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Development of Advanced Grid Stiffened (AGS) FRP Tube-Encased Concrete Columns

INTRODUCTION

In recent years, the use of fiber reinforced polymer (FRP) tube-encased concrete columns for new construction and rebuilding of engineering structures has increased. The purpose in FRP tube-encased concrete columns is to replace the steel rebar by a corrosion-resistant laminated FRP shell. The FRP tube serves as a stay-in-place formwork during construction; during service, the tube confines the lateral expansion of the concrete core and transfers the core to a triaxial compressive stress condition. As a result, the compressive strength and ductility of the column are enhanced significantly. Also, owing to the inherent corrosion-resistance of FRP, it is maintenance-free, providing long-term cost benefit. However, it is found that the FRP tube only provides passive confinement to the concrete core such that the FRP tube cannot confine the concrete core before the concrete cracks/crushes. The reason for this is as follows: (1) Due to the orthotropic structural properties and various couplings, a FRP tube usually has a much larger radial (out-of-plane) Poisson's ratio than that of the concrete core. Subjected to the same axial strain, the larger transverse Poisson's ratio of the FRP tube leads to a radial deformation larger than that of the concrete core. Consequently, the FRP tube cannot confine the concrete core in this region, i.e., the first region or elastic region in the stress-strain curve. (2) For most FRP tubes, fibers are aligned towards the hoop direction in order to provide higher confinement. As a result, the axials stiffness of the FRP tube may be lower than that of the concrete core. A lower axial stiffness also translates to a higher transverse or radial deformation.

A viable way of solving this problem is to use grid stiffened composite tube. It was proved that, by using a hybrid tube – a lattice of steel grids that were wrapped by a FRP skin, a mechanical interlocking between the tube and the core was developed. This ensured that the grid tube was activated or engaged in confining the concrete core once the axial load was applied. As a result, the steel grid tube confined concrete cylinders had a higher elastic region than the solid FRP tube confined counterparts. Because FRPs behave linearly elastic while steel behaves elastic-perfectly plastic, it is interesting to find how FRP grid tube encased concrete cylinders behave.

OBJECTIVE

In this project, a new type of confining device, a latticework of interlacing FRP ribs that are jacketed by a FRP skin, is proposed, manufactured, tested, and modeled to encase concrete cylinders. The objective of this study is to investigate the structural behavior of this novel advanced grid stiffened (AGS) tube encased concrete cylinder through systematic experimental testing and finite element modeling. Parameters that determine the structural response will be evaluated. The fire resistance will be enhanced through nano-reinforcement. A life-cycle economic analysis will be conducted to evaluate the potential application of this novel column in bridge construction.

SCOPE

The scope of this project focused on lab-scale testing and numerical modeling. Field-level study was out of the scope of this study. This was a six-stage study. In the first stage, an extensive literature survey was conducted. The research focus in Stage 2 was on validating the concept.

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In Stage 3, focus was on the automatic manufacturing and parametric study through experimental testing. Stage 4 focused on non-linear finite element modeling. In Stage 5, the enhancement of fire tolerance by nanoclay and fire retardant incorporation was investigated. The last stage concentrated on life-cycle cost-benefit analysis. The test results and modeling results were analyzed and some meaningful conclusions were obtained.

METHODOLOGY

Stage 1: Literature survey. A thorough literature survey was conducted and the state-of-the-art knowledge in this research area was obtained.

Stage 2: Proof-of-concept study. In this stage of study, AGS tubes were fabricated by the hand lay-up technology per a pin-guided mandrel system. Both circular and square AGS tubes were manufactured, and encased concrete cylinders and beams were tested using uniaxial compression and transverse bending.

Stage 3: Automatic manufacturing and parametric study. In this stage of study, a pin-guided system assisted by a collapsible mandrel was developed to filament wind the AGS tubes automatically. A "building-block" test was conducted to reveal the step-by-step development of the composite action. After that, the effect of the rib thickness, skin thickness, and bay area on the structural behavior was evaluated experimentally. Also, the effect of rib thickness on the interfacial bonding strength was investigated using a push-out test.

Stage 4: Fire tolerance test. The purpose of this stage of study was to investigate the enhancement of fire tolerance of AGS tube encased concrete cylinder as a result of incorporating organically modified montmorillonite (MMT) and a traditional fire retardant additive (TSWB®) into a vinyl ester (VE) matrix. Two series of specimens were prepared, fire-tested, and compression-tested to determine their residual load carrying capacity.

Stage 5: Finite element analysis. A non-linear finite element analysis considering the nonlinear behavior of concrete, assisted by a non-associative Drucker-Prager plasticity criterion, was implemented to validate the experimental results and conduct a parametric study.

Stage 6: Engineering economic analysis. In this study, the life-cycle cost of the new cylinders was compared to conventional steel reinforced concrete cylinders.

CONCLUSIONS

In this study, a novel confining device, a FRP skin wrapped AGS tube, is proposed and validated through a systematic experimental and theoretical program. The results from this study show that this new confining device outperforms the traditional FRP tubes because it develops a positive composite action with the concrete core through mechanical interlocking and fully utilizes the load carrying capacity of the fibers; it increases the elastic range of the confined cylinders so that the enhanced compressive strength can actually be used in design. Also, the AGS tube can be manufactured automatically using a two-axis filament winder per a pin-guided collapsible mandrel system. The AGS tube encased concrete cylinder can be modeled and designed using finite element analysis by considering the non-linear, stress-strain constitutive law and by using the non-associative Dryger-Prager failure criterion. The incorporation of nanoclay increases both fire tolerance and compressive strength of AGS-FRPC.

RECOMMENDATIONS

It is concluded that this new confining device has a great potential to replace traditional FRP tubes and to be used as piers, piles, fenders, columns, etc. in the infrastructure. However, the scope of study is limited. More detailed studies are needed before it can be deployed. The following further studies are recommended:

1. Beam-column testing;
2. Joining with other structural members such as footing;
3. Drivability testing;
4. Impact testing;
5. Development of design-oriented confinement model;
6. Analytical modeling without smearing or homogenizing; and
7. Structure optimization.