# <u>CASE STUDY</u>

## <u>RELATING BLAST EFFECTS TESTS</u>

## TO THE

## EVENTS OF APRIL 19, 1995
## ALFRED P. MURRAH FEDERAL BUILDING
## OKLAHOMA CITY, OKLAHOMA

**UTILIZING:**

**TEST RESULTS FROM:**
**ARMAMENT DIRECTORATE**
**WRIGHT LABORATORY**
**EGLIN AIR FORCE BASE**

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**JANUARY 22, 1997**

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# INTRODUCTION

This study has been undertaken and this report has been prepared in order to develop parametric data for use in analyzing the event of April 19, 1995 in which the Alfred P. Murrah Federal Building was destroyed by a terrorist attack utilizing explosive compounds.

Due to a limited amount of information in the public domain regarding blast effects against structures, a study was undertaken in which photographic data combined with known test parameters was analyzed to provide baseline data for estimating the effectiveness of explosive devices against reinforced concrete structures. The maximum potential blast pressure is used as the determinate factor in establishing resistance to blast and overall blast effect.

A study was conducted to map the pressure regions on a vertical face wall of a reinforced concrete test structure to provide baseline data. Data for the study was obtained from General Benton K. Partin, USAF (Ret). This information was supplied to him at his request by the Armament Directorate, Wright Laboratory, Eglin Air Force Base, Florida. A copy of this memorandum can be found in Appendix B.

Utilizing data from this study various conclusions can be drawn about the nature and components of the event of April 19, 1995 at the Murrah Federal Building.

This report is limited in scope to providing basic data and furnishing certain limited conclusions about the events in Oklahoma City and is being produced as part of a larger more detailed study of the events which occurred there.

# TEST STRUCTURE CONSTRUCTION

The test structure constructed at Eglin Air Force Base while not as large as the Alfred P. Murrah Federal Building in Oklahoma City has many similarities and therefore provides an excellent source for data.

The Eglin Test Structure (ETS) was constructed of reinforced concrete and had a footprint of 80 feet in length and 40 feet in width. The ETS was comprised of

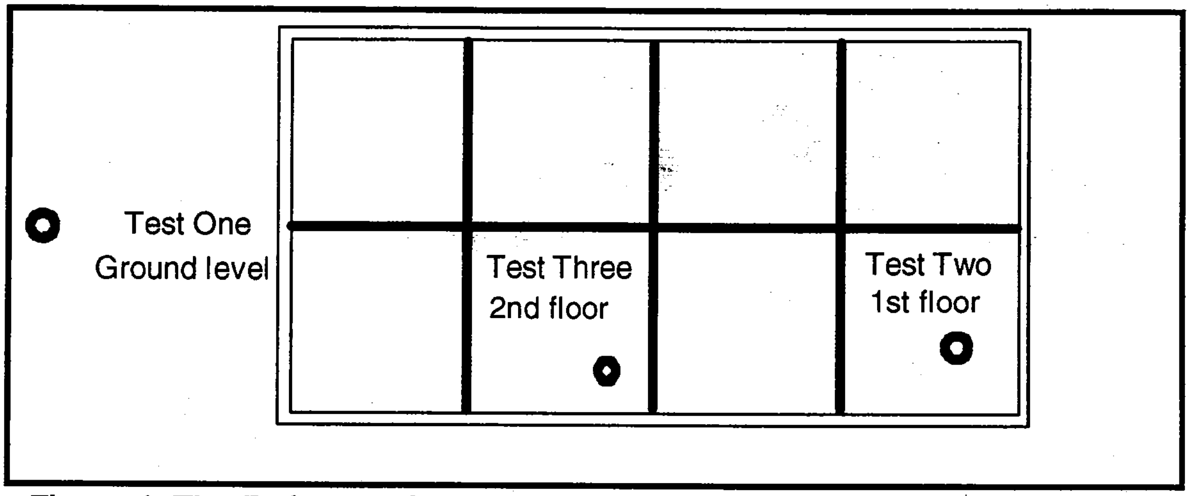


**Figure 1 The Eglin Test Structure layout**

three stories with a total height of 30 feet. The ETS is similar to Murrah in its basic layout with three rows of columns in the long axis and a series of narrow bays in the shorter axis. The ETS was constructed of six inch thick concrete panels similar to the six inch thick floor panels of Murrah. In addition a series of 14 inch square columns supported the panels in the corners of each room and at the edge of the floor panels. This configuration bears a similarity to the Murrah buildings system of columns, T-beams and floor panels.

The ETS does not appear to have the extensive series of piers that the Murrah Building had for its' foundation. The ETS appears to be built on a spread footing which would be consistent with the design in the area of Eglin Air Force Base. The walls and columns are monolithically poured one story at a time. On top of the column the next floor and edge beam combination is formed then poured and then the next story is formed and poured on top of this. The building appears to have several cold joints in the walls thereby producing a structure that has diminished strength. The normal concrete strength utilized in this type of construction and in this area of the country is 3,000 psi. The Murrah building was constructed with 4,000 psi concrete and it would be reasonable to expect that the Murrah building concrete would have tested in the area of 4,500 psi or above on April 19, 1995.

Steel reinforcement for the ETS is provided by a single layer of #4 (1/2") rebar placed 18 inches on center in the wall and floor panels and the columns which are 14 inches square appear to have two #4 rebar vertical reinforcing bars. The reinforcement in the Murrah Federal building by contrast was much greater, with approximately five times the amount of steel in a typical floor panel. Typical reinforced would call for two layers of #5 rebar with a spacing of nine inches.

The ETS while similar to Murrah must be considered an inferior structure in terms of strength and blast resistance, however direct application of the data will be used to estimate probable damage to the Murrah Federal Building even though the Murrah Federal Building should be expected to provide significantly more blast resistance than the ETS.

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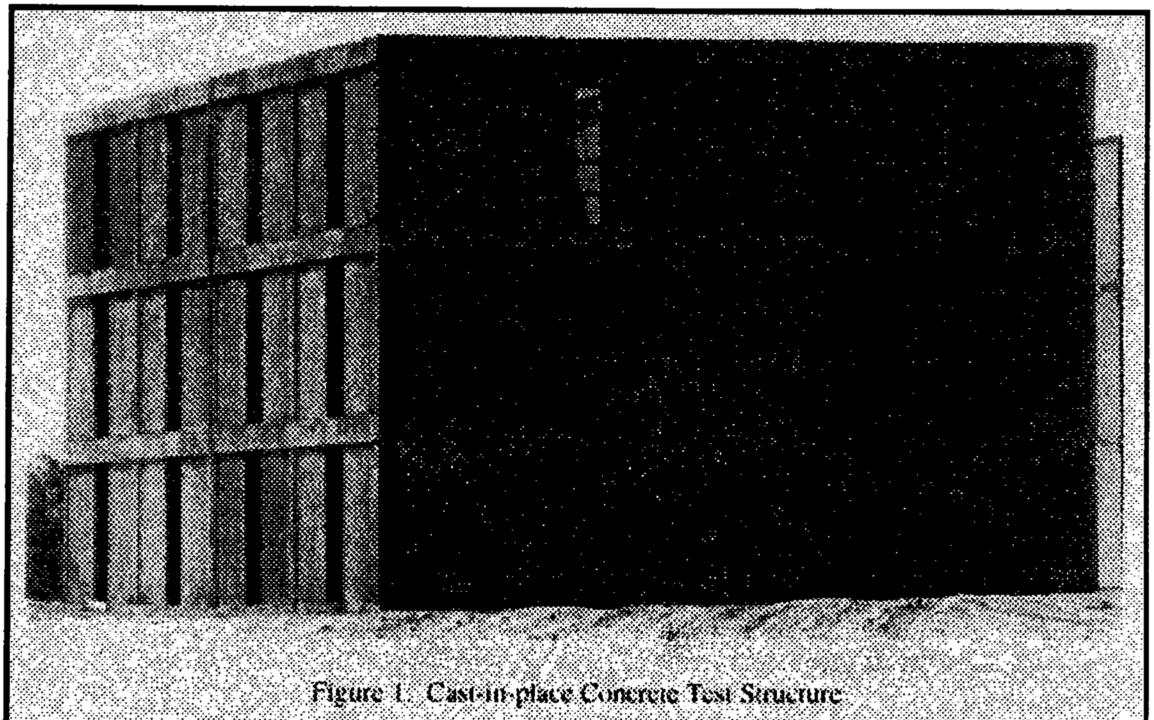

Figure 1. Cast-in-place Concrete Test Structure

**Figure 2 Eglin Test Structure prior to Blast Effect Testing**

The ETS while having a slab on grade and a second floor 10 feet above the first and the third 10 feet above the second was not constructed with a roof panel as can be seen in the photo of the structure. This lack of roof panel it should be noted reduces the overall rigidity of the structure and in particular the third story wall panels making the third story more susceptible to damage from an explosive device.

While no age for the ETS is given, it is known that this is a purpose built test structure and all indications are that the testing was conducted soon after the structure was completed thereby ruling out additional strength development by the concrete as a function of time. This process is normal to concrete as the strength ratings for concrete are for 28 day cures. Concrete while attaining the specified strength in 28 days will continue to increase in strength over time as a natural process.

In general it can be noted that the ETS exhibits some minor flaws in construction but it can be generally assumed to have been constructed correctly due to the general appearance as shown in the photos. The reinforcement however is not up to industry standards as a general rule for structural purposes. This structure is actually more indicative of some structures to be found in third world countries and is not representative of concrete structures to be found in the United States.

# THE BLAST EFFECT TEST SERIES

The United States Air Force conducted a series of live fire tests on the ETS in order to demonstrate-determine the efficacy of various weapon systems components and explosives. Three different explosives tests were conducted on the ETS.

The first test used 704 lbs. of Tritonal which is equivalent to 830 lbs. of TNT or roughly 2,200 lbs. of properly prepared Ammonium Nitrate and Fuel Oil mixture. Because this test most closely parallels the Truck bomb at the Murrah Building this test will be of particular interest to this report. The device was placed 25 feet from the vertical surface of the 40 foot side wall of the ETS. It was encased in a light aluminum case thereby closely duplicating the lightweight enclosure of the device used on the Murrah Federal Building. This is important because the Murrah device was composed of ammonium nitrate - fuel oil contained in blue plastic drums in the back of the Ryder truck, which either was constructed of aluminum skin or of plastic laminate on the cargo body itself. This is in contrast to the other devices in the testing which had heavy casings around the explosive. The heavy casings while providing shrapnel which then causes damage, consume a lot of the energy of the explosive in order to break up the casing itself. This energy consumption is manifested in a reduced peak blast pressure in the shock wave which emanates from the explosion. It is a tradeoff in which a denser mass (bomb casing) is accelerated and causes damage by colliding with the target. This effect will be described in looking at test two and three.

The second test used a standard Mk-82 warhead placed inside the structure on the first floor approximately four feet from the exterior wall. The Mk-82 is a heavy cased weapon designed to hit its' target and provide damage from the case fragmenting and becoming shrapnel when the explosive is detonated as well the damage provided from the resultant shock wave which follows the shrapnel. The casing provides close in mechanical coupling of the blast energy which is always preferable to attempting to destroy a target with an air coupled blast wave. Figure three provided by Wright Laboratory shows a large area of catastrophic structural failure resultant from the target being damaged by first the shrapnel and then in a weakened condition the blast wave which follows. This is a good example of what direct mechanical coupling of explosive energy can produce in terms of damage when contrasted with damage produced from air coupled blast waves alone.

Analysis of the photograph (figure 3) of the post-test structure shows nearly complete destruction of the wall panel and column from the first floor, This is due to damage caused by the shrapnel effect of the bomb casing striking the structure at high velocities and causing the concrete to shatter from the impact. Blast wave effect upon the column would be negligible while the overpressure

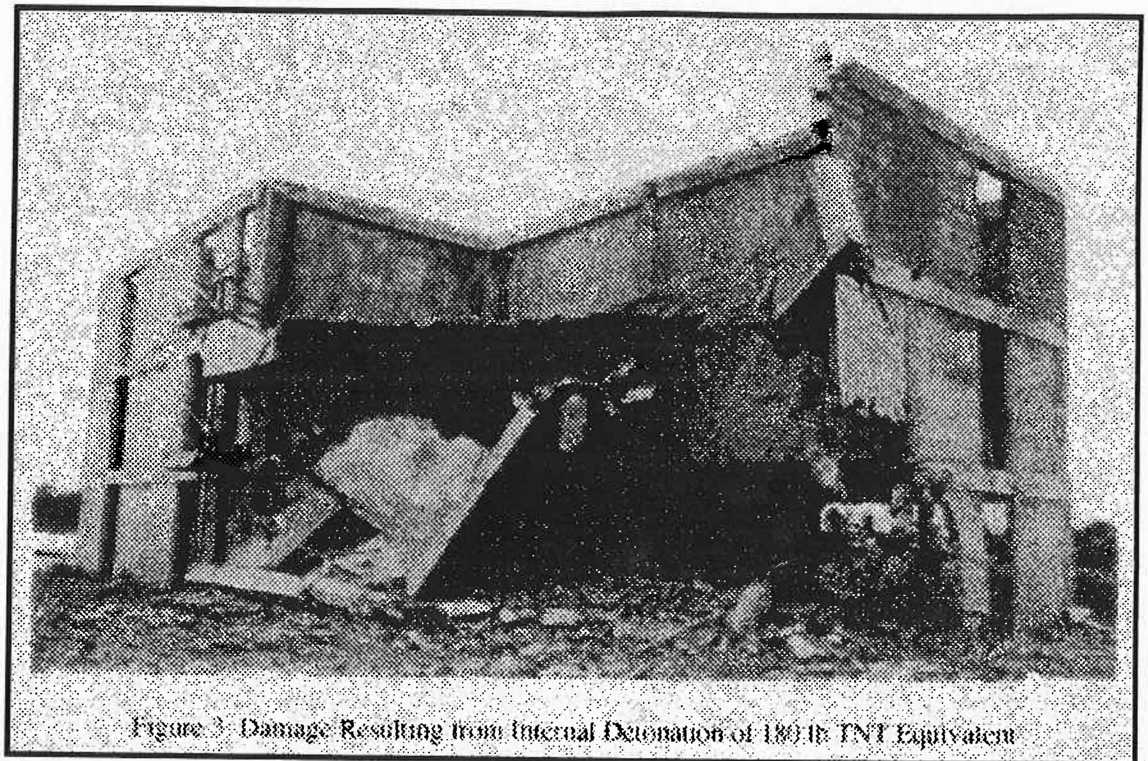


**Figure 3 Mk-82 Warhead test result**

generated from the explosion of the device placed internally would exceed the limits of the six inch panel. However due to the light reinforcement, peripheral damage caused by loads induced from the panel deflections would be highly improbable due to insufficient reinforcing steel to carry the loads before complete break-up of the panel. While the second floor panel had direct pressure damage, the third floor panel is indicative of gravity induced failure caused by the direct damage to the wall panel, column, and second floor panel from the Mk-82 warhead on the first floor.

The third test involved a 250 lb. class penetrating type warhead with an explosive charge equivalent to 35 lbs. of TNT. Once again as can be seen in the image in Figure three as supplied by Wright Laboratory, the damage caused by even a small amount of explosive when mechanically coupled to the target can be considerable. In this case the Mk-82 device was placed on the second floor in an outside corner approximately 2.5 feet from the walls. As in the case of the Mk-82 warhead, considerable damage is actually produced by the shrapnel effect of the casing of the device itself. It should also be noted that the second test involving the Mk-82 warhead was conducted adjacent to this area. The second test occurred to the right of the third test are as shown in the photograph.

Two things should be noted from the photo. The first item is that the area was cleaned and the remaining second and third floor panels were removed prior to the third test. A visual reference can be seen in the ladder from the Figure four photograph, this ladder can be seen just to the left of the damaged area in figure three. The generally smooth appearance of the third floor support beam in Figure four indicates that the structure was constructed with cold joints in certain areas and is not truly monolithic in terms of floor construction. This condition reduces the stiffness of the structure as well as its total strength. The second item is some of the damage shown in Figure four, particularly in the case of the first floor wall panel must be attributed to the second test and not the third. This damage also provides the third test with a locally weakened structure so as to effectively produce somewhat more damage than would be effected by the same explosive device on an undamaged structure.

Figure four also provides an excellent example of erosion damage caused by the bomb casing. The second floor column in the blast area shows a definite pattern of damage caused by the bomb case fragments impacting and shattering the concrete. This is manifested by the irregular pattern on the edges as can be seen in the photograph. Also bare rebar can be seen in the third floor beam just to the left of the column where this type of damage has occurred. This shows the pattern of damage in which concrete is damaged by debris and then carried away in the trailing shock wave.

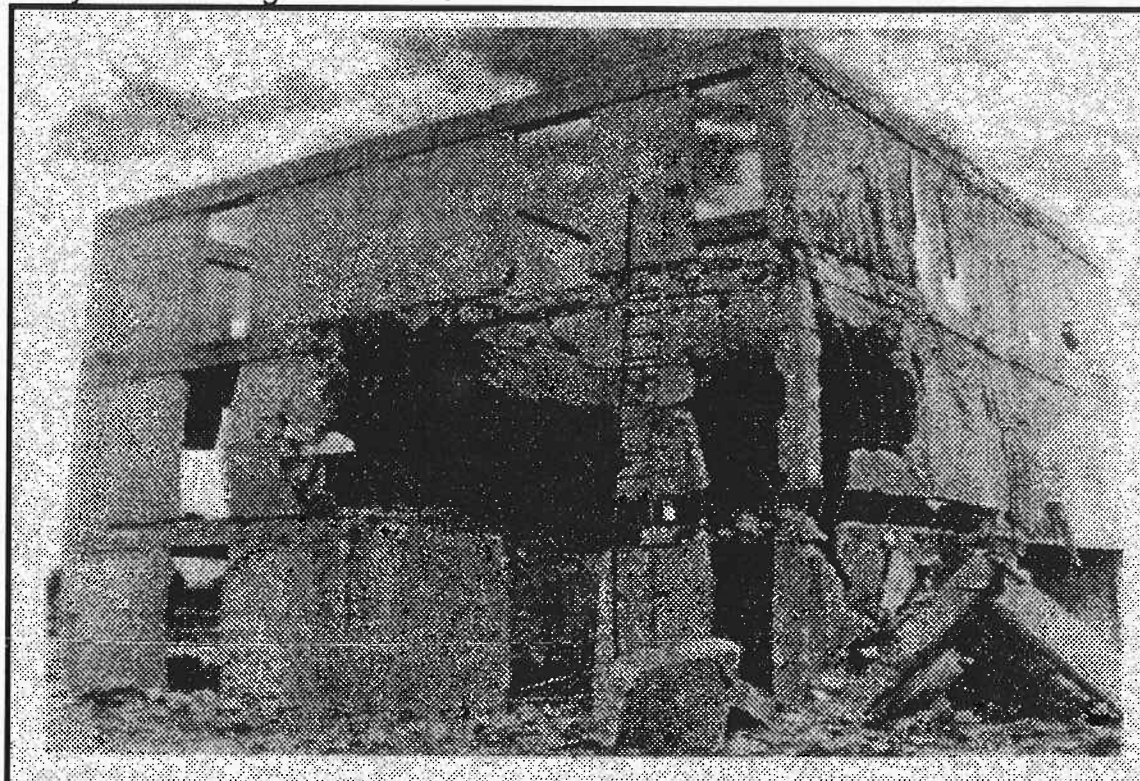

Figure 4: Damage Resulting from Internal Detonation of 35 lb TNT Equivalent

**Figure 4 250 lb. Penetrating warhead test result**

This photograph also reveals the inherent toughness of concrete, in that much of the structure is remaining even after significant damage caused by the third test.

It should be noted that both the Mk-82 and the 250 lb. penetrator are designed for gravity drop from aircraft and not for static deployment as was the case in these series of tests on the ETS.

The first test is of particular interest because of the similarities to the Murrah Building device and conditions, however tests two and three are of interest because they show the inherent resistance of monolithically constructed reinforced concrete structures and the characteristics of damage caused by mechanical coupling of the explosive forces to the target.

## ANALYSIS OF THE FIRST BLAST EFFECT TEST

Detailed analysis of the first blast effect test was undertaken in order to provide a baseline for predictive yield points of reinforced concrete in explosive conditions. The method devised was to compile a matrix of the maximum potential blast pressure for the face of the structure as calculated from the maximum possible yield of the aluminum cased device based upon the information supplied by the Armament Directorate at Wright Laboratory, Eglin Air Force Base, Florida.

A pressure map matrix was prepared for the vertical face of the structure by mapping the structure in a one foot grid with allowance for the 1.22 foot radius of the explosive material. This pressure map matrix was then transferred to the stations laid out on an elevation of the north face. The maximum potential blast pressures at various damage areas could thus be noted in this manner. The entire pressure map matrix is found in Appendix A. of this study.

Maximum potential blast pressure was calculated by using the straight line distance from the center of the explosive device to the station on the face of the test structure. Maximum potential blast pressure is calculated as the inverse function of the distance (in radius units) cubed, or it can be expressed as the following equation:

$$p2 = p1 / (d \cdot d \cdot d) \quad \text{or} \quad p2 = p1 / d^3$$

where:

**p1** is the blast pressure of the explosive(in this case TNT is 1,500,000psi.)
**p2** is the blast pressure at the distance from the center of the device
**d** is the distance expressed in radius units of the sphere of explosive material (in the case of TNT 830 lbs. is a sphere of 2.4 feet in diameter therefore producing a radius of 1.2 feet)

In this equation the explosive material is assumed to be in spherical form.

Straight line distances for the matrix were calculated with standard trigonometric right triangle equations with the center of the explosive device placed at 25 feet from the vertical face per the data given by the Armament Directorate, and 1.2 feet from the horizontal plane which is assumed to be the ground. Maximum dynamic pressure or maximum potential blast pressure occurred at a point 20 feet from the corner of the building in the center of the face and 1.2 feet in altitude from the ground, the maximum pressure at this point is calculated at 174.3 psi.

It should be noted that these are maximum potential blast pressures and actual pressures can be affected by the final configuration of the explosive, chemical efficiency of the explosive charge ambient conditions such as temperature and pressure at the site. Also the actual pressure experienced by the test structure in