BRIDGE MANAGEMENT IN NAMIBIA: EXISTING INITIATIVES AND THE WAY FORWARD

by

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ABSTRACT

The Namibian proclaimed trunk, main and district road network of 46 000 km has a compliment of over 600 bridges and over 20 000 culverts of which 2 000 have a span equal to or greater than 3.0 m. The biggest percentage of the bridges and culverts were constructed during the early 30's when the design loading was based on the size of heavy vehicles operating on roads at the time. Structural analysis techniques at the time also had limitations as compared to the available computer modelling tools available today.

This paper reviews bridge management in Namibia through a stand-alone Bridge Management System which has been successfully used to identify distress in road structures from a number of shortcomings and how the records in the system have been utilised for the detailed inspection of the suspect structures. Specific reference is made to two case studies with design and environmental defects and the corrective measures implemented thereof.

Further development of the Bridge Management System as part of an Integrated Road Management System incorporating other sub-systems is briefly discussed.

1. INTRODUCTION

Namibia covers some 824 000 km^2, with a population of 1.8 million projected at 3% annual growth from the 1991 census. The country is served by a proclaimed trunk, main and district road network of 46 000 km consisting of about 5000 km of bitumen sealed roads, and about 41 000 km of unsealed roads, with standards varying from earth, gravel, to salt-gypsum roads. Because of the size of the network and the low population, the km per capita of 0.0025 km is among the highest on the continent. Figure 1 presents the country's proclaimed road network categorised into trunk, main, district and farm roads.

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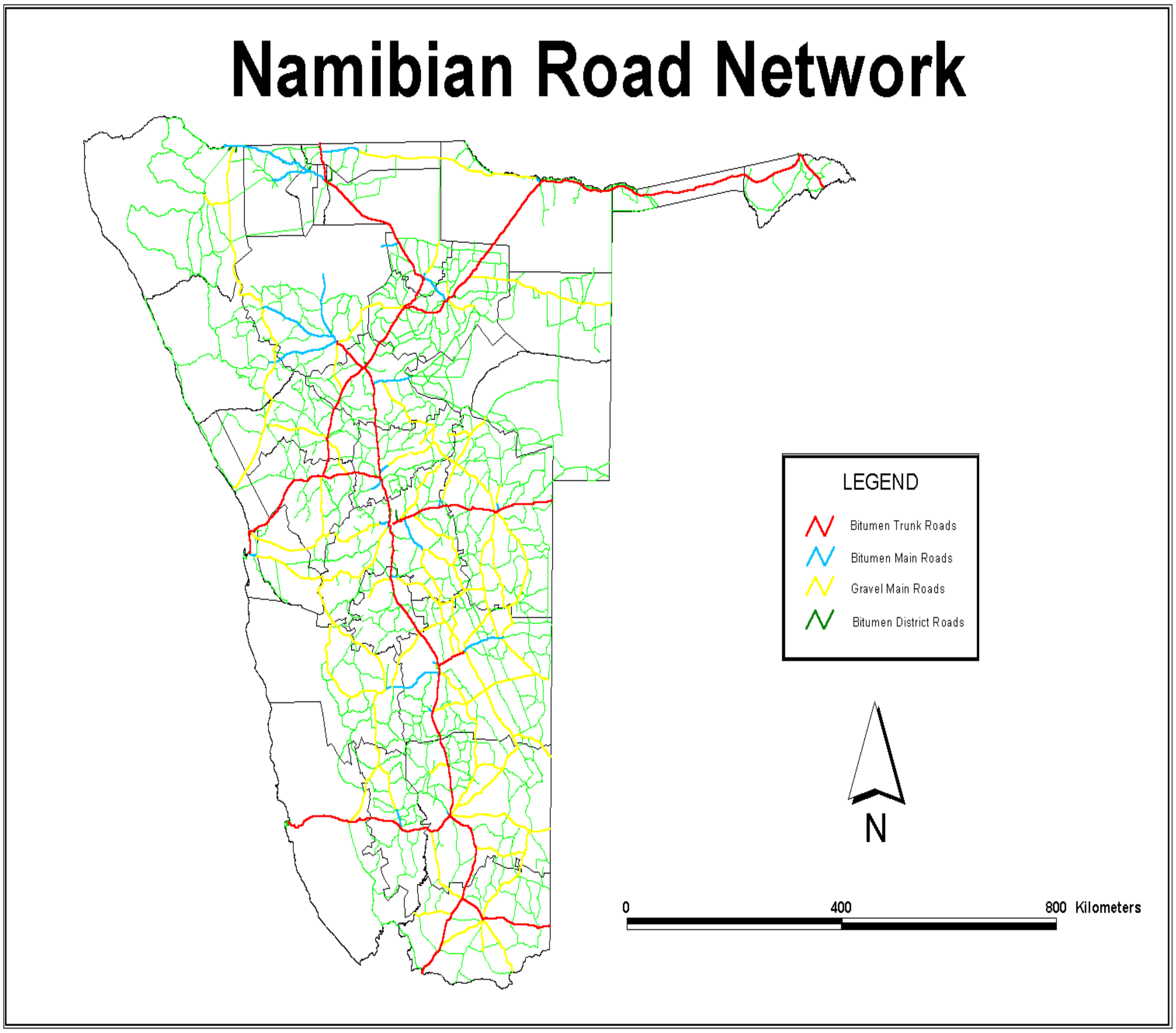


Figure 1: Namibia Road Network

Although 95% of the land is classified as semi-arid, with the Namib and Kalahari deserts covering a significant share of the country, the road network is complemented by over 600 bridges and over 20 000 culverts of which about 2000 are major culverts (>=3 m spans), with the biggest percentage of the structures constructed in the late 30's and early 40's or before and therefore with remaining service lives of between 5-10 years and are already showing signs of distress.

The design loading of these structures was based on the size of heavy vehicles operating on the road network at the time. Due to firstly, advances in technology, the size of heavy goods vehicles and the loads they carry has increased significantly which has resulted in the revision upwards of the design loads currently used for road structures. Secondly, the structural analysis techniques at the time had their limitations, unlike the modelling tools available today that can be used to accurately determine the effects of heavy vehicle movements on the structures.

2. INSPECTIONS PRIOR TO 1990

Prior to the implementation of a stand-alone Bridge Management System (BMS) in 1990, bridge and culvert inspections were only carried out when major events occurred, like overtopping of the structures by floods, an accident on the structure that was suspected of resulting in structural damage or when evaluating routes for the passage of abnormally heavy vehicles. The inspections carried out were therefore limited in nature to individual structures and the routes identified for passage of the abnormal vehicles.

It was felt then that to ensure the safety of the travelling public and to protect the capital investment in road structures and facilities their maintenance at minimal cost, a management system was necessary for the purpose of keeping a record of the condition of the structures at the same time identify those with major defects, to provide a basis for prioritising their maintenance rehabilitation. The Bridge Management System was therefore implemented in 1990, to monitor the condition and performance of the said structures on the same basis as a pavement management system as the structures are an integral part of the road network.

3. THE BRIDGE MANAGEMENT SYSTEM

The System contemplated at the time was to consist of the following:

- a bridge/culvert inventory data file
- a principal and detail inspection file
- a management model

The Bridge/Culvert inventory data was extracted from the as-built drawings, reports and records and recorded the design and construction details of the structures. These were augmented by field measurements and observations.

The Principal Inspections are visual assessment of the structures, waterways and approaches recorded on a standard Bridge Inspection Report form. This is supplemented with photographs where the elements are in a poor or critical condition.

Detailed Inspections are carried out for those structures with major defects based on the outcome of the Principal Inspections. These detailed inspections are used to determine the cause of the defects and the most cost-effective way of correcting the defects. It was not possible at the time due to budget constraints to develop a management model, whose functions was to predict the deterioration of the elements of the structures together with costs for the purpose of providing budget estimates for maintenance and rehabilitation.

4. PROGRESS TO DATE

The first principal inspections were carried out in the 1991/92 financial year and the second ones during 1995/96. The inspection data was recorded as a data file from which the history of the structures can be extracted. The principle inspections identified 16 suspect structures with defects classified as:

Table 1: Number of Structures and Defects

No of structures	Type of defect
10	Design
4	Environmental
2	Overloads

4.1 Design Defects

A total of ten (10) structures mostly constructed in the 30's and 40's were identified with design defects.

The design defects identified in most of the superstructures occurred in skew beam and slab decks. These structures were subjected to detail inspections, which included structural analyses to determine their capacities.

4.1.1 Loading

At the time, the traffic loading was in accordance with the recommendations of the British Ministry of Transport (MOT) which specified the following:

- A uniformly distributed load = 10.9 kN/m^2
- A knife edge load (KEL) = 39.5 kN/m

The above loads are similar to the NA loading used today for the design of bridge decks, as recommended by both the SATCC Code of Practice for the Design of Road Bridges and Culverts and TM7: Code of Practice for the Design of Highway Bridges and Culverts in Southern Africa. BS5400: Specifications for Loads also specifies a similar load referred to as the HA Loading. However today on top of the loading referred to above, two additional loads are recommended specifically to take into account the effects of abnormal loads and superloads.

- NB Loading – representing an abnormally heavy vehicle
- NC Loading – representing superloads

Two case studies have been used in this paper to illustrate the results of the detail inspections carried out on firstly a typical case of design defects and secondly a case where the defects are solely a result of the environment especially the salty environment along the west coast of Namibia.

4.1.2 Case study 1

The bridge used for this case study to illustrate the design defects is B0383: UGAB River Bridge on one of the trunk roads, with traffic estimated at 550 vehicles per day with a 6% heavy vehicle content. The traffic volumes are low when compared to the other trunk roads with averages of 3000 vehicles per day with 10-15% heavy vehicle content. The defects on this bridge were similar to the other nine structures identified with design defects, although the level of distress for the others was more severe due to higher levels of traffic.

The structure consists of 6x15.24 m single simply supported beam and slab decks at skew angles of 45^0, on solid wall type piers on spread footings as shown in Figure 2. It was constructed in 1969.

Inspection of the superstructure revealed the following:

Longitudinal members	Torsional cracks up to 0.2 mm
Transverse members	Vertical cracks up to 0.2 mm
Deck slab	Longitudinal cracks up to 0.4 mm
	10-20 mm thermal movement. Creep deflection.

The deck was analysed using a finite element model of line elements with a space frame layout in which the structure is defined in the global X, Y and Z co-ordinates with each node having six degrees of freedom. The output includes six deflections per mode, i.e. translation in the X, Y and Z directions and rotations about each of the axes. In addition six internal forces per member are calculated i.e. shear, torsion and moments.

The structural analysis was carried with both the MOT loading and the SATCC: Code of Practice load recommendations. The results of analysis comparing the load effects as a ratio of the carrying capacities are presented in Table 2 overleaf:

Table 2: Results of analysis as a Ratio of Carrying Capacities

Load Case	Effect	T-Beams		L-Beams	
		Midspan	Supports	Midspan	Supports
MOT Load	M_D	0.64	1.07	0.58	0.35
KEL Mid-span	V_{ST}	3.33	2.26	0.81	0.85
MOT Load	M_D	0.46	0.90	0.45	0.34
KEL Supports	V_{ST}	2.57	2.06	0.57	0.86
NA Load	M_D	0.62	1.05	0.56	0.35
KEL Mid-span	V_{ST}	3.29	2.23	0.77	0.84
NA Load	M_D	0.47	0.91	0.46	0.34
KEL-Supports	V_{ST}	2.62	2.06	0.58	0.86
NB Load	M_D	0.51	1.47	0.62	0.59
Mid-span	V_{ST}	2.27	2.85	0.73	1.32
NB Load	M_D	0.48	1.35	0.56	0.47
Supports	V_{ST}	2.86	2.68	0.65	1.20
NC Load	M_D	0.64	0.95	0.47	0.13
	V_{ST}	3.40	2.16	0.56	0.48

M_D -Moments; V_{ST} -Combined shear and torsion stresses; KEL -Knife Edge Load

4.2 Environmental Defects

Four structures on the coastal belt of Namibia registered the effects of chloride ion penetration into the concrete and carbonation which resulted in the spalling of concrete due to the corrosion of reinforcement. The detailed inspection of the structures included potential mapping of chloride activity levels on the elements supplemented by tests on drilled cores.

4.2.1 Case study 2

The Swakop River Bridge, B0190, is on Trunk Road 2 Section 1 between Walvis Bay and Swakopmund, which is part of the SADC Regional Trunk Road Network (RTRN) designated as Route 40, meant to link the Walvis Bay Harbour to the land-locked countries to the east and north-east of Namibia. The road carries an average of 3350 vehicles per day with a 13% heavy vehicle content.

The structure consists of 14 prestressed beam and slab decks on prestressed pier head beams, on wall type piers founded on caissons. The bridge was constructed in 1969. Figure 3 presents the elevation and plan of the bridge. Measurement of concrete cover to reinforcement was found to be in keeping with good practice, with the exception of the decks where it was 40 mm instead of the recommended 50-60mm. For structures exposed to marine environment, the recommended limit of chloride-ion concentration is 0.2% expressed as a percentage by mass of cement. It was common practice in the 60's and 70's to utilize additives containing chloride for the purpose of activating fast setting of the concrete. Significant carbonation penetration was also measured as was indicated by the reduction of the PH to as low as 8 at depths of up to 50 mm. To maintain the protective layer against corrosion a ph of 12 is required. Measured chloride concentrations on the elements are presented in Table 3.

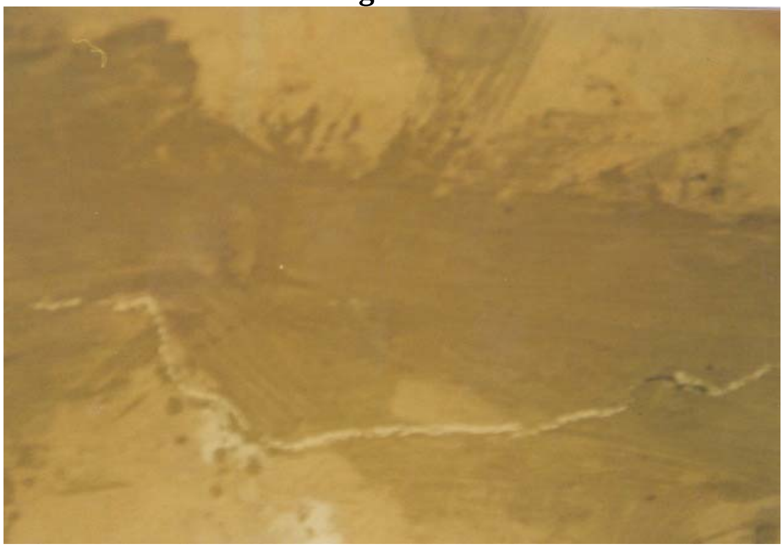
Table 3: Chloride Profiles by Depth as a ratio of the allowable concentration

Location of Sample	0-25 mm	25-50 mm	50-75 mm	75-100 mm
Pier 12, North face cross-head	2.25	0.45	0.20	0.20
Pier 12, South face RHS top East	14.05	5.70	1.00	0.45
Pier 12, North face West	23.30	2.00	0.65	0.25
Pier 12, LHS South face near PT, End in	24.95	10.60	2.00	0.30
Pier 12, LHS West end – PT, End in	15.40	1.30	0.45	0.30
Pier 12, West side ground level	15.10	8.40	8.70	6.65
Pier 4, South face 2,5 m above ground	3.75	1.40	0.70	0.75
Pier 4, North face 0,5 m above ground	2.20	1.00	0.70	0.40
Pier 8, South face cross-head	5.05	1.30	0.60	0.50
Pier 8, South face LHS, no 2 high	11.85	3.50	2.95	2.20
Pier 6, West side 1,5 m above ground	1.85	0.50	0.80	0.70
West side wall 200 mm from bottom	4.40	0.30	0.35	0.30
West side wall 400 mm from bottom	1.85	0.65	0.45	0.40
Beam 2, near Pier 12, soffit	1.30	0.30	0.25	0.40
Beam 2 near Pier 12	3.25	1.15	0.50	0.35
Beam 1 near Pier 12 West face	11.25	8.20	4.35	1.00
Beam 2 near Pier 12 soffit	3.05	0.60	0.40	0.25
Pier 12, LHS end cap	12.4	-	-	-
Pier 12, LHS end cap	12.3	-	-	-

5. DISCUSSION

From Case Study 1, it is evident that the deck design accounted for the moment capacities for the applied MOT loading. The design for shear however, only accounted for direct shear and ignored the effects of torsion and for all the load cases the combined shear and torsion stresses exceed the capacities of the T-beams. For the L-beams the combined shear and torsion stresses are within the capacity of the beams with the exception of the NB loading at midspan and near supports. Even for the MOT loading, the combined shear and torsion stress exceeded the carrying capacity by up to 233%, and were in excess up to 162%, 127% and 240% for the NA, NB and NC loading. For example for the MOT loading with the KEL at midspan, the contribution of torsion to the combined stress at midspan for the T-beam is 98% and at the supports is 77.7%. The shear reinforcement provided therefore only catered for direct shear hence the distress in the beams as shown in Figure 4.

Cracking of the Deck



Torsional Cracks on Main Beams

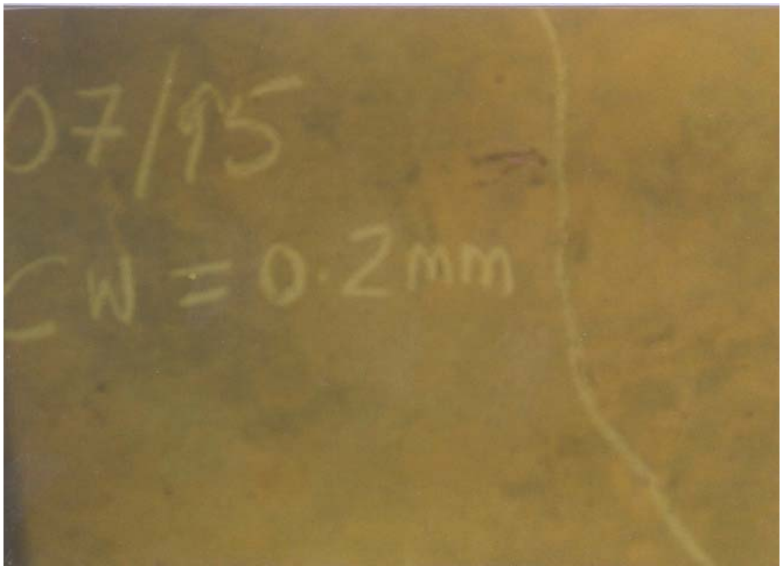


Figure 4: UGAB River Bridge

It can be concluded that the design did not take into account the effects of skew, which for especially beam and slab decks results in significant torsional moments. For most of the structures with this problem, most of the superstructures especially those on the heavily trafficked routes have been reconstructed as solid slab decks where the degree of deterioration could not allow their strengthening. Those on lightly trafficked routes are to be strengthened.

Chloride concentrations especially on the pier heads at the end cap and the pier wall interface at ground level were all above 2.0 %. The concentration reduced to lower levels within the 40 mm concrete cover but is higher than the 0.2 % recommended level. This proves the concrete spalling that has occurred on the members as a result of the corrosion of the reinforcement. Figure 5 presents the effects of chloride ion penetration on the members.

Spalling of Concrete at the End of Prestressed Pier

Corrosion of Cage Reinforcement at Prestressing Anchor Ends

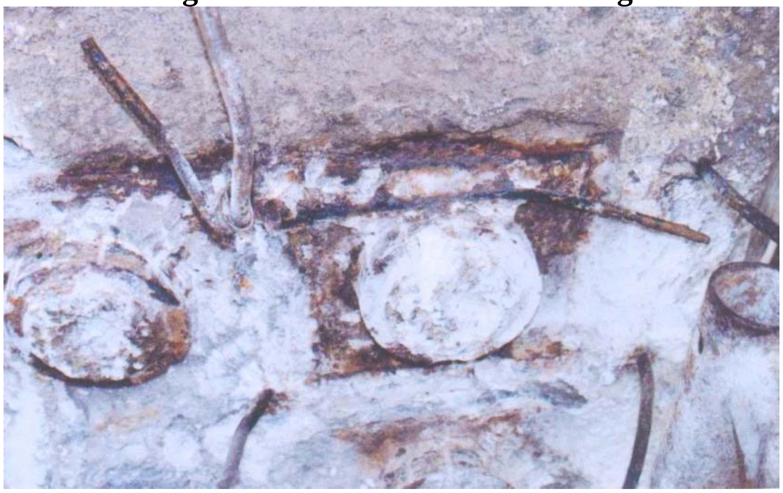


Figure 5: SWAKOP River Bridge

Cathodic protection has been used on a number of structures with chloride ion penetration and carbonation problems. The system involves after the repair of the defects, the installation of circuitory that reverses the movement of the ions. An electronic data logging system is also installed for monitoring and to ensure the effectiveness of the protection.

Although the existing stand-alone Bridge Management System (BMS) has been effectively used for monitoring the condition of structures on the road network, current trends incorporate the BMS as a sub-system, of an Integrated Road Management System. As such the Roads Authority has initiated the incorporation of the existing data into a new system as part an Integrated Road Management System.

6. RECOMMENDATIONS

The stand-alone Bridge Management System developed for the Namibian road network has assisted in the identification of a number of suspect structures which upon detail evaluation has resulted in recommendations for either reconstruction or rehabilitation by strengthening those elements identified.

With the current drive within the SADC region of harmonisation of the regional road network, it is important that re-evaluation of the especially older road structures is carried out to determine their carrying capacities in comparison with the required regional standards. The rehabilitation, strengthening or reconstruction can then be phased according to the annual budgetary allocations.

In order for Roads Authorities to monitor the performance of and to protect the investment in road structures, it is essential that Bridge Management Systems are developed similar to the traditional Pavement Management Systems. The system with incorporation of a structures deterioration model is essential for the prioritisation and budgeting for maintenance and rehabilitation of road structures as part of a larger Integrated Road Management System.

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