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Finite Element Analysis of Plain and Reinforced Concrete Walls under Blast Loading: Stress, Strain and Deformation Characteristics

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Abstract
Blast-induced loading on civil and military infrastructure has become a critical concern in terrorism-prone regions. This paper investigates the structural response of plain concrete (PC) and reinforced concrete (RC) walls under blast loads using finite element analysis in ANSYS AUTODYN. Three wall geometries—flat, L-shaped, and U-shaped—were modeled with and without reinforcement. A 100 kg TNT charge at a 1 m stand-off distance was simulated to assess stress, strain, deformation, and damage progression. Results showed that RC walls, particularly U-shaped configurations, exhibited superior blast resistance, sustaining minimal stress (0.3 MPa), strain (~3 mm/mm), and deformation (<10 mm), with negligible structural damage. Conversely, plain walls suffered catastrophic failures, with peak deformation exceeding 385 mm. A one-way ANOVA confirmed statistically significant differences in damage across wall types. Findings underscore the critical role of geometric optimization and reinforcement in mitigating blast effects and inform practical strategies for resilient infrastructure design.

Keywords: **Blast loading, Reinforced concrete, Finite element analysis, Structural response, ANSYS AUTODYN, Protective structures**

1. INTRODUCTION

The vulnerability of infrastructure to blast-induced loads has increased due to terrorist activities and armed conflicts in many parts of the world. Conventional concrete block and plain concrete walls, commonly used in schools, government buildings, and transportation terminals, are not designed to withstand such high-intensity, short-duration pressures. Their failure has led to casualties, structural collapse, and significant socio-economic disruption [1,2].

Reinforced concrete (RC) walls, by contrast, offer improved ductility, energy absorption, and resistance to progressive collapse. Research has shown that both reinforcement and structural geometry influence a wall's ability to resist blast effects [3,4]. However, limited experimental studies have been conducted due to cost, political, and safety restrictions, making numerical simulation a vital tool for analysis.

This study numerically evaluates plain and RC walls under blast loading using finite element modeling in ANSYS AUTODYN. The aim is to compare performance across wall geometries—flat, L-shaped, and U-shaped—under a 100 kg TNT blast scenario. Stress, strain, deformation, and damage are analyzed to identify optimal configurations for protective structures.

2. RESEARCH METHODOLOGY

2.1 Wall Configurations

Three wall geometries were modeled: flat, L-shaped, and U-shaped, each in plain (PC) and reinforced (RC) conditions. Panels measured 3.0 m × 3.0 m × 0.23 m. Soil–structure interaction was neglected.

2.2 Material Properties

Concrete, steel, TNT, and air properties were obtained from ANSYS AUTODYN libraries. Reinforced concrete was modeled using modified material properties to replicate steel–concrete composite behavior. TNT was modeled as an explosive source, while air was represented as an ideal gas.

2.3 Blast Loading

A 100 kg TNT charge at 1 m stand-off distance was applied. The detonation produced a pressure wave governed by the Friedlander equation, which propagated through air before impacting the wall.

2.4 Numerical Modeling

Finite element simulations were conducted in ANSYS AUTODYN. Dynamic parameters extracted included:

- Equivalent stress (MPa)
- Equivalent strain (mm/mm)
- Total deformation (mm)
- Damage indices

2.5 Statistical Analysis

A one-way ANOVA was used to validate the statistical significance of differences among wall types at a 95% confidence level.

3. RESULTS AND DISCUSSION

3.1 Stress Distribution

Plain flat walls exhibited peak stresses of ~9.2 MPa, while RC flat walls recorded ~8.6 MPa. The U-shaped RC wall sustained minimal stress (~0.3 MPa), showing superior capacity for energy dissipation.

3.2 Strain Response

The plain flat wall reached peak strain levels exceeding 13 mm/mm, while RC flat walls showed ~11.5 mm/mm. L-shaped RC walls reduced strain to ~5 mm/mm, and U-shaped RC walls achieved the lowest (~3 mm/mm).

3.3 Total Deformation

Plain flat walls deformed up to 385 mm, and RC flat walls up to 410 mm. L-shaped RC walls limited deformation to ~150 mm, while U-shaped RC walls showed negligible deformation (<10 mm).

3.4 Damage Progression

Plain walls failed rapidly, showing extensive damage. RC reinforcement improved resilience, but only U-shaped RC walls achieved near-zero damage. The combination of reinforcement and geometry proved critical in mitigating blast effects.

3.5 Statistical Validation

ANOVA confirmed significant differences among wall types ($F = 3.308$, $p < 0.05$). This validates that reinforcement and geometry are decisive in enhancing blast resistance.

4. CONCLUSIONS

This study demonstrated that wall performance under blast loads is highly dependent on reinforcement and geometry:

- Plain walls failed catastrophically under blast loads.
- Reinforced flat walls improved performance but remained vulnerable.
- U-shaped RC walls minimized stress, strain, and deformation, achieving negligible damage.

Implications: U-shaped RC walls represent a practical and cost-effective solution for protective design in terrorism-prone regions. Future work should integrate experimental validation and explore alternative reinforcement methods.

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