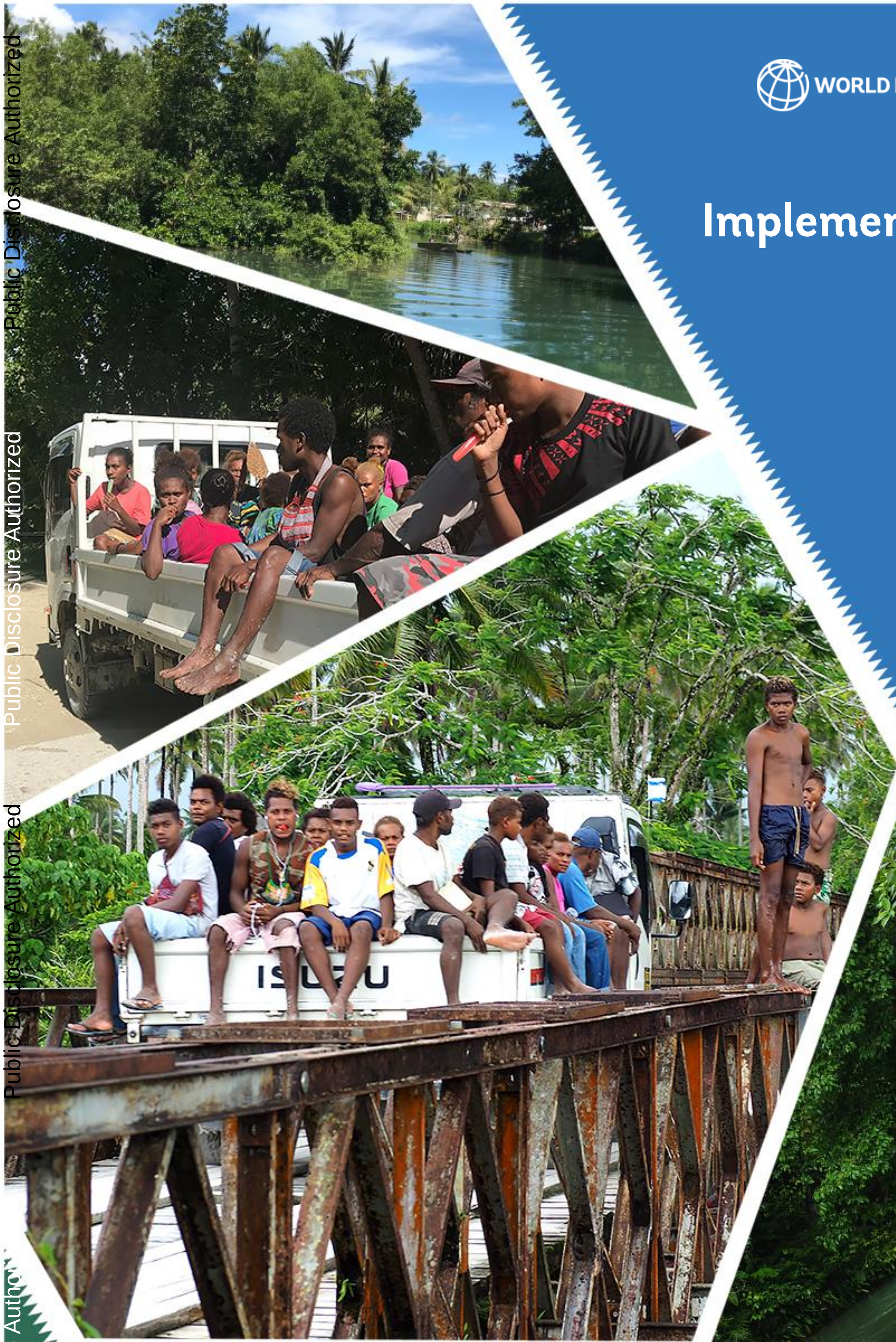
WORLD BANK GROUP

QUALITY INFRASTRUCTURE INVESTMENT PARTNERSHIP

Implementation of Innovative Bridge Technologies

Technical Guidance Note



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Implementation of Innovative Bridge Technologies – A Case Study in Solomon Islands

The Pacific region is highly vulnerable to the impacts of climate change and natural hazards. Each year, natural hazards result in critical infrastructure being destroyed or severely damaged, leading to loss of life, injury, and disruption to social and economic activity.

Bridges are critical components in the transport network and serve as vital links underpinning social connection and economic production across the Pacific. Bridges are intrinsically exposed to natural hazards and impacted by climate change. Delays associated with the ongoing maintenance of bridges can also put additional strain on this infrastructure and leave them more susceptible to damage.

Collectively, these issues serve to catalyze the continuing efforts of donors to support the research, exploration, development, and implementation of bridge solutions that consider a local context (in this instance, developing countries in the Pacific region).

This Technical Guidance Note highlights the methodology and lessons learned from the Implementation of Innovative Bridge Technologies assessment study and its application under the World Bank-funded Solomon Islands Roads and Aviation Project (SIRAP).[1] The assessment was funded by the Quality Infrastructure Investment Partnership.[2] This case study focused on the use of a selected range of modular bridges that provide a low maintenance, long-term, whole of life bridge solution which illustrates how the quality of infrastructure investment can be improved by improving economic efficiency and building resilience. It also outlines a way forward for the implementation of these bridge technologies across the Pacific region.

[1] SIRAP (P166622) was approved on March 28, 2019, with US$51 million International Development Association financing. It aims to improve operational safety and oversight of air transport and associated infrastructure, strengthen the sustainability and climate resilience of the Project Roads, and in the event of an Eligible Crisis or Emergency, to provide an immediate response.

[2] Quality Infrastructure Investment Partnership is a World Bank Trust Fund supported by the Government of Japan to advance the Principles of Quality Infrastructure Investment in developing countries through financial support for project preparation, implementation, and analytical works.

1. Overview of Modular Bridges

1.1 What are Modular Bridges?

These are precast concrete or prefabricated steel bridge sections (deck superstructure only) that are manufactured in a quality-controlled factory and then shipped to site where they can be rapidly assembled and completed. They are comprised of standardized components which are connected in a modular nature. In addition, some suppliers can offer prefabricated abutments and piers.

1.2 Where might Modular Bridges be used?

Modular bridges can be used over river crossings where rapid deployment is required in the event of an emergency, or, as a long-term solution where the modular bridge can be procured for a specific site.

One common example of use of a modular bridge is a steel truss Bailey bridge. They have traditionally been used as a temporary bridge crossing, where rapid deployment is required in the event of an emergency. They are comprised of standard steel panels which can easily be assembled rapidly and launched across a river, from stockpiles held by local road authorities. While Bailey bridge benefits are recognized by many road authorities, they are susceptible to corrosion in the long term, especially in saline environments on coastal roads, and where the required maintenance regime is deferred in its design life.

Other types of modular bridges available on the market, which are designed with a longer design life, represents a new opportunity to use modular bridge as a long-term solution where the modular bridge can be procured for a specific site. These types of modular bridges require less maintenance, and therefore can result in a lower whole of life cost.

While the decisions to use modular bridges for a specific site needs to be considered in a wider context, there is the benefit of increased resilience through use of modular bridges. If the bridge was to be damaged during a natural disaster, it can be easily repaired or replaced due to its standardized modular nature. Bridge components could be ordered in quickly, or if the bridge components are held in stock by the local road authorities, this could enable an even more rapid repair.

In general, modular bridges are ideal for short, single-span bridge crossings of between 10 and 20 m as these short spans will require components of relatively modest length and weight that are easier to ship, transport, and erect on site with smaller cranes and equipment.

Regardless of where the bridges are located, the transport of bridge components requires access roads that are able to support the relevant vehicle loads and construction equipment. Small modular bridge components will be lighter, and thus easily supported by existing roads and bridge crossings. In addition, some modular bridge types require a supply of ready-mixed concrete.

Modular bridges offer many advantages compared to conventional bridges. The use of modular bridges as a long-term solution for a specific site must be considered in a wider context. Critical decision points include procurement and installation time, cost, availability of materials, desired function, and acceptable design life which is explored through this case study.

1.3 Why consider Modular Bridges instead of Conventional Bridges?

They have a number of potential benefits over conventional bridges as a long-term solution for a specific site, including:

- Quick procurement
- Reduced duration of road closures
- Reduced design timeframes
- Less disturbance to the local environment
- Less need for labour on site
- High-quality bridge components prefabricated in controlled settings
- Social and economic benefits to local community and businesses
- More contractors able to undertake bridge replacements, especially local contractors.

One of the main advantages of modular bridges, when compared to conventional bridges, is the shortened design and construction time. Faster construction means a shorter period of time while the road cannot be used, and hence a relatively brief period while the vital links it normally serves remain unavailable. The greater connectivity translates into increased resilience for the community served.

Due to the shortened construction time, modular bridges can also enhance a post-disaster recovery program. When disasters impact infrastructure, there is the opportunity to increase resilience by building back better. Modular bridges have the potential to address post-disaster situations by facilitating rapid reopening of permanent infrastructure—for example, bridges with a design life of 100 years—rather than provisional restoration using temporary Bailey bridges, which typically do not have a design life of 100 years.

This is particularly beneficial if a bridge is a critical link in the transport network. Conversely, if alternative routes exist (such as another river crossing nearby, or the opportunity to construct a conventional bridge in a low rainfall period where the river can be safely and easily crossed) the benefits of a modular bridge may not be fully realized.

Modular bridges could also have major social and economic benefits through expanding the number of contractors who could undertake bridge replacements. Although the concepts behind these technologies have been thoroughly tried and tested in developed countries, they are new to most developing countries.

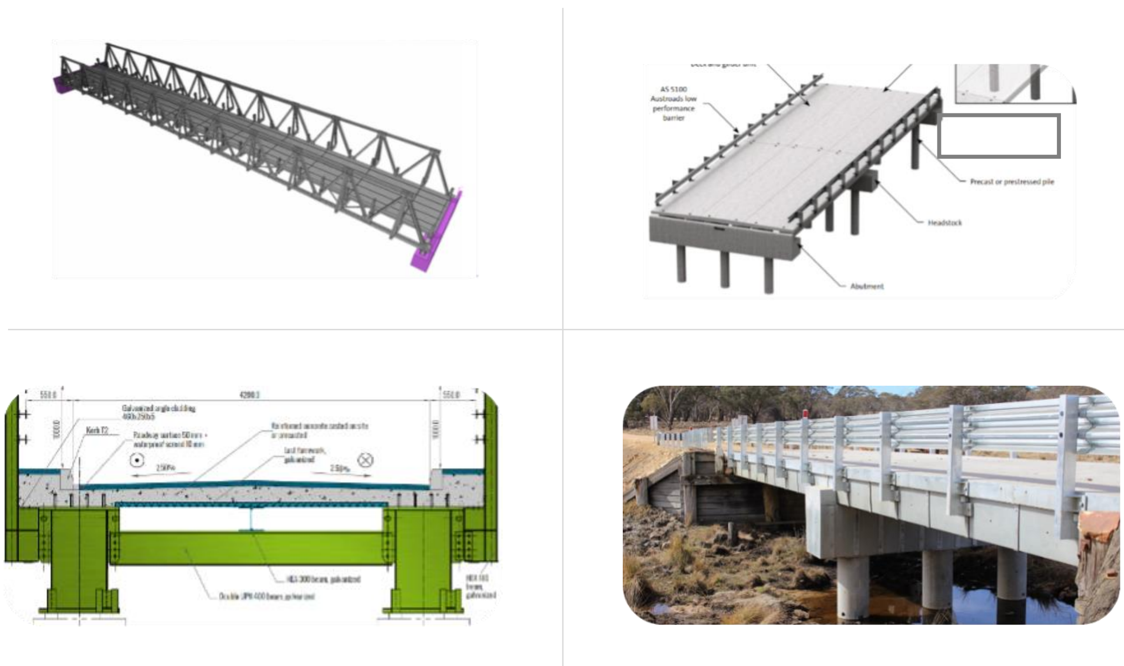
1.4 Types of Long-term Modular Bridges

Long-term modular bridges differ from other low-cost bridges (such as the Bailey bridge) because they require much less maintenance, lowering their whole-of-life cost and improving efficiency.

Four common types of long-term modular bridge are currently on the market (**Figure 1**):

1. Steel Truss Bridge
2. Precast Concrete Deck
3. Steel Girders with In-situ Deck
4. Steel Formwork with In-situ Deck

Figure 1: General Long-Term Modular Bridge Types



Note: Clockwise from top left: steel truss bridge,[3] precast concrete deck,[4] steel formwork with in-situ deck,[5] and steel girders with in-situ deck.[6]

Hybrid versions of these types are also available.

[3] Eastbridge Ltd, Thru Truss Bridge, 2010, New Zealand, as an example.
[4] Holcim Pty Ltd, HumeDeck Bridge System, April 2014, Australia, as an example.
[5] InQuik Pty Ltd, InQuik Bridging Systems – Catalogue, 2018, Australia, as an example.
[6] Matiere, Unibridge Prefabricated Modular Bridge, 2019, France, as an example.

2. Selection Criteria for Long-term Modular Bridges

Implementation will be preceded by the use of selection criteria to determine the most appropriate modular bridge for the location. General selection criteria, both technical and site-specific, can be grouped into four categories:

1. Design requirements
2. Site location and conditions
3. Site access and constructability
4. Procurement, maintenance, and ongoing support

2.1 Design Requirements

There are a number of modular bridge system suppliers on the market whose products meet a variety of specifications. In order to capitalize on the potential benefits of modular bridge systems and create a competitive environment for a range of bridge suppliers, there is a need to apply suitable—yet not onerous—specification requirements during design phases.

Naturally, each bridge specification should take local site conditions and individual project design specifications and requirements into consideration. However, overspecification can limit the opportunity to use modular bridges, by severely restricting the number of available modular bridge systems that could comply with the overspecification. For example, specification of the maximum structural depth of the bridge, or an onerous design load, would tend to be highly restrictive.

The Following Are Key Design Considerations:

Design Standards: The nominated design standards will provide a code for design on a given site.

Design Life: The design life will affect the duration of bridge operations and maintenance regime. A design life of 100 years is recommended.

Traffic Loading: The traffic loading will affect the type and quantity of vehicles that can use the bridge.

Traffic Barriers: The barrier performance level will affect the permissible quantity of annual vehicular flow on any given bridge.

2.2 Site Location & Conditions

Site considerations are key in the assessment of appropriateness of a modular bridge at a given location, and the type of modular bridge that could be adopted.

Hydrology and flooding hazards are design drivers for any bridge type. Local hydrological conditions will govern the levels of the approaches and bridge deck, and the ability of the structure to resist the force of water flowing beneath it. The design also needs to consider the issue of whether the bridge might ever be washed away, or whether the abutments are susceptible to scour damage.

Local geotechnical conditions will define the substructure type, abutment requirements, and scour protection.

The land use around the bridge and how it will change during the life of a bridge can impact the performance of the bridge and should therefore be considered when considering the site. For example, introduced forestry can change the hydrology of a catchment and render the design insufficient to cope with the new conditions. Similarly, squatting or the erection of shacks on access roads can obstruct access to the site and the feasibility of landing containers on private land in the vicinity.

Site visits, surveys, and investigations early in the project can help those implementing the bridges to better understand site conditions and potential limitations.

The Following Are Key Site Considerations:

Exposure Design: For design, a highly exposed site imposes limits depending on the proximity of the proposed bridge to the coastline or other bodies of salt water.

Span Range: The span range of a specific modular bridge type will affect the feasibility of a clear bridge crossing at any given site. A 10–20 m single span with a straight alignment is recommended.

Number of Lanes. The lane configuration will affect the permissible traffic flow on any given bridge. One to two lanes are recommended, depending on expected traffic volume, local pedestrian flows, sight lines, and road geometry along the approaches.

Hydrology: River flood levels define the approach and bridge deck levels.

Geotechnical: Ultimately, geotechnical conditions will dictate the feasibility and cost of any given bridge. Ground conditions influence substructure, abutments, approaches, and scour considerations.

2.3 Site Access & Constructability

A bridge construction project is a significant logistical exercise, involving site access, transport of materials to site, as well as housing and other requirements for the construction workers. The logistics of maneuvering plant and equipment should also be considered, as there are often only limited areas near the bridge location that could accommodate large equipment and cranes. Understanding the complexity of these logistics—and how best to deliver the project despite any specific site constraints—will be key to the success of any bridge project.

The Following Are Key Logistical Considerations:

Ease of Transport: The ease of transport of components will determine suitable modes of transport and the adequacy of site access roads. Compact components are recommended.

Lightweight Components: The weight of bridge components will affect the need for cranage and other types of site construction equipment. Not requiring heavy cranage is recommended.

On-site Activity: The level of on-site activities will affect the suitability of bridge sites, based on their capacity to install the bridge product (for example, the need for adequate concrete supply for in-situ concrete pouring). Minimal on-site activity is recommended.

2.4 Procurement, Maintenance, & Ongoing Support

Due to the proprietary nature of modular bridges, engagement with a modular bridge supplier is required to produce a detailed design. Procurement often requires open tenders, where a supplier is not identified, to ensure a competitive process. This requirement will shift the detailed design of the modular bridge to a later stage in the project lifecycle. That may in turn shift the nature of the relationship with the modular bridge supplier and may impact the project’s ability to realize all of the advantages of a modular bridge. Earlier engagement may be more collaborative, with greater potential to direct the design, whereas later engagement of the supplier may lead to a more transactional relationship where the ability to impact design is achieved through a commercial or contractual mechanism.

The Following Are Key Procurement, Maintenance, & Ongoing Support Considerations:

Proprietary versus Open Tender Considerations: Engagement with a proprietary modular bridge supplier is often required; however, procurement approaches often require open tenders.

Supply and Installation: The bridge supplier should provide a complete and simple set of bridge components for effective and efficient installation. It is recommended that the bridge supplier also install the bridge. If the bridge supplier was also given the responsibility for the design and construction of the approach embankments, this would allow flexibility in the choice of structural depth for the bridge to clear the flood level or clear waterway area. The flood level or clear waterway area is usually specified as a client's performance requirement.

Maintenance Access: Ease of access for maintenance of the bridge structure (particularly for steel bridges) will invariably affect the maintenance regime and design life. Good maintenance access is highly recommended. In addition, an appropriate standard of corrosion protection should be specified for the steelwork, and any damage to the coatings during transport and installation should be repaired on site.

Industry Setup: A support and fabrication office should be located nearby, to provide ongoing maintenance assistance, including spare parts, for the operational life of the bridge.

Scale of Infrastructure Work: There are potential cost savings that can be realized, through constructability efficiencies, for the implementation of a larger infrastructure project involving multiple bridges, when compared to a single-bridge project.

2.5 Project Context

The World Bank, with funding from the Quality Infrastructure Investment Partnership financed by the Government of Japan, sought an opportunity to gain a deeper insight into modular bridge technologies in the Pacific.

When the Solomon Islands Ministry of Infrastructure Development (MID) included implementation of modular bridges under SIRAP, such an opportunity emerged, facilitating observation of the feasibility, design, and procurement of modular bridges in the Pacific.

2.6 Project Inception

The SIRAP inception phase established specific site constraints and requirements to support design. Key stakeholder engagement and site visits provided important information for site consideration. Engagement with stakeholders was essential because only limited formal records or asset management frameworks were available.

A Capacity Training and Pilot Study Plan of Action workshop, held with government and industry stakeholders in Honiara on February 13, 2020, introduced modular bridges and identified the relative importance of the selection criteria (outlined above in Section 2). Key criteria included logistics, ease of transport, constructability, hydrology, future land use and planning, the overall scale of the infrastructure work, and a Pacific-based supplier.

The engagement with key stakeholders also highlighted key design requirements, including the use of AS5100 Bridge Design Code and the New Zealand Transport Agency Bridge Manual for seismic design. The engagement also identified practical recommendations including T44 vehicle loading and Class B2 Marine Exposure (as per AS/NZS 5100) or minimum C4 corrosion category for steel structures (as per AS5100.6) for coastal roads.

2.7 Modular Bridge Feasibility & Site Selection

SIRAP assessed three potential sites along Malaita North Road. The assessment considered the practical feasibility of a modular bridge for the sites and then selected the most favorable of the three. The sites have different existing and proposed spans, as outlined in Table 1.

Table 1: Existing and Proposed Spans for the Three Bridge Locations

Bridge	Existing Span (m)	Proposed Span (m)
Koa Bridge	14	18.19
Bio 1 Bridge	7.9	11.0
Bio 2 Bridge	10.6	13.3

Source: **MID. 2020.** ***Detailed Design Report for Malaita Bridge Replacement and Approach Works.***

The assessment considered the various modular bridge technologies on the market (Steel Truss Bridge, Precast Concrete Deck, Steel Girders with In-situ Deck, Steel Formwork with In-situ Deck) for construction within the site constraints. As access to sites along Malaita North Road require crossing several bridges with uncertain loading capacity, a lightweight easily transportable solution was favorable.

The Steel Formwork with In-situ Deck modular bridge was considered applicable because its lightweight elements are transported to site and lifted using a small crane, and its design performs better than others under earthquakes. It also requires no temporary framework or supports, the deck can be integrated into the abutment or approach slab to form a solid mass of concrete, and the permanent steel formwork provides additional protection and durability to concrete. In addition, no specialized skills (other than concreting) or specialized machinery is required.

The three sites were then compared for feasibility. Bio 1 Bridge (**Figure 2**) was deemed the preferred site, because its shorter span means that only a single module (easier to transport and lift) and a single pour (only low-level concreting skills) are required. The longer spans of Koa Bridge and Bio 2 Bridge would require a two-stage deck pour (requiring medium-level concreting skills), and their components would be more difficult to transport due to length and weight.

Figure 2: Bio 1 Bridge – Steel Truss Bridge with Timber Planks on Timber Bearer

Source: Arup

2.8 Preliminary Design

The preliminary design phase involved assessing specific site constraints and requirements to produce a workable design. During this phase, the Terms of Reference allowed overall flexibility, and a Design Philosophy Report provided a reference design, outlined all client requirements, maintenance requirements, and performance specifications.

Due to procurement requirements, the preliminary design included a performance specification for the modular bridge but did not detail the bridge design or recommend a particular supplier. Although there are benefits to that aspect—because it opens up the number of available suppliers—it may result in a delay to the overall construction program. It may also lead to risks in design coordination at a later stage, because the structural depth remains unknown until a modular bridge system has been selected. This can affect road design levels and flood immunity.

The preliminary design phase highlighted the importance of on-site geotechnical considerations, as they influenced the ability to implement particular bridge types.

Another key consideration identified in this phase was the connection between the superstructure and substructure: this drives the cost and viability of a project.

2.9 Design Development & Documentation

Based on the Bridge Feasibility and Site Selection phase, it was envisaged that only one modular bridge would be constructed (Bio 1 Bridge).

During design development, the modular bridge was increased from one lane to two lanes. This design change took into consideration the sight lines and safe sight distances for the roads at the bridge locations, as well as the potential for increased future traffic loading due to predicted future development along the road. The project will also install a separate footpath along with the bridge; this will improve the safety of pedestrians, especially schoolchildren.

Cost estimations provided in the report were based on engagement with modular bridge system suppliers; this served to clarify estimated costs.

The completed Detailed Design report specified a maximum structural depth of 700 mm. This structural depth appears to be suitable for a limited number of the known modular bridges available on the market, though there are other modular bridges which may require deeper structural depth. The Detailed Design report notes that the road level could be raised to accommodate a different modular bridge type, or alternatively a more conservative structural depth could have been used in the design, allowing for a greater range of systems to be used.

2.10 Procurement

At the time of this publication, the Contract had only recently been awarded. As noted above, during Design Development it was envisaged that only one modular bridge would be constructed, and conventional bridges would be constructed at the other two sites. During negotiations following the award of the contract, it became apparent that cost savings could be achieved if modular bridges were used for all three sites, and this approach has been adopted for the project.

The following considerations for the procurement of modular bridges in the Pacific also emerged during the project.

The use of modular bridges will require the use of proprietary products; however, there is still a need to have an open tender to achieve a competitive procurement process. If a bridge is selected during design, the procurement documentation will still need to allow for a competitive procurement process.

The type of procurement envisaged varied over the life of the project. Initially, open international procurement was considered. Then the focus shifted to the possibility of creating an opportunity for a national contractor to be strongly supported by the modular bridge supplier, with the latter perhaps providing on-site instruction during construction, thus ensuring the quality of the finished product. However, an open international call for tenders was ultimately chosen, for two reasons: first, some local stakeholders and communities expressed a preference for international contractors owing to their previous experience with local contractors; and second, the design consultant’s recommendation that an international contractor might be most suitable for this activity.

3. Lessons Learned & Recommendations

3 Lessons Learned & Recommendations

Through the project undertaken in Solomon Islands, four key lessons were identified that should be considered when implementing a similar exercise in other Pacific nations:

To capitalize on potential benefits of modular bridge systems and enable potential use of a range of bridge supplies, a design that is suitable yet not unduly onerous should be used to determine specification requirements. There are a number of modular bridge system suppliers on the market whose products meet a variety of specifications. Each bridge specification should take local site conditions and project specifications into consideration, but overspecification can limit the opportunity for incorporation of modular bridges. For example, the SIRAP Detailed Design report specified a maximum structural depth of 700 mm for a 11m span, which was suitable for a select few modular bridge systems. Alternative options—such as raising the road level, or applying a more conservative structural depth—would have allowed more modular bridge systems to be considered.

Understanding the complexity of logistics, and how best to deliver the project despite logistical constraints, are key determinants of a successful bridge project. Logistics can include ease of transport (determining the suitability of modes of transport and access routes), weight of components (determining the need for cranage and other site construction equipment), and the level of on-site activity. Logistical considerations were key factors leading to the decision to adopt the Steel Formwork with In-situ Deck modular bridge at Bio 1 Bridge, as the shorter span means that the bridge components will be easier to transport and install compared to the proposed bridges at other locations that require longer spans.

Local geological and hydrological site conditions are key determinants of a decision to use a modular bridge rather than a conventional bridge. If extensive abutment piling and scour protection works are required, the efficiencies of a modular bridge may not be realized. Site visits at an early stage can help those implementing the bridges to better understand site conditions and potential limitations.

Procurement of modular bridges is most effective through early engagement with the modular bridge suppliers, and if the scale of the infrastructure project can be considered. Due to their proprietary nature, engagement with a modular bridge supplier is often required to produce a detailed design for the modular bridge. Procurement approaches often require open tenders, where a supplier is not identified, to ensure a competitive procurement process is achieved. Earlier engagement may be more collaborative—with greater potential to direct the design—whereas later engagement of the supplier may lead to a more transactional relationship where the ability to impact the overall bridge design is achieved through a commercial or contractual mechanism. For SIRAP, a design-and-build approach served to address these constraints, but the performance basis of design requirements limited the range of modular bridge systems available for use. In addition, potential cost savings and construction efficiencies can be realized on large scale projects where multiple modular bridges are being procured.

4 Conclusion

The case study explored the implementation of prefabricated modular bridge technologies in Solomon Islands. First, modular bridges were shown to be economically preferred to conventional bridges in the context of this project setting. Capacity can be developed in country to enable design, construction, and supervision of modular bridges by local staff with support from international staff, which further enhancing economic efficiency.

Second, modular bridges are a long-term solution for building resilience against climate change and natural disasters. They have the potential to address post-disaster situations by facilitating rapid reopening of permanent infrastructure than provisional restoration using temporary bridges.

Lastly, applying the innovative bridge technologies can promote integration of social considerations in infrastructure investment. Modular bridges can improve the safety of construction workers due to the speed of construction which reduces worker's risk exposure. They can also improve the safety of pedestrians as road safety barriers and footpaths are integrated into many standard modular bridge deck designs. The rapid replacement of failed bridges can also improve the safety of road users, who are often forced to use unsafe alternatives.

5 Acknowledgement

This note was prepared by a team of World Bank staff and consultants, including **Naoki Kakuta** *(Transport Specialist),* **Dung Anh Hoang** *(Senior Transport Specialist),* and experts from **Arup Australia** including *Victor Andrade, Tim Mote, Gabrielle McGill,* and *Caitlin Jay.* The team benefited from peer reviewers, **James Robert Markland** *(Senior Transport Specialist),* and **Tesfamichael Nahusenay** *(Senior Transport Engineer),* who provided valuable guidance to the draft of this note.

THANK YOU.

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