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Assessment and Reconstruction of Bridges in Trinidad and Tobago

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Abstract: *In Trinidad and Tobago (T&T), the Roads and Bridges Programme of the National Highway Programme under the Inter-American Development Bank (IDB) Loan (No. 932/OC-TT – Year 3) which started in 2002 is nearing its end. A joint venture firm of engineering consultants, WSP (United Kingdom) and BBF (T&T), carried out the planning and design phases of the programme. The Ministry of Works and Transport provided an initial list of ninety-six (96) short and medium span bridges for preliminary inspection. Seventy (70) bridges were then short-listed for a detailed condition survey. Finally, forty (40) bridges were selected for total reconstruction and one for partial reconstruction (i.e., a deck replacement). This paper gives an overview of the project.*

Keywords: *Bridges, condition survey, bridge loads, economic evaluation, design, procurement*

1. Introduction

The Government of Trinidad and Tobago (T&T) had received a loan from the Inter-American Development Bank (IDB) for the partial financing of the National Highways Programme (IDB Loan No. 932/OC-TT – Year 3). The Ministry of Works and Transport (MoWT) is the executing agency for the programme. In August 2002, the Project Implementation Unit (PIU) of the Ministry asked the consultants, WSP Group (UK) and BBF (T&T), to carry out an economic evaluation of the required rehabilitation treatments, possible reconstruction or major repairs, of bridges on the Programme (MoWT, 2003). This initiative addressed a critical list of bridges on their road network that had been reported as being structurally deficient or functionally obsolete. All of these bridges potentially compromised public safety and mobility.

Initially, 61 structures in Trinidad and 9 structures in Tobago were selected by the PIU to make up the quantum of bridges for the programme. These structures are widely distributed across the mainland of Trinidad and sister island of Tobago. It became clear during the bridge identification exercise, that a substantial number of these bridges were in reasonably good condition, and so the PIU added 26 structures to the list. A preliminary inspection of these 96 bridges was carried out. Of these, forty (40) were expected to be selected for detailed design studies. Finally, forty (40) bridges were selected for total reconstruction and one for partial reconstruction – a deck replacement.

The selected bridges ranged from old colonial concrete beam and slab, steel and concrete composite decks, steel truss structures to modest timber beams and decking or reinforced concrete slabs in varying stages of disrepair. There was a preponderance of short span bridges, up to 9 metres, which reflects the location and rural nature of the project roads. A typical obsolete single lane colonial truss bridge is shown in Figure 1. The obelisk indicates it was commissioned in 1912.

Figure 1. Plymouth Bridge (Tobago)

Some of the bridge decks had several maintenance interventions since they were constructed and exhibited a wide range of engineering awareness in the treatments. There were examples of properly designed reconstruction solutions, as well as ad hoc emergency repairs of questionable effectiveness. There were several examples of the original bridge decks being overlain by newer ones, presumably to save on temporary formwork or deck supports. Figure 2 shows a typical example.

2. Methodology

The objective of the initial phase of the Year 3 project was to select forty (40) bridges out of the identified

Figure2. B2/1 La Lune

project quantum for detailed design studies. It was noted by the joint venture technical team that:

- Basic records, namely, construction/as-built plans, specifications, traffic data, flooding data, inspection history, were generally unavailable.
- Critical data would have to be quickly and reliably collected: span lengths, deck width, depth to riverbed, skew, river alignment, scour.
- Up-to-date information about alternate routes was not readily available.

This type of inventory data exemplifies what was required to apply the prevailing North American bridge condition manual (AASHTO, 1994), which was used by some engineers in the MoWT.

Given these limitations, a 4-step procedure was adopted to document, evaluate and prioritise the selection of the replacement bridges. These steps are elaborated below:

Step 1: Verification of the bridges forming the project quantum

This exercise was carried jointly with representatives of the PIU and District engineers and involved the visiting of the bridge sites to confirm their location and suitability for consideration into the feasibility study. The locations and UTM (Universal Transverse Mercator) co-ordinates, corrected to the local Trinidad Grid, of the bridges were recorded by the consultant using a hand held Global Positioning Satellite receiver, Garmin 12XL model, to allow the sites to be easily identified by the bridge inspection teams, environmentalists, and surveyors on subsequent visits.

Step 2: Visual Condition Survey

Once the bridges forming the project quantum had been confirmed, it was possible to complete a qualitative assessment of the existing structures condition and determine if any treatment works were required. Inspection forms that had been developed and refined from similar projects worldwide by the consultant team were used to ensure the comprehensiveness and consistency of the data gathering exercise.

It was essential that any qualitative assessment be carried out consistently to avoid wide discrepancies in the perceived condition of the various elements of the inspected structure. Two of the consultant team's experienced bridge engineers carried out the majority of the inspections within a four-week period; and consistency was ensured by using the same engineers for all the inspections. The requirements and effectiveness of a qualitative inspection are discussed in the state-of-the-practice survey (FHWA, 2001).

Four (4) basic sets of data were required from the condition survey. The first involved the bridge type and its geometry. This was especially important since drawings and construction details were generally not available for the bridges. Indeed, several bridges had been poorly constructed and detailed, which suggested that adequate construction drawings were not produced for use at the time of construction.

Secondly, the course and other salient characteristics of the river were also noted: meandering, stability of banks, and flooding etc. River training or protection works can be a significant cost item in the overall cost of the project, thereby affecting its economic viability. The third set of data comprised the identification of all utilities in the vicinity of the bridge: water, natural gas, electricity and telephone lines. The relocation of such utilities can also add significant costs.

The last set of information was a series of "condition ratings" assigned to the bridge superstructure, substructure and foundations. These condition ratings give an overall measure of the condition of a bridge by considering the severity of deterioration in the bridge and the extent to which it is distributed throughout each component. The ratings assigned to each element are based on a standard set of definitions associated with numerical ratings between zero (i.e., excellent condition) and ten (i.e., failed). This is essentially what is recommended in the guide (FHWA, 1995). The structural condition in conjunction with other variables including scour, current maintenance practices, wearing surface condition and average daily truck traffic (ADTT) were used to estimate a subjective probability of failure within a band of 0-2 years, 2-5 years, 5-10 years and over 10 years, and therefore an indication of the remaining life of a bridge.

Step 3: Identification and Selection

The various types of bridge treatments considered were identified in the terms of reference for the study: new construction, partial reconstruction, major repairs or widening. After reviewing the results of the condition survey, all of the bridges were determined as the candidates for replacement because of their age and/or poor condition or level of service.

Only three (3) bridges were deemed to have satisfied the criteria in the event that they failed the economic test for replacement. It was recommended that the other bridges, which did not achieve the minimum Economic Internal Rate of Return (EIRR), should be included in any future replacement programme.

Step 4: Refining Selection

More than forty (40) bridges qualified for treatment as described before. However, the final list was not based purely on an economic ranking. A decision matrix was used in achieving a fair balance of socio-politico-economic and technical parameters. Some of the criteria suggested (in Step 2 above) were included.

3. Bridge Loading

The consultants were also asked to review the highway loading employed in two previous rehabilitation programmes and to make recommendations. The American Association of State Highway and Transportation Officials was used in one programme with a modified HS-25 truck instead of the standard HS-20 truck (AASHTO, 1989). The other programme utilised loading specified in BS 5400, Part 2 (BSI, 1978). These bridges were designed for normal British Type HA loading and checked for 37.5 units of abnormal Type HB loading at the ultimate limit state.

The approach adopted was to update the study done by Khan-Kernahan (1994). Analysis of the permit load applications lodged with the Transport Board revealed that transport contractors were always lobbying for increased maximum gross vehicle weights (MGW's) and axle loads. Several important points emerged as below:

- The legal MGW was still unusually low, 15,240 kg (15 tons). As a result, virtually every application to license a heavy vehicle must be referred to the Transport Board.
- Transport contractors were continuously requesting heavier vehicles and axle loads.
- Tandems of up to 21,000 kg were routinely licensed.
- The legal limit of a tandem axle conforming to HS-25 loading was around 21,000 kg.
- Overloading of bridges would ensue and lead to gradual premature deterioration, giving rise to expensive maintenance or rehabilitation work, possibly even loss of capacity.
- HA and/or 25 units of HB loading would provide a capacity similar to that of the HS-25 design truck.
- The standard AASHTO (1989) specifications had been superseded by the newer load and resistance factor design (LRFD) specifications (AASHTO 1998).

Based on this evidence and an influence line study of truck convoys on simple spans up 30 metres, several recommendations were made. These are:

- The BSI (1978) specification should be retained as the base code for highway loading.
- HA and/or 37.5 units of HB loading should continue to be used on major roads of strategic importance. This will allow for the movement of exceptionally heavy industrial loads, to key locations.
- HA and/or 25 units of HB loading should be used on main roads.
- HA loading should be used on other roads.

It was also recommended that earthquake loads be computed using the specifications AASHTO (1998). Seismic analysis and detailing would be done in accordance with its provisions. A presumptive acceleration coefficient of 0.29 was adopted. In other words the bridges were assumed to be in AASHTO seismic zone 3.

4. Preliminary Considerations

A span classification of the seventy (70) bridges selected for prioritisation is given in Table 1. The terms of reference of the consultancy stated that bridge designs undertaken by the MoWT over the previous six years be reviewed, with respect to the possible establishment of standardised bridge designs and construction methods. The specification of the six-year period essentially limited the review to a small number of bridges undertaken in the Roads and Bridges Programme, National Highway Programme – Years I and II. It was therefore decided to include earlier bridges, those done in Phases II and III of the Rural Access Roads and Bridges Rehabilitation Programme (MoWT, 2003).

Table 1. Classification by span

Span	Number of bridges
up to 9m	33
9 - 15m	20
15 - 20m	6
20 - 30m	6
Multi-span > 30m	5

The PIU had indicated that steel beams should be avoided, which in their opinion would reduce maintenance costs. At the same time local content should be maximised. Therefore a survey was carried out to determine the local precast concrete bridge element industry for capability and capacity. The survey revealed that there were two (2) experienced manufacturers of these precast bridge components: AASHTO I and Bulb-Tee beams, solid slabs, slabs with voids and piles.

Based on these studies and taking into account economic and constructability factors, three (3) types of replacement bridges were recommended. These are:

- Single-cell box,
- Semi-integral single span bridge, and
- Multi-cell box.

5. Economic Evaluation

A full account of the economic assessment of the selected bridges can be found in the government report by the Ministry of Works and Transport and the Tobago House of Assembly (MoWT, 2003). Essentially, a spreadsheet for the economic assessment of the selected bridges was developed and refined for Trinidad and Tobago. A twenty-year discounting period was used. The spreadsheet carried out calculations based on the input data, as follows:

- ADTT at the bridge site,
- Traffic composition at the actual count site,
- Length of the normal route,
- Length of diverted route,
- Probability of failure of the existing structure, based on a qualitative assessment from the visual inspections,
- Proposed replacement bridge span,
- Replacement bridge cost based on the average cost per square metre of deck,
- Construction time for the new structure,
- Temporary bridge cost, and
- Construction time for the temporary bridge.

Estimation of the cost of replacement bridges was based upon an analysis of the tendered cost of bridges constructed under the Year 1 and Year 2 phases of the Roads and Bridges Rehabilitation Programme (IDB Loan No. 932/OC –TT). The financial costs of the nine (9) bridges built in the Year 1 phase were based on 1994 prices, while the financial costs of the ten (10) bridges to be built under the Year-2 phase were based on 2002 prices. It was noted that all of these bridges were located in Trinidad, and so an adjustment was made for the expected additional cost for construction works on the island of Tobago arising from the need to import materials from Trinidad. Costs were derived from the tendered bill of quantities of the selected contractors and grouped according to the following description of works:

- Demolition and clearing,
- Relocation of utilities,
- Road diversions and temporary bridges,
- Substructure,
- Superstructure (including sidewalks),
- Road approaches, and
- River paving / training.

The key output from the spreadsheet was the EIRR of the bridge treatment. The target EIRR was 12%, but not all the bridges achieved it. A sensitivity analysis of the EIRR results to key input parameters was performed. A twenty-year discounting period was used using the main input data generated from the visual inspections generating a probability of bridge failure, physical traffic counts, the cost to the road users in using alternative diversion routes in the event of bridge failure and, from traffic delays arising from the existing structures road width. All discounted back to the net present value (NPV).

The diversion routes were identified initially from maps of the area supplemented by the joint venture consultants' local knowledge. In those cases where no diversion exists, for example on the Windward road in Tobago, an equivalent diversion length was calculated based on equivalent delay times arising from shuttle travel and transfer at the site of the bridge.

6. Bridge Designs

As soon as the structures were approved by the PIU for the recommended treatments, they were taken into the detail design phase. Some delays were encountered in obtaining the results of the geotechnical and hydraulic investigations. However, this did not prevent the work from progressing smoothly as a whole. Most of the designs were substantially complete by the end of April 2004. The designs were reviewed internally by the joint venture team and also by officials of PIU.

The distribution of the bridges in the twin island republic is given in Figure 3 and Table 2. It can be seen that the coverage is quite uniform. A classification of these bridges by type and span is given in Table 3. It will be readily observed from this table that achieving a realistic degree of standardisation was a primary consideration. For example, during the alignment phase a great deal of effort was made to avoid skew.

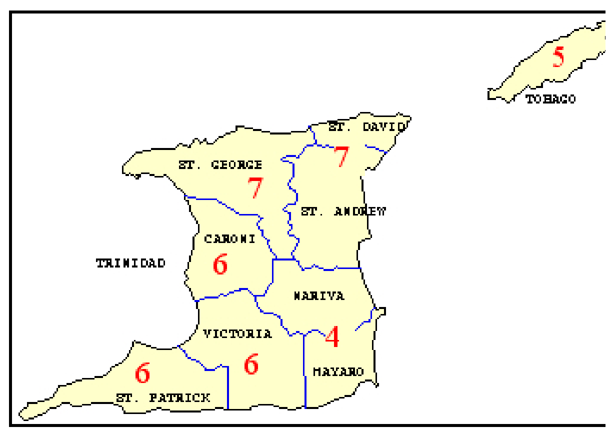

Figure 3. Bridge designs: Geographical distribution

Table 2. Bridge designs: Phases

Region	Phase 1	Phase 2	Total
TRINIDAD			
St. George	2	5	7
St. Andrew/St. David	2	5	7
Caroni	2	4	6
Nariva/Mayaro	2	2	4
Victoria	4	2	6
St. Patrick	5	1	6
TOBAGO	4	1	5
	21	20	41

Table 3. Bridge designs: Type

Bridge type	No. of bridges	Span (m)	Remarks
Single cell box culvert	2	< 6	
Single cell box	14	6	Two (2) with skew
Single cell box	12	9	Three (3) with skew
Twin cell box	1	6-6	
Triple cell box	2	9-9-9	One with 1:6 skew
Four cell box	1	9-9-9-9	1:6 skew
Slab + Abutments	1	9	Alternative
Beam and slab + Abutments	8	25	AASHTO III beams + 200mm slab
Deck replacement and widening	1	17-22-17	Skew of 5˚

All of the bridges were analysed using a refined computer based method: grillage analysis. The cellular (box) bridges were idealised as space frames sitting on Winkler springs. The beam-and-slab decks were analysed in accordance with the recommendations of West (1973).

7. Construction

The implementation of the bridge designs fell under the purview of the PIU. The selected method of procurement was the traditional design-bid-build process. The joint venture team prepared the tender documents: drawings, conditions of contract and specifications. The PIU assumed direct responsibility for land acquisition and the relocation of utilities, mainly water pipelines, telephone poles and electricity poles. Previous experience had shown that these matters could lead to inordinate delays unless properly managed.

The PIU had put time and effort into development of a system of quasi-standard designs. The major task left was to devise a strategy to encourage greater contractor participation thus ensuring competitive prices and future availability of a greater local pool of management and technical skills. In this regard, it was decided to invite tenders for small packages of bridges. The number of bridges in each package varied from one (1) to five (5). A full breakdown is given in Table 4. In all thirty-nine (39) bridges were treated. Two (2) bridges were omitted because of economic factors.

At the time of writing this paper thirty-six (36) of the thirty-nine (39) bridges have been completed. Independent consultants supervised the construction as required by the terms of reference. The PIU have reported that the four-cell box in Tobago was replaced by an alternative design, submitted by the contractor, which has a deck of precast truncated AASHTO III beams with a composite concrete slab. This particular contractor had invested in a self-stressing form that permitted the fabrication of the AASHTO III beams in Tobago

Table 4. Composition of contract packages

Phase 1	Region	No. of Bridges	Types of Bridges
Contract 1	Caroni/Victoria	3	25m beam-and-slab (2), 6m Box (1)
Contract 2	St. Patrick	5	6m Box (3), 9m Box (1) and 9m Slab (1)
Contract 3	Nariva/Mayaro/Victoria	3	25m beam-and-slab (2), 6m Box (1)
Contract 4	St. George/Caroni	3	25m beam-and-slab (1), Twin Box (1) and Triple Box (1)
Contract 5	St. Andrew/St.David	2	9m Box (2)
Contract 6	Tobago	2	25m beam-and-slab (2), 6m Box (1)
Contract 7	Tobago	2	25m beam-and-slab (2), 9m Box (1)
Phase 2	**Region**	**No. of Bridges**	**Types of Bridges**
Contract 1	St. George	3	2.4m Box (1) and 6m Box (2)
Contract 2	St. Andrew/St.David	5	25m beam-and-slab (1), 9m Box (1) , 6m Box (2) and 4.3m Box (1)
Contract 3	St. George	2	25m beam-and-slab (1) and Deck widening (1)
Contract 4	Caroni	3	6m Box (2) and 9m Box (1)
Contract 5	Caroni/Victoria/Nariva/ Mayaro	3	6m Box (2) and 9m Box (1)
Contract 6	St. Patrick/Victoria	2	9m Box (2)
Contract 7	Tobago	1	Four Cell Box

Figures 4 to 9 illustrate some of the bridges before and after construction. The bridge in Figure 4 had timber beams and one (1) steel edge beam. The timber beams were propped, presumably to avoid collapse under the passage of heavy loads. The new bridge is shown in Figure 5. The Single-Single Mabey bridge in Figure 6 was installed when the original bridge got washed away a few years earlier. The extremely poor alignment of the roadway is easily seen. A Twin-Box now stands in its place (see Figure 7). The riveted steel bow arch in Figure 8 was found to be in very poor condition. Many of the transoms were heavily corroded, to the extent where large holes had appeared. This bridge was replaced by a 25m span semi-integral bridge (see Figure 9).

Figure 4. B2/35 Paria Main Road

Figure 5. Replacement : 9m Box

Figure 6. B1/68 Paria Main Road

Figure 7. Replacement : 6m-6m Twin Box

Figure 8. B1/1 San Rafael

Figure 9. Replacement: 25m Beam-and-Slab

8. Conclusions

The Year 3 bridge programme may be aptly described as having mixed success. The design phase was completed in a straightforward manner without any major difficulties or delays. However, the construction phase is still not complete after a period of approximately seven (7) years. The PIU have attributed this to the fact that the cost of the programme exceeded the initial budget and the required additional funding was not readily available. In this regard, it should be noted that the construction industry became overheated because of the prevailing petrodollar boom during the period of 2006-2009. The large increase in the cost of labour and materials was not anticipated when the initial estimates were prepared.

During this study, the MoWT recognised the need to formulate a programme for regular and comprehensive inspection of its bridges. Reactive inspection, in response to a specific complaint, was the norm. Furthermore, these inspections were performed by staff without any formal training.

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