Bulletin 48
(Part 1 of 4 Parts)

THE SHOCK AND VIBRATION BULLETIN

Part 1
Keynote Address, Invited Papers, Panel Sessions, Modal Test and Analysis

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The 48th Symposium on Shock and Vibration was held at the Von Braun Civic Center, Huntsville, Alabama on October 18–20, 1977. The U.S. Army Missile Research and Development Command, Redstone Arsenal, Huntsville, Alabama was the host.

Office of
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KEYNOTE ADDRESS

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Adequate testing is an essential step in the development process. Much of the success in developing better weapons and delivering them to the soldier is due to insistence that they survive adequate environmental tests. Designers scream that their sophisticated hardware is being torn up but testing continues because the real world on the battlefield is the wrong place to find design weaknesses. Designers should analyze and simulate the environments which their components will have to endure before they are incorporated into missile and rocket systems. Certainly the analysis of the response of these components to the shock and vibration stimuli is significant to their survival. Testing in the US Army Missile Research and Development Command (MIRADCOM) laboratories, to the shock and vibration criteria which have been developed and continuously updated, reveals how well the analysis has been done. This booklet will discuss shock and vibration from the Army viewpoint and highlight some areas where improvements in test methods would be especially helpful.

In February 1977 the US Army Missile Command (MICOM) was divided into two new commands: the US Army Missile Material Readiness Command (MIRCOM) and the US Army Missile Research and Development Command (MIRADCOM).

MIRCOM, the readiness command, as the name implies, has responsibility for production of missile and related hardware, supplying this material to the troops in the field. It is responsible for material maintenance until it is obsolete and must be replaced. MIRCOM is commanded by MAJ GEN Louis Rachmeler.

MIRADCOM is the research and development side of the house at Redstone and is responsible for missile research and development management, the Missile Intelligence Agency, and the in-house laboratories. MAJ GEN Charles F. Means is the commander of MIRADCOM.

These two commands, teamed with the US Army Missile and Munitions Center and School, also located at Redstone, work together to develop, produce, maintain, and train soldiers in the use of the weapons necessary for the modern army to defend itself against outside threats to the security of the United States.

MIRADCOM has the in-house, "hands on" technical expertise and facilities. It supports the production side in requalificaton of new production hardware, modification and improvement of existing systems, and incorporation of new developments into fielded systems. However, MIRADCOM is primarily involved with the development of new advanced systems.

MIRADCOM has full responsibility for the development and initial procurement of all Army missile systems. A quick look at some of the new systems will illustrate the challenge of developing realistic shock and vibration analysis and simulation testing of missiles. PERSHING II is an extremely accurate long-range missile system currently in advanced development. PERSHING II will provide improved military effectiveness against the complete target spectrum, while limiting collateral effects to the military target.

The accuracy for PERSHING II is obtained by the use of a terminally guided reentry vehicle, which contains both the guidance and warhead. The termainal guidance approach for PERSHING II utilizes a radar area correlation process which compares a live target scene from a scanning radar with a stored reference scene of the target area.

The tactical reentry vehicle will use the current PERSHING solid propellant boosters and can be accommodated by present PERSHING IA ground equipment with minor modifications.

The VIPER system is a short-range, manportable, antitank weapon. The tactical round consists of a free-flight in-tube burning rocket which is packaged, sealed, and transported in an expendable launcher that also serves as the tactical storage container. This system satisfies the operational requirement to provide a higher hit probability, greater lethality, longer effective range, and increased reliability. The VIPER weapon will be capable of being treated as a round of ammunition, will be maintenance free, capable of long term storage without significant degradation, and will be relatively impervious to worldwide environmental conditions.

The general support rocket system (GSRS) is envisioned to be a modular, multiple rocket launcher system designed to provide rapid, nonnuclear, indirect fire support against time-sensitive targets. The rocket will be unguided and will have a high degree of accuracy. The launcher/loader will be a self-propelled tracked vehicle with the capability to support multiple rocket launchers. The fire control equipment will be part of the launcher/loader vehicle. The rocket pod will serve as a shipping container, a storage container, as well as a launch pod for the rocket.

The mission of GSRS is to provide field artillery fires in general support of a division of corps by delivering large volumes of effective firepower in a very short time against critical, time-sensitive targets with a variety of warhead options and without the necessity to mass large numbers of weapons and men.

HELLFIRE – The HELLFIRE weapon system will consist of the HELLFIRE missile system, laser designators, communication network, and scout and attack helicopters. Ground designation and scout helicopter designation provide the attack helicopter with a launch-and-leave capability. Fire-and-forget missile/seeker configurations will allow target acquisition and firing from the attack helicopter without the assistance of any type of target designation.

The HELLFIRE missile system will include a helicopter launcher missile equipped with a terminal homing seeker and a shaped charged warhead. The missile configuration will have the capability for modular seeker replacements.

The HELLFIRE modular missile system is designed to defeat hardpoint targets in the forward battle area over a wide operating envelope of speed, flight profiles, and attack scenarios.

STINGER – STINGER is the shoulder-fired member of the family of short range air defense (SHORAD) weapons protecting the field army units. The system will normally be employed to provide low-altitude air defense for units operating near the forward edge of the battle area. The system may also be employed to provide air defense for vital areas when no other ground-based air defense means are available. The complete STINGER weapon system consists of the weapon round, battery coolant unit, identification friend or foe, containers, and support and training equipment.

The US ROLAND is an all-weather, low-altitude, command-to-line-of-sight (CLOS) air defense weapon system designed to perform the SHORAD mission. Salient features of the US ROLAND are as follows:

1. A missile can be launched at an attacking aircraft in a matter of seconds.

2. Each fire unit contains 10 missiles that can be fired during the course of a single mass raid.

3. The fire unit is mounted on the self-propelled, M109 tracked vehicle.

4. The surveillance radar can perform target search during fire unit movement.

5. The fire unit can halt and fire at attacking aircraft within seconds after target detection while on the move.

6. The fire unit can move from a deployed position within seconds after receiving a march order.

The modularity of the fire unit provides potential for usage on a variety of platforms in the future. The system is almost identical to the European version of the system. Almost all components will be fully interchangeable. One major difference is the mounting of the air defense components into a self-contained module which can be removed from the vehicle.

A broad spectrum of land combat and air defense, ranging from shoulder fired infantry weapons to long range nuclear missiles is being developed. As a result, there are wide variations in environmental criteria. These operational environments and some of the types of simulated tests used to develop and produce these systems will be summarized in the following paragraphs.

MIRADCOM must concern itself with two types of transportation and handling: the commercial or logistical transportation from point of manufacture to the final use area and the field or tactical transportation associated with training and combat.

Anyone who has used the US mail or commercial freight lines is well aware of the problems associated with this form of transportation. Military equipment shipped by commercial truck, rail, air, or ship fares no better. In World War II, it was found that more than half of the equipment arrived at the scene of operations in either a damaged or unusable condition due to handling and transportation induced shock and vibration. All Army equipment is packaged in an attempt to protect it from damage by loading, transporting, or accidental dropping. All containers used for Army equipment are designed and tested to this anticipated environemnt.

For example, within the last 18 months at MIRADCOM, a new 18,000 force-lb shaker and a high performance shock machine were purchased. The shaker sustained over $2000.00 in damages in shipment from the manufacturer. The shock machine was so badly damaged in a train derailment that it was returned to the manufacturer.

Those who procure military equipment should be aware that the commercial shipment and the shock and vibration problems associated with this environment cannot be overlooked.

During the other form of transportation referred to as field or tactical use, the Army has a large number of shock and vibration problems to overcome. Some systems while still packaged for commercial transportation may be transported by military truck, tracked vehicle, or helicopter before they are removed from their protective containers. Once the item is removed from its container, it may be mounted to a helicopter, tank, truck, trailer, or man carried. Each of these forms of field use has a unique vibration and shock environment that must be considered when it is designed. Self-induced shock and vibration during equipment use can be severe and must not be discounted.

Obviously, each system fielded by the Army is unique to its environment; each system must be tested differently. The environment for a helicopter mounted missile is different from that experienced by a man carried weapon.

Some of the tests that may be used at MIRADCOM to see that this toughness is built in may be a series that starts with a design verification test on prototype hardware to make modal studies, determine dynamic response, and conduct preflight vibration tests to ensure basic integrity.

Later in the development cycle, prequalification tests may be conducted to apply military standard shock and vibration tests to hardware representative of production type items is an effort to discover any design deficiencies prior to full qualification and subsequent production.

Next, safety tests are conducted in which these items are overstressed with shock and vibration to determine if any hazards to the field troops exist due to extreme environments. Safety tests will also be conducted at normal vibration or shock levels to satisfy requirements for a flight release on new designs for equipment to be installed on aircraft.

Qualification tests are conducted to insure that the equipment will meet those environments anticipated in world-wide development. These items are tested in larger samples than previous tests for statistical confidence and consist of a full sequence of shipping, handling, field, and operational tests.

When a system is fielded and in the hands of the combat troops, continual testing is still required. This program is called "fly-to-buy." The fly-to-buy plan has been very successful from the Army's standpoint in assuring the Army that the hardware bought is reliable, and maintains the standards developed into it. These tests may be called first article tests, lot acceptance, or production verification; but in essence, it means that for each production lot, a sample is taken, environmentally treated, and operated. If these tests are successful, then the lot is accepted.

Since weapons undergo this wide diversity of stimuli, MIRADCOM is confronted with the difficult problem of establishing shock and vibration tests which are realistic and adequate to insure survival in the real world. All criteria are important: the first, because inadequate tests mean inadequate weapons for the soldier; the second, because excessive requirements drive up weight and costs.

There is an expression "a good test is worth a thousand expert opinions." It is not all that simple until it is determined just what a "good test" is. A good test was once defined as "one which fails equipment which will fail in service and will not fail equipment which is satisfactory for service."

Many times project managers will very comfortably specify a procedure, curve, and figure from a military standard and then move on to what they think are more important things. The result is often a waste basket full of parts and a frantic cry for help. This is never a good test. The solution is proper analysis and simulation prior to testing.

Another important consideration is how the vibration community can best communicate this complex and specialized technology to managers in a form most useful to them in selecting requirements and establishing test specifications.

The answers to these questions should be an important part of this symposium's theme. From the Army's standpoint (at MIRADCOM) this technology should be used efficiently so that it transfers to cheaper, lighter, and more reliable equipment in the field. Of course, MIRADCOM along with anyone else in the development process, is always constrained by the state-of-the-art, cost, schedules, and standardization. Much of the time, aspirations are not realized. All that is accomplished here should be directed toward something constructive whether it is better military hardware, advancing the state-of-the-art, or creating a better life style for all.

MIRADCOM has an excellent shock and vibration capability which is used as a means of staying abreast of what is going on in the entire shock and vibration community. The technology has been moving rapidly in the past few years and gatherings like this symposium are valuable. Close coordination and communication help to prevent wasting resources and resolving problems someone else has already solved.

In any technical endeavor there is always room for improvement. There are two areas that deserve increased attention.

The first one is a way this community can best communicate vibration and shock to a manager in a form more useful to him in developing hardware. There are military specifications which are used almost universally in establishing initial requirements but may not always be applicable to the product being developed. These specifications are sometimes overly severe when interpreted literally and can lead to laboratory failures which are not reproducible in the field. General specifications have been used for many years at Redstone with much success, but sometimes it is difficult to apply a general standard specification to a sophisticated design intended for specialized use.

Tests that have been proposed to circumvent this problem and tailored to a particular system or subsystem have in some cases been worse due to the cost and time involved. These tests generally require extensive facilities such as multiple shakers or computer control systems, thus few groups can perform them. This really becomes a problem when new subsystems or components are developed and need qualifying. Another disadvantage to tests of this type is that they are difficult to describe in, and interpret from, a procurement document.

A second challenge is one of data exchange and presentation. The Army fields equipment which is transported by a multitude of commercial and tactical ground and airborne vehicles. Many government agencies and contractors have conducted field tests on most of these vehicles and have recorded and analyzed hours and hours of data. It would obviously be of immense value to everyone involved to have all of these data compiled at one location and made available to participating members of the shock and vibration community. MIRADCOM's dynamics people have received many inquiries from project managers looking for such information. For example, a project manager may want to know if he can install his system in a "Y" vehicle without conducting a large scale measurement and test program even though the system was orginally designed for the "X" vehicle. Such

questions could be handled much better if immediate reference could be made to a document presenting summarized data from both the "X" and "Y" vehicles.

These are the challenges for future developments in the field of shock and vibration systems.

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INVITED PAPERS

SHOCK RESPONSE RESEARCH AT THE WATERWAYS EXPERIMENT STATION

Colonel John L. Cannon
U.S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

Background

The Waterways Experiment Station (WES) was established in 1929, two years after the most devastating flood ever to strike on the lower reaches of the Mississippi River basin. The Waterways Experiment Station is located in Vicksburg, Mississippi, which is situated midway between Memphis and New Orleans. An aerial view of the Waterways Experiment Station, (Figure 1) gives some idea of the physical plant located on 600 acres of beautifully wooded areas that have been recognized this past year as an arboretum by the Garden Clubs of Mississippi.

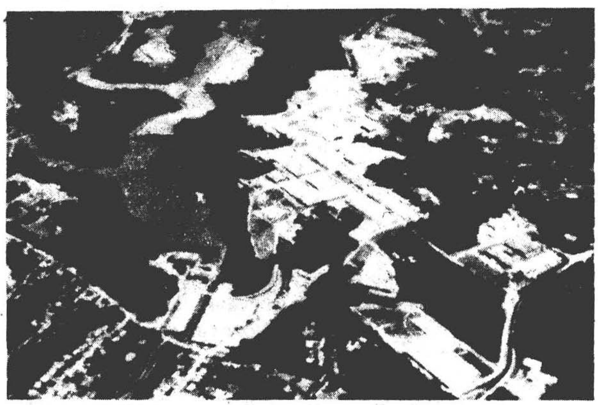


Figure 1 – Aerial view of Waterways Experiment Station

The original technical responsibilities of WES involved hydraulic engineering with the physical model being the principle tool for early investigators. Since then the technical mission has grown and now includes research in soils, concrete, mobility, weapons effects and environmental engineering. The technical missions are accomplished by six technical laboratories, (Figure 2). The administrative and supporting technical staff, i.e., Instrumentation, ADPC, Shops, etc., are also shown. Our current strength is about 1400 employees.

Shock Response Research

Today, I would like to discuss the shock and vibration work done at the Waterways Experiment Station primarily in the Weapons Effects, Soils and Pavements, and Hydraulics

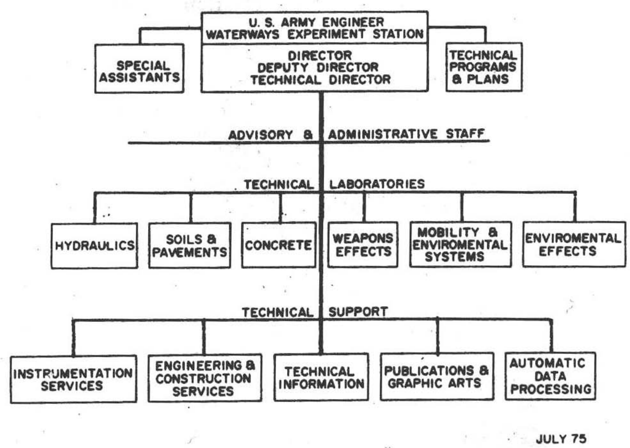


Figure 2 – Technical missions of the Waterways Experiment Station

Laboratories. As the origin of the Waterways Experiment Station WES was based on the use of physical models for hydraulic studies, we have employed this tool to other fields, coupled with theoretical studies as well as complex laboratory and prototype testing. I have selected several projects that will serve to exemplify the shock response research conducted.

Dams

North Fork Dam. This 150-feet-high, 620-feet-long (crest length) arch dam is located on the North Fork River in Northern California several miles upstream from the site of the Auburn Dam now under construction, (Figure 3).

A 1/24-scale model dam was constructed and subjected to vibratory loads; in one case, two mechanical vibrators were placed on the crest and vibrated in-and-out of phase with each other, (Figure 4). A large hydraulic shaker was also used to excite the base of the model dam for comparison with results obtained from the tests using vibrators on the crest. Shaking the dam at its base more nearly represents the loadings that might be induced by an actual earthquake. Vibration tests similar to those on the model were conducted on prototype.

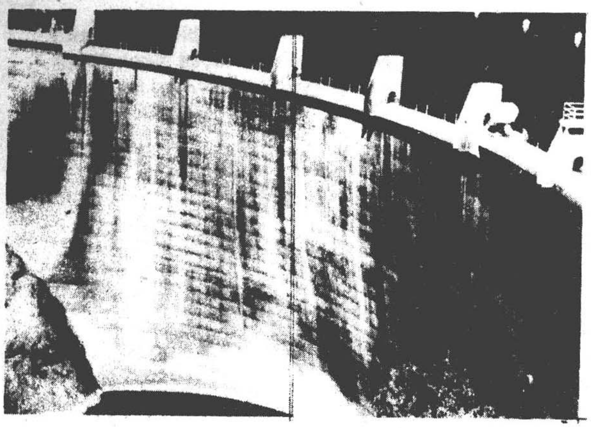


Figure 3 – North Fork Dam

Figure 4 – Vibration test of 1/24 scale model North Fork Dam

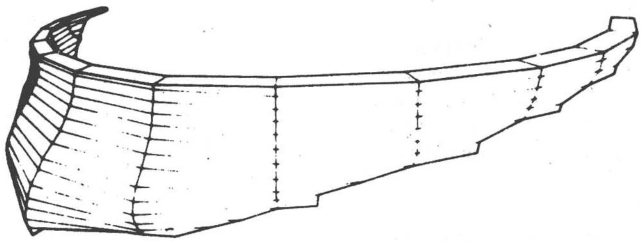


Figure 5 – Finite element model of perfectly fixed dam

In addition to the model and prototype tests, finite element calculations were made for the case where the dam was considered perfectly fixed, (Figure 5) and another where the dam was considered to be tied to the foundation material, (Figure 6).

The mode shapes for model results scaled to prototype compared very favorably, (Figure 7). The finite element prediction also compared favorably with test results, (Figure 8). Note that the predictions for the finite element code that included the foundation material compared best with the experimental results.

In addition, the damping factors for the dam with the reservoir full and empty were determined as well as the participation of the water mass in influencing the natural frequency of the dam for various modes of vibration.

A comparison of the calculated natural frequencies, those measured on the prototype, and the model results scaled to the prototype, show excellent agreement and, therefore, add to the confidence in the role of both the physical and analytical model in making predictions, (Figure 9).

As a result of the near failure (Figure 10) of the lower San Fernando Dam during the San Fernando Earthquake of 9 February 1971, the Corps of Engineers has been reevaluating its hydraulic fill dams. The Waterways Experiment Station has been assisting Districts in performing seismic analysis of these structures. Shown Figure 11 is the finite element grid of Fort Peck Dam that was used in the computerized portion of the dynamic analysis of the Fort Peck Dam.

Controlling the high-velocity flow that occurs in some sluiceways in hydraulic structures can cause flow-induced hydroelastic vibrations. These vibrations can cause substantial damage to even massive structures. An example of such damage occurred at Libby Dam on the Kootenai River, see Figure 12. In this case, severe cavitation damage occurred along the floor and walls of the sluice and shock-type noises came from the gate, see Figure 13 and 14. The sluice was repaired, the control valve was instrumented with accelerometers and pressure transducers were installed in the sluice floor, see Figures 15 and 16. The test results showed no correlation between the flow-induced vibration of the control gate and the large pressure fluctuations along the floor of the sluice. Since the alternate reason for the large pressure fluctuation involved the slope of the sluice (which causes low pressures to exist along the sluice floor) and the roughness of the floor (which causes large turbulent fluctuations in the flow) the problem was further studied by means of hydraulic model tests, see Figure 17. The results of these tests indicate that an aerator could be placed in the sluice so as to eliminate the cavitation damage in the sluice and that the gate vibration could be prevented by limiting the gate opening or modifying the intake roof shape and; hence, the problem was solved through the use of a model.

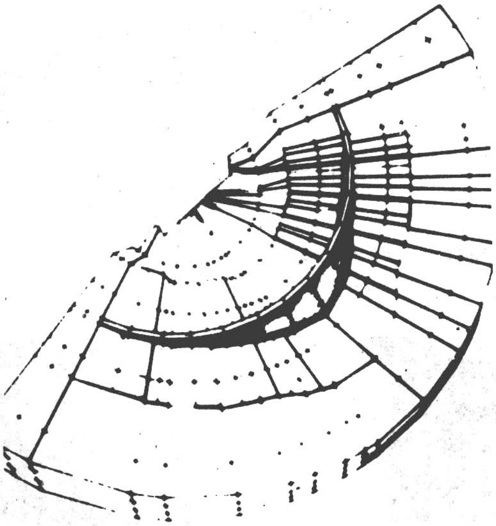


Figure 6 — Finite element model of dam tied to foundation material

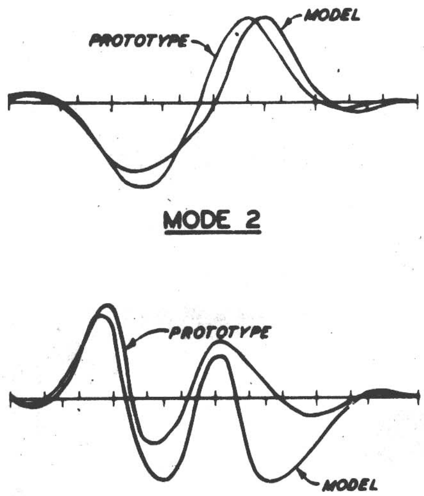


Figure 7 — Comparison of normalized full scale and model mode shapes, radial crest deflections

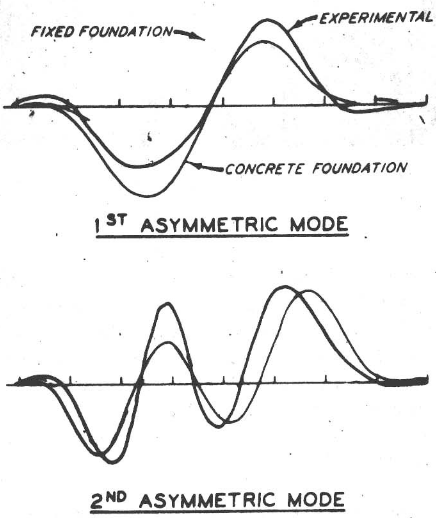


Figure 8 — Comparison of experimental and analytical normalized mode shapes, reservoir full

	NATURAL FREQUENCY, Hz		
MODE	FULL SCALE	MODEL (SCALED)	ANALYTICAL (SCALED)
1	-	-	5.17
2	5.80	4.29	5.08
3	6.30	6.12	6.29
4	7.47	7.29	7.58
5	8.53	10.10	-

Figure 9 — Comparison of natural frequencies

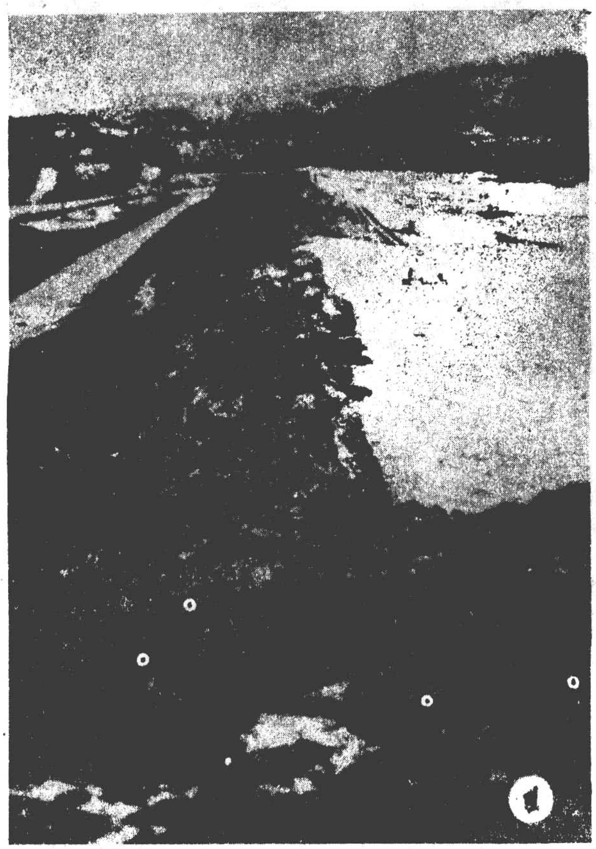


Figure 10 — Lower San Fernando Dam

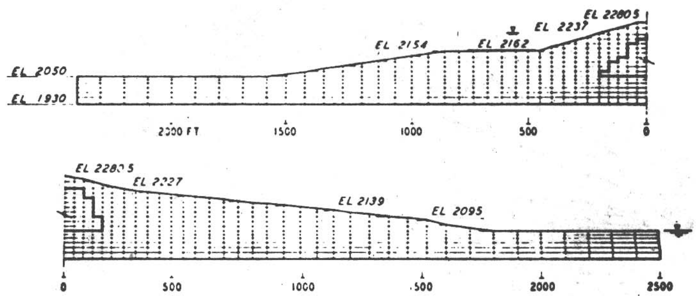


Figure 11 — Finite element dynamic analyses, Fort Peck Dam

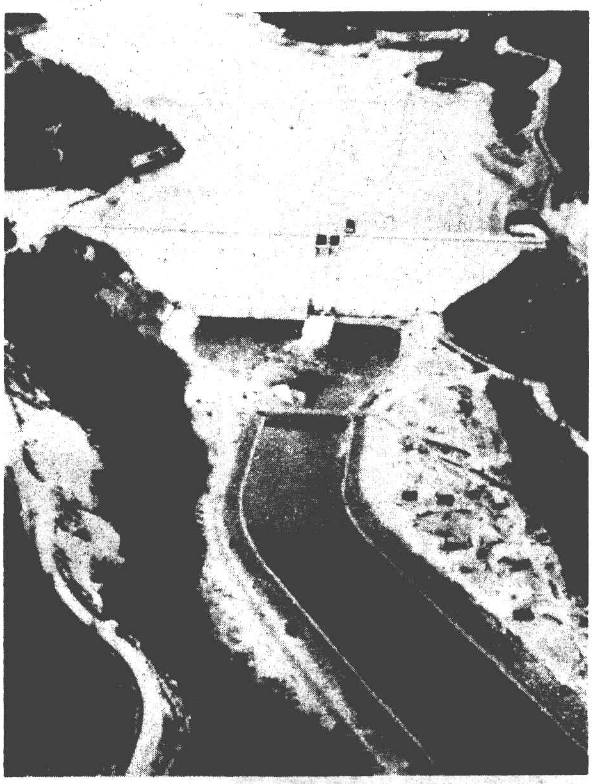


Figure 12 — Libby Dam

Structures

The shock and vibration transmissivity characteristics of the Perimeter Acquisition Radar (PAR) building, was studied by conducting model tests. The building is 125 feet high, 194 feet wide at its base, has walls that are 6 feet thick at the base, and floors that are 3 feet thick, see Figure 18.

A 1/12-scale model of the prototype was constructed and tested in the DIAL PACK Event (500-tons of HE) conducted at the Suffield Experimental Station in Canada, see Figure 19. Interface surface pressures as well as internal acceleration and strain were measured.

After the DIAL PACK Event, tests were conducted by systematically placing mechanical vibrators on the outside

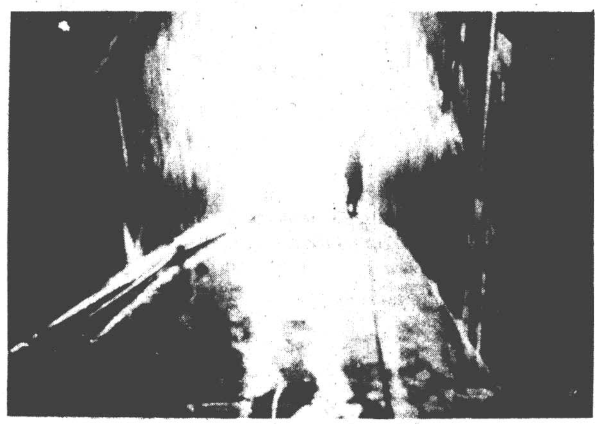


Figure 13 — Damage to floor and walls of sluice of Libby Dam

roof and walls of the structure so that the entire external surface was mapped and the signals recorded by accelerometers located at fixed locations within the structure produced signatures indicating how energy was transferred from an external location to an internal location, (Figure 20). This signature is called the transfer function and relates some external location to an internal location for a range of frequenceis, (Figure 21).

By knowing the transfer function for all the patches over the entire surface of the structure, it was possible to engulf the structure with the actual DIAL PACK airblast load, apply the appropriate transfer function and predict the transient acceleration of particular points within the structure, (Figure 22).

Comparisons of predicted (using the transfer functions), and measured results of the DIAL PACK tests, are in close agreement thereby giving some confidence in the use of transfer function, (Figure 23).

Vibration tests were then conducted on the prototype; however, it was not practical to map the entire structure because of the size of the vibrator and the building. Therefore, by verifying the principle of reciprocity, it was also possible to map the walls, (Figure 24). First the vibrator was placed on the roof as shown, and a measurement made at a point on one of the floors. Then the drive point and measuring point

Figure 14 – Damage to floor and walls of sluice of Libby Dam

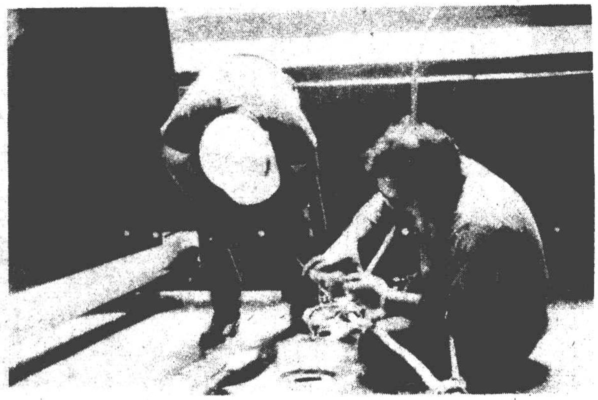


Figure 15 – Installation of pressure transducers in sluice floor, Libby Dam

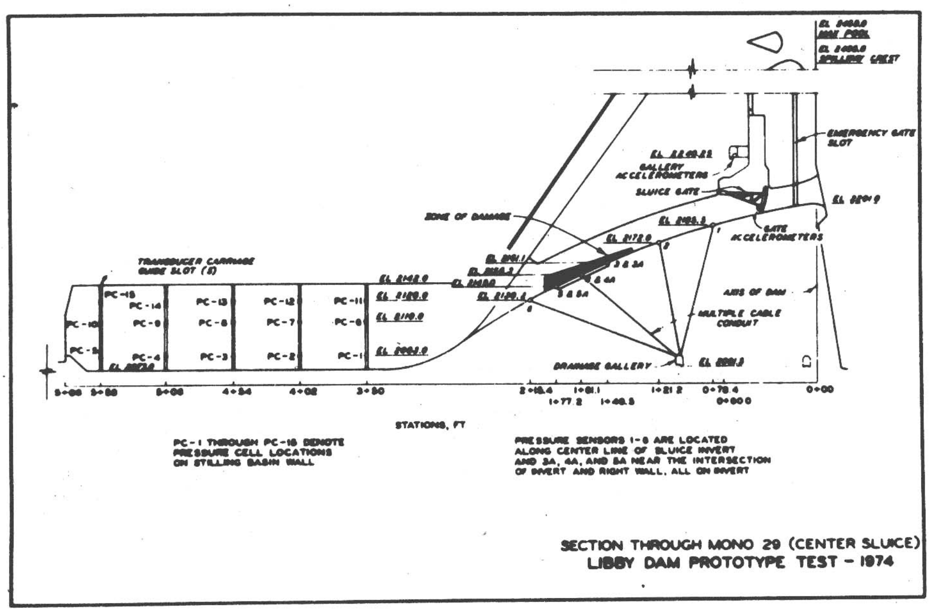


Figure 16 – Instrumentation in sluice of Libby Dam

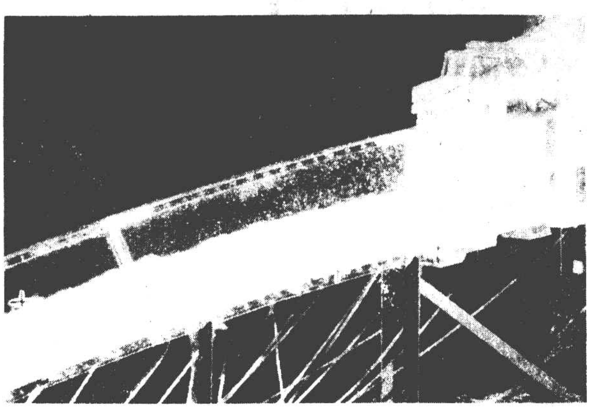


Figure 17 – Hydraulic model tests of sluice of Libby Dam

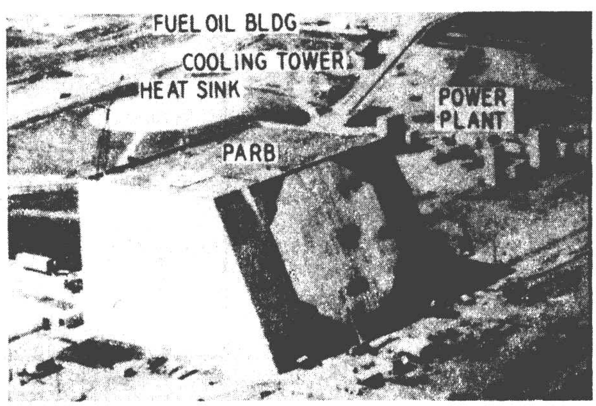


Figure 18 – Perimeter acquisition radar (PAR) site

Figure 19 — One-twelfth scale model of perimeter acquisition radar building

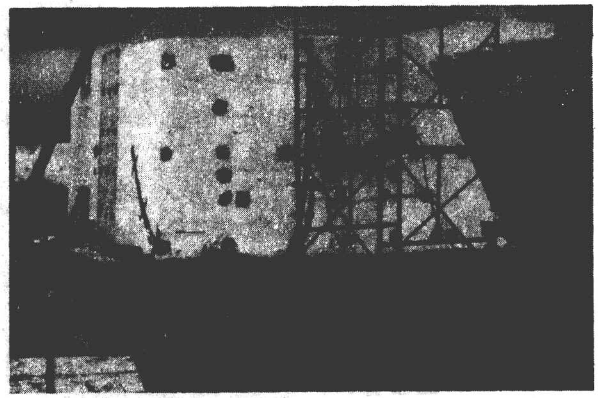


Figure 20 — Arrangement for measuring transfer function on wall of scale model perimeter acquisition radar building

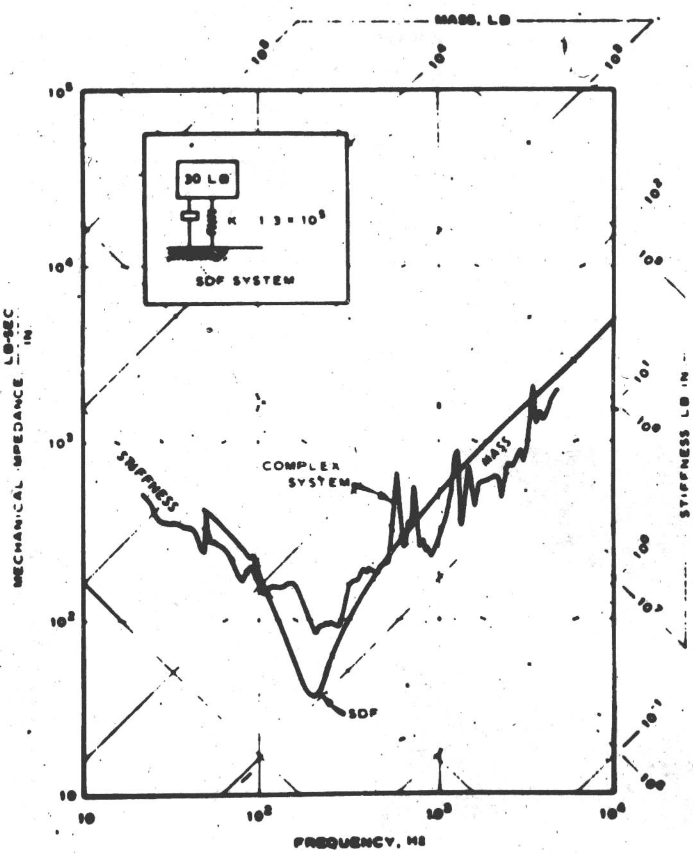


Figure 21 — Typical transfer function

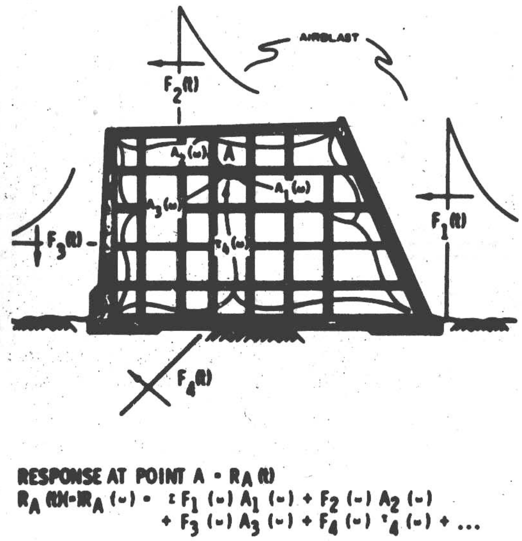


Figure 22 – Schematic load and transmission paths for scale model perimeter acquisition radar building

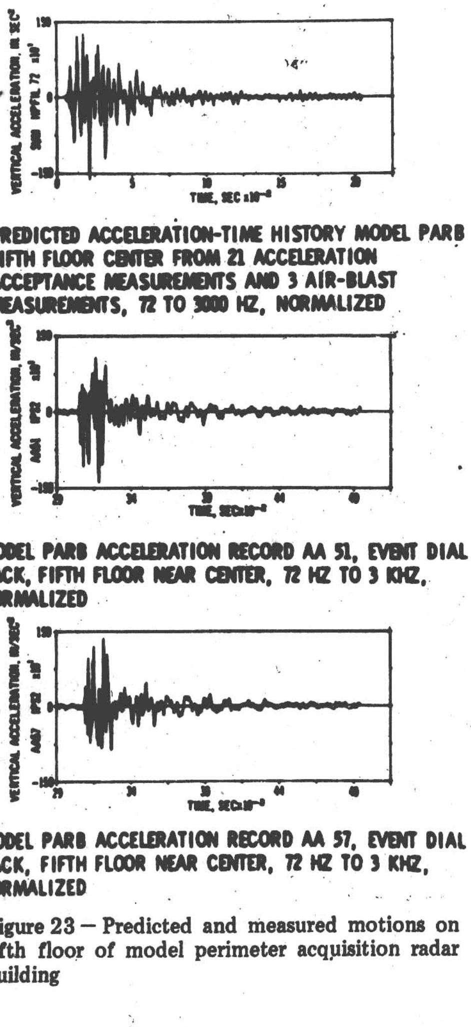


Figure 23 – Predicted and measured motions on fifth floor of model perimeter acquisition radar building

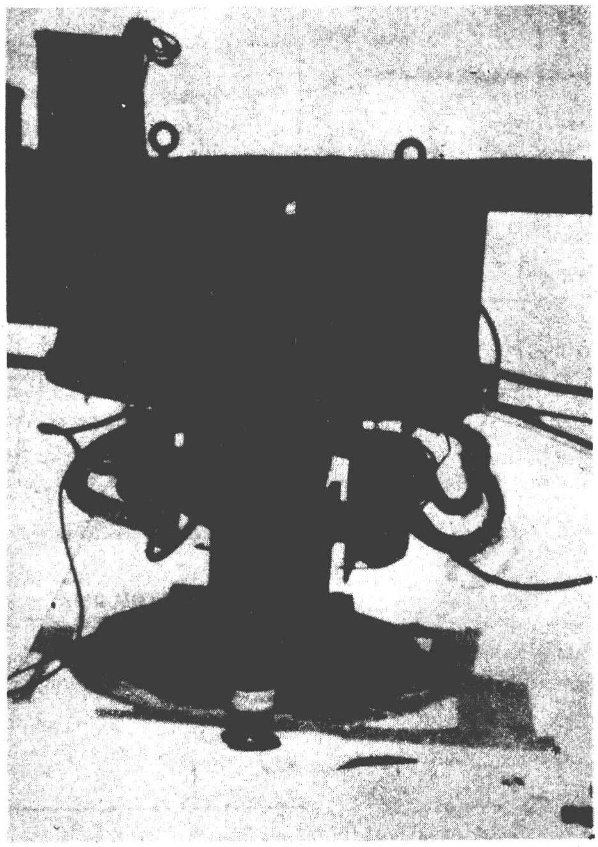


Figure 24 – Vibration input on roof of perimeter acquisition radar building

were interchanged; i.e., the vibrator was placed on the floor and the measurement made at the former drive point on the roof.

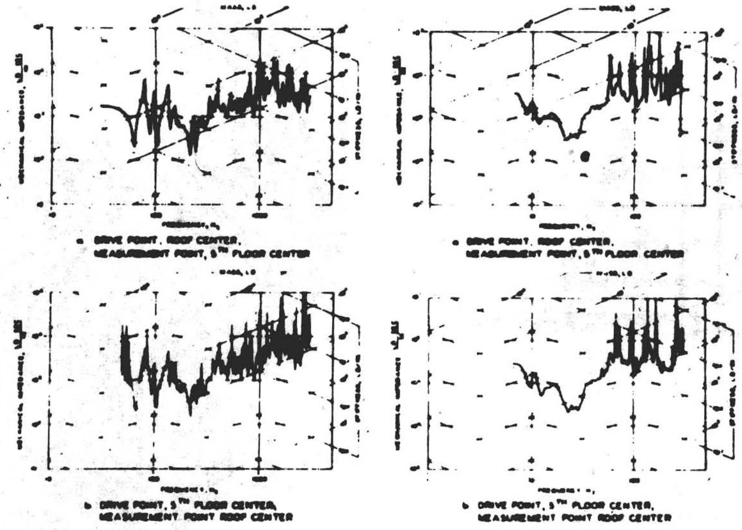
A comparison of records for such a situation shows that reciprocity does exist for both the model and prototype, (Figure 25). Thus, the transfer function could be obtained without placing the vibrators on the external walls of the prototype.

It was also shown that the transfer function for the model can be scaled to the prototype condition, see Figure 26.

By using these functions, it was possible to predict the acceleration response within the prototype structure at selected points for a variety of external airblast loads.

Equipment Fragility

During the same timeframe of the PAR prototype testing, a test series was conducted on the shock isolation platforms of the complete SAFEGUARD System. The areas of these rectangular platforms range from 15 sq ft to more than 3000 sq ft, and the isolated weight ranges from 1400 lb to 284,000 lb. Shown in Figure 27 is one of the typical large platforms with the shock isolators on the left. The shock



1/12 SCALE MODEL DATA
(30-LB DRIVER FORCE)

PROTOTYPE PARB DATA
(5000-LB DRIVER FORCE)

Figure 25 — Comparison of mechanical impedance records for scale model and prototype perimeter acquisition radar

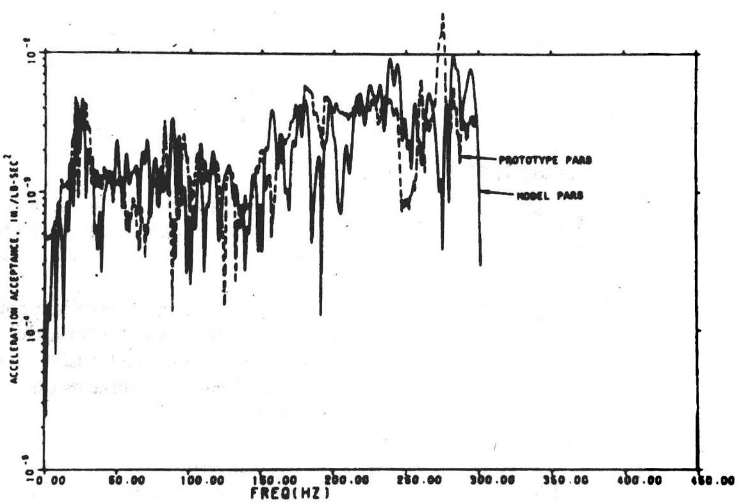


Figure 26 — Comparison between scale model and prototype perimeter acquisition radar building transfer functions

isolators were of a variety of types (undamped mechanical springs, friction damped mechanical springs and pneumatic).

The Waterways Experiment Station developed techniques for shock testing these platforms in-place under full operation. The test consisted of a high-frequency pulse train and a drop test. The pulse tests were at threat level in order to test electronic equipment to high-frequency inputs and the drop test was used to evaluate the rattle space design as well as the low frequency of response of the cable system.

The techniques developed were successful in applying threat magnitude motion to the platforms. Under the threat motions, none of the platform-mounted electronics failed to perform their function. We now have techniques that can be used to test an operational weapon system to the full threat loads.

Recently, we fabricated an inertial mass transportable vibrator that can be programmed to provide a constant force throughout a specific frequency range. Forces exceeding 50,000 pounds can be achieved through a limited portion of the overall frequency spectrum form 0 to 200 Hz. The dual moving masses have combined weight of 12,000 pounds and

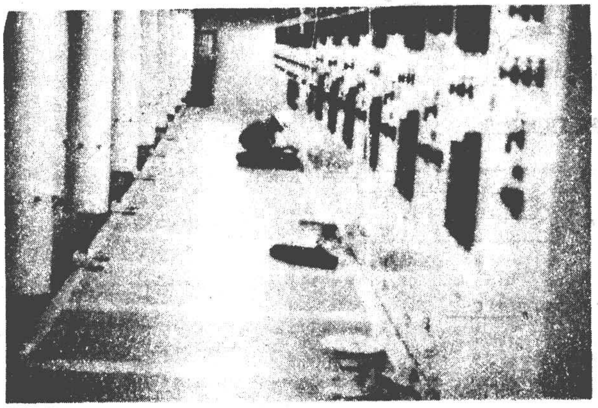


Figure 27 – Shock isolation platforms for SAFEGUARD system

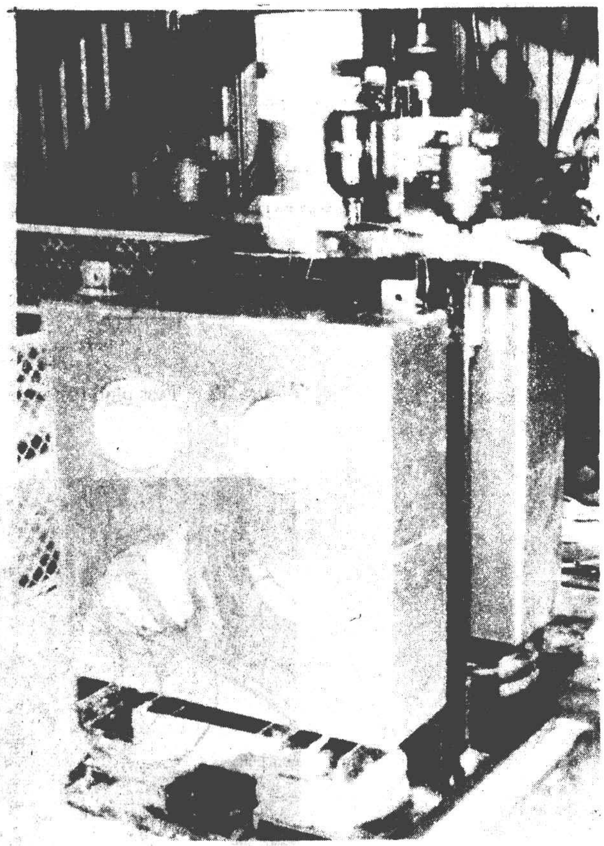


Figure 28 – Transportable vibrator for exciting large structures

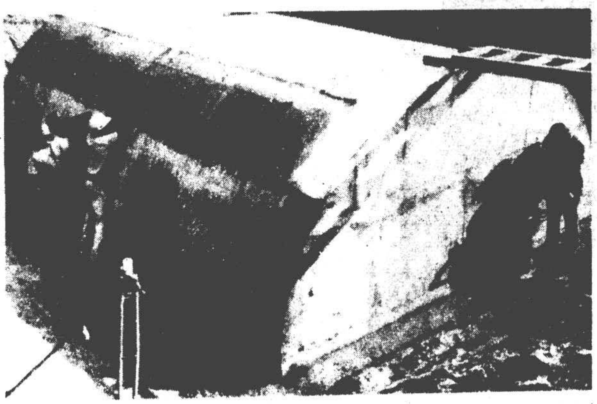


Figure 29 – Scale model reinforced concrete arch for underground command and control center

can be accelerated to approximately 5 g. Since the actuator is servo controlled, complex waveforms can be duplicated in addition to the more common sine wave forcing functions. In the inertial mass configuration, the vibrator system can be used to excite extremely large prototype or model structures so that a dynamic performance assessment can be made, see Figure 28. (It should be noted, however, that the actuator assembly is top mounted to facilitate removal for testing in the conventional reaction mass mode. In all cases, the system is hydraulically powered by a 70 gpm supercharged pump, supplied by approximately 250 amp, 440 volt, 3-phase electric power.)

Buried Structures

A model buried arch for use as a command and control center was recently subjected to the shock effects detonations simulating near misses of conventional bombs. A view of the arch before being covered with soil is shown in Figure 29. The test plan is shown in Figure 30. It was interesting to note that the vertical acceleration across the entire floor slab attenuated very slightly and no noticeable attenuation occurred for the horizontal acceleration across the floor indicating the structure moved as a rigid body. Procedures were developed for predicting the acceleration levels within the structures from free-field values predicted at the leading edge of the structure. The close-in charge, 21 pounds located 3 feet from the arch, caused a significant breach, see Figure 31.

Conclusions

In summary, we have used physical models, mathematical models, and vibration tests to determine the response of real systems to shock and vibratory loads. Such approaches using state of the art analytical and testing techniques have made it possible to solve difficult design problems as well as verify the capability of systems to function when subjected to transient forces resulting from earthquakes and turbulent water flow as well as shocks produced by the detonation of explosives.