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Blast Load Mitigation of Concrete Bridge Circular Piers by External Strengthening of Pier

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Abstract: ***This paper investigates the effect of blast load on various materials used for external strengthening of a circular pier of concrete bridge. In this paper a circular bridge pier of 400mm with 3.75m is used with three different conditions. CFRP laminates are wrapped around the circular pier in first case, CNT rubber lining (composite of LaRC-SI polymer and 1% fraction of SWNT) is used in second case and in the third case conventional concrete is replaced by CNT reinforced concrete. The blast load is applies at mid-height of the pier with 100kg of TNT with varying standoff distance. The results are obtained analytically using LS DYNA software. Results indicate that all three materials are effective in reducing the lateral deflection of pier.***

Keyword: Blast Load, Mitigation, CFRP laminates, CNT, TNT.

I. INTRODUCTION

In recent years, due to the increased terrorist attacks on various important civil structures the need of analysis, design, and protection against blast is necessary. These attacks are carried out using high explosive devices, resulting in destructive effects on survivability of structure and occupants. One of the most important examples of such incident is September 11, 2001 attack at World Trade Centre, New York, U.S., which led to change in focus of more research emphasis towards structure safety against such manmade devastating attacks.

Research so far are on the response of structures to blast loads primarily on buildings. Historical data show, however, that attacks on transportation assets have increased in recent years and that bridges are the most frequently attacked transportation structure. Highway infrastructure can be an attractive terrorist target because the loss of a critical component. Bridges pose unique challenges because these structures must remain accessible to the motoring public. Consequently, adequate standoff cannot often be achieved to protect critical bridge members, and many bridge components are loaded directly rather than indirectly through a facade system. Based on this threat level, the acceptable damage to the structure is decided and designed accordingly. For common bridge structures, the dynamic response of columns subjected to blast load usually results in partial or even progressive collapse of the bridge.

II. METHODOLOGY

Strategies to protect structure against the blast can be divided into two major categories: strengthening of members and protection/mitigation strategies. The effect can be reduced mainly by increasing the standoff distance from the threat, because the blast pressure decays very rapidly and even a small distance is important. These mitigation measures are less expensive than the strengthening strategies.

The standoff distance can be increased only where sufficient space is available; however, in a city environment, many times it is not possible to adopt the strategies that require space. In such situations, the sacrificial blast wall provides a better solution and can be adopted or designed against an explosive induced threat.

The various lightweight materials used for this purpose further add to increase blast resistance in comparison with conventional materials. Here instead of using a Sacrifice wall another layer of CFRP laminate and CNT rubber is implemented and its effect is studied.

A. Sectional Properties

Here a Pier of 400mm diameter and 3.75m length is considered for the analysis of results. The Pier is reinforced with 10-12mm diameter longitudinal bars and 10mm diameter ties with 150mm and 100mm spacing. Table shows the input parameters for the concrete and reinforced material models.

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B. Material Modelling

The column is modelled using LS-DYNA software. Here solid element is used for modelling concrete and beam element is used for reinforcement. And material property used for concrete is CSCM_CONCRETE and for steel PIECEWISE_LINEAR_PLASTICITY is used. Solid element used is a 8 noded under-integrated solid hexahedron element. For avoiding hourglassing effect control energy card is being used with HGEN value is 2. Beam Elements is used for modelling both longitudinal and transverse reinforcement in the RC columns (Kyei C. et. al. (2017)).

For concrete there are several material models that can be used like CONCRETE DAMAGE REL3, WINFRITH CONCRETE, JOHNSON HOLMQUIST CONCRETE, CSCM CONCRETE etc. here CSCM Concrete is being used. For reinforcement material type used are Piecewise linear plasticity and plastic kinematic isotropic. Here Piecewise linear plasticity material is used. For making a perfect bonding between the concrete and the steel bars. In the first method, meshing of the concrete and the steel bars is done in such a way that they share common nodes on the interface ensures perfect bonding. In the second method coupling of two parts can be done using constrained lagrangian function. The command only requires, as input parameters of master and slave which will be parts of the model.

The parameters used for modelling of concrete and reinforcement is shown in table 1. Where different parameters like yield strength, modulus of elasticity is given. Figure 1 shows the finite element part of reinforcement and figure 2 shows finite element model of pier before application of blast load.

1) *CFRP Laminates:* CFRP laminate is used for external strengthening of pier/column. Flexural as well as shear strengthening is done along longitudinal direction and circumferential direction. The material model used for CFRP Laminates is ENHANCED_COMPOSITE_DAMAGE model and cylindrical shell section is used for modelling of CFRP. The material properties used is shown in Table 2 (Elsanadedy et. al.(2011)).

Table 1: Parameters Used For Modelling Circular Pier

	Concrete	Longitudinal Bar	Stirrup
FEM Model	Beam element	Solid element : hexahedron	
Yield Strength (Pa)	-	4 X 10^8	3 X 10^8
DENSITY (Kg/M^3)	2500	7850	7850
Elastic Modulus (Pa)	-	2 X 10^11	2 X 10^11
Poisson's Ratio	0.15	0.3	0.3
Tangent Modulus (Pa)	-	2 X 10^9	2 X 10^9
Failure Strain	-	0.15	0.19
Unconfined Compressive Strength	40000000 Pa	-	-

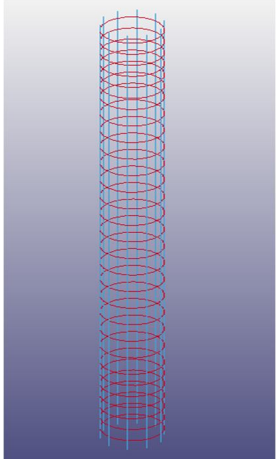


Fig. 1. FEM model of reinforcement

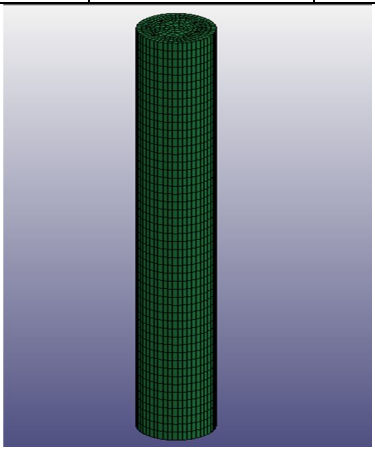


Fig. 2. FEM model of Circular pier before application of Blast load

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Table 2: Material Properties Used For Cfrp Laminates

Material model	Enhanced composite damage model
Thickness	2 mm
Young's modulus in longitudinal Direction	82000 MPa
Young's modulus in Transverse direction	8200 MPa
Poisson's ratio	0.25
Longitudinal Tensile Strength	834MPa
Transverse Tensile strength	83.4

For the modelling of CFRP sheets, 4-node shell elements were employed. Perfect bond is assumed between CFRP laminates and the pier by using tied_shell_edge_to_surface. The material type used is capable of defining orthotropic material characteristics. Figure 3 shows finite element model of shell element and figure 4 shows finite element model of the pier along with CFRP laminates.

2) *CNT Polymer Lining:* CNT reinforced polymer lining is tested for blast loading. Table 3 shows the material properties used for modelling CNT polymer array. Composite made of the LaRC-SI polymer and the twisted SWNT arrays is used with 1% fraction of SWNT. In order to obtain the polymer/nanotube composite properties, a conventional micromechanics model (self-consistent field model [80]) is used. Modelling the interaction between the carbon nanotube and the polymer is very complex. In the model it is assume that there is a perfect load transfer between the polymer and the nanotube. (Madhavi T. C. et. al. (2013)

Table 3: Material Properties Used For Modelling Cnt Polymer Array

Material model	Enhanced composite damage model
Thickness	2 mm
Young's modulus in longi Dirc	25840 MPa
Young's modulus in Transverse direction	14690 MPa
Poisson's ratio	0.35
Longitudinal Tensile Strength	8160MPa
Transverse Tensile strength	5160 MPa

3) *CNT Reinforced Concrete:* The use of CNT with varying percentage in concrete is taken under consideration. An increase in compressive and tensile strength with increasing CNT content is observed and the changed physical and chemical properties of concrete due to presence of carbon nanotubes are implemented and the effect of blast load on that material is studied. M30 grade concrete is used. Ordinary Portland cement of 43 grade is used with Multi walled Carbon Nanotubes. Coarse aggregate of size 20mm and water cement ratio 0.4 is used with river sand passing through 4.75mm sieves. Different cases are considered with varying CNT content.

C. Blast Loading

For Blast loading load_blast_enhanced keyword is used. This key produces empirical pressure loads that are applied directly to the nodes of the lagrangian, concrete column (Slavik 2012). The blast load produced by this card is very similar to the results obtained from the semi-empirical blast load calculation program. This method is less expensive when compared to experimental method and the detailed Arbitrary Lagrangian Eulerian (ALE) method.

TNT of 100kg weight is applied from 1m standoff distance at mid-height of the pier. This loading effect is considered for 60msec for all the cases. Further the standoff distance is increased and its effect is observed.

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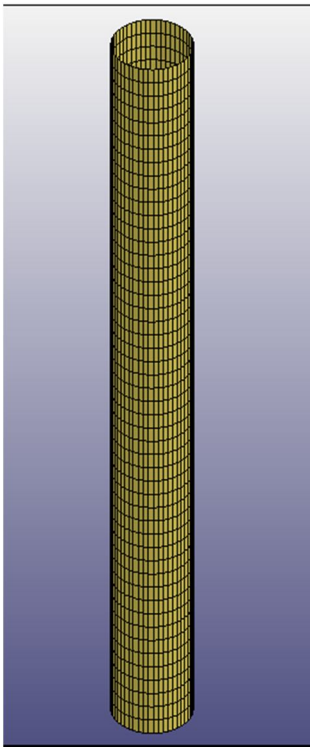


Fig. 3. Fem model of shell element

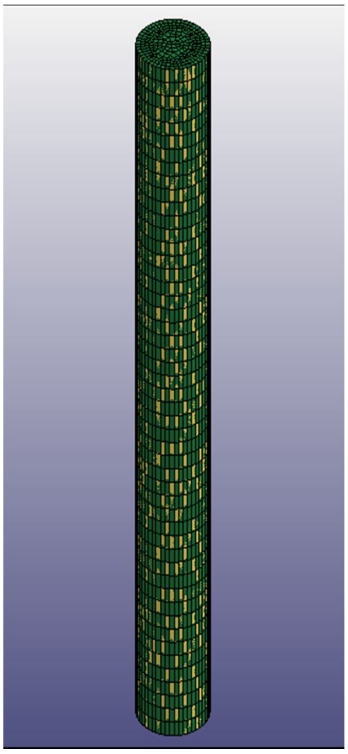


Fig. 4. Model of Circular Pier with CFRP Laminate

III. RESULTS

After application of Blast load the pier is displaced with some lateral displacement figure 5 and 6 shows the model of displaced pier with conventional concrete and with CFRP laminate. Due to the application of blast load, displacement and cover spalling was observed in the pier/column. Graph 1 shows the displacement vs. time variation. The maximum lateral displacement obtained is 55.055mm.

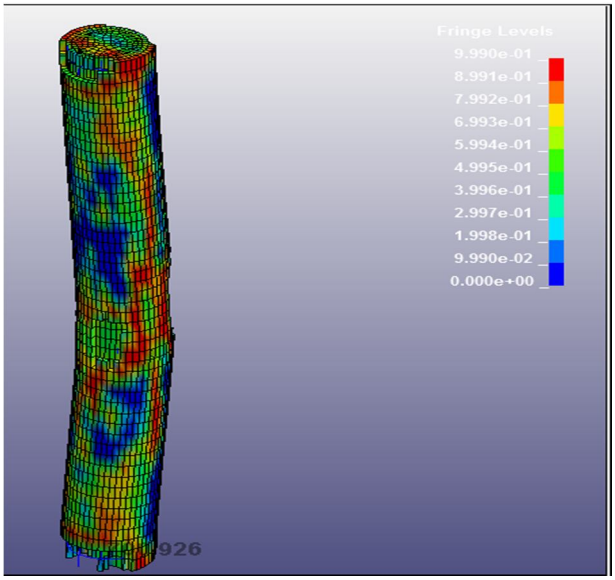


Fig. 5. Model of Circular Pier after application of Load

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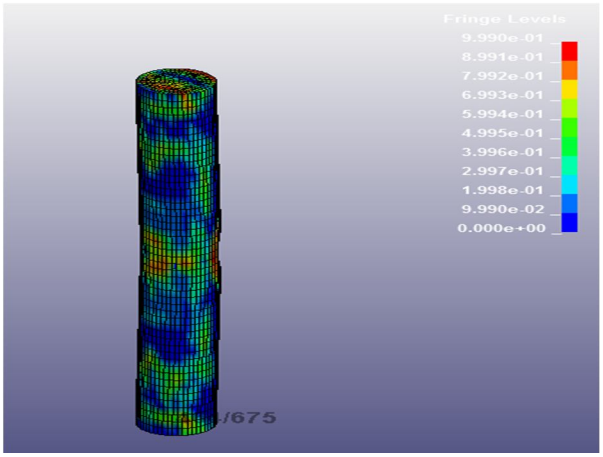
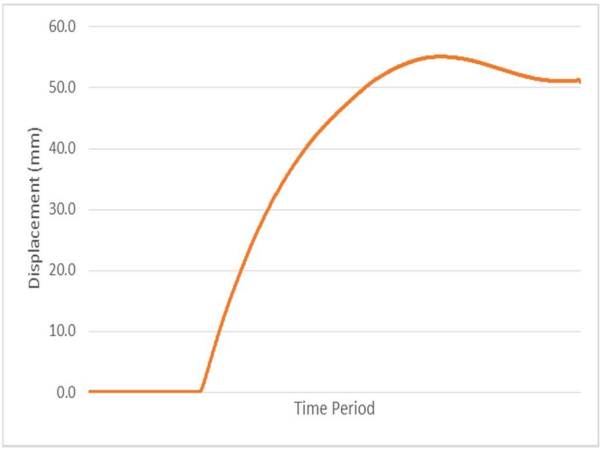
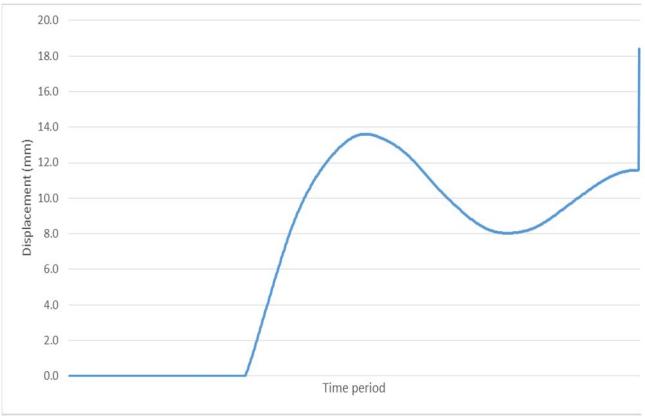


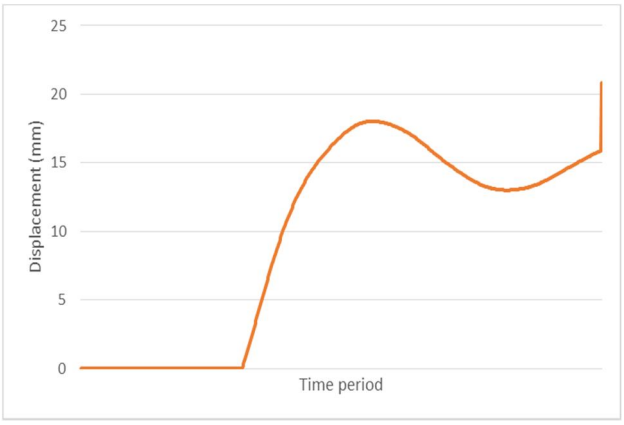
Fig. 6. Model of Circular Pier with CFRP Laminate after application of Blast load



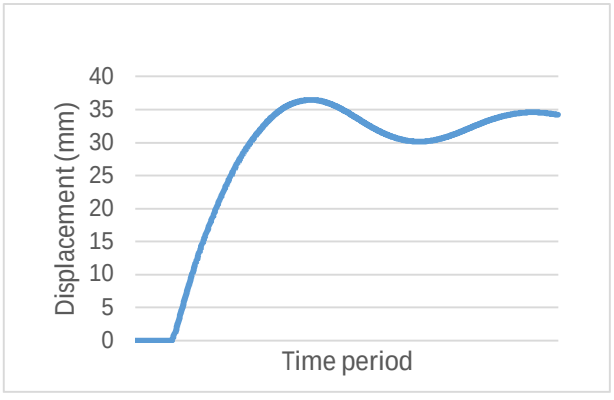
Graph 1: Displacement Vs. Time graph of Circular Pier



Graph 2: Displacement vs. Time graph of Circular Pier with CFRP Laminates



Graph 4: Displacement Vs. Time graph of Circular Pier with CNT polymer array



Graph 5: Displacement Vs. Time graph of Circular Pier with CNT concrete

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Due to the application of blast displacement was observed in the pier/column. Graph 2 shows the graph of displacement vs. time. The maximum lateral displacement obtained is 18.2 mm. Graph 3 shows the graph of displacement vs. time. The maximum lateral displacement obtained is 20.84 mm. Graph 4 shows the graph of displacement vs. time. The maximum lateral displacement obtained is 38.4 mm.

IV. DISCUSSION

Here three different cases are considered. Circular pier of bridge is considered with 400mm diameter and height 3.75m is used with one edge fixed and other end is pinned. In Case I conventional concrete is considered and 100kg TNT charge weight is applied. In Case II CFRP laminates are wrapped around the Pier of case I. In case III CNT reinforced polymer is assumed to be wrapped as lining around the pier. In case IV the conventional concrete is replaced with CNT concrete and first with same steel content another pier is designed and similar pier with another diameter is compared and most effective is taken for further discussion.

By varying the standoff distance as 1m, 2m and 3m with 100kg of TNT is applied on the four cases and the displacement results are shown in table 4. The displacement is for 60 msec and the peak lateral displacement and permanent lateral displacement is noted which is shown in table 4. Here the peak displacement as well as permanent displacement decreases with increased standoff distance. If the meshing is fine in modelling the displacement can be further decreased.

After application of different materials it is observed there is noticeable decrease in the peal displacement and lateral displacement due to different material properties of the different materials. The maximum decrease is observed in CFRP laminates in peak displacement. But of permanent displacement is to be considered CNT lining shows somewhat better results when the standoff displacement is increased. Table 4 shows the comparison of different cases with their behaviour of displacement along time.

Table 4: Lateral Displacement Of Piers With Varying Standoff Distance

	Conventional		CFRP Laminar		CNT lining		CNT concrete	
	Peak displacement	Permanent displacement	Peak displacement	Permanent displacement	Peak displacement	Permanent displacement	Peak displacement	Permanent displacement
1m	55.1	51.055	13.6	18.42	18.1	20.84	36.4	34.4
2m	18.73	8.9	3.6	2.7	5.18	0.9	14.6	13.7
3m	11.35	10.5	1.6	3.81	2.25	2.3	9.52	12.4

V. CONCLUSION

Based on the research, the following conclusions may be made:

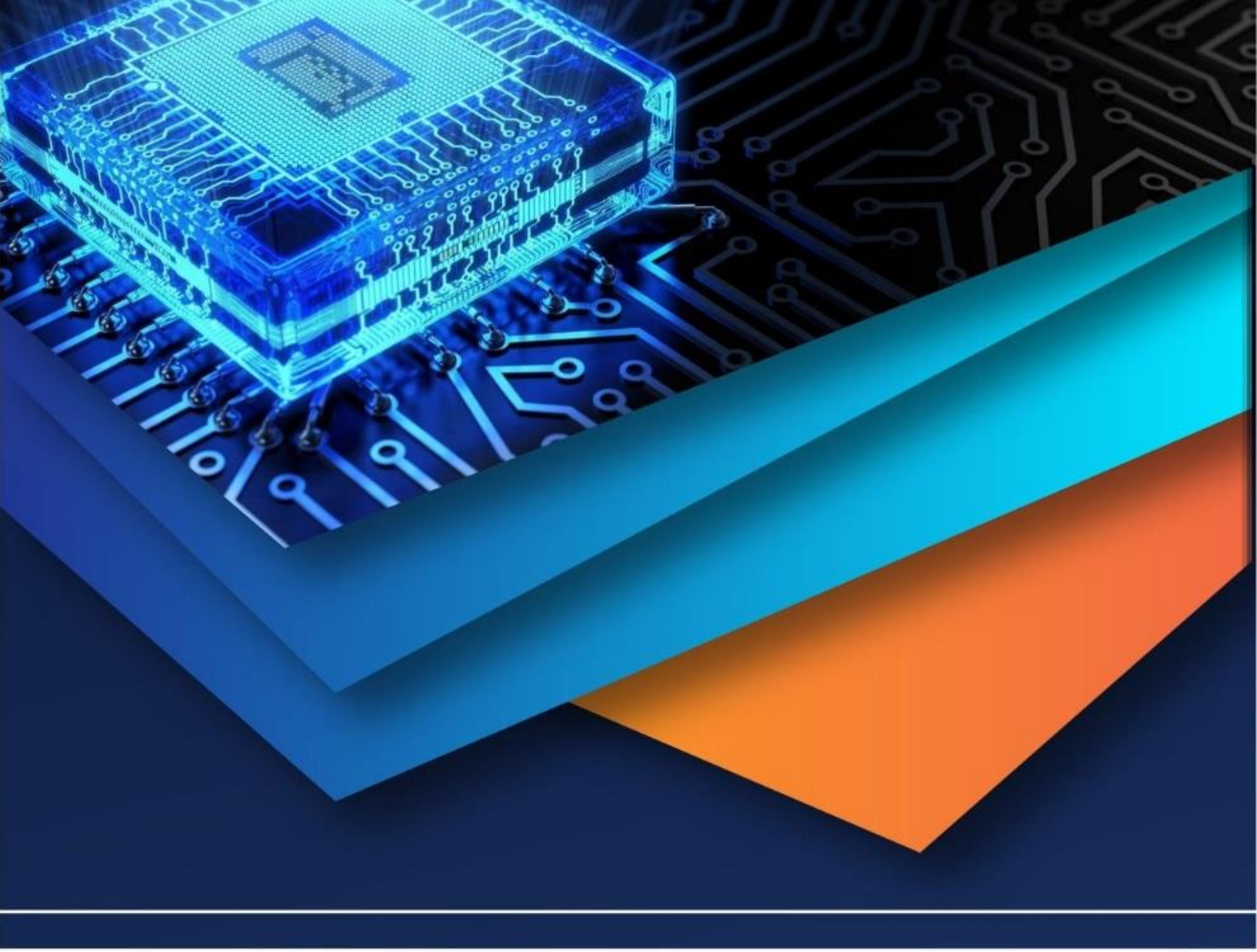
A. The maximum displacement is observed in the circular pier of 55.055mm but when CFRP laminate is wrapped around the pier the displacement is reduced to 18.2mm (66.9 % reduction).
B. When CNT polymer array lining is provided around the pier the displacement observed is 20.84mm (62.14 % reduction for 0.1% CNT content))
C. When concrete is replaced with CNT concrete observed displacement is 39.39mm (28.45 % reduction for 0.1% CNT content).
D. With the increase in standoff distance the lateral displacement is reducing. More will be the standoff distance less will be the damage.
E. When the standoff distance is 1m from the charge weight CFRP laminate shows less displacement in comparison with the other two materials.
F. When the standoff distance is 2m from the charge weight CNT lining seems to be more effective in terms of permanent displacement.

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