Guideway Steel Fiber Reinforced Concrete Hybrid Girder Design

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ABSTRACT: This paper describes the General Atomics (GA) Urban Maglev Guideway Steel Fiber Reinforced Concrete (SFRC) Hybrid Girder design, development and testing. It is currently planned to test and install SFRC hybrid girders of varying spans up to a maximum of 30 meters for each span as an extension to the existing GA test track. The spans and the length of proposed extension may vary depending on funding availability.

1 INTRODUCTION

Strength, durability, and low cost of concrete structures can be achieved with SFRC. These structures are constructed without the use of conventional reinforcing steel bars. SFRC is ultra high-strength concrete with unique properties including high flexural and shear strength. It is also strong in compression, durable and has high impact resistance. Structures can be either precast or poured in place. GA originally developed SFRC over a decade ago under contract with the US Air Force. In early 2004, GA and San Diego State University further optimized the mix design with excellent results (US Patent pending) and presented a paper in Oct 2004 at the Maglev 2004 proceedings (Ref 8.1). Since then, some design and development of the concrete Guideway (GW) beams have been performed. Flexural and compressive tests in lab and field trials were conducted. The results showed enhanced compression and flexural properties with significant cost reduction and a promising future for a SFRC hybrid girder.

2 DESIGN

A key feature of SFRC is the increased flexural strength with the use of lab-configured steel fibers (Figure 1) that provide effective bonding. This high bond strength results in micro stitching of small cracks thus significantly limiting crack propagation under loading compared to conventional Reinforced Concrete (RC) with solid reinforcing bars. Also during testing, it was observed that the SFRC crack propagation in the test samples was very gradual and Observable even after the first crack.

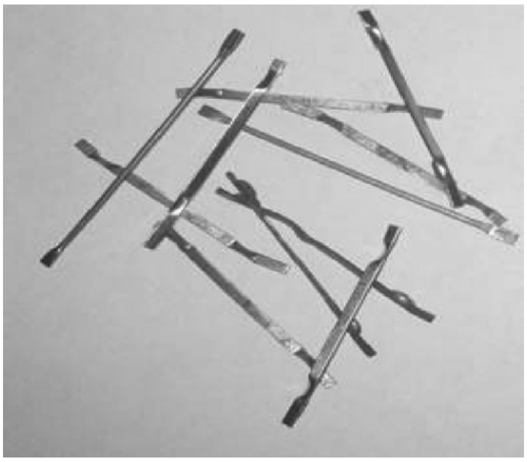


Figure 1: Fibers in the SFRC Concrete

The SFRC mix design developed in association with SDSU is poured into forms (Figure 2) and samples tested per American Concrete Institute (ACI) standards. Tables 1 shows the actual test results of ultimate compressive, flexural and first crack stresses after 7-day and 28-day curing of test samples with calculated working stress allowables. The SFRC flexural working stress allowable for the beam design is about four times that of the similar allowable for the conventional Reinforced Concrete with f'_c = 34.5 MPa (5000 psi).

As a result of increased flexural strength and increased first crack strength that limits crack propagation, the SFRC members result in smaller and lighter structures. If deflection rather than flexure is governing the design, it may be necessary to include prestressing to limit deflection. Also increased Modulus of Elasticity (E) for the SFRC concrete to about 75% should also help in reducing beam deflection (E values for RC & SFRC are shown in Figure 5, Section 5).

Figure 2: Fiber concrete poured into forms

Table 1: SFRC Flexural and Compressive Stresses

Type of Stress	Ult Stress MPa (psi)	Std Dev MPa (psi)	SFRC Allowable Working Stress* MPa (psi)	RC Allowable Working Stress** MPa (psi)
First Crack flexural f'_b, f_b	13.8 (2001)	1.2 (172)	5.7 (823)	—
7-day wet cure flexural f'_b, f_b	18.1 (2618)	0.7 (101)	7.8 (1133)	—
28- day dry cure flexural f'_b, f_b	19.4 (2818)	0.9 (125)	8.4 (1212)	2.0 (290)
28-day Compressive f'_c, f_c	85.5 (12,391)	2.5 (368)	37.3 (5410)	15.5 (2250)

*Allowable Stress (Working Stress Design) = 0.45(Ultimate – Std Dev) per Uniform Building Code (Ref 8.3)
** Calculated per ACI Hand Book SP-3 (Ref 8.4) with loading on the similar RC samples with f'_c = 34.5 MPa (5000 psi)

Based on the test results as shown in Table 1 above, the Hybrid Girder size can be economically designed for flexural working stress allowable of 8.4 MPa (1212 psi) for spans up to 24 m. In the case of the 30-m Hybrid Girder design, the T section box girder is cast monolithic with a 2000 mm wide x 150 mm thick top decking. The girder depth of 1200 mm is governed by deflection rather than flexure (1050mm) in this case. The increased Modulus of Elasticity also contributed to the increased stiffness of the SFRC girder.

Figure 3a through 3c show the design details of a 30-m long span SFRC girder for a elevated support structure with the embedments for the LSM & Litz Track attachments. These embedments are positioned and accurately aligned in the beam's mold prior to pouring the concrete. The embedments are integrated with the studs that are welded to the plates providing a solid anchor to the concrete (see Fig 3a). After the concrete is cured and striped out of the mold, the Hybrid Girder provides the accurate interfaces required for the Urban Maglev system along with the structural features of the SFRC girder, all combined into a small efficient package.

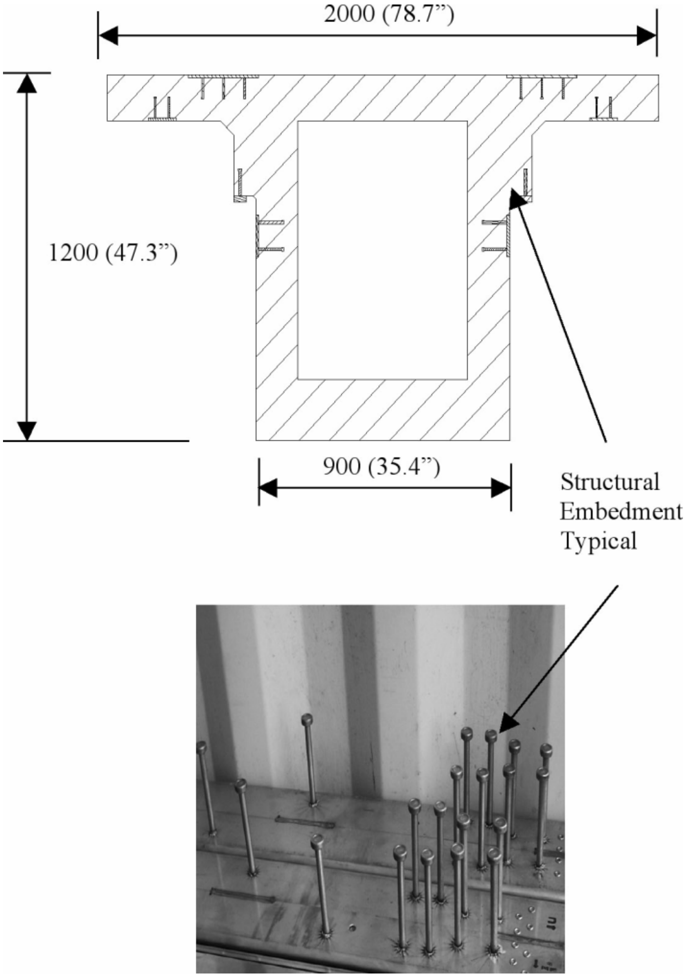


Figure 3a: Section through Hybrid Girder with Embedments

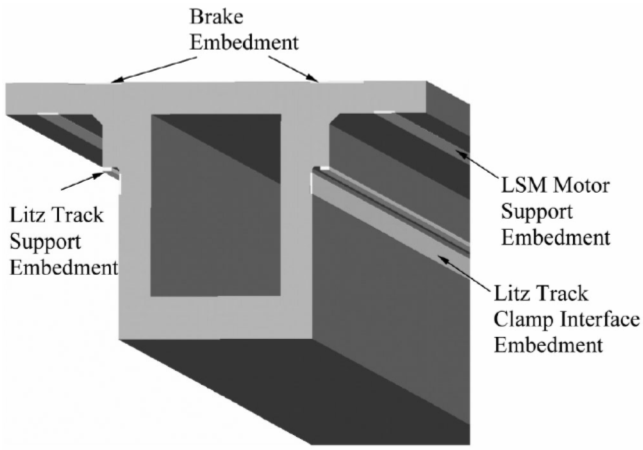


Figure 3b: Hybrid Girder Isometric View

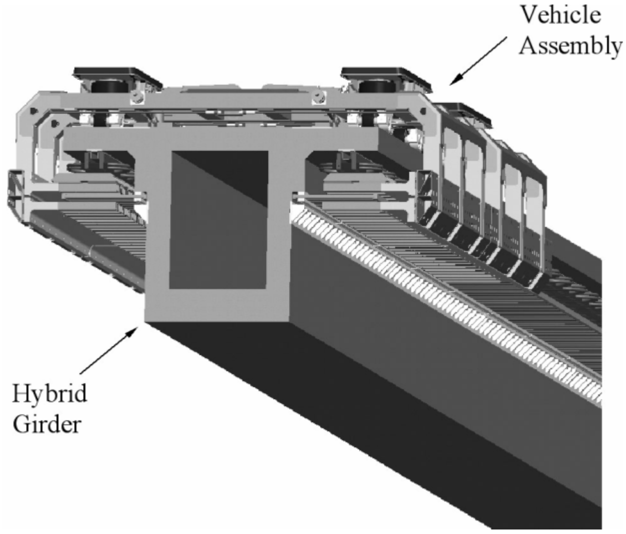


Figure 3c: Hybrid Girder with Maglev Components

3 CODE APPLICABILITY

The SFRC (also called Ultra High Performance Concrete) has been in use in concrete structures and pavements for over a decade with excellent performance results. In 2003, the non-profit ICC Evaluation Services (Ref. 8.2) in California, USA, (www.icc-es.org) provided interim recommendations for structural applications for incorporation into the Uniform Building Code (Ref 8.3). Over the past two years precast contractors such as San Diego Precast Company, Santee CA (www.sdpc.com) have been using SFRC in structural load carrying members.

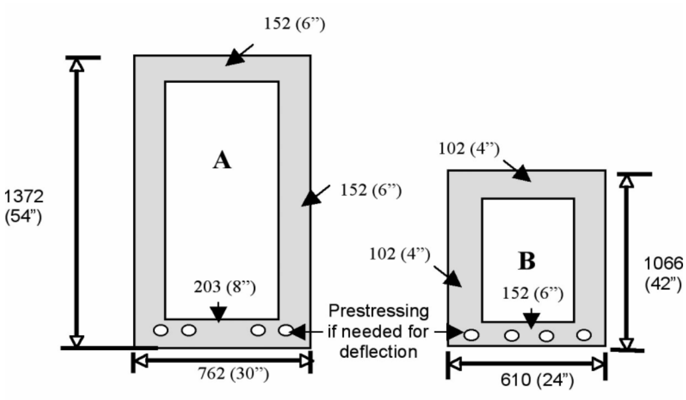
4 PROPOSED PLAN

Currently there is an existing Urban Maglev track at the General Atomics facility in San Diego, California, USA. The 120-meter at-grade concrete track with segmented steel modules was completed in 2004 (Ref. 8.5). It is planned to extend the existing track using 30-meter long SFRC hybrid girders supported by columns. The number of spans and the length of proposed extension may vary depending on funding availability.

The elevated Hybrid Girders will be cast at San Diego Precast Company, tested, evaluated and transported to site for installation. Modifications if required such as prestressing will be added at the precast yard prior to shipping and installation.

5 COST ESTIMATE

The RC and SFRC beam costs can be best compared by taking an example of a 30m (98.4') long elevated box girder. For illustration, a simply supported rectangular box girder (without the top decking) for each of the RC and SFRC structures will be considered as shown in Figure 4. The design governed by flexure in both cases resulted in a reduced depth of about 33% for the SFRC. In 2006 US Dollars, local San Diego cost for casting an SFRC beam is about \$360 per cubic meter (\$275 per cubic yard) using carbon steel fibers and the corresponding cost for an RC beam is about \$262 per cubic meter (\$200 per cubic yard). Even though the cost per cubic yard is more for the SFRC, the overall cost of the SFRC beam resulted in 25% cost savings because of 45% reduction in concrete volume. Also, in the case of RC beam, there would be an additional trade of labor intensive solid rebar fabrication and installation in the forms which may result in a schedule impact. Over a period of time with more application of SFRC to concrete structures, the cost should come down further.



A. With Solid Rebar
f'_c= 34.5 MPa (5,000 psi), f_b = 2 MPa (290 psi)
W = 9.4 kg/m^3 (150 pcf), E = 28,275 MPa (4.1x10^6 psi)
w = 1396 kg/m (938 lbs/ft), Cost = \$152/m (\$46.30/ft)

B. With SFRC and No Rebar
f'_c= 83 MPa (12,035 psi), f_b = 19 MPa (2,775 psi)
W = 9.4 kg/m^3 (150 pcf), E =49,655 MPa (7.2x10^6 psi)
w = 770 kg/m (517 lbs/ft), Cost = \$115/m (\$35/ft)

Imposed Loads

13m long vehicle with passengers equivalent to 20,000kg uniform distributed load

Figure 4: Comparison of RC and SFRC Box Girder Design

6 CONCLUSION

Innovative concrete structures are available for enhanced strength, durability and low cost with the use of SFRC. This is achieved with steel fibers mixed in cement and other ingredients to produce high flexural strengths without the need for conventional steel bar reinforcement. Both precast and poured in-place construction techniques are available. Cost saving of SFRC over RC is achieved by reduction in volume of concrete required for a given application.

In the GA Urban Maglev development program, it is currently planned to extend the track at GA facility using 30 meter Hybrid Girders supported by columns as discussed in Section 4 above. The plan is to initially cast two to three prototype SFRC short span beams precast locally and load tested to ascertain flexure, shear and other properties. After evaluation, it is intended to cast and transport the full size 30-meter girders and install them at the GA test track.

7 ACKNOWLEDGEMENTS

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