ACCELERATING BRIDGE CONSTRUCTION – PRECAST ABUTMENT SOLUTIONS

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ABSTRACT

The ever-increasing demands placed on the transportation network across the nation, coupled with the decaying infrastructure, have led to the omnipresent need to rapidly replace, widen, and build new infrastructure. Bridges form an integral element of the highway network, linking sections of highway pavement into a seamless network. They also require substantial design and construction effort, lending to extended project development and completion time. Due to rapid economic and population growth, transportation planners are under increasing pressure to improve highway systems in accelerated time.

In an effort to address these acceleration pressures, the California Department of Transportation (Caltrans) has begun investigating viable alternatives to conventional construction. The vast majority of structures constructed in California are cast-in-place reinforced concrete box girders. However, precast construction has made inroads into the marketplace as the Department seeks to reduce on-site construction time. To date, precast elements employed have been limited primarily to girders and a few specific retaining wall types. Recently, with political pressures mounting to complete transportation improvement projects quickly, the Department has tested the use of precast abutments. This paper highlights the lessons learned from the use of precast abutments and discusses further advances made in this area for future applications.

Keywords: Precast, Prefabricated, Bridge, Abutment, Rapid Construction, Innovative, Planning

INTRODUCTION

California boasts one of the largest and most complex transportation networks in the United States. It's nearly 45,000 miles of pavement linked by more than 24,000 bridges are essential to support one of the world's most vibrant economies. This network of highways was first conceived in 1895 when three men; R. C. Irvine of Sacramento, Marsden Manson of San Francisco, and J. L. Maude of Riverside, were commissioned by the California Legislature to modernize the rutted dusty wagon trails into more accessible roads[1]. The middle of the twentieth century witnessed a massive buildup of the network, leading to the basic structure, which heralded the dawn of the 21st Century.

The weather coupled with the availability of jobs in many sectors places substantial burden on society to maintain and enhance the existing highway network. Population increases, particularly centering in large metropolitan regions such as Los Angeles and the Bay Area, have led to heavy congestion, adversely affecting economic growth and stability. Local, regional and state transportation partners grapple constantly with congestion relief strategies. Traffic patterns are now affecting these transportation improvement decisions, with rapid construction techniques in the forefront of technologies contemplated. Transportation planners, engineers and contractors are under increasing pressure to reduce overall impacts to the motoring public while completing improvements quickly. Typical planning processes in place for decades, and requiring long project development lead times, are no longer acceptable norms[2].

The California Department of Transportation, in association with its local and regional partners, continues to strive for innovative ways to expedite project delivery while maintaining stewardship of entrusted public funds. A case in point is the recent reopening of the Oakland I-580/880 Connector after a fuel tanker burst into flames and destroyed two spans. The damaged connector was rebuilt within twenty-one days of the inferno. Reacting to emergency scenarios such as this is hardly new to the Department; consider the post-earthquake reconstruction efforts in the Bay Area after the 1989 Loma Prieta Earthquake, as well as that in response to the 1994 Northridge Earthquake. The difference herein is that the public is demanding similar efforts on all projects.

Typical project schedules are often controlled by the design and construction of bridges, which are frequently the more complicated elements and require the most time to complete. Accelerating bridge design and construction poses difficulties by virtue of the importance of these structures to resisting collapse, particularly in regions prone to damaging seismic activity - notably California. However, planners, engineers and academicians recognize now that the concept of rapid renewal is an essential mechanism to mitigate traffic impacts. Substantial research into advancing accelerating technologies is the focus of expanded national attention today. Prefabricated elements, such as precast concrete girders, lead the discussion of ways to accelerate on-site project completion. An added benefit to prefabricated components, when produced in an established manufacturing facility, is enhanced quality control due to repeatability in controlled environments not necessarily possible in field construction.

PRECAST ABUTMENTS

A TIMELY SOLUTION

While most structures built in California over the past several decades are conventional cast-in-place post-tensioned box girders[3,4] for a variety of reasons, precast girder structures are also prevalent. Other structural elements incorporating precast solutions include retaining walls, decks, and bent caps. Mechanically Stabilized Embankment (MSE) walls have received widespread use recently; precast decks have been employed sparingly, as have precast substructure elements. In general, the above has largely defined the extent of prefabricated components used in California transportation structures. More recently, a pilot project utilizing precast abutments was completed on Interstate 40 in the Mohave Desert. The project required the replacement of twelve bridges (pairs of "left" and "right" bridges at six locations) along nearly twenty miles of the heavily traveled interstate highway. Interstate 40, a two-lane separated roadbed highway snaking across the bleak arid terrain of the Mohave Desert in southeastern California, plays an important role in national commerce as trucks laden with commodities from the Ports of Los Angeles and Long Beach traverse the route daily to destinations across the nation.

A biennial maintenance inspection early in 2006 revealed severe deterioration on six pairs of T-beam bridges clustered along a twenty-mile stretch of highway eighty miles east of Barstow. Noted signs included deck delamination, as well as shear cracking in the bent caps and several girders. Emergency shoring was installed to maintain a single lane of traffic on each roadbed, while designs were completed for the structures located on the eastbound roadbed first (designated as the "right" bridges). Traffic was diverted to the westbound lanes with two detours: one wrapping around the bridge at Marble Wash (Right), and the second encompassing the remaining five "right" structures. The fact that Marble Wash was nearly ten miles separated from the remaining five affected structures on the eastbound roadbed allowed the two-detour plan to assist in alleviating traffic congestion by providing an intermediate passing lane through the project limits. Upon completion of these six structures, traffic was rerouted off the westbound road (reference Figure 1) and the six damaged "left" structures therein were replaced.

Clearly, the challenge to the bridge engineers was to devise plans that emphasized accelerated construction through parallelism. Precast girders were specified for all twelve structures to accommodate concomitant construction activities. Thus, girder fabrication was completed at established precast yards off-site while demolition and substructure work commenced in the field, thereby allowing concurrent operations. The girders were designed to accommodate the additional dead load of stay-in-place deck forms to expedite cast-in-place deck construction. Precast deck panels were considered, but discounted due to concerns over girder camber and connection details. Where plausible, both I- and bulb-tee girders were specified at several locations to allow the fabricator to fully utilize the precast yard capacity. However, not all structures could be economically designed with both girder options.

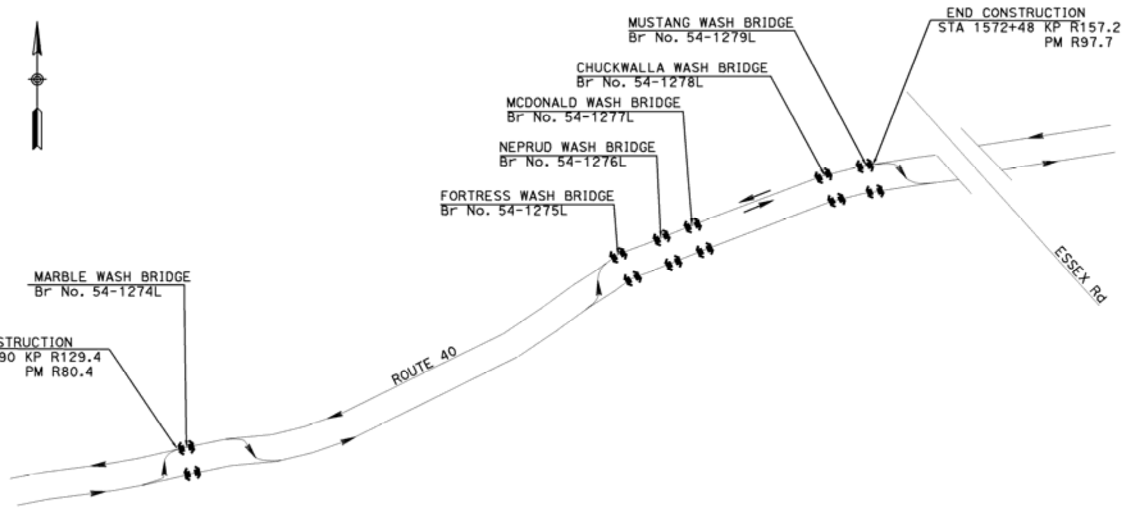

Fig. 1. I-40 project route detour map for the “left” structure replacements on the westbound roadbed; note two traffic detours along the twenty-mile length of I-40.

In an effort to mitigate traffic impacts during reconstruction of the westbound structures, an innovative strategy was employed at the detour around the Marble Wash (Left) location. The idea was to precast as much of the structure as necessary to expedite on-site construction. The existing two-span, nearly 106-feet long bridge was replaced with a single-span structure designed to reduce substructure construction efforts. Furthermore, site geology permitted the use of spread footings, thereby facilitating a precast abutment solution (reference Figure 2). The advantage of this strategy was that the abutments could be placed and the girders set nearly immediately thereafter. Installation of rock slope protection beneath the structure to protect the abutment footings from scour was the only factor disallowing immediate placement of the girders once the abutments were set. Specifications were written which deferred the detour at the Marble Wash (Left) location until the precast abutments and girders were cast. The detour was then implemented, demolition operations commenced, and the abutment subgrade prepared to receive the precast abutment. Additionally, the specifications limited the length of the detour at this location, forcing the Contractor to shift forces from other operations as necessary to affect the expeditious opening of the westbound roadbed crossing the new bridge at Marble Wash (reference Figure 3).

In the end, the detour at Marble Wash (Left) was removed after only twenty-eight days. The remaining structures on the westbound roadbed were completed and the road opened to traffic in only three months. The project was a huge success and set the stage for more innovative uses of prefabricated components to reduce construction traffic delays.

Fig. 2. Digital image portraying the placement of the precast abutment at the Marble Wash (Left) Bridge

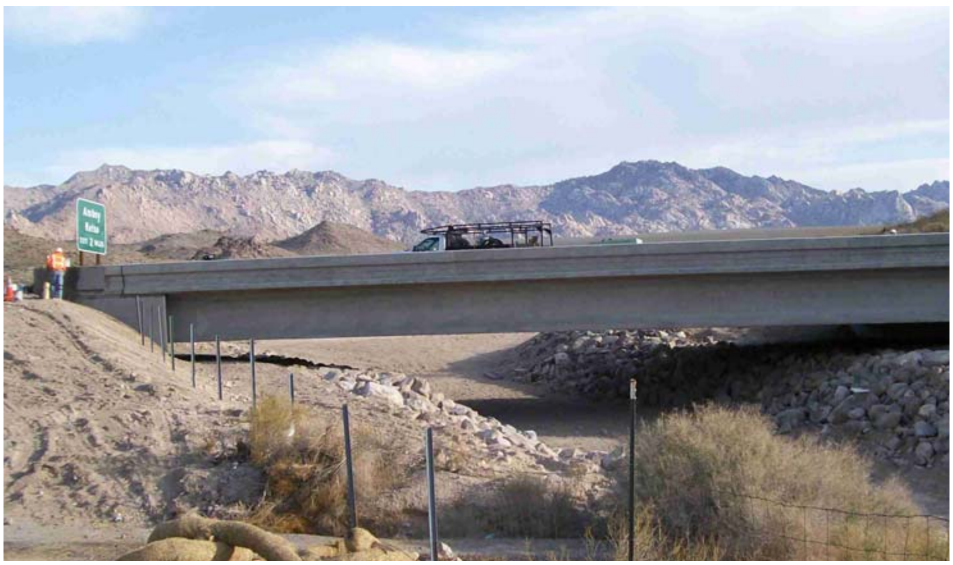

Fig. 3. Digital image of the completed Marble Wash (Left) Bridge

SEGMENTED PRECAST ABUTMENT DESIGN

The abutments designed for Marble Wash (Left) were whole-width structures (reference Figure 4). The heavier of the two weighed approximately 82-tons, requiring transport permits and a larger crane for lifting than might otherwise be found on a similar transportation project of this size. Only the abutment seat and a portion of the footing were precast; cast-in-place concrete for a footing shear key, the abutment backwall, and the approach fill wingwalls were considered to have minimal affect on the overall construction schedule. These operations proceeded simultaneously with the cast-in-place concrete deck construction.

The reason that a whole-width abutment design was used at the Marble Wash (Left) Bridge was due to the inherent design schedule pressures. It was however, not the preferred solution due to the constraints noted previously. Obviously, a segmented abutment design would reduce or eliminate the need for securing transport permits, lessen the premiums paid for trucking fees, and allow the use of cranes already expected on-site for other operations such as setting girders. Another advantage to segmenting precast abutment design is that bridges can be built in stages, with traffic allowed on earlier stages as existing structures are demolished to facilitate structure completion.

Since the successful application at the Marble Wash (Left) Bridge, California Department of Transportation engineers have developed details for segmented precast abutments. The design criteria stipulated maintaining ease of on-site construction. One important consideration is that the precast solution should avoid and/or minimize any additional on-site operations such as prestressing transverse rods to lock segments together. Besides requiring specialized construction equipment not otherwise typically required on-site for precast superstructures, this solution also could induce larger temporary easement and potentially amplify the excavation needs, thereby increasing the project costs.

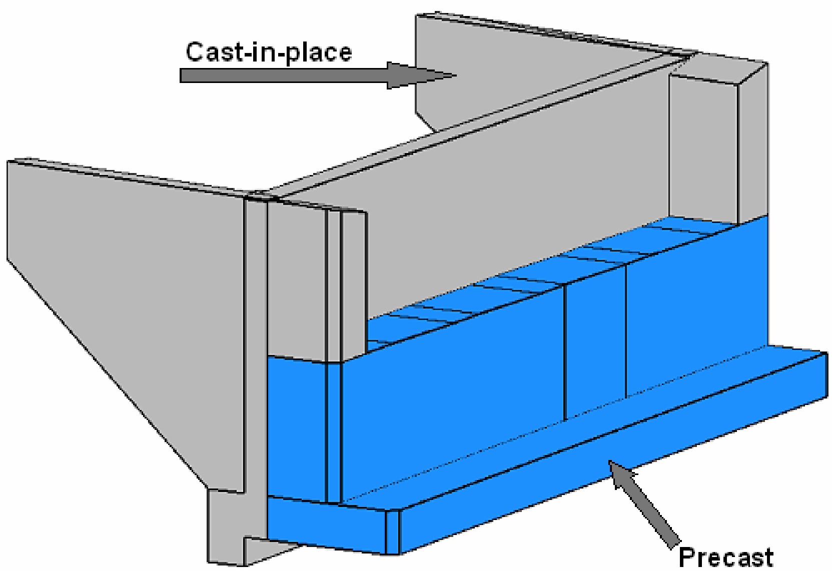

Fig. 4. Three-dimensional schematic of precast abutment used at the Marble Wash (Left) Bridge; the blue (or darkened) portion indicates the precast abutment seat and footing, with the light gray portion representing cast-in-place elements.

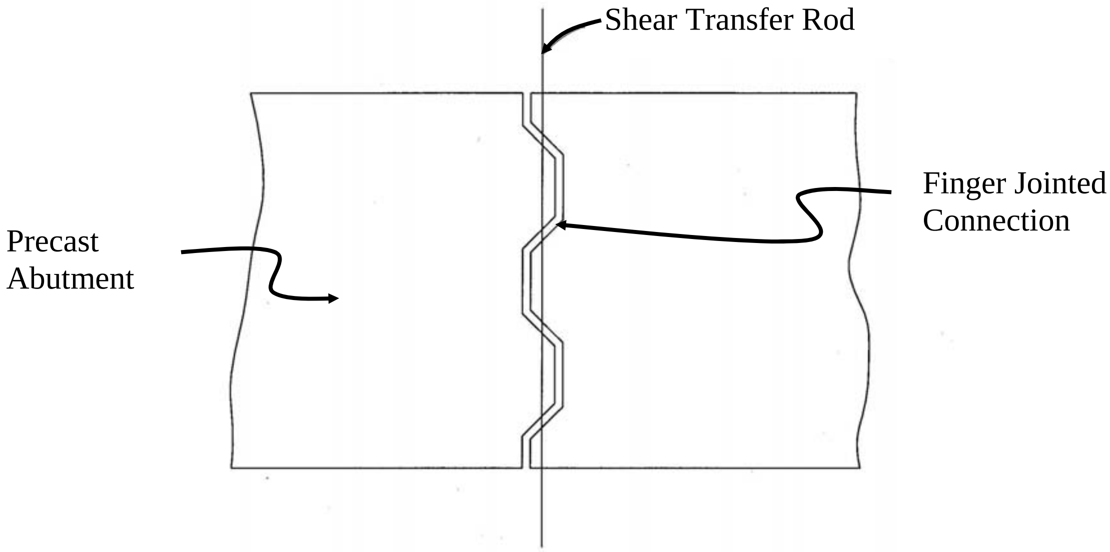

Figure 5. Conceptualization of finger jointed precast abutment with grouted shear transfer rods

The segmented abutment design developed stipulates cast-in-place connections. Alternative solutions considered included transverse prestressing incorporating strands or high strength rods, and fingered joints with vertically inserted shear rods grouted in place (reference Figure 5). The first solution was discounted quickly for reasons stipulated previously. The latter, while simple in concept, was ultimately abandoned due to concerns over constructability, considering abutment placement with cranes so as not to damage the concrete fingers. The final solution, which employs cast-in-place joints, was deemed the easiest and most efficient to construct (reference Figure 6). The simplicity of this connection detail lies in the fact that the imposed loads do not require reinforcement splicing across the joint. Additionally, analyses of various loading configurations, including full-width live loads for a given segment, substantiate the viability of this method. In fact, a segment can be employed in stage construction, with traffic shifted on to the completed section of structure resting on abutment segments while additional segments are joined and the remaining superstructure constructed. Engineers using these segmented abutments in such fashion simply need to validate stress demands where they intersect the joint face and incorporate additional confining steel as appropriate (reference Figure 7).

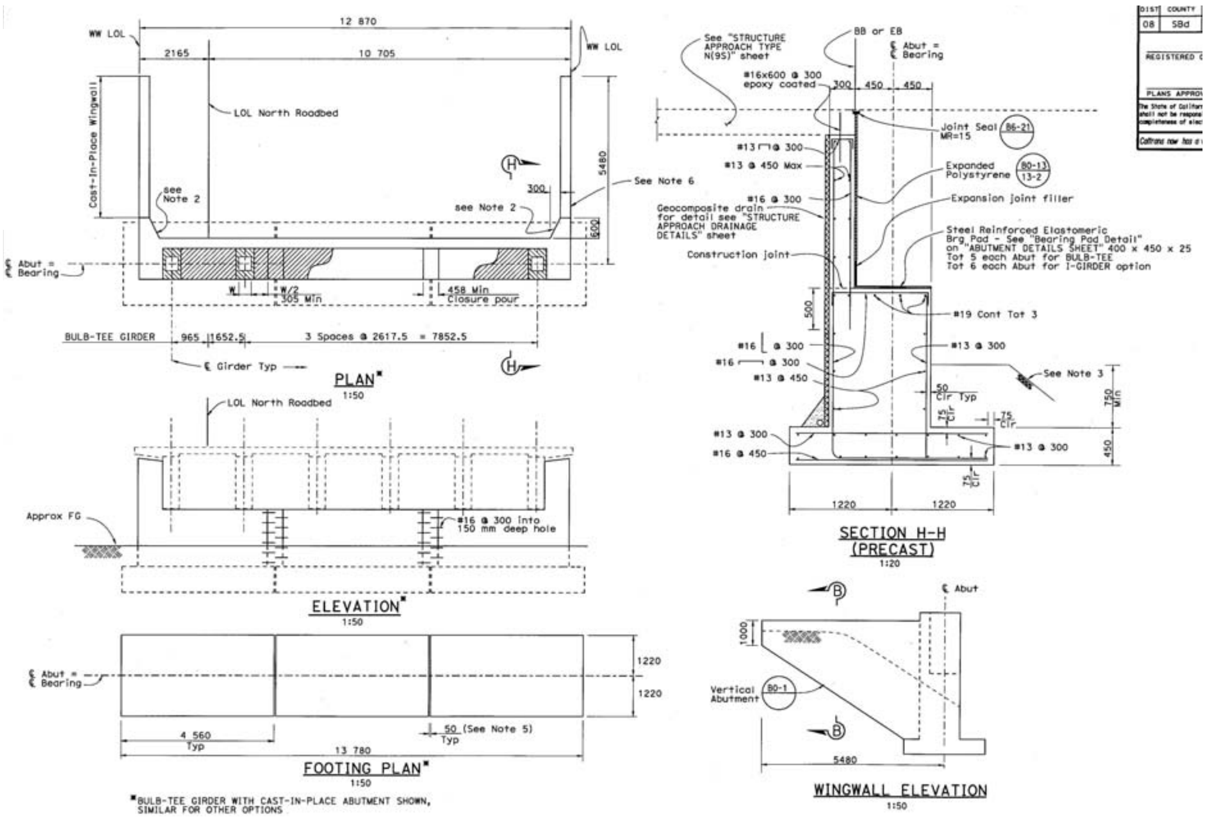

Fig. 6. Details of the segmented abutment concept utilizing cast-in-place joints

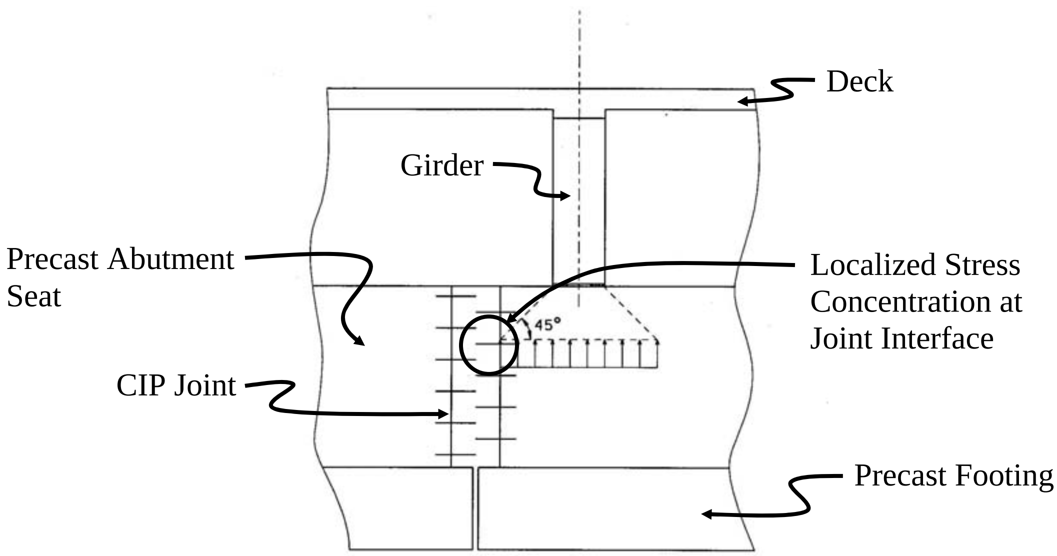

Fig. 7. Approximate location of stress concentrations at joint face which require attention when utilizing segmented abutments in stage construction applications where traffic loads will be applied prior to completion of the abutment

ADVANCING PRECAST ABUTMENT DESIGN

Uniform bearing is essential to spread footing design, and can be achieved either as done in this example with a low strength cast cementitious self-leveling pad, or by post grouting as is often done with precast slabs. As shown herein, segmented abutment designs can be accomplished in a number of different ways, depending on project constraints. The proposed design accommodated the advantages of precast abutments, while avoiding additional on-site operations such as post-tensioning. Since many bridges are founded on piles, segmented abutments designed to facilitate pile cap attachment are necessary. This paper focused on precast abutment designs for spread footings; subsequent work by the authors proposes viable technologies for precast segmented abutments on pile foundations. This is obviously the natural evolution of development.

CONCLUSIONS

The concept of precast abutments is new in California, and has not yet been implemented widely throughout North America on highway bridges. The design of the abutments for use on the Marble Wash (Left) Bridge were developed internally by California Department of Transportation engineers using information gathered from other State DOT's and academic studies. It was deemed appropriate to expend the effort in design to save time in construction, especially while the work on the westbound roadbed was delayed until completion of the bridge replacements. Segmented abutment design was the next logical step in developing precast abutments as a viable option for designers seeking competitive time saving solutions.

The days of blazing new highways in virgin territory are largely past. Today's transportation officials must not only be cognizant of the impacts their planned works have on traffic, but must also proactively find solutions to minimize such disruptions. Political pressures manifested through regional funding leveraging have solidified the above as a basic parameter in the transportation improvement equation across the nation and throughout much of the civilized world. Thus, it is anticipated that prefabricated elements will become more mainstream in California and other states as planners and engineers seek viable engineering solutions that address schedule compression demands.

Rapid bridge construction has been a leading focus of national and international research, with numerous funded projects in academia and industry. Recently in the United States, funding focused efforts to investigate viable solutions and develop associated design and construction specifications has increased with the realization of the importance of the topic. The need for accelerating transportation construction is not limited to North America; European and Asian countries have embraced the idea and in many senses are leading the innovations. In the end, widespread implementation of these technologies will benefit commerce and the traveling public, leading to a "win-win" scenario.

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