PROJECT

Honolulu Authority for Rapid Transportation Airport Guideway and Stations Project

by William (Bill) Elkey, Parsons Corporation, and Chris Hall, SYSTRA International Bridge Technologies

In the Hawaiian capital city of Honolulu, the highway congestion is considered among the worst in the United States. For example, Honolulu ranked high in the *2019 Urban Mobility Report* for traffic congestion and commuter delays for medium-sized cities; the report found that in 2017 drivers in Honolulu spent an additional 64 hours per year delayed in traffic.[1]

While the greater area of Honolulu has a robust bus system, the city does not have high-capacity transit. To address this need, the Honolulu Authority for Rapid Transportation (HART) is constructing 20 miles of grade-separated rail in the most-populated part of the island, connecting the communities along the leeward side of Oahu to the center of Honolulu.

Figure 1. Full project build out of the Honolulu rail system, which is officially named the Skyline. Figure: Honolulu Authority for Rapid Transportation.

Project Background

The HART system will extend 20 miles and include 21 stations, starting from the suburban city of Kapolei located east of Honolulu, navigating to the city core, and terminating at the Ala Moana Mall, one of the busiest shopping centers in the state and adjacent to the popular visitor area of Waikiki (**Fig. 1**).

The project path will intersect suburban communities, popular destinations, and major work centers. Pearl City, Aloha Stadium, the Honolulu International Airport, and the Pearl Harbor Naval Base will all be included. The strategic placement of this alignment will provide access to 70% of the total population of Hawaii and 80% of the job centers.

Because the transit corridor is largely located in an urban environment, the system is designed as an elevated structure for nearly the entire length of the alignment. Even in sparsely populated areas, an elevated guideway was chosen to allow for greater flexibility in future development.

An initial operating segment covering the western 10 miles of alignment was opened in July 2023. The next major segment, which is being built under a design-build civil construction package known as the Airport Guideway and Stations (AGS) project, is nearly complete.

profile

HART AIRPORT GUIDEWAY AND STATIONS PROJECT / HONOLULU, HAWAII

OWNER'S ENGINEER: Stantec Consulting, Edmonton, AB, Canada

BRIDGE DESIGN ENGINEERS: Parsons Corporation, Centerville, Va., and SYSTRA/International Bridge Technologies, San Diego, Calif.

GEOTECHNICAL ENGINEER: Shannon & Wilson, Seattle, Wash.

CONSTRUCTION ENGINEER: McNary, Bergeron, & Johannesen, Broomfield, Colo.

PRIME CONTRACTOR: STG—a joint venture with Shimmick Construction, Traylor Bros., and Granite Construction, Honolulu, Hawaii

CONCRETE SUPPLIER: HC&D LLC, Honolulu, Hawaii

General Description

The AGS project is 5.2 miles long and entirely above grade on an elevated structure. The four stations along the alignment are integrated within the elevated structure and feature themes that reflect historical and traditional uses of the station sites.

The structure carries dual tracks for the trains, with a center walkway for emergency egress and maintenance personnel. The walkway is constructed from prefabricated concrete components with an interior void capable of carrying the low-voltage cables necessary for the operation of the train (**Fig. 2**).

Over the length of the AGS segment are many different conditions, which require customized engineering and construction solutions. The guideway structure typically consists of a trapezoidal concrete box girder that is supported by single-column piers and built using the segmental precast concrete construction method. Under this approach, individual precast concrete segments are delivered to the site in 8- to 11-ft-long sections that are assembled with an overhead erection gantry. This strategy is very useful within the dense urban environment of Honolulu, and a typical 140-ft span can be erected very quickly. In total, 2703 segments were cast for this project.

In addition to an urban landscape, the alignment crosses three environmentally sensitive streams, abuts a major military base, and encounters challenging geotechnical conditions for foundations. While the Honolulu region is defined as a moderate seismic zone, poor soil properties affect seismic-loading conditions in certain locations. Near the convergence of the Moanlua and Kalihi streams, the soil conditions amplify the seismic accelerations by a factor of 2.5 above the free-field response.

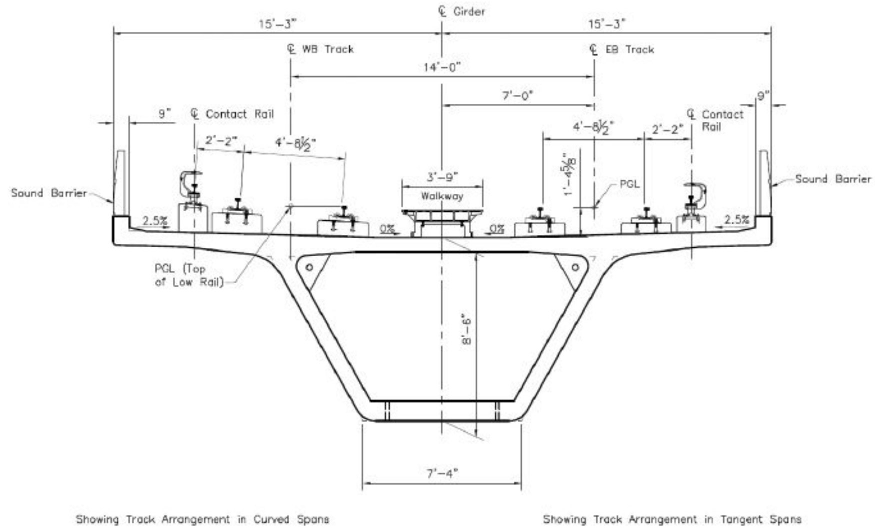

Figure 2. Typical guideway cross section. Figure: Parsons Corporation and SYSTRA International Bridge Technologies.

Typical Guideway Superstructure

The HART AGS project was originally planned as a traditional design-bid-build contract, and the construction plans were developed to a high level during that time. When the decision was made to deliver the project under a design-build procurement, the design-build team had an opportunity to refine the well-developed design details and optimize opportunities that are not usually available in a design-build project.

The first area of opportunity involved the typical span unit, the structure type for most of the alignment. Implementing concepts from other projects, the typical cross section was refined with an alternative shape that used 25% less concrete (**Fig. 3**). This change substantially reduced component weights, which led to savings in post-tensioning steel in the span and lighter loads on the foundation, while still meeting the train dynamic limits of 2.5 Hz of fundamental frequency per span. The typical 140-ft span has four tendons per web, including two tendons with sixteen 0.6-in.-diameter strands and two tendons with fifteen 0.6-in.-diameter strands.

A second design refinement optimized the length of the precast concrete segments. The original segment length of 9 to 10 ft was increased to a typical length of 10 ft 6 in., with a maximum length of 11 ft. That change resulted in fewer segments per span. Compared with the original design concept, the number of segments was reduced by 10%, which translated into fewer segments to cast and transport to the site.

These modifications are indicative of the creative collaboration in a design-build

HONOLULU AUTHORITY FOR RAPID TRANSPORTATION (HART), OWNER

POST-TENSIONING SUPPLIER: Schwager Davis Inc., San Jose, Calif.

ERECTION GANTRY AND PRECAST CONCRETE FORM SUPPLIER: Rizzani de Eccher/DEAL, Italy

BRIDGE DESCRIPTION: 5.2 miles of elevated guideway with segmental precast concrete construction carrying twin train alignments, with typical spans of 120 ft and maximum spans of 166 ft. The alignment includes the construction of four integral passenger stations.

STRUCTURAL COMPONENTS: Typical 8-ft 6-in.-deep precast concrete segments with a 30-ft 6-in.-wide deck. Segment lengths range from 8 to 11 ft. Specialty 4-ft 6-in.-deep segments are used for locations with reduced overhead clearance. Support piers are conventionally reinforced concrete with a round shaft and widened pier cap to support the span. Piers are typically supported on a single large-diameter reinforced concrete drilled shaft.

BRIDGE CONSTRUCTION COST: $963.6 million (estimate as of August 2023)

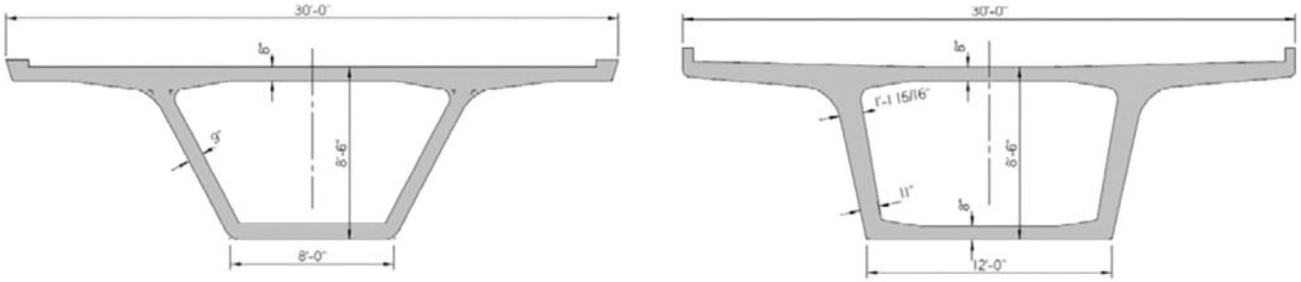

Figure 3. The guideway section on the left shows the optimized precast concrete segment section developed during the design-build refinements. The section on the right is the originally proposed section. The optimized section resulted in a 25% reduction in concrete. Figure: Parsons Corporation and SYSTRA International Bridge Technologies.

procurement. Design options can be developed with a construction team to optimize constructability and operations.

Airport Alignment

The path through the Daniel K. Inouye International Airport (HIA) presented some of the most difficult challenges along the AGS guideway alignment. The guideway configuration into the airport begins at an unusually high elevation above ground. With a maximum column height of approximately 72 ft, the HART alignment was set for future expansion of the airport and to accommodate clearance above the tail of an A380 Airbus jet.

AGS guideway construction through HIA required managing very tight geometry for both the final guideway configuration and the construction equipment and gantry, while minimizing the impact of construction on the active airport and the central post office for the island. Another concern was the project's effects on airport parking. During the construction of the guideway through this area, HIA had three parking structures and a fourth under construction. All of these structures are served by a series of at-grade and elevated roads and walkways. **Figure 4** illustrates the challenges of constructing through this highly developed and compact facility.

The entrance into the station area at HIA required some of the tallest piers constructed on the project. These piers also support the spans having the project's tightest radius of 400 ft, followed by a reverse curve and another 400-ft radius as the alignment approaches the new HIA station. This intricate route created significant uplift at certain bearings, which was accounted for by incorporating specialized uplift bearings at locations where uplift was experienced during normal (nonseismic) operations. For locations with bearings that are only subjected to uplift under seismic loadings, typical elastomeric bearings with tie-down rods were provided.

After leaving the airport terminal area, the alignment follows Ualena Street. A notable feature within this zone is the limited airspace above the guideway. Given its proximity to the airport, this part of the alignment is identified as an emergency egress for flight paths out of the airport. Because clearance below the guideway is required for vehicles, and with limited space above, a shallow superstructure was necessary.

The original design concept envisioned a cast-on-falsework guideway over 1775 ft in length. Given the limited allowable structure depth of 4 ft 6 in., a cast-in-place structure would be considered conventional. However, because the rest of the alignment has a depth of 8 ft 6 in. and was built with segmental precast concrete, the change in construction method would have required an interruption of the overhead gantry, which would have had cost and schedule implications.

Collaboration between the design and construction teams led to the development of a precast concrete solution that relied on continuous spans to make the structure feasible. The reduced structure depth was required for 722 ft along the alignment, which was divided into three- and four-span continuous units, with the last two spans requiring straddle bents with integral pier caps (**Fig. 5**). For the shallow

Figure 4. Nighttime installation of precast concrete segments within the footprint of Daniel K. Inouye International Airport. More than 2700 segments were cast at a nearby facility and transported approximately 20 miles to the jobsite. Photo: Shimmick, Traylor, and Granite Joint Venture.

Figure 5. To accommodate overhead clearance requirements at Ualena Street, shallower-depth precast concrete guideway segments are used. Photo: Parsons Corporation.

superstructure in this area, the post-tensioning was slightly modified from the typical spans and consisted of four tendons per web, typically with twenty 0.6-in.-diameter strands per tendon and additional continuity tendons over the piers. Access for future inspections and maintenance is provided by access hatches through the bottom slab of the boxes or from span-to-span through-access "doghouses."

Special Piers and Foundations

In the urban area of Honolulu, pier placement became more challenging. It was preferable for each pier to be centered directly under the guideway; however, the ground space was not always available, and offset columns or straddle bents were needed.

The offset columns are often referred to as C-bents and L-bents, with the difference being the placement of the foundation. For a C-bent, the foundation is centered under the guideway, while for an L-bent, the foundation is centered under the column. The permanent, offset loads of the guideway to the column create significant flexural demands. The most efficient means of resistance is to provide post-tensioning; however, this option is inherently nonductile, which is not desirable in a moderate- to high-seismic zone. In the C-bents, if the tendons were bonded, the strain deformations in the strand would occur over the crack widths within the hinge zone. To overcome this challenge, the vertical tendons in the column were unbonded and avoided participation with the ductile portion of the column. Thus, in the current detail, the deformation in the tendon is distributed over the height of the pier.

L-bents were used when there was limited access to place a pile cap, and the most extreme case on the project occurred over the Aolele Canal. The design was originally envisioned as a straddle bent, but construction access was extremely difficult at this location, so the design team developed an L-pier solution. The dimensions included an offset of 17 ft between the center of alignment and the column, a 7 × 9 ft oblong column, and a 12-ft-diameter drilled shaft (**Fig. 6**).

Because Oahu is a volcanic island, subsurface conditions along the AGS corridor are quite varied. Several types of soil encountered on this project present notable challenges:

- Coralline detritus and coralline reef rock: These soil layers consist of the fossil remains of coral reefs and related debris and marine deposits. The soils can be very porous and weakly cemented, and therefore are not considered for tip (bearing) resistance.
- Recent alluvium: Thick, layered, continuous beds of fine-grained marsh sediments. These medium- to very-loose sediments include organic material, shells, clays, and silts. Total layer thicknesses in some areas, such as near Kalihi Stream, exceeded the boring depths.
- Ko'olau basalt: The oldest geologic unit, it generally consists of lava flows with mantles of cobbles and boulders.

In areas toward the west end of the project, basalt elevations were relatively shallow, resulting in shaft lengths on the order of 20 ft. These dry, shallow drilled shafts were generally installed using standard auger equipment, and were either 7.2 or 9.8 ft in diameter. In contrast, in Kalihi Stream, the maximum 9.8-ft-diameter shaft is approximately 350 ft deep, which at the time was the deepest shaft of its kind ever drilled.

Conclusion

The HART AGS guideway is an example of efficient, repetitive, and economical construction that is ideal for elevated

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

"Improving aesthetics always adds cost!" How many times have you heard that one? Well, here's an example where improved aesthetics *reduced* cost. The segment cross section was optimized by the design-builder to reduce the guideway's cost, but the resulting changes also improved its appearance. The shallower angles on the webs and the more definitively rounded corners on the box give the guideway a sleeker and more streamlined shape, making the structure more transparent and thus a more welcome component of the communities through which it passes. Such "twofers" are available more often than most people imagine. They should be the goal of all engineering refinement.

There is sometimes a tendency to make decisions based on the optimization of one part of a structure, ignoring the costs that it might add to other aspects of the construction. Following widely accepted rules of thumb is one way to fall into this trap. For example, everybody knows that shorter spans are more economical, unless the additional piers cost more than the savings on the superstructure. For this project, the conventional wisdom was that the Ualena Street segment would be more economical as cast-in-place construction, but the design-builder recognized that this choice would impose costs elsewhere in the project due to the need to redeploy the construction gantry. Instead, they developed an innovative way to use segmental precast concrete construction on Ualena Street. As a result, the guideway looks the same throughout the length of the light-rail transit system, giving the whole project a visual continuity that makes it a welcome neighbor in all the varied communities it serves.

Figure 6. L-bents were used when there was limited access to place a pile cap. The most extreme case on the project occurred over the Aolele Canal, where there is a 17 ft offset between the center of the guideway and the column. Photo: SYSTRA International Bridge Technologies.

transit structures. The segmental precast concrete design allows construction on multiple fronts, with minimal impact to the surrounding work site. The design adapted the typical structure for use in multiple challenging conditions and with various configurations at the stations, at longer spans, and at tightly curved spans.

Project design started in 2017, and construction is scheduled to be completed in early 2024. Visit https://i5mc1f.p3cdn1.secureserver.net/wp-content/uploads/2023/07/2022-March-Webinar.pdf for project details that were presented in an American Segmental Bridge Institute webinar.

Reference

1. Schrank, D., B. Eisele, and T. Lomax. 2019. *2019 Urban Mobility Report*. College Station: Texas A&M University Transportation Institute. https://rosap.ntl.bts.gov/view/dot/61408.

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