Numerical study on Ultra High Performance Fiber Reinforced concrete for application in shear walls with boundary elements

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ABSTRACT

The negative issues of concrete structures include the large dimensions of concrete members due to the low resistance of concrete compared to steel structures, the high density of reinforcements in some parts, and the brittle behavior of concrete due to weakness in tension. The use of fine aggregate and a lower water-to-cement ratio increases the strength, adding fibers to high-strength UHPC concrete increases the softness and tensile strength of concrete, which is called high-strength concrete with UHPFRC fibers with a compressive strength up to 200 MPa and a tensile strength of up to 14 Mpa.

In this research, a technique for the numerical modeling of UHPC concrete is proposed using the LS-DYNA finite element software and modifying the tensile part of a normal concrete material model and the available test data. The validated LS-DYNA model is used to study this concrete on the cyclic behavior of short and thin shear walls. The use of this concrete in the boundary element of the walls has a significant effect in improving their seismic behavior. In this research, the effects of different parameters were investigated. It will be shown that an increment in the percentage of fibers up to 3%, the wall's lateral resistance and initial stiffness increase significantly.

KEYWORDS

Ultra High Performance Concrete, Ultra High Performance Fiber Reinforced Concrete, Finite element analysis, LS-DYNA, Cyclic behavior

1. Introduction

Concrete is widely used in construction, but it has limitations, particularly its brittleness and poor performance under tensile loads [1]. Conventional

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reinforced concrete structures, especially shear walls, are critical for resisting lateral forces such as those caused by earthquakes. However, challenges like reinforcement congestion and inadequate crack control make traditional concrete less ideal for seismic applications.

Ultra High-Performance Fiber-Reinforced Concrete (UHPFRC) addresses these issues by offering compressive strength up to 200 MPa and tensile strength up to 14 MPa. The addition of steel fibers improves the tensile capacity, crack control, and ductility of the concrete [2]. This makes UHPFRC a promising material for use in critical structural elements such as the boundary elements of shear walls, where tensile and compressive forces are concentrated during seismic events.

This study focuses on developing a numerical model using LS-DYNA software to simulate UHPFRC behavior in shear walls and investigate how this material affects the walls' seismic performance, specifically in terms of lateral resistance and energy absorption.

2. Methodology

This research employed finite element analysis (FEA) to simulate the behavior of UHPFRC in shear walls. LS-DYNA, a powerful software tool for advanced dynamic and static analysis, was used to carry out these simulations. The concrete material model used in LS-DYNA, known as the Winfrith model, was adapted to incorporate the tensile characteristics of UHPFRC, particularly its ability to carry tensile loads and resist crack propagation. This was achieved by adjusting key parameters of the material model [3], including tensile strength, post-cracking behavior, and energy absorption properties.

The numerical model was built using brick elements to represent the concrete and beam elements to model the steel reinforcements. The walls were subjected to cyclic loading to replicate the conditions experienced during seismic events. The cyclic loading protocol applied horizontal forces that simulated the lateral loads experienced by shear walls during an earthquake.

The study also conducted a parametric analysis to explore the effects of varying fiber content in UHPFRC and the amount of steel reinforcement in the boundary elements. Three different fiber content levels were considered: 1.5%, 2%, and 3%. The reinforcement ratio in the boundary elements was also varied to assess the potential for reducing steel reinforcement without compromising the performance of the walls.

3. Results and Discussion

The numerical simulations produced several key findings related to the seismic performance of shear walls with UHPFRC boundary elements:

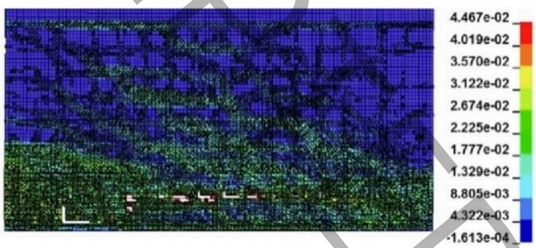
- **Increased Lateral Strength**: Shear walls with UHPFRC in their boundary elements demonstrated a significant increase in lateral strength compared to those constructed with normal concrete. Specifically, the walls showed a 79% increase in lateral strength when the fiber content was increased to 3%. This improvement is attributed to the high tensile strength of UHPFRC, which enables it to resist the tensile forces that typically cause cracking in conventional concrete.

- **Crack Control and Ductility**: UHPFRC proved to be highly effective in controlling crack propagation. The walls that incorporated UHPFRC experienced fewer and narrower cracks under cyclic loading compared to those made from traditional concrete. This enhanced crack control not only improved the overall structural integrity of the walls but also reduced the likelihood of failure under seismic loading conditions. Moreover, the walls exhibited increased ductility, allowing them to deform more before reaching failure, which is a critical characteristic for structures in seismic zones. The cracking pattern and principal strain contour for wall W1 can be seen in Figure 1.

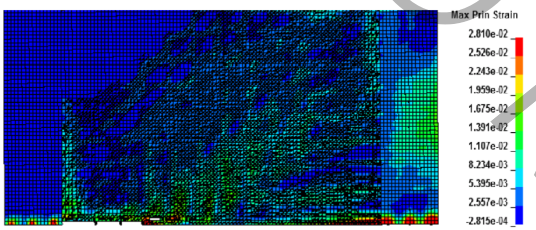
- **Energy Absorption and Reduced Stiffness Degradation**: UHPFRC's ability to absorb energy was another significant finding. The walls with UHPFRC showed better energy absorption, meaning they could withstand more cyclic loading without suffering major stiffness degradation. This is crucial for earthquake-resistant structures, as it allows them to maintain their integrity over the course of multiple load cycles, reducing the likelihood of sudden failure.

- **Reduction in Steel Reinforcement**: One of the most notable outcomes of this study was the potential for reducing steel reinforcement in boundary elements when using UHPFRC. The results indicated that with UHPFRC, the steel reinforcement in the boundary elements could be reduced by up to 75%, while still maintaining or improving the overall performance of the walls. This is particularly beneficial from a construction standpoint, as it reduces reinforcement congestion, making the construction process more efficient and cost-effective.

- **Parametric Study Results**: The parametric analysis revealed that as the fiber content in UHPFRC increased, so did the lateral strength and ductility of the walls. For example, increasing the fiber content from 1.5% to 3% resulted in a substantial improvement in the seismic performance of the walls. Additionally, the reduction in steel reinforcement was more pronounced in walls with higher fiber content, as the UHPFRC compensated for the reduced steel content through its enhanced tensile and energy absorption properties.



a) Wall with normal concrete



b) Wall with UHPFRC concrete with 3% fiber

Figure 1. Cracking pattern and maximum principal strain fringe of W1 at 1.5% drift ratio

4. Conclusion

The findings of this study demonstrate that UHPFRC offers significant advantages for the seismic design of shear walls, particularly when used in boundary elements. The use of UHPFRC in these critical areas of the walls results in several key benefits:

- **Enhanced Seismic Performance:** UHPFRC significantly improves the lateral strength, ductility, and energy absorption of shear walls, making them more resilient to the forces experienced during earthquakes.
- **Crack Control:** The superior crack control provided by UHPFRC reduces the spread and severity of cracks, which in turn enhances the durability and long-term performance of the walls.
- **Reduction in Steel Reinforcement:** The ability to reduce the amount of steel reinforcement in boundary elements without sacrificing performance is a major advantage of UHPFRC. This not only simplifies the construction process but also lowers material costs and reduces reinforcement congestion, which can be a challenge in complex structural designs.
- **Energy Absorption:** The increased energy absorption capacity of UHPFRC enables the walls to withstand repeated cycles of seismic loading without significant stiffness degradation, which is critical for the safety and performance of buildings in earthquake-prone regions.

5. References

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