

# Structure Response to Open Air Explosions

## Socorro, NM

Two structures located at the Socorro General Hospital, Socorro, NM were instrumented to measure the effects of air overpressure in the absence of ground vibrations generated by open air explosions conducted on a daily basis by EMRTC (Energetic Materials Research and Testing Center). EMRTC is a research division of at New Mexico Institute of Mining and Technology and routinely performs open-air detonations at its 40 square mile field testing laboratory.

Explosive charge weights detonated during testing at EMRTC have increased over the recent years. Although these charge weights and resulting scaled distances to structures within the community of Socorro are well within the safe limits that are protective of structures, some community residents may perceive air overpressures from field tests as potentially damaging to their homes

Figure 1 presents a satellite image of the test range showing the location of the instrumented structures and locations of the blast sites. Car bomb sites 1 and 2 are used during counter-terrorist training with ANFO charge weights ranging from 50 to 2,500 lbs. Diamond blasts are for commercial production and use 9000 lbs of ANFO. Distances from test sites to the instrumented structures range from 15,000 ft to 25,000 ft (2.8 to 4.7 miles).

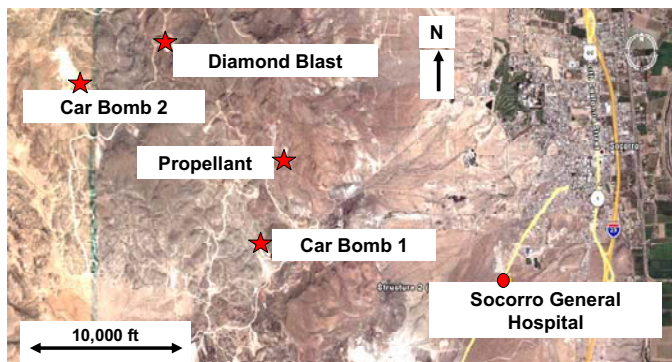


Fig. 1 Location of instrumented structure and test sites.

Instrumentation placed on the two structures shown in Figure 2 were designed to record and compare whole structure and mid-wall displacements during dynamic loading from blasts, thunder, wind, and helicopter operations. The steel frame Hospital is 14 ft in height with a stucco exterior and slab foundation. The Surgery Office is a manufactured structure resting on unmortared CMU piers. One corner of each structure was instrumented with single-axis velocity sensors at the roof and foundation to measure whole or gross structure displacements and compute in-plane tensile and bending wall strains. Mid-wall sensors were affixed to the adjoining walls to measure mid-wall bending



Fig. 2 Socorro General Hospital (left) and Surgery Office (right)

displacements. Blasting seismographs, recording air overpressures and structure motions were connected in series, producing time-correlated measurements.

An existing candidate crack was instrumented to compare displacements during long-term environmental (static) effects of weather with crack width changes during dynamic events. A 0.16-in. (4 mm) wide diagonal structural crack at a lower left window corner at the Hospital was employed. Two Kaman® eddy-current displacement gages, shown in Figure 3, were used to record crack movement and movement on an uncracked wall section. A high-capacity gage was employed for the large environmentally-induced crack movements (0.47 in. or 12 mm displacement range). The small sensor mounted on uncracked stucco was designed to measure up to 0.04 in. (1 mm) of wall movement. The gage data recorded was connected in series with the seismographs to record time-correlated dynamic crack and wall motions when the air pressures sensor triggered. Dynamic measurements were recorded at 1000 samples/sec while static wall and crack displacements were sampled every hour. Wind speed, wind, direction, temperature and humidity were recorded every 5 to 10 min.

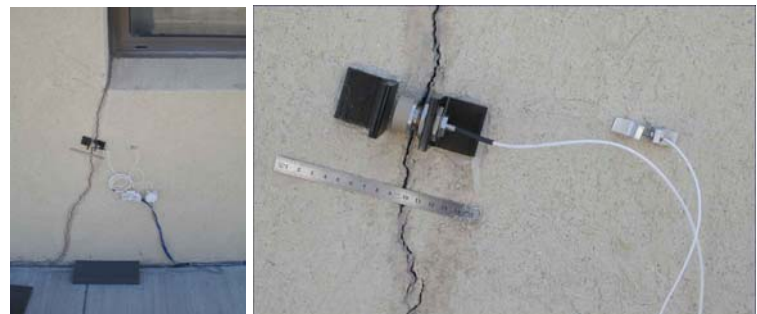


Fig. 3 Instrumented crack at Socorro General Hospital

## Results

A total of 114 blasts triggered the instrument system over an eight-month period. The highest air overpressures recorded at the structures was 0.009 psi (airblast of 131 dB). Peak frequencies associated with pressure-time histories were 4 to 20 Hz for car bomb blasts and 2 to 7 for diamond shots.

Figure 4 shows a typical structure response to a 9000-lb open air explosion (diamond shot). These plots compare crack motion (top) and air pressure time history (second row) with mid-wall (MW) (third row) and upper structure (S2) (bottom) displacement time histories. Upper structure motions

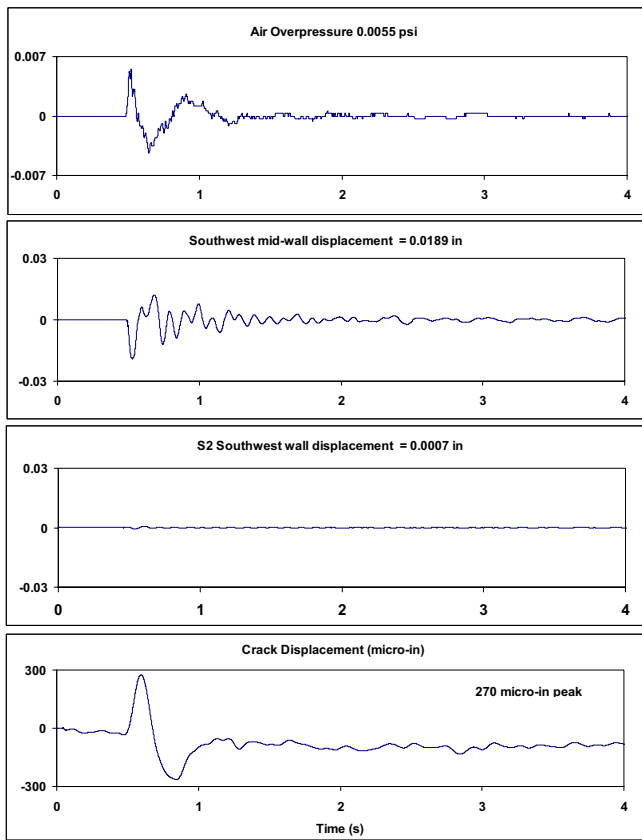


Fig. 4 Southwest upper structure (S2), mid-wall, and crack response for a 0.0055 psi peak air overpressure diamond blast, Structure 1.

are insignificant compared with those in the mid-wall. In the absence of ground vibrations, air pressures affect mid-walls while racking motions that generate in-plane wall strains are minimal. A similar plot is shown in Figure 5 for Structure 2 to show the same effects on a manufactured structure.

In-plane and bending strains were computed from displacement time histories. The following summary demonstrates that small whole structure motions can not contribute to cracking potential in walls:

Structure	Tensile strain	Bending strain
	(micro-strain)	(micro-strain)
1	2.4	22.4
2	4.8	42.0

Bending strains were 8 to 10 times greater than in-plane strains. The failure strains for stucco and drywall are approximately 1000 and 300 micro-strains, respectively. Therefore it is not possible that the air pressures generated from open-air explosives at EMRTC could contribute to cracking in these structures.

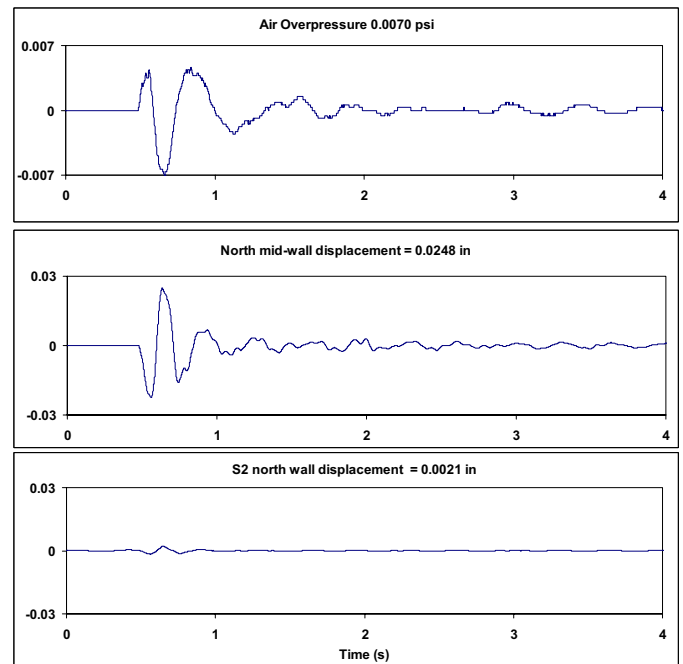


Fig. 5 North upper structure (S2) and mid-wall response for a 0.0070 psi peak air overpressure diamond blast, Structure 2

Long-term weather-induced crack width changes over a 6.5-day period are shown in Figure 6 along with changes in temperature and humidity. Typically when the temperature drops at night and humidity increases, the crack opens (positive crack width change). In the morning as temperature increases to mid-day, the humidity decreases and the crack closes (negative width change). Past studies have indicated that changes in crack width are more sensitive to changes in ambient temperature than to humidity variation. This is most likely because thermal expansion and contraction of construction materials take place rapidly compared with the uptake of moisture in the same materials. The influence of ambient humidity results in a lag in time before corresponding changes in crack width can be measured. Often the temperature decreases and increases during rain and dry periods, respectively, overshadow the effects of humidity alone. Furthermore, it is rare that humidity effects may be measured during times of constant temperature whereas it is common that the effects of temperature fluctuations may be measured during relatively constant humidity.

Figure 7 is a plot over an 8-day period that includes the largest 12-hour width change over the project duration. This change represents a 206,705 micro-inch (0.207 in) day-to-night closing that occurred during a typical fall day in the southwest desert. The overall change in crack width for the entire project was 248,578 micro-in or 0.25 in. Weather-induced crack displacements are 766 to 921 times greater than the largest blast-induced dynamic event registered for the diamond blast (270 micro-in).

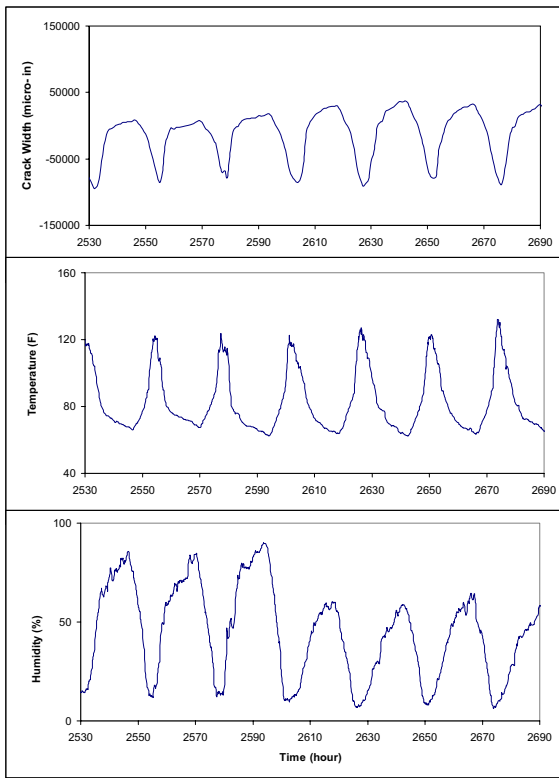


Fig. 6 Variations in crack width (top) with temperature (middle) and humidity (bottom) over 6.5 days

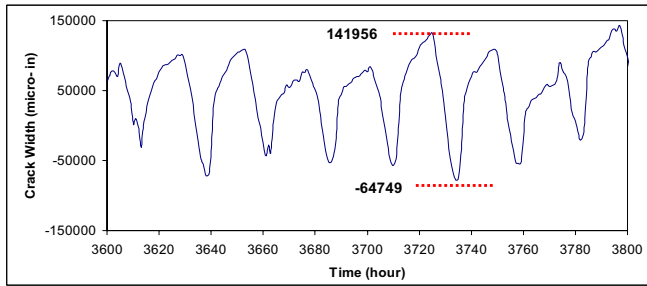


Fig. 7 Largest 12-hour crack width change of 206705 micro-inch (0.207 in)

Figure 8 is a 48-hour window of crack movement over which time the diamond blast producing the largest crack displacement occurred. Plotting the dynamic event on the same scale as the static, weather-induced opening and closing renders the blast as a small “dot” (shown in red). This comparison emphasizes how insignificant the influence of blasting is on an existing crack to induce strains at the crack tips relative to the strain imposed by normal and expected variations in temperature and humidity.

Non-blasting event time histories are compared in Figure 9 through 11 for 30 mph wind gusts, thunder, and the rotors of a helicopter taking off from the Hospital helipad adjacent to the southwest wall, respectively. Of these events, the sustained wind gusts produced 413 micro-in of crack displacement (sustained opening) that was 1.5 times greater than the largest blast. It is often the case that wind gusts of 80

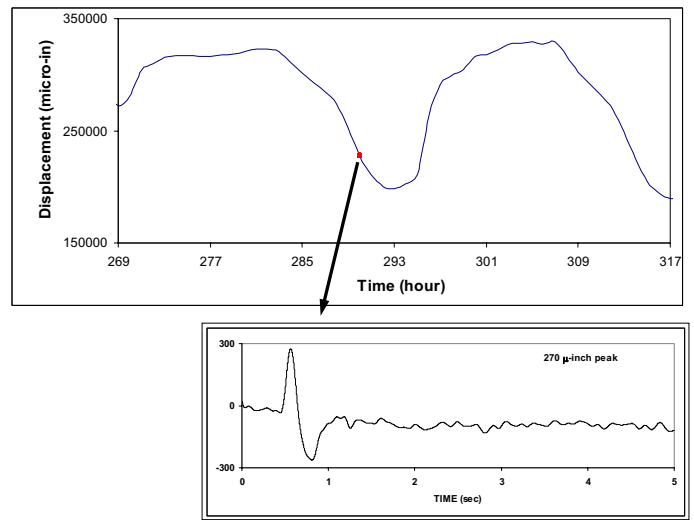


Fig. 8 Comparison of static crack displacement with largest blast-induced dynamic crack motion (red “dot” in real-time and amplitude scale, top) and enlarged amplitude and time scaled (bottom)

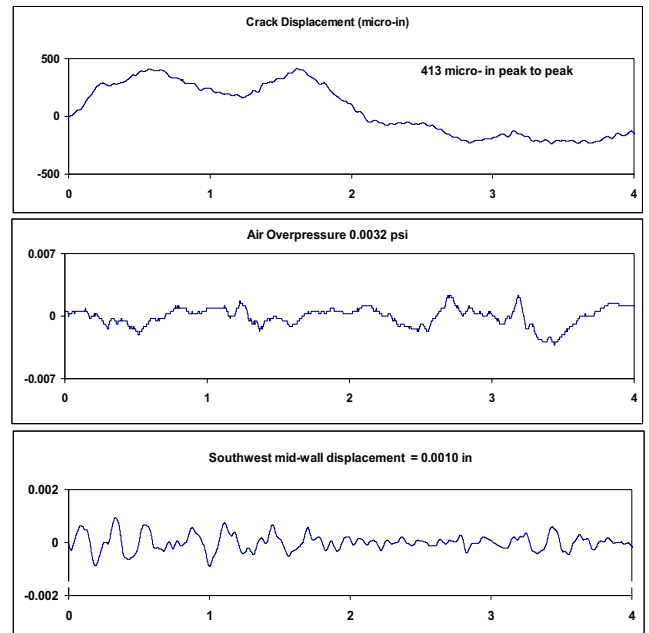


Fig. 9 Wind gust events of 30 mph producing 413 micro-in crack displacement (top), 0.0032 psi peak air pressure (middle) and mid-wall response of Structure 1 (bottom)

mph are common in the Socorro area, possibly creating structure mid-wall displacements far greater in magnitude.

High-frequency thunder produced the largest mid-wall peak displacement while the crack motions exhibited a lower-frequency response with a peak of 45 micro-in. The air over pressure was 0.0017 psi.

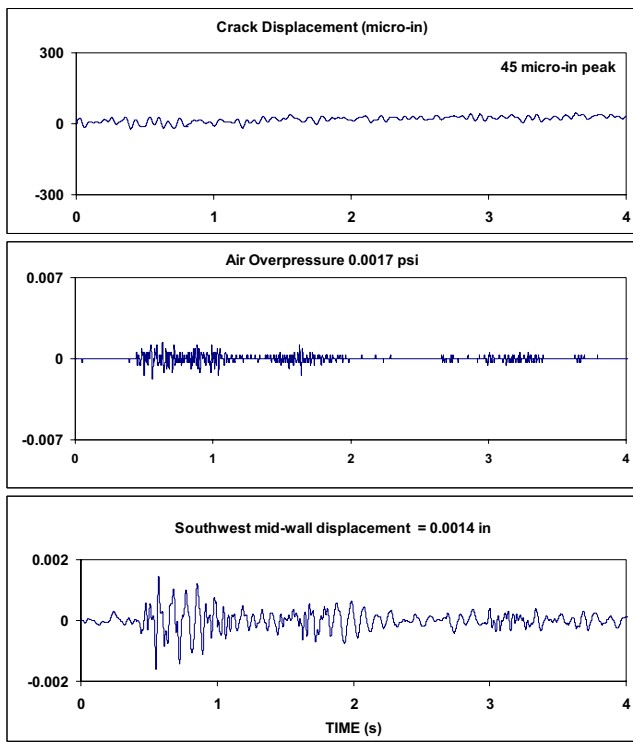


Fig. 10 Thunder event producing 46 micro-in crack displacement (top), 0.0017 psi peak air pressure (middle) and mid-wall response of Structure 1 (bottom)

The departure of a helicopter generated high-frequency crack displacement oscillations in which the crack base-line increased in time with sustained air pressure. The peak pressure was 0.0017 psi, similar to thunder. The overall net effect was a crack opening of 175 micro-in.

### Findings

The largest blast-induced crack width change is compared below with other non-blasting dynamic events and weather-induced static displacements. This is further illustrated by the histograms of Figure 12 in which relative peak crack displacements for all events are compared. The findings of this study verify that the effects of blasting at EMRTC on instrumented structure wall motions are insignificant compared with wind-induced and weather-induced wall displacements.

Influence	Peak Crack (micro-in)
Blast	270
Temperature/ Humidity	248,578 (long) 206,705 (12 hour)
Wind	413
Thunder	43
Helicopter	175

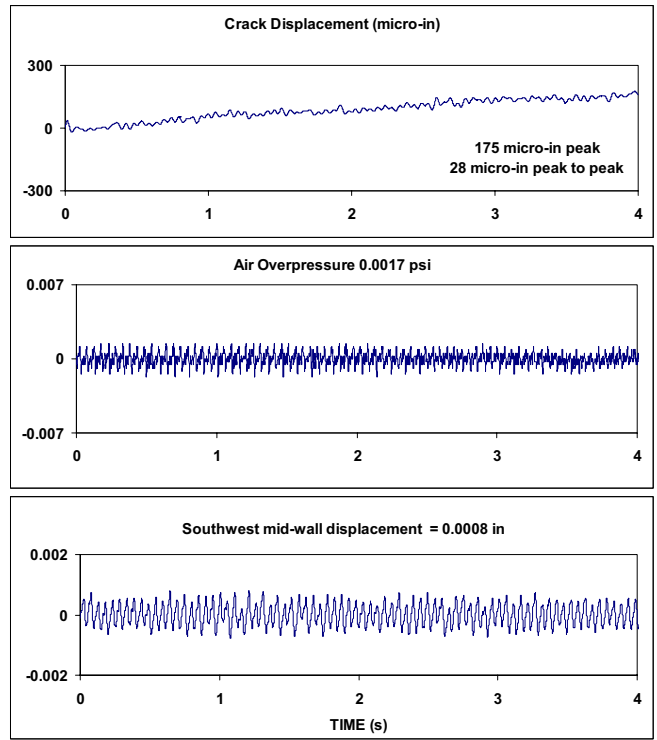


Fig. 11 Departure of a helicopter producing 175 micro-in crack displacement (top), 0.0017 psi peak air pressure (middle) and mid-wall response of Structure 1 (bottom)

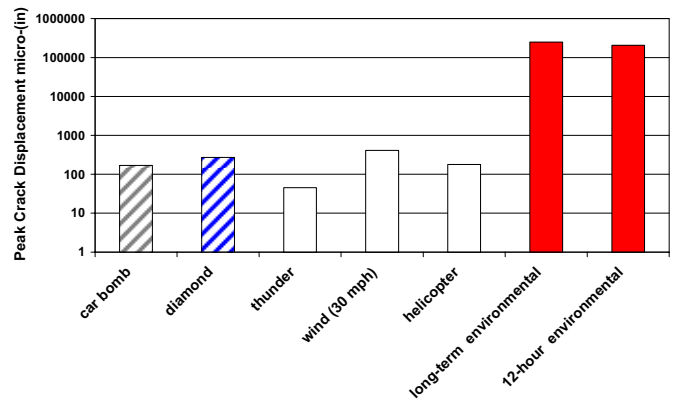


Fig. 12 Relative peak crack width changes for blasting and non-blasting influences on Structure 1 wall

Hence, open-air blasts near the City of Socorro cannot possibly contribute to structure cracking given the current distances to structures and charge weights used in testing.

### Acknowledgements

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