State-of-the-Art Review on Dynamic Analysis of Underground Bunkers Subjected to Explosions

Rajat Raj Sinha, Mr. Vijay Kumar Shukla**, Dr. R. N. Khare****

** M.Tech Scholar, Department of Civil Engineering, Vishwavidyalaya Engineering College, Ambikapur, Chhattisgarh*

***Assistant Professor, Department of Civil Engineering, Vishwavidyalaya Engineering College, Ambikapur, Chhattisgarh.*

****Principal, Vishwavidyalaya Engineering College, Ambikapur, Chhattisgarh*

***Abstract**:*

This paper reviews the current state of bunker design and analysis, with a focus on the structural integrity and resilience of bunkers under explosive forces and seismic activities. By examining a range of studies, the review highlights the advancements in numerical simulations and time history analysis used to predict the behavior of bunkers on hard soil and soft soil. Key findings include the importance of material properties, optimal structural configurations, and the impact of mesh size in simulations. Additionally, the cultural and historical significance of bunkers is discussed, emphasizing their evolving role from military applications to civilian uses such as disaster shelters. This comprehensive review underscores the necessity for continued research to enhance bunker design, ensuring both safety and functionality in extreme conditions.

Key Words: Bunker design, Time history analysis, Reinforced Concrete.

1. INTRODUCTION

Bunker design and analysis have gained significant attention due to the critical need for structures capable of withstanding explosive forces and other extreme conditions. Historically, bunkers have been pivotal in military strategy, providing secure locations for storage and protection. In recent years, the scope of bunker research has expanded to include not only military applications but also civilian uses such as disaster shelters and secure storage facilities. Advances in engineering and technology have driven the development of sophisticated design methodologies, employing numerical simulations and time history analysis to predict structural behavior under various load conditions. This paper reviews the current state of bunker design and analysis, highlighting key findings and methodologies from recent studies. It underscores the importance of understanding material properties, structural configurations, and the impact of explosive forces to develop resilient and effective bunkers.

2. LITERATURE REVIEW

Rajvee Patel, Et. Al. 2023[1], This study mainly wants to look at the existing research on blast loads that buildings may face. Also, it aims to figure out how vulnerable those structures are & give helpful tips to architects. To find cost-effective ways to lessen blast impacts while keeping people & infrastructure safe from explosions. We really want lay out a method for calculating how much blast load structures can take. This applies whether the buildings have openings or are simple frame designs. It is important to understand that if a building is designed with a specific safety level in mind, it can handle blasts better. It is crucial to examine how concrete & steel reinforcement behave under the high strain caused by these explosive pressures. The big aim of blast-proof design is to avoid total collapse and major damage. People always need to keep looking for affordable ways to withstand anticipated blasts, especially as better methods come up. There is a strong demand for safer buildings, which means more chances for research & development. With dedicated work on building protective structures, we will find better materials & improved construction methods over time.

Balsukuri Mahesh, Et. al. 2023[2], This paper looks at an underground R.C.C. bunker that faces blast loads. It deals with lots of things, like different blast sizes, how far away the explosion is, the types of concrete & three kinds of soil. The bunker parts are the same each time we check things out. In this used finite element analysis to really dig into how the bunker reacts to those blast loads. We studied all these cases and compared important numbers like total deformation and normal stress. In the end, we aim to suggest which type of soil works best for staying safe when there is a blast.

Anjana Manohar, Et. Al. 2022[3], Terrorist attacks are on the rise every day. Because of this, we really need blast-resistant buildings more than ever. Blast forces can lead to either partial or complete structural collapse, depending on how strong they are. These blast loads are progressive, so it is super important to calculate them rightly. In this paper, we talk about what happens when blast hit a 5-story R.C.C. building. For our analysis and design, we looked at 100 kg of TNT placed 30 meters away from the building. We did the calculations for the blast loads manually using ETABS. We also compared how these blast loads affect the structure with how it behaves under static conditions. Peak displacements, velocity, & acceleration were carefully studied too. When an explosion happens close to or inside a building, it can cause big damage. There is a release of thermal energy and debris, resulting in overpressure. This can lead to injuries and even deaths from the force of the wave front. Blast-resistant structures are helpful in saving lives and protecting property to a great extent. Steel-framed buildings are also good because they are ductile and they can absorb shocks better and keep everything safe.

Ancuta Alexandra Petre, Et. al. (2021)[4], This paper shares some cool ideas about how to design, model & build bunkers storing and unloading solid materials. It is important to understand how granular materials behave inside a bunker. This knowledge helps in making a better design that allows for smooth flow of materials. Engineers have to make sure the bunkers are built strong enough to handle the tasks during use. Many industries use small & shallow bunkers when they don't have a lot of space. But here is a Shallow bunkers can lead to funnel flow problems. This might cause things like segregation or clumping of materials inside, which can really mess up the final product. Also, figuring out where to set up the power supply & how to create an efficient outlet is super crucial. It's actually seen more as a science than anything else.

Deepika Khandelwal, Et. al. 2020[5], this paper is based on some new and different considerations in analysis and design aspects and optimization. One of the objective is to study the difference between analysis and design of conventional structures and important structures or special structures. There are huge different machines in Military bunker which are subjected to axial thrust as well as vibrations. The structure results are found by means of 'ANSYS'. Optimum analysis results in optimum design. As earthquake ground shaking affects all structures below ground in case of a Military bunker and since some of them must sustain or withstand the strongest earthquake ground motion, they have to be designed and checked for different types of design earthquakes.

In this study soil structure interaction of Military bunker is studied using FEA tool ANSYS 16. After applying El-Centro data it is observed that the total deformation, normal stress, shear stress and equivalent (von misses) stress are less in clayey soil as compared to Silty soil and Sandy soil.

Bennett, Luke (2020) [6] This special issue examines the demilitarization and repurposing of former mining bunkers that have continued for fifty years after the collapse of the Berlin Wall and the end of the Cold War. The Introduction clarifies that the contributions have the same goal of investigating how possible innovations and meanings relate to these uncooperative constructs. It is not possible to physically erase these substantial defensive fortifications. The introduction illustrates how sources find those other locations dead or trapped by military aims through their encapsulated discovery and informational investigation by adopting a particularly wide interpretation of 'cultural life' (that is able to accommodate the mould, instrumentation, and sarcasm as cultural trends). Instead, it has been shown that bunker life is a topic of ongoing cultural formation that functions via a variety of contemporary adaptations.

Young-Jun Park and Sangwoo Park (2020) [7] The piece the effects of decreasing the appropriate distance were evaluated for underwater semiautomatic weapons in comparison to surface bump stocks. Based on the results, the anticipated environmental and economic effects of land-type semiautomatic weapons were investigated. Then, in order to build the underground ammunition store and cut down on journey time, numerical simulations were suggested. Within the bunkers, consideration was given to the arrangement of compartments at different depths and the use of explosion prevention equipment. Ultimately, a donation and licensing project approach was examined as the most correct model to construct the underground munitions magazine based on previous research. It was determined that more research into design techniques for subsurface semiautomatic weapons was desperately required to give the subterranean ammunition magazine project life.

Ian Klinke and Bradley Garrett and was published in 2018. [8]. The focus of this investigation was on the bunker, a political platform that was widely present during the 20th century but has consistently been overlooked. This study primarily focuses on the influential research conducted by the late Paul Virilio on the German Atlantic Wall in the 1970s. It also includes an analysis of various historical contexts and incorporates multiple theoretical frameworks. Virilio's theoretical perspective provides valuable information. However, there is a lack of current discussions on the purpose, characteristics, and dimensions of a shelter. The objective is to address this constraint by utilizing three different methodologies. Firstly, we challenge the idea that bunkers provide a feeling of safety and instead present a broader viewpoint that regards bunkers as places where individuals could potentially be eliminated. Furthermore, it is recommended to implement a more extensive classification system that encompasses not only the presumed concrete composition of the bunker but also includes additional materials and media. Ultimately, bunker readings are utilized to showcase the continuous process of generating, acquiring, and interpreting an architectural structure as an antiquated artifact.

Khurshid, Zahid Ahmad Siddiqi, and Hisham Jahangir Qureshi (2018) [9]. In the study Concrete bunkers and silos are commonly used for storing large quantities of commodities. The susceptibility of these structures to seismic forces makes them highly fragile. The current design and development standards for these architectures necessitate the use of specific source code methodologies. The investigation and analysis of complex silos yielded the profiles of bending time, frictional strength, and axial force for a specific sample silo. The validity of the proposed development plan was confirmed through an evaluation of the Finite Element Method (FEM) values for different silo components, including the plates, walls, and hopper. The results of the FEM model and the analysis of various pressures, stresses, forces, and reinforcement ratios in different components of the silos showed a significant level of agreement. Efficient construction of steel and concrete silos requires the implementation of a recommended study methodology.

D. Lecompte, J. Vantomme, A. Caçoilo, R. Mourão, B. Belkassem, and F. Teixeira-Dias. [10]. The purpose of this study is to establish and evaluate a numerical model for analyzing the propagation of a detonation wave. The model utilizes finite element analysis (specifically LS-DYNA) and a simplified representation of a composite surviving box. It incorporates composite reliability (CR) as a key factor. This article explores the design methodology used to create an explosive charge capable of detonating a crayon drawing depicting a survival container. The model collects pressure-time data from multiple locations. The numerical findings were presented in the second segment, subsequent to a comparison of the collected data.

Damir Varevac and Hrvoje DraganiT, [11] The results of numerical simulations in this study are greatly affected by the mesh used. It is crucial to determine the ideal mesh size to minimize computation time and achieve satisfactory results, especially considering the longer processing times required for these simulations. In addition, coupled loading experiments were performed to study the phenomena of occurrences and deflected bubble waves. The purpose of these experiments was to generate optimal meshes for further theoretical calculations of Earthquake Excitation Interactions and Overpasses, with a maximum deflection of 5 m. The hydro coding technique employed the ANSYS Autodyn software to conduct simulations of axisymmetric bombardment by incoming forces and the 3D environment for reflection forces. In the context of axisymmetric analysis, the focus was solely on studying detonation waves. However, in the three-dimensional analysis, the investigation extended to the interaction of blast waves and their reflection off a solid surface. The determination of the most suitable mesh diameters for the analyzed explosion scenarios was achieved by applying Richardson's extrapolation.

Dr. K Subha and Aswin Vijay (2017) [12] The population of the planet is, as we all know, growing tremendously. The needs of enormous population increase are being met by the massive global infrastructure growth. In various regions of the world, there are numerous bridges, urban centers, tunnels, flyovers, etc. that are built every day. These structures might be constructed out of steel, reinforced concrete, etc. The majority of these structures are still made of concrete. Even with the modification and viaducts, the pipes may continue to be supported by reinforced cement piers. Accidents have grown along with the population. There has also been a rise in terrorist activities and vandalism worldwide. Blows may result from these two incidents in separate locations. The vicinity of the viaduct, subway, and bridge foundations is one of the primary locations where these explosions might occur. There might be a multitude of reasons why these steel and concrete piers fail, especially if the piers supporting viaduct projects like metros, fly overpins, bridges, etc. are damaged by explosions. Many different types of loads are produced in the event of an explosion. These loads put stress on the foundations, perhaps ruining the piers completely or in part.

Abass Braimah and Alok Dua (2016) [13] According to the scaled distance used in this article, blow loads may be categorized as long and relatively close loads. Explosions that take place at scaled distances greater or equal to 1,18 m/kg 1/3 are associated with the loading of distant and nearby objects. The explosive waves from a far-off explosion simultaneously arrive at and exert force on a uniformly distributed target. Sub equations (charts) as stated in UFC-3-3 40, ConWep, or high-level physics tools like LS-DYNA, AUTODYN, and ABAQUS software can be used to calculate the response. It is feasible to compute. On the other hand, the relationships between blast waves and structures get more complex when explosives are close by. High fireball and very high level, non-uniform tensile tension both regionally and temporally are characteristics of approaching events. The unreliability of contemporary literature linkages to determine blasting parameters for explosives that are somewhat near has been shown in several investigations. The explosion mechanism, shock wave propagation, and surprise interaction are all represented by numerical programs. However, there isn't much solid scientific evidence to support these theories. Furthermore, test results are given regarding the behavior of the stainless steel plates, façade elements, and sheets/walls for reinforced concrete (RC). The review of the literature indicates that there is limited testing being done on RC columns in the near future, especially with regard to contact explosives. The state-of-the-art situated near and contact explosives are covered in this study in order to understand the current understanding and identify research gaps and requirements.

William A. Wilson, Reisa Dookeeram, and Rupert G. Williams (2016) [14] The expected risks of explosive cargo attacks or similar structural mishaps have significantly grown in recent history. As a result, blast design is a crucial component of building design everywhere and needs to be properly modified. Design Blast This is an attempt to determine the numerical response of a seismically placed Single Degree of Freedom (SDOF) work for blast loading. As a portal structure, the SDOF idea was created to withstand the typical seismic activity in Trinidad's northern region. The 500 kilogram TNT charge was then weighted at standing distances of 45, 33, and 20 meters to establish blast loads for the model. The blast load on the frame was calculated using intermolecular forces. The seismically produced SDOF planar aset reached the plastic region during transmission of the blasting load up to the critical stop-over distance.

Muhammad B. Siddiqui, Nourhan H. Shaker, Sayed M. Soleimani, and Nader H. Ghareeb (2016) [15] Thus, modeling and simulation might be considered a good choice in this study if the right technology is used. In these studies, the behavior of steel sandwich panels in hexagonal and squared waves under the explosive effects of different concentrations of trinitrotoluene (TNT) is analyzed using the Finite Element ABAQUS® tool. The results of modeling in a certain wave configuration are first validated by comparison with current observations that have been published. After that, she looks at a number of setups using different wall geometrical elements and contrasts the results with the original model. Lastly, we assess the wall thickness and the core form's efficiency and make conclusions.

Carl Lofquist (2016) [16] The goal of this master's thesis is to investigate and develop dynamic models for structures subjected to explosive wave pressures that combine suitable accuracy with computational economy. One way to accomplish this would be to compare two scenarios that handle the seismic excitation burden differently. The cargo is treated as a triangular pulse charge in the first scenario, while the load is treated as a change in speed according to the moment and impulse laws in the second scenario. Both a Ritz vector model and a full model are used to illustrate these instances.

Jiwon Kang, Young Jun Park, and Sangjin Park (2016) [17] The expansion of urban areas and the development of infrastructure have raised concerns about the stability of underground buildings beneath or in close proximity to munitions dumps, as evidenced by this research. Nonetheless, there is some literature on the impact of unintentional explosions on subterranean structures. This work proposes a method for assessing the stability of subsurface structures and validates its use through a case study. The AUTODYN and SPACECLAIM are constructed and mechanically analyzed. The impacts of an explosion are assessed, and vibration speeds are calculated. It has been determined from the outcomes of this test case that the underground structure formed 70 meters below earth might seldom ever be impacted by the fictitious explosion. The subsurface munition complex might be constructed using the research's methodology, which can also be used to examine the stability of subterranean facilities subject to periodic vibration.

Gauri Dilip Ambekar, Et. al. 2015[18], The main goal of this study is to look at how the Bunker performs under linear static conditions. We also want to find the best size & weight for it without breaking the bank. To do this, we checked the Ansys against acceptable stress limits to ensure safety. The linear static analysis used the finite element method. We looked at different loads: live loads, wind loads, and dead loads. Then, we talked about the weak points in the structure. We compared what we saw performance and damage patterns with the results from STADD Pro's linear static analysis. Overall, the results showed that our bunker design stays within the safe limits for IS 2062 grade B steel material. Plus, data from STADD Pro v 8i matched up nicely with the ANSYS results.

Jiriceka, Pavel, and Marek Folgar (2015) [19] Several numerical simulations were used in this article to introduce the topic. The simulations look at how regular and subcaliber rounds affected the pre-World War II army bunkers in Czechoslovakia. The infiltration of military equipment is analogous and well-documented. A portion of a wall with defensive devices makes up the model numeral. A sub-caliber and standard bullet has an impact on the concrete block. The model is divided into layers to aid in evaluating the results. The program ANSYS AUTODYN is used to process simulations. A material model with built-in strain and nonlinear damage was used. The results of the numerical simulation are analyzed because of the harm that the concrete block did. Time-based damage progression is provided. The reported penetrations match the numerical simulation quite well.

T. Ngo Et.al. 2007[20], This paper gives a friendly look at how explosions affect structures. First, let’s chat about what explosions are, plus how blast waves act in the air. It shares some handy ways to figure out blast loads & how buildings might respond. For places with high risks think tall buildings in cities. It’s crucial to consider how to design against big events like bomb blasts or swift impacts. It’s a good idea to think about adding some guidelines for unusual load situations. Also, making sure there are rules for preventing progressive collapse should definitely be part of current Building Regulations & Design Standards. It is requirements for ductility levels can really make a difference in how buildings hold up when things get tough.

3. CONCLUSION AND PROPOSED WORK

The reviewed literature spans a diverse range of topics related to the design, analysis, and adaptation of structures subjected to explosive forces. One study emphasizes the need for more research into design techniques for subsurface semiautomatic weapons and the development of subterranean ammunition magazines. Another highlights the ongoing cultural formation and repurposing of former military bunkers, while additional research focuses on theoretical frameworks and historical contexts surrounding bunkers. Research addresses the seismic fragility of concrete bunkers and silos, validating design methodologies through time history analysis. Other studies explore the propagation of detonation waves using time history analysis, emphasizing the importance of composite reliability. Investigations also look into the impact of mesh size on numerical simulations of explosions and the interaction of blast waves with solid surfaces, recommending optimal mesh diameters for accurate results. Additional studies analyze the behavior of steel sandwich panels under explosive effects, assess the stability of underground structures subjected to vibrations and explosions, and evaluate dynamic models for structures under explosive wave pressures. This comprehensive review underscores the multifaceted nature of blast-resistant design and the critical need for continued research to enhance the resilience and functionality of these structures. Bunker and some of them have to be developed and controlled for many kinds of earthquakes because they need to maintain or stand up to the greatest earthquake movement. By examining a range of studies, the review highlights the advancements in numerical simulations and finite element analysis used to predict the behavior of bunkers on hard soil and soft soil by using STAAD Pro.

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