The development and implementation of a Bridge Management System for the Provincial Government of the Western Cape, South Africa

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ABSTRACT
This paper describes the development and implementation of a bridge management system for the Provincial Government Western Cape (PGWC). During the first phase of the project, the inventory and inspection modules were customised to meet the needs of the Department, which included integration of the BMS with the PGWC Road Network Information System. The second phase of the project involved the appointment of structural engineers to carry out the visual assessments, which is based on a defect rating system in order to determine a priority ranking of all inspected structures. The third phase of the project involved the validation of assessments and prioritisation of structures in terms of maintenance needs and the selection of suitable rehabilitation projects.

KEYWORDS
Bridge Management System, structure defects, bridge inspections, bridge repair

INTRODUCTION
The Western Cape is one of the nine provinces in South Africa and the Roads Infrastructure Branch of the PGWC Department of Transport & Public Works, is currently responsible for the management of 6 000 km of paved and 10 000 km of unpaved roads. These are basically all rural roads in the province that are not national routes, and include approximately 2 200 bridges and major culverts. Prior to 2000, a bridge database with limited inventory information on each bridge, a plan database consisting only of a listing of as-built drawings of each bridge and condition-based bridge inspection forms were used to manage the structures on provincial roads. This "system" did not produce meaningful results and thus there was no real management of bridge maintenance and rehabilitation.

The PGWC identified the need to acquire a management system to motivate for and allocate limited available funds to rehabilitation projects where most needed and to projects where the long-term benefit would be the most cost effective, i.e. to have a BMS in place in order to be able to identify projects in order of importance and also to maintain long-term bridge rehabilitation at an optimum level. It was imperative that the system generate credible information in the eyes of the decision-makers, thereby building confidence in the identification, prioritisation and planning processes in order to prevent regress to traditional *ad hoc* and political decision-making processes. As in the case of most road authorities, bridge and road maintenance and rehabilitation are funded from the same budget and have to "compete" for funds.

In order to effectively integrate bridge rehabilitation with road rehabilitation (which normally occurs more frequently), it was important that the BMS be sufficiently reliable and effective for future integration with other management systems, such as the Pavement Management System and Road Maintenance Management System. A further requirement was that the system should be able to cater for other road structures such as culverts and retaining walls. A culvert module was thus developed and incorporated into the system. The BMS was required to make provision for structure *type* for the purpose of visual assessments and structure *classification*, in accordance with the PGWC definitions based on minimum span length and total structure length. The retaining wall module is expected to be completed during 2005.

In 2000 the Provincial Government Western Cape adopted the STRUMAN Bridge Management System [1] developed by the Roads and Transport Division of the Council for Industrial and Scientific Research (CSIR Transportek) together with Stewart Scott International. During the past 3 years, all 2 200 bridges and major culverts on the provincial road network have been inspected and the data have been captured into the Bridge Management System.

During the past few decades, little attention has been given to the overall condition of structures in general, and many of the bridge rehabilitation projects that were commissioned were done on an *ad hoc* basis. Using the BMS, the Design Directorate now proposes a programme of rehabilitation of all bridges and major culverts in the province that are in need of remedial work and/or safety-related improvements.

DESCRIPTION OF THE PGWC BMS

During the first phase of the project, the inventory and inspection modules were customised to meet the needs of the Department, which included the development of a culvert module and the integration of the BMS database with the Road Network Information System (RNIS). A map module front end was also developed and integrated with the other BMS modules for graphical viewing of the structure data. This was based on shape files exported from the Department's Geographical Information System (GIS). The system is currently being updated to include access to bridge and culvert drawings in electronic format. The BMS will in the near future be accessible to regional offices and other authorised users via the internet.

As in the case of most bridge management systems, the STRUMAN BMS consists of an Inventory module, Inspection module, Condition module and Budget module. Its main distinction is perhaps in the Inspection module where the focus is on the observed defects of the various bridge or culvert elements rather than the overall condition of each element.

The PGWC's system therefore basically consists of the following:

Inventory Module

This is the basic module of a BMS and consists of detailed inventory data for bridges and culverts. The original inventory module was customised and expanded to meet the requirements of the PGWC. The main sections are as follows:

- Location details
- Contract details
- Structural features
- Design characteristics
- Hydraulic data
- Dimensions & geometry
- Services details
- Road configurations & traffic volumes
- Archive details – electronic linking of drawings for each rehabilitation project
- Rehabilitation history – information and photo links for each rehabilitation
- Factors influencing field inspection
- Inventory photos – photographic history of structure

Inspection Module

This module contains the detailed inspection data for each structure. The main sections are:

- Inspection heading & summary
- Ratings
- Remedial work activities
- Inspection photos – photos of all observed defects

DERU Rating System. Being a defect-based system, each defect of a bridge or culvert element is rated according to its degree (D), extent (E), and relevancy (R). An urgency (U) rating is also given to indicate the perceived urgency of the proposed remedial activity. Only the worst defect (highest relevancy or highest degree for the same relevancy) on each item or sub-item is rated, but each defect is assigned a remedial work activity with an urgency rating.

Each of the DER ratings is rated on a scale of 1 to 4 as follows:

D = Degree of severity of defect (1 = minor to 4 = severe; 0 = no defect)
E = Extent of defect on bridge element (1 = local to 4 = general)
R = Relevancy of defect to serviceability of bridge element (1 = minimum to 4 = critical)

The Relevancy rating forces the bridge inspector to evaluate the consequences of the defect in terms of the bridge serviceability and safety. Each of these parameters is combined in the condition module to determine a priority index for each structure. A remedial work sheet is used during structure inspections to summarise the items requiring repair. In the case of an element that does not exist or is missing (e.g. guardrails, invert slab), both D and E are rated as 4. The bridge inspector is therefore not required to rate the condition of each structure item, but only the defects observed on each item. A visual assessment manual was also developed to improve uniformity of the inspector rating standards.

Condition Module
Bridges and culverts are prioritised according to pre-set parameters. In the Condition Module structures are prioritised in order of the need for repair/rehabilitation. All structure items have adjustable weighting factors built into the prioritisation algorithm so that important items such as abutments, piers and decks (in the case of bridges) that have defects with a high degree (D) rating combined with a high relevancy (R) rating have a greater influence on the Priority Index (PI) of a structure than other minor items such as parapets, deck joints and bearings. The Condition Index (CI) is used to rank the structures in terms of overall condition as opposed to the need for receiving maintenance. The Functional Index (FI) is combined with the Priority Index to take into account the strategic importance of the structure and/or route on which it is located.

Budget Module
The pre-defined remedial work activities that are utilised during the visual assessments for identifying required repairs to defects have associated unit costs. These costs are used in the budget module to determine estimated repair costs for individual structures. Optimisation is done using the relevancy/cost ratio per defect and budget limits per year. Repairs are allocated to the 'Current year', 'Year 2' or 'Years 3 – 5' based on the urgency rating (U). In the case of structures that have been identified for repair, either selected or all repair items for these structures are allocated to the 'Current year' and the budget is re-optimised.

INSPECTION PROCESS & VERIFICATION OF RESULTS
The next phase of the project involved the appointment of suitably experienced structural engineers to carry out the visual assessments. The first round of inspections included all bridges and major culverts (all structures with span lengths in excess of 3.0m). Due to the importance of the impact of the DER rating (and especially the relevancy rating (R)) of defects on the prioritisation process, only professional engineers and technicians with a minimum of 5 years experience in bridge design/rehabilitation could qualify as bridge inspectors. Prospective inspectors were required to apply for accreditation as individuals to perform bridge inspections for the Department. Upon review of the applications, all engineers with suitable experience were invited to attend a compulsory three-day BMS training course (with specific focus on the assessment methodology) in order to be accredited.

During a period of approximately two years (2001 to 2003), 15 bridge inspectors (most of them based in the Cape Town area) were used to inspect the 2 200 structures (850 bridges and 1350 major culverts) in the province's five District Municipality areas and the Cape Town Unicity (excluding structures that fall under the jurisdiction of the City of Cape Town). As many as possible of the locally-based bridge engineers were given the opportunity to engage in bridge inspections for the PGWC.

The inspectors were not only required to carry out principal inspections, but also to obtain all the relevant inventory information of each structure – either from as-built design drawings, if available, or from measurements on site if drawings were not available. Inspectors were required to record all visual defects – not because it is the intention that all defects will eventually be repaired, but to have a reference base for all the defects. This information, together with the inventory and inspection photographs, was then captured by the inspector into the BMS – each bridge inspector received a copy of the BMS inventory and inspection modules for this purpose. On completion, the electronic data was submitted to the PGWC for incorporation into the main database.

Although significant emphasis was placed on quality and uniformity during the training course and the briefing sessions, the recorded inventory information and especially inspection ratings were not always of the required consistency necessary to obtain reasonably accurate prioritisation of rehabilitation needs. The reason for this inconsistency could be attributed to the fact that not all the inspectors had similar previous bridge design and rehabilitation experience, and 15 bridge inspectors are perhaps too many to achieve a satisfactory degree of consistency

This was the first round of inspections with the STRUMAN system and thus electronic comparisons with previous inspections were not possible. However, for a certain number of structures where the conditions of the structures were well known, the results obtained from the BMS were verified. By observing the defects shown on the inspection photos for these structures and through verification inspections of the structures, the BMS prioritisation of these structures (relative to each other) could be assessed. By being able to calibrate various system and weighting factors in the condition module, it was possible to optimise the BMS output to produce results that were considered to be accurate and realistic as far as these structures were concerned. The most important aspect was to verify that the structures at the top of the priority list were in fact those most in need of repair i.e. to verify the calibration of the prioritisation algorithm.

At this stage it is envisaged that principal (lower cost) inspections will be undertaken every 5 to 7 years as well as on completion of the repair and rehabilitation of structures. The inspections are only visual, but they are the BMS's primary data source for determining the structure's condition, and diagnostic testing is generally only used for detailed project level inspections after identification of repair projects.

PRIORITISATION AND PROJECT IDENTIFICATION

Prioritisation of all the inspected structures on all the roads (Trunk-, Main- & Divisional Roads) in the province was done. All structures with a priority index value below 60 were identified as requiring attention and displayed in the Map module. 170 structures met this criterion. Areas (with a radius of approximately 50km) were identified where the highest concentration of structures in the above category were situated. Each of these areas was earmarked as a project and all the structures in these areas were identified to be included in the project.

For sound economic reasons (e.g. cost of site establishment) it is beneficial not only to rehabilitate the high priority (worst condition) structures on the higher road classes – which were evidently scattered over the whole province – but also to include structures situated on lower road classes and with a lower priority (but with high benefit-cost rehabilitation needs) that are in close proximity to the identified project areas. The aim is therefore to group bridge rehabilitation into projects of suitable size that can be awarded to one construction firm. The final selection of structure maintenance projects also takes into account planned road maintenance projects.

Such an area is the south western region of the province, which has 55 structures with a priority index less than 60, as well as many other structures requiring lesser rehabilitation and safety improvements. Some of these structures are given in Table 1 .

Rehabilitation needs include the following:

- Routine maintenance repairs
  - Approach embankment and scour protection works
  - Approach and deck re-surfacing
  - Cleaning of waterways and siltation inside culverts
  - Removal of vegetation from sidewalks and deck joints
- Road safety improvements
  - Installation, extension and attachment of guardrails at bridge abutments
  - Warning signage
  - Reconstruction/repair of bridge parapets and handrails
- General serviceability repairs & protection
  - Repair of spalled concrete
  - Replacement of bearings
  - Replacement of deck joints
  - Crack sealing and durability enhancement coatings

Table 1. List of structures in the south western region requiring repair

Structure	Road	PI	PI Rank	CI	CI Rank	Remarks
C10447	MR174	10.3	6	89.7	1415	Severe delamination of top slab soffit
C10352	DR1113	25.1	20	83.7	969	Corroded cell floor, undermined invert slab
C11377	MR199	33.1	22	58.9	43	Severe spalling of deck soffit & cell wall
B3018	MR234	35.1	32	75.8	442	Severe abutment & pier cracking, spalling
B3902	TR11/2	37.5	37	63.1	81	Collision damage, joints, bearings, AAR
B5654	DR1423	37.6	39	81.8	818	Spalling underneath deck bearing plate
B4750	TR2/1	37.7	40	63.8	94	Collision damage, joints, spalling, no handrails
B4113	TR9/2	37.8	41	88.6	1345	Collision damage, joints
C10072	MR215	43.2	45	91.5	1576	Undermined invert slab
B2983	MR201	43.3	46	66.6	143	Spalled deck beams, no parapets
B2927	TR11/1	43.5	56	71.1	267	Spalling underneath deck bearing plate
C10771	MR191	43.6	59	56.3	27	Cracking in walls & top slab
B4334	MR207	43.7	61	57.7	35	Spalling, AAR cracking, joints, no handrails
B2960	MR159	50.0	74	72.7	318	Collision damage, AAR cracking, joints
B2167	TR2/1	50.1	76	72.3	306	Spalled trestle beams, failed bearings
C10061	DR1161	51.3	86	78.2	578	Severe spalling of deck soffit
C10033	MR 227	51.5	98	52.1	12	Corroded cell floor, cell deformation
C10009	MR 230	51.8	110	79.4	666	Corrosion of cell walls, undermined invert
B4947	TR 2/1	54.6	123	67.5	164	Deck seepage, approach settlement

Typical defects identified on these structures are shown in Figures 1 to 4.

Fig. 1. Delamination of large areas of concrete at soffit of culvert top slab (C10447).

Fig. 2. Severe AAR cracking on abutment breast wall (B2960).

Fig. 3. Spalling of concrete at deck beam soffit (B2983).

Fig. 4. Spalling of deck beam seating on top of pier trestle beam (B2167).

The most common deterioration mechanisms to reinforced concrete in the Western Cape Province (especially in the coastal regions) are alkali aggregate reaction (AAR) and carbonation- and chloride-induced corrosion. Apart from the typical AAR crack patterns observed on several structures (Figure 2), the existence of carbonation and chlorides in the concrete and their effect on the reinforcement, could not be assessed during the visual inspections. The maintenance actions as indicated in the inspection reports were based purely on observed physical defects, and the early stages of concrete deterioration (and subsequent corrosion of reinforcement) are seldom visually evident. It is therefore considered essential to perform detailed diagnostic testing and forensic investigation on a representative sample of structures in this area [2]. As far as the other defects in the area are concerned, the following are the most common:

Scouring of approach embankments, settlement of bridge approaches, siltation of culverts, inadequate or damaged guardrails at bridge approaches, missing (stolen) handrails, spalling of concrete due to lack of cover or inadequate movement gaps, deteriorated/leaking bridge deck joints, cracks in concrete due to shrinkage or settlement/movement of concrete elements.

Initially, a pilot rehabilitation project will be launched in the Oudtshoorn area during which issues such as rehabilitation specifications, repair and safety improvement policy, remedial work cost implications, rehabilitation expertise requirements of consultants, suitable project sizes, etc. will be assessed. Once the documentation and cost estimates for the pilot project have been completed, the rehabilitation of the structures in the remainder of the province will be programmed and budgeted. The Department has proceeded with the pilot project and has appointed consulting engineers to carry out a detailed investigation (which in a number of cases will include forensic/diagnostic testing), prepare a rehabilitation design, compile contract documentation and supervise the contract. The brief to the consultants involved in compiling rehabilitation specifications, was that not all defects as indicated by the BMS (and observed by subsequent project inspections) are to be repaired – as some defects can, without risk or unacceptable aesthetic consequences, be ignored for the remaining life of the structure.

It is expected that the first BMS cycle will be completed with the award of this pilot project during the first half of 2005

CONCLUSIONS

The development and implementation of the STRUMAN BMS for the Western Cape Provincial Government has led to a significant improvement in the management of structures on the provincial road network. All 2 200 major structures have been visually assessed using a defects-based system and the 170 worst structures have been identified for inclusion in a bridge repair and rehabilitation programme. Other structures with a lower priority will also be included in the rehab projects due to their location in relation to the high priority structures. A pilot project in the Oudtshoorn area will be implemented after which projects for the repair of the remaining high priority structures will be carried out. Diagnostic testing of a representative sample of structures in selected areas will be done to determine the extent of non-visual deterioration.

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