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Effectiveness of User-Load-Control on Reinforced Concrete Bridges

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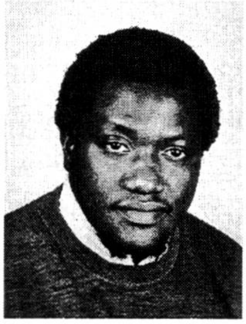

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Summary

The paper discusses the effectiveness of weighing bridges which were constructed as user-load-control points so as to limit the truck axle loading on a 900 km long TanZam highway road in Tanzania to those intended in the design. A number of reinforced concrete bridges have shown signs of distress which are typical to overloading and at least one ultimately collapsed. It is important, in design stage, to forecast effectiveness of measures used to control vehicle weights on a road.

1. Introduction

A site investigation was conducted to assess the condition of the superstructure of 66 RC (Reinforced Concrete) bridges located between two weighing bridge stations 600 km apart on the TanZam highway which are utilised as user-load-control points for trucks using the highway in Tanzania. The two lane 900 km road connects the port of Dar es Salaam with the southern part of the country and neighbouring countries namely north of Zambia, north of Malawi and south of Zaire. The user-load-control points were constructed at certain intervals so as to limit the truck axle loading on the TanZam highway road in Tanzania to those intended in the design. A number of RC bridges have shown indications which are characteristic to overloading and at least one bridge collapsed. It has been observed that RC bridges on the TanZam highway designed according to AASHTO [1] to carry trucks of up to about 40 tons 25 years ago [2] have been in the cause of time supporting trucks of up to 90 tons. It should be noted that bridge designing in the southern countries, outside europe, in the moment is done based on various european or north american structural design codes directly or indirectly through local structural design codes of practice.

2. Axle Loading of Trucks Plying on TanZam Highway

The RC bridges on TanZam highway were designed 25 years ago on the basis of the three-axle trucks with axle loading distribution of 36 kN--144 kN--144 kN and width 1.83 m. This truck has a maximum axle loading of 144 kN within a 4.27 m of road length. In comparison, the survey in 1995 shows that there are diverse configurations and capacities of truck axle loading plying on the TanZam highway as summarised in Fig. 1. These have axle loadings capacity of up to 480 kN within 2.6 m of road length. The total truck loading capacity now reaches 960 kN whereas the total load of the design truck was 324 kN. The truck axle load configuration keeps on changing with time as transporters strive as much as possible to acquire higher load carrying capacity per truck.

Configuration of Axle Loading Capacity of Trucks on TanZam Highway	Total Truck Load Capacity	Minimum Axle Spacing	Load on Minimum Axle Spacing	Effective Burden Increment Factor
[36] [144] [144] [kN] o———o———o (4.27) (4.27) (m)	324 kN	4.27 m	288 kN	1
[60] [200] [kN] o———o (3.0) (m)	260 kN	3.0 m	260 kN	1.3
[60] [200][200] [kN] o———o o (3.0) (1.3) (m)	460 kN	1.3 m	400 kN	4.67
[60] [200][200] [200][200] [kN] o———o o———o o (3.0) (1.3) (3.0) (1.3) (m)	860 kN	1.3 m	400 kN	4.67
[60] [200][200] [160][160][160] [kN] o———o o———o o o (3.0) (1.3) (3.0) (1.3)(1.3) (m)	940 kN	1.3 m 2.6 m	320 kN 480 kN	2.8 3.7
[60] [200][200] [200] [150][150] [kN] o———o o··········o———————o o (3.0) (1.3) (3.3) (6.7) (1.3) (m)	960 kN	1.3 m	300 kN	1.04

Fig. 1. Axle loading configuration of trucks plying on TanZam highway.

The effective burden increment has been determined by considering increment of axle load on minimum axle spacing and decrease of minimum axle spacing of a truck in comparison to the design truck. In comparison, the main loading system (load model 1) with a tandem system of characteristic axle load of 600 kN within 1.2 m of road length and a uniformly distributed load of 9 kN/m^2 are specified for design in Eurocode 1: part 3 [3].

3. Investigation of RC Bridges Between Two User-Load-Control Points on TanZam Highway

User-load-control points are weighing bridges which were constructed at certain intervals along the TanZam highway so as to limit the truck axle loading on a 900 km long TanZam highway road in Tanzania to those intended in the design. Between the two selected user-load-control points 600 km apart there are a total of 72 bridges. These are steel deck-steel beam, steel truss-steel deck, RC slab-steel beam, RC slab and RC slab-RC beam bridges. The number of each is as summarised in the table shown in Fig. 2.

No.	Type of bridge superstructure	Total number	Total length	Number of spans	Maximum span
	steel deck-steel beam	4	14 - 24 m	1	13 - 23 m
	steel truss-steel deck	1	104 m	3	50 m
	RC slab-steel beam	1	123 m	4	30 m
	RC slab	46	4 - 20 m	1-3	3 -10 m
	RC slab-RC beam	20	10 - 77 m	1-5	9 - 20 m

Fig. 2 Table showing the number of bridges between the two user-load-control points.

In this investigation only RC slab and RC slab-RC beam bridges lying between the two user-load-control points were considered. The RC bridges have a transverse curb to curb width of 7 m to 9.5 m. The total transverse bridge width varies from 9 m to 10.5 m. The RC bridges have clear spans ranging from 3 m to 20 m and total lengths ranging from 4 m to 120 m each.

4. Results Showing the Condition of the Superstructure of RC Bridges on TanZam Highway

4.1 Large Cracks on RC Beams and RC Slabs

Some 5 RC bridges on the TanZam highway showed large cracks on the RC beams and slabs which was an indication of the bridges being subjected to overloading. One other bridge eventually collapsed after its RC slab deck failed due to overloading. A typical case of a bridge beam on the TanZam highway with 2 mm wide cracks is shown in Fig. 3.

4.2 Damages Due to Accidental Impacts by Vehicles

Most of the RC bridges on the TanZam highway have damages on the top part of their superstructure namely on railing and apron. The damages are mostly due to accidental impact by vehicles on the bridge superstructure. The shock due to impact has short term reverberations on the load carrying structural part of the bridge and adds up to the existing overload due to normal daily traffic loads.

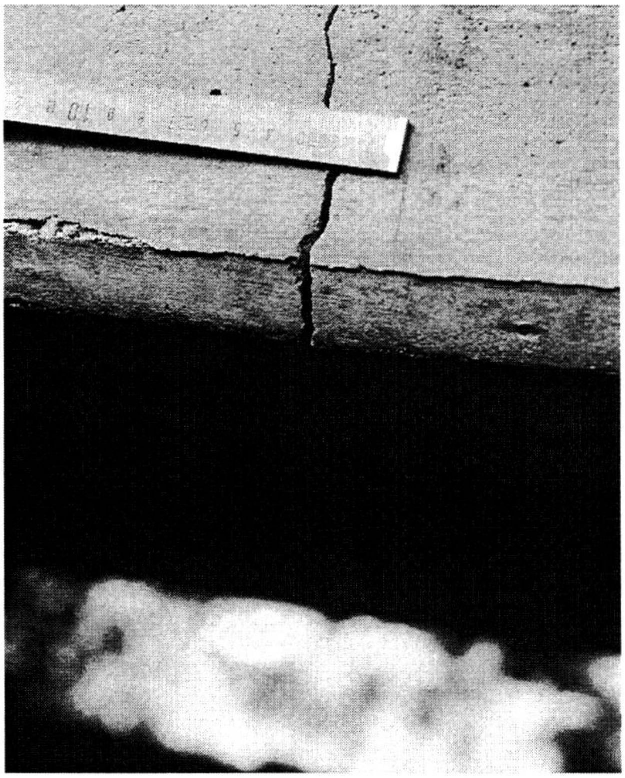

Fig. 3. A Photo showing typical large cracks in RC beam of a bridge on TanZam highway.

4.3 Classification of the Condition of the RC Bridges on TanZam Highway

The condition of the RC bridges between the two user-load-control points were ranked as follows:

- RC bridges without any damages.
- RC bridges with damages on the top auxiliary parts of the bridge.

- RC bridges with small cracks on the RC beams and/or RC slabs in addition to damages on top auxiliary parts.
- RC bridges with large cracks on the RC beams and/or RC slabs in addition to damages on the top auxiliary parts of the bridge.

The Table in Fig. 4. shows a summary of the condition of RC bridges on the TanZam highway according to the above ranking.

Category	Proportion in Percent of RC Bridges on TanZam Highway in Each Damage Classification				
	Good Condition	Damages on Top Auxiliary Parts Only	Small Cracks on Beams and Slab	Large Cracks on Beams or Slabs	Sum
According to Type of Bridge					
RC Slab Bridges	31	60	7	2	100
RC Slab-RC Beam Bridges	0	43	38	19	100
According to Maximum Free Span of Bridge					
3 m to 10 m	29	63	8	0	100
11 m to 20 m	0	33	39	28	100
According to the Distance from User Load Control Points					
0 to 200 km	33	67	0	0	100
200 to 400 km	18	51	22	10	100

Fig. 4. Table summarising the condition of the RC bridges on TanZam highway.

4.4 Type of RC Bridges Showing Higher Distress Condition

The results in Fig. 4 have shown that large cracks appeared on bridges with comparatively large clear spans. Also, large cracks were mostly present on RC slab-RC beam bridges in comparison to RC slab bridges. But most of the RC slab-RC beam bridges had large spans which is the main reason that they showed higher degree of deterioration compared to the slab bridges. In addition, RC bridges located between 200 and 400 km showed higher distress conditions than those located within 200 km from both ends.

5. Discussion

5.1 Estimation of Design Loading

It is usually economical to use local data on trends of vehicle loading to estimate future loading for design purposes. But the 900 km long TanZam highway was an upgrading of an existing unpaved road to a paved road. Hence it was expected that by estimating future traffic loads based on evaluation of traffic loads of the then existing unpaved road and extrapolation of local vehicle trends at that time could lead to underestimation because the user's response to changes in such an extreme road upgrading is a sharp increase in the utilisation of the road due to the availability of a much better road and bridges. The relation of design loading, user response and load control is shown in Fig. 5.

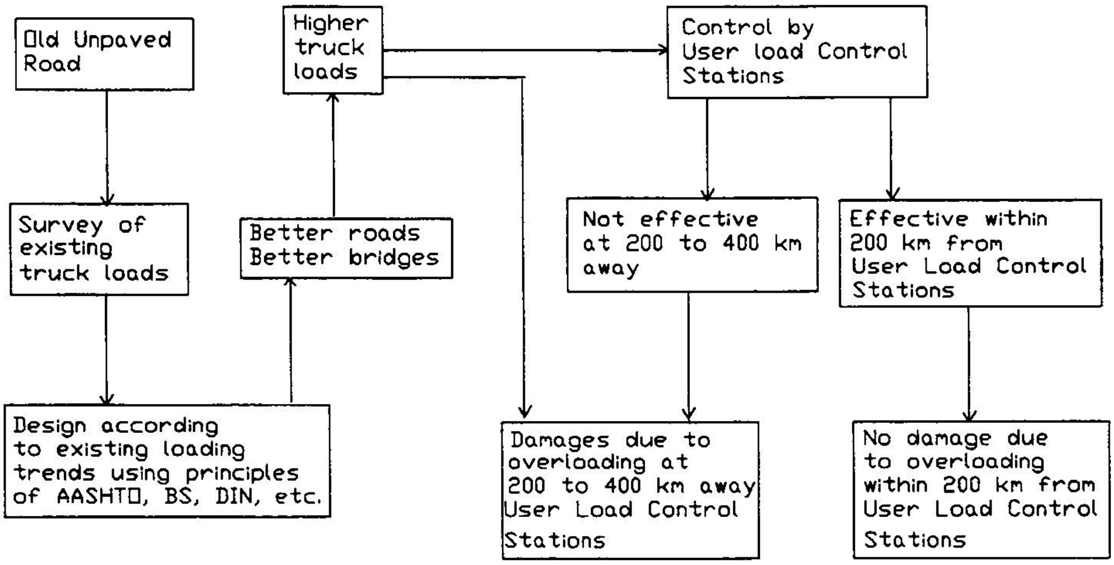

Fig. 5. Chart summarising the relation of design loading, user response and load control.

In this particular case, the increase was from a maximum of 40 ton truck loads expected during the upgrading to more than 90 ton truck loads at present in the normal daily traffic. The solution to the expected increase of truck axle loading capacity was to install user-load-control points.

5.2 Effectiveness of User-Load-Control Points

It is seen from the results in Fig. 4 that bridges with large cracks are concentrated at a distance of between 200 to 400 km from the two user-load-control weighing bridges. This shows that the control of truck axle loads at the user-load-control points benefits structures of up to a distance of 200 km on TanZam highway. For distances further than 200 km, there is not much influence of the truck axle load control done at the user-load-control points. The influence of user-load-control points is also illustrated by the graph shown in Fig. 6 below.

The concentration of damages on bridges located at a distance between 200 and 400 km along the TanZam highway is attributed to the intermediate truck traffic whose axle loading could not be controlled. This intermediate traffic is confirmed by the fact that trucks with high axle load capacity shown on the table in Fig. 1 move on this highway and road users naturally tend to move as much load as the truck can carry when there is no control.

Therefore risk of overloading the bridges increases in proportion to the distances of bridges from the user-load-control points, especially in the region beyond the influence of the user-load-control points.

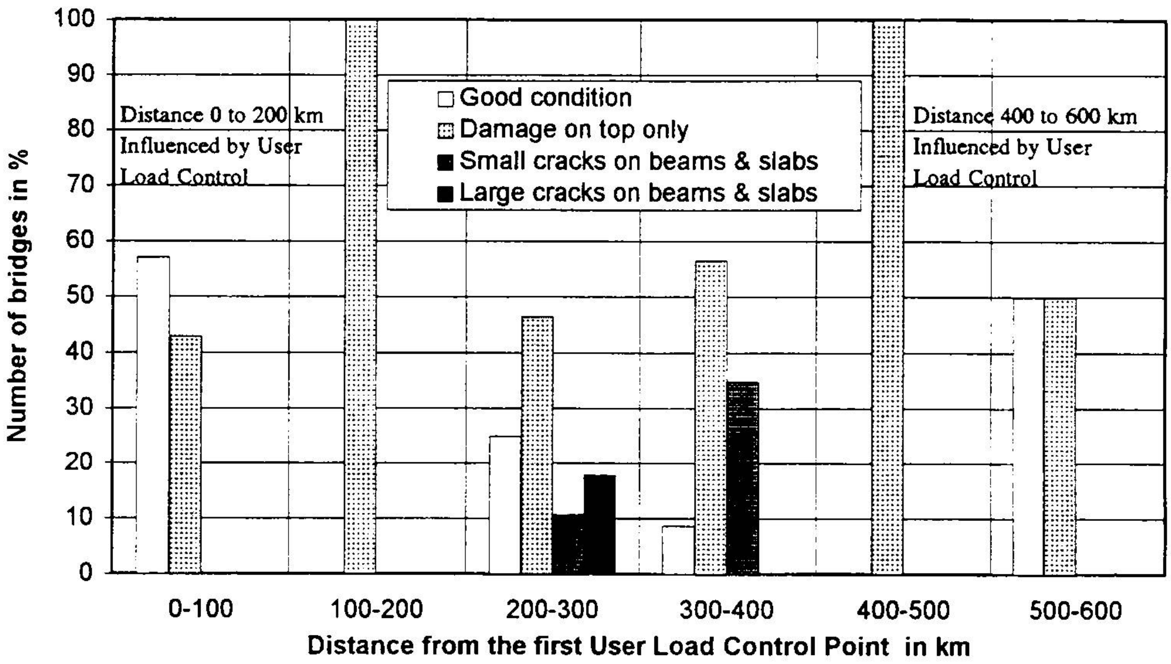

Fig. 6. Distribution of bridge damages on the 600 km road length.

5.3 Eurocode 1 on Bridges for Restricted Weight of Vehicles

Eurocode 1 part 3 [3] specifies in section 4.1 that, "for bridges to be equipped by appropriate road signs intended to limit strictly the weight of any vehicle, specific models may be defined or authorised by relevant authority". But the specific load models will tend to assume reduced design loads for all bridges on the entire road with restricted vehicle weights. Therefore, it is suggested from the results of this investigation that it is essential to add a statement to section 4.1 of Eurocode 1: Part 3 that the specific models have also to consider the effectiveness, to each bridge, of the control measures taken to limit the vehicle weights on the road and to appropriately increase the design loading for bridges which might be beyond the influence of the load control measures.

6. Conclusions

The results of the investigation indicate that overloading on RC bridges was apparently severe the further the RC bridges were away from the user-load-control points intended for the purpose of limiting the traffic load. This was due to intermediate traffic which could not be controlled by the weighing bridges.

The results show also that availability of better roads and bridges increased the utilisation from expected 40 ton truck loads during design to more than 90 tons at present. In addition, RC bridges with larger spans tended to show greater deterioration due to overloading than those of smaller spans.

Therefore, the aspects of traffic loads listed above should be considered in future design of bridges on roads under similar circumstances. That means safety factors should therefore be increased in proportion to the risk of overloading instead of applying a uniform reduced value to all bridges on the specific road. For example, in this particular case, the safety factors values could be increased in proportion to the distances of bridges from the user-load-control points.

Acknowledgement

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References

[1] American Association of State Highway and Transport Officials (AASHTO), *Standard Specifications for Highway Bridges*, Washington D.C., 1977.

[2] Ministry of Communications and Works, *Engineering Design of Bridges*, Dar es Salaam, 1990.

[3] Eurocode 1, *Basis of Design and Actions on Structures - Part 3: Traffic Loads on Bridges*, CEN, Brussels, 1993.