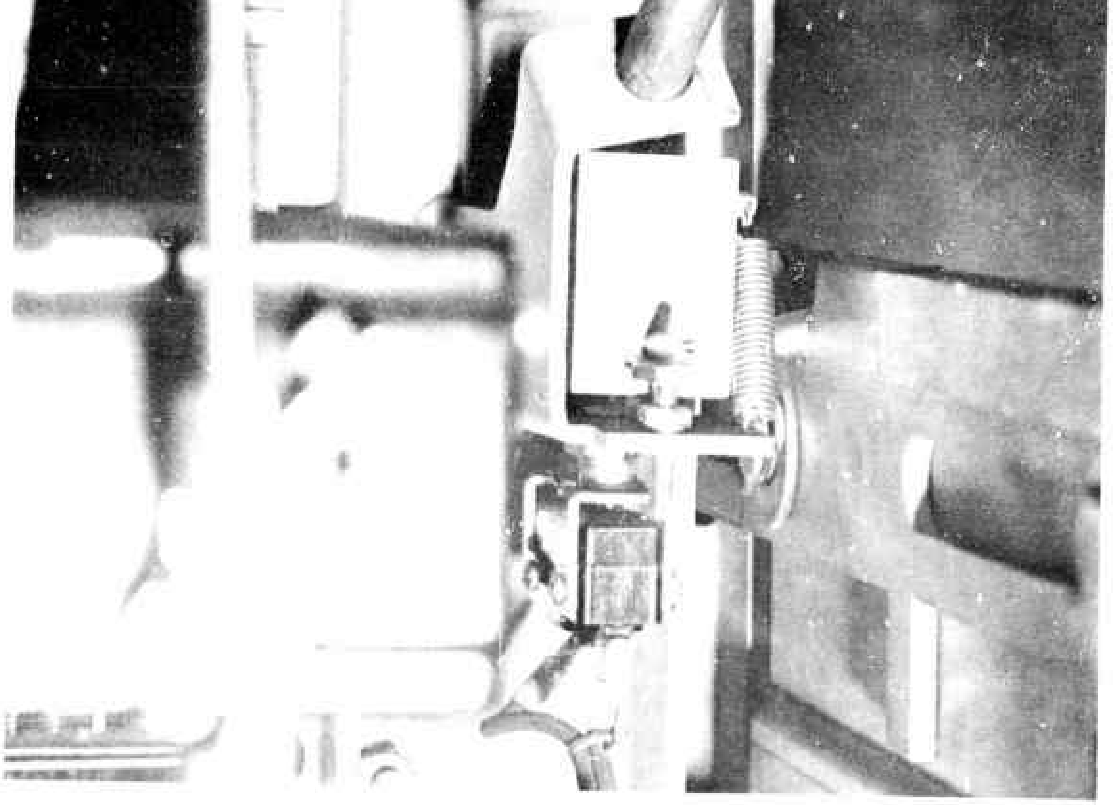


Fig. 29 - Damage from Vertical Shock. Detail of damage to 2400 A breaker interlock mechanism after Blow 3.

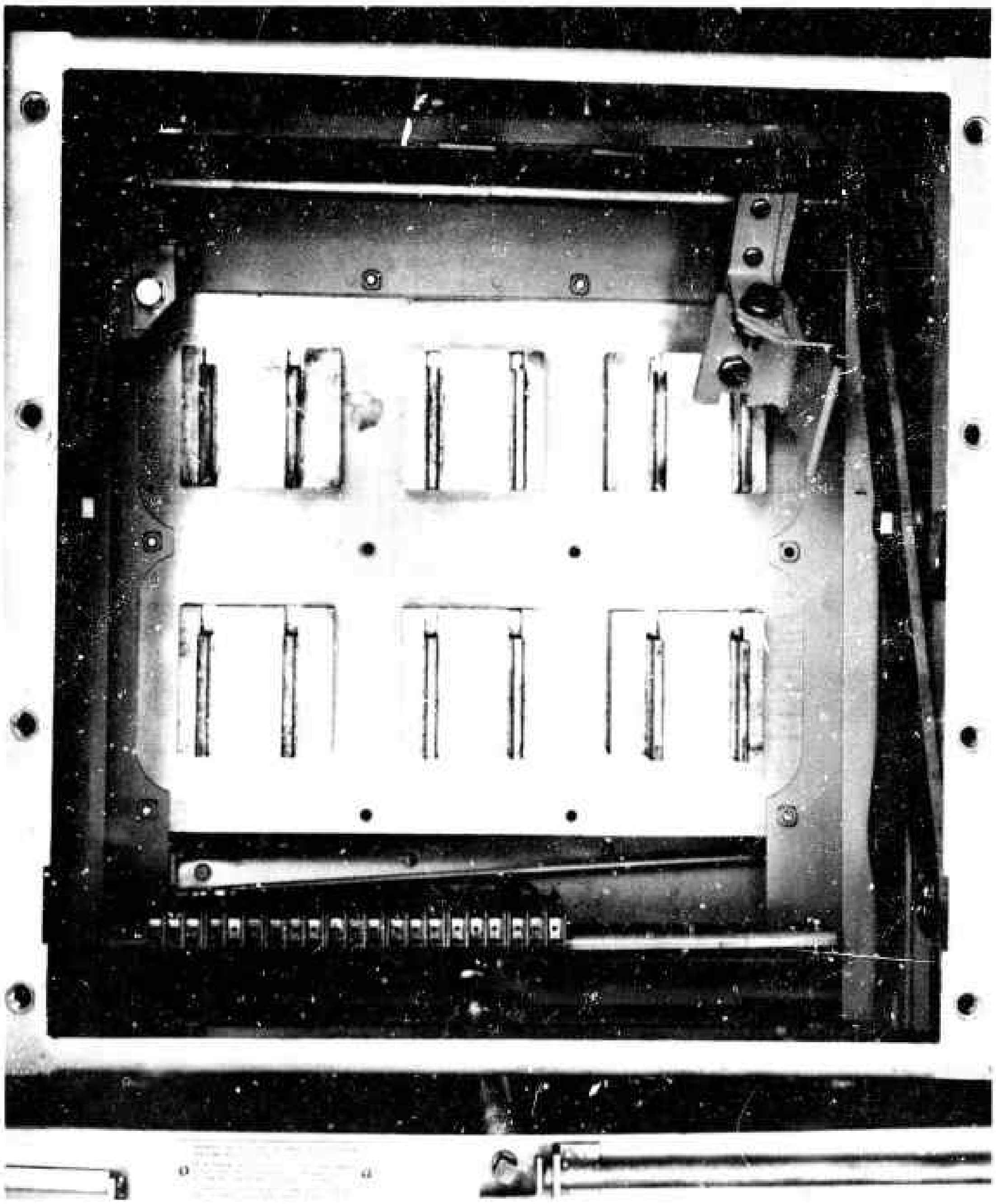


Fig. 30 - Damage from Vertical Shock - 2400 A Breaker Compartment. Note deformation of breaker support frame, broken support bracket (upper right). The eight bolts holding the melamine board to the metal frame with captive nuts were sheared off. The four bolts through the holes in the board survived, but have been removed here for repairs. (After Blow 3).

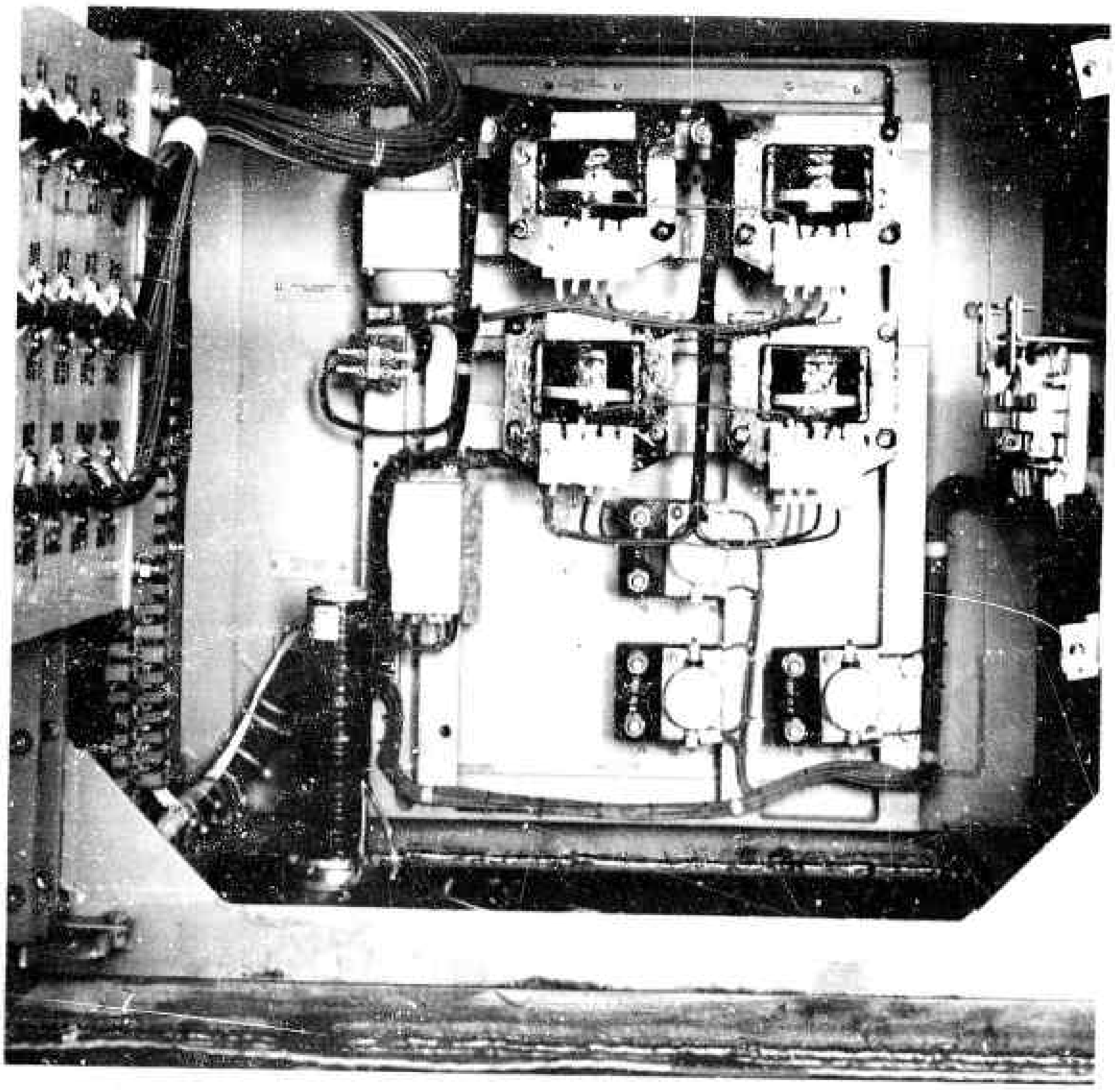


Fig. 31 - Damage from Vertical Shock - Fuse Compartment. Note slippage of fuse board hinge and damage of fuse board and fasteners. The vertical black cylinder at lower left is the velocity meter. (After Blow 3).

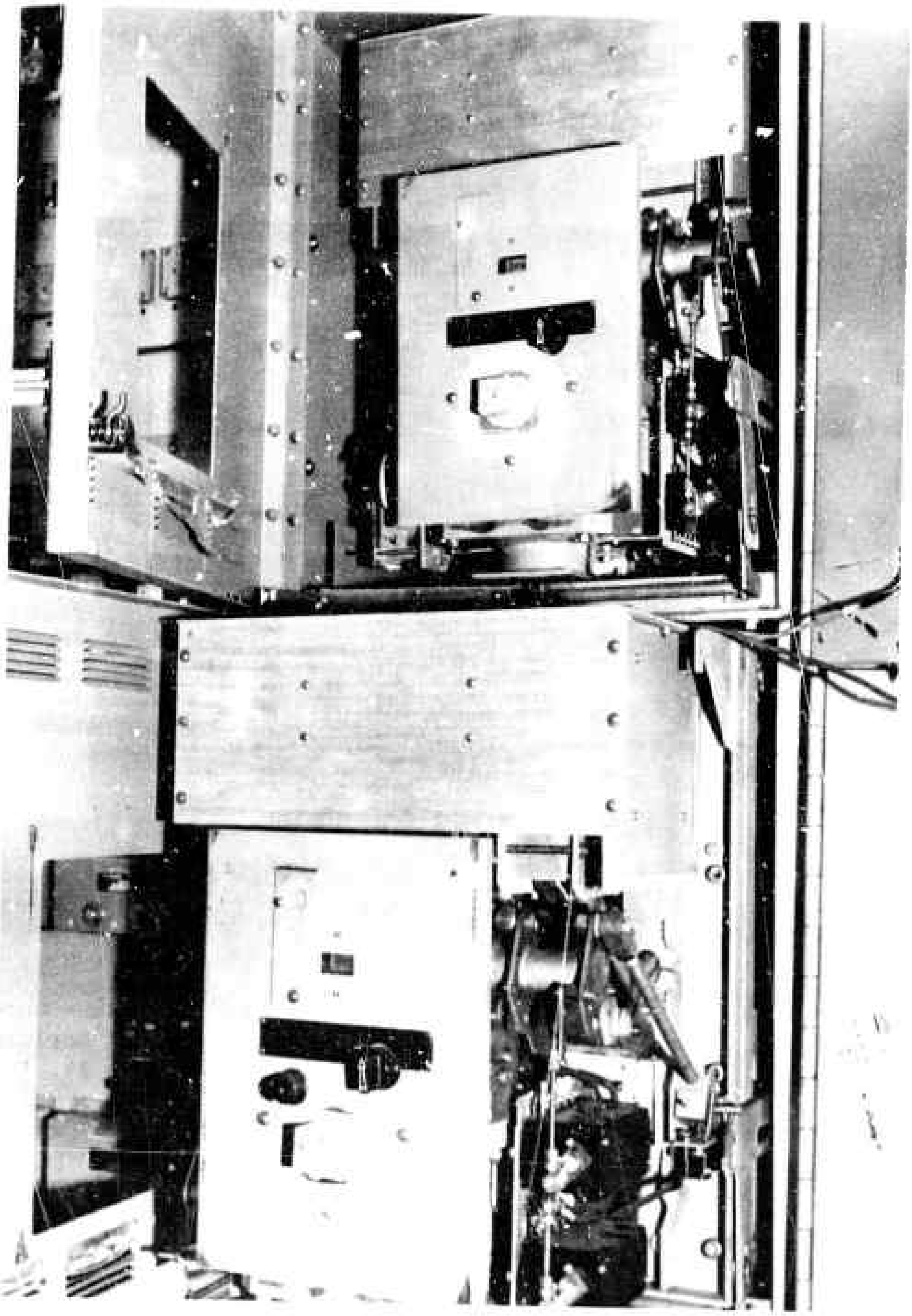


Fig. 32 - Damage from Vertical Shock - 1600 A Breaker Compartments. Note damage to panel door louvers and locks. (After Blow 3).

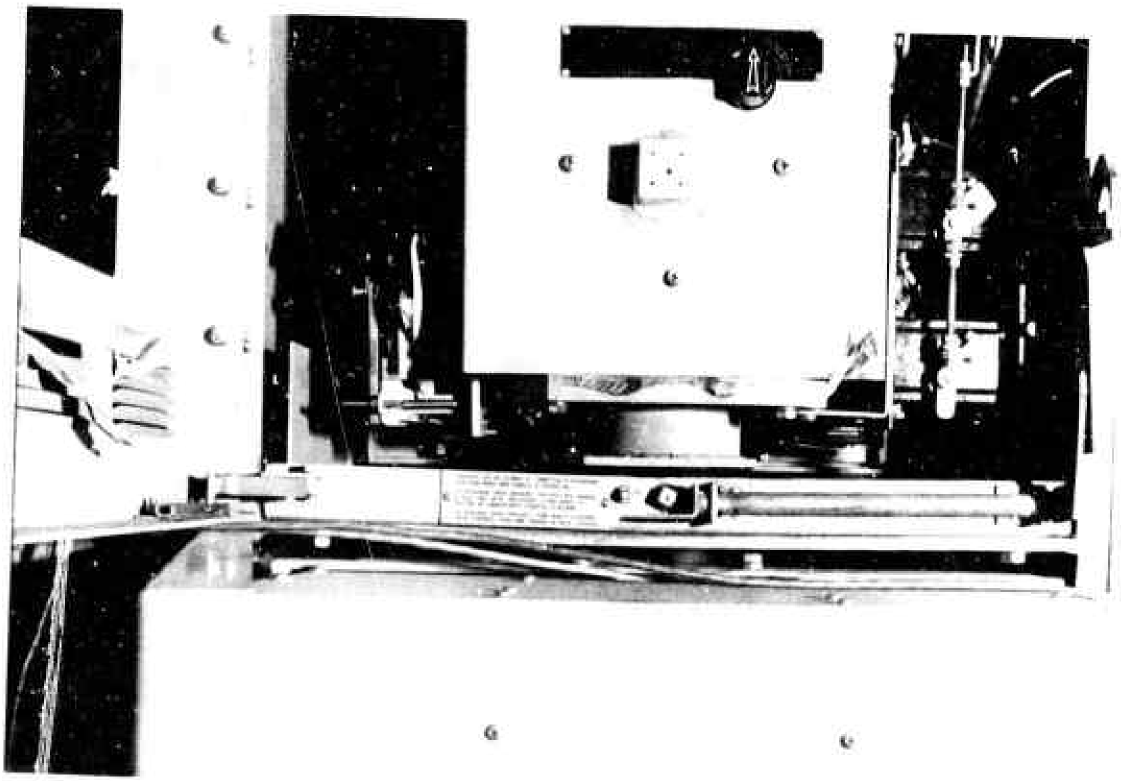


Fig. 33 - Damage from Vertical Shock - upper 1600 A Breaker Compartment. Note deformation of breaker support upper and horizontal frame member, and damage to panel door. (After Blow 3).

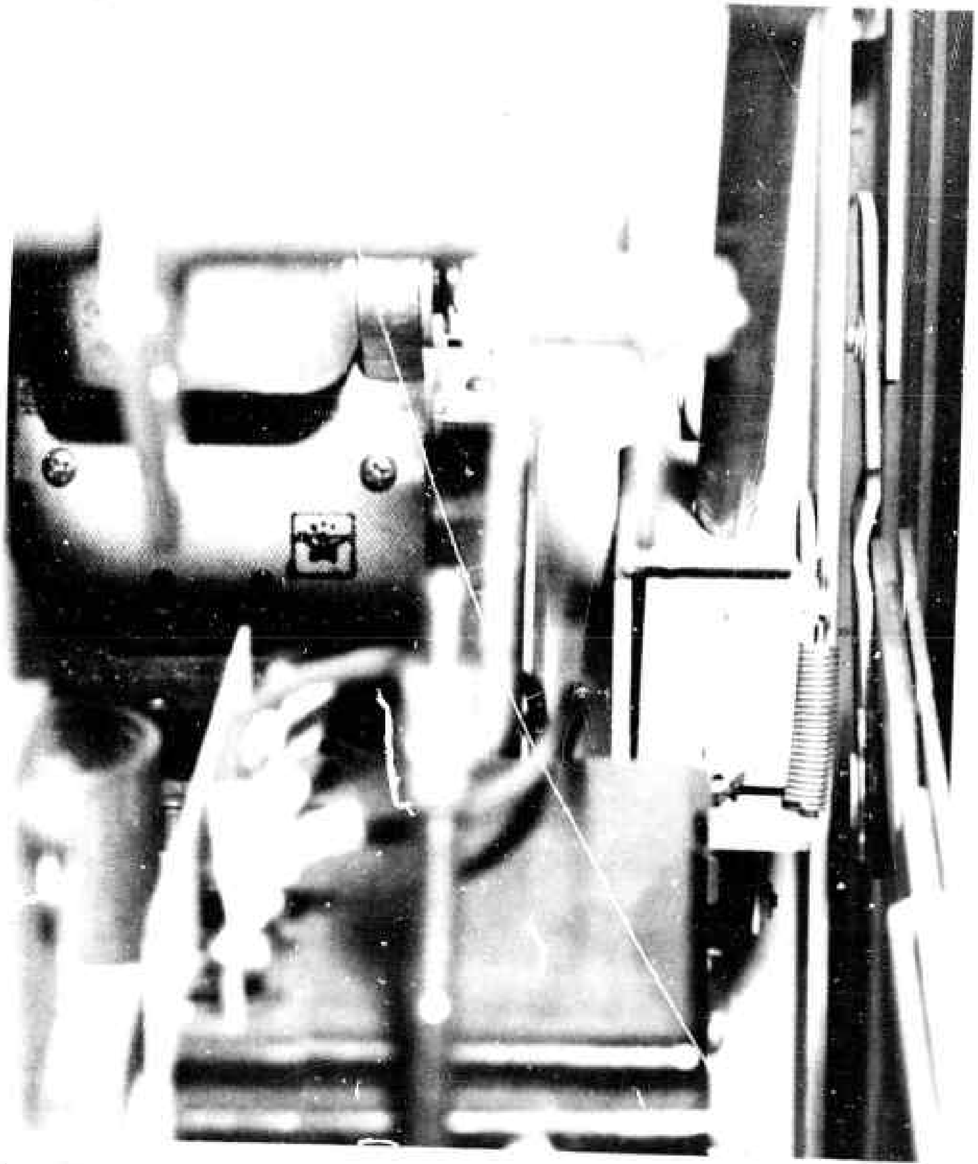


Fig. 34 - Damage from Vertical Shock - upper 1600 A Breaker Compartment. Detail of damage to interlock mechanism. (After blow 3).

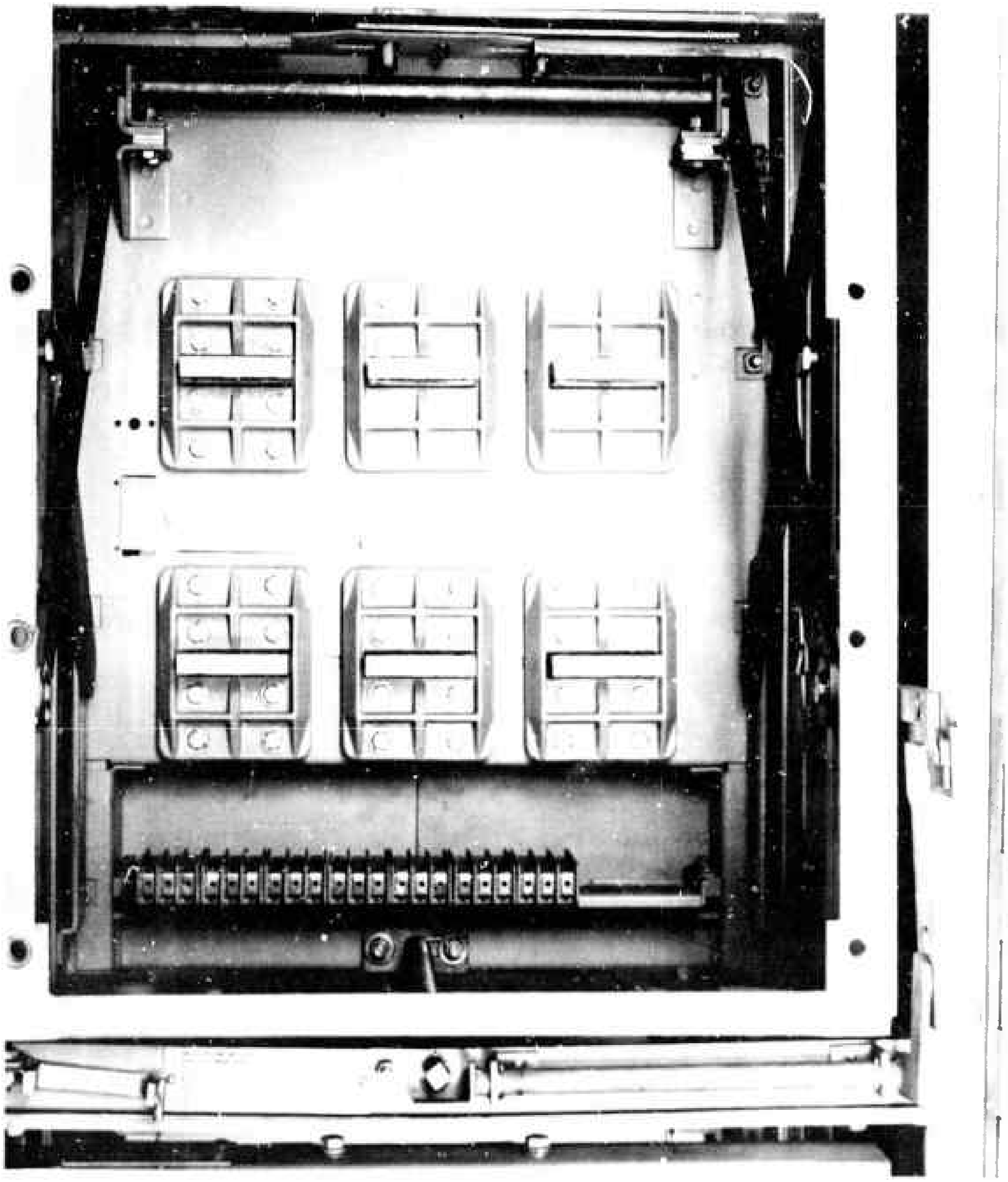


Fig. 35 - Damage from Vertical Shock - upper 1600 A Breaker Compartment. Note deformation of breaker support frame, particularly at top. (After Blow 3).

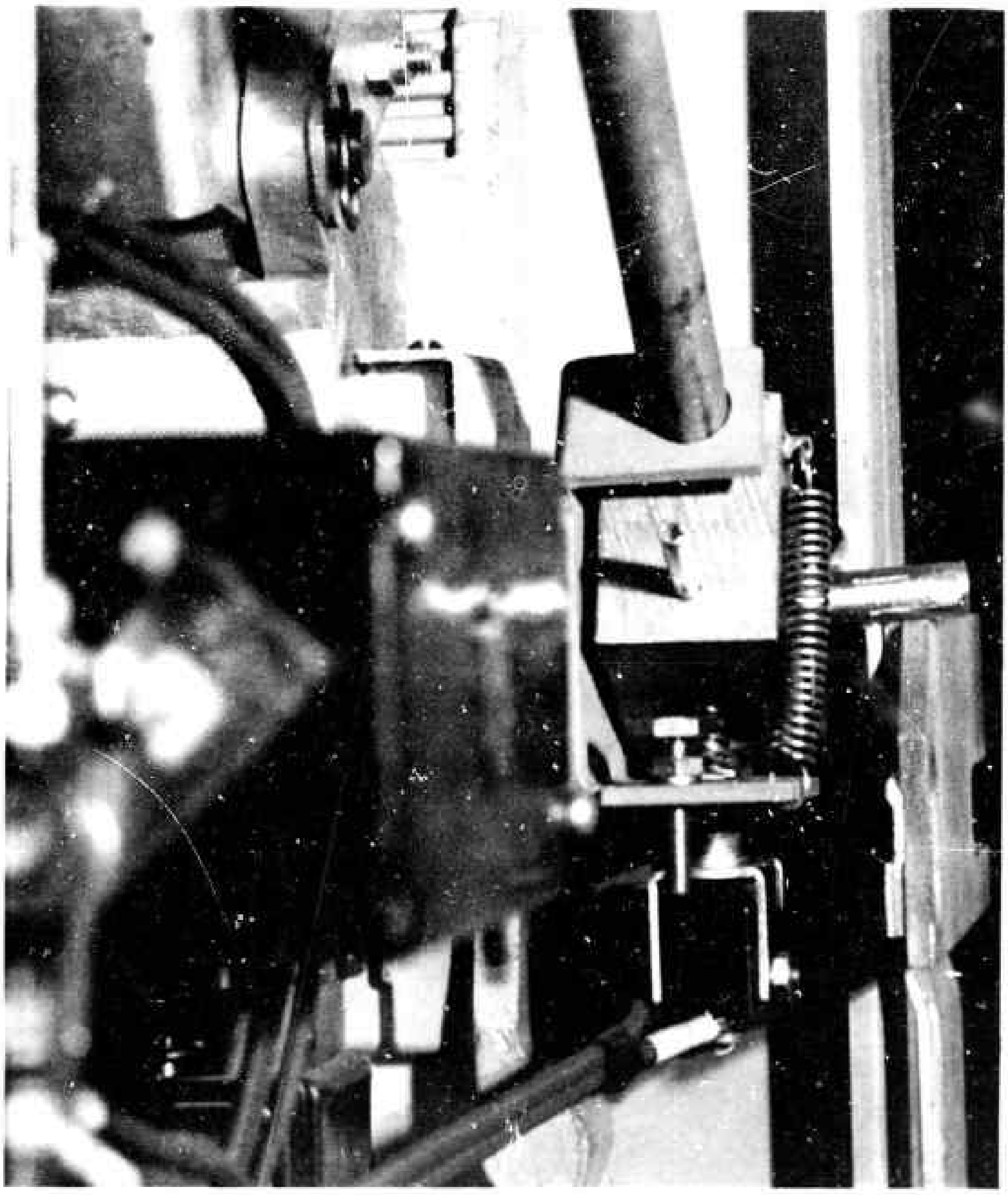


Fig. 36 - Damage from Vertical Shock - lower 1600 A Breaker Compartment. Detail of damage to breaker inlock mechanism. (After blow 3).

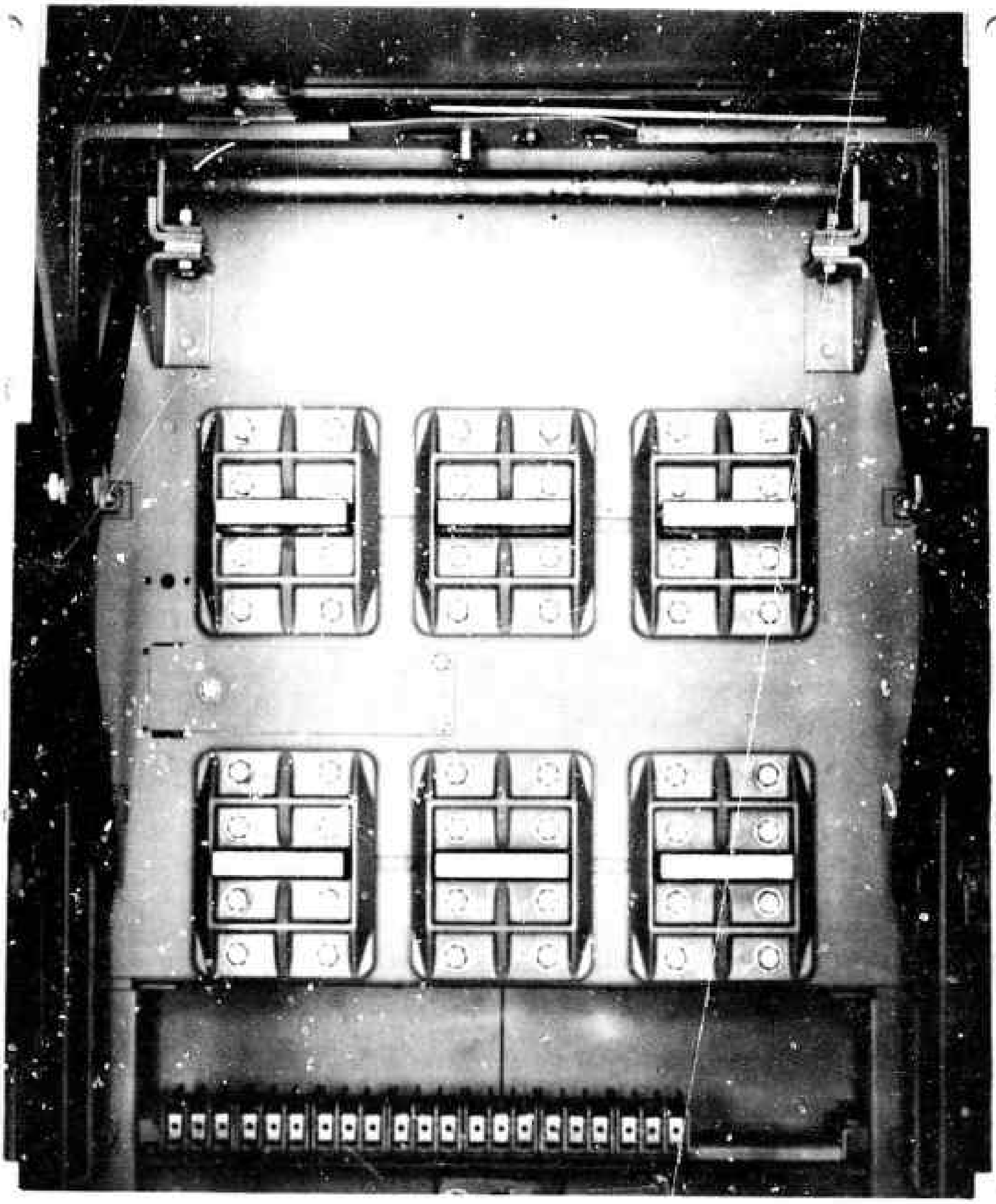


Fig. 37 - Damage from Vertical Shock - lower 1600 A Breaker Compartment. Note deformation of breaker support frame. (After Blow 3).

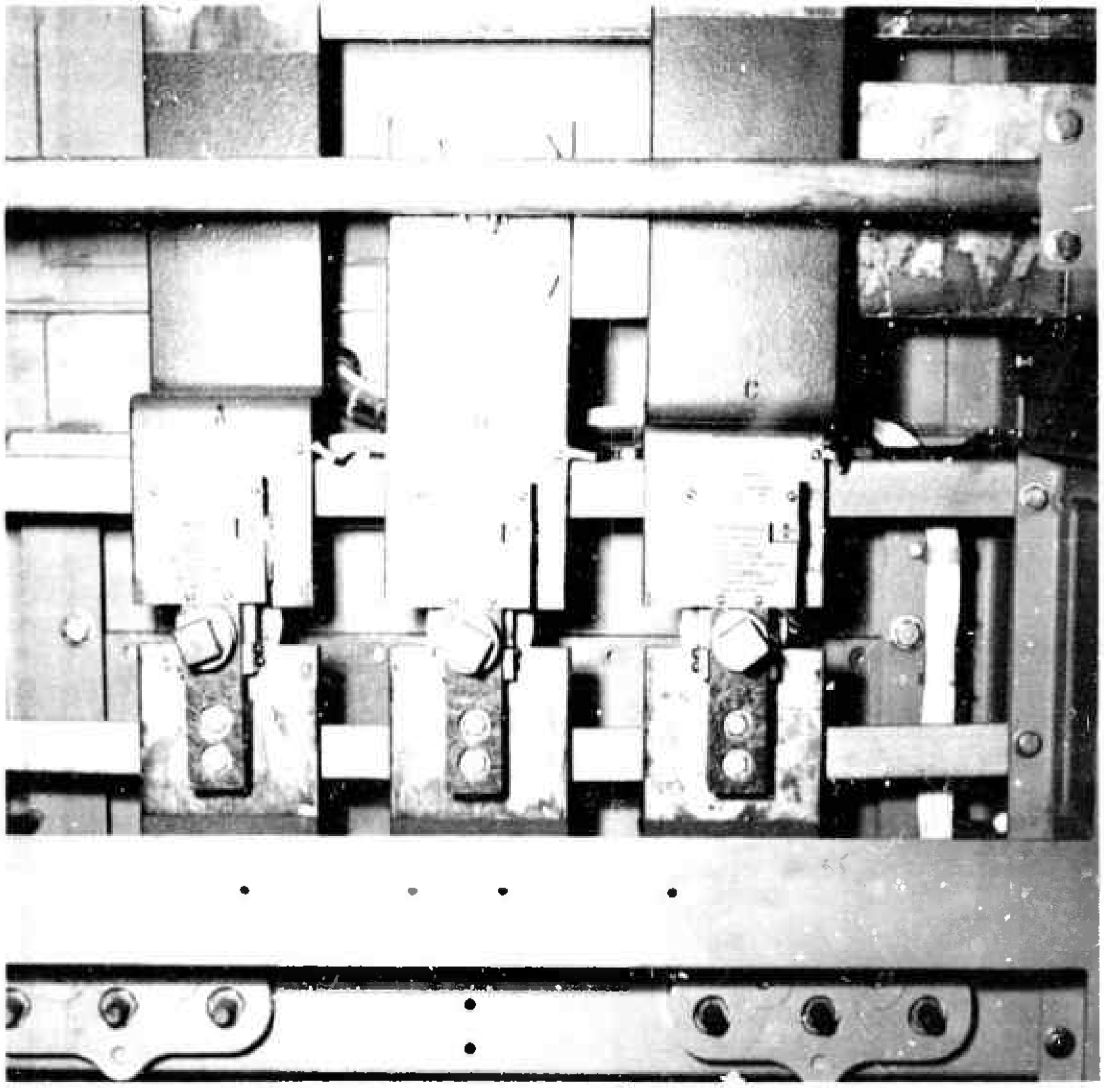


Fig. 38 - Damage from Vertical Shock - 2400 A Breaker Bay (Rear). Note sheared bolts at top of melamine board (approximately in line with bus disconnects). (After Blow 3).

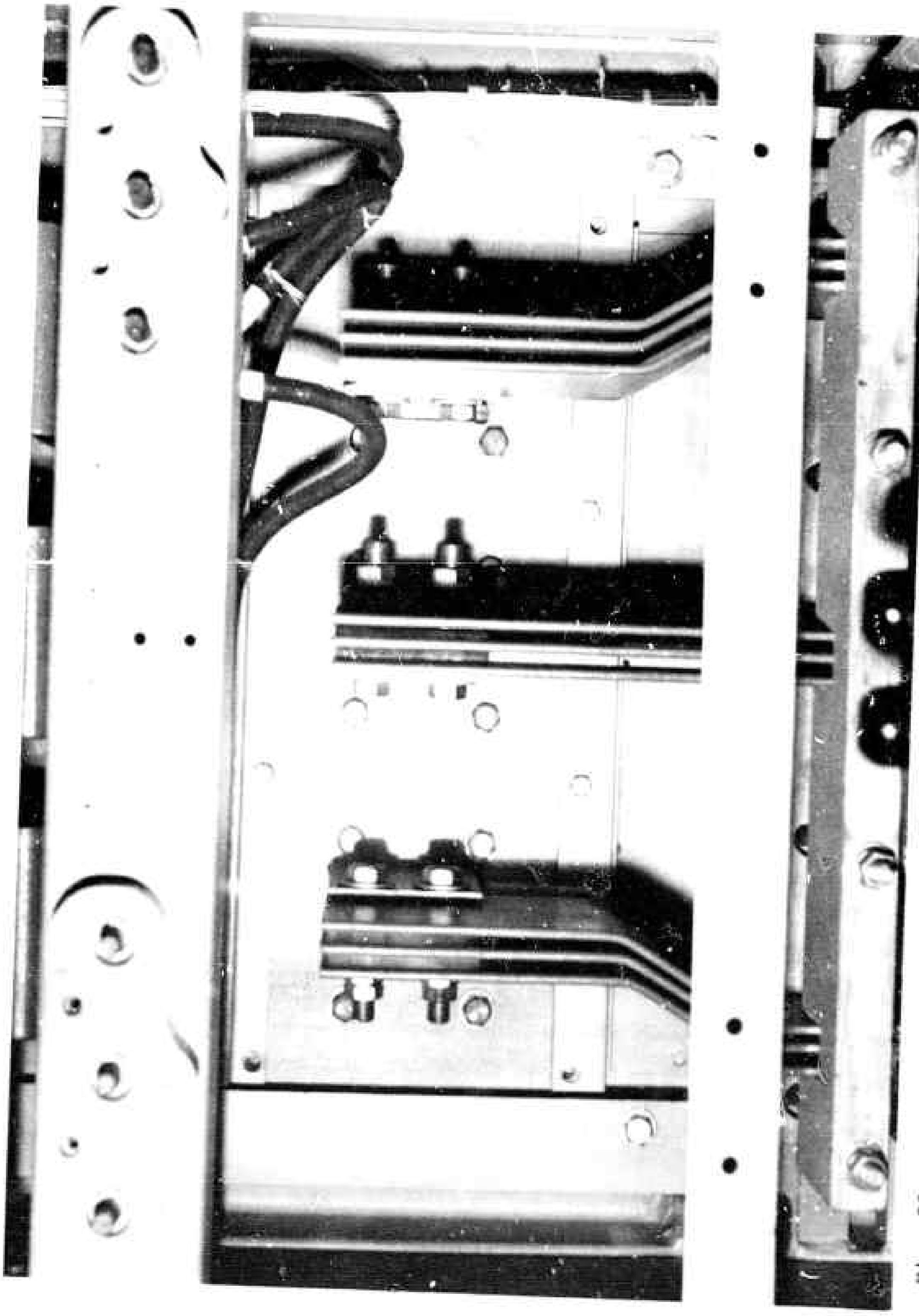


Fig. 39 - Damage from Vertical Shock - 2400 A Breaker Bay (Rear). Sheared bolts in lower half of melamine board. (After Blow 3).

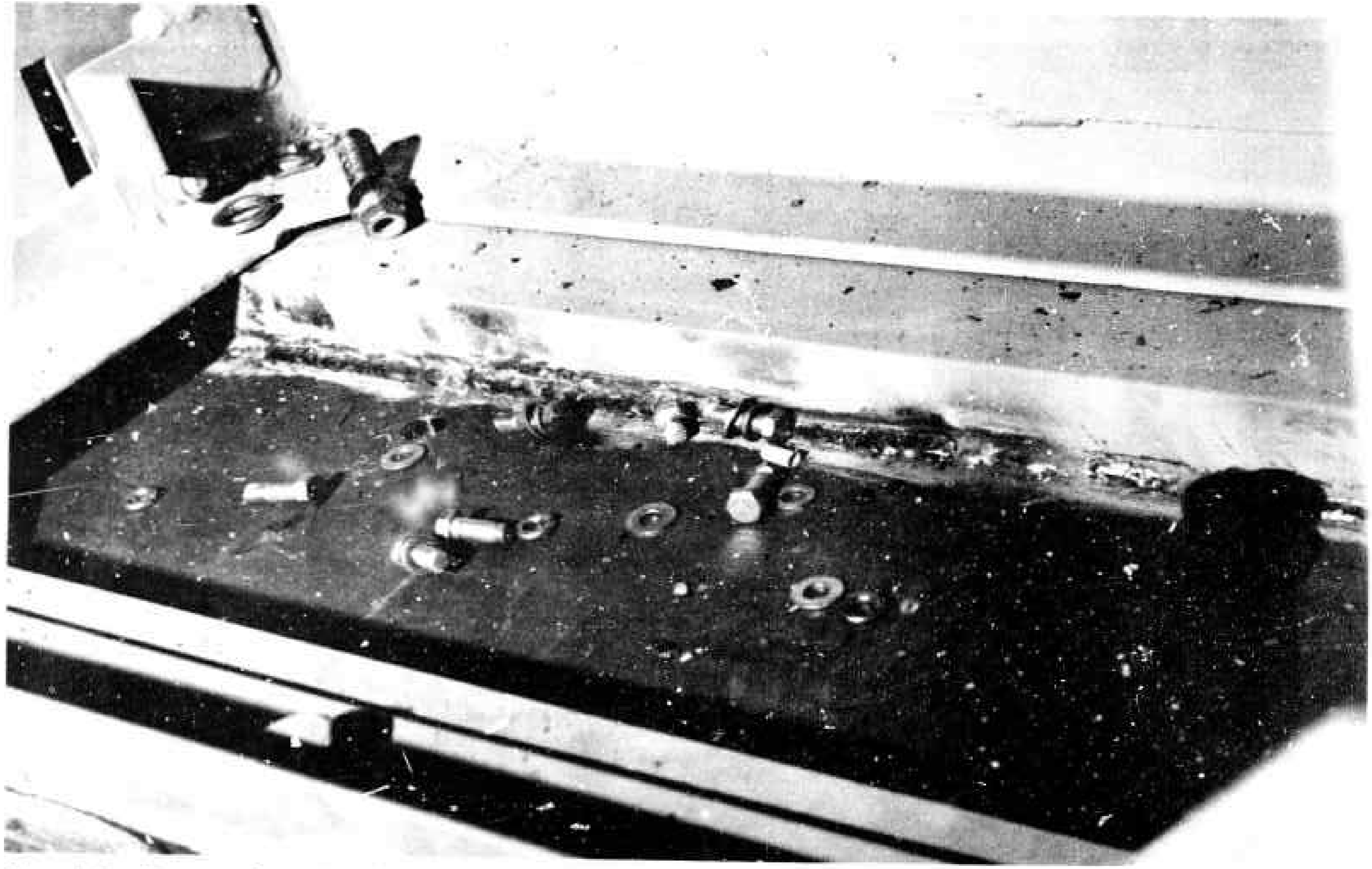


Fig. 40 - Damage from Vertical Shock - 2400 A Breaker Bay (Rear). The smaller bolts were the support bolts for the melamine board. The large bolt at upper left was a switchgear hold-down bolt which was stripped out of the hole in the corner.

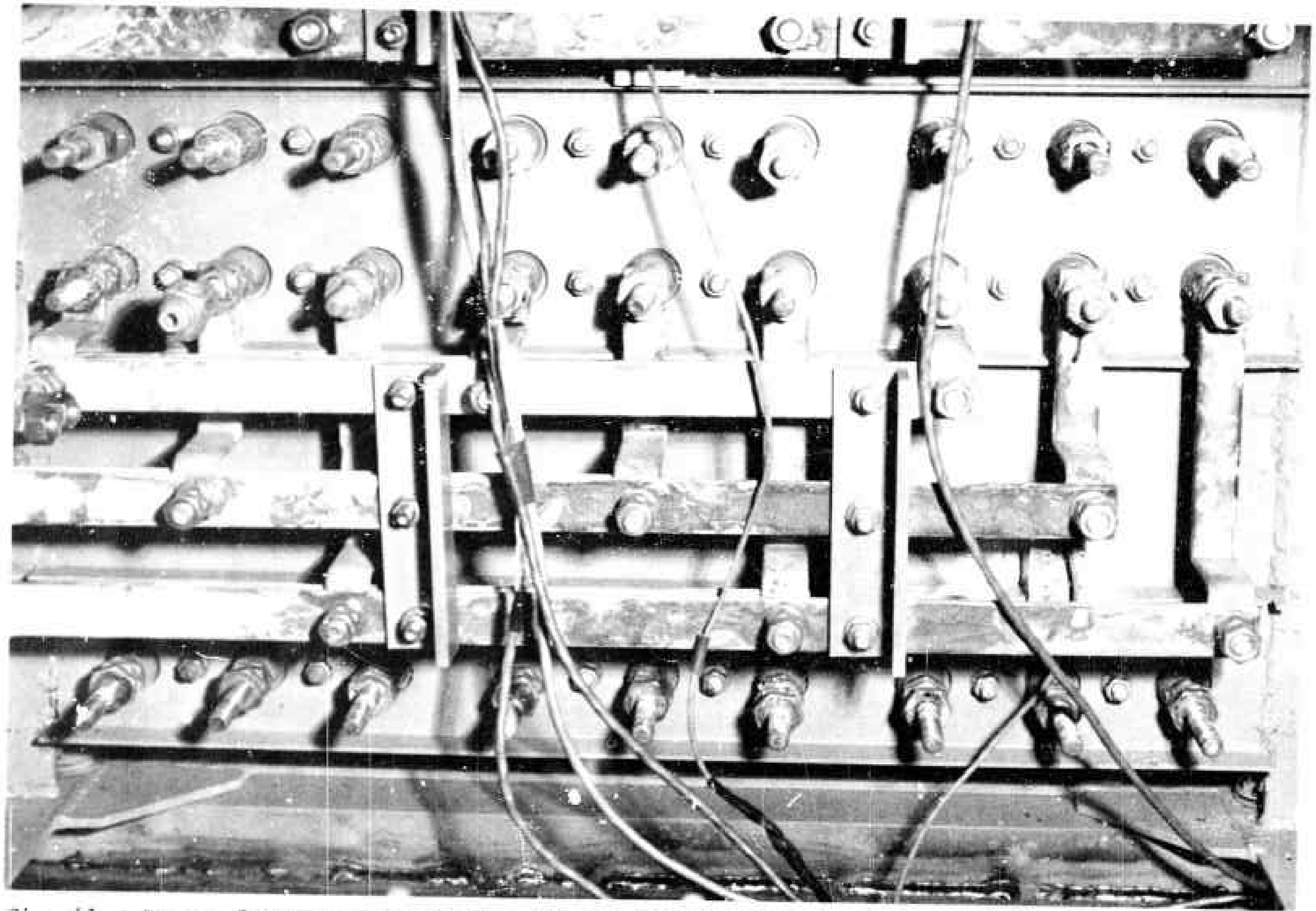


Fig. 41 - Damage from Vertical Shock - AQB Breaker Bay (Rear). Note cracked welds at each end of the lower frame member. (After Blow 3).

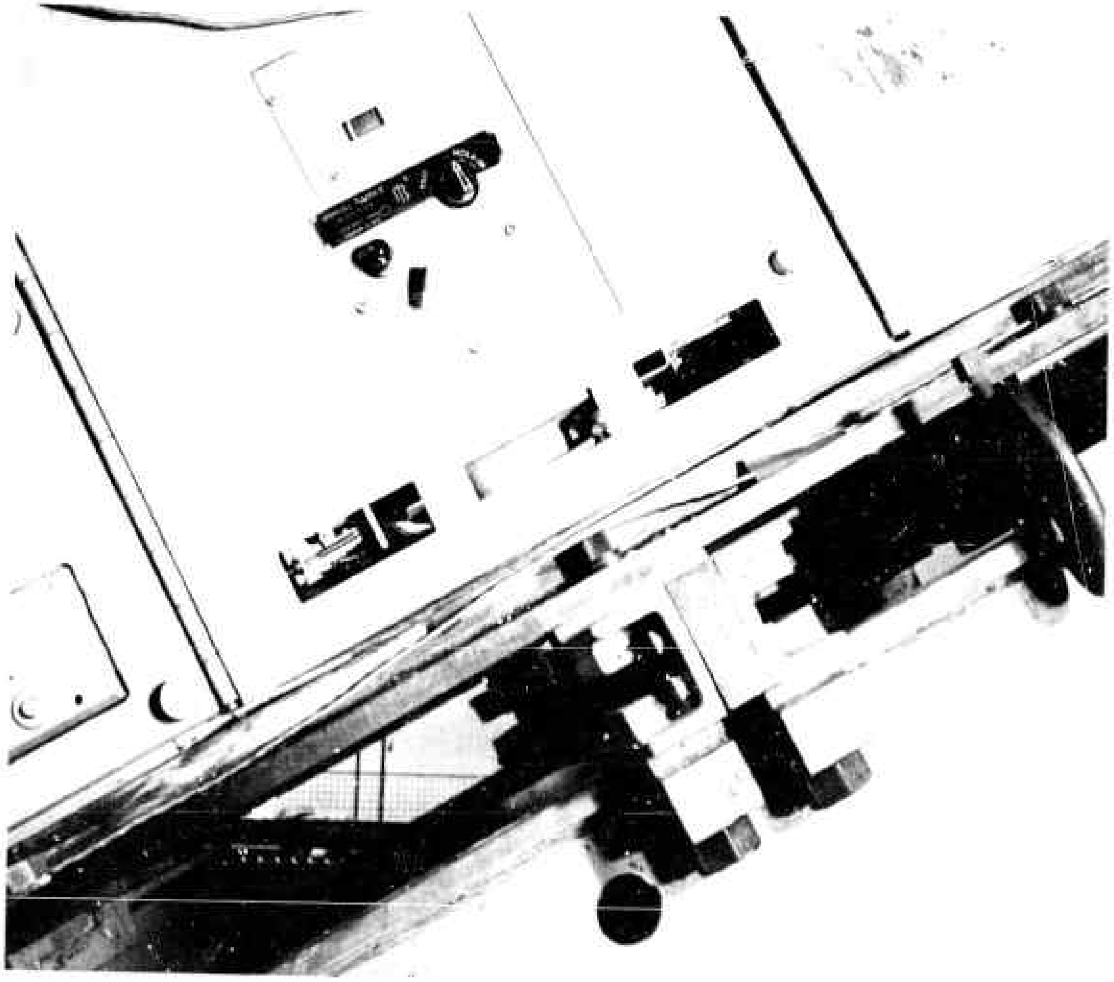


Fig. 42 - Damage from Vertical Shock. Note breakage and deformation of switchgear base frame member below bay junctions. Switchgear is oriented for Inclined Shock. (After Blow 6).

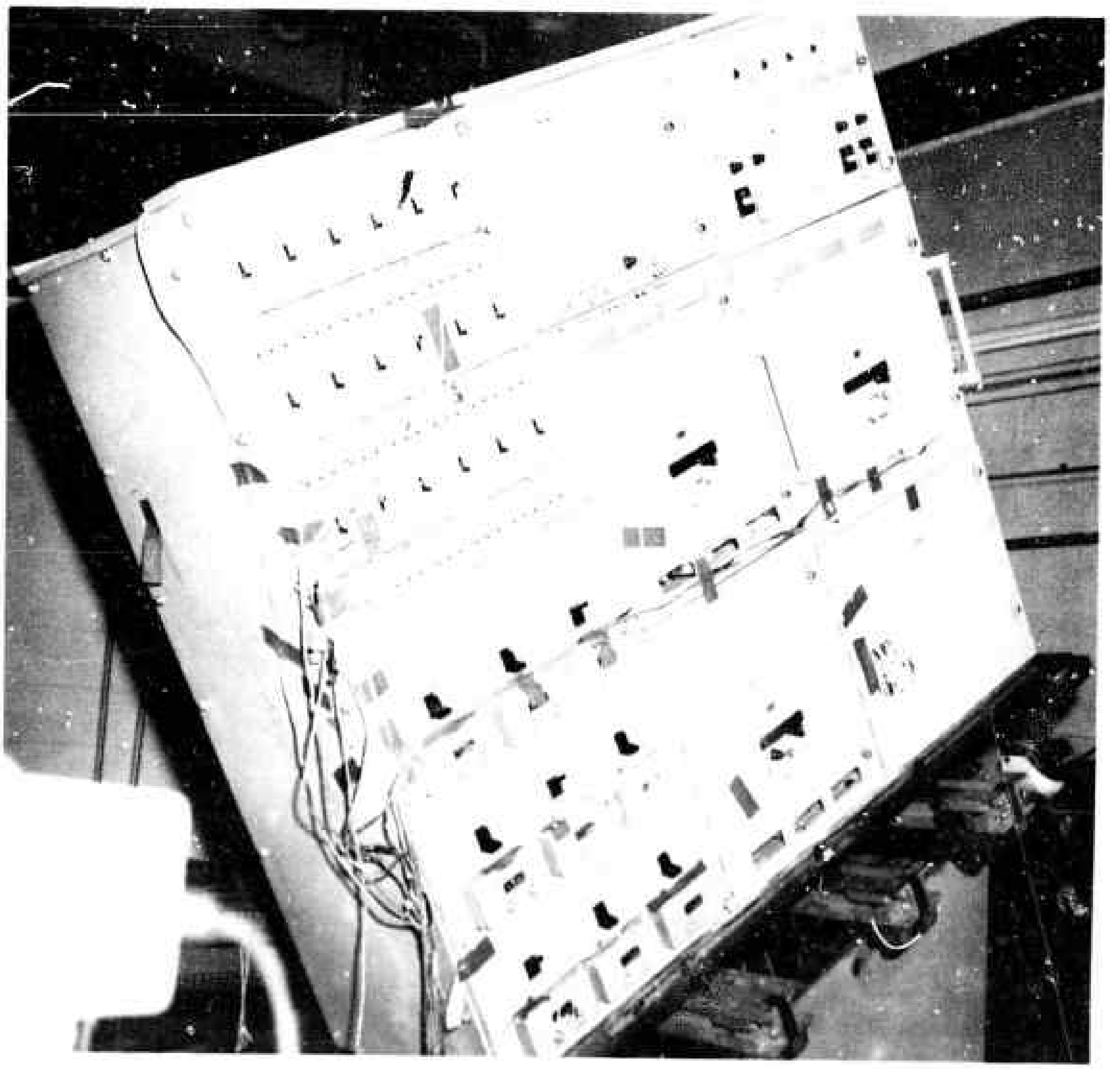


Fig. 43 - Shock Test Setup. The switchgear is shown oriented for Inclined Shock.

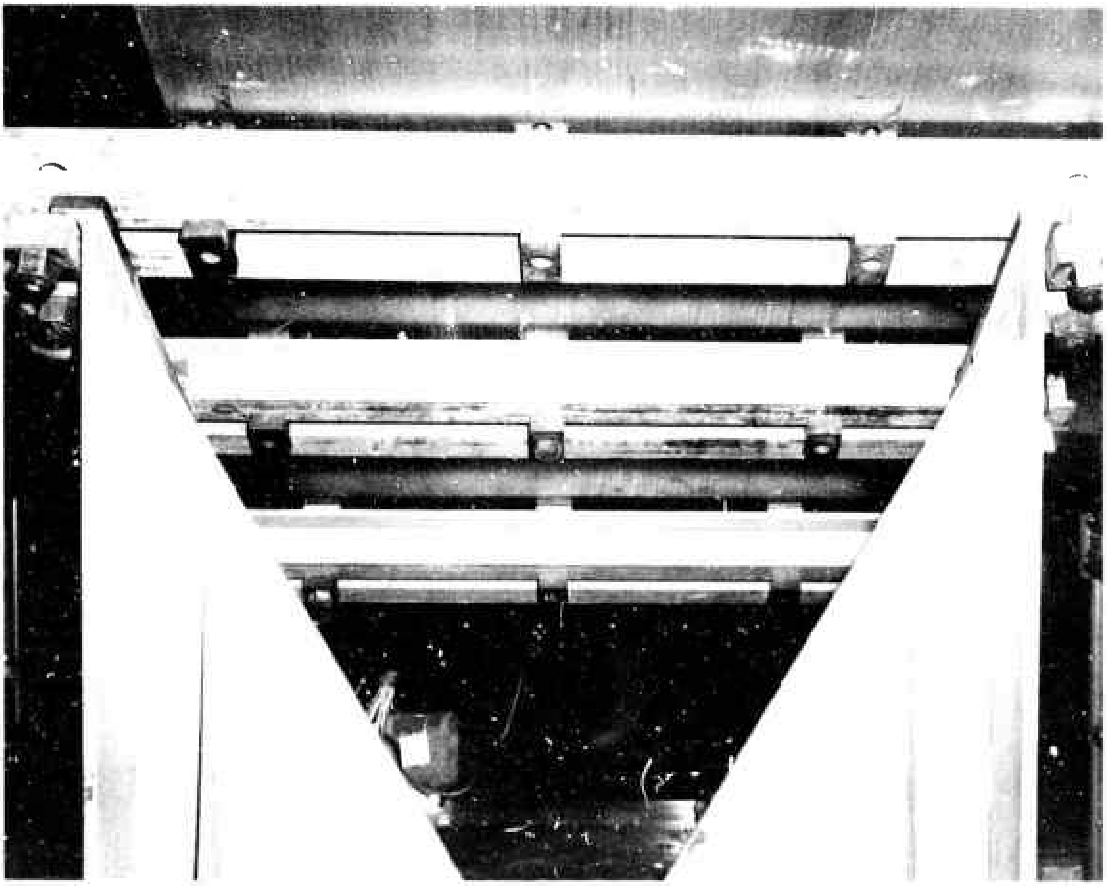


Fig. 44 - Shock Test Setup. Detail of the mounting channel and space pad arrangement for Inclined Shock. The arrangement for Vertical Shock was similar.

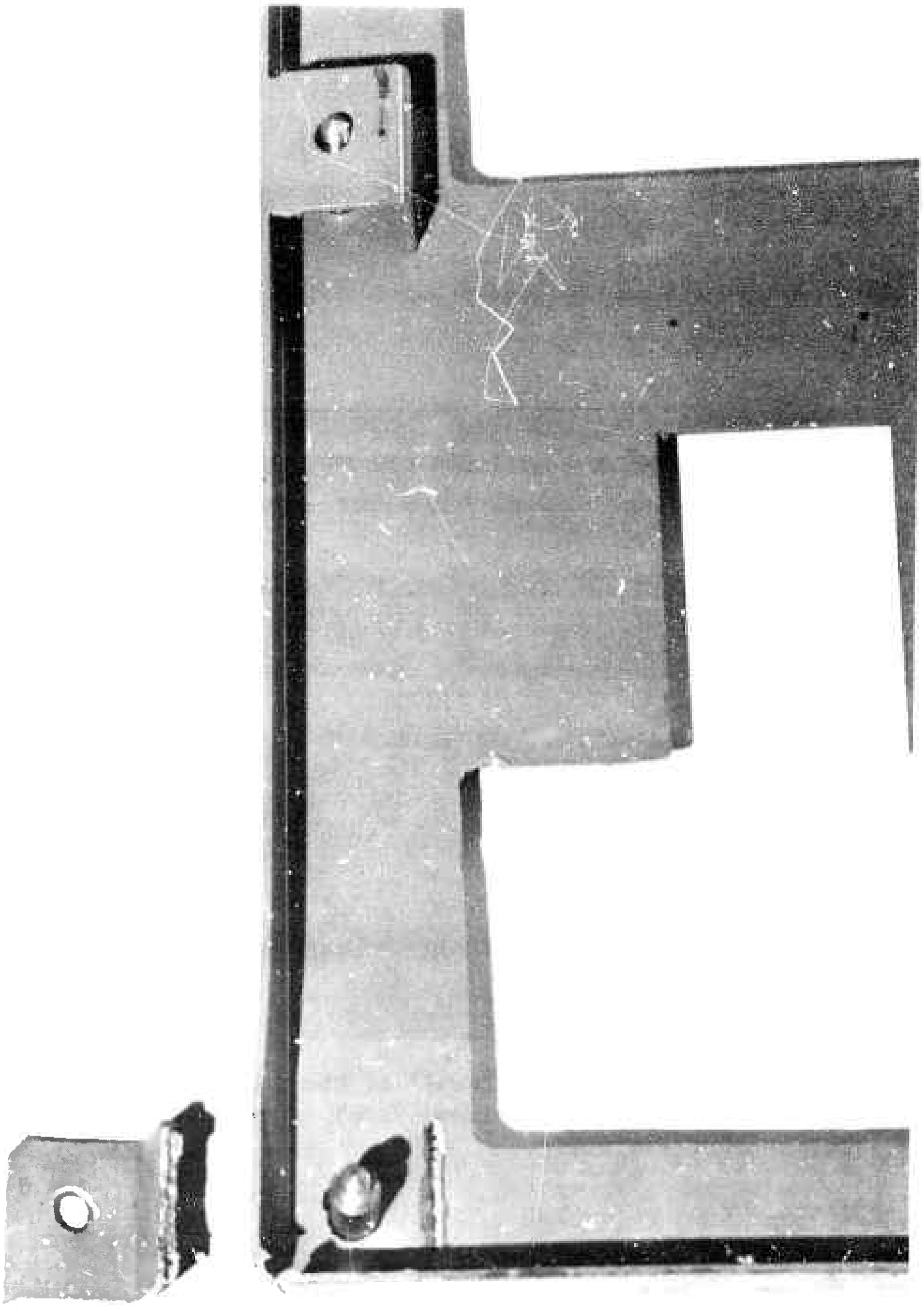


Fig. 45 - Damage from Shock Test. Broken corner and support of LF250 cover panel.

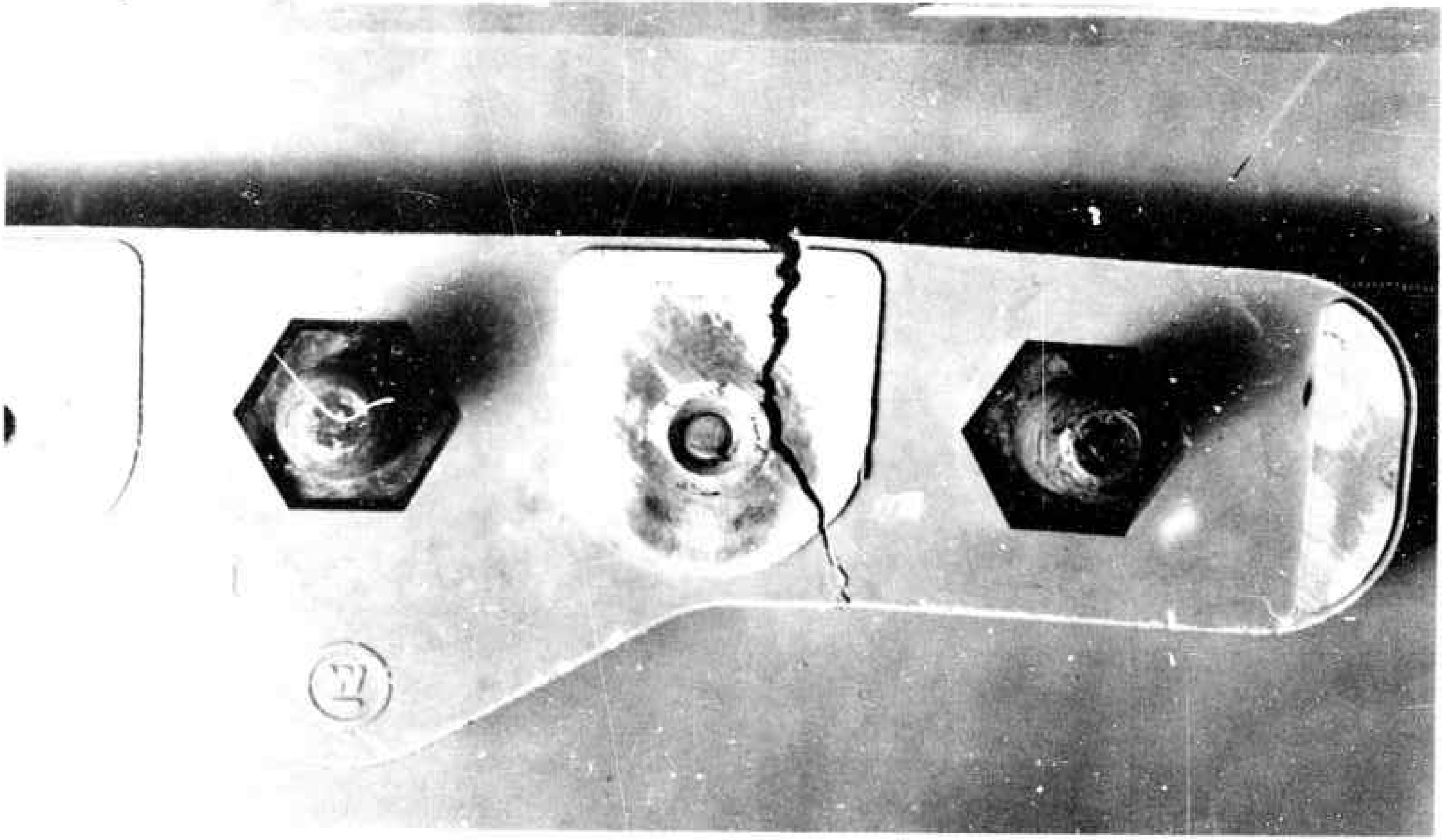


Fig. 46 - Damage from Shock Test. Broken upper mount and sheared breaker hold-down bolt for LF250 No. 9.

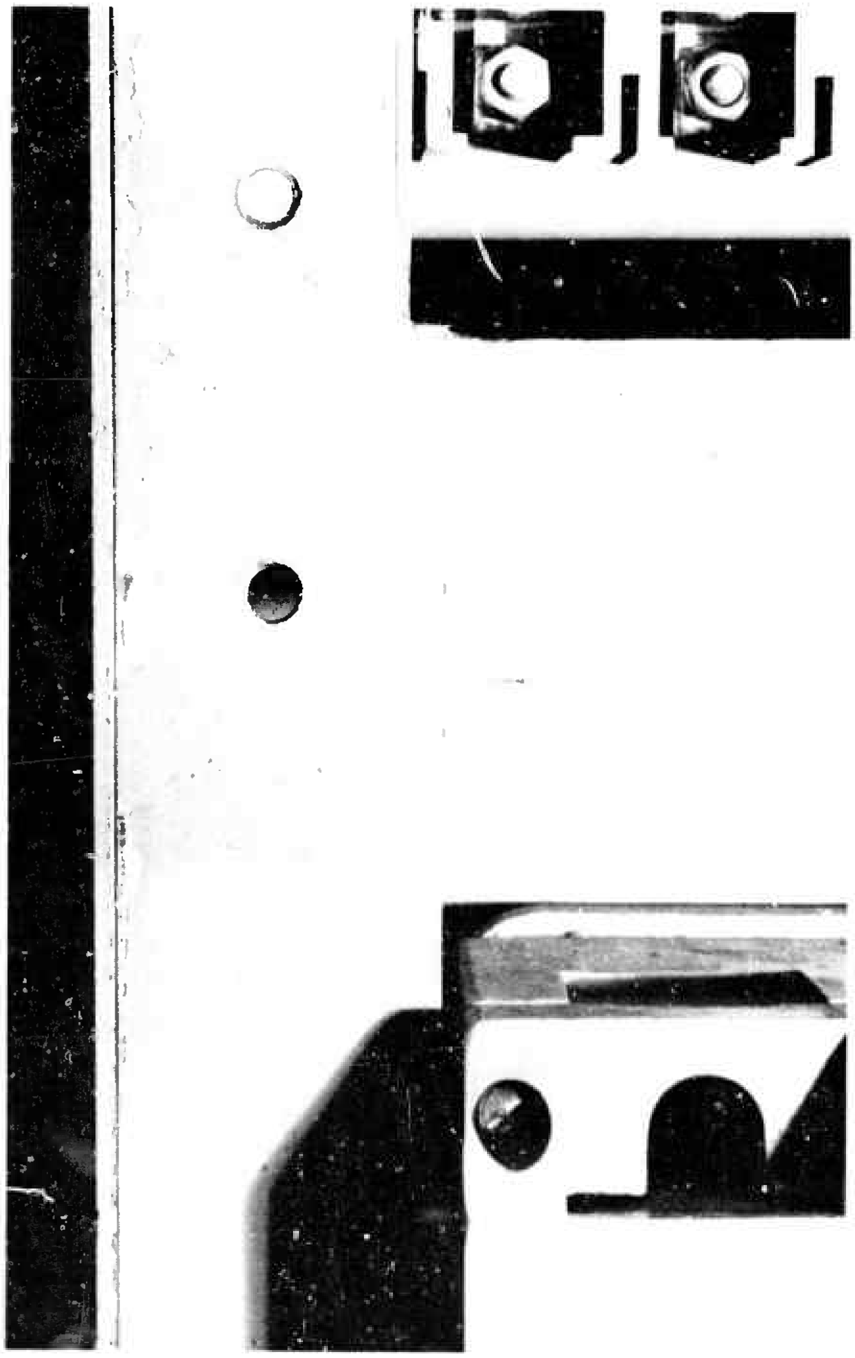


Fig. 47 - Damage from Shock Test - AQB Breaker Bay. Cracked weld at outer end of central horizontal frame member (front of bay).

Fig. 48 - Damage from Shock Test - AQB Breaker Bay. Outer Vertical frame member broken completely loose at base of frame, and shifted outboard 1/4".

Fig. 49 - Damage from Shock Test - AQB Breaker Bay. Inner vertical frame member broken loose at base, and horizontal bottom member shifted over.

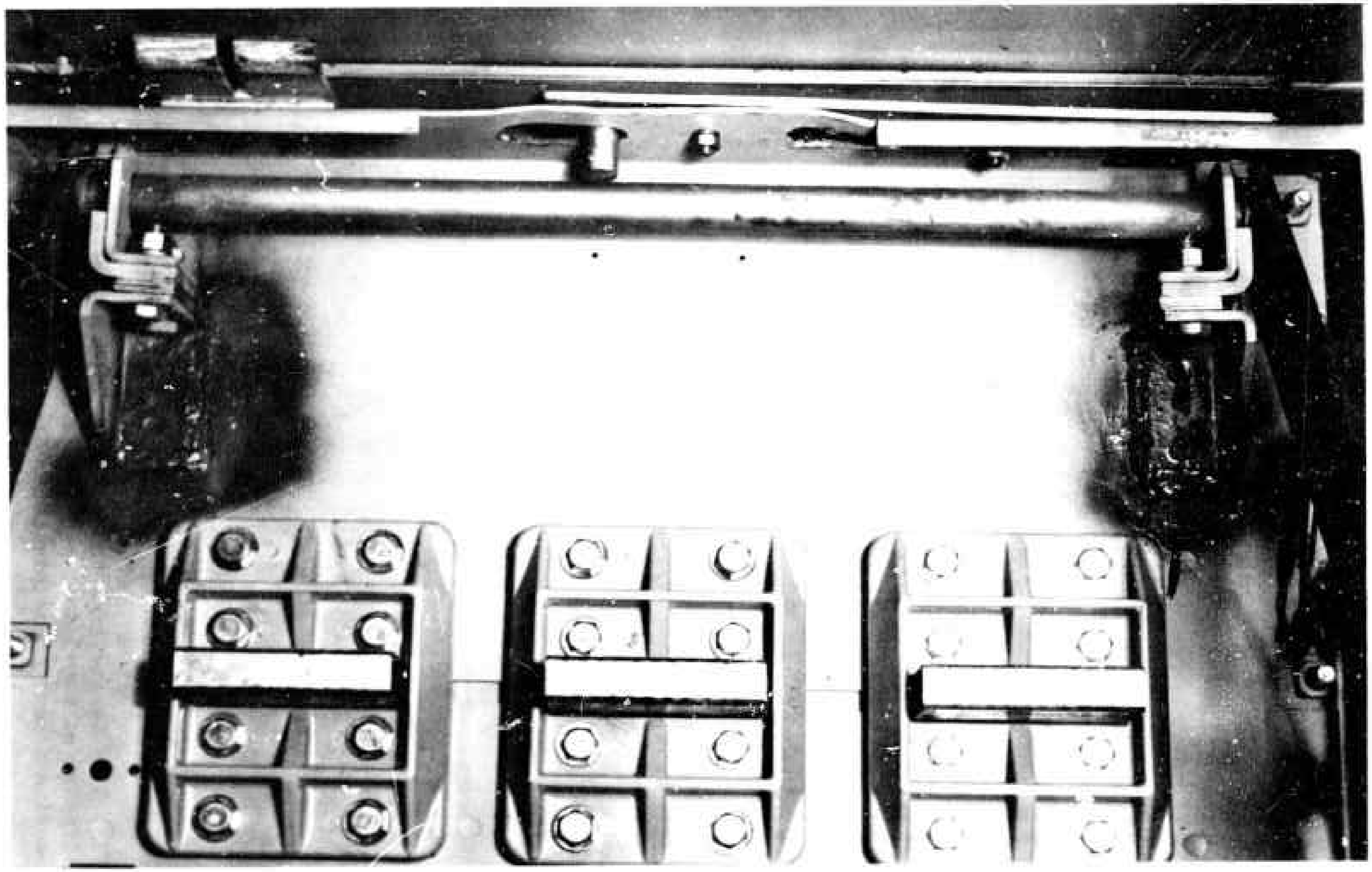


Fig. 50 - Damage from Shock Test - upper 1600 A Breaker Compartment. Damage to breaker support frame.

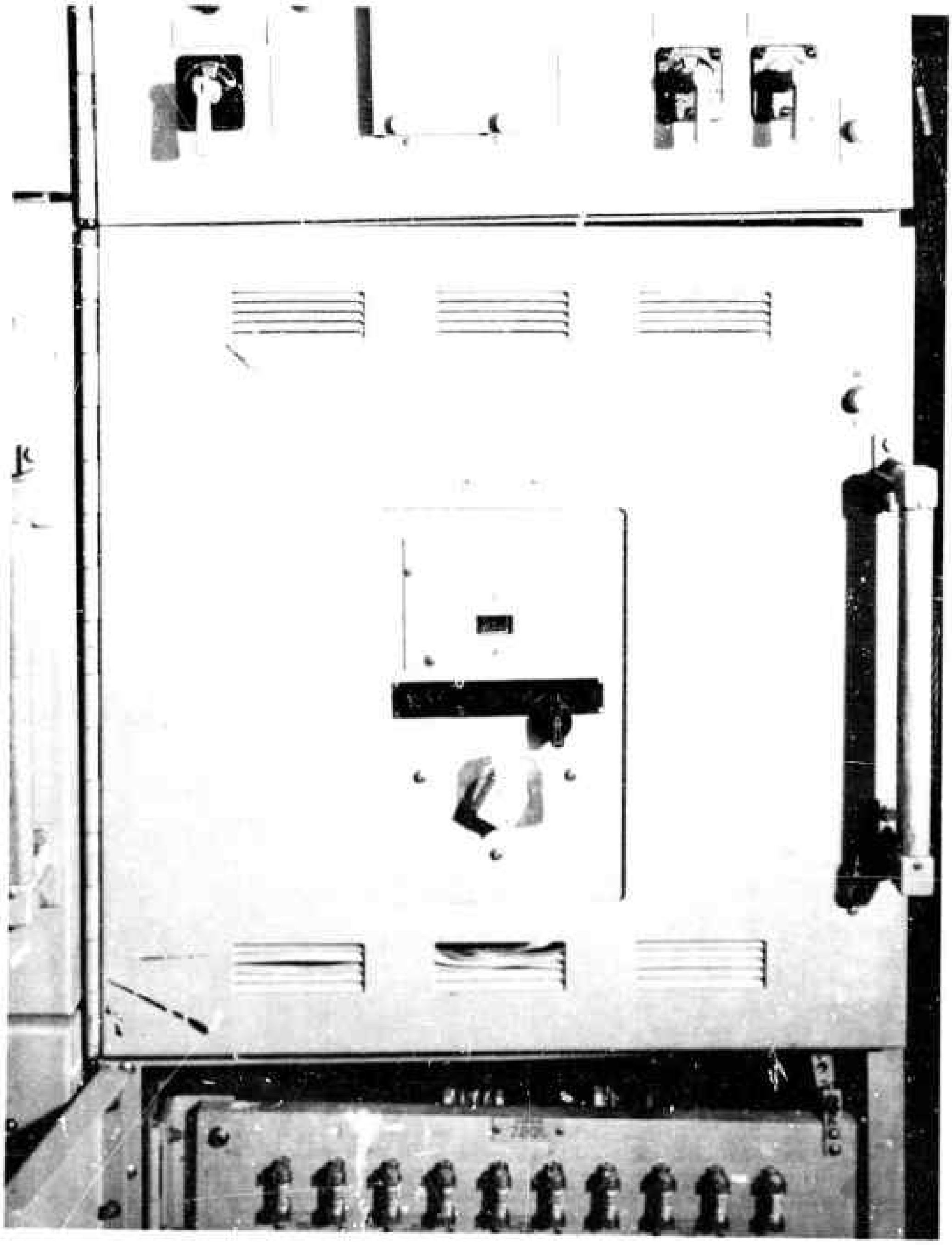


Fig. 51 - Damage from Shock Test - 2400 A Breaker Bay. Note slippage of panel door and damage to louvers, slippage of fuse panel and damage and panel and fasteners.

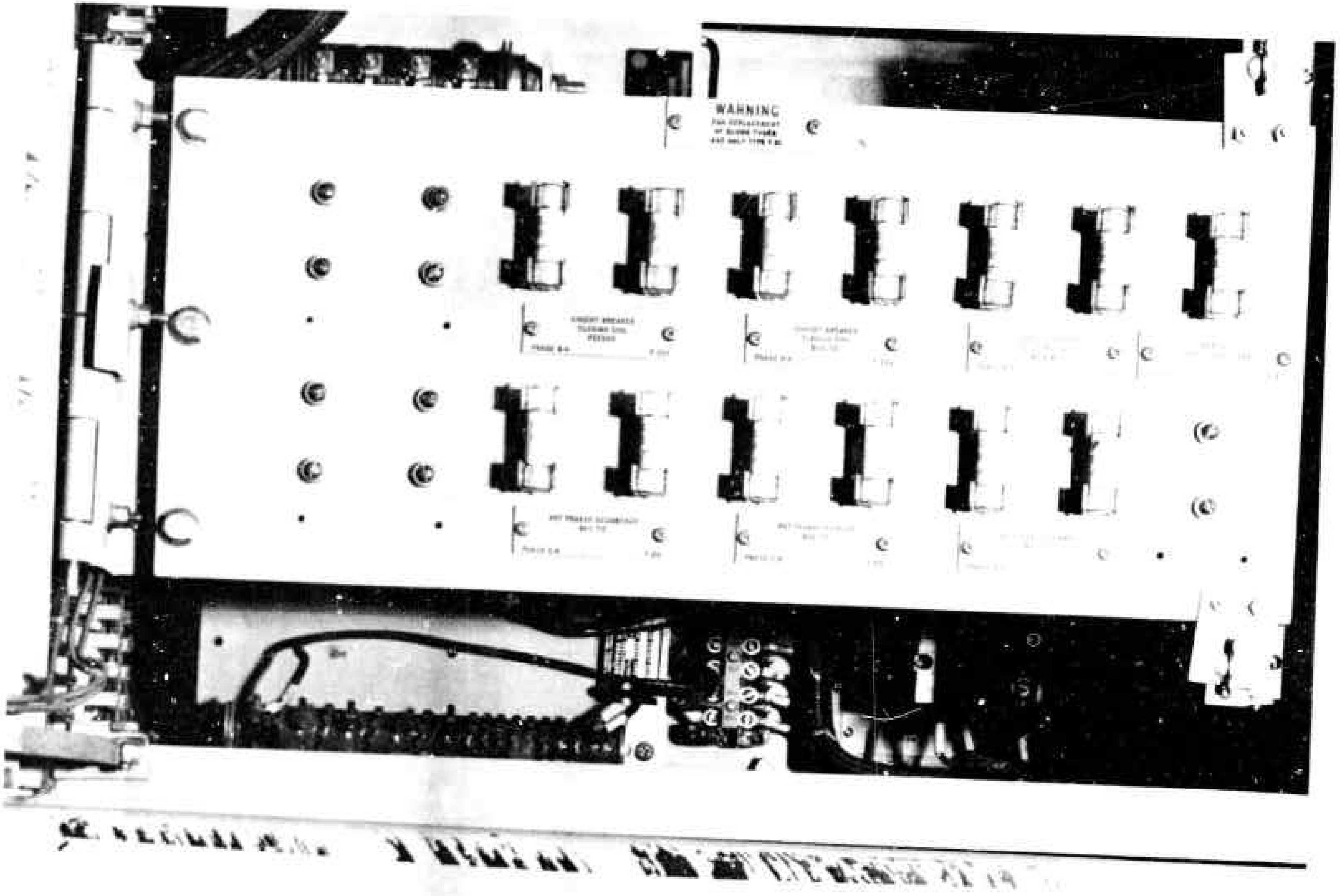


Fig. 52 - Damage from Shock Test - Fuse Compartment. Note slippage of fuse panel hinge and travel of hinge pin.

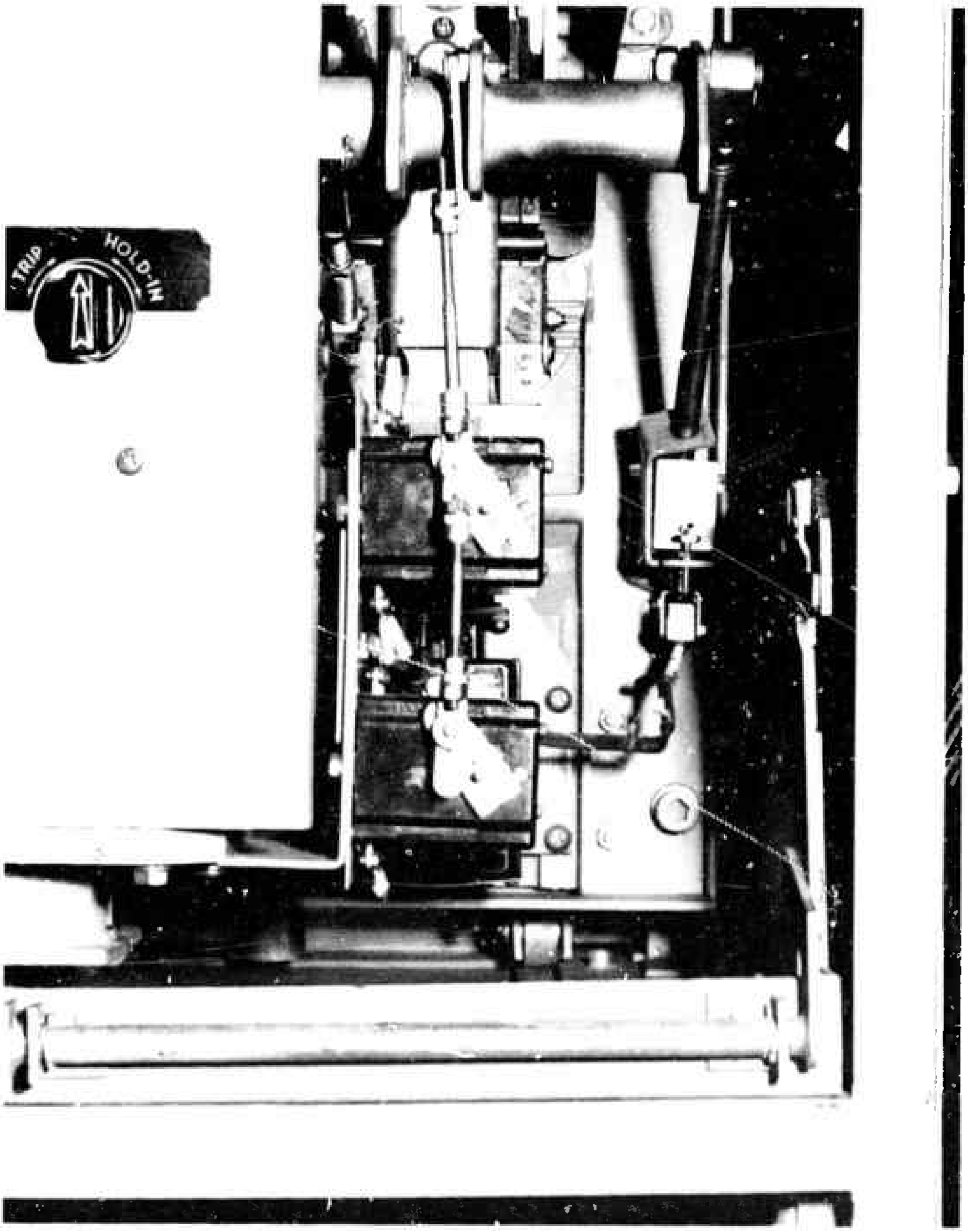


Fig. 53 - Damage from Shock Test - 2400 A Breaker Compartment. Note damage to interlock mechanism and deformation of accessory bracket and linkage.

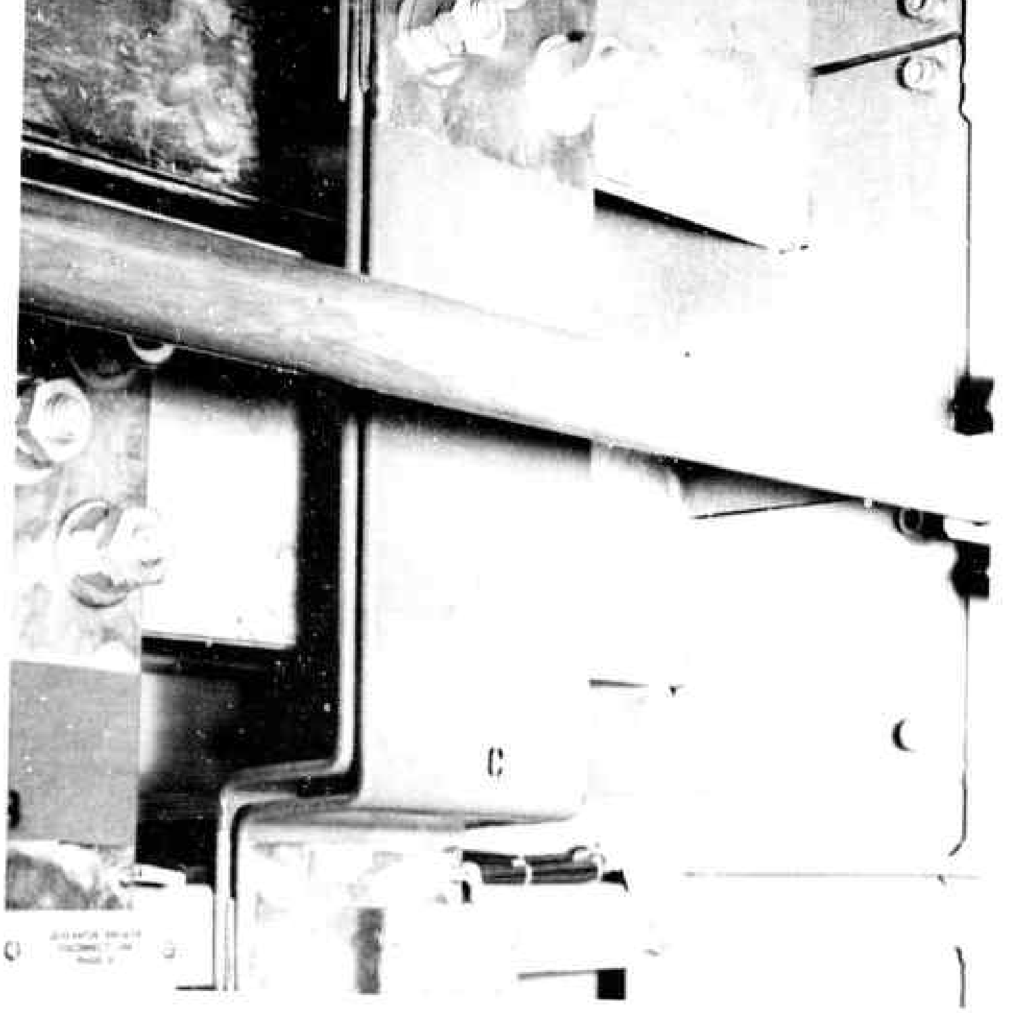


Fig. 54 - Damage from Shock Test - 2400 A Breaker Bay (Rear). Note cracking and abrasion of melamine support for main horizontal bus between 2400 A and 1600 A Breaker Bays.

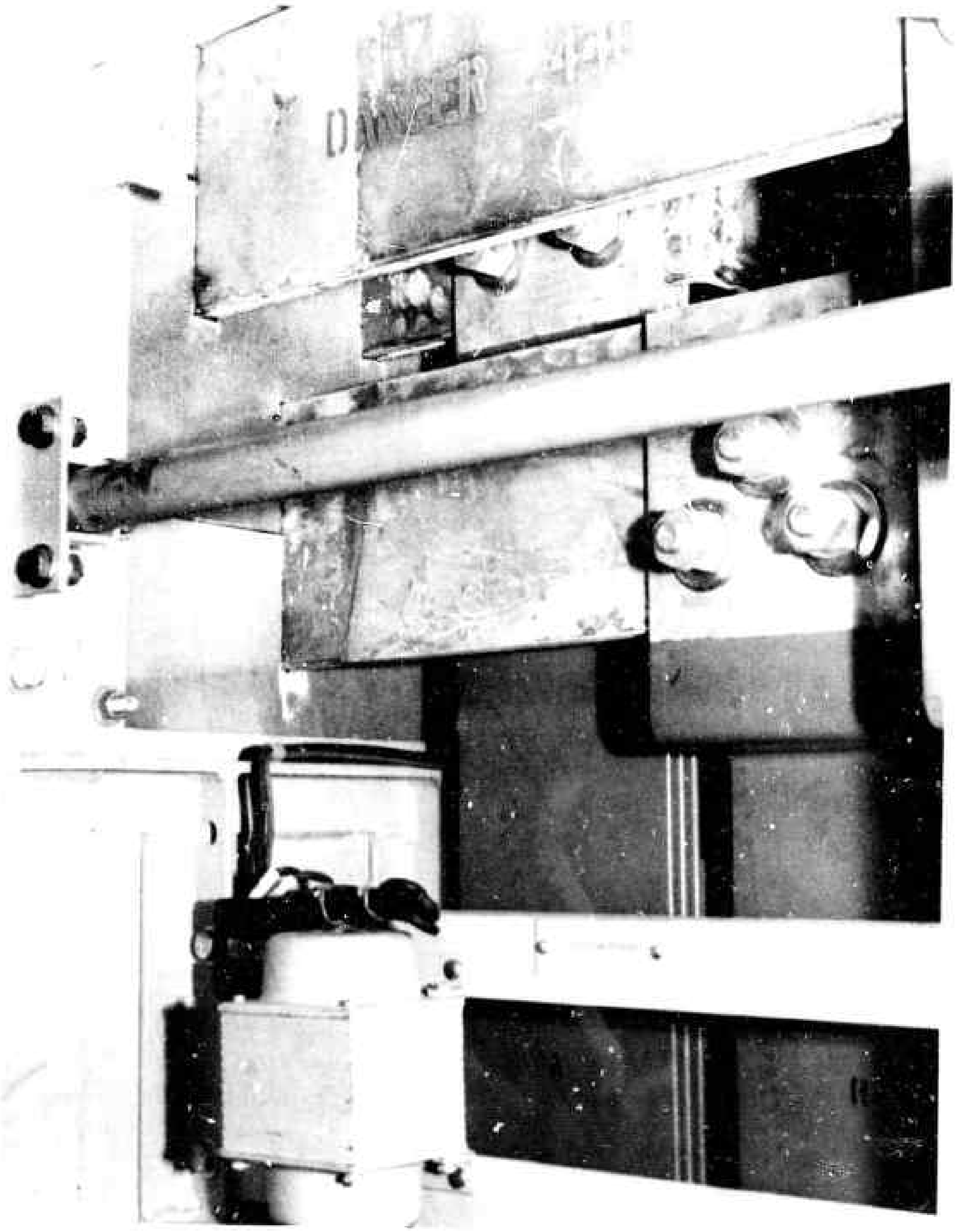


Fig. 55 - Damage from Shock Test - 1600 A Breaker Bay (Rear). The same damage as Figure 48 from the 1600 A Breaker Bay side.

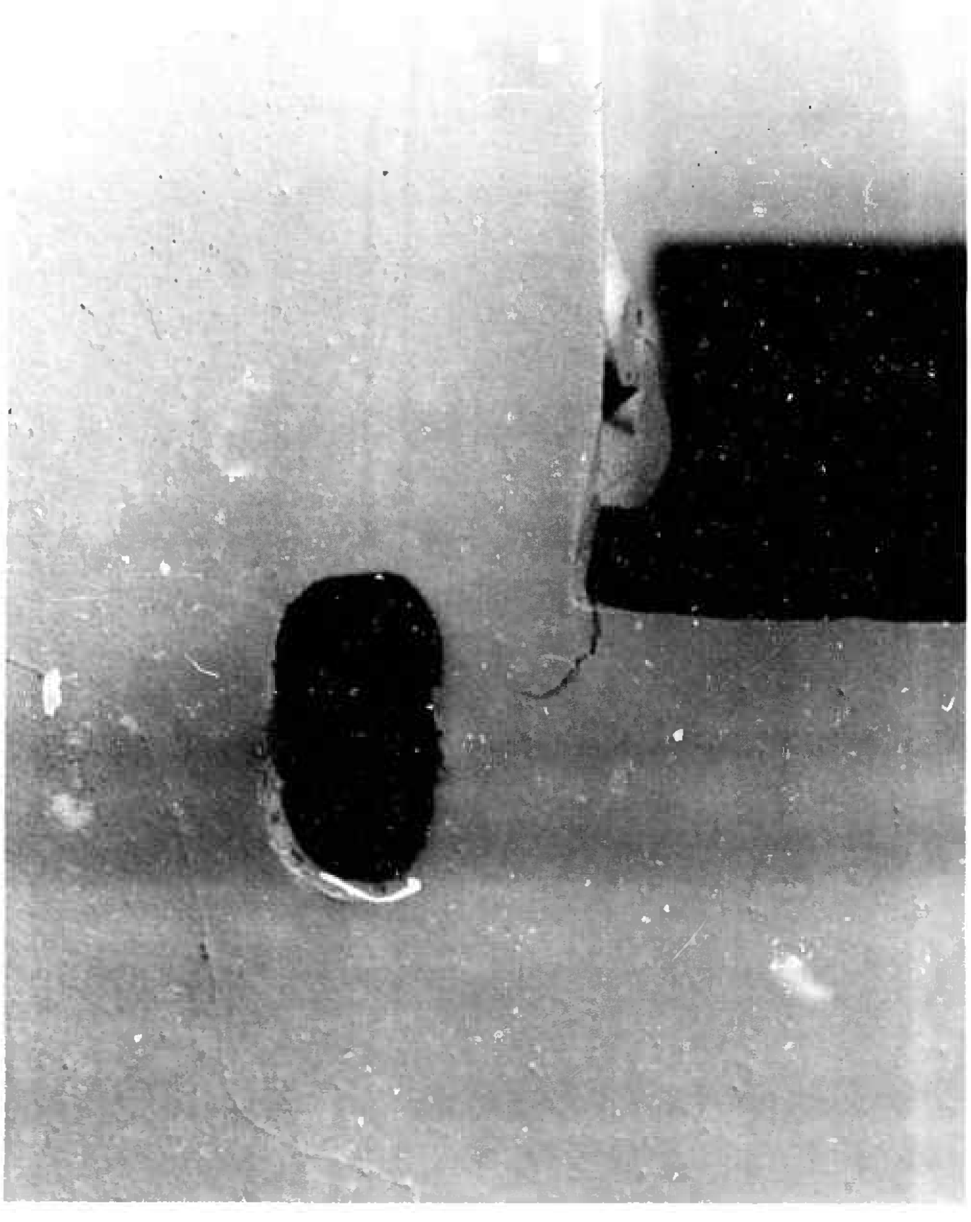


Fig. 56 - Damage from Shock Test - 1600 A Breaker Bay (Rear). A small crack in the central horizontal frame member at the vertical frame member adjoining the 2400 A Breaker Bay. The crack started in the weld and progressed into base metal.

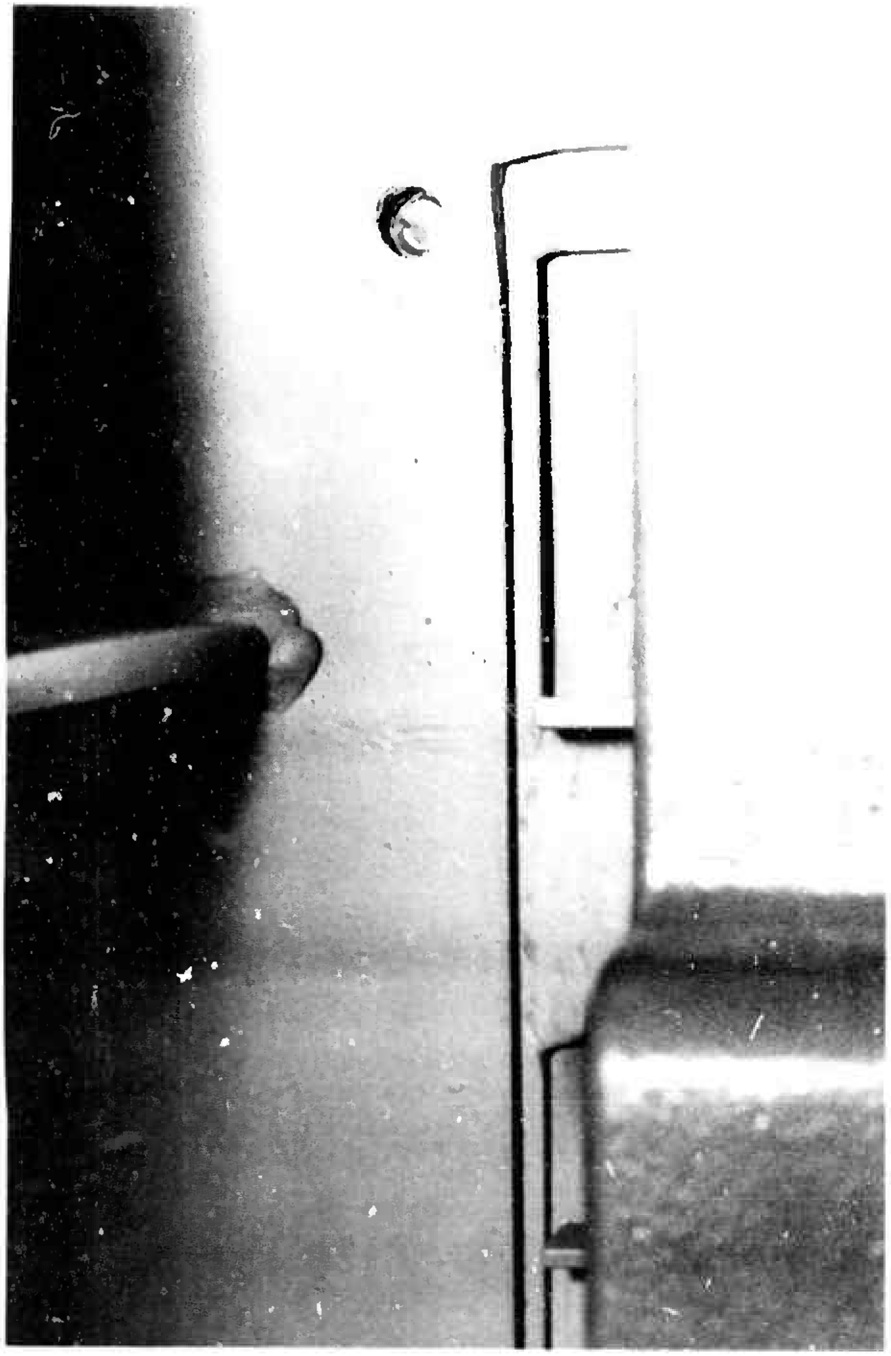


Fig. 57 - Damage from Shock Test - 1600 A Breaker Bay (Rear). Sheared bolt supports upper end of the lower 1600 A Breaker base.

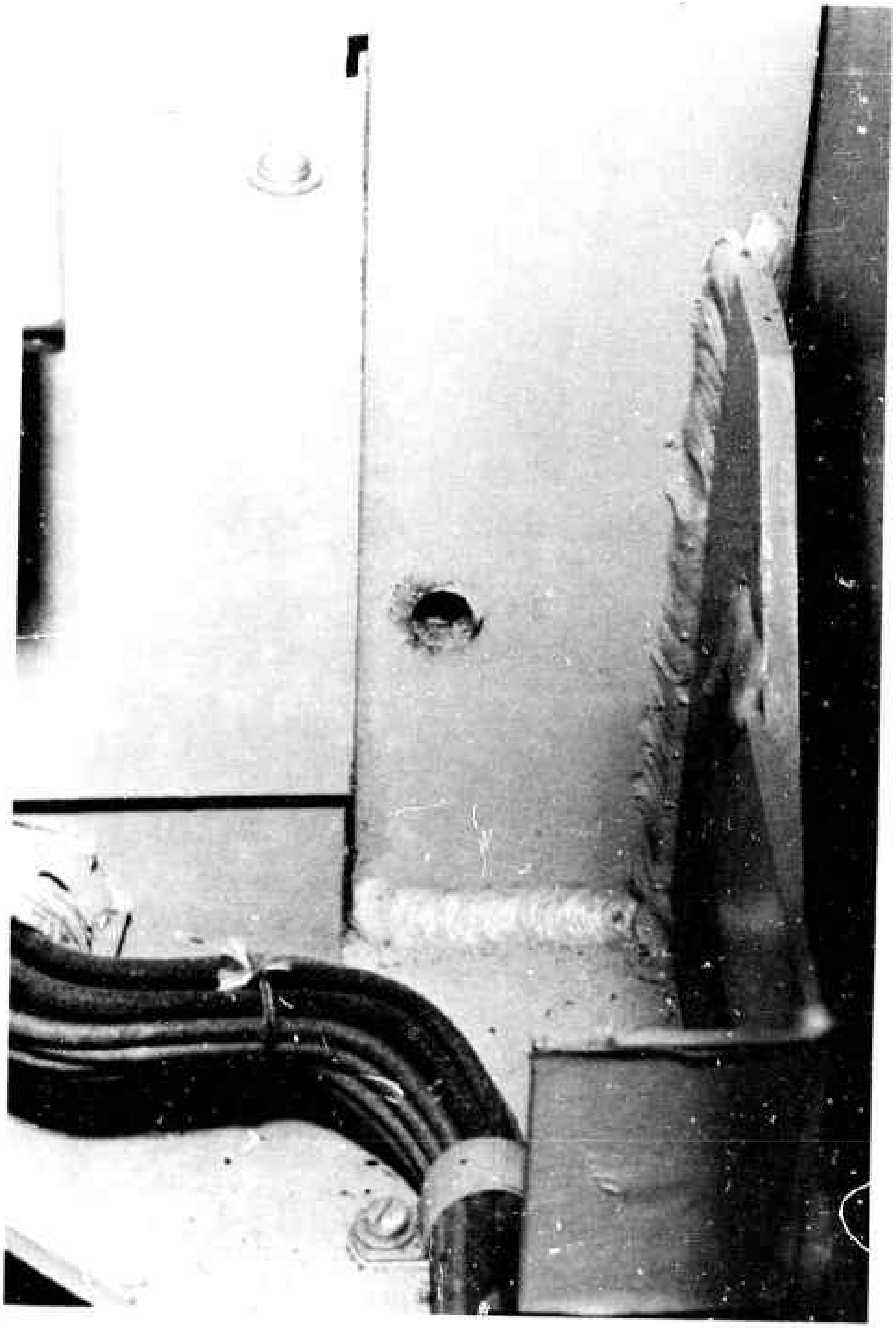


Fig. 58 - Damage from Shock Test - 1600 A Breaker Bay (Rear). Sheared bolt supports lower base frame for the lower 1600 A Breaker.

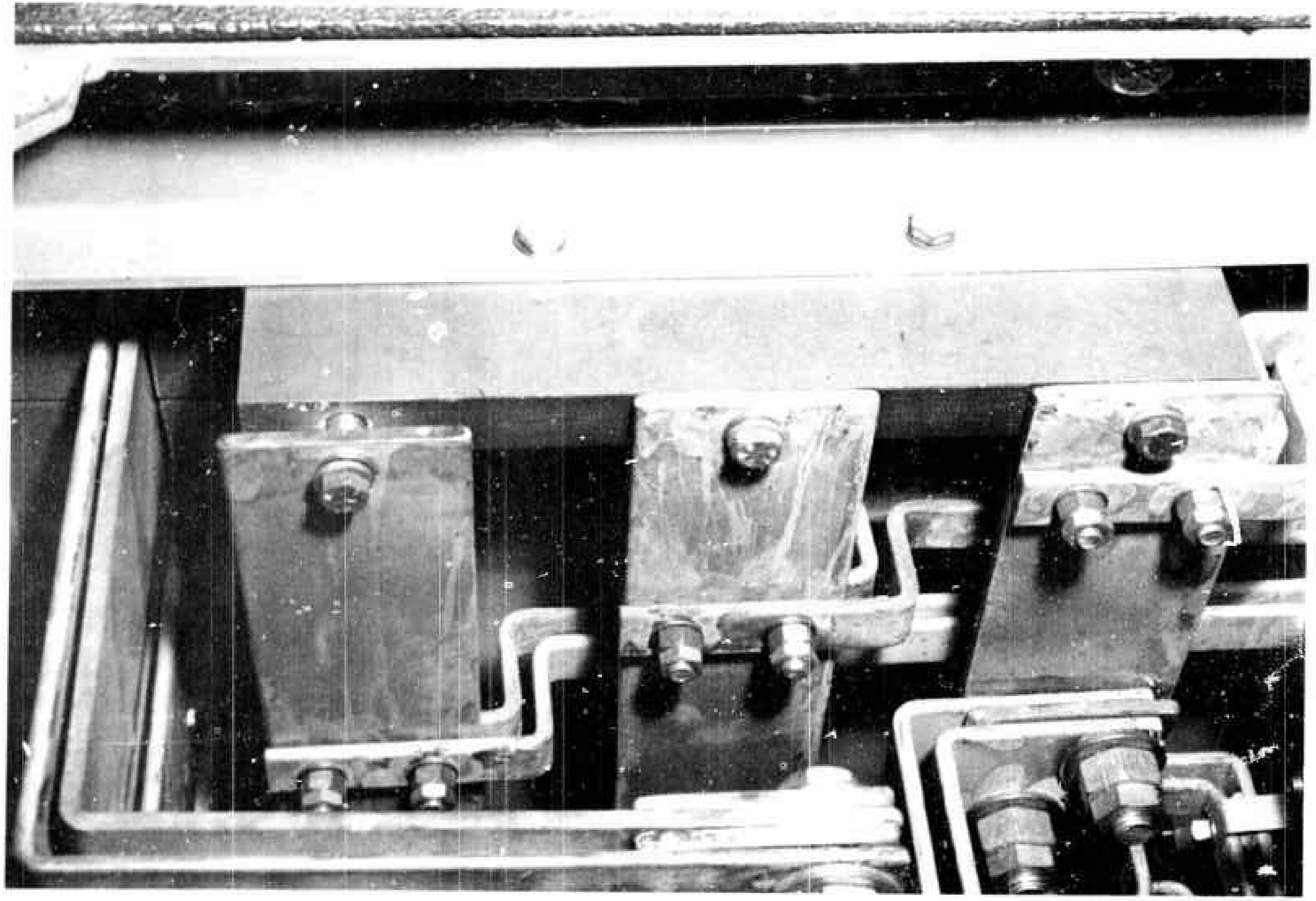


Fig. 59 - Damage from Shock Test - AQB Breaker Bay (Rear). Stripped helicoil in the melamine support at upper end of main vertical bus.

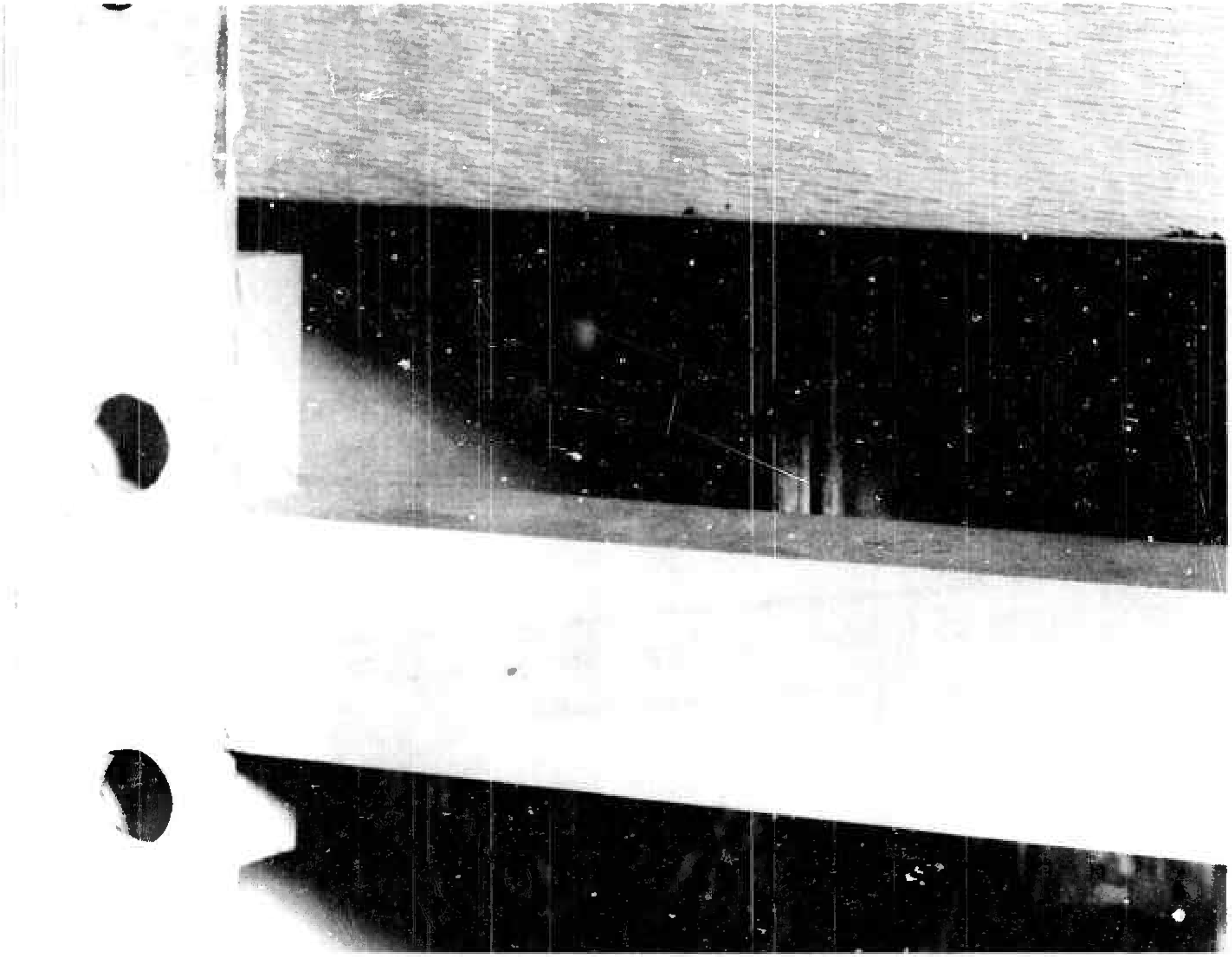


Fig. 60 - Damage from Shock Test - AQB Breaker Bay (Rear). Cracked weld at inboard end of central horizontal frame member.

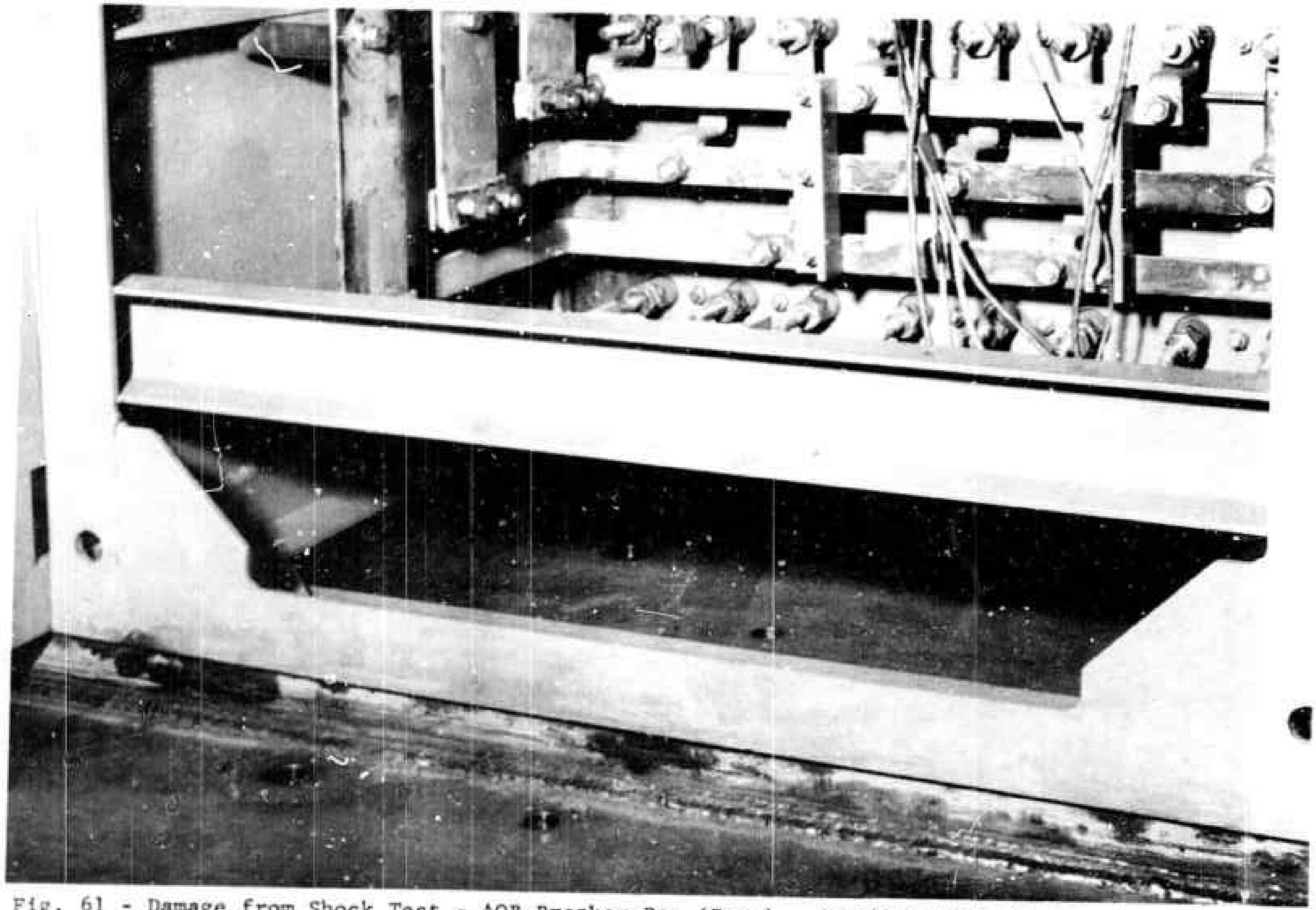


Fig. 61 - Damage from Shock Test - AQB Breaker Bay (Rear). Cracked welds in gussets at base of frame.

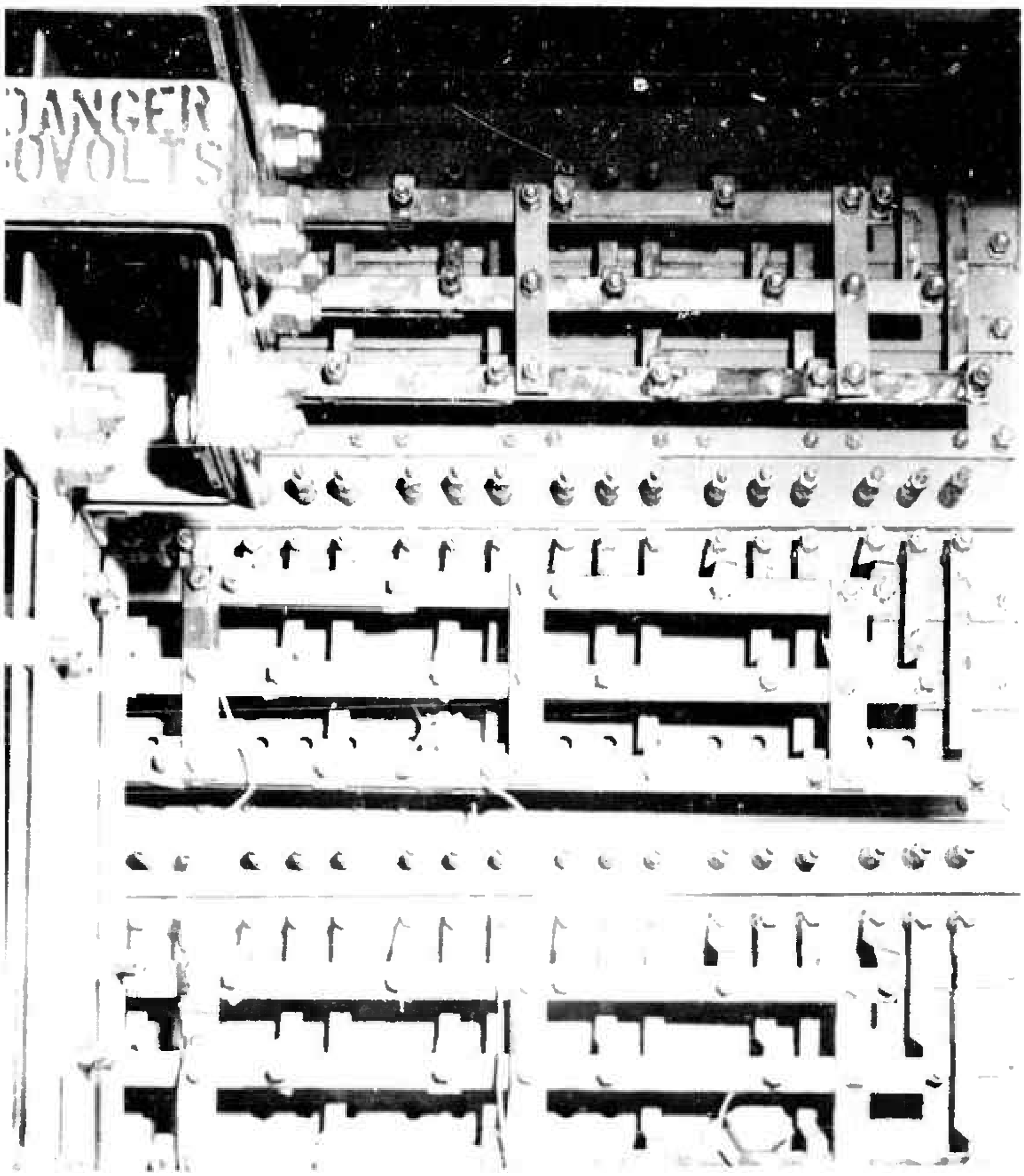


Fig. 62 - Damage from Shock Test - AQB Breaker Bay (Rear). Downward tilt of LF100 horizontal buses and deformation of breaker pickoffs.

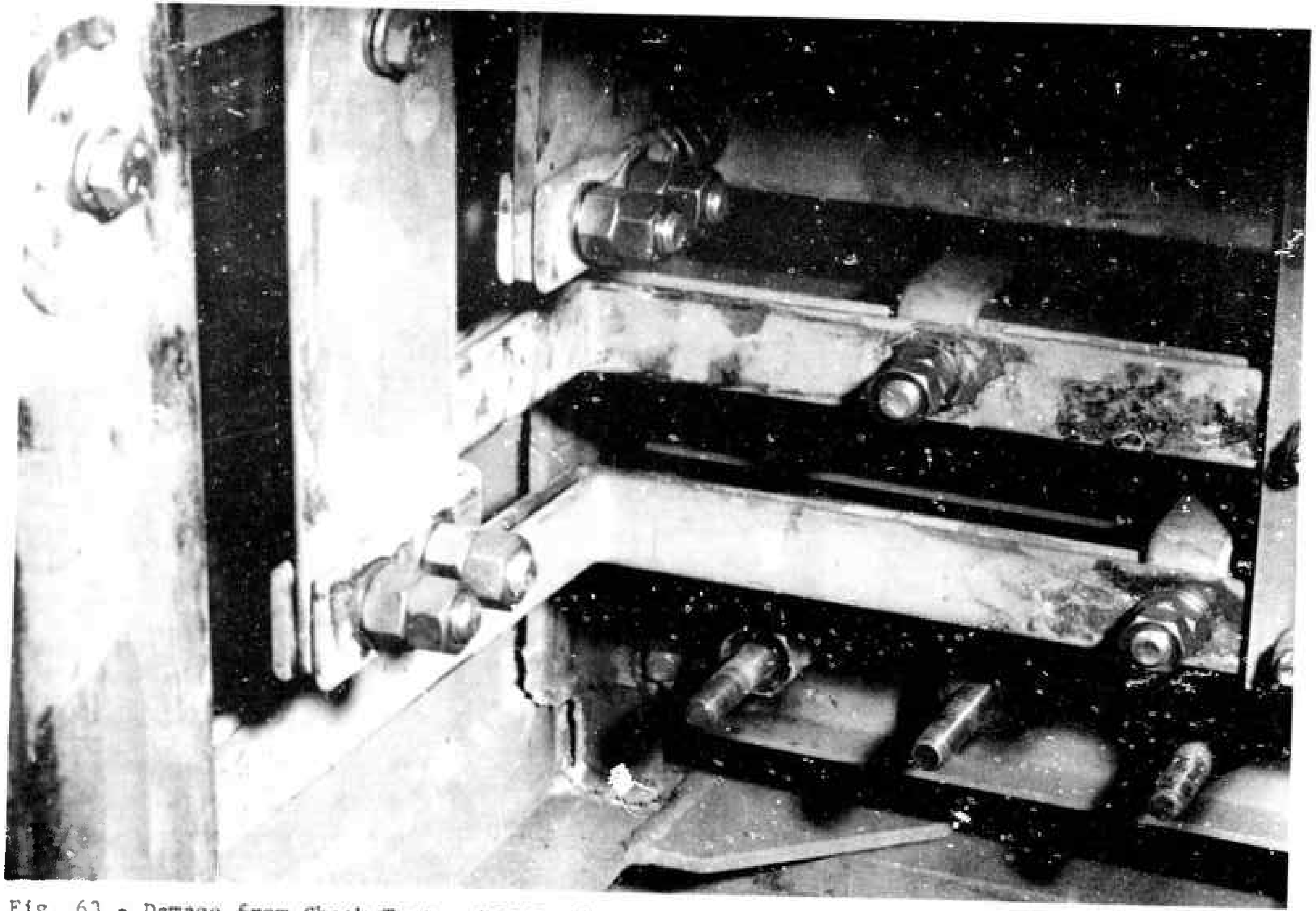


Fig. 63 - Damage from Shock Test - AQB Breaker Bay (Rear). Broken welds in frame base structure, inboard end.

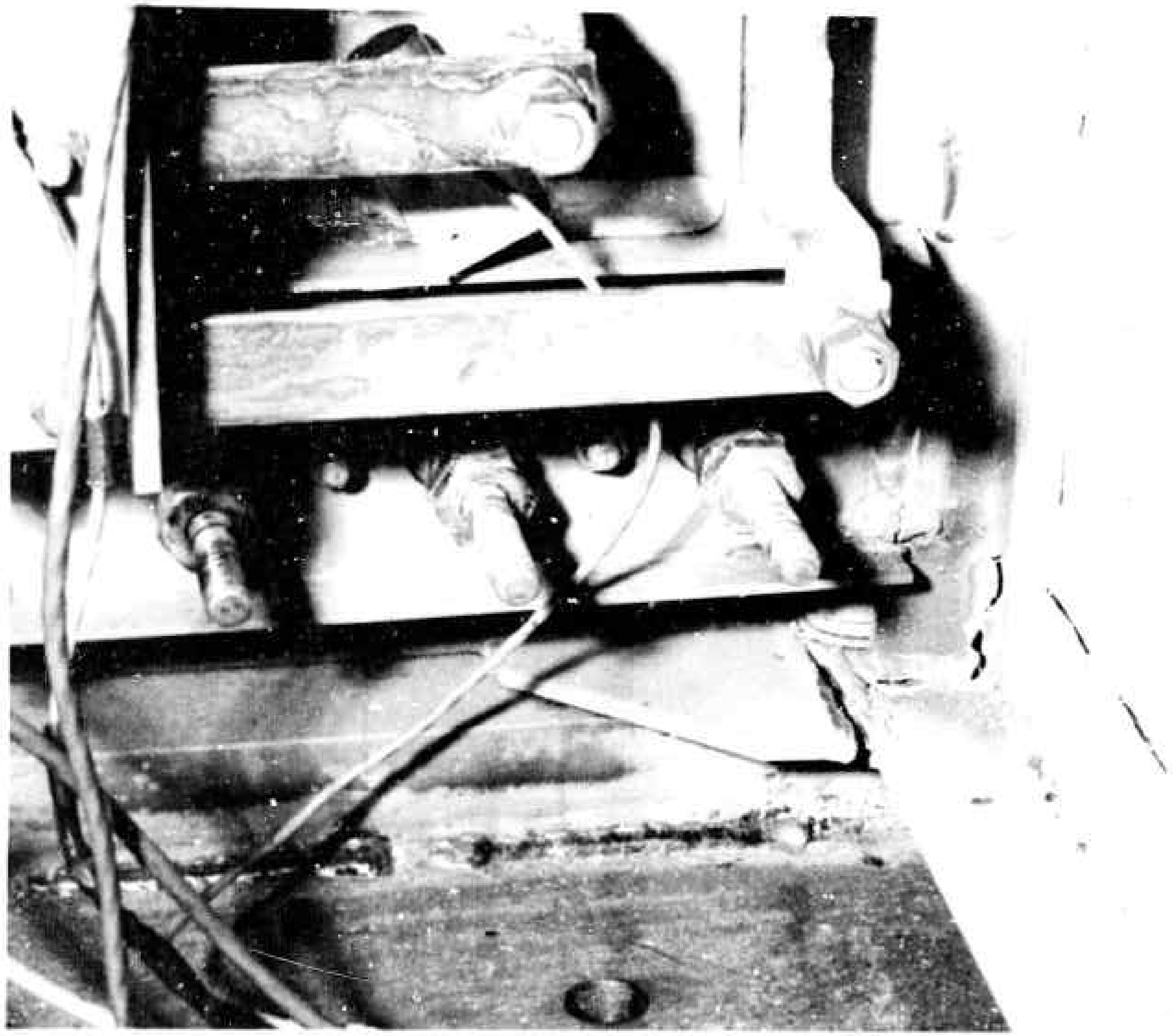


Fig. 64 - Damage from Shock Test - AQB Breaker Bay (Rear). Broken welds in frame base structure, outboard end.

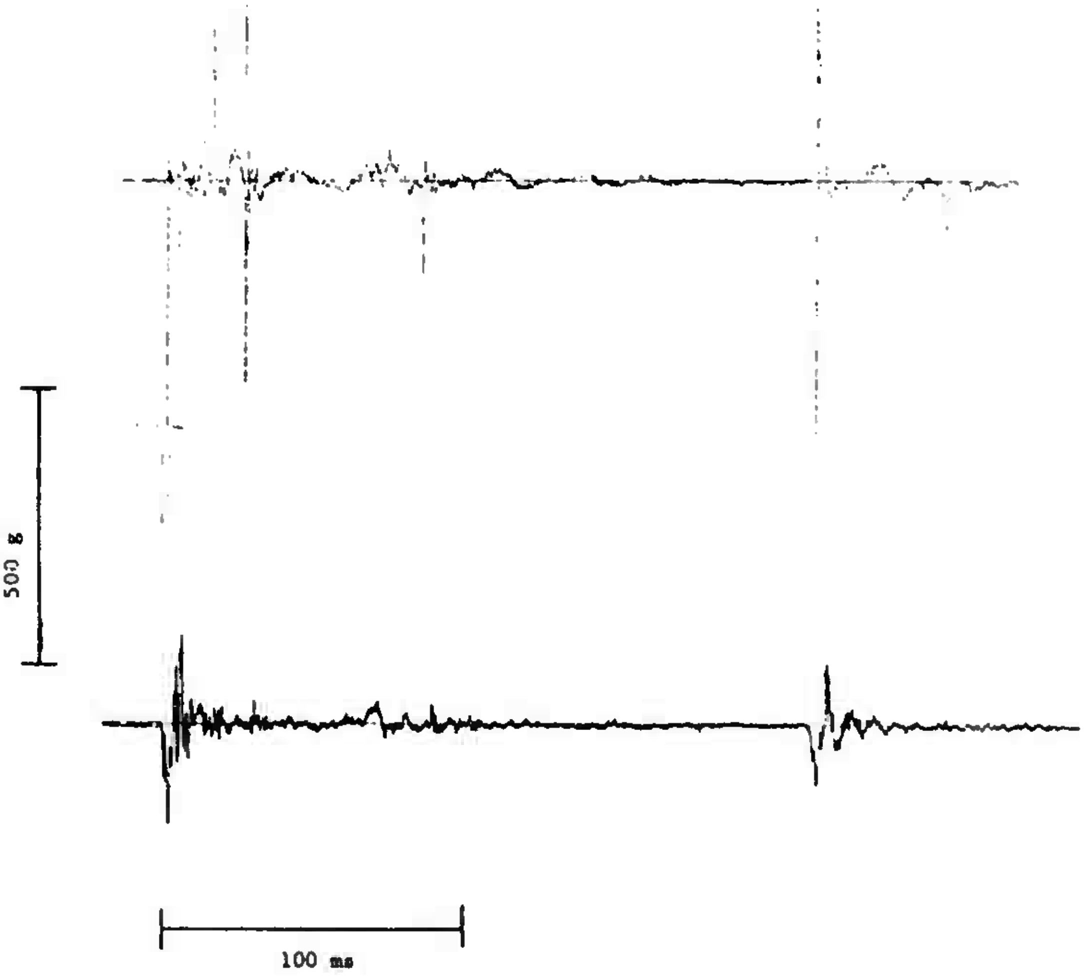


Fig. 65 - Acceleration-time records from the fuse block (upper) and mounting panel (lower) of AQB-LF101 No. 10A during Blow 4 (5-1/2 ft. 3 in.) (Vertical). Note spikes which probably indicate collision of the breaker and the cover panel.

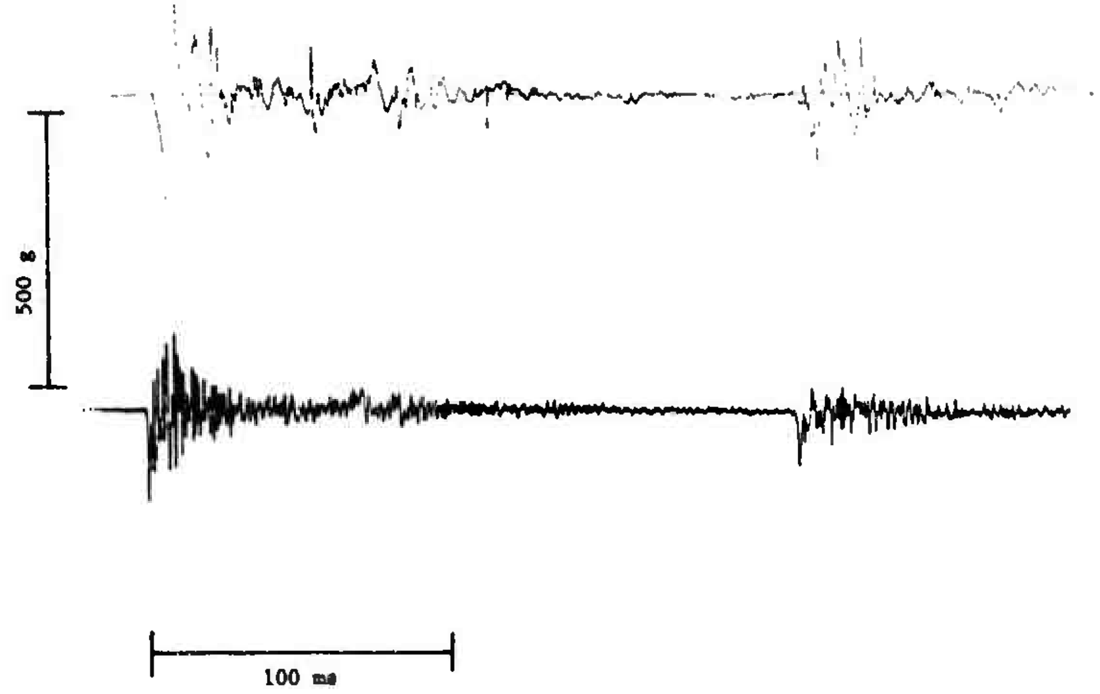


Fig. 66 - Acceleration-time records for the fuse block (upper) and mounting panel (lower) of AQB-LF250 No. 5A during Blow 4 (5-1/2 ft. 3 in.) (Vertical).

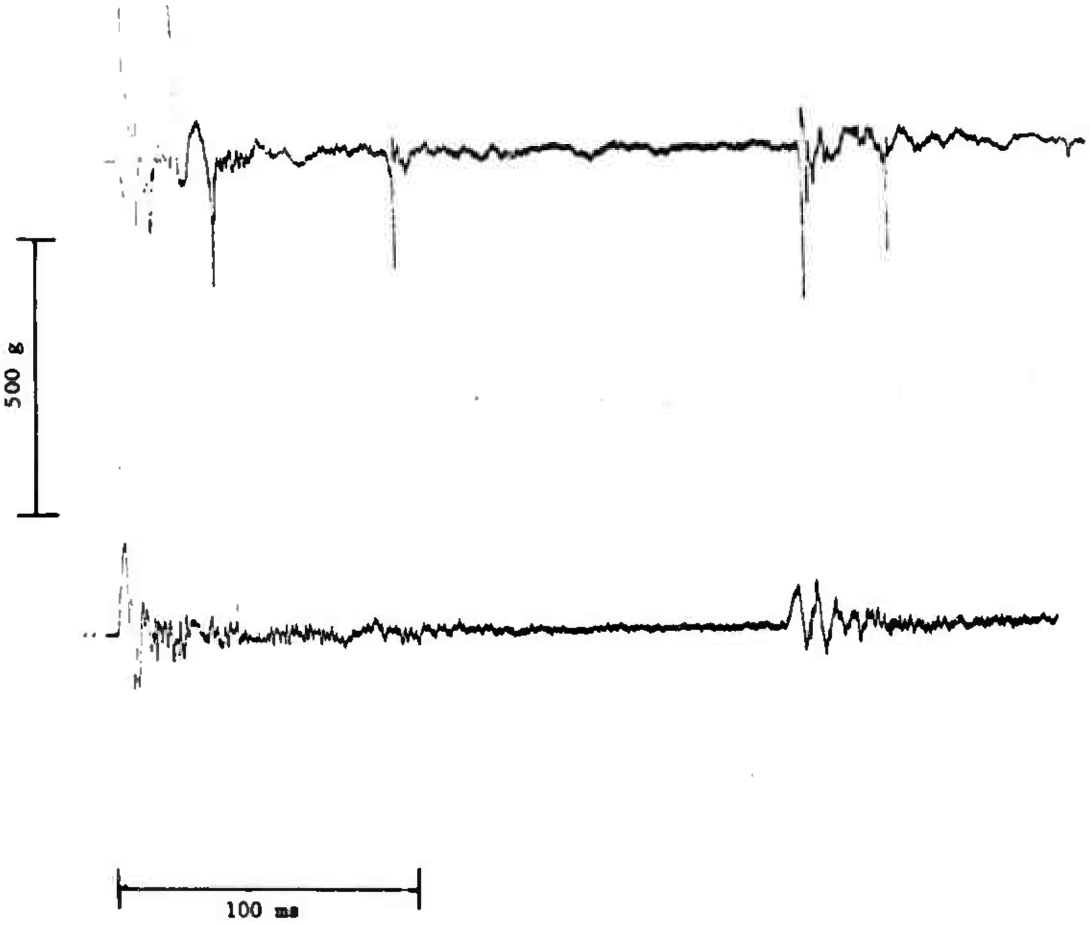


Fig. 67 - Acceleration-time records for the fuse block (upper) and mounting panel (lower) of AQB-LF101 No. 10A during Blow 9 (5-12/ft. 3 in.) (30°- Inclined). Note possible collision spikes.

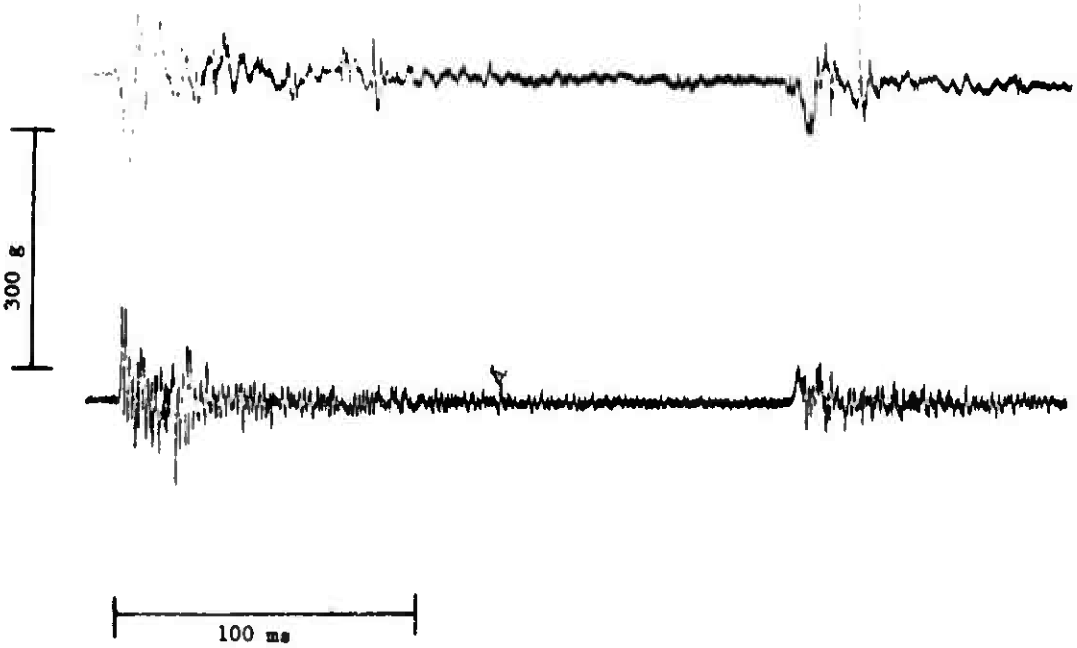


Fig. 68 - Acceleration-time records for the fuse block (upper) and mounting panel (lower) for AQB-LF250 No. 5A during Blow 9 (5-1/2 ft. 3 in.) (30° -Inclined).

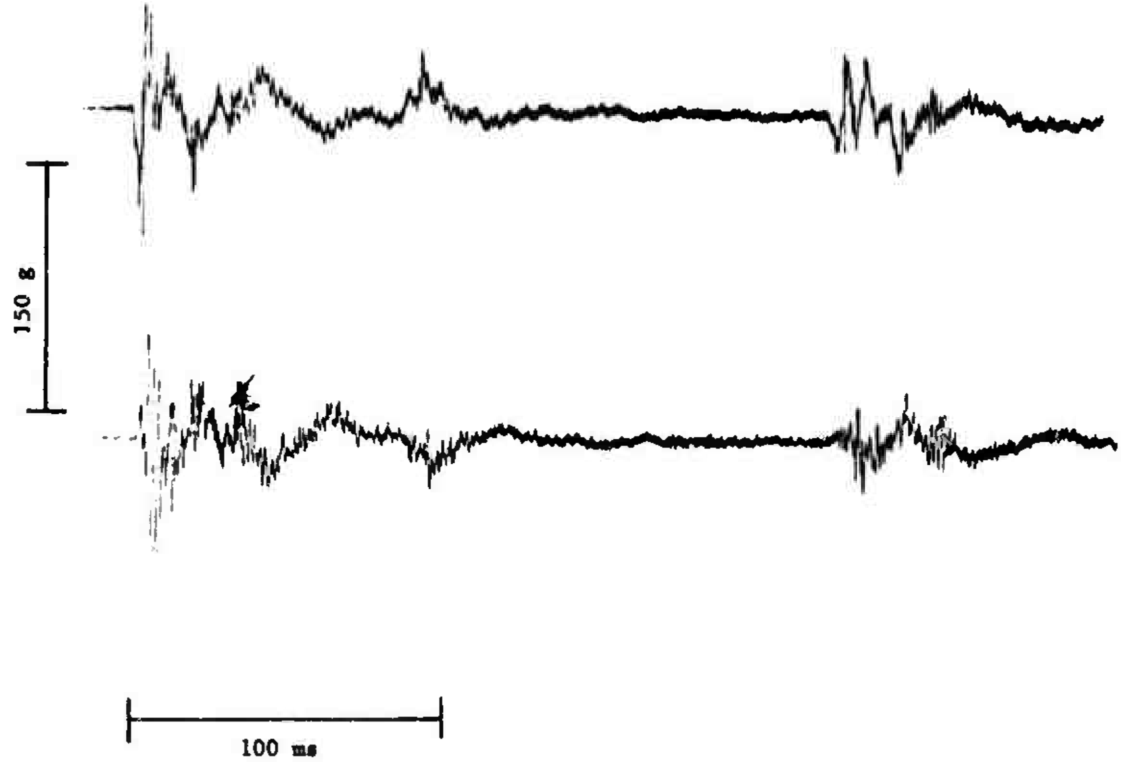


Fig. 69 - Acceleration-time records for the fuse block (upper) and mounting panel (lower) of AQB-LF250 No. 10A in the direction normal to the mounting panel during Blow 9 (5-1/2 ft. 3 in.) (30°-Inclined).