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Prediction of Blast Loading and Its Effects on Waffle Slab

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Abstract: Explosions are occurring in recent days which cause total destruction of structure. Blast explosions caused due to gas leakage, bomb attacks, terrorist attack, nuclear explosions etc. Studies were conducted on the behaviour of structural concrete subjected to blast loads. These studies gradually enhanced the understanding of the role that structural details play in affecting the behaviour. The blast load expands as a high heat shock wave with high strength and velocity for a short duration. The strength and velocity of wave decays with increase in distance and time. The RC structures designed are without considering the blast load which result in large dynamic loads, greater than the original design loads, of many structures. The response of waffle slab subjected blast loads was examined. Waffle slabs are commonly used for car parking .It is a slab which can span larger distance using ribs without intermediate columns. In the analysis waffle slab with steel girders are used for analysis. The effect of blast loading by varying the distance of detonation and weight of TNT were analysed. The finite element package ANSYS was used to model waffle slab with boundary conditions. The mitigation effect over the slab also examined by using the aluminium foam sheet and carbon fiber reinforced polymer sheet. Results indicate that the CFRP is effective in mitigation of blast load than aluminium foam. The spalling of concrete and rupture of reinforcement of slab occur during the blast loading with decrease in distance of detonation.
Keywords— Blast loading, Blast pressure, Finite element modelling, ANSYS, , FRP-Fibre Reinforced Polymer, CFRP-carbon Fibre Reinforced Polymer, TNT-Trinitrotoluene, UFC-Unified facilities criteria

I. INTRODUCTION

Nowadays blast explosions are common. Explosions such as terrorist attack, accidental explosions, bomb explosions, explosions in petrochemical facilities etc are occurring day by day. It results in spalling of reinforced concrete, high strain rates and further failure of structure. Explosion is defined as a large-scale, rapid and sudden release of energy. Explosions can be categorized on the basis of their nature as physical, nuclear or chemical events. In physical explosions, energy may be released from the catastrophic failure of a cylinder of compressed gas, volcanic eruptions or even mixing of two liquids at different temperatures. In a nuclear explosion, energy is released from the formation of different atomic nuclei by the redistribution of the protons and neutrons within the interacting nuclei, whereas the rapid oxidation of fuel elements (carbon and hydrogen atoms) is the main source of energy in the case of chemical explosions.[1] Alternative system of construction for blast resistant construction using Steel concrete composite(SCC),Laced reinforced concrete (LRC),Oil palm shell, Aluminum foam, Laced steel concrete composite(LSCC).In this thesis blast response study of laced steel concrete composite is done. .It is found that the LSCC have high ductility which prevents the shear failure .Under blast loading shear failure are common. By using LSCC the damages due to blast can be prevented to a extent. The rotational capacity of LSCC makes it continuous transfer of shear and thus failure is prevented. Disasters such as the terrorist attack of the U.S. embassies in Nairobi, Kenya and Dar es Salaam, Tanzania in 1998, the Khobar Towers military barracks in Dhahran, Saudi Arabia in 1996, the Murrah Federal Building in Oklahoma City in 1995, and the World Trade Center in New York in 1993 have demonstrated the need for a thorough examination of the behavior of columns subjected to blast loads. To provide adequate protection against explosions, the design and construction of public buildings are receiving renewed attention of structural engineers. Difficulties that arise with the complexity of the problem, which involves time dependent finite deformations, high strain rates, and non-linear inelastic material behavior, have motivated various assumptions and approximations to simplify the models. These models span the full range of sophistication from single degree of freedom systems to general purpose finite element programs such as ABAQUS, ANSYS, and ADINA etc..

For studying the effects of blast loading on structure waffle slab is considered for blast analysis in this thesis. Waffle slab is a reinforced concrete slab with equally spaced ribs parallel to the sides having a waffle appearance from below. Waffle slab gives more structural stability without using a lot of additional material. In the thesis waffle slab with steel girders are used instead of reinforced concrete ribs.Due to different accidental or intentional events, the behavior of structural components subjected to blast

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loading has been the subject of considerable research effort in recent years. Conventional structures, particularly that above ground, normally are not designed to resist blast loads; and because the magnitudes of design loads are significantly lower than those produced by most explosions, conventional structures are susceptible to damage from explosions. Due to this in mind, developers, architects and engineers are seeking solutions for potential blast situations, to protect building occupants and the structures. How blast loads different from seismic loads.

Blast loads are single high pressure impulses acting over milliseconds. It acts directly on the exterior envelope. It generally cause localized damage .But seismic load are vibrational load of earthquakes which is act for seconds. It acts at the base of the building. And seismic load cause global response. For blast proof structure IS 4391-1968, UFC-3-340-02 and for seismic proof structure IS1893-2002(Part-I) are used. Blast loads are applied over a short period of time than seismic loads.

Effects on Structures

A. Blast effects on building structures can be classified as

1) Primary effects

2) Secondary effects.

Secondary effects can be fragments hitting people or buildings near the explosion. They are not a direct threat to the bearing structure of the building, which is usually covered by a facade. However, they may destroy windows and glass facades and cause victims among inhabitants and passers-by.

B. Primary effects include

1) *Air blast:* The blast wave causes a pressure increase of the air surrounding a building structure and also a blast wind.

2) *Direct Ground Shock*: An explosive which is buried completely or partly below the ground surface will cause a ground shock. This is a horizontal (and vertical, depending on the location of the explosion with regard to the structural foundation) vibration of the ground, similar to an earthquake but with a different frequency.

3) *Heat:* A part of the explosive energy is converted to heat. Building materials are weakened at increased temperature. Heat can cause fire if the temperature is high enough.

4) *Primary Fragments*: Fragments from the explosive source which are thrown into the air at high velocity (for example wall fragments of an exploded gas tank).

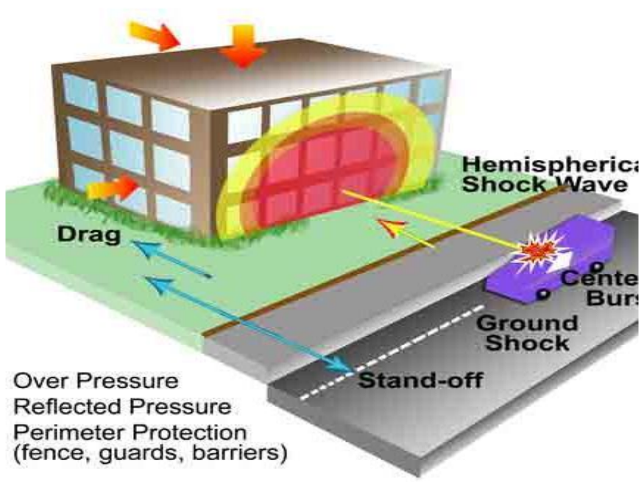

Fig 1: Blast Wave Propagation

II. ANALYSIS

Blast analysis is a subset of structural analysis and in the calculation of the response of a building structure subjected to blast load. It is part of the process of structural design, earthquake engineering or structural assessment, retrofit in regions where earthquakes are prevalent and the vulnerability of structures. FEMA 356(ASCE 2000) outlines four different analysis procedures for a performance-based evaluation of a structure: 1. Linear static procedure 2. Linear dynamic procedure 3. Non-linear static procedure (Push-over analysis) 4. Non-linear dynamic procedure (Time history analysis).

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III. LITERATURE REVIEW

Various literatures reviewed on blast loading are carried out below.

Jayarajan .P (2015) , Proposed a procedure and concepts to obtain dynamic response of reinforced concrete flexural members subjected to blast loading is explained. The software's such as AUTODYN, DYNA3D, LSDYNA and ABAQUS can be used. The blast load calculations are explained .The SDOF used for dynamic analysis is explained. The calculation of blast load and the parameters such as weight of explosive and standoff distance to be considered during blast pressure calculation.

Mujtaba M. N. Shuaib et al (2015), Conducted a parametric study of reinforced concrete slabs under blast loads. The slab considered was subjected to close-in detonations of three different charge weights for a constant standoff distance. For the study, the slab was analysed using the numerical method by means of nonlinear finite element analysis. From the parametric studies, it is found that slab deflection can be controlled by adjusting slab reinforcement ratio or explosive standoff distance.

Russell P. Burrell et.al.(2014) . Studied the response of SFRC columns under blast loads . SFRC improves the blast performance of columns .The maximum residual displacements are reduced. Damage tolerance increased due to the presence of SFRC. Ability to eliminate secondary blast fragments in SFRC columns.

Manmohan Dass Goel et.al.(2014) . studied the blast-resistant design of structures .In this paper various strategies for blast mitigation are reviewed. And the fundamental aspects of blast-induced impulsive loading & material characterization at high strain rates are explained. The local and global responses of structure under last loading such as spalling, breaching, shear failure flexural failure etc are explained. The spread of shock wave during blast loading is shown in fig .1.

T.Krauthammer (2014). Made a numerical assessment for blast resistant design. In this paper the Computational approaches, essentiality of blast resistant design, simple approaches of SDOF, numerical approaches (finite difference) are explained.This paper is a step for blast resistant design by using numerical method.

Jakob C. Bruhl et.al.(2014). Conducted a preliminary study of blast response of steel –plate reinforced concrete walls. An analytical study on steel plate concrete walls is done. The deflection computed using SDOF and FEM provide similar results. In this paper compared the blast response of reinforced concrete (RC) and steel concrete panels (SC). SC panels provide better protection to a blast load than an RC panel. It is found that sandwich steel panels are efficient in blast mitigation.

Amr A. Nassr et.al.(2012). Investigated the performance of steel beams under blast loading is explained. Blast tests on wide flange steel beams are done. It is found that higher permanent deformation close to the bottom because of non uniform pressure distribution and large deformations due to reduced ductility. The Strain rate is maximum at the time of zero displacement and it decrease with increased displacement

Chenqing Wu et.al.(2011). Conducted the blast testing of aluminium foam–protected reinforced concrete slabs .Studied the performance of Aluminium foam protected RC slabs against blast loads and found effective in mitigating blast effect on RC slab. It provides better responses than non protected RC slab. The resistance of aluminium foam increases with increase in density of the foam instead the thickness of foam.

Song F. Jan et.al.(2008). Investigated the behaviour of FRP-RC slabs under multiple independent air blasts . Behaviour of RC slabs strengthened by an FRP sheet under blast is studied .It is found that FRP effective in improving the ductility of test slabs under blast. Independent explosions are conducted on test slabs. CFRP, GFRP are also tested and found effective in blast resistant design.

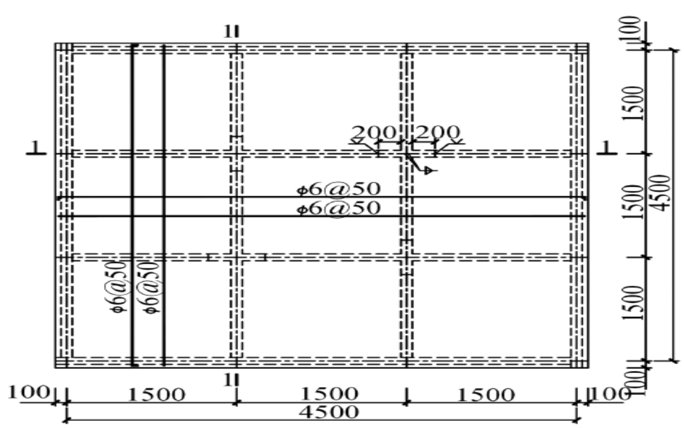

Fig 2 Dimension of slab

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IV. MODEL OF SLAB

Waffle slab are used nowadays for car parking's, airports etc. A new kind of composite waffle slab is proposed in ASCE journal. It is waffle slab with flat slabs and steel girders. The ribs in the waffle slab are replaced by steel girders .A static analysis of this slab is done using ANSYS 15. Fig.2 shows the dimensions of slab. A quarter span of the slab is analysed in ANSYS by using symmetry boundary conditions. A steel concrete composite waffle slab was analysed in this study shown in Fig 3. The specimen of size 4700x4700mm with clear spam 4500x4500mm.The RC slab of 50 mm thick and the steel girder 200 mm in height, reinforcing bars of 6 mm diameter spaced at 50mm with a cover of 6mm, and shear studs are provided with 10 mm diameter, 40mm height, 50 mm transverse spacing, and 80 mm longitudinal spacing. The concrete strength 33.8 MPa. The elements used are SOLID 65, LINK 8, LINK 180.The simply supported boundary condition is provided. To analyse quarter span symmetry boundary condition is provided. The model is validated by static analysis.

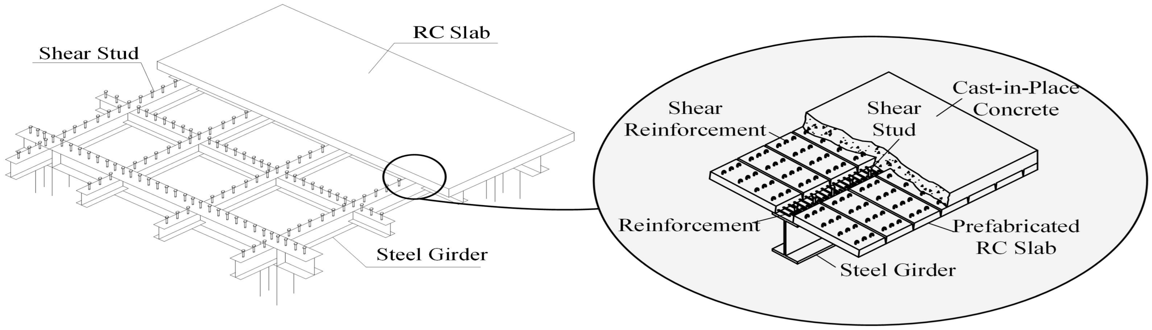

Fig 3 Steel Concrete Composite Slab

V. BLAST LOAD ANALYSIS

The blast load was calculated using the UFC 3-340-02 by varying standoff distance and weight. The simplified triangle shape of the blast load profile was used. The pressure time obtained from UFC 3-340-02 is used for analysing the stresses and deflection time history of slab when subjected to blast loading. In the study the resistance of waffle slab to blast loading is by providing CFRP sheet, effect of aluminium sheet etc are studied. In this thesis one standoff distances and three TNT are chosen. The distance of detonation considered is 0.5m,1m,1.5m.The weight of TNT chosen 1kg.Using the distance of detonation and weight of explosive scaled distance is calculated. Using UFC-3-340-02 the pressure, arrival time, positive phase duration, velocity of shock wave etc are calculated developed for each scaled distance. The pressure and time duration of shock wave obtained from UFC-03-340-02 is used for analysis of waffle slab in ANSYS explicit dynamics. By varying the distance of detonation and weight of explosive the effect on waffle slab is measured. The stresses, displacement developed in the slab are measured.

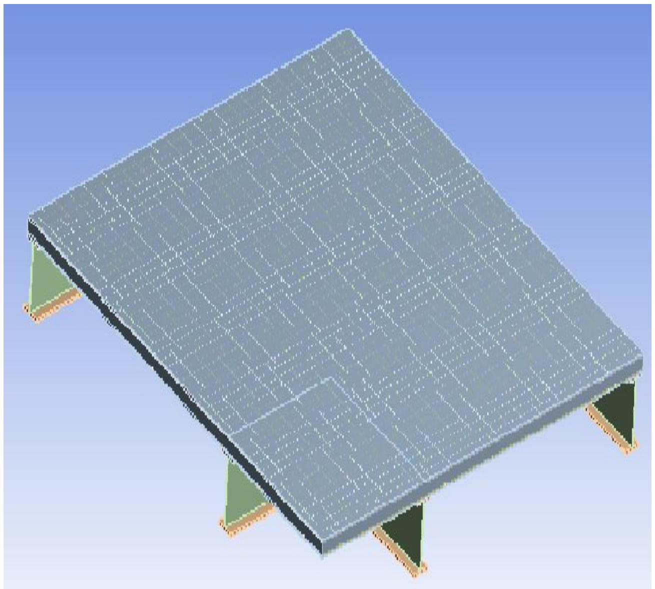

Fig.4 Model of Waffle Slab

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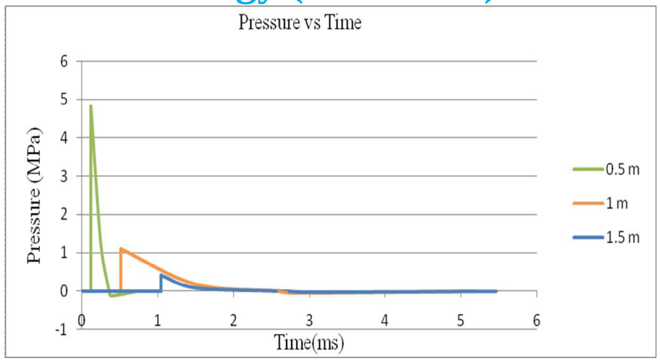

Fig 5 Pressure Time graph for 1 kg TNT

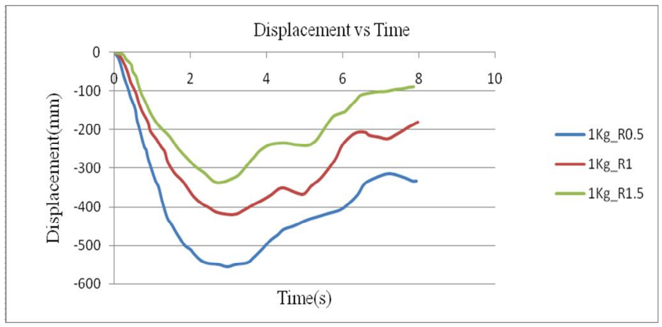

Fig..6 Displacement Time curve for 1 kg TNT

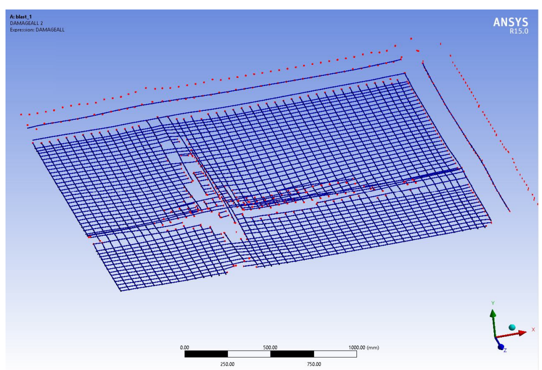

Fig 67Damage level of reinforcement for 1kg of TNT

The Fig 7 above shows the damage of reinforcement during blast loading. The rupture of reinforcement occurs in the region of steel girders because the stresses developed during blast loading are taken by the steel girders below the slab .When the stresses reach max the failure of slab occurs. At first the crushing of concrete and followed by rupture of concrete.

A. Waffle slab modified with CFRP sheet

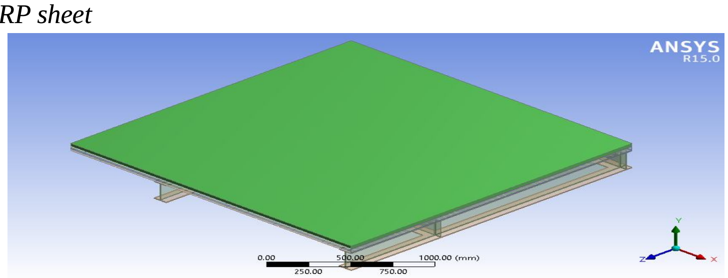

Fig 8 Waffle slab with CFRP sheet

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The model of the slab with CFRP sheet is shown in above Fig 8. The CFRP sheet is bonded by using epoxy coatings in usual practice. It has high strength and flexibility. It resists the blast load by energy dissipation. By using CFRP the displacement of slab is reduced. It is found that with increasing thickness of CFRP the displacement of slab also decreased. The displacement –time curve of waffle slab strengthened with CFRP sheet is shown in Fig.8.The displacement of the slab decreased in the range of 42% to 82% by using CFRP sheet of varying thickness from 10 mm to 40 mm. It has high strength and flexibility. It resists the blast load by energy dissipation. By using CFRP the displacement of slab is reduced. It is found that with increasing thickness of CFRP the displacement of slab also decreased. The displacement –time curve of waffle slab strengthened with CFRP sheet is shown in Fig.9.The displacement of the slab decreased in the range of 42% to 82% by using CFRP sheet of varying thickness from 10 mm to 40 mm.

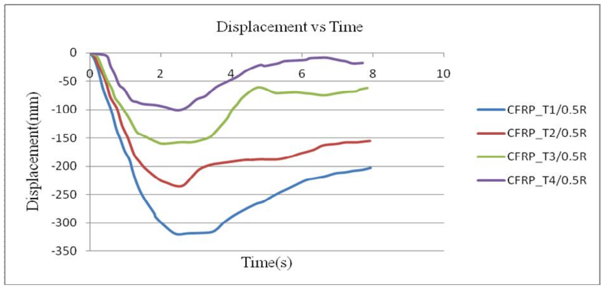

Fig 9 Displacement – time curve for 1kg TNT of varying thickness

B. *Waffle slab modified with Aluminium Foam sheet*

.Aluminum foam sheet is used as sandwich panels with light weight and have good energy dissipation. The properties of aluminium foam sheet are obtained from static tests. The properties are Poisson’s ratio-0.34, density-450 kg/m^3, elastic modulus-52 MPa ,shear modulus -199 MPa .[21]The aluminium foam of varying thickness ranging from 10 mm to 40 mm of constant density is analysed in this thesis . Aluminium foam sheet is light weight and found it have high energy dissipation capacity. The foam sheet with varying thickness of 10mm, 20mm, 30mm, 40mm is used. The displacement time curve of aluminium foam sheet is shown in Fig.10. By using aluminium foam sheet the displacement of the slab is decreased in the range of 16% to 56%.The displacement of the slab decreased from 555mm to 170 mm by using foam sheet of 40 mm thickness. It is found that with increasing thickness of foam sheet the displacement of the slab decreases by energy dissipation. The foam sheet reduces the impact of blasting loading by energy dissipation.

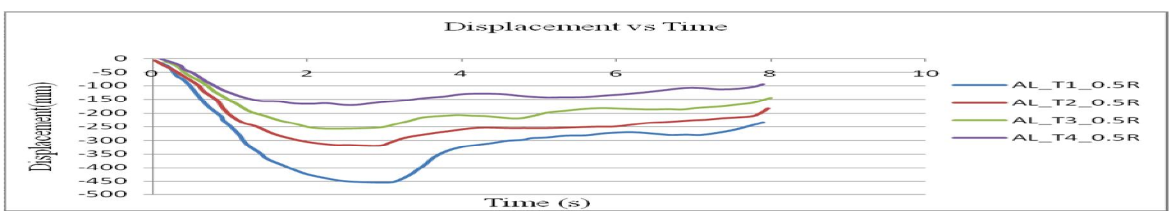

Fig 10 Displacement–Time curve with varying thickness of Aluminum foam sheet

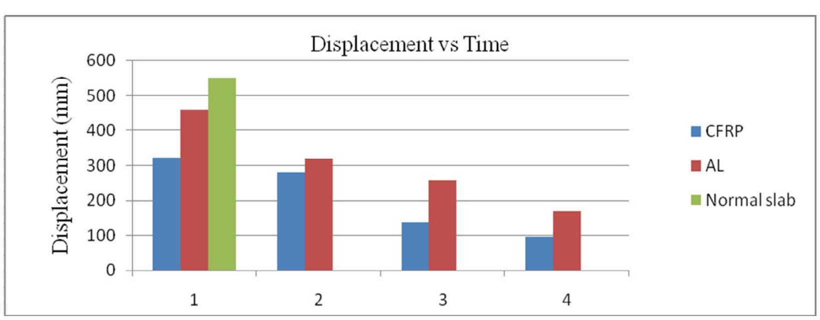

Fig 11 Comparison of Displacement – time curve for waffle slab with & without polymer sheet

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From the chart shown above we can see that by using CFRP sheet and aluminium foam are effective in blast mitigation and have found significant decrease in displacement. From this we can infer that by proving this deformation is prevented by energy dissipation of the polymer sheet.

VI. CONCLUSION

From the study of the blast and pressure loading effects the pressure calculations, duration of shock wave ,velocity are determined using UFC. The rotational capability of the structure is main characteristics under blast loading. If the structure has sufficient rotational capability it resists the effects of blast loading. With increase in distance pressure decreases with 1 kg of TNT.The deflection increases with increase in TNT weight and decrease in standoff distance. The failure of the slab occurs with this chosen charge weight means further improvements required in design by changing reinforcement ratio, grade of concrete.

A. Structural upgrades done using polymer sheet like CFRP, Aluminum foam etc are found to be effective in blast mitigation.
B. With increasing thickness of CFRP and aluminium foam displacement decreases.
C. From these analysis found that 30 mm thick is more effective in energy dissipation of blast loaded slab.
D. The effects of blast loading are reduced by using the CFRP sheet, Aluminum foam by energy dissipation.
E. The CFRP mitigation reduced the overall displacement of the slab by approximately 60% and retained flying debris.
F. The CFRP mitigation did not prevent the breach, but did reduce the residual displacements of the slab and velocity of the back face by approximately 75%.

VII. FUTURE SCOPE

A. By changing the reinforcement ratio and its effects on waffle slab can be studied.
B. By using high strength concrete the difference in the stresses developed can be studied
C. The optimum strength required to resist blast load can be analysed.
D. The effect of mitigation by using CFRP sheet and Aluminum foam by varying density of sheet, by providing anchorages etc on the waffle slab and the improvement in the strength can be studied.
E. By providing LSCC on waffle slab and its effects under blast.
F. Check whether the rib spacing, thickness have effect on resistance under blast.

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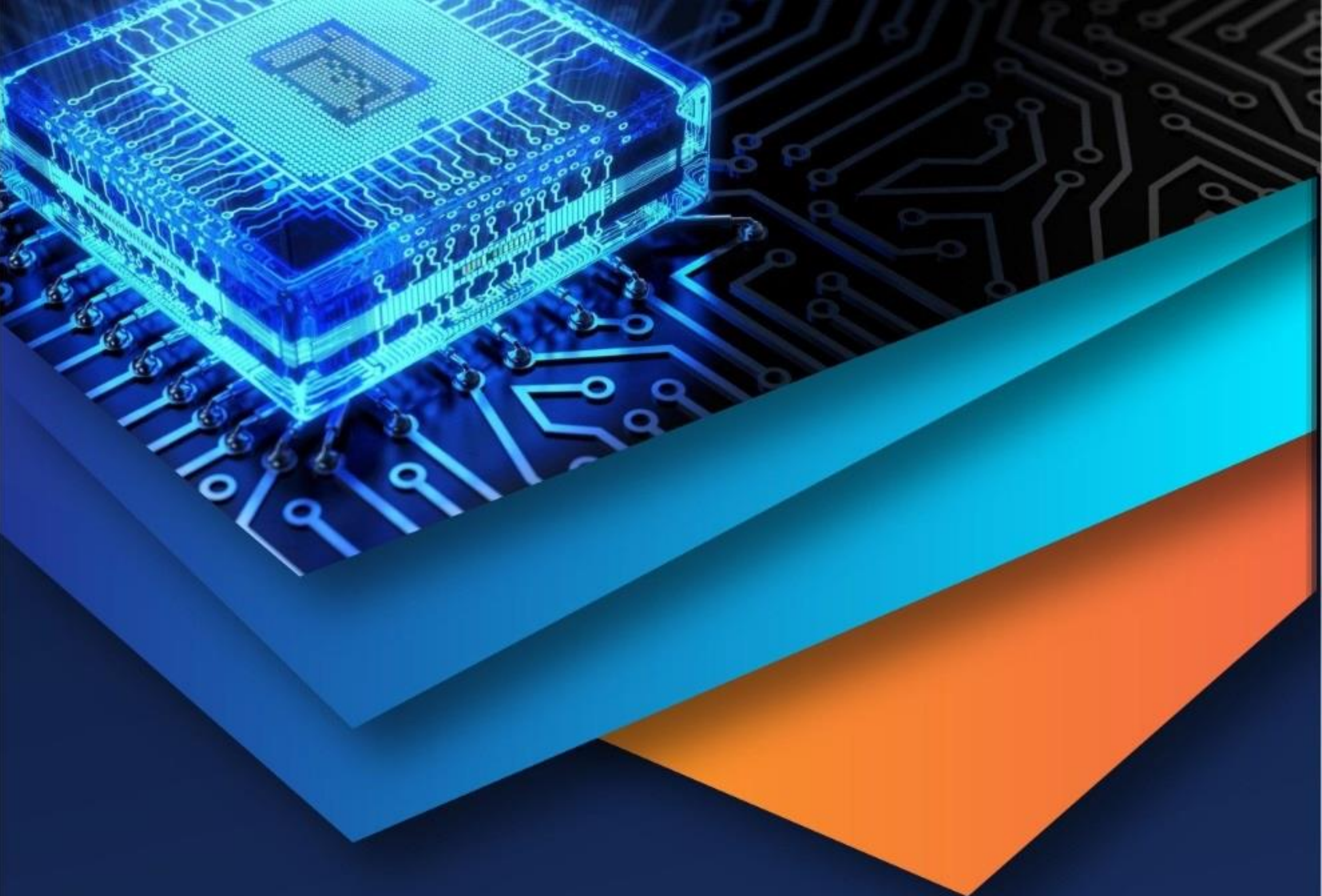

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