Urban Maglev Integrated Guideway Girder Module
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Key Words

Abstract
This paper describes the design of the General Atomics (GA) Urban Maglev Integrated Guideway Girder Module (IGGM) to replace the currently designed Steel Guideway Module supported by the concrete foundation. The IGGM offers an efficient, lightweight, cost effective and structurally strong alternative to the current design. It consists of a Steel Fiber Reinforced Concrete (SFRC) box girder with embeds in the sidewall. The Linear Synchronous Motor (LSM) windings and Litz Track attachments are anchored to these embeds. The attachments provide the needed propulsion, magnetic levitation, guidance and braking. The overall weight of the IGGM is significantly lower than the currently designed combination module and also has a smaller envelope.

1. Introduction
The low speed Urban Maglev program is sponsored by the Federal Transit Administration and cost shared by the Pennsylvania Department of Transportation and the Industrial Partners. GA leads the team of companies in the USA to develop an innovative approach of using passive, permanents magnet system with LSM windings and Litz Track attachments providing the needed propulsion, magnetic levitation, guidance and braking.

GA is currently in the process of testing the levitation system on a support system with concrete foundation and eight segmented Steel Guideway Modules. Figure 1 shows one of the segmented steel Guideway Module installed over the concrete support foundation for the 120-meter Urban Maglev Test Track at the GA site. For commercial deployment, an elevated concrete girder supported by columns will be used in place of the current concrete support foundation.

This paper discusses optimizing the current design of the steel guideway module over a concrete support foundation to a hybrid IGGM design. The IGGM structural design also considers a number of key features such as levitation, propulsion, braking and guidance. The major components of these key features are LSM windings and Litz Track that are anchored to the embedments of a shop fabricated IGGM. This integrated hybrid structure will have a smaller envelope, lightweight, cost effective and can be shop fabricated and field installed to precise dimensions and tolerances.
2. Integrated Module Design
The efficient design of the Urban Maglev IGGM is to integrate the features of the current Steel Guideway Module with the structural strong precast concrete girder. By combining these two structural functions into an integrated structure, the goals of creating a lightweight and a smaller envelope support system can be met.

Figure 1 Steel Guideway Module installed over the concrete support foundation

Figure 2. Original Integrated Guideway/Girder Module Assembly
Several designs were considered. Figure 2 shows an IGGM with a concrete box beam and a concrete deck cast monolithic with the girder. The LSM windings are attached to the underside of the concrete deck and the Litz Track attachments are clamped to the
sidewall of the box girder. Steel plates are embedded in the top of the deck as rolling surfaces for the wheels when the vehicle is stationery.

This design concept was simplified to include casting of the box beam with hardware embedments in the sidewall and eliminate the casting of the top concrete deck slab. The LSM winding and the Litz Track attachments are then installed in the shop either as an integral unit or as two separate attachments. These attachments are connected to the embedments in the sides of the box beam to the needed tolerances and alignment. Figure 3 shows the arrangement of the IGGM with the attachments. The required accuracy in aligning the box beam with respect to the attachments is achieved by secondary machining and tapping operation imposed on the concrete embedments after the concrete girder has fully cured. These operations will be performed in the shop prior to transport to site for installation.

![Diagram of IGGM with LSM windings & Litz bar attachments](image)

(a) Prestressed Box Beam cast with side wall embedments  
(b) LSM & Litz Track components attached to side walls and aligned

(c) Completed assembly

Figure 3. Integrated Guideway Module with LSM windings & Litz bar attachments
3. Steel Fiber Reinforced Precast Concrete Girder

To further enhance the strength and durability of the IGGM, the concrete box beam is precast with Steel Fiber Reinforced Concrete (SFRC) with no conventional metal reinforcement. SFRC is a high-strength concrete with unique properties. Structures cast with SFRC are strong in compression, flexural bending, ductility and impact resistance. In addition, the use of the SFRC instead of the conventional reinforced concrete significantly enhances the magnetic performance of the IGGM components. Prestressing will be added to the SFRC if required to limit the deflection due to the imposed loading.

In 2003, under a separate federally funded program, General Atomics developed a new SFRC mix design with the help of a local University. Comprehensive tests were conducted with lab and field trials of the various mix designs. The test results of the selected mix design were very encouraging and yielded results with significant cost savings. Because of continuous micro-stitching properties of the randomly distributed steel fibers, there is a significant increase in the flexural strength. The maximum ultimate flexural bending stress of the test samples attained was 23 Mpa (3,335 psi) and the ultimate minimum compressive strength was 72.3 Mpa (10,480 psi). It is intended to design the IGGM with fiber reinforcement for an allowable flexural bending stress of 10.3 Mpa (1500 psi). Figure 4 shows the stress deflection curve of the selected mix design. Figure 5 shows the lab tests of compression and flexural bending of the test samples, while Figure 6 shows the field casting of the optimized SFRC mix design.

The beam samples were also subjected to fatigue tests and the results were encouraging. At a flexural bending stress of 14.3 Mpa (2,063psi), first crack was observed at 6,894 loading cycles and the total failure occurred at 8,668 loading cycles. At a higher bending stress of 19.4 Mpa (2,813 psi), first crack and failure both occurred at 8 loading cycles. This means
that an IGGM girder can withstand about 6000 loading cycles safely at a flexural bending stress of around 2000psi with fiber reinforcement and without prestressing.

Figure 5 Lab tests showing 28-day compression and flexural bending tests

Figure 6 Field trial test casting of the optimized SFRC mix design

Similar tests on the fiber reinforced concrete have been conducted in recent years. Federal Highway Administration (FHWA) in their Turner-Fairbank Highway Research Center in McLean, VA, have tested a steel fiber reinforced prestressed precast Ultra High Performance Concrete (UHPC) 24 meter (80 feet) I-section girder with promising results.
The test girder consisted of steel fibers with no solid metal reinforcement and with some prestressing cables as needed. The UHPC girder deflected 480mm (19”) before breaking. At 300mm (12 inches) deflection, cracks could not be seen even with a magnifying glass. The strength and durability characteristics of the UHPC ingredients are discussed in detail in Ref 6.2.

4. Conclusions
The use of the SFRC (similar to UHPC) for the Urban Maglev Integrated Guideway Module as discussed above will further enhance strength, durability and impact resistance characteristics for a given span. Some Precast contractors in USA and Canada ([www.imagineductal.com](http://www.imagineductal.com)) are already using SFRC for partial structural load resistance in prestressed concrete girders and industrial buildings. The ICC Evaluation Services ICC-ES (formerly ICBO) in California has recently provided recommendations for such future structural applications and provided recommendations for incorporation into the Uniform Building and International Building Codes in USA (Ref 6.3).

The above discussion of the IGGM lends itself to a simplified design of the support system for the Urban Maglev Levitation projects. Budget permitting, after successful completion of the current GA site testing of the Urban Maglev Levitation, it is planned to work on the details of the design, analysis, fabrication and testing of a long span girder (in the order of 30 meters span).

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6. References