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FIRING COMPLEX FOR EXPLOSIVE PULSED POWER*

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PURPOSE

A modern firing complex has been constructed for the dedicated development and application of explosive pulsed power (i.e., flux compression generators). The complex consists of three underground and interconnected buildings. The buildings, which employ several types of structural design, are engineered for above ground, open air detonations involving up to 1000 kg (TNT-equivalent) of high explosive. The explosive rating is necessary for the production of electrical pulses with energy content of hundreds of megajoules. Numerous examples of development efforts and applications are discussed throughout these proceedings by other Los Alamos colleagues.

LAYOUT

The conceptual arrangement of the complex is shown in Fig. 1. The complex consists of a central control bunker (AC 88), an adjoining bunker (AC 95) containing a multi-megajoule capacitor bank, and an underground bay (AC 97) designed to house a large recording trailer. A short stairwell connects the two bunkers. A walk-through tunnel connects the control bunker to the trailer bay. The photograph in Fig. 2 shows the exterior of the completed complex.

The floor plan for the complex is provided in Fig. 3. The firing table is located above ground and behind the two bunkers. Set-back distances from the rear of the bunkers are indicated for two charge sizes.

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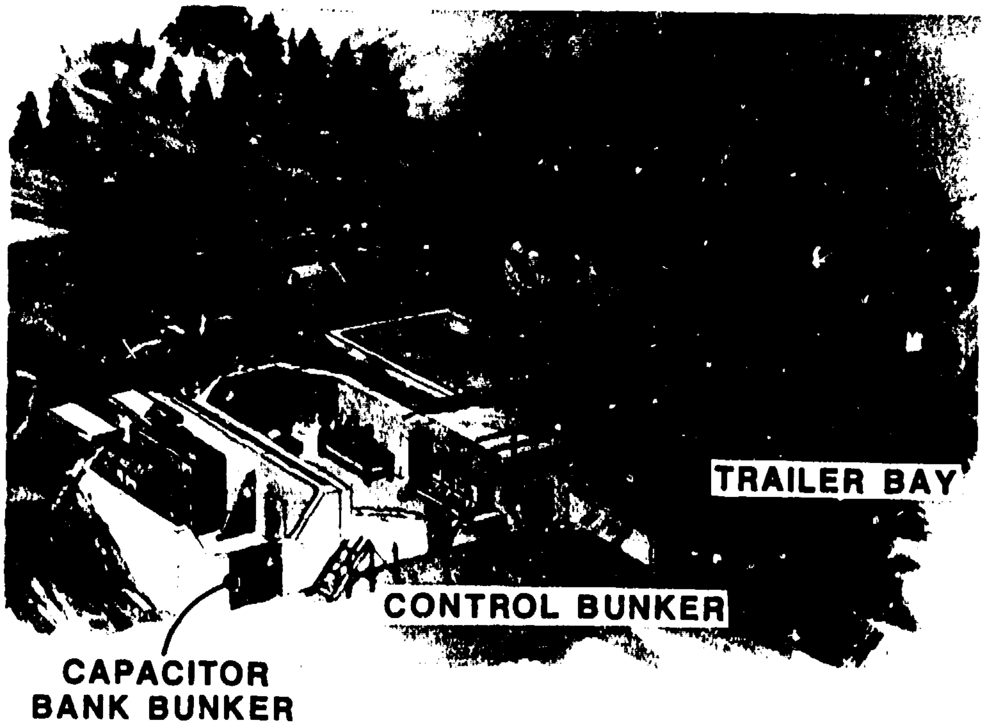

Figure 1. Concept.

Figure 2. Completed Explosive Pulsed Power Complex.

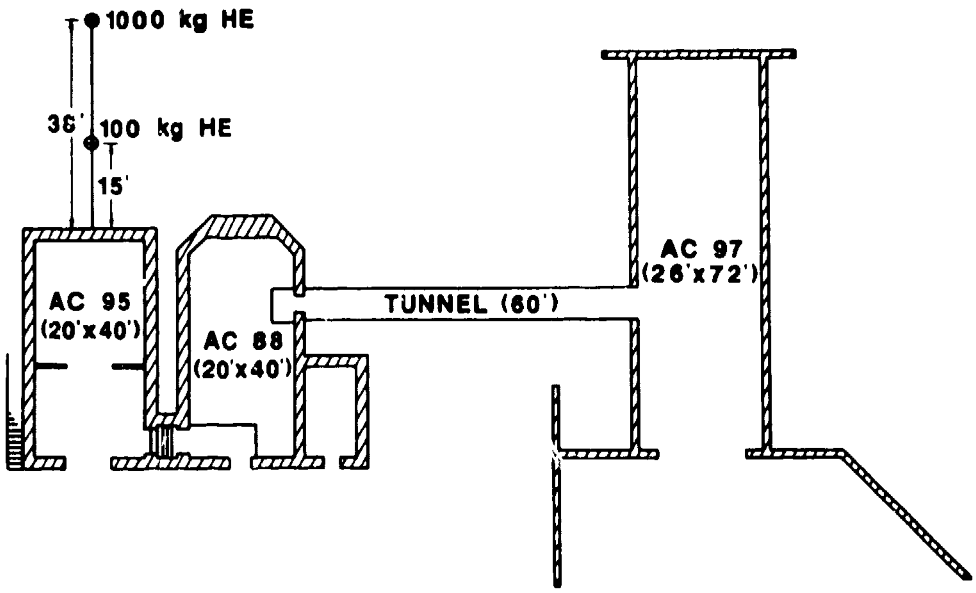

Figure 3. Floor Plan.

Control Bunker

The control bunker is used for facility control, data recording, and imaging diagnostics. Ceiling height is eight feet, less the thickness of a computer floor. The interior of the bunker, including control and recording racks, is shown in Fig. 4. The ceiling at the rear of this bunker contains eight 30-cm-diameter ports and ten 15-cm-diameter ports for viewing the firing table.

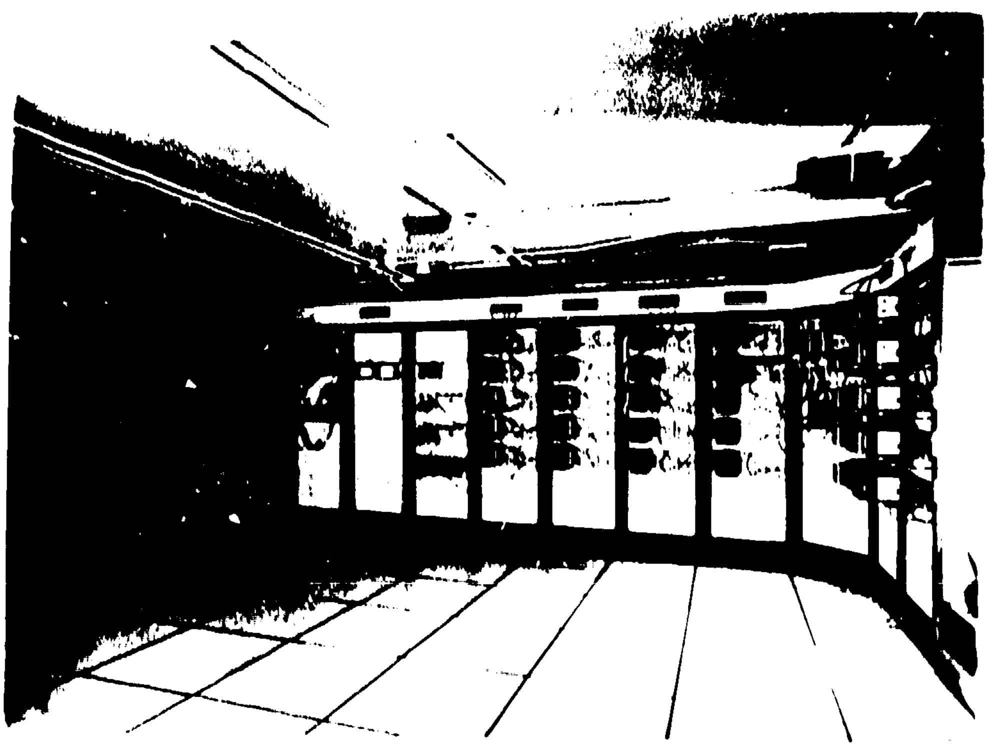

Figure 4. Interior of control bunker.

Capacitor Bank Bunker

This bunker is divided into two areas. The ceiling height is 12 feet. The front area is used for mechanical assembly. The rear, shown in Fig. 5, houses a modularized 2.4-MJ capacitor bank[1] for flux priming explosive generators. Electrical energy is transferred from the capacitor bank to the firing table by means of cable bundles which rise through rectangular ceiling penetrations.

Figure 5. High energy capacitor bank for flux priming of explosive generators.

Trailer Bay

The structure accommodates a recording trailer 62 feet long, 12 feet wide, and 14.5 feet high. A tractor backs the trailer into the bay through the large front door. The tractor is then removed and the door closed. Cooling the interior of the trailer is accomplished with portable air conditioning units. The units sit outside and are connected to the trailer via special ducts.

STRUCTURAL CONSIDERATIONS

Because of the close proximity of the firing table, the control and capacitor bank bunkers were designed as two-way reinforced concrete box structures buried on the back and sides, with minimum roof earth covers and exposed headwall fronts for access. An ultimate-strength-concrete section design was utilized that coupled plastic structural behavior from appropriately factored dynamic air blast, soil, and ground shock loadings and dynamic material strengths. The analysis and design of the various components of the box structures took into account the worst possible combinations of pulse peak pressure, reflected pressure, rise time, duration, and wave shape from the explosive at distances scaled from the firing line configurations. Design loadings were computed from direct blast pressures, blast-induced soil waves, and direct shock loadings for various points and forces on the structure. To assess dynamic behavior of the site soil and the resulting loading of the soil-structure interface, samples of the foundation soils and compacted backfill soils were tested dynamically at the New Mexico Engineering Research Institute. Wave velocities, dynamic soil loading and unloading moduli, and anticipated soil strengths were determined as a function of pressure. Test results from research at the U.S. Army Waterways Experiment Station[2] were used to assess the coupling effects of near surface air bursts with direct induced ground shock motions. Since the entire complex is in a relatively closed canyon, wall reflected loads were also reviewed.

The complexity of the steel reinforcing in the control bunker is shown in the left photograph of Fig. 6. The right view shows the structure after the concrete pour. Wall and ceiling thicknesses in these structures are typically two feet. The floors were poured over sand beds and are decoupled from the unitized wall-ceiling combinations.

Figure 6. Construction of control bunker.

After construction of the two bunkers, the capacitor bank bunker was instrumented with air pressure gages, strain gages, and accelerometers at various points on the structure and the blast doors. The structure was subjected to two explosive test shots. The first used a small quantity of explosive to verify instrumentation. The second employed about 225 kg of explosive positioned on the firing table to produce maximum design loading. The bunker responded within design expectations. The air pressure gages verified that the air blast loading was predicted by scaling laws.

The trailer bay, because of its greater distance from the firing table, employed a less expensive construction technique. The major feature in this structure is an earth mounded, super-span steel multiplate arch shape, with springline concrete beam stiffeners and integral steel-fiber concrete covering. As shown in Fig. 7, the arch is supported on concrete stem walls and continuous footings. The rear headwall is fully buried. The front headwall is exposed for access. Additional guidance for the design was obtained from a 12:1 scale model of the structure,[3] which was field tested to assess dynamic response. The front wall accommodates a power-operated sliding blast door suspended from a top rail. The door, which covers a 15′ × 16′ opening, is designed to seal flush to the outside face of the concrete wall at the head, sill, and jambs.

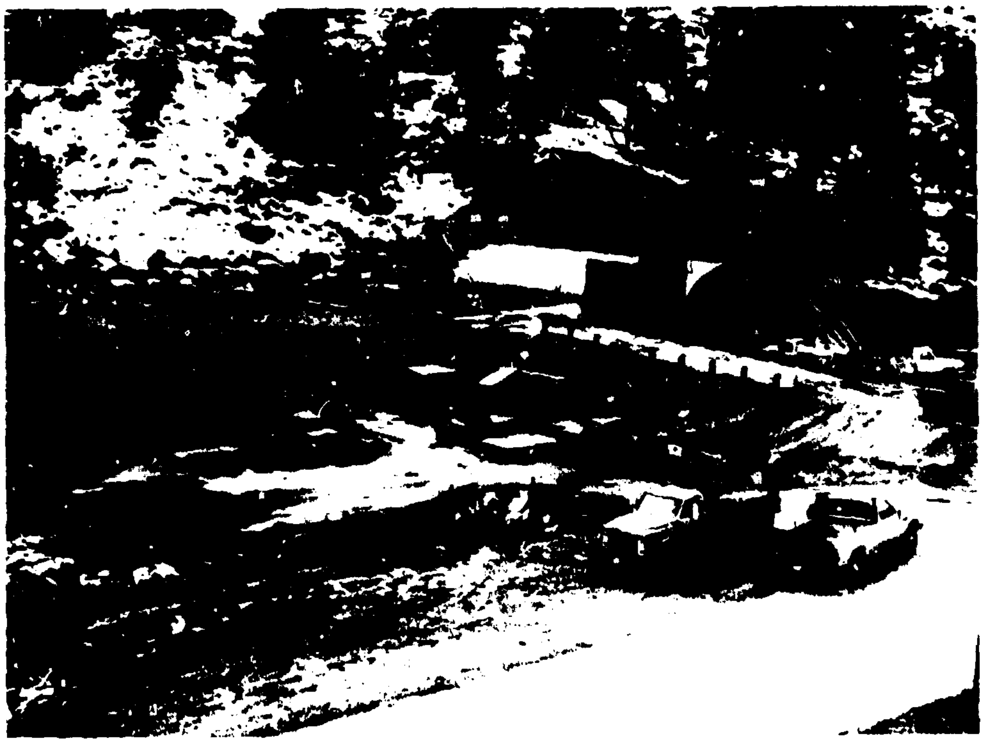

Figure 7. Construction of trailer bay after assembly of multiplate arch.

FACILITY CONTROL

Because, in practice, each explosive pulsed power experiment requires a unique combination of high voltage, high current, explosives and detonators, vacuum apparatus, data recording, and safety interlocks, it was felt that the ability to make quick changes based on operator judgments far out weighed the benefits of automatic controls. The control system, therefore, was designed and built with the intent that all operations would be controlled by skilled operators; there is no automated firing sequence. Thus it is the operator who controls when the flux priming bank and the capacitor discharge units (CDUs) for detonator firing are charged, when the diagnostic equipment is armed, and when the shot is fired. The operator also determines the appropriate response to unexpected events.

Another overriding consideration in the design of the control system concerned data integrity. Since equipment is distributed throughout the complex, much work has been done to assure avoidance of ground loops. All equipment is either electrically isolated from the experiment or is uniquely referenced to a single point ground on top of the control bunker. Electric power to the control system, diagnostic equipment, and recording instrumentation located in the control bunker passes through a 75-kVA isolation transformer, whose output is referenced to the single point ground.

Control of the experiment is handled from a single control panel.[1] The operator can control with this panel the safety interlocks, capacitor bank modules (see Table I and Fig. 5), and up to 10 independent CDUs, and can produce the trigger pulse which initiates the experiment. Door and barricade interlocks, warning lights, and warning siren are all connected to the control panel by fiber optic links. Fiber optic links with numeric readouts monitor CDU voltages and the high voltages/charging currents in the capacitor bank modules. Remote high voltage switching needed for operation of the CDUs and capacitor bank is done pneumatically. One or more of the CDUs are used to fire explosive closing switches which connect the capacitor bank to the experiment.

Table I. Capacitor Bank Specifications

	Per Independent Module	Per Four Modules
• Capacitors	24	96
• Capacitance	3 mF	12 mF
• Stored Energy @20 kV	600 kJ	2.4 MJ
• Inductance	65 nH	16 nH
• Resistance	1.5 mΩ	0.4 mΩ

Note: Uses constant current (2 A @ 20 kV) power supply with SCR control.

DATA RECORDING

Most of the data recorded in our experiments are produced by standard power flow diagnostics (B-dot probes, Rogowski loops, Faraday rotation probes,[4] and voltage dividers) and assorted imaging devices. Electrical signals from the experiment travel in a bundle through a single ceiling port in the control bunker and are routed to appropriate recording devices. The base instrumentation employed in the control bunker is listed in Table II and shown in Fig. 2.

The digital equipment listed in Table II are controlled by a Digital Equipment Corporation VAX 730 computer. The computer is used to initialize, arm, monitor, and collect data from the instruments. The computer has both CAMAC and GPIB interfaces for communicating with the instruments. All connections linking the computer to instrument interfaces, terminals, and other remote computers are made with fiber optics.

ACKNOWLEDGEMENTS

We are grateful to T. Crawford, R. Dewitt, B. Todd, and O. Reed of our Laboratory's Analysis and Testing Group for their measurements of structural response.

Table II. Base Recording Instrumentation

	Type	Quantity	Specifications
ANALOG	Oscilloscope	20	Bandwidth - 1.2 GHz
	Oscilloscope	10	Bandwidth - 640 MHz
DIGITAL	Time Interval Meter	5	Channels - 8 per meter
			Dynamic Range - 24 bit
			Resolution - 1 ns
			Accuracy - ±0.5 ns
	Time Interval Meter	1	Range - ±10 s
			Resolution - 100 ps
	Waveform Recorders	6	Analog Bandwidth - 70 MHz
			Sample Rate - 2×10^8 s^{-1}
			Voltage Resolution - 8 bits
			Memory - <64,000 points
	Waveform Recorders	6	Channels - 2 per recorder
			Analog Bandwidth - 70 MHz
			Sample Rate - 2×10^8 s^{-1}
			Voltage Resolution - 8 bits
			Memory - 2048 points
IMAGING	Electronic Camera	1	Number Frames - 8
			Frame time - 10 ns (min)
			Streak rate - 1 mm/ns (max)
	Rotating-Mirror Cameras	1	Number Frames - 25
			Frame time - 1 μs (min)
		1	Streak rate - 20 mm/μs (max)
	Pulsed X-Ray Sources	2	Energy - 480 keV
			Resolution - 10 ns

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