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BEHAVIOR OF BUNKER UNDER THE BLAST LOADING

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Abstract:

This research offers a thorough approach to the design of bunker structures exposed to blast loads, employing STAAD.Pro V8i for analysis and modeling. The increasing need for efficient and secure storage facilities in industrial settings calls for a robust design methodology that considers potential explosive incidents. This work details the theoretical framework for calculating blast loads, taking into account factors such as charge weight, distance, and structural response. The design and analysis of bunkers under blast loads are crucial for maintaining the safety and structural integrity of essential infrastructure in areas vulnerable to explosive threats. Using STAAD.Pro V8i, various blast scenarios are simulated to assess the static behavior of bunker structures. The model integrates material properties, geometric configurations, and boundary conditions relevant to real-world applications. The results emphasize the concrete design parameters for blast loads and contribute to structural safety. The results highlight the significance of incorporating advanced modeling techniques into the design process, resulting in optimized bunker structures that adhere to safety standards while ensuring functionality.

Keywords: *Bunker design, Blast load, STAAD.Pro V8i, Structural analysis, Safety engineering.*

1. INTRODUCTION

A bunker is a fortified structure created to shield against a range of threats, including explosions, missile attacks, and natural disasters. Constructed from robust materials such as concrete, steel, or earth, bunkers are designed to protect occupants, equipment, and valuable assets from blasts, debris, and other dangerous conditions. They are commonly utilized in military, civil defense, industrial, and even private sectors where security and protection from external dangers are essential. While the specific function of a bunker may vary based on its intended use, its main objective remains to provide safety against high-impact incidents like explosions or assaults.

Bunker design focuses on constructing structures that can endure severe blast forces, often resulting from explosions like those from bombs, missiles, or accidental detonations. Such structures are typically located in military installations, hazardous material storage sites, and occasionally in critical infrastructure or facilities that demand heightened security. The primary aim of bunkers is to safeguard individuals, equipment, or materials from external dangers, especially explosions. Blast loading refers to the pressure applied to a structure during an explosive incident, and effectively managing these forces is a key priority in bunker design.

1.1 Contemporary Applications of Bunkers

- **Nuclear Shelters:** Numerous modern bunkers are specifically engineered to safeguard against nuclear detonations and the resulting fallout. These structures are equipped with robust shielding and are typically situated underground to shield occupants from radiation, heat, and explosive forces.

- **Data Facilities:** Certain data centers, particularly those that manage sensitive or critical information, are located within fortified bunkers to defend against cyber threats, physical attacks, and environmental hazards.

- **Personal Shelters:** In recent years, individuals and families have increasingly constructed bunkers for personal safety, especially in regions prone to natural disasters, civil unrest, or the potential for nuclear conflict.

- **Protect People:** Bunkers primarily safeguard individuals and valuable resources from the destruction caused by enemy bombs. They help prevent ear and internal injuries from nearby explosions by deflecting the blast waves generated by detonations.

1.2 Objectives of study:

1. Modeling the structure for blast loads in both the normal zone and seismic zone IV.
2. Designing concrete for both models.
3. Comparing the concrete design results, specifically for columns and beams, across both models.

2. LITERATURE REVIEW

Chen, et al. 2015[1], A research study examined bunker blast analysis through the use of SAP2000. The authors created a model of a reinforced concrete bunker and applied different blast loads by utilizing a time-history function to replicate the pressure pulse. The findings indicated that dynamic analysis (time-history) yielded more precise predictions of structural behavior compared to static loading assumptions, particularly regarding plastic deformation and failure modes. Key Findings of this paper is Hybrid material bunkers demonstrate enhanced blast resistance. The integration of reinforced concrete with steel can improve structural performance in blast scenarios.

Wu, et al. 2016[2], utilized SAP2000 to model the dynamic response of a military bunker subjected to different sizes of explosive charges and varying distances. Their findings revealed that the interaction between the blast wave and the structure had a significant impact on the bunker's performance, emphasizing the necessity of time-history analysis in the software for obtaining precise results. The study also investigated the post-explosion behavior of bunkers, specifically how they deform and preserve their structural integrity following a blast. By employing both static and dynamic modeling techniques, they analyzed the progression of damage, stress redistribution, and failure propagation within the bunkers. Their results underscored the critical need for designing bunkers with adequate resilience to ensure continued functionality after an explosion, especially for essential infrastructure. Key finding in this paper is Bunkers must be constructed with resilience as a priority, ensuring they remain operational even after experiencing substantial blast damage. Conducting a post-blast evaluation is essential for determining the bunker's capacity to endure secondary impacts such as fires and debris..

Bansal and Singh, et al. 2016[3], This study investigated the design of military bunkers under blast loads utilizing STAAD.Pro. Their research underscored the advantages of nonlinear dynamic analysis in forecasting the structural response, particularly when reinforced concrete was employed for the bunker shell. The study specifically examined steel bunkers exposed to blast loads, employing both linear and nonlinear dynamic analyses to evaluate stress distribution, deformation, and failure modes. The authors concluded that nonlinear analysis offered a more accurate depiction of the bunker's performance, especially regarding plastic deformation and energy absorption. Finding in this study is Steel bunkers exhibit superior performance under blast loads due to their high ductility. Accurate simulation of real-world blast events necessitates the use of nonlinear dynamic analysis.

Swamini T. Gaikwad, et al. 2017[4], Aim to demonstrate that blast loading can be analyzed both analytically and through software simulations. Given the rise in terrorist attacks in our country, it is crucial to design structures with blast loads in mind to enhance security. The protection of buildings against blast effects should be integrated into both architectural and structural design processes. A comprehensive understanding of blast characteristics will facilitate the development of more effective blast-resistant building designs. This paper discusses essential techniques for improving a building's capacity to withstand blasts, addressing both architectural and structural perspectives. The increasing frequency of terrorist attacks in recent years underscores the importance of considering blast loads in the design process.

D. Yogeswar, et al. 2017[5], In this paper examined the effects of blast loading from nuclear explosions on buildings. The recommendations provided focus on the structural integrity necessary to endure the forces generated by a surface burst of a nuclear weapon. The study outlines the key parameters influencing the forces acting on a structure, followed by a description of the peak force magnitudes and their time variations. It also includes specific details regarding the net forces impacting various fundamental structural types. Given the complexity of designing for blast loading, a solid understanding of mitigation strategies is essential, as the approach is not only technical but also cost-sensitive. The discussion further addresses how the size and function of a structure affect its performance, along with an overview of the fundamental properties of reinforced concrete and steel. The protective structural analysis is grounded in established guidelines, including the Tri-Service Manual TM 5-1300, ASCE Manual 42, FEMA guidelines, and Indian Standards.

M. Meghanadh, et al. 2017[6], In this study examined the impact of blast loads on a five-story reinforced concrete (R.C.C) building. The analysis focused on a blast source of 100 kg of trinitrotoluene (TNT) located 40 meters from the structure. Blast loads were calculated manually in accordance with IS: 4991-1968, and a force-time history analysis was conducted using STAAD Pro. The study compared the effects of blast loads on the structure with its behavior under static conditions, investigating parameters such as peak displacements, velocity, and acceleration. The concept of blast-resistant design aims to enhance the structural integrity of buildings to prevent complete collapse. This study on a G+5 residential building demonstrates that increasing the stiffness of structural members by enlarging their dimensions yields better performance, which also helps counteract uplift forces on footings by increasing dead weight.

Rohini, et al. 2017[7], In this study STAAD.Pro was employed to model the loading effects of blasts on a reinforced concrete bunker. The findings highlighted that dynamic loading (time-history analysis) is crucial for accurately predicting displacements and stresses, particularly in reinforced concrete bunkers exposed to significant explosions. The authors provided an in-depth examination of finite element analysis (FEA) and computational techniques for assessing the structural response of bunkers to dynamic blast loads. Their research utilized both STAAD.Pro and ABAQUS to simulate various explosive scenarios, including near-field and far-field blasts. The study underscored the necessity of incorporating dynamic load cases to effectively simulate the impacts of explosions. Key Findings is FEA is vital for capturing the nonlinear behavior of bunker structures under blast loading. Implementing dynamic models yields more precise stress analysis and deformation forecasts.

Deeks and Chen, et al. 2017[8], In this study conducted a review of current design codes and standards related to bunker design under blast loads. Their research primarily examined international codes, including those from the U.S. Army Corps of Engineers (USACE) and the British Standard (BS), focusing on how these codes calculate blast load intensities, impulse durations, and perform dynamic analyses. The study found that, although these design standards offer valuable guidelines, there remains a significant gap in comprehensive quantitative data for extreme blast scenarios. In this research International standards for designing blast-resistant bunkers should integrate dynamic analysis and material-specific information. Many existing standards tend to rely on static load assumptions, which may lead to an underestimation of the bunker's performance under actual blast conditions.

Balasubramanian, et al. 2018[9], conducted a study examining how bunker geometry impacts its capacity to endure blast loads. They utilized finite element modeling to simulate different bunker shapes, including circular, rectangular, and dome configurations. The findings revealed that curved structures, particularly dome roofs, mitigate the effects of blast waves by evenly distributing pressure. The research highlighted the critical role of optimized geometry in reducing localized blast effects. Key Findings is Dome-shaped roofs and curved bunker walls provide superior blast resistance compared to flat or angular designs. The bunker's shape plays a significant role in the distribution of blast forces.

Ashish Kumar Tiwari, et al. 2018[10], conducted a thorough investigation into the behavior of concrete walls under dynamic loading conditions. The study involved modeling concrete walls subjected to blast loading using the Finite Element Analysis (FEA) software Ansys, followed by analysis in Autodyn, both with and without the inclusion of a steel plate, to assess the effects of blast loading. Ansys Autodyn is highlighted as an effective and user-friendly tool for simulating explosive impacts, seamlessly integrating with the workbench environment. The blast simulations utilized the Jones-Wilkens-Lee (JWL) equation of state for explosive materials. The concrete walls, which come in various shapes and may or may not be clad with steel plates, are analyzed using Autodyn to generate pressure contours and pressure time history plots. This analysis aims to investigate the behavior and impact of incorporating steel. The Autodyn simulation provided a reliable estimate of the pressure time history for both the positive and negative phases observed.

Ian Klinke and Bradley Garrett, 2018[11], They focusing on the bunker—a political platform that was prevalent throughout the 20th century yet often overlooked. This study primarily examines the significant research of the late Paul Virilio on the German Atlantic Wall from the 1970s. It also analyzes various historical contexts and integrates multiple theoretical frameworks. While Virilio's insights are valuable, there is a noticeable gap in contemporary discussions regarding the purpose, characteristics, and dimensions of shelters. This study aims to fill that gap by employing three distinct methodologies. First, we challenge the notion that bunkers offer a sense of safety, proposing instead a broader perspective that views them as potential sites of elimination. Additionally, it is advisable to establish a more comprehensive classification system that not only addresses the suspected concrete composition of the bunker but also incorporates other materials and media. Ultimately, bunker readings serve to illustrate the ongoing process of creating, acquiring, and interpreting an architectural structure as a historical artifact.

Akinyemi et al. 2019[12], They utilized SAP2000 to model a reinforced concrete bunker subjected to blast loads. The findings indicated that with the right reinforcement, the bunker could effectively endure the blast wave. The time-history analysis facilitated the assessment of plastic deformation and potential failure modes. Akinyemi et al. specifically examined the design of reinforced concrete bunkers under blast conditions, emphasizing the structure's capacity to resist both peak overpressure and impulsive forces. Their results highlighted the critical role of reinforcement detailing and structural ductility in reducing damage during explosive events. The research concluded that dynamic analysis, such as time-history analysis, provides more precise predictions than static models. Key Findings is Reinforced concrete is commonly utilized for its resilience in blast scenarios. Dynamic analysis is crucial for accurately forecasting displacements and failure mechanisms.

Lu, et al. 2020[13], In this study investigated how varying explosive charge sizes affect the response of military bunkers using SAP2000. Their findings revealed that dynamic analysis yielded significantly more accurate predictions of deformation patterns than static load assumptions. The researchers conducted an extensive study modeling bunker structure subjected to different explosive charges and distances. Their results indicated that time-history analysis offered deeper insights into deformation patterns and failure mechanisms that static loading assumptions could not adequately capture. Additionally, the study compared the blast resistance of various materials, including reinforced concrete and steel. Key Findings is Dynamic load analysis is essential for evaluating the real-time response of bunkers in extreme conditions. Reinforced concrete is favored for bunker construction due to its superior energy-absorbing properties under blast loads.

Sriram, et al. 2020[14], In this study conducted a review of emerging trends in bunker design aimed at withstanding extreme blast conditions. Their research emphasized the use of advanced materials, including high-performance concrete and composite materials, as well as innovative design strategies such as active damping systems to mitigate shockwaves. The authors also underscored the potential of machine learning (ML) and artificial intelligence (AI) in enhancing bunker designs for improved efficiency and safety. Key Findings in this study is Advanced materials, such as ultra-high-performance concrete (UHPC) and carbon fiber composites, demonstrate significant potential for enhancing blast resistance. The integration of AI and machine learning could transform blast-resistant design by optimizing material choices and structural configurations.

S. P. Bhat, et al. 2021[15], present a project focused on the analysis and design of a bunker built on three distinct soil types. While the components and machinery of each bunker are largely similar, the analysis and design of civil structures within a facility are approached with unique concepts and optimized techniques. This paper introduces novel considerations in the analysis, design, and optimization processes. It includes a study of dynamic analysis and various soil-structure interaction models, with results obtained using ANSYS software. The findings indicate that optimal analysis leads to optimal design. Given that earthquake ground shaking impacts all underground structures, military bunkers must be engineered to endure the most severe seismic events, necessitating evaluations for various design earthquake scenarios. The military structure is evaluated for each of the three soil types mentioned earlier. Parameters such as Total Deformation, Normal Elastic Strain, Shear Stress, and Equivalent Stress are compared to determine the most suitable soil type.

3. METHODOLOGY WORK STUDY

Designing a bunker with STAAD. Pro (a Structural Analysis and Design software) entails a sequence of steps to effectively model, analyze, and design the structure to withstand blast loads as well as other significant forces, including seismic, wind, and live loads.

3.1 Step-by-Step Process for Bunker Design in STAAD.Pro:

Steps in STAAD.Pro for Bunker Design:

1. **Define project parameters** (blast load, codes etc.).
2. **Create the model geometry** for bunker components (walls).
3. **Define material properties** (concrete reinforcement).
4. **Apply loads** (blast loads, dead loads, seismic,).
5. **Model the supports and boundary conditions.**
6. **Run static analysis** to evaluate the blast load response.
7. **Design structural elements** (reinforced concrete).
8. **Verify results**, ensuring safety, serviceability, and performance.
9. **Generate reports and drawings.**

3.2 Load Combinations:

i. Dead load + blast load.
ii. Dead load + live load + blast load (if live loads are considered).
iii. Seismic load + blast load (if the bunker is in a seismic zone).

3.3 Design Codes:

Choose the appropriate design codes for the bunker. For example, if a U.S. Army Corps of Engineers standard, it might be TM 5-1300. You may also need to reference ISO 16933 or Eurocodes for blast-resistant designs.

4. PROBLEM FORMULATION

AutoCAD

AutoCAD software is used for planning the bunker. The building is planned 6.7 m x 6.7 m floor Area. Detail of components are as follow:

For column :- Column size - 400 mm x 400 mm

- Concrete - M30
- Main bar grade – Fe415
- Min size of main bar – 12 mm
- Links (Stirrups bar) grade – Fe415
- Links min size of bar – 8 mm

For beam :- Ground Beam size and Secondary beam - 230 mm x 460 mm Slab Beam Size-460 mm x 460 mm

- Concrete - M30
- Min reinforcement spacing – 40 mm
- Cover : Top – 25 mm
- Main bar grade – Fe415
- Min size of main bar (Top) – 12 mm
- Shear bar min size – 8 mm
- Min no. of legs – 2

For Foundation : - Fixed support

Calculation of blast loads:-

Calculate the Peak Overpressure

$P_{peak}=K\cdot W^{1/3}/r^2$

$= 0.1 \times 10^{1/3}/50^2 = \mathbf{86Pa}$

AT a distance of 50 m

Calculate the Blast Impulse

$I=P_{peak}\times t_d$ $t_d=0.4$ sec

$=86 \times 0.4 = 34.4$ Pa S

AT a distance of 50 m

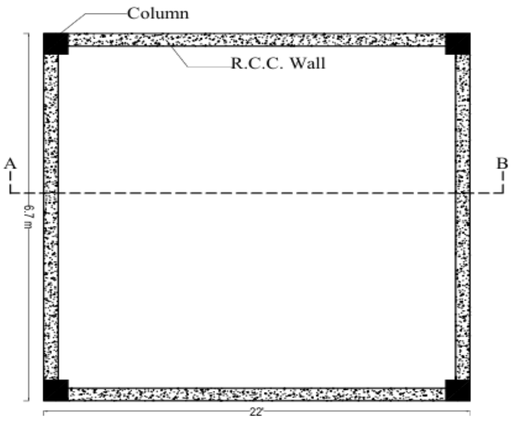
Blast Load to the Structure

$F=P_{peak}\times A = 86$ kN/m^2

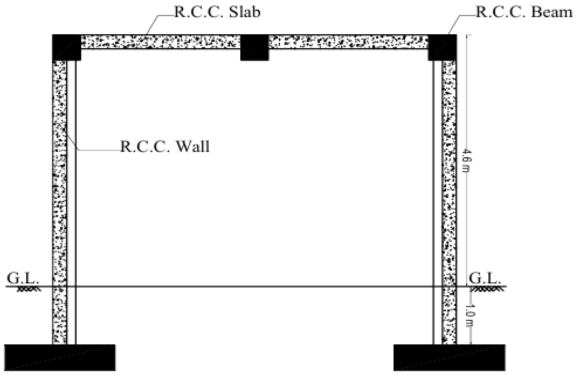
AT a distance of 50 m

5. RESULT AND DISCUSSION

5.1 Modelling and Analysis



Bunker



Section A-B

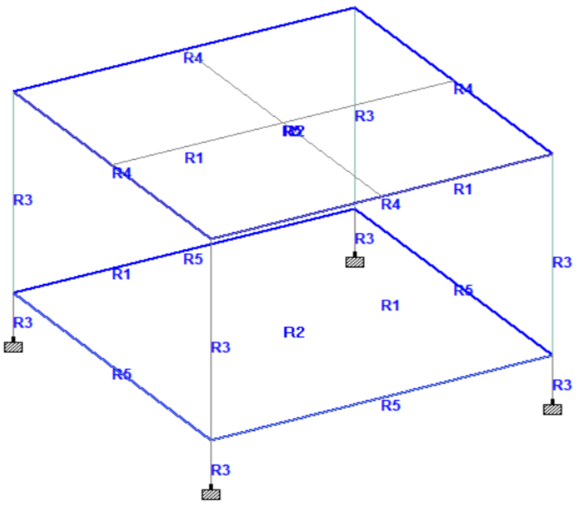


Fig. – Property of the Structure

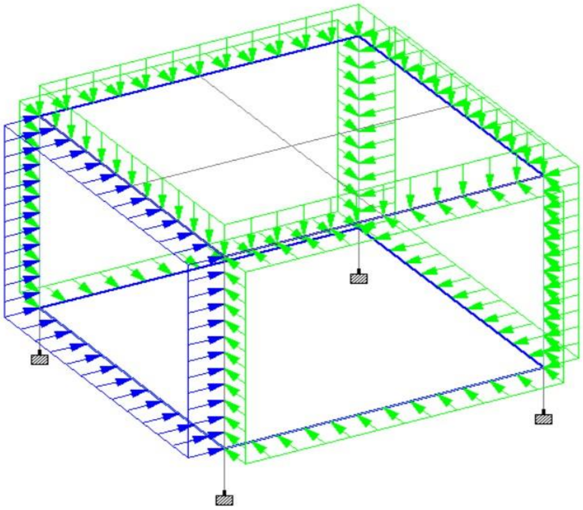


Fig. - Bunker subjected to Blast Load

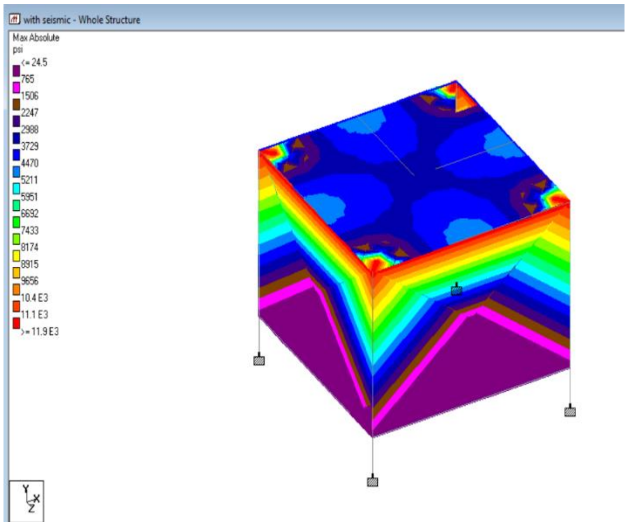


Fig. – Max. Absolute pressure subjected to blast load

5.2 For Plain Area Concrete Design

Name of member	Size of Beam	Cover	Main Diameter	Shear Reinforcement
Secondary Beam SB2	230 mm X 460 mm	25 mm	2-12 mm Top 7-16 mm Bottom (center) 6-16 mm Bottom (end)	2 legged 8 mm @300 mm c/c
Slab Beam SB1	460 mm X 460 mm	25 mm	5-12 mm Top (at end) 4-12 mm Top (at center) 4-12 mm Bottom	2 legged 8 mm @195 mm c/c
Ground Beam GB	230 mm X 460 mm	25 mm	7-10 mm Top (at end) 3-10 mm Top (at center) 3-10 mm Bottom (at end) 4-10 mm Bottom (at center)	2 legged 8 mm @300 mm c/c
Column below GL	400 mm X 400 mm	40 mm	4-20 mm	8 mm @300 mm c/c
Column above GL	400 mm X 400 mm	40 mm	8-12 mm	8 mm @190 mm c/c

5.3 For Seismic Zone IV Concrete Design

Name of member	Size of Beam	Cover	Main Diameter	Shear Reinforcement
Secondary Beam SB2	230 mm X 460 mm	25 mm	2-12 mm Top 7-16 mm Bottom (center) 6-16 mm Bottom (end)	2 legged 8 mm @300 mm c/c
Slab Beam SB1	460 mm X 460 mm	25 mm	8-10 mm Top (at end) 6-10 mm Top (at center) 4-12 mm Bottom	2 legged 8 mm @195 mm c/c

Ground Beam GB	230 mm X 460 mm	25 mm	7-10 mm Top (at end) 3-10 mm Top (at center) 3-10 mm Bottom (at end) 4-10 mm Bottom (at center)	2 legged 8 mm @300 mm c/c
Column below GL	400 mm X 400 mm	40 mm	8-16 mm	8 mm @255 mm c/c
Column above GL	400 mm X 400 mm	40 mm	12-12 mm	8 mm @190 mm c/c

5.4 Reinforcement Details:

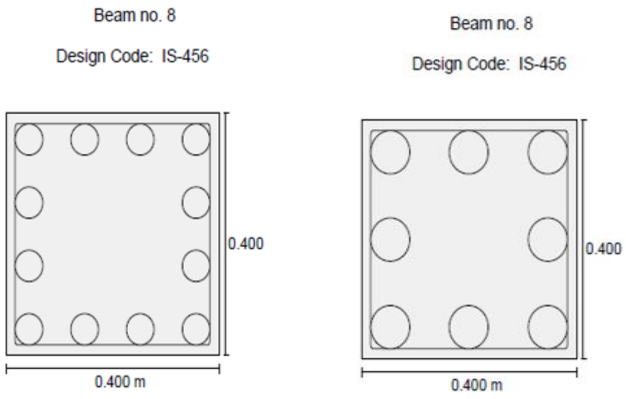


Fig. - Column above Ground level for seismic zone IV and normal zone

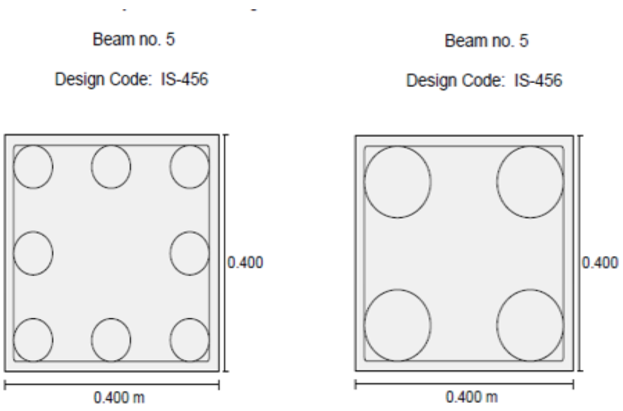


Fig. - Column below Ground level for seismic zone IV and normal zone

6. CONCLUSION

Upon comparing the design specifications of the two models, the following observations were made:

1. For columns located below ground level, the seismic zone IV requires 8 bars of 16 mm, which is significantly higher than the 4 bars of 20 mm needed in a normal zone.
2. In the case of columns, seismic zone IV necessitates 12 bars of 12 mm, which is 4 more than the 8 bars of 12 mm required in a normal area.
3. There is no difference in the reinforcement requirements for ground beams and secondary beams in both the cases.
4. For slab beams (SB) in seismic zones, the reinforcement needed is 5 bars of 12 mm at the top and 4 bars of 12 mm at the bottom, while in normal conditions, it is 8 bars of 10 mm at the top and 4 bars of 12 mm at the bottom.
5. There is no change in the shear reinforcement for slab beams (SB) in both cases.

The analysis results indicate that static blast loads in highly seismic zones do not require significant design modifications compared to those in normal zones. Additionally, Staddpro proves to be an effective tool for analyzing accidental blast loads in structural design.

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