PREFABRICATED BRIDGE SYSTEMS FOR MINIMUM LANE CLOSURE DURING CONSTRUCTION

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This paper presents the current state of the art on the use of innovative prefabricated systems and elements to limit traffic disruption during construction or rehabilitation of bridges. The currently used systems are discussed, and the evaluation of their effectiveness in bridge construction, rehabilitation and replacement is documented. The paper also presents results of a survey questionnaire addressed to the state/province Departments of Transportation in the United States and Canada. The survey is devised to evaluate the state of practice as far as the use of innovative prefabricated systems/elements for bridge construction, rehabilitation and replacement is concerned. The analysis of the responses from the questionnaire is presented in terms of the effectiveness of innovative prefabricated systems/elements in bridge rehabilitation and replacement. The major problems that inhibit the widespread use of innovative systems and elements are identified. Finally, the paper provides some perspectives with regard to the use of innovative prefabricated systems/elements for bridge construction, rehabilitation, and replacement.

INTRODUCTION

A significant number of bridges in the US require rehabilitation or replacement. The biennial report of the Secretary of Transportation to the U.S. Congress pointed out the structurally deficient conditions of bridges in the nation and emphasized the urgent need to improve safety and efficiency of highway travel. About 28% of the 590,000 bridges in the US need to be rehabilitated or replaced. Repair, rehabilitation and replacement have important consequences on bridge users. For instance, a full lane closure in large urban centers or highways can cause a significant economical impact on commercial and industrial activities. In addition, work zone safety is an important parameter to consider in such situations. Therefore, minimizing traffic disruption during bridge construction is a crucial issue in addition to maintaining construction quality and reducing the life cycle costs and environmental impact.

It is considerations like those mentioned above that have led researchers and bridge authorities to investigate more elaborate integral prefabricated systems to improve work zone safety and minimize traffic disruptions. Mass-produced elements can be quickly assembled, and can reduce design time and cost, minimize forming and labor costs, and minimize lane closure time. Even at a higher cost, the use of prefabricated systems on bridges subjected to a high volume of traffic is justified because of the excessive lane closure times that can be avoided.

In the 1990s, prefabrication and prestressing of concrete were combined to give a system of quasi-total prefabrication of bridges, such as full-depth prefabricated-prestressed deck and double-tee prefabricated-prestressed deck. These systems were used to replace bridge decks during off-peak traffic and demonstrated that they were a good solution in terms of minimizing traffic disruption[1].

Prefabrication has also been extended to the bridge's substructure, and systems have been proposed for segmental piers and bents, prefabricated abutments, and composite piles. It is currently possible to replace almost any portion of a bridge with a prefabricated element/system and to complete the installation during off-peak traffic periods with minimal traffic disruption.

A new type of high performance materials, Fiber Reinforced Polymers (FRP), has been developed and used in pilot projects in the bridge industry over the last several years in the USA, Canada and Europe. These types of innovative projects have been described elsewhere[2].

The objective of this paper is to assess the use of new and innovative prefabricated systems/elements and methods in bridge construction. A review of existing literature and available information is presented along with the results from a survey questionnaire to assess the current use and demand for totally prefabricated systems.

PREFABRICATED SUPERSTRUCTURES

A system is defined here as a combination of prefabricated elements (concrete, steel or any advanced materials) which eliminates or considerably limits cast-in-place concrete. The use of prefabricated elements such as pier caps, columns, full-depth decks, etc. can effectively minimize construction time, traffic disruption and the impact of construction activities on the environment. Elements in this context exclude common elements, such as typical beams. The most innovative prefabricated systems are those using high performance materials that are lightweight, durable, and suitable for prefabrication in large sizes.

The construction of the superstructure is a time consuming part of cast in-place bridges; therefore, its prefabrication, in-part or totally can significantly reduce construction time and traffic disruption.

Prefabricated concrete decks: Prefabricated decks offer advantages for deck construction since bridge components can be prefabricated offsite and assembled in place. Other advantages include removing the deck placement from the critical path of bridge construction schedules, cost savings, and increased quality due to controlled factory conditions.

Re-decking with prefabricated modular deck panels is a viable method of deck replacement that minimizes traffic disruption. More importantly, this construction method allows opening part of the bridge under construction to traffic. In addition, nighttime re-decking with prefabricated concrete modular panels, although slightly more costly than daytime re-decking, can further minimize interruption of traffic. Also, the existing composite concrete deck could be replaced in stages. In each stage, a portion of the transverse section is removed and replaced along the full length of the bridge, while other lanes are maintained open for traffic.

Full-depth deck panels: The re-decking of the Woodrow Wilson Bridge is a relevant example for using the full-depth panels. The Woodrow Wilson Bridge carries Interstate I-95/495 over the Potomac River in Washington, D.C. The bridge, which carries over 110,000 vehicles per day, was built in 1962 and re-decked in 1984 (Figure 1). The bridge is 5,900 feet (1798 m) long with span lengths between 62 feet (18.9 m) and 184 feet (56 m). The bridge carries six lanes of traffic on four main girders with floor beams at 16 to 26 feet (4.87 to 7.9 m) on center. Five rolled beam stringers that are continuous over the floor beams carry each roadway.

The replacement deck system is composed of transversely post-tensioned lightweight precast concrete deck units [3] as shown in Figure 2. A total of 1026 precast panels weighing approximately 22 tons each were used to re-deck the structure. The completed deck was post-tensioned in the transverse and longitudinal directions with strand tendons. The deck panels are supported on polymer concrete between the panel and stringers and are held in place with bolted hold-down devices.

The primary goal of the project was to minimize disruption to traffic during deck replacement. The contractor achieved an average replacement of 1,554 square feet (144.4 m^2) of deck per calendar day and 2,745 square feet (255 m^2) per workday. This was accomplished while being restricted to night work only and the requirement for maintaining two lanes of traffic during work.

Another interesting example of using the prefabricated systems to minimize traffic disruption[4] is the re-decking of the Jacques-Cartier Bridge in Montreal, Canada. The Jacques-Cartier Bridge (Figure 3) is a five-lane bridge 11,236 feet or 2-1/6 miles (3.4 km) in length, spanning the St. Lawrence River between the cities of Montreal and Longueuil, Canada. Approximately 43 million vehicles cross the bridge every year.

During two construction seasons in 2001 and 2002, the 71 year old Jacques-Cartier Bridge underwent complete re-decking of the 5 lanes wide long bridge deck. The new deck is constructed of prefabricated, prestressed and post-tensioned panels as shown in Figure 4. The high performance concrete (HPC) panels were prefabricated in a temporary plant installed near the south end of the bridge. A total of 1680 prefabricated deck units, representing a surface area of about 62,000 m^2 (667,000 $ft.^2$) were installed principally during night time from April to October in 2001 and 2002. The new prestressed concrete deck panels were post-tensioned transversally and longitudinally to control water infiltrations through construction joints made of rapid setting mortar. The entire project was completed without disturbing normal rush hour traffic.

Full-depth full-width deck panel: An innovative design and construction methods for off-system bridges in Texas was recently proposed [5]. The "off-system" bridges are those for which TxDOT does not have ownership or maintenance responsibilities; however, the owners require TxDOT to help in their design, construction and financing. Many of these off-system bridges are located in rural and remote areas. Replacement of these bridges most often require lengthy detours and therefore presents great negative impact to the public and the surrounding economy. Statistics of such bridges needing replacement indicate that the majority have a single span over a stream. A typical bridge has 50 ft (15.2 m) span and is 24 ft -wide (7.23 m). Innovative bridge systems that minimize construction time present possible solutions. Full-width, full-depth precast deck panels attached to traditional precast concrete or steel I-beams with multi-directional shear and leveling screws is proposed as a possible solution.

The proposed superstructure system is illustrated in Figure 5 which shows conceptual drawings of a bridge span before closure pours and the completed span. The individual deck segments, which are approximately 8 ft (2.44 m) long, 26 ft (7.92 m) wide, and 8 in (20.3 cm) deep, are connected to each other and to the longitudinal I-beams with grouted pockets. The maximum weight of a deck panel is less than 21 kips (93.4 kN), a load that a 22 ton (195 kN)-crane can handle at a 29 ft. (74 m) reach. The I-beams are installed on the abutments and then the deck panels are mounted on the I-beams. Although concrete I-beams are shown, steel I-beams are envisioned in the concept. The case of concrete I-beams requires a 30 ton (267 kN) crane in the streambed or two cranes, one on each abutment. Transverse prestressing and possibly longitudinal post-tensioning will be performed. Shear pockets are located in each panel at two locations per supporting beam. At least two shear and leveling screws are within each shear pocket as shown in Figure 6.

The composite action of the panels and the I-beams is provided by grouting the shear pockets after the panels are placed, adjusted, and positioned properly. The panels are grouted to the beams using "top-only" construction which is an advantage to this construction method enhancing the speed and the safety. Finally, the proposed system allows the installation of the superstructure in one day after the abutments are ready.

FRC Arch-panel decks: Fiber Reinforced Concrete (FRC) deck slabs without internal tensile reinforcement are also known as steel-free and corrosion-free deck slabs. The design criteria for the cast-in-place version of these slabs is implicitly approved by the Canadian Highway Bridge Design

Code (2001) and has already been applied to four highway bridges in Canada. The prefabricated version of steel-free deck slabs was developed after extensive experimental investigation. Tests of full-scale prefabricated slab prototypes have been implemented in one forestry bridge and one marine structure.

The typical cross-section for all Arch-Panels used in the experimental work, carried out by Mufti et al. [6], is shown in Figure 7. Weight is an important consideration when transporting precast elements, particularly to remote locations. The panel in Figure 7 is supported by steel girders spaced 11.5 ft (3.5 m) apart. The Arch-Panel has a constant thickness of 6-in. (150-mm) through the middle 7.2 ft (2200 mm) portion of its width yielding a nominal span to depth ratio of 23.3 : 1. The studs shown in Figure 7 anchor the straps in the concrete slab. In order for the system to be fully composite, the Arch-Panel must also be connected to the supporting girders.

The panels have been proven to be durable during transportation and handling. Once fully installed, the Arch-Panels are capable of sustaining loads several times larger than the nominal ultimate loads required by a variety of design vehicles. Recent project examples include two-girder bridges in remote locations where cast-in-place construction was not feasible for concrete decks in marine structures and prefabricated modular assembly was preferred for speed, quality control and lack of formwork requirements [6].

Transversally Post-Tensioned Double-Tees: In many states (Colorado, Florida, Wyoming, New Mexico, etc.), prestressed double-tee beams have been used for rural and secondary roads. However, this structural system is aimed at state and interstate class highway bridges with spans measuring up to 80 feet (24.4 m) in length. The prestressed prefabricated beams are transported to the construction site and erected adjacent to each other as shown in Figure 8. Next, the beams are tied together transversely by a simple joint and transverse post-tensioning. The joints are then filled with a high strength non-shrink grout and the transverse post-tensioning is applied to transfer the lateral load.

The elimination of cast-in-place elements is associated with speed of construction and reduction in labor costs. Only two skilled workers and a crane are needed to erect the superstructure of the bridge. All initial studies [7, 8] indicate that this system is very economical and cost effective for short and medium span bridges up to 65 ft (19.8 m). For spans ranging between 65 to 80 ft (19.8 to 24.4 m), transportation and erection constraints may prevail. The level of transverse post-tensioning is an important parameter to insure a monolithic behavior of the bridge deck. Shahawy[7, 8] reported that a minimum uniform compression of 250 psi across the longitudinal joints is required to develop monolithic behavior.

Decked concrete girders can eliminate the requirement for cast-in-place concrete and reduce the construction time associated with conventional I-girder bridges. A decked girder is a precast, prestressed concrete I-beam or bulb-tee girder with an integral deck that is cast and prestressed with the girder. Figure 9 shows a typical decked bulb-tee system. Decked girders are manufactured in precast concrete plants under closely controlled and monitored conditions, transported to the construction site and erected such that flanges of adjacent units abut each other.

Load transfer between adjacent units in decked systems is provided using specially designed connections. Sections that are not too long or too heavy for transportation by truck can be used to construct long-span girder bridges. Generally, decked systems require a deck overlay to improve rideability; however, bridges without a deck overlay have been successfully built in the past.

In spite of the benefits of decked precast prestressed concrete girders, their use has been limited because of concerns about certain design, construction and performance issues that are perceived to influence the structural integrity of the bridge system. These issues include long term performance of the connections between adjacent units, longitudinal camber and cross slope, live load distribution, continuity for live load, lateral load resistance, skew effects, maintenance, replaceability and other factors that influence constructability and performance.

Proprietary systems: Numerous proprietary deck and superstructure replacement systems are being marketed or evaluated at this time[9]. The Exodermic Bridge Deck system is a good example of these proprietary systems. It is a composite modular system that is lightweight and strong. It consists of a reinforced concrete slab on top of, and composite with, an unfilled steel grid. The Exodermic Deck panels provide the durability and strength of reinforced concrete but weigh 35-50% less[5] and can be placed rapidly with minimum traffic disruption.

In 1990, Jean Muller International introduced a new segmental system called the Channel Bridge System[9]. In this system, the supporting beams of the channel cross-section serve as traffic barriers above the deck which increases the vertical clearance above a roadway or a navigational channel. Longitudinal and transverse prestressing provides strength and durability by maintaining compressive stresses in the concrete when loaded. Segments of 8.2 ft (2.5 m) long can be connected to form 114.75 ft (35 m) long spans.

The state of New York was the first to use this system in the United-States. In 1997, two bridges were replaced with the Channel Bridge system: (a) Carpenter Road over Metropolitan Transportation Authority Metro North Railroad in East Fishkill in Dutchess County and (b) State Route 17M over State Route 17 in Wallkill in Orange County.[10]

In Australia, the case of the Sorell Causeway bridge replacement is a good example of use of the channel type bridge [11]. The replacement structure was built adjacent to the existing bridge which was retained in service during the construction works. An important criterion in the bridge system selection was its shallow depth which allowed the required vertical clearance. The road level adopted was therefore considerably lower than was required for conventional design and a significant reduction of off-structure earthworks resulted from the lowering of the roadway surface. The construction loading governed the transverse design since the construction procedure required the use of a 150-ton crane to lower the precast units from the span just completed. Units were suspended by the underside of their flanges and placed onto temporary steel girders launched between piers as shown in Figure 10. The final results of the project indicate that reduced time and cost were obtained due to the use of this prefabricated system.

Total superstructure systems: Increasingly, innovative bridge designers and builders are finding ways to prefabricate entire segments of the superstructure. Pre-constructed composite units may include steel or concrete girders prefabricated with a composite deck, cast off-site and then lifted into place in one operation. Truss spans can also be prefabricated. Prefabrication at this scale offers potential advantages in terms of constructability, on-site construction time and the requirement of equipment at the construction site. For example, the George P. Coleman Bridge (Figure 11) located in Yorktown, Virginia, which is the largest double-swing bridge in the United States, was replaced in record time in 1995[12]. A major goal was limiting bridge closure to avoid disrupting traffic of more than 27,000 vehicles a day. Lighter-weight modern materials allowed Virginia DOT designers to widen the new bridge by using the existing foundation. Truss spans were prefabricated and fitted with concrete decks at a nearby location and then barged to the construction site. Six old spans were removed and six new ones placed in only nine days.

The Lions' Gate Suspension Bridge above Vancouver's First Narrows is a relevant example of total superstructure system [13] (Figure 12). It has average daily traffic of between 60,000 and 70,000 vehicles. A rehabilitation project of the bridge included replacement of the three-lane bridge deck and trusses encompassing widened lanes for traffic, widened sidewalks for cyclists and pedestrians as well as seismic strengthening. The deck and trusses were replaced simultaneously while allowing traffic to use the bridge. Individual deck sections between 33 and 66 ft. (10 and 20 m) long were cut away and lowered with a jacking traveler to a waiting barge, and the replacement section was lifted into place. When assembled on the bridge, each section was connected to its neighboring section with more than 700 high-strength steel bolts. Most of the reconstruction occurred at night-time during the period of September 2000 to September 2001.

Prefabricated Substructures

Prefabricated substructure design provides an opportunity to apply advanced technologies and new materials to bridge systems. Specifically, the prefabricated substructure system consisting of segmental piers and bents offers an alternative that combines prefabrication and high performance materials resulting in rapid construction, durable performance, and an attractive appearance.

Total substructure systems: Bridge design can combine the bent cap and its column into one prefabricated unit, eliminating the need for individual substructure elements and using a prefabricated approach for the entire substructure. Cast-in-place bent caps require extensive formwork and curing times. If they are fabricated off-site, curing times are not a factor. As a result, bridge owners and contractors are increasingly turning to prefabricated bent caps. For over-water bridges, they reduce the amount of time that workers need to operate over-water. Also, for bridges over existing roadways, they minimize formwork required, reducing disruption to traffic on the lower roadway. For bridges with job-site constraints, such as power lines that affect work zone safety, they limit the amount of time that workers are at risk.

The US 290 Ramp E-3 bridge project in Austin, Texas is a relevant example (Figure 13). After the contract had been let and work started, it became clear that formwork for the proposed cast-in-place cap would interfere with traffic and require closing of the ramp for an estimated 7 days [12]. With

TxDOT's approval, the contractor instead prefabricated the straddle bent cap at the work site and lifted it into position. Once it was in place, it was post-tensioned and the cap-to-column connections were grouted. The time necessary for closure of the ramp was reduced from an estimated 7 days to 4 hours.

Bridge construction times can be greatly reduced by using prefabricated columns on cast-in-place footings. Columns can be segmental, post-tensioned, either hollow or concrete-filled. For example, the Dallas/Fort Worth International Airport People Mover located in the Dallas/Fort Worth Metroplex, TX, will be upgraded [12] and the project is planned to be completed in 2004 (Figure 14). Initial cost analysis indicate that the cost per day of casting conventional concrete columns is high due to space that would be used at the airport. Instead of closing aircraft terminals and gates, the DFW Airport People Mover Team decided to design and build a prefabricated post-tensioned segmental system of columns.

The SH 249/Louetta Road Overpass located in Houston, Texas and completed in 1994 is an example of a bridge using the total prefabricated substructure system [12] (Figure 15). The bridge has three 130 ft (39.6 m) spans. At the interior bents, each beam is supported by a single post-tensioned pier.

The Edison Bridge replacement is another example of a bridge using a prefabricated substructure system. The Edison Bridge carries U.S. Route 41 over the Caloosahatchee River in Fort Myers, Florida. The original structure, 4623 feet (1409 m) long was built in 1931 and replaced with dual structures in 1991 (Figure 16). One of the most unique aspects of the new structures is that the substructure above the footings is entirely prefabricated. All columns and cap beams are prefabricated and weigh up to 90 tons. The prefabricated elements are connected with a unique bar-splicing system. By prefabricating the substructure, the erection of the columns and caps was completed quickly and contributed substantially toward the early completion of the project. The construction for both bridges, 9,850 feet (3002 m) of structure, was completed in 25 months [14].

The Ferguson Structural Engineering Laboratory at the University of Texas in Austin conducted a research project through the Center for Transportation Research with the goal of improving the efficiency, appearance, durability and time required for the construction of short- and moderate-span bridge systems. One of the outcomes of the study was a proposed segmental prefabricated concrete substructure system for standard highway bridges[15].

The proposed prefabricated substructure system is made up of three basic segment types: match-cast column segments, a ''template'' segment, and an inverted-T cap match-cast to the template (Figure 17). Inverted-T caps are proposed to improve visibility through the bridge, as well as increase the clearance underneath the substructure.

The proposed system has been designed to produce a wide range of straight and skewed substructure units, including single column, straddle, and frame bents. Four column sizes were designed to produce varying bent configurations. The pier segments are hollow, high performance concrete segments with a wall thickness of 13.8 in. (350 mm) to accommodate inserts in the formwork for exterior relief or texture. Hollow sections keep the weight of the elements low for hauling and erection. The walls of the hollow pier segments provide enough room for the post-tensioning bars, as well as the multi-strand tendons. The hollow pier segments also provide room for internal drainage ducts.

Prefabricated Abutment: A prefabricated abutment system based on prefabricated counterfort-ribbed wall sections anchored to footings using tensioned bars or tendons was developed[13]. Variations in abutment-wall and wing-wall configurations made it difficult to develop standardized elements. It was decided, therefore, to use cast-in-place footings as a base for the prefabricated counterfort elements.

Figure 18 shows an 8-ft (2.44 m) high abutment front wall and the two-lift wing-wall in place. Segments are typically 16 ft (4.88 m) in length with two stems per segment. Post-tensioning tendons are placed at the front and back of the stems to tie the abutment unit to the cast-in-place footing. Dowels from the footing are connected to the tendons by couplers near the base of the prefabricated unit.

No bracing is required during installation due to the stable configuration of the prefabricated unit. Abutment units are limited to 8 ft in height for ease of transportation. For higher walls, two or more lifts can be used as demonstrated in the wing-wall arrangement. The use of prefabricated abutment elements requires that loads be transmitted across horizontal joints. This can be accomplished by either match casting or grouted joints. At the interface of the cast-in-place footings and the prefabricated units, a grouted joint is necessary.

A demonstration project based on the design concepts described above was developed for a bridge replacement project in PennDOT District 11-0, Allegheny County, on S. R. 3026 over Miller's Run Creek. It was estimated that the use of prefabricated abutment units allowed the bridge to be opened about two weeks earlier than would have been possible in the case of a standard cast-in-place abutment system.

Totally Prefabricated Bridges

Totally prefabricated bridge systems offer the maximum advantage for rapid construction, and depend on a range of prefabricated bridge elements that are transported to the work site and assembled in a rapid-construction process. The case of Baldorioty de Castro Avenue Overpasses in San Juan, Puerto Rico (Figure 19) is a relevant example of a totally prefabricated bridge system [12]. To ease congestion on a road that carries more than 100,000 vehicles per day, the Department of Public Works provided two overpasses at each of two intersections: two 700-foot-long (213.4 m) and two 900-foot-long (274.3 m) overpasses. To minimize traffic disruption, the project was built in two stages. Piles were driven and footings cast with special forms to facilitate connections. Then, the prefabricated components were erected and post-tensioned. Box piers were positioned and post-tensioned to the footings, caps placed, and piers vertically post-tensioned. When the first two piers were installed, the 100-foot-long (30.48 m) superstructure box beams were set in place. Each span then was post-tensioned transversely as it was completed. The first bridge was erected in 36 hours, and the others took as little as 21 hours.

PRESENTATION AND ANALYSIS OF SURVEY

A survey questionnaire addressed to the state/province DOTs was devised to evaluate the practices in their respective states and provinces as far as the use of innovative prefabricated systems/elements for bridge construction, rehabilitation, and replacement.

The survey includes 16 questions and was subdivided into four sections covering various areas of interests. The first section aims at identifying the type and the frequency of use of prefabricated systems and elements for bridge construction, rehabilitation, or replacement in order to accelerate construction time. It also aims at identifying the reasons for using such innovative prefabricated systems and elements. The second section of questions addresses the locations of the prefabrication plants, their distances to the bridge sites, as well as the means used to transport the prefabricated systems and elements to the sites. The third section is concerned with the cost of the systems/elements in comparison to alternative solutions. Finally, the last section of questions is about successful pilot projects and incentive contracts that may accelerate bridge construction. The present survey received 22 responses from 19 US DOTs and 3 Canadian Provinces.

Extent of Use of the Prefabricated Systems/Elements

A nation-wide questionnaire was used in 1984 to evaluate the use of prefabricated elements and systems in bridges [16]. The survey indicated that only about 0.5 % of bridges contained a completely prefabricated superstructure. It also revealed that less than 0.1 % had a prefabricated substructure.

The present survey showed an increasing use of prefabricated bridge systems. The prefabricated bridge systems are used on all types of roads from interstate roads to secondary roads. However, the majority of these bridges (53 %) are used on interstate and primary roads with high traffic volume (i.e., more than 10,000 daily vehicles).

Figure 20 presents the geographical distribution of prefabricated bridges and covers only those states that responded to the survey questionnaire. As indicated in the figure, innovative prefabricated bridges are concentrated in Texas (21 %), Virginia (19 %) and Tennessee (13 %). Note that the states having less than 2% of such bridges were omitted from the distribution.

The survey showed that the distance between the fabrication plant and the bridge site is generally more than 50 miles (54 %). The survey also revealed that the large majority of prefabricated elements of the different innovative systems were transported to the bridge site by trucks (78 %). The development of the prefabrication process and of elaborated systems allowed these systems to be made of elements whose dimensions and weights are easily transportable by truck. As a result, the questionnaire did not reveal any problems related to transportation.

Reason of Use of Prefabricated Systems

The major reasons for using prefabricated systems according to the survey are presented in Fig. 21. It is observed from the figure that the reasons for using prefabricated systems are as follows, by order of importance:

1. To facilitate construction (28 %),
2. To minimize construction delay (22 %),
3. To minimize lane closure time (17 %),
4. To improve quality and durability,
5. To increase safety, and
6. To minimize environmental impact and costs.

The analysis of these responses shows that these bridges were mainly developed to overcome construction difficulties and to minimize the lane closure time. This is evident, since about two-thirds (63 %) of these systems were used in rehabilitation or replacement of bridges in the United States. This also explains why cost may become a secondary criterion for selecting the bridge construction method and materials. Note that Figure 21 excludes bridges with partial-depth deck panels, transversally post-tensioned boxes and stay-in-place steel forms. It focuses, rather, on the use of innovative bridges recently developed, and used as pilot projects, on quasi-totally prefabricated or on bridges using advanced composite materials.

It should be mentioned that although the environmental impact is commonly given in the survey as a reason for using prefabricated bridges, it remains of a secondary order (Figure 21). This can be partially explained by the fact that these systems are generally used in special conditions, such as the urban centers or highway roads where the traffic lane closures and the resulting economic consequences predominantly govern the choice.

Aspects in Need for Development

Figure 22 shows the relative importance of aspects in the bridge prefabrication industry, which require further development. As can be observed, the aspects often raised in the survey are related to the initial cost (22 %), the design and the standardization (22 %), the contractors' experience (21 %) and the connections (18 %). Despite the great effort that has been dedicated to the development of connections and standardization in the field, the old connection problems are still not fully solved. Clearly, there is an urgent need for continued and sustained research and development in these areas. Also, the initial cost presents a continuing disadvantage of the prefabricated systems (22 %), compared to conventional methods. The high initial cost of these prefabricated systems is related to the lack of standardization, and to the fact that these systems are innovative and imply new expensive materials and specialized equipment. However, the introduction of the life-cycle cost attenuates the effect of the initial cost inconvenience. The problem of durability seems to be of lesser importance, since it is mentioned in only 8 % of the survey responses. Also, the problems related to the weight and length of the elements has become less important owing to the development of better performing installation equipment.

CONCLUSIONS

This paper presents results of an investigation on the use of innovative prefabricated elements and systems to limit traffic disruption during construction, rehabilitation, widening or replacement. The main objective of the study was to assess the extent of use of new and innovative prefabricated systems/elements and methods in bridge construction, rehabilitation and replacement, in terms of the system's design effort, on-site construction time, minimum lane closure time, and minimum environmental impact.

From the literature review and the survey, the following conclusions can be drawn:

(a) New systems were developed to prefabricate the decks, the superstructures and the substructures. The new orientation is towards the development of totally prefabricated systems which minimize traffic disruption.

(b) According to the survey, the three major reasons for using innovative prefabricated systems by order of importance are as follows: 1.) to facilitate construction, 2.) to minimize the construction delay, and 3.) to minimize the lane closure time. All these principal reasons lead to minimizing traffic disruption.

(c) The quality of the prefabricated bridges is improved and safety at the construction site is increased. In addition, the global performance of the innovative bridges is better, since these bridges generally have less dead load, and therefore, allow for greater useable live load.

(d) The aspects in the bridge prefabrication industry still requiring development, according to the survey results, include connections, design and standardization, and the experience of the contractors. The initial cost presents a continuing disadvantage for prefabricated systems, compared to conventional methods. However, the introduction of the life-cycle cost and the benefits of shorter lane closure time attenuate the effect of the initial cost inconvenience.

Finally, emphasis should be placed on efficient collaboration between DOTs, researchers and contractors to communicate concerns, to orient the research projects, and to generalize the successful aspects leading to design standardization and construction guidelines for practicing engineers.

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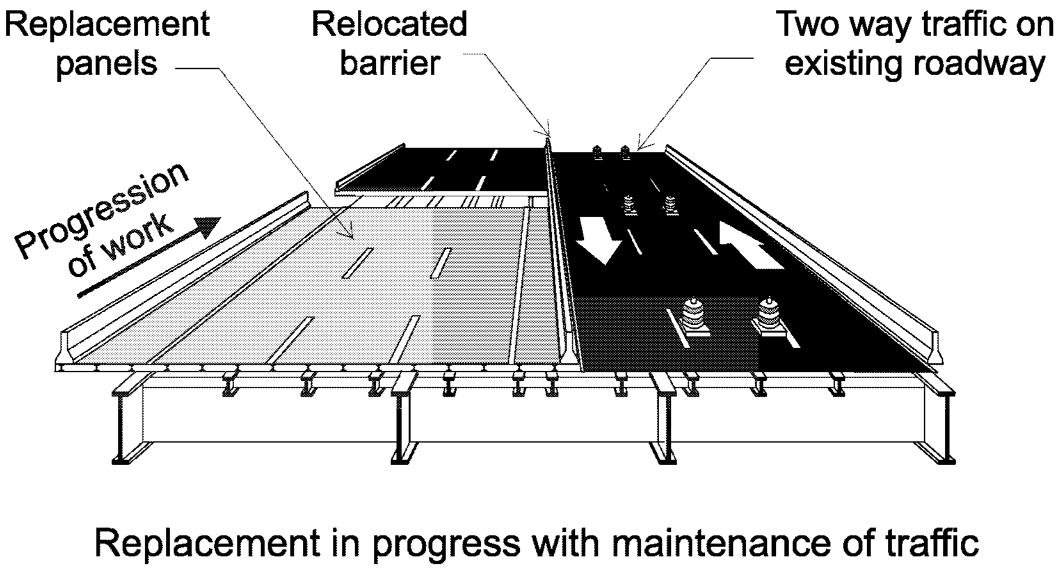

Figure 1. Re-decking View of the Woodrow Wilson Bridge

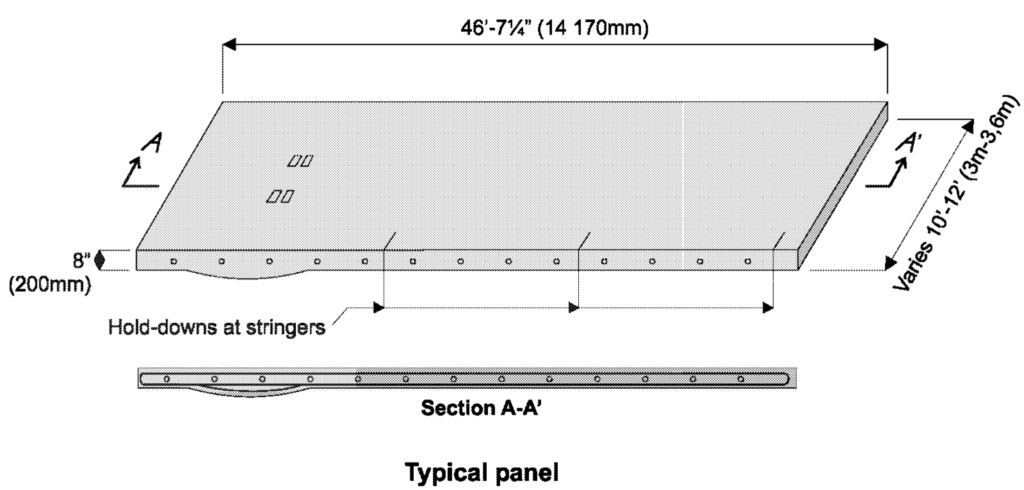

Figure 2. Prefabricated Concrete Deck Panel

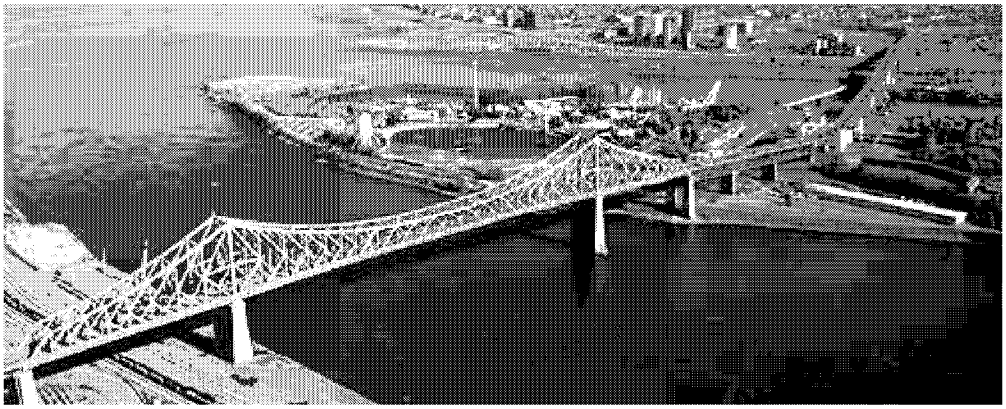

Figure 3. Jacques-Cartier Bridge (Source: www.pjcci.ca)

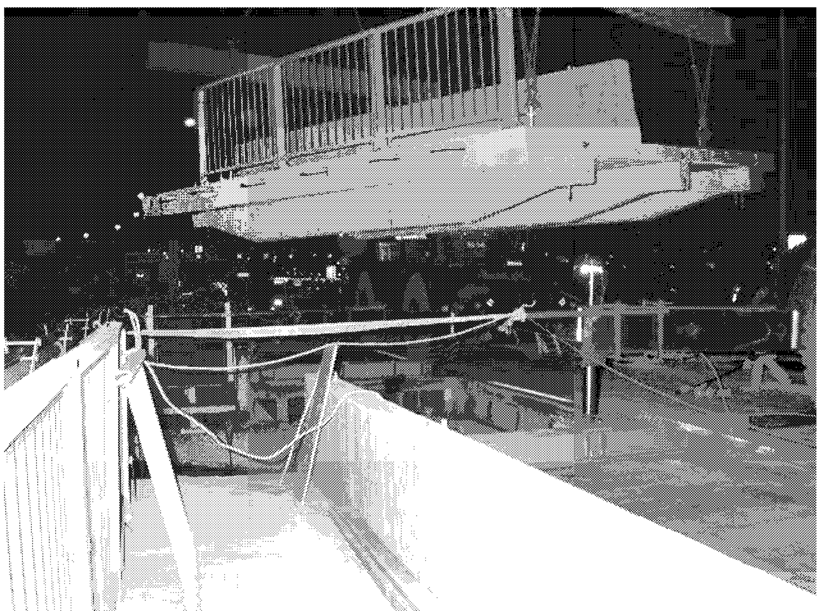

Figure 4. Prefabricated Deck Panel (Source : www.pjcci.ca)

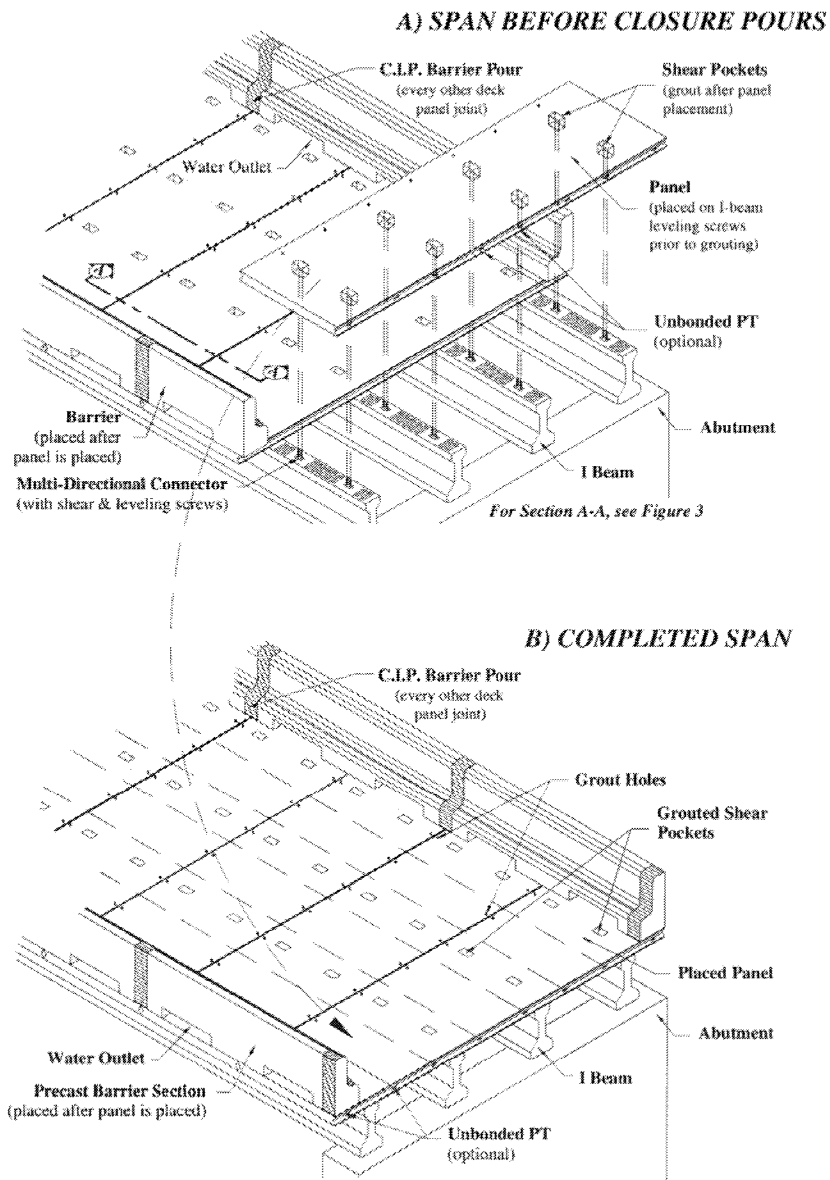

Figure 5. Superstructure System Using Full-Width, Full-Depth Prefabricated Panels (Source: Phelan and Vann 2004)

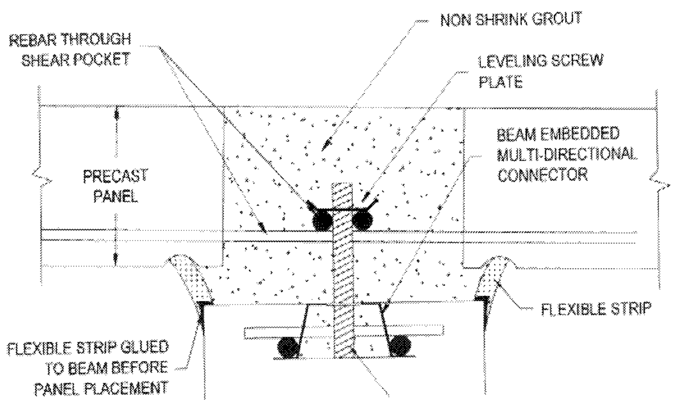

Figure 6. Grouted Shear Pocket (Source : Phelan and Vann 2004)

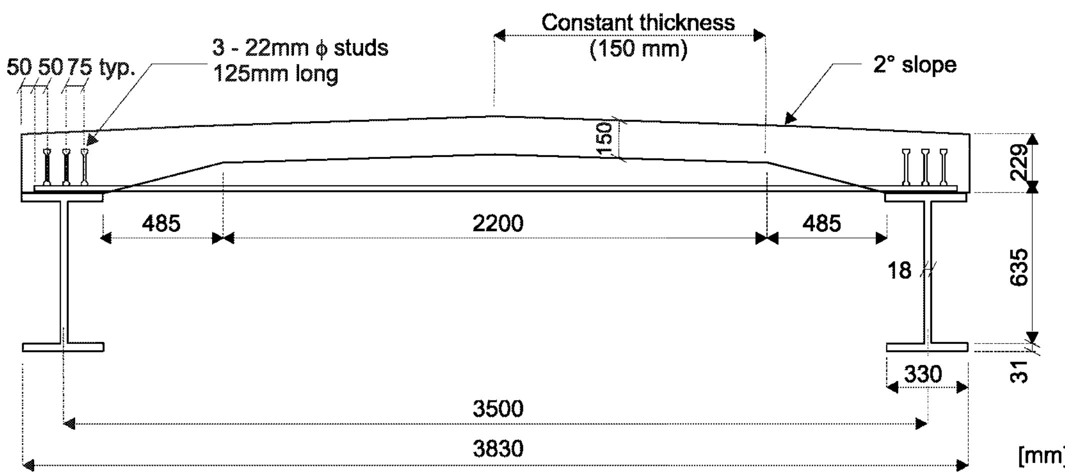

Figure 7. Typical Cross-Section of Experimental Arch-Panel on Steel Support Beams

Figure 8. Double-Tee Bridge System

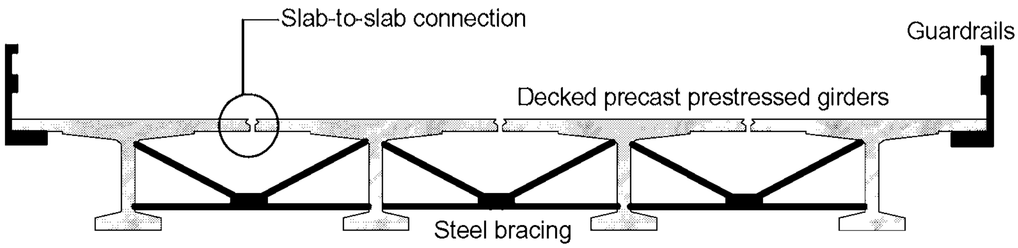

Figure 9. Decked precast prestressed bulb-tee bridge

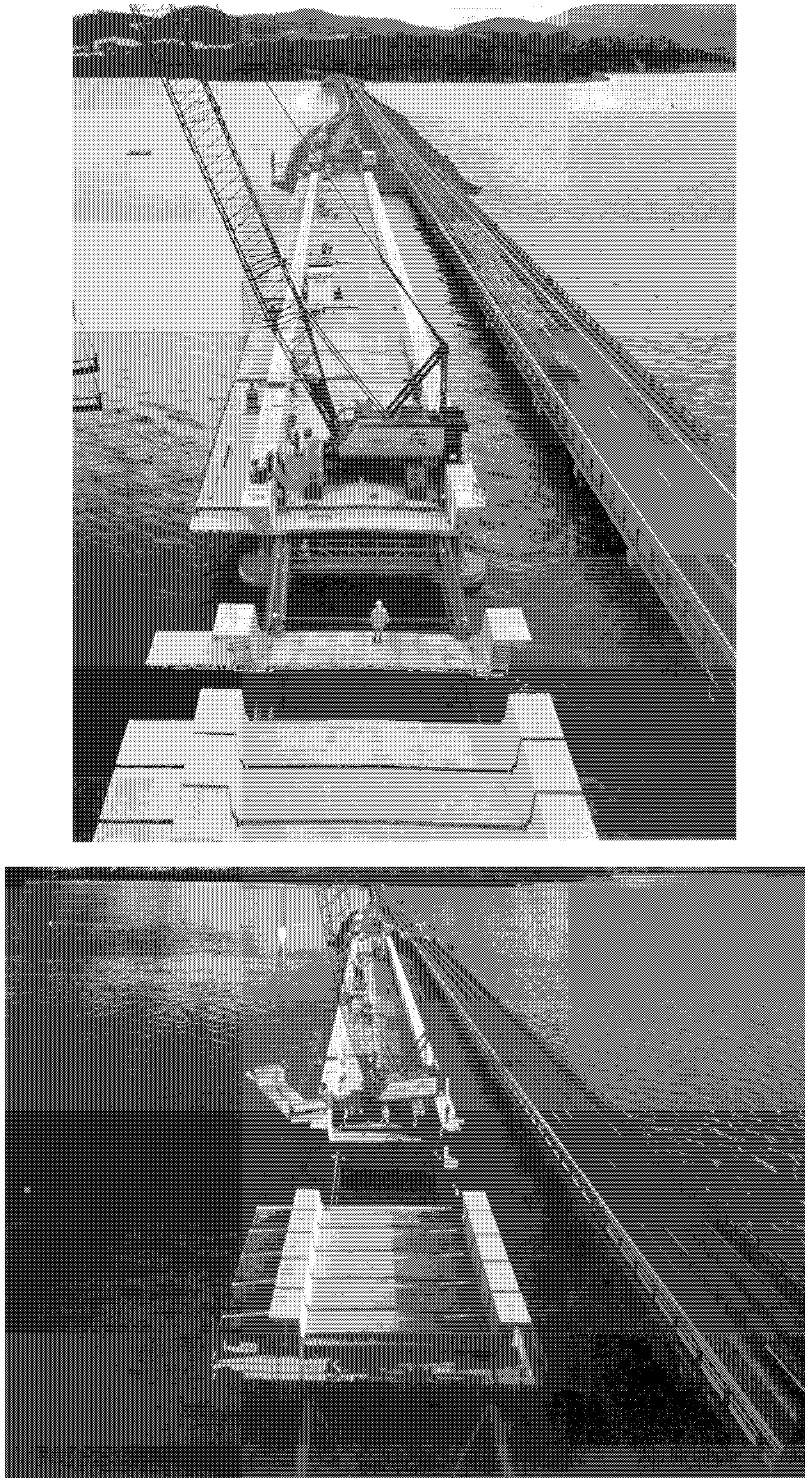

Figure 10. **Installation of Channel Segments of Sorell Causeway Bridge (source: Gibbens and Smith 2003)**

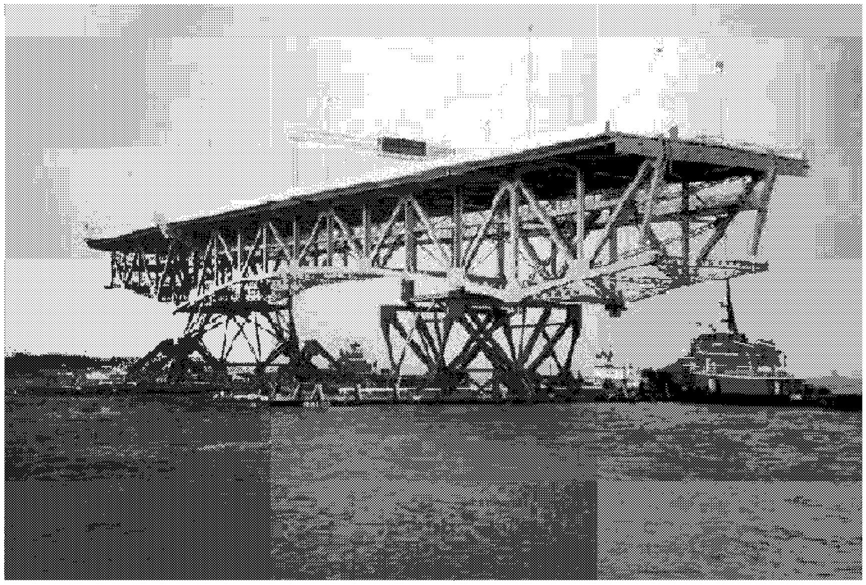

Figure 11. George P. Coleman Bridge
(Photo Credits: Virginia Department of Transportation)

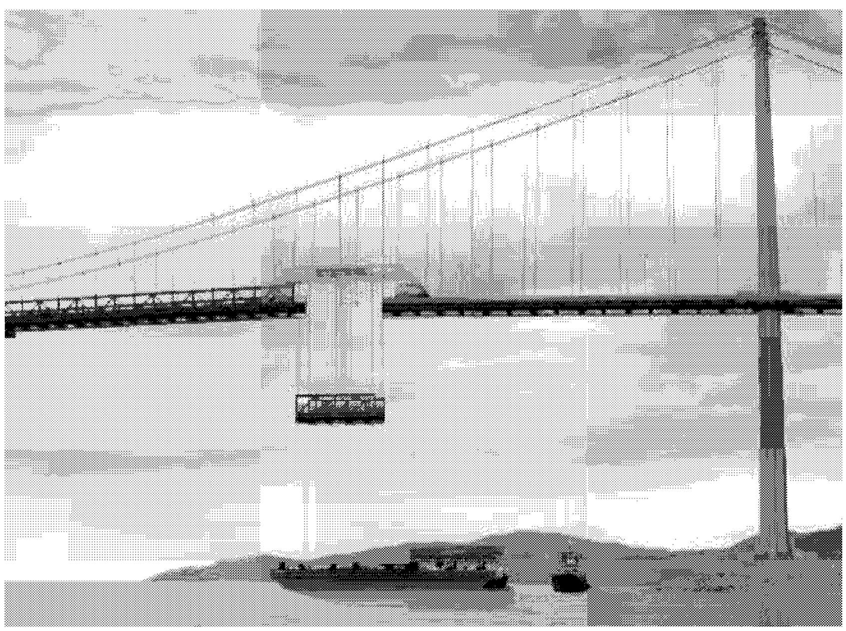

Figure 12. Lions' Gate Suspension Bridge
(source: www.aashtotig.org . Photo credit : British Columbia Ministry of Transportation)

Fig. 13. US 290 Ramp E-3 **Bridge**
(source: www.aashtotig.org Photo Credits: Texas Department of Transportation)

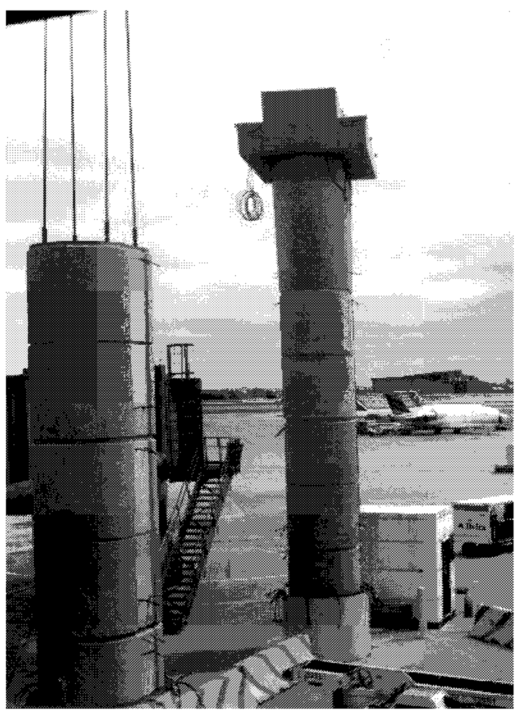

Figure 14. Dallas/Fort Worth International Airport People Mover
(Source www.aashtotig.org, Photo Credits: STOA/Carlos + Law, AE)

Figure 15. SH 249/Louetta Road Overpass
(Source: www.aashtotig.org, Photo Credits: Texas Department of Transportation)

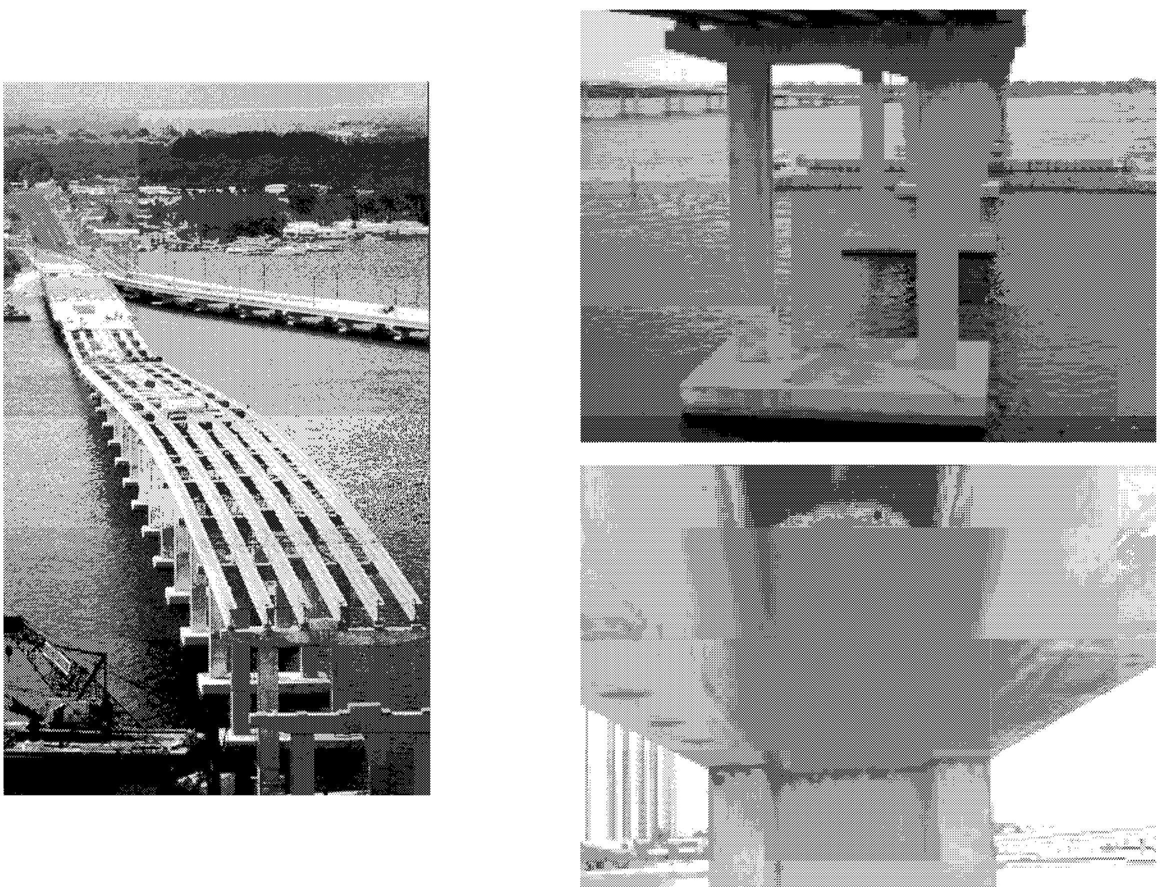

Figure 16. View of Prefabricated Substructure and Girders of Edison Bridge

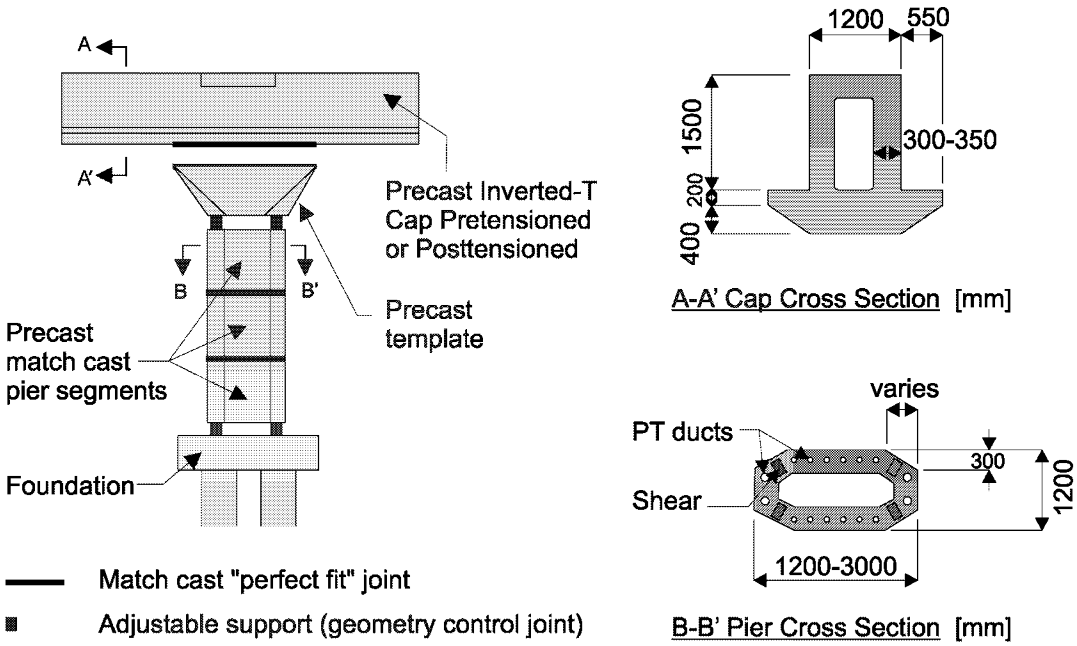

Figure 17. Segmental Pier System (Source: Billington et al. 2001)

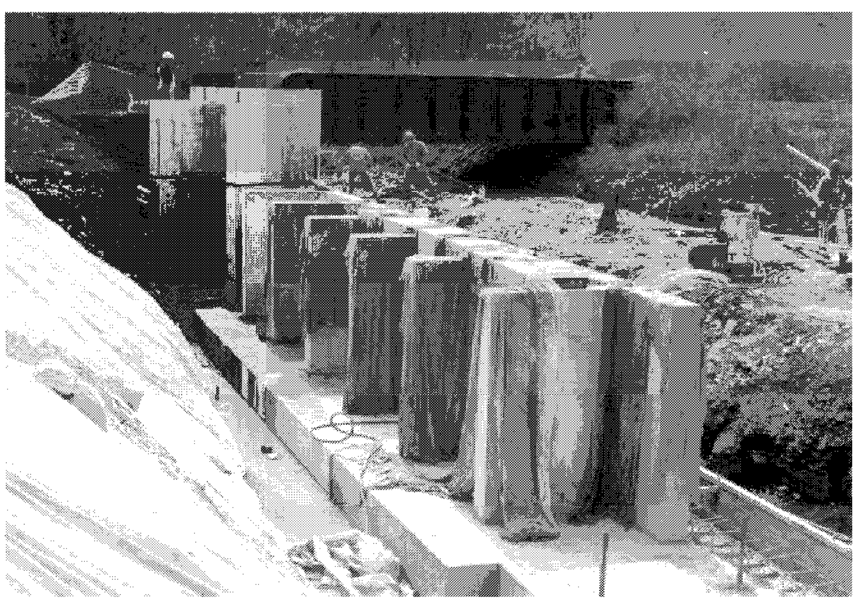

Figure 18. View of Counterfort Abutment System (Source: Scanlon et al. 2002)

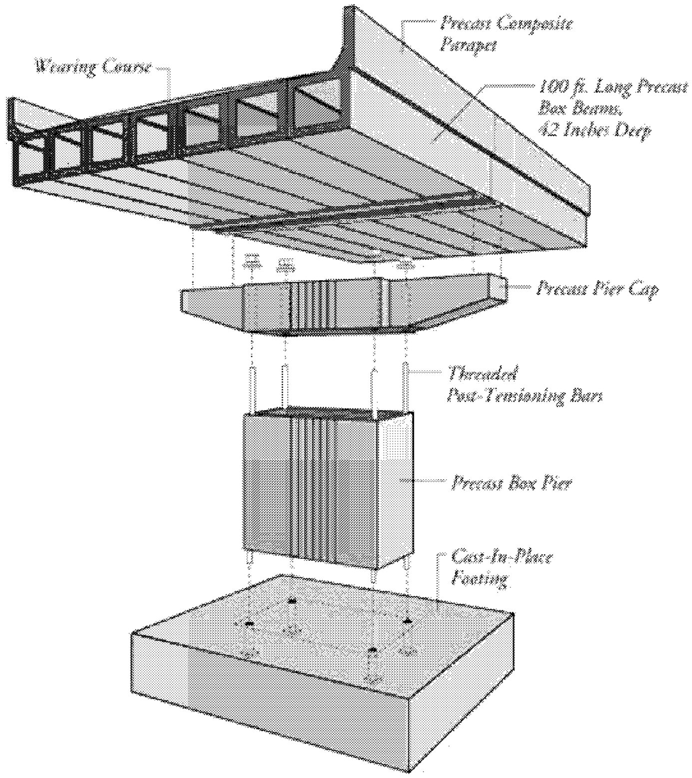

Figure 19. Baldorioty de Castro Avenue Overpasses
(Source : www.aashtotig.org, Photo Credits: Departamento de Transportación y Obras Públicas de Puerto Rico)

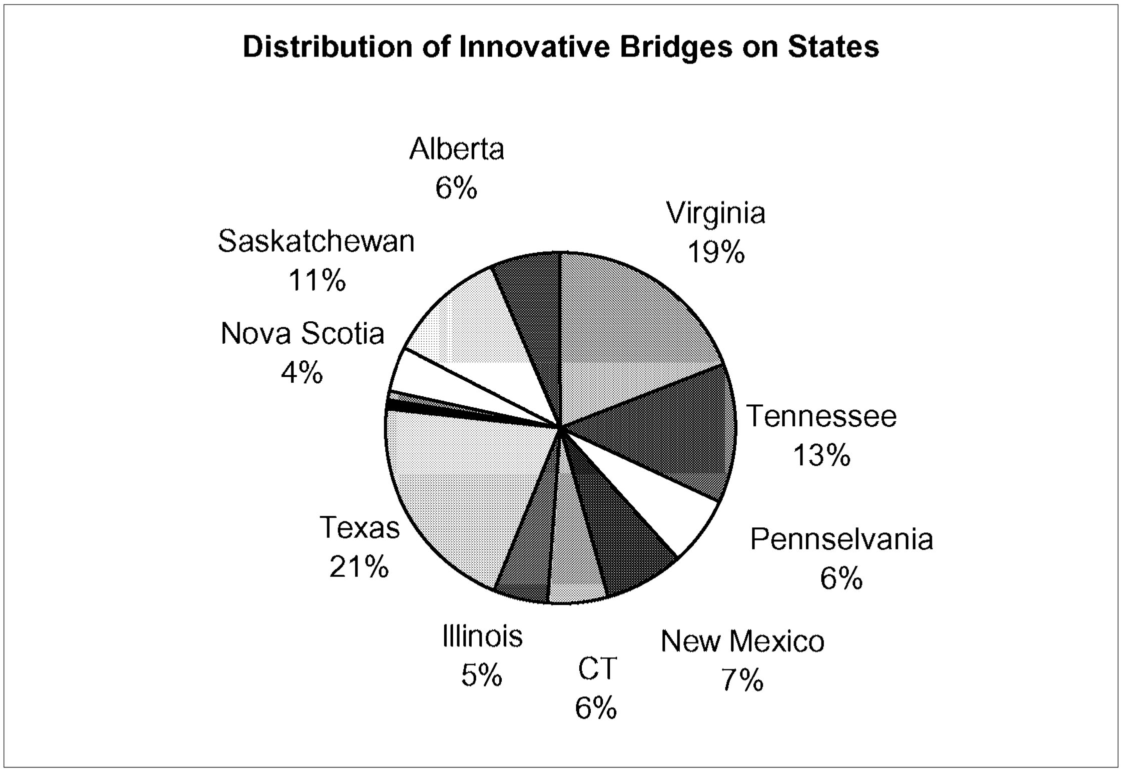

Figure 20. Distribution of Innovative Bridges among States

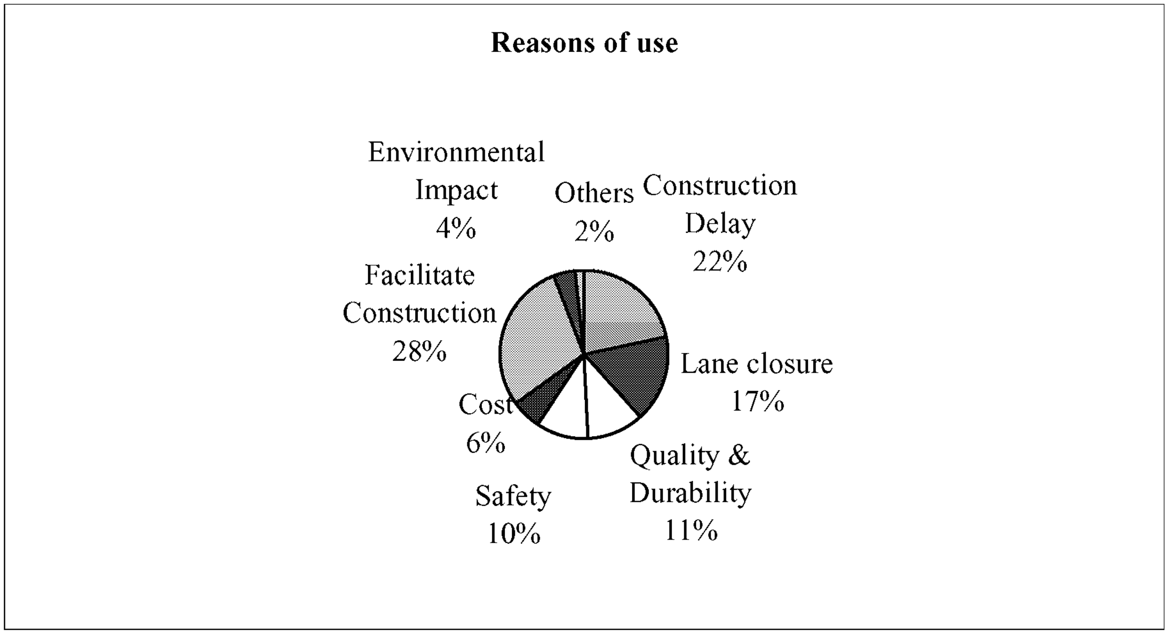

Figure 21. Reasons for Using Innovative Prefabricated Bridges

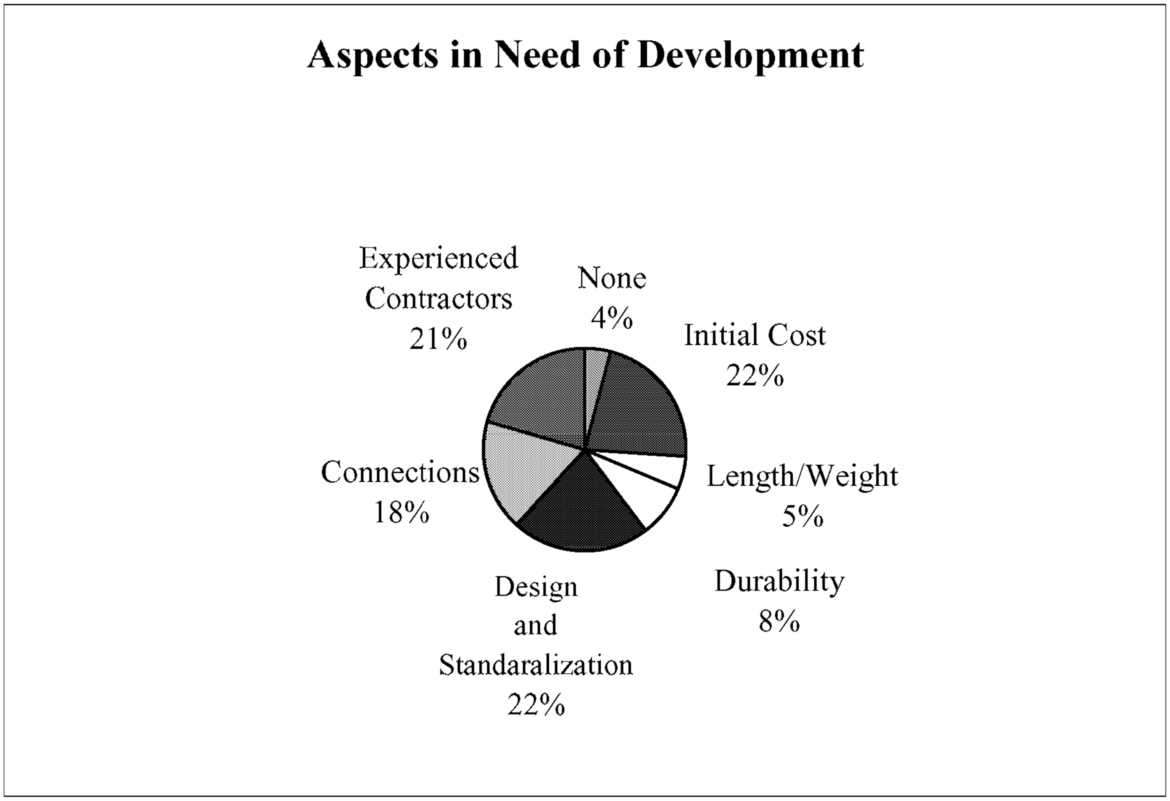

Figure 22. Aspects in Bridge Prefabrication Requiring Further Development