BE CIVIL ENGINEERING
PROJECT REPORT

Capacity Assessment of Confined Block (Eco-block) against Blast Loading

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This to certify that the

BE Civil Engineering Project entitled

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SUBMITTED BY

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Has been accepted towards the partial fulfillment of the requirements for

BE Civil Engineering Degree

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Dr. Sarfraz Ali, PhD
Syndicate Advisor

DEDICATION

Dedicated to all martyrs of war against terror and our beloved Parents and Teachers, whose prayers and guidance have always been source of inspiration and motivation.

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All thanks and praise to Allah Almighty.

We bow our heads before Almighty Allah for providing us opportunity and resources to complete our research work. We are greatly obliged to the people without whom it would not have been written. Our deepest gratitude goes to our respected teachers particularly our advisor Dr. Sarfraz Ali and Co-adviser Engr. Azmatullah Mausood who are always been a symbol of encouragement and inspiration to us and were the driving force behind this research. They contributed valuables ideas and there reception of our ideas and suggestions has always been extremely encouraging. Through their exemplary guidance and leadership, we were able to achieve the objective of this research. Special thanks to our parents for their never-ending love and prayers. To those who in some way contributed in this research, your kindness means a lot to us.

ABSTRACT

Targeted acts of terrorism all over Pakistan have remained an issue for past few decades. Where they have made Pakistan to suffer from a great loss of lives they have also damaged the key significant infrastructure of country. This study is primarily focused on finding a suitable way to enhance the resilience of the structure against blasts. While designing, it is the common practice of Civil Engineers that they do not take into account the load which acts on the structure as a result of blast. Impeding the effect of blast waves produced as result of explosion will not save only the structure but will also save countless lives. A new construction material named as "Eco-blocks" was introduced in market claiming to be more blast resistant and more economical than the ordinary means of construction like brick masonry structure. This research work will enable reader in making a decision, on the basis of experimental results, whether the use of "Eco-blocks" in place of brick masonry structures, is justified or not.

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INTRODUCTION

1.1 Background

In recent years, targeted acts of terrorism in Pakistan, focused on critical economic infrastructure, produced cascading social and economic effects over very wide scales. According to “south Asia terrorism portal” more than 22215 civilian and 6921 military personnel have lost their lives in terrorist attacks. Government infrastructure, like educational institutes, health facilities, police and army check posts and government offices etc. were badly damaged in militancy.

1.3 Existing Design Philosophy

As designers consider other loads in designing such as gravity load, wind load and seismic load, blast load should also be considered. Normally engineers do not consider blast loading because of low probability of occurrence, but in third world countries where the security condition is not adequate, blast loading must be considered. Although the designing of such a robust building to resist a blast can be very expensive and may impedes the activities for which it is constructed. Because of these reasons it is rarely desirable to mock-up such structure which totally immune the conceivable incidents. But those structures which are at the target of terrorists, such as security check posts, headquarters of intelligence agencies, foreign offices and other important buildings must be designed or retrofitted in such a way to resist the impact of blast loading.

Masonry structure is the preferred type of construction in Pakistan up to three stories. Concrete block and burnt clay bricks laid in cement sand mortar are used for masonry building. It has been observed that the performance of masonry structure towards blast loading is not up to the mark. It is very much important to work on new material which gives good results towards blast load. In most of the cases it has been noticed that masonry fails at the joint because of low strength of mortar due to lateral loading (blast loading and seismic loading). Therefore a concrete block having self-interlocking mechanism is selected for the research purpose. This concrete block is the new introduction in the construction industry having sufficient strength, best architectural features and apparently good self-interlocking mechanism which might give sufficient shear strength to resist lateral load.

1.4Problem Statement

Due to terrorist activities in country, it is very much important to consider the blast loading in the designing of check posts. It has been observed that performance of existing Masonry structures is not satisfactory towards blast loading. So an effort is requisite to have a construction material which gives good result towards blast loading.

1.5Scope

Scope of research includes the verification of blast resistance of Eco blocksintroduced by Eco Enterprises, and effects of blast load will be determined with respect to different quantities of charge.

1.6Objectives

Primary objectives of the study include:

- Collection of data of terrorist attacks.
- Study of different types of explosives and their effects.
- Evaluate the performance of newly introduced self inter locking concrete blocks (Eco-Blocks) masonry against blast loading (shock wave).
- Study the variation of peak pressure with respect to standoff distance ($Z=R/W^{1/3}$.)
- Examine the hazard level of dry block masonry based on velocity of debris.

1.7Research Question

- What types of explosives have been used in different terrorists' activities?
- What is the performance of existing materials used for construction of check posts against blast loading?
- Which one is the weakest material in structure against blast loading?
- What is strength of eco-blocks against blast loading?
- What is the safe standoff distance for eco-block check posts
- How confined blocks are better than brick masonry?
- Cost comparison of different blast loading compromising techniques with our technique.

1.8Methodology

A full scale block masonry building (called as test building hereafter) and four panels will be tested under blast loading. The pressure produced by the explosion will be applied incrementally in increasing order. The pressure produced by the detonation is a function of weight of detonation and standoff distance (distance from the explosion). As the charge weight increases, the pressure produced by the charge weight will also increases for same standoff distance. Similarly, by decreasing the standoff distance the pressure will increases for the same weight detonation. Both methods can be used as the target is to expose the structure to different pressures to check its capacity. But the latter is more appropriate method i.e. by changing the standoff distance, on the basis of which the location of barrier can be decided. The peak pressure will be measured with the help of pressure gages, speed of debris will be captured with the help of high speed cameras and the strain will be measured with the help of strain gages.

1.9 Significance

- The successful implementation of this research work will be of great significance in mitigating the disastrous effects of blast loading on the buildings, thus will save many lives in case of any terrorists activities in the coming future.

- The existing techniques used for blast loading are uneconomical and may impede the utility of the building (sand and concrete walls). This research could give a better replacement of the said options.

- Helpful in security planning against blasting.

- Easy and speedy construction, good architectural features, self-interlocking mechanism is the additional significance of this research.

1.10Conclusion

This chapter provides a background of research. It gives an over view of the objectives set for the study, the proposed methodology that will be followed and significance of Eco-blocks in construction of blast resistant structures which are anticipated to be cost effective , resistant and safer than conventional construction materials

Chapter 2

LITERATURE REVIEW

2.1 General

Security check posts being the most vulnerable structure of most the government as well as private building are prone to the deadliest attacks by the terrorists. Thus the structure of the check post can easily be destroyed. As the current check posts are not designed according the required standards to impede the effects of blasts, so a study is required to improve the behavior of material towards blast loading. This chapter mainly deals with the mechanism of the blast and the propagation of blast waves. Moreover it also deals with the evolution of various type ofmaterial to mitigate the effects of blast on the building.

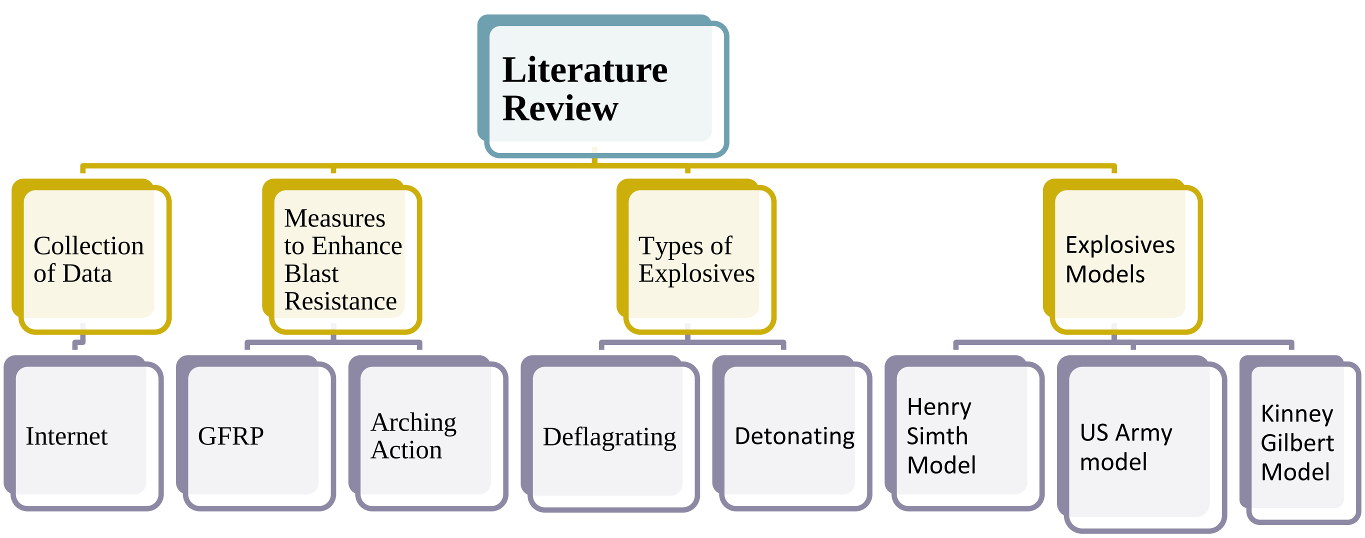


Figure 2.1 Flow chart of literature reviewed for the project

2.2 Terrorist Attacks in Pakistan

Pakistan has been worst victim of terrorist attacks, since 2000s we have lost 6934 security force personnel and 22230 civilians. A brief summary of terrorist attacks from 2000-2018 reported through different sources has been compiled and available on website www.satp.org as shown in Fig 1 and Fig 2 and Fig 3 most of the attacks were carried out in year 2009 and most casualties were also in same year.

Table 2.1: Mortalities in Terrorist Ferocity in Pakistan 2000-2018

Year	**Inhabitants**	**Security Personnel**	**Extremists/Bombers**	**Total**
2000-2004	737	224	313	1274
2005-2009	7039	2648	14449	24136
2010-2014	12323	3175	15326	30824
2015-2018	2131	887	3862	6880

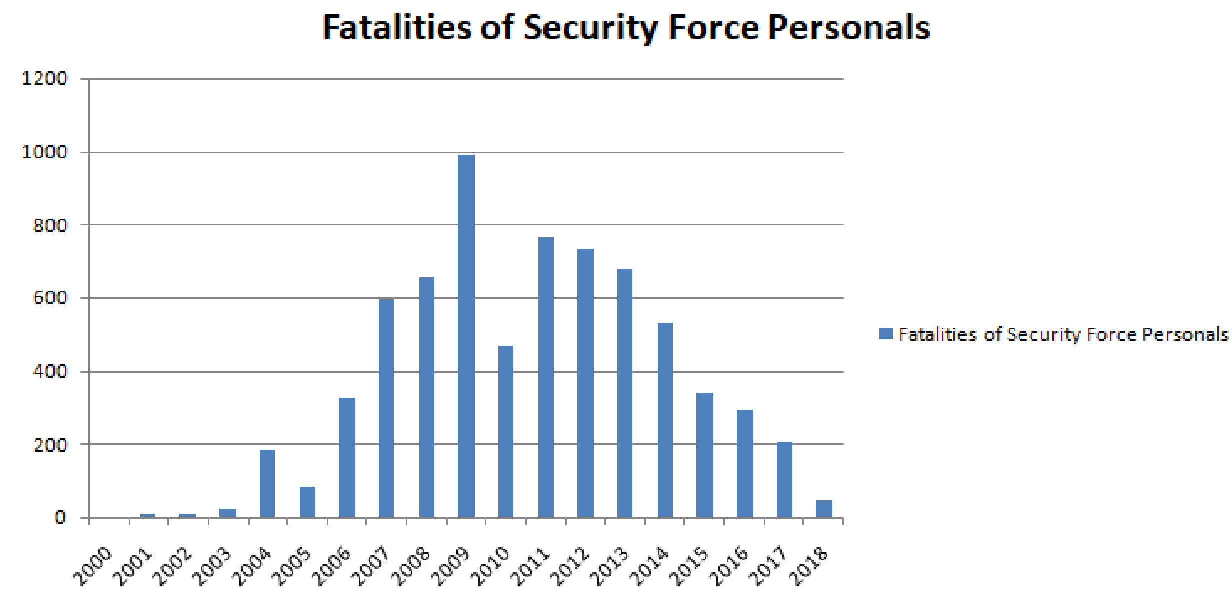


Figure 2.2 Year wise fatalities of security personal

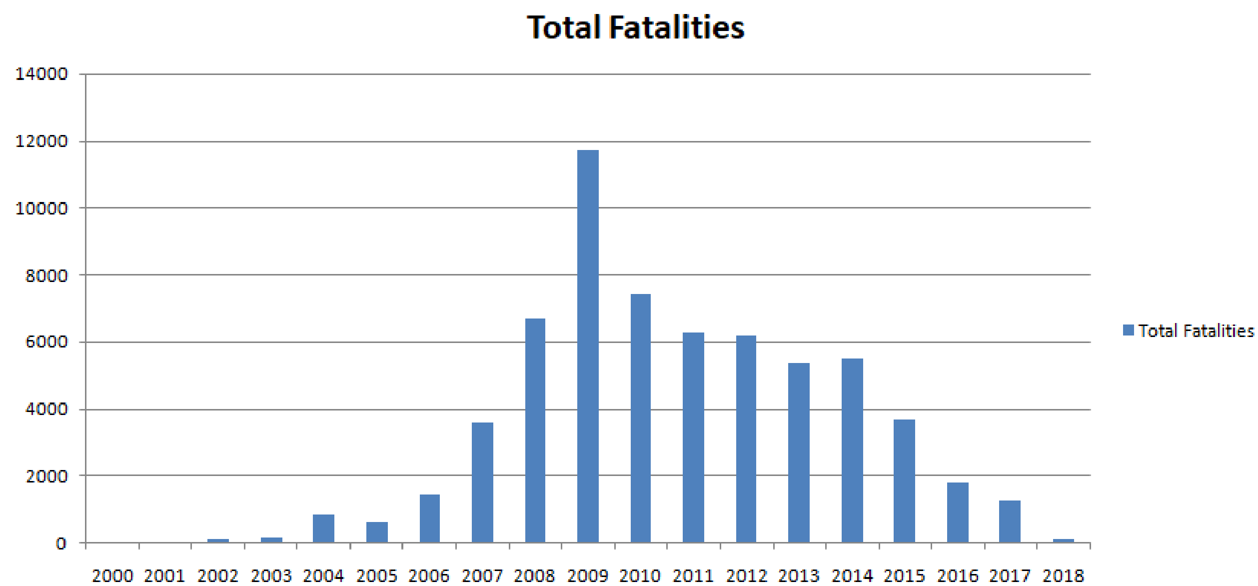


Figure 2.3 Year wise fatalities of civilians

2.3Explosions

An Explosion is sudden release of energy which generates heat, sound, gases and the most important factor is pressure

There are two types of explosions

- **Deflagrating Explosions:**

  Slow and progressive burning explosives are known as deflagrating explosives. The heat transfer depends on the external factors such as atmospheric pressure and temperature. This type of explosives propagates with subsonic speed, and speed of burning is slower than the speed of sound in that medium. Deflagration burns outward radically and its propagation speed depends on the quality of fuel available.

- **Detonating Explosions:**

  Detonation explosives have high energy release, temperature and peak pressure in very short time span. Energy dissipation is through shock wave and shock wave propagates with supersonic speed. Examples of detonations are

- TNT (trinitrotoluene)
- nitroglycerine
- dynamite
- picric acid
- C4

2.4 Comparison of Brick/Cement Block with Eco block

Eco-Blocks are high quality and cost effective material which can be used in commercial, residential and military structures.

Enhanced properties of Eco-Blocks are followings,

- Armorpiercing bulletproof

- Water resistant
- Self- insulated
- Blast- resistant
- No white salt residue
- Sound and wind proof
- Earthquake resistant

The following table shows the comparison of eco blocks with brick/cement blocks

Table 2.5.1: Comparison of eco-Blocks with brick/cement Blocks

Comparison item	Eco-Blocks	Brick/Cement Block
Attributes		
Compressive Strength	1700 psi	400 to 700 psi
Bullet-Proof	Yes, armor précising grade	No
Reuse (of brick/block)	up to 90%	No reuse possible
Lateral strength	70 psi	10 psi
Efflorescence	None	Yes, for brick
Usable in retaining and security wall	Yes	No
Thermal Efficiency	3x better then cement block	Inefficient
Build Requirement		

Plaster thickness required	5mm	12.5mm
Insulation required	None	Required
Water before use	None	Required
Mortar and Plaster	None	Required
Pillars for boundary wall	Every 20 to 40 feet	Every 10 feet’s

2.5 PreviousResearch Works

- **P. Carney and J.J. Mayer**

Studies have been conducted for performance of unreinforced masonry wall connections retrofitted with FRP under static and blast loading in out of plane directions. Two type of bond pattern were used i.e. stacked and running bond. Two retrofitting techniques were utilized including the Glass Fiber Reinforced Polymers (GFRP) veneered to the wall’s surface and the installation of Near Surface Mounted (NSM) GFRP rods. In both techniques, the retrofitting material was anchored to the boundaries of the wall, above and below. The research work was divided into two phases. Phase the performance of retrofitted out of plane walls were evaluated using static tests. Phase II, consist of field blast test on two walls to verify the results obtained in phase I. It was concluded that additional strength was achieved by retrofitting techniques with exception to the case on (NSM) rod used in stacked bond. Bond pattern had limited effect on strength of out of plane walls. The laminate strips greatly reduced the hazard level by holding the wall intact after failure.

- **D. Aloka.And B. Abass**

He carried out a review study on the effect of near field and far field explosion on reinforced concrete column. The explosion that occur at scaled distance less than or greater 1.18 m/kg1/3 are termed as near field and far field respectively. The response computation of far field explosion can be performed using the charts presented in UFC-3-340 design manual, ConWep program or high fidelity physics based commercial software like ABACUS, AUTODYNE, and LS-DYNA. On the other hand the behavior of near field blast is more complex and characterized by a fireball of high temperature, and extremely high magnitude non-uniform pressure. Under such situations existing empirical equations for far field explosions give inaccurate results to determine the near field blast parameters (Smilowitz& Tennant, 2010), Cormie et al. (2014a), sherkar et al. (2010), Wang et al. (2008), Liccioni et al. (2006). Therefore it is very vital to determine the exact blast pressure or impulse for near field blast to accurately predict the response of the structure. The structural system may be designed using SDOF approach; however the P-Delta effect, localized deformation, panel zone deformation and other localized response characteristics associated with near field explosions are not captured (Smilowitz& Tennant, 2010). In the near field explosion the duration of blast loading is very short as compared to the duration of maximum response of the structure; therefore such a member has to be analyzed for impulse loading rather than blast overpressure. The near-field blast loading is spatially non-uniform and hence the structural members (beams/columns) are likely to fail in shear due to impulse take-up (Rigby et al., 2014b). In case of far-field explosions the pressure and impulse take-up of the members is uniform thereby resulting in bending action..

- **Zaki.M.Al Zahri**

"Studied the response of GFRP (glass fiber reinforced polymers) strengthened infill masonry walls against blast loading. He noticed the failure of masonry wall leads to flying fragments resulting to loss of life and injuries to large number of people. This research consist of two phase , phase I testing the un-strengthened wall panels and phase II is testing fiber reinforced wall panels against blast loading at different scale distance. Both walls blast fails after three blasts but un-strengthened wall produce large no of fragments but GFRP strengthened wall didn't produced any fragments which can save many lives.

- **B.M.Abou-Zeid (2009)**

When performing blast resistance of unreinforced masonry (URM) concrete walls he considered exterior infill panels, as these walls are vulnerable in case of explosion outside the building. Basically he emphasized on arching action of URMs. The experiment was based upon "Arching Action Theory of Masonry Walls". A total of 12 full-scale URM concrete walls were constructed and tested using live explosives. In the paper the results of two of those walls were presented. He correlated the hazard level and damage with the charge size and the stand-off distance. It was concluded that forcing URM walls to arch against rigid supports significantly enhances their blast resistance.

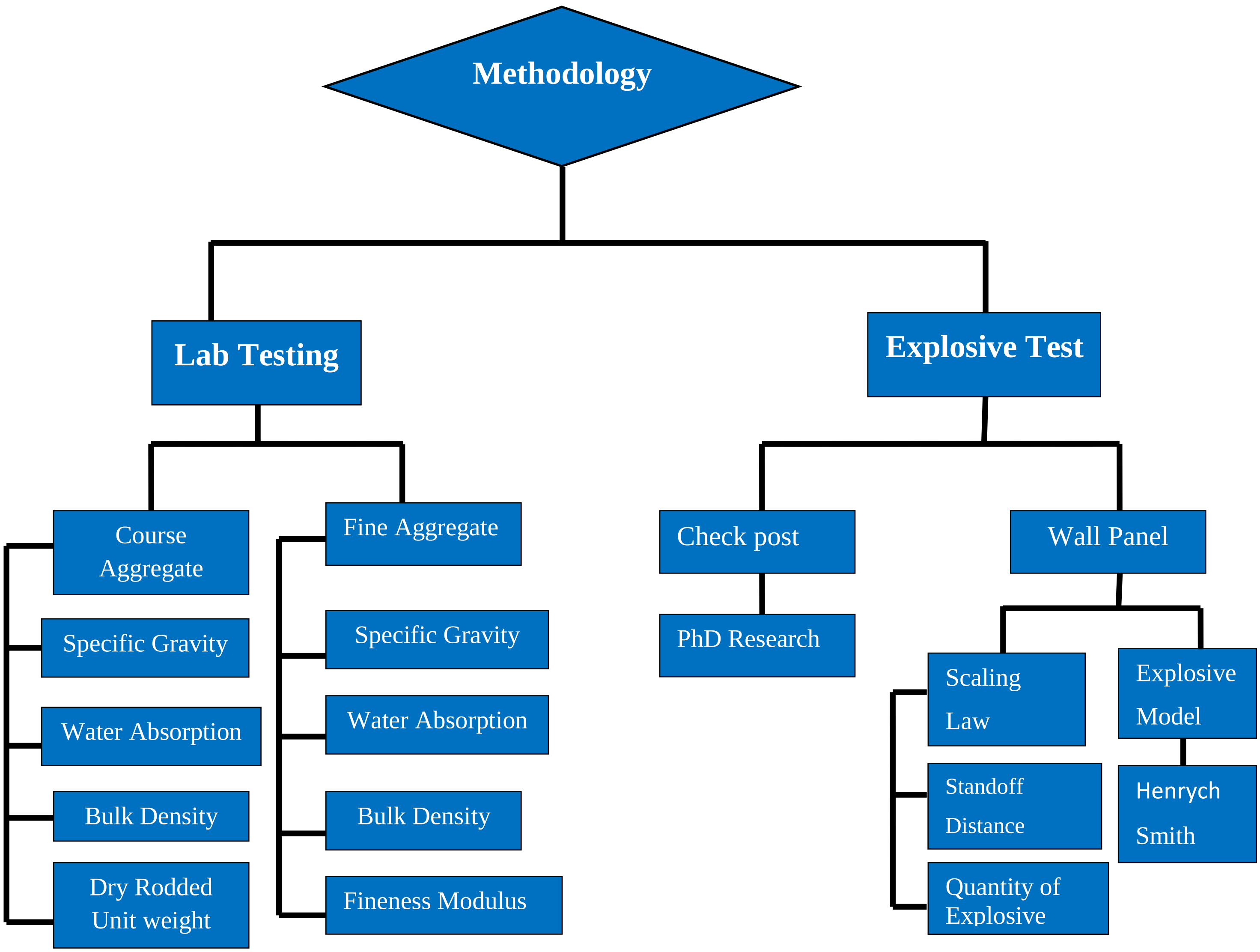
2.5Knowledge gaps

Knowledge gaps of our research topic are following

- There was no proper design philosophy for designing of structures against blast loading
- Data is not available for designing of structure against blast loading.

- Performance of newly introduced self inter locking (Eco-Blocks) was not tested against blast loading
- hazard level of Eco-blocks based on velocities of debris needs to be studied
- Safe scale distance is not knownfor Eco-Blocks.

METHODOLOGY



3.1 Methodology:

A wall panels will be tested under blast loading. The pressure produced by the explosion will be applied incrementally on wall panel. The pressure produced by the detonation is a function of weight of detonation and standoff distance (distance from the explosion). As the charge weight increases, the pressure produced by the charge weight will also increases for same standoff distance. Similarly, by decreasing the standoff distance the pressure will increases for the same weight detonation. Both methods can be used as the target is to expose the structure to different pressures to check its capacity. But the latter is more appropriate method i.e. by changing the standoff distance, on the basis of which the location of barrier can be decided. The peak pressure will be measured with the help of pressure gages, speed of debris will be captured with the help of high speed cameras and the strain will be measured with the help of strain gages. Theexperimental setup of both proposals is given in figure 1.P

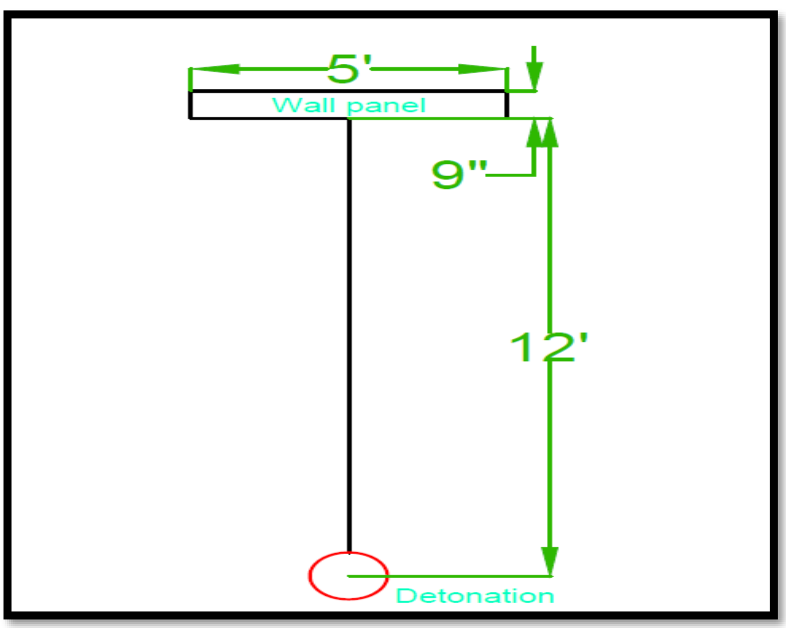


Figure 3. 1 Plane view of wall panel

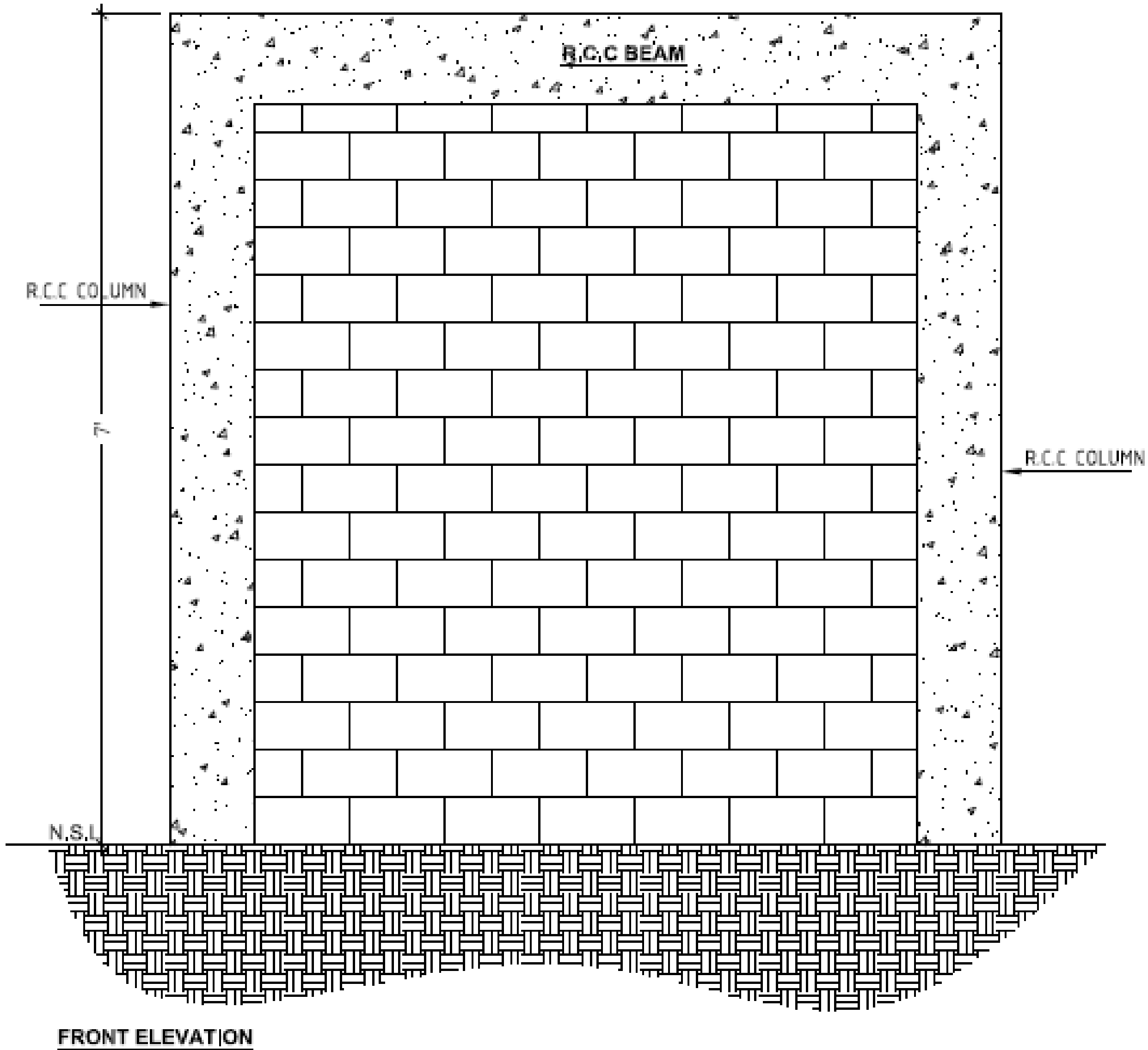


Figure 3. 2 Elevation of wall panel

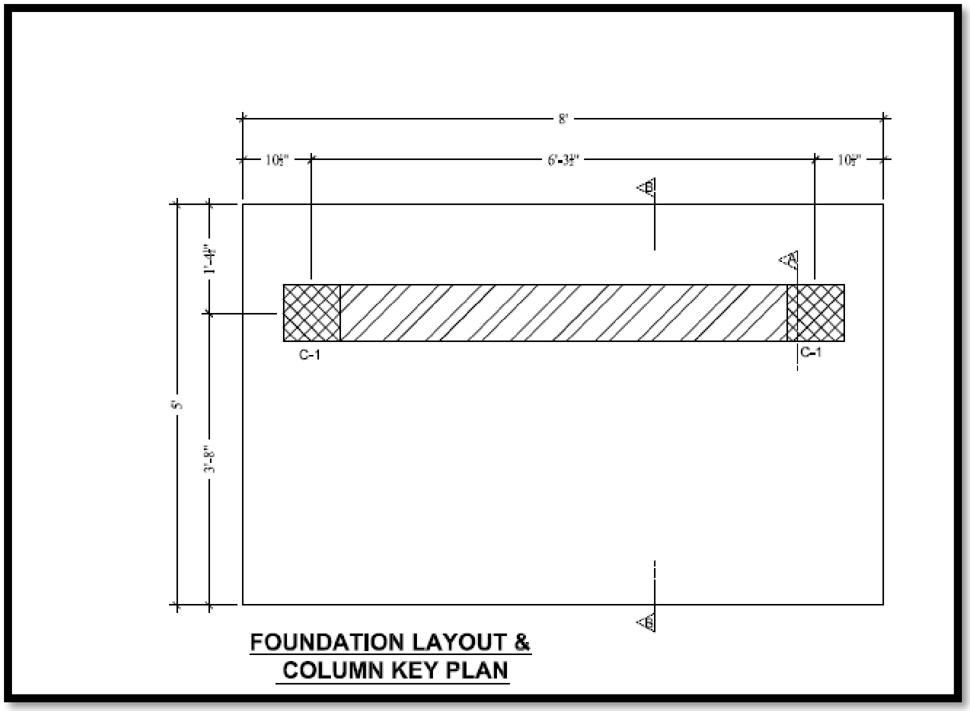


Figure 3. 3 Foundation layout and column plan

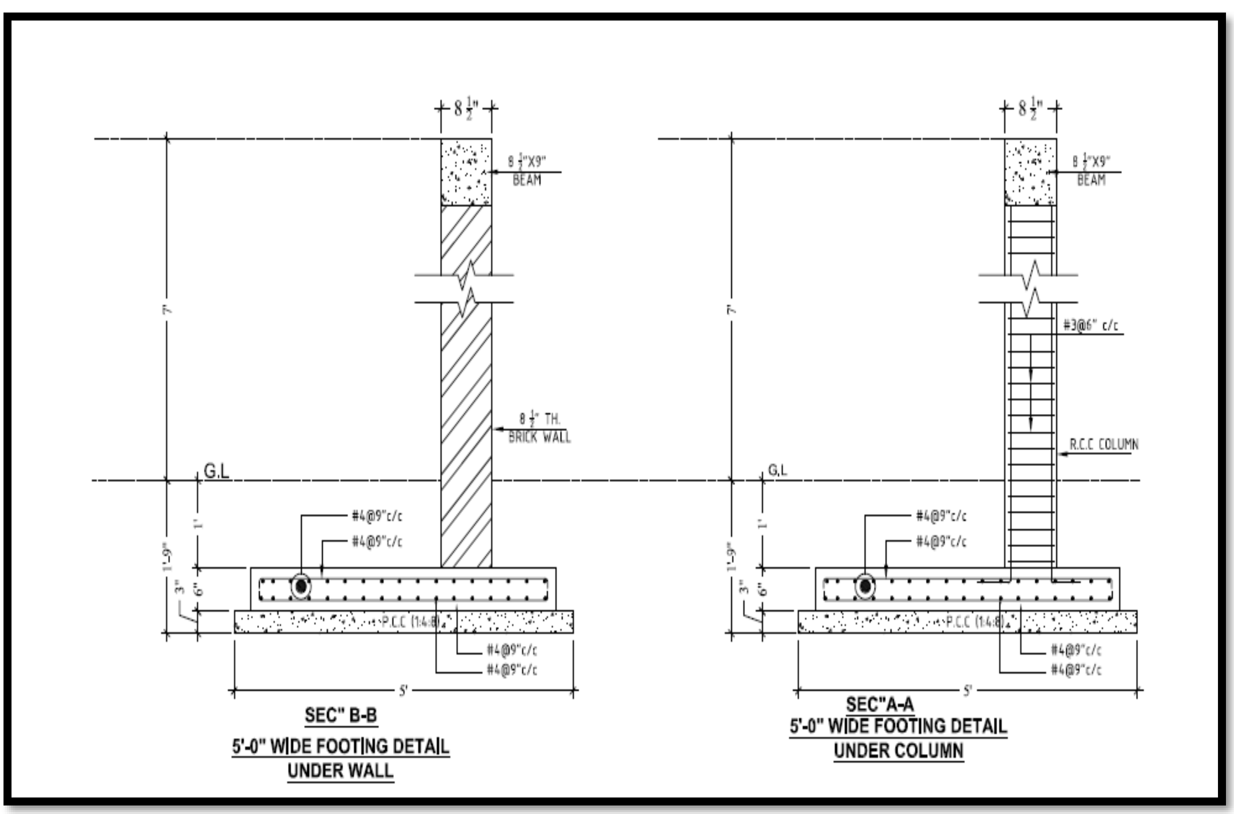


Figure 3. 4 SEC B-B and SEC A-A

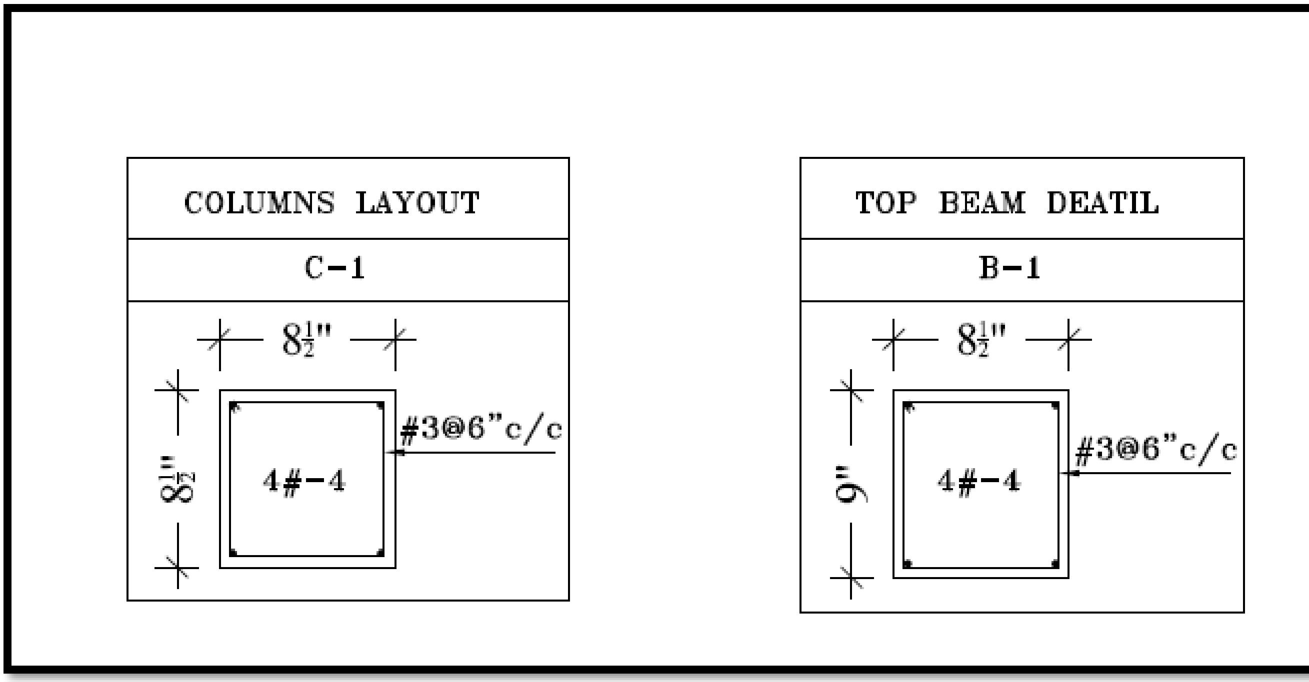


Figure 3. 5 Top Beam and Column Layout

3.2Scaling Laws

The amount of energy released as a result of explosion and the medium though which the blast wave propagate is the determinant of characteristics of the blast wave, produced by explosion. A number of tests have been carried out to quantify the properties of blast waves under controlled environment with the help of different set of explosion data. Scaling laws are then used to determine the data for different explosions on the basis of the tests results obtained from actual explosions.

Most commonly used scaling law for blast scaling is the cube root scaling law. The shock waves produced by two charges of same geometry detonated in same geometry are similar in nature at the same scale distance. Identical results of blast wave peak over pressure are expected to occur at the distances which are proportion to the cube root of their energy release. Eight times more the energy release is required to produce twice the blast peak overpressure at a certain distance;e.g., a person who is 30 feet away from the blast receives 9 times less blast force than somebody who is 15 feet from the explosion.

The scaled distance or the proximity factor Z [Cooper 1996]:

$$Z = \frac{R}{(W\,T_a\,/\,P_a\,)^{1/3}} \qquad (\text{Eq.3.1})$$

R = distance from the center of the explosion to the target location

W= the energy release, or amount of charge in KG's.

$\mathbf{T_a}$= the ambient temperature in Kelvin

$\mathbf{P_a}$=the ambient pressure in "bars".

Table 3.1 displays typical safe distance for various weights of explosives.

Description	Explosive mass (TNT equivalent)	Building Evacuation Distance	Outdoor evacuation distance
Pipe Bomb	2.3 kg	21m	259m
Suicide Belt	4.5 kg	27 m	415 m

Suicide vest	9 kg	34 m	415 m
Compact Sedan	227 kg	98 m	457 m
Small Moving Van/Delivery Truck	4536 kg	263 m	1143 m
Moving Van/ Water Truck	13608 kg	375 m	1982 m

Table 3.1 Safe Distance Matrix [Adapted from FEMA 2004].

3.3Explosive Models

In real time molding of blast effects, it is mandatory to properly model the deleterious properties of blast waves. In order to use any explosive model, scaling laws are used. By using scaling laws, blast peak pressure produced by some specific explosion may be scaled up or down to study the effect of explosion at different distances. All explosive models which are under consideration either used one pound TNT curve.

Impulse is one of the vital controlling factors due to its damage causing ability for short duration. In most part of impulse, positive phase is dominant. The blast overpressure decay doesn't follow any typical relation because the over pressure takes infinite time to drop to zero. A quasi-exponential *a* form for pressure, in terms of a decay parameter, and of a time *t*, for the instant shock front arrives can be defined as [Gilbert and Kenneth 1985]:

$$p = p_o \left[1 - \frac{t}{t_d}\right] e^{\frac{-at}{t_d}} \qquad \text{(Eq . 3.2)}$$

Where;

p = Overpressure at time t,

p_o = The maximum or peak overpressure observed when *t* is zero,

t_d = Time duration.

3.3.1 Henrych Smith Model

Explosive models favor far-field effects compare to near-field. To resolve this problem Henrych Smith [Shrapnack, Jhonson, and Phillips 1991] gave the following set of equations.

$$P = \frac{14.072}{Z} + \frac{5.540}{Z^2} + \frac{0.357}{Z^3} + \frac{.00625}{Z^4} \; 0 \leq Z \leq .3 \quad \text{(Eq . 3.3)}$$

$$P = \frac{6.194}{Z} + \frac{0.326}{Z^2} + \frac{2.132}{Z^3} \; 0.3 \leq Z \leq 1.0 \quad \text{(Eq . 3.4)}$$

$$P = \frac{0.662}{Z} + \frac{0.405}{Z^2} + \frac{3.288}{Z^3} \; 1.0 \leq Z \quad \text{(Eq . 3.5)}$$

Where, Z is the scale distance.

3.3.2 US Army Model

The U.S. Army uses the following equation to estimate the peak overpressure at a given distance from the point of explosion [Mayo and Kluger 2006].

$$P_O = \frac{4120}{Z^3} - \frac{105}{Z^2} + \frac{39.5}{Z} \quad \text{(Eq . 3.5)}$$

Where, Z is the scale distance.

3.3.3 Kinney Gilbert Model

Kinney and Gilbert developed the following equation [Gilbert and Kenneth 1985] which is now used in blast loading literature and research.

$$\frac{P}{P_a} = 101325 \frac{808.0(1+\frac{Z}{4.5})^2}{\sqrt{1+(\frac{z}{.048})^2}\sqrt{1+(\frac{z}{.32})^2}\sqrt{1+(\frac{z}{4.35})^2}} \text{(Eq . 3.6)}$$

Where, P= Overpressure

P_a = Atmospheric Pressure

3.4. Lab Testing:

3.4.1 Coarse Aggregate

3.4.1.1 Specific gravity:

Specific Gravity of the coarse aggregate was determined in accordance to the ASTM C127-15 standards. 1kgof sample was passed through a #4 sieve to remove the finer particles. Whole sample was then transferred toa vessel and the vessel was completely filled with water. Weight of vessel assembly along with water was noted. Aggregate was then spread over a cloth to make the sample dry & then the weight of vessel completely filled with water was noted again. Sample weight after being dried with cloth was noted and then it was transferred to the oven for 24 hours. After 24 hours the weight of dried sample was again noted.

Table 3.2: specific gravity of coarse aggregate

Weight	Unit	Symbol
Dry aggregate in SSD condition	Grams	C
Sample aggregate + Vessel	Grams	A
Vessel filled with water	Grams	B
Oven dried sample	Grams	D

Specific gravity of coarse aggregate = $\frac{\boldsymbol{D}}{\boldsymbol{C}-(\boldsymbol{A}-\boldsymbol{B})}$(Eq . 3.7)

3.4.1.2 Water Absorption:

The water absorption of coarse aggregate was also determined using the above ASTM standards. Formula for calculating the water absorption of coarse aggregate is given bellow.

%age Water Absorption = $\frac{(C-D)}{D} \times 100$ (Eq . 3.8)

3.4.1.3 Bulk Density:

Bulk density of the aggregate was determined using the ASTM C 29/C 29M. Firstly, a cylinder of known volume was selected and its weight was determined. Aggregate was then filled loosely in that cylinder assembly. Combined weight of cylinder and aggregate was then determined.

Table 3.3: Bulk Density of coarse aggregate

Quantity	Unit	Symbol
Weight of cylinder	Grams	A
Weight of cylinder + Aggregate	Grams	B

Volume of cylinder	Liters	C

$$\text{Bulk Density}= \frac{(B-A)}{C} \quad \text{(Eq . 3.9)}$$

3.4.1.4 Dry Rodded Unit Weight:

Dry rodded unit weight was determined using the ASTM C 29 standards. A cylinder of known volume was taken and weight of cylinder was determined. Then the cylinder was filled to its 1/3 and was compacted with 25 blows of a rod. Combined weight of cylinder and aggregate was determined. Net lose weight of aggregate was then determined by the method of difference. Bulk density was then determined by the formula.

Table 3.4: Dry Rodded Unit Weight of coarse aggregate

Quantity	Unit	Symbol
Weight of cylinder	Grams	A

Weight of cylinder + Aggregate	Grams	B
Volume of cylinder	Liters	C

$$\text{Dry rodded unit weight} = \frac{(B-A)}{C} \quad \text{(Eq . 3.10)}$$

3.4.2Fine Aggregate

3.4.2.1 Specific gravity:

Specific gravity of sand was determined using ASTM C 127-15 standards. The sample was soaked for 24 hours and then it was dried to on burner to achieve the SSD condition. Then a known amount of sample was taken in the pycnometer and it was filled with water to the top. Weight of whole assembly was determined and the weight of pycnometer filled with water was also determined. Sand was then oven dried and weight of the sand was then determined.

Table 3.5: Specific gravity of Fine aggregate

Weight	Unit	Symbol
SSD sample	Grams	C
pyscnometer + sample	Grams	A
pyscnometer filled with water	Grams	B
Oven dried sample	Grams	D

$$\text{Specific gravity of coarse aggregate} = \frac{D}{C-(A-B)} \text{(Eq . 3.11)}$$

3.4.2.2 Water Absorption:

Water absorption of sand was determined using ASTM C 128-15standards.above test were used to determine various parameters and the following formula was then used to finally calculate the water absorption of fine aggregate.

$$\%\text{age Water Absorption} = \frac{(\boldsymbol{C}-\boldsymbol{D})}{\boldsymbol{D}} \times \mathbf{100} \qquad \text{(Eq . 3.12)}$$

3.4.2.3 Bulk Density:

Bulk density of the sand was determined using the ASTM C 29/C 29M standards.. Firstly, a cylinder of known volume was selected and its weight was determined. Sand was then filled loosely in that cylinder assembly. Combined weight of cylinder and sand was then determined.

Table 3.5: Bulk Density of Fine aggregate

Quantity	Unit	Symbol
Weight of cylinder	Grams	A
Weight of cylinder + Aggregate	Grams	B
Volume of cylinder	Liters	C

$$\text{Bulk Density} = \frac{(\boldsymbol{B}-\boldsymbol{A})}{\boldsymbol{C}} \text{(Eq . 3.13)}$$

3.4.2.4 Fineness Modulus of Sand:

Fineness modulus of sand was determined in accordance to the ASTM C33/33M. Sample of sand was passed through a combination of sieves consisting of #4, #8, #16, #30, #50, #100, #200 and pan respectively. Cumulative percentage of on each sieve was determined and the fineness modulus was determined with the help of following formula.

$$\text{Fineness Modulus} = \frac{\boldsymbol{Comulative\ percentage\ retained}}{\mathbf{100}} \quad \text{(Eq . 3.14)}$$

Chapter 4

Result and Analysis

4.1 Test Results and Calculations

4.1.1 Coarse Aggregate:

Specific gravity of coarse aggregate:

Dry aggregate in SSD condition = C

Sample aggregate + Vessel = A

Vessel filled with water = B

Oven dried sample = D

Table 4.1: specific gravity of coarse aggregate

Serial No.	Weight Type	Unit	Quantity
1	C	Grams	727
2	A	Grams	1800
3	B	Grams	1315
4	D	Grams	715.5

Specific gravity of coarse aggregate $= \frac{\boldsymbol{D}}{\boldsymbol{C}-(\boldsymbol{A}-\boldsymbol{B})}$(Eq . 4.1)

$$= \frac{\mathbf{715.5}}{\mathbf{727-(1800-1315)}}$$

= 2.95

4.1.1.2 Water absorption of coarse aggregate:

Table 4.2: Water absorption of coarse aggregate

Serial No.	Weight Type	Unit	Quantity
1	C	Grams	727
2	A	Grams	1800
3	B	Grams	1315
4	D	Grams	715.5

%age Water Absorption = $\frac{(\boldsymbol{C-D})}{\boldsymbol{D}} \times \mathbf{100}$ (Eq . 4.2)

$$= \frac{\mathbf{(727-715.5)}}{\mathbf{715.5}} \times \mathbf{100}$$

= 1.60%

4.1.1.3 Bulk density of coarse aggregate:

Table 4.3: Bulk Density of coarse aggregate

SNo.	Weight type	Unit	Quantity
1.	A	Grams	7500
2.	B	Grams	20000
3.	C	Ft^3	0.33

Bulk Density= $\frac{(B-A)}{C}$ (Eq . 4.3)

= $\frac{(20000-7500)}{0.33}$

=37879 gm/ft^3

=**84 lb/ft^3**

4.1.1.4 Dry Rodded Unit Weight:

Table 4.4: Dry Rodded Unit Weight of coarse aggregate

Serial No.	Weight type	Unit	Quantity
1.	A	Grams	7500
2.	B	Grams	20500
3.	C	Ft^3	0.33

Dry Rodded Unit Weight= $\frac{(B-A)}{C}$ (Eq . 4.4)

= $\frac{(20500-7500)}{0.33}$

= 93.5 lb/ft^3

4.1.2 Fine Aggregate

4.1.2.2 Specific gravity:

Table 4.5: Specific gravity of Fine aggregate

Serial No.	Weight Type	Unit	Quantity
1	C	Grams	500
2	A	Grams	1630
3	B	Grams	1315
4	D	Grams	489

Specific gravity of fine aggregate $= \frac{\boldsymbol{D}}{\boldsymbol{C}-(\boldsymbol{A}-\boldsymbol{B})}$(Eq . 4.5)

$$= \frac{\mathbf{489}}{\mathbf{500}-(\mathbf{1630}-\mathbf{1315})}$$

= 2.65

4.1.2.3 Water absorption of fine aggregate:

Table 4.6: Water absorption of Fine aggregate

Serial No.	Weight Type	Unit	Quantity
1	C	Grams	500
2	A	Grams	1630
3	B	Grams	1315

4	D	Grams	489

%age Water Absorption = $\frac{(C-D)}{D} \times 10$(Eq . 4.6)

$$= \frac{(500-489)}{489} \times 100$$

=2.25%

4.1.2.4 Bulk Density of Fine Aggregate:

Table 4.7: Bulk Density of Fine aggregate

Serial No.	Weight type	Unit	Quantity
1.	A	Grams	2611
2.	B	Grams	6374
3.	C	Ft^3	0.0935

Bulk Density= $\frac{(\boldsymbol{B}-\boldsymbol{A})}{\boldsymbol{C}}$(Eq . 4.7)

$$= \frac{(\mathbf{6374-2611})}{\mathbf{0.0935}}$$

= **88.63 lb/ft^3**

4.1.2.5 Fineness Modulus:

Table 4.8: Fineness Modulus of Fine aggregate

Sieve No.	Mass Retained (Grams)	Cumulative mass Retained %	Cumulative % Retained
3/8 in	0	0	
#4	0	0	
#8	45	45	9
#16	150	195	39
#30	92	287	57.40
#50	115	402	80.40
#100	64	466	93.20
Pan	34		

Total Cumulative %age Retained = 279.60

Fineness Modulus (FM) $= \frac{279.60}{100}$

(FM) $= 2.80$

Concrete Mix Design

Job Specification

Construction type:	Reinforced Concrete footing
Size of aggregate:	1/2in
Specified 28 days strength:	3000 psi

Characteristics of Material

	Cement	Fine aggregate	coarse aggregate
Specific Gravity	3.15	2.65	2.95
Bulk Density(lb/ft^3)	196	162	168
Dry Rodded unit weight(lb/ft^3)	—	—	93.5
Fineness Modulus	—	2.8	—
Moisture Deviation %	+2.25	—	+1.6

Calculations

Step: 01

Value of Slump = 3-4 in

Step: 02

Max Aggregate size = 1/2 in

Step: 03

Required Water Content = 365 lb/yd^3 (ACI Code Table 6.3.3)

Amount of air entrapped = 2.5% (ACI Code Table 6.3.3)

Step: 04

Average Required Strength = f_{cr}+1.34ss (ACI 5.3.2) $\therefore$ f_{cr} = 3000psi &

ss = 300

Strength = 3000 + 1.34×300 = 3400psi

Water/Cement = 0.63

Step: 05

Cement Content = $\frac{365}{0.636}$ = 574lbs

Step: 06

Volume fraction of gravel = 0.55 (ACI Code Table 6.3.6)

Dry rodded volume of gravel = 0.55×27 = 14.85ft^3

Weight of gravel = 14.85×93.5 = 1388lbs

Step: 07

By using unit weight method:

Unit weight of Concrete = 3890 lb/yd^3 (ACI Code Table 6.3.7.1)

Weight of Sand = 3890-(365+574+1388)

= 1563 lbs

Using absolute volume method:

Volume displaced by water = $\frac{365}{62.4}$ = 5.85ft^3

Volume displaced by cement = $\frac{574}{196}$ = 2.93ft^3

Volume displaced by gravel = $\frac{1388}{168}$ = 8.26ft^3

Volume displaced by air = 27×0.025 = 0.675ft^3

Total =17.04ft^3

Weight of sand = (27-17.04)×162 = 1613lbs

4.2 Theoretical calculations of Blast tests

Theoretical calculations cover four scenarios as standoff remains constant 12 feet and the amount of charge increases 4kg, 8kg, 12kg and finally 16kg.

4.2.1 Scenario I: 4kg Explosion at standoff distance of 12 ft

Standoff distance	=	12 ft = 3.65m
Charge mass	=	4kg
Conversion factor to TNT	=	1.3
Equivalent TNT mass	=	4 x 1.3 = 5.3 kg
Ambient pressure	=	1 bar

Scaled Distance

$$Z = \frac{R}{(W\,T_a\,/\,P_a\,)^{1/3}} \text{(Eq . 4.8)}$$

$$Z = (3.657) / (5.3)^{0.33}$$

Z = 2.1

Peak Static Pressure

$$P = \frac{0.662}{Z} + \frac{0.405}{Z^2} + \frac{3.288}{Z^3} \text{(Eq . 4.9)}$$

Z = 2.1

$$P = \frac{0.662}{2.1} + \frac{0.405}{2.1^2} + \frac{3.288}{2.1^3}$$

P_s = 22.9 psi

Blast Wave Front Velocity

$$U = \sqrt{\frac{6\,Ps + 7Po}{7Po}}\ \alpha \qquad \text{(Eq . 4.10)}$$

Speed of sound = α= 343 m/s

Ambient pressure = Po = 1.00 bar

$$U = \sqrt{\frac{(6\ (0.762) + 7(1))}{7(1)}}\ X\ (343)$$

U = 675.18 m/s

Air Density behind the wave front

$$\rho = \frac{6\ Ps + 7Po}{Ps + 7Po}\ .\rho o \qquad \text{(Eq . 4.11)}$$

Ps = 1.58

Po = 1 bar

Density of air at ambient pressure = **1.225 kg/m^3**

$$\rho = \frac{6\ (0.762) + 7(1)}{0.762 + 7(1)}\ x\ (1.225)$$

Air density behinf wave front = ρ = 2.24 Kg/m^3

Maximum Dynamic Pressure

$$q = \frac{6\ Ps^2}{2(Ps + 7Po)}$$

$$q = \frac{6\ (0.762)^2}{2(0.762 + 7)}$$

Maximum dynamic pressure = q = 0.21 Bar

4.2.2 Scenario II: 8kg Explosion at standoff distance of 12 ft

Standoff distance	=	12 ft	=	3.65m
Charge mass	=	8kg		
Conversion factor to TNT	=	1.3		
Equivalent TNT mass	=	8 x 1.3 = 10.4 kg		
Ambient pressure	=	1 bar		

Scaled Distance

$$Z = \frac{R}{(W\ T_a\ /\ P_a\ )^{1/3}}$$

$$Z = (3.657)\ /\ (10.47)^{0.33}$$

$$\mathbf{Z = 1.67}$$

Peak Static Pressure

$$P = \frac{0.662}{Z} + \frac{0.405}{Z^2} + \frac{3.288}{Z^3}$$

Z = 1.67

$$P = \frac{0.662}{1.67} + \frac{0.405}{1.67^2} + \frac{3.288}{1.67^3}$$

P_s = 2.25 bar

P_s = 36.60

Blast Wave Front Velocity

$$\mathrm{U} = \sqrt{\frac{6\ \mathrm{Ps} + 7\mathrm{Po}}{7\mathrm{Po}}}\ \alpha$$

Speed of sound = α= 343 m/s

Ambient pressure = Po = 1.00 bar

$$U = \sqrt{\frac{(1\ .25 + 7(1))}{7(1)}} \mathrm{X}\ (343)$$

U =1002 m/s

Air Density behind the wave front

$$\rho = \frac{6\ Ps + 7Po}{Ps + 7Po}\ .\rho o$$

Ps = 1.25

Po = 1 bar

Density of air at ambient pressure = **1.225 kg/m^3**

$$\rho = \frac{6\ (1.25) + 7(1)}{1.25 + 7(1)}\ x\ (1.225)$$

Air density behinf wave front $= \rho = 3.20$ Kg/m^3

Maximum Dynamic Pressure

$$q = \frac{6\ Ps^2}{2(Ps + 7Po)}$$

$$q = \frac{6\ (1.25)^2}{2(1.25 + 7)}$$

Maximum dynamic pressure = q = 0.13 Bar

4.2.3 Scenario III: 12kg Explosion at standoff distance of 12 ft

Standoff distance = 12 ft = 3.65m

Charge mass = 12kg

Conversion factor to TNT = 1.3

Equivalent TNT mass = 12 x 1.3 = 15.6 kg

Ambient pressure = 1 bar

Scaled Distance

$$Z = \frac{R}{(W\,T_a\;/\;P_a\,)^{1/3}}$$

Z = (3.657) / (15.6)$^{0.33}$

Z = 1.46

Peak Static Pressure

$$P = \frac{0.662}{Z} + \frac{0.405}{Z^2} + \frac{3.288}{Z^3}$$

Z = 1.67

$$P = \frac{0.662}{1.46} + \frac{0.405}{1.46^2} + \frac{3.288}{1.46^3}$$

P_s = 48.9 psi

Blast Wave Front Velocity

$$\mathrm{U} = \sqrt{\frac{6\ \mathrm{Ps} + 7\mathrm{Po}}{7\mathrm{Po}}}\ \alpha$$

Speed of sound = α= 343 m/s

Ambient pressure = Po = 1.00 bar

$$U = \sqrt{\frac{(1.7 + 7(1))}{7(1)}} \text{X } (343)$$

U = 1295 m/s

Air Density behind the wave front

$$\rho = \frac{6 \text{ Ps} + 7\text{Po}}{\text{Ps} + 7\text{Po}} \ .\rho o$$

Ps = 1.7

Po = 1 bar

Density of air at ambient pressure = **1.225 kg/m^3**

$$\rho = \frac{6\ (1.7) + 7(1)}{1.7 + 7(1)} \text{ x } (1.225)$$

$$\text{Air density behinf wave front} = \rho = 4.06 \ \ \text{Kg/m}^3$$

Maximum Dynamic Pressure

$$q = \frac{6 \text{ Ps}^2}{2(\text{Ps} + 7\text{Po})}$$

$$q = \frac{6\,(1.7)^2}{2(1.7 + 7)}$$

Maximum dynamic pressure = q = 0.10 Bar

4.2.4 Scenario IV: 16kg Explosion at standoff distance of 12 ft

Standoff distance	=	12 ft = 3.65m
Charge mass	=	16kg
Conversion factor to TNT	=	1.3
Equivalent TNT mass	=	16 x 1.3 = 20.8 kg
Ambient pressure	=	1 bar

Scaled Distance

$$Z = \frac{R}{(W\,T_a\,/\,P_a\,)^{1/3}}$$

$$Z = (3.657) / (20.8)^{0.33}$$

Z = 1.29

Peak Static Pressure

$$P = \frac{0.662}{Z} + \frac{0.405}{Z^2} + \frac{3.288}{Z^3}$$

Z = 1.67

$$P = \frac{0.662}{1.29} + \frac{0.405}{1.29^2} + \frac{3.288}{1.29^3}$$

$$P_s = 60.33\text{psi}$$

Blast Wave Front Velocity

$$\mathrm{U} = \sqrt{\frac{6\ \mathrm{Ps} + 7\mathrm{Po}}{7\mathrm{Po}}}\ \alpha$$

Speed of sound = α= 343 m/s

Ambient pressure = Po = 1.00 bar

$$U = \sqrt{\frac{(2.25 + 7(1))}{7(1)}}\,\mathrm{X}\ (343)$$

U = 1567 m/s

Air Density behind the wave front

$$\rho = \frac{6\ \mathrm{Ps} + 7\mathrm{Po}}{\mathrm{Ps} + 7\mathrm{Po}}\ .\rho\mathrm{o}$$

Ps = 2.25

Po = 1 bar

Density of air at ambient pressure = **1.225 kg/m^3**

$$\rho = \frac{6\ (2.25) + 7(1)}{2.25 + 7(1)}\ \mathrm{x}\ (1.225)$$

Air density behinf wave front = $\rho = 4.85$ Kg/m^3

Maximum Dynamic Pressure

$$q = \frac{6\ Ps^2}{2(Ps + 7Po)}$$

$$q = \frac{6\ (2.25)^2}{2(2.25 + 7)}$$

Maximum dynamic pressure = q = 0.08 Bar

4.3 SETUP FOR BLAST LOADING TEST

The specimen was subjected to shock wave generated by WABOX explosive in ascending order. The load was applied in four increments started from four kg followed by eight, twelve and finally sixteen kg. Three pressure sensors were mounted on the specimen at the bottom, middle and the top of the specimen. As shown in figure 1.

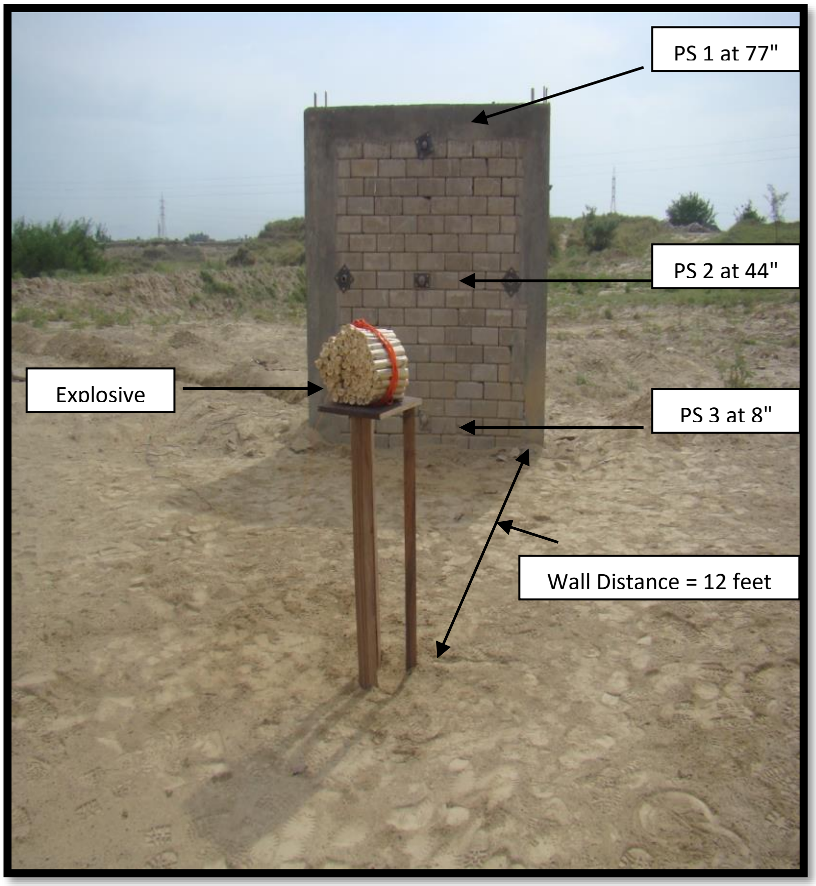


Figure 4. 1 Setup For Blast Loading Test

4.3.1 Test No. 1

Test No. 1 conducted with 4kg of explosive;

- No major cracking or failure was observed in blocks or confinement element as shown in figure 2.
- Figure no 3 to 6 describes the pressure time curves of all the pressure sensors.

Figure 4. 2 Condition of wall after test # 1

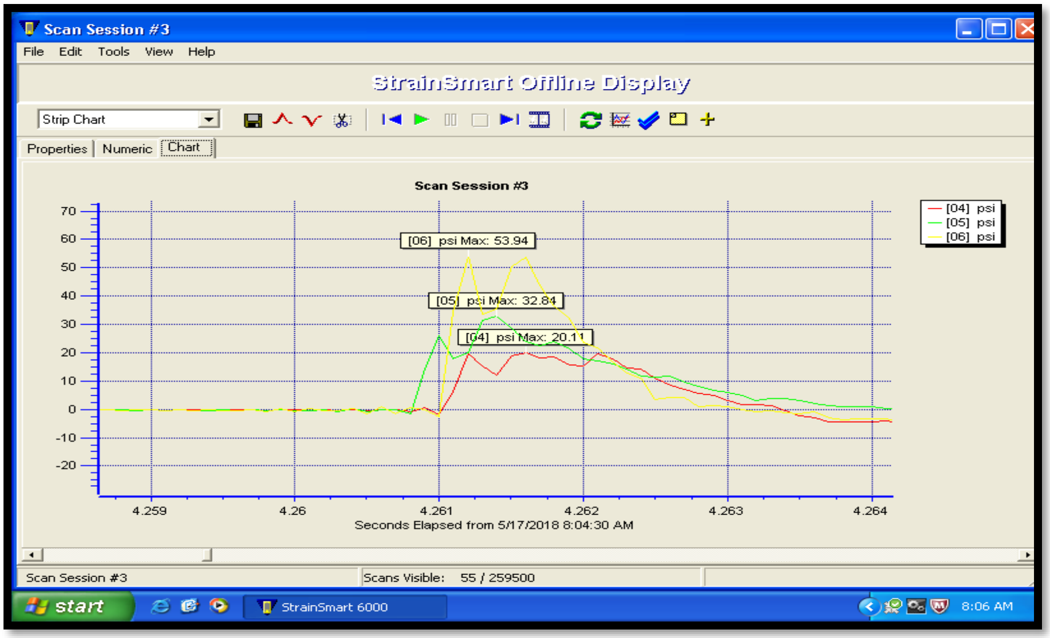


Figure 4. 3 Blast Over Pressure Curve Of Test # 1

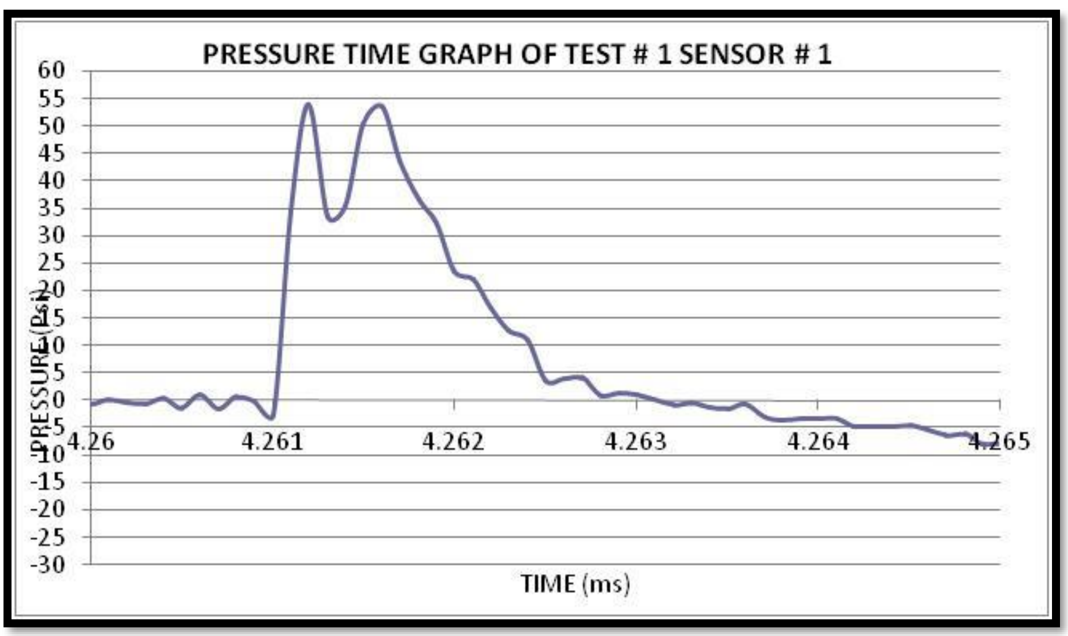


Figure 4. 4Pressure Time Graph Of Test # 1 Sensor # 1

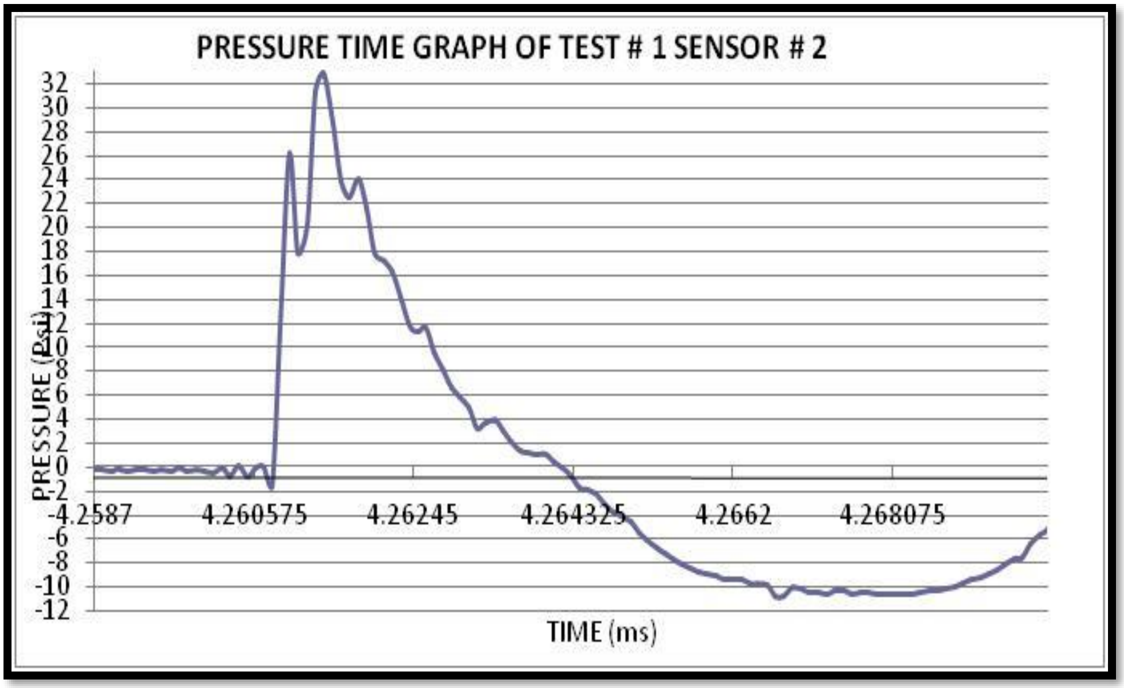


Figure 4. 5Pressure Time Graph Of Test # 1 Sensor # 2

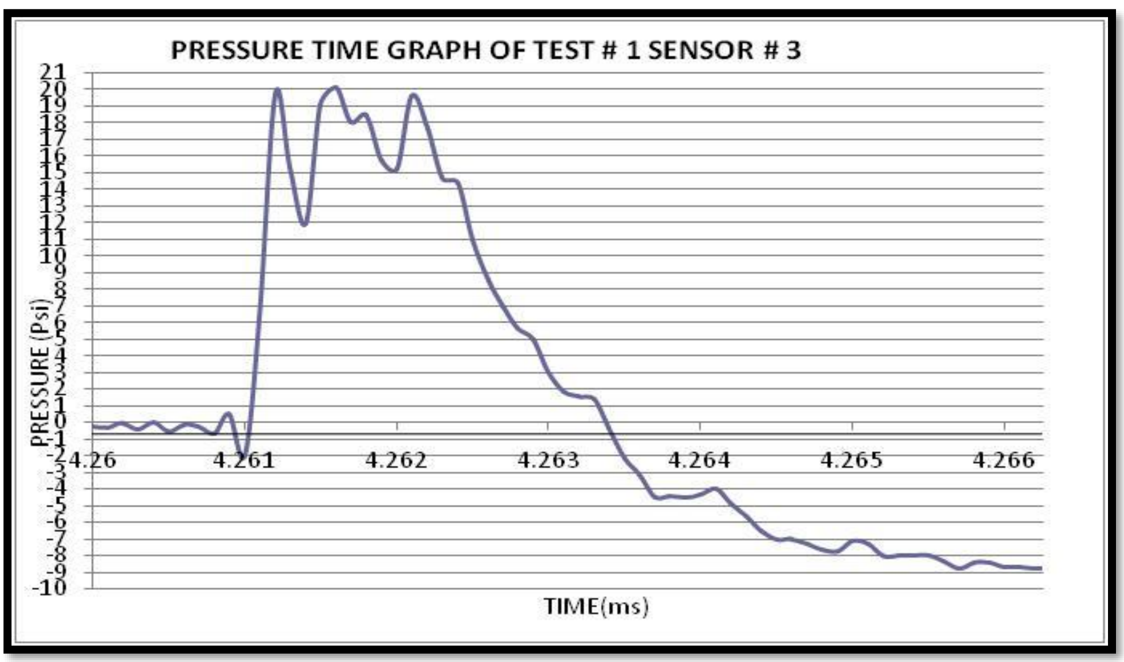


Figure 4. 6Pressure Time Graph Of Test # 1 Sensor # 3

4.3.2 Test No. 2:

Test No. 2 conducted with 8kg of explosive, following observations were taken after the test:

- Minor cracks were observed at joints of column and blocks
- Minor cracks were observed in blocks at bottom of wall.
- Minor cracking in block close to confinement can be seen as shown in figure no 7 .
- Rightward movement of foundation was observed after test No. 2
- Figure no 9 to 12 describes the pressure time curves of all the pressure sensors.

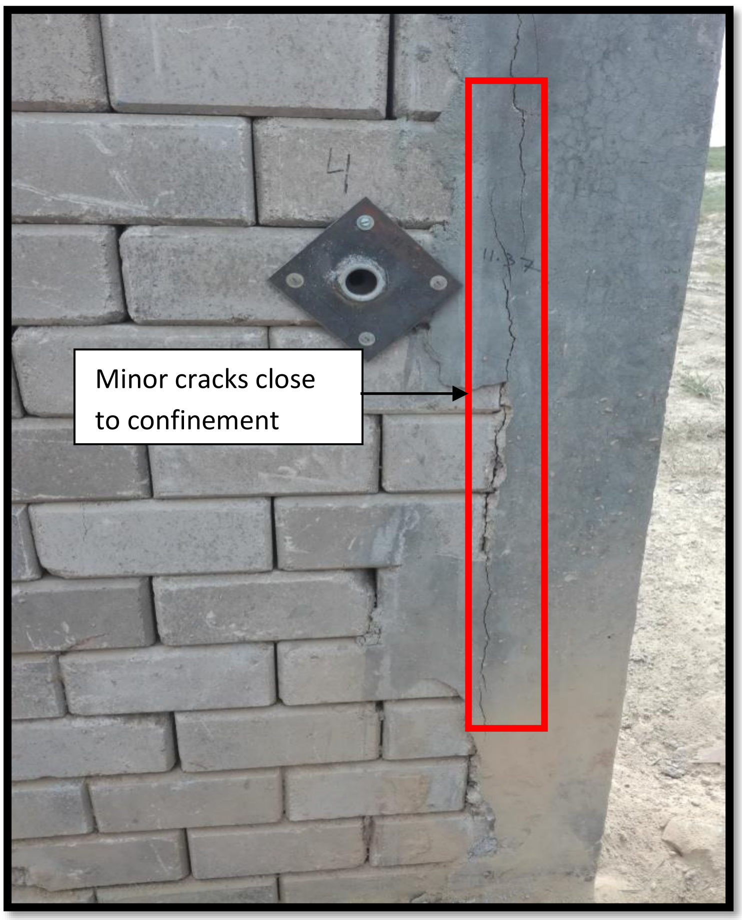


Figure 4. 7Cracks at the joint of confinement element and block masonry

Figure 4. 8Hair line cracks in the blocks.

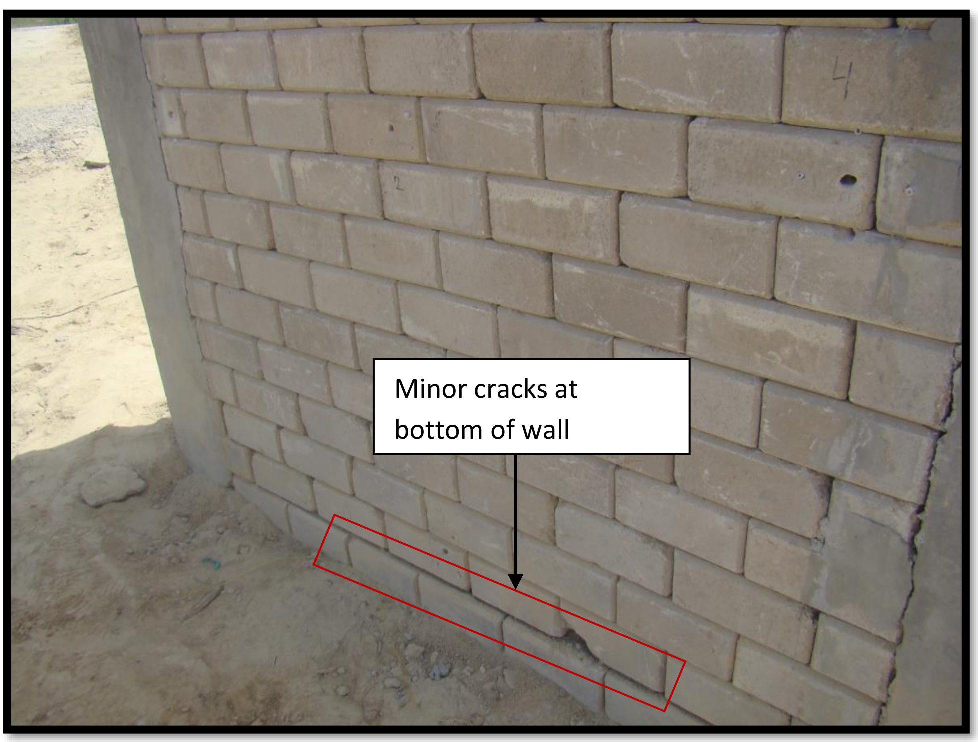


Figure 4. 9Minor Cracks At Wall Bottom

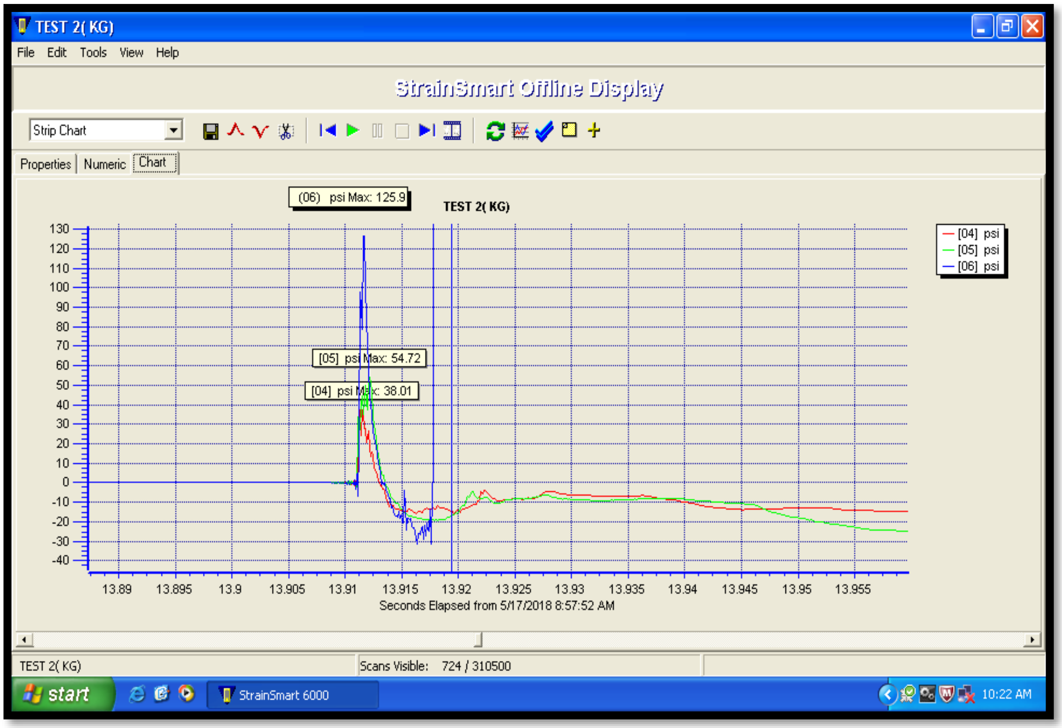


Figure 4. 10Blast Over Pressure Curve Of Test # 2

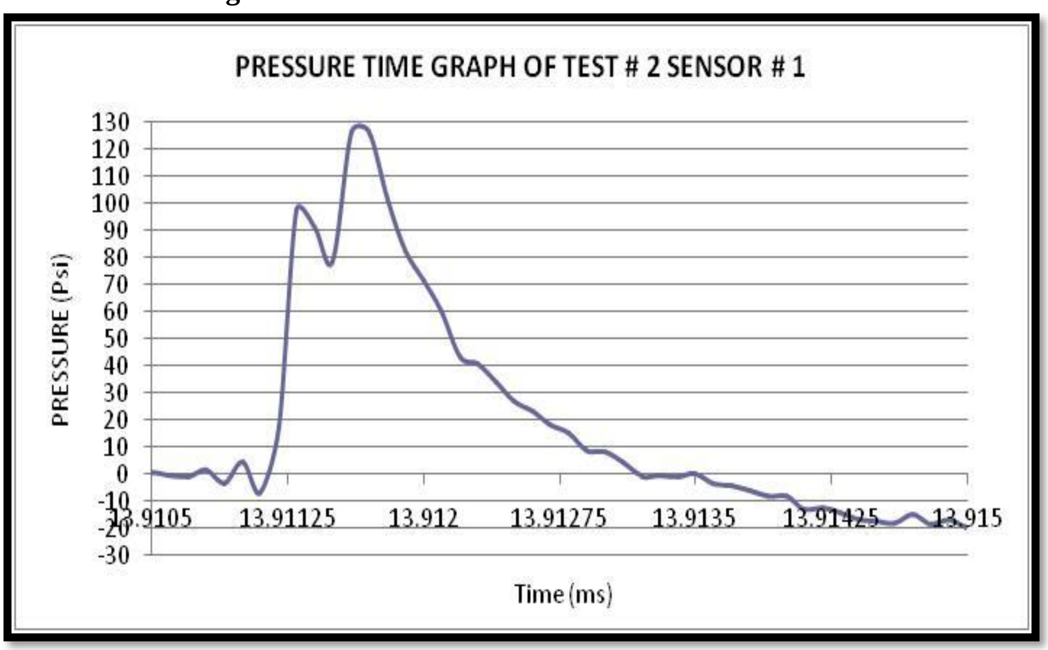


Figure 4. 11Pressure Time Graph Of Test # 2 Sensor # 1

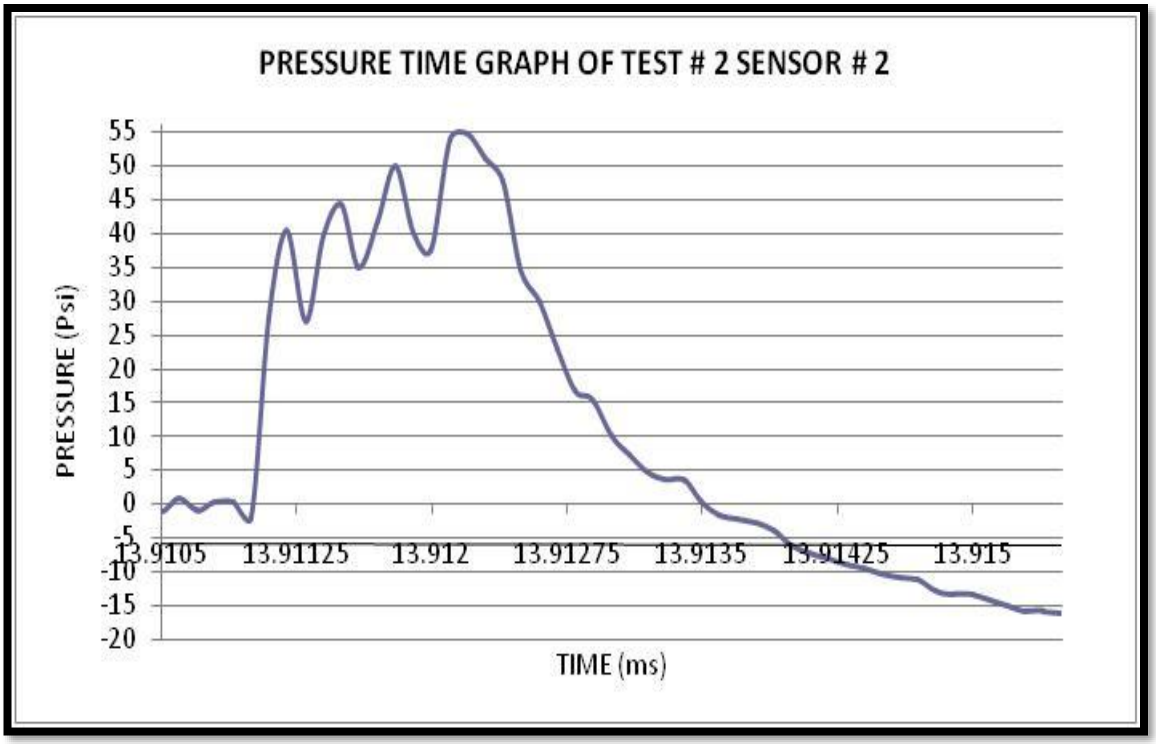


Figure 4. 12Pressure Time Graph Of Test # 2 Sensor # 2

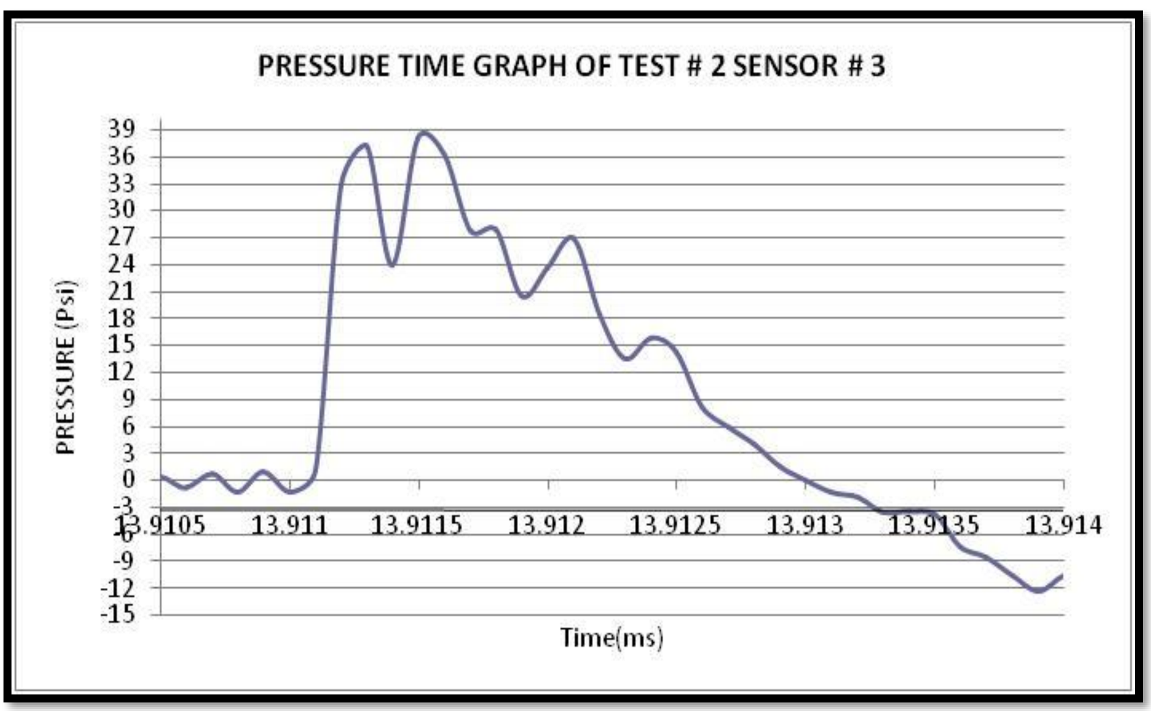


Figure 4. 13Pressure Time Graph Of Test # 2 Sensor # 3

4.3.3 Test No 3:

The third trail was conducted with 12kg's of explosive and following points were noticed

- The wall bulges out in the direction of shock wave. The bulging of wall started from bottom and decreases in upward direction, maximum bulging has been observed in 2nd layer of blocks which was almost one inch as shown in figure 5.
- Cracks at the joint of confinement element and masonry wall had been widened as shown in figure 6.
- At the back side of wall 3rd, 5th and 6th block from bottom were failed in compression.
- Cracks have been observed at bottom of both columns
- Cracks have been observed at the joint of horizontal and vertical confinement elements as shown in figure 7.
- After the third the trail the sensors have been removed to avoid any damaged to the wires and the sensors as these are not only expensive but also not easily available in the market.

Figure 4. 14Bulging of wall after blast test

Figure 4. 15Cracks at the bottom of column

Figure 4. 16Cracks at the joint Horizontal and vertical confinement element.

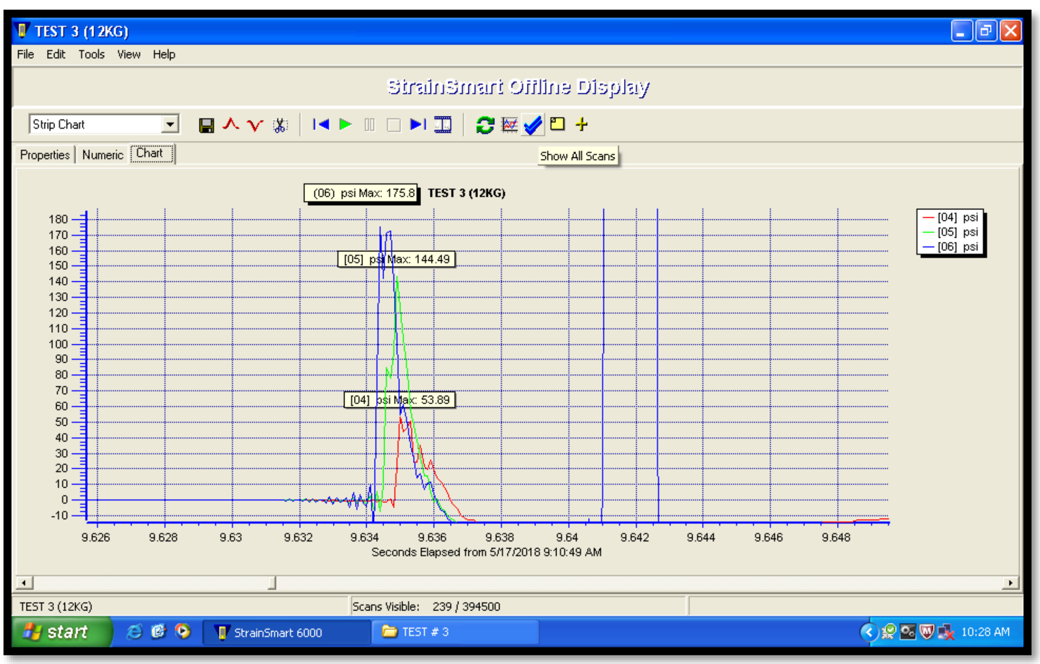


Figure 4. 17Blast Over Pressure Curve Of Test # 3

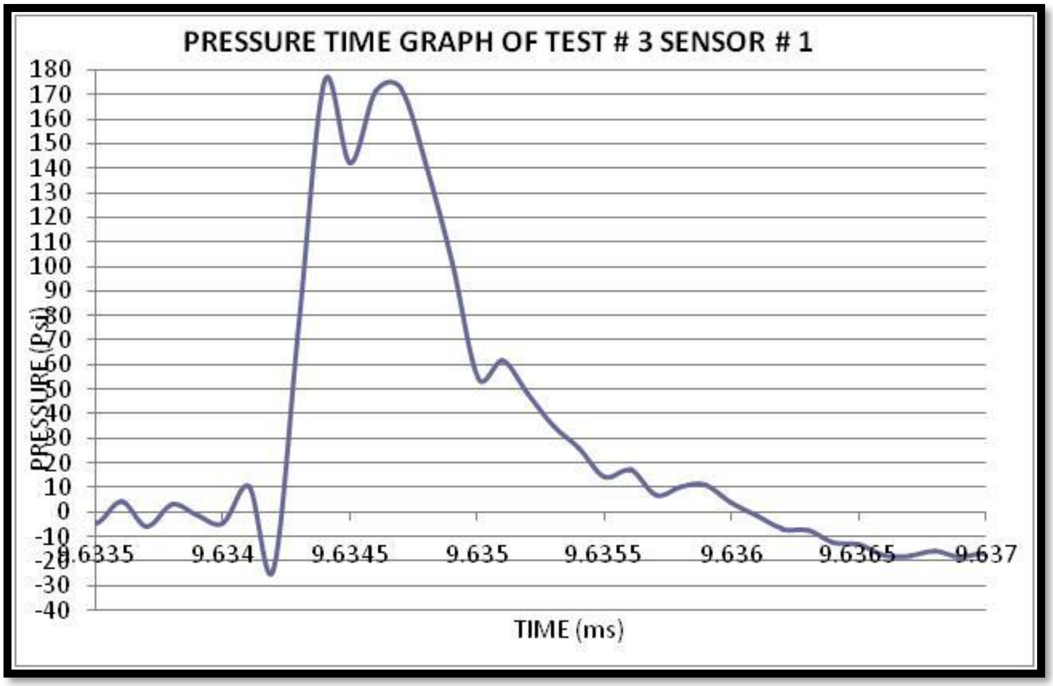


Figure 4. 18Pressure Time Graph Of Test # 3 Sensor # 1

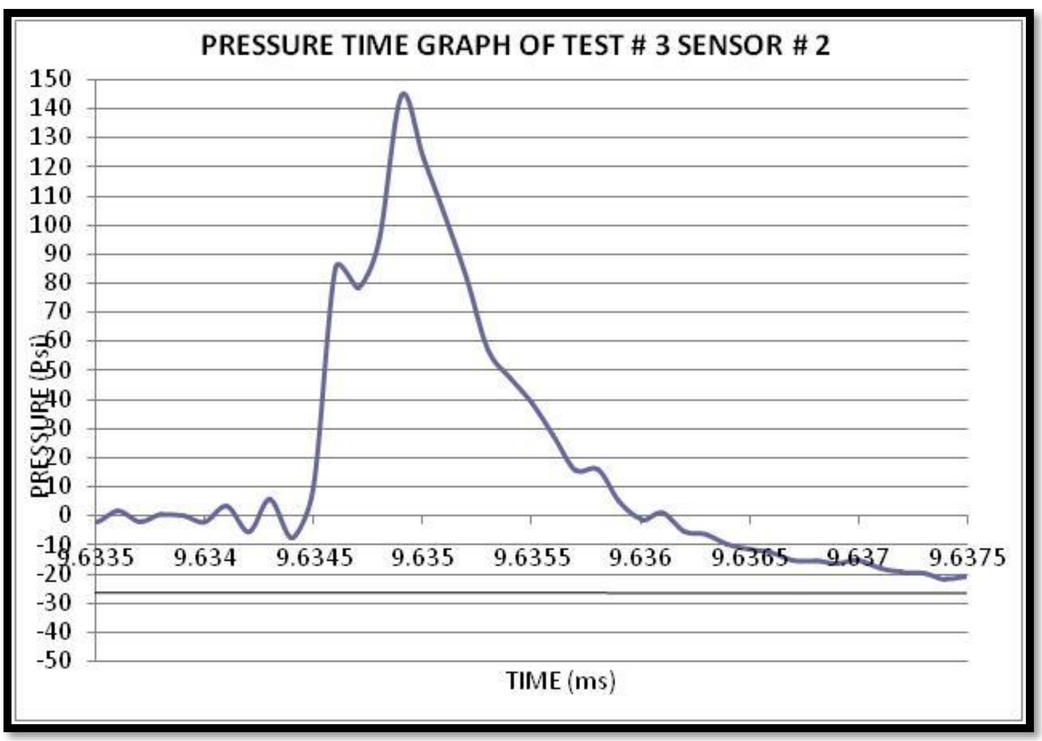


Figure 4. 19Pressure Time Graph of Test # 3 Sensor # 2

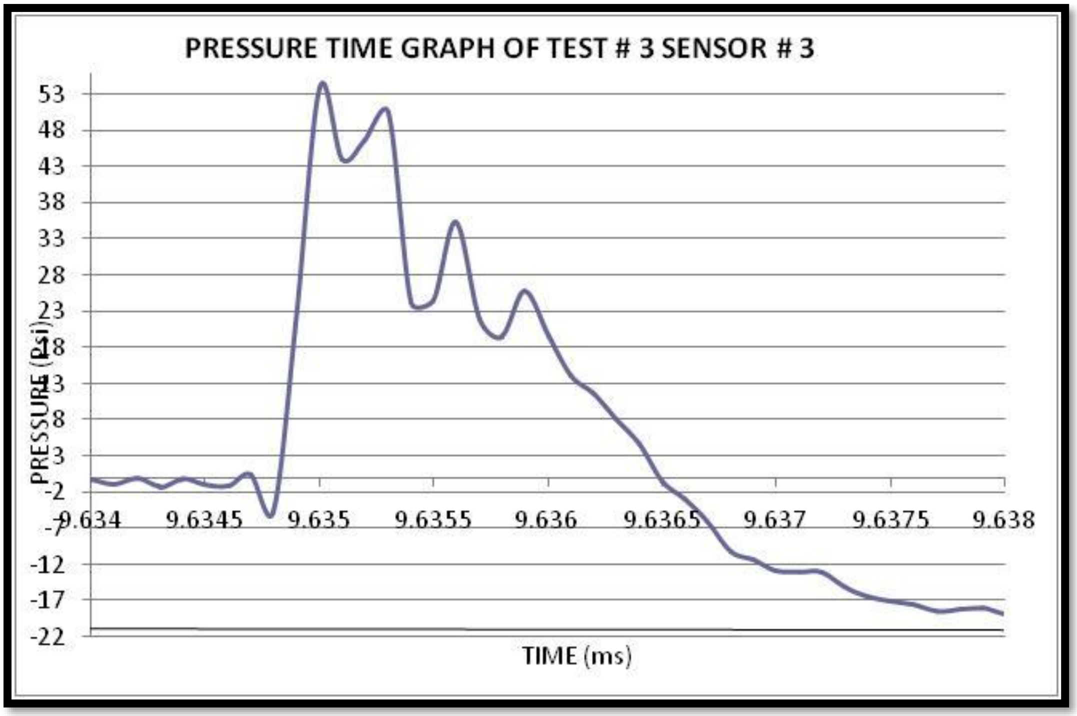


Figure 4. 20Pressure Time Graph of Test # 3 Sensor # 3

4.3.4Test No4:

In the fourth trail, the wall was subjected to 16 kg of explosive. In this trail, the sensors were removed and only observed with high speed camera. Some key observations are as under;

- The joint between horizontal and vertical elements have been failed as shown in figure 8 as a result the right portion of the wall has been demolished
- The joint failure is because of improper connection of confinement elements.

Figure 4. 21Blast Test 4

Figure 4. 22Failure of Right top joint

Figure 4. 23Groves of eco-blocks after test 4

Conclusion

From the studies of past data of terrorist attacks, it is palpable that we have lost countless precious lives in our war against terror. These numbers go up to 22230 civilians as well as numerous military personnel. Now it is the need of time to adopt such measures which have proven them to be a viable solution in safeguarding the military personnel against terrorist attacks. Eco-block is one of the most economical solutions that have emerged in recent past.

A thorough study of various types of blast materials ranging from TNT to Picric Acid was done and a result of which, TNT was selected as basic material of blast. Various blast materials were then converted in terms of the equivalent TNT through their conversion factor.

It is also evident from the study that because of self inter locking mechanism ,the performance of Eco-blocks have enough shear strength to withstand the impact of shock waves produced as a result of blast .it has been observed that the performance of eco block depends upon the strength of the confinement. The block has been failed because due to the failure of the joints of the confinement element . The performance of Eco-block is quite satisfactory as compared to the conventional masonry structures. While they have proved to be a better solution in term of safety, they are also an economical mean of construction.

It has been observed that the pressure produced by the shock waves varies along the height of wall, maximum at the bottom and minimum at the top. This variation is due to the reflected waves.

Debris of eco blocks were not observed as the result of blast which indicates that it has lower hazard level and the person standing behind the wall will be safe against the debris of material

Now, the time has come to further investigate and improve the performance of this material to enable it for the construction of safe check posts and other government installations.

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