MODELING THE BEHAVIOUR OF A BRIDGE UNDER LOAD OBSERVED THROUGH TOPOGRAPHICAL METHODS

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Abstract. Bridges are works of art whose exploitation must be carried out under conditions of complete safety. Most of the bridges in this country were built in the past century. As a result, works are needed to obtain information about the degree of stability of the analyzed bridge and to identify the measures that must be adopted to ensure its safe operation. This paper presents aspects regarding the study of the behavior of a road bridge in order to determine the solutions so that it can continue to be used safely.

Keywords: topographical methods, construction monitoring, behaviour modeling.

INTRODUCTION

Bridges - works of art - provide passage over (a watercourse, a valley, a strait, communication routes). Their use must be carried out in complete safety conditions. When the bridge is located in a town, it is even more necessary to monitor the conditions in which the traffic takes place, given the increased traffic intensity.

Fig. 1 Location of the studied bridge

The studied bridge (Fig. 1) was made out of monolithic reinforced concrete 6-7 decades ago. It has a total length of 17.5m, with two openings of 7.25m each. The superstructure, made with four beams over which the slab was cast, rests on two concrete abutments and one concrete pier. The bridge has two traffic lanes and is 6.5m wide.

At the lower part of the beams, towards the right bank, the covering layer is destroyed and the reinforcements are visible (Chira et al., 2014). The slab has portions with a macroporous appearance and surface aggregates, and the unevenness of the asphalt layer leads to water stagnation on the bridge.

In order to assess the state of the bridge and establish measures to ensure safe operation, observations were made regarding the vertical movement under static loads and under dynamic loads also to determine some dynamic characteristics.

The paper presents the modeling of the behaviour of the bridge under static loads, using the elevation values determined by precision geometric leveling.

MATERIAL AND METHOD

Observations in the field were carried out using the precision geometric leveling method. A KoNi 007 type level and mire with invar tape was used.

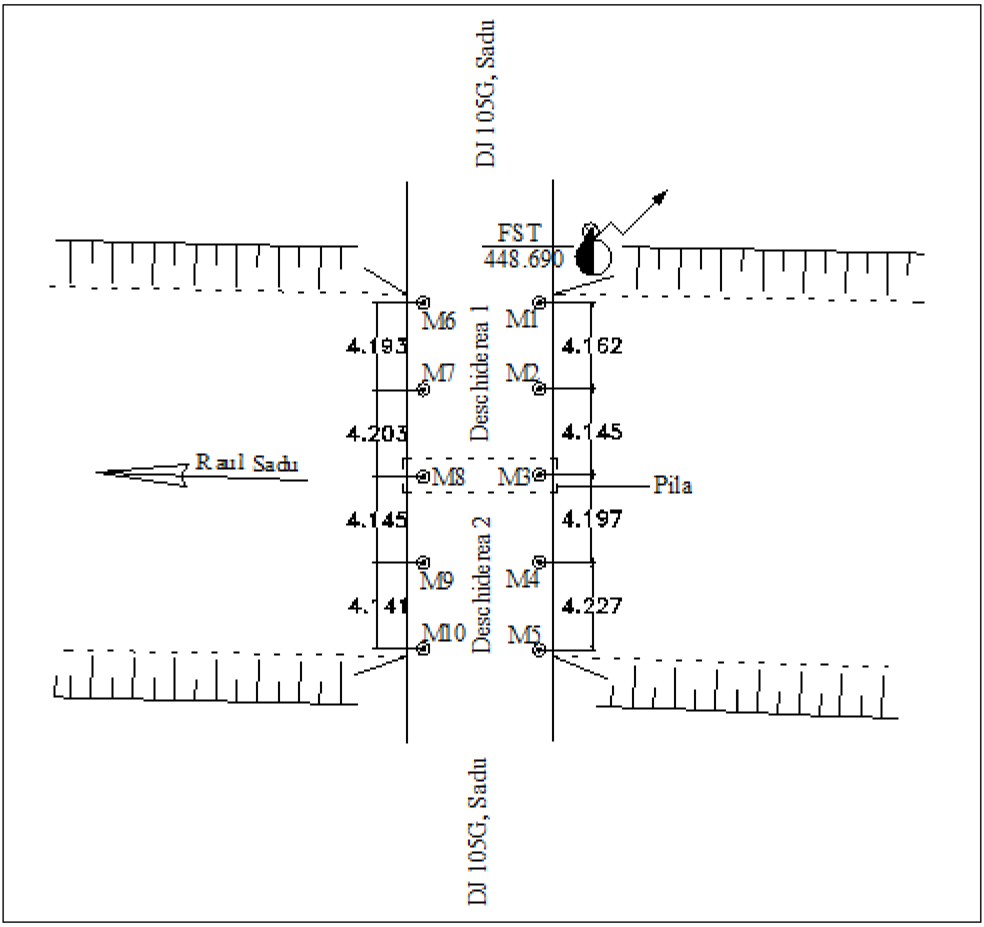


Fig. 2 Location of the measured points

The measured points (M1-M10) were materialized from metal nails embedded in the bridge slab, and the landmark located near the bridge was used for reference (Fig. 2).

The measurements were performed with the same instrument and under the same conditions in the three distinct stages (Arsene et al., 2016):

I. no load;
II. under static load of 30t on the first opening;
III. under static load of 30t on the second opening.

Data processing was carried out rigorously, using the method of the smallest squares.

RESULTS AND DISCUSSIONS

After rigorous processing, the elevation value of each measured point was determined for each measurement stage. The results obtained are shown in Table 1; Table 1 also shows the values of the distances between the control marks, measured on each side of the bridge.

Table 1

ELEVATION ESTABLISHMENT SHEET Objective: The bridge over the Sadu river, DJ 105G km 20+500 Reference landmark: Foundation St. el = + 448.69000					
crt. no.	Landmark or mark name	Distance between points [m]	Point elevation:		
			no load [m]	under load on the first opening [m]	under load on the second opening [m]
	F_{ST} reference		448.69000	448.69000	448.69000
	East side				
1	M1		448.68286	448.68333	448.68329
2	M2	4.162	448.71986	448.71940	448.71948
3	M3	4.145	448.76292	448.76203	448.76212
4	M4	4.197	448.81705	448.81676	448.81661
5	M5	4.227	448.85512	448.85404	448.85361
	West side				
1	M6		448.71219	448.71197	448.71221
2	M7	4.193	448.75542	448.75490	448.75542
3	M8	4.203	448.78786	448.78767	448.78793
4	M9	4.145	448.83165	448.83154	448.83139
5	M10	4.141	448.87766	448.87766	448.87775

The *TableCurve 2D* program was used for modeling. The input data for each point was taken in the following order: determination without load, determination with static load on the opening opposite the location of the point, determination with static load on the opening on which the point is located.

Running the program results in a list of regression equations. From this list, the equation with the value of the coefficient of determination r^2 must be chosen (expressed as a percentage, it indicates the percentage in which the respective equation explains the variation of the dependent variable) close to 1 (greater than 0.95 for a 95% confidence level), the graph of the function as close as possible to the movement graph and the values of the residuals to be distributed somewhat symmetrically with respect to the 0 value line and having a mean value close to 0; if the chosen equation does not simultaneously meet the conditions, another equation is sought that meets them all.

Regression analysis allows making predictions. The closer r^2 is to 1, the closer the estimated values are to the real displacement values (Arsene et al., 2020).

The process of choosing the regression equation is reproduced for point M9, located in the middle of opening 2, on the West side (Fig. 2). Fig. 3 shows the graph of the vertical movement of the point; in this diagram the elevation value is equal to 448m + the subunit part displayed on the vertical axis.

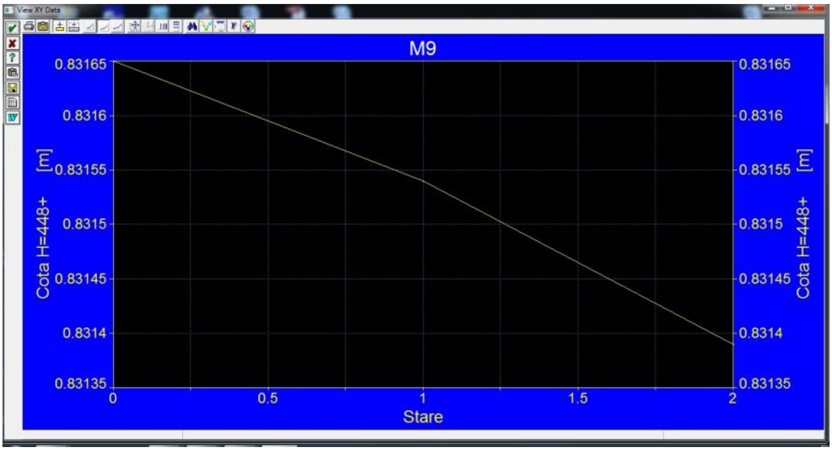
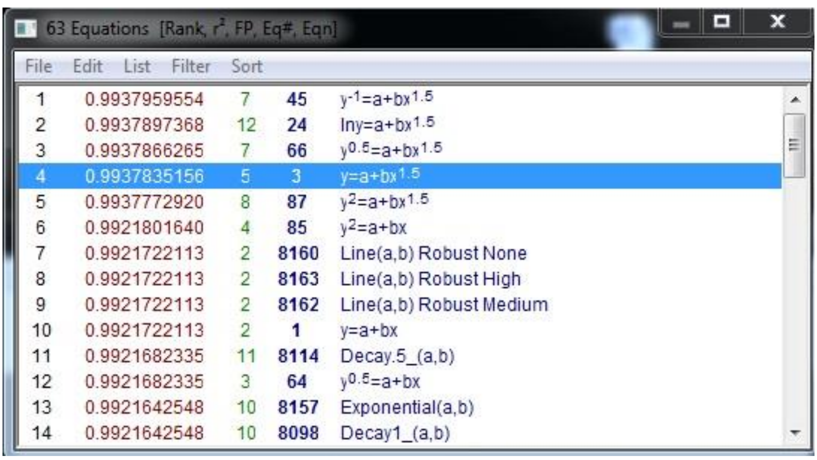


Fig.3 Vertical displacement graph of point M9

By running the program, the list of equations is displayed, in this case ordered by the value of the coefficient of determination r^2 (Fig. 4).



63 Equations [Rank, r², FP, Eq#, Eqn]

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1	0.9937959554	7	45	$y^{-1}=a+bx^{1.5}$
2	0.9937897368	12	24	$\ln y=a+bx^{1.5}$
3	0.9937866265	7	66	$y^{0.5}=a+bx^{1.5}$
4	0.9937835156	5	3	$y=a+bx^{1.5}$
5	0.9937772920	8	87	$y^2=a+bx^{1.5}$
6	0.9921801640	4	85	$y^2=a+bx$
7	0.9921722113	2	8160	Line(a,b) Robust None
8	0.9921722113	2	8163	Line(a,b) Robust High
9	0.9921722113	2	8162	Line(a,b) Robust Medium
10	0.9921722113	2	1	$y=a+bx$
11	0.9921682335	11	8114	Decay.5_(a,b)
12	0.9921682335	3	64	$y^{0.5}=a+bx$
13	0.9921642548	10	8157	Exponential(a,b)
14	0.9921642548	10	8098	Decay1_(a,b)

Fig. 4 List of regression equations for point M9

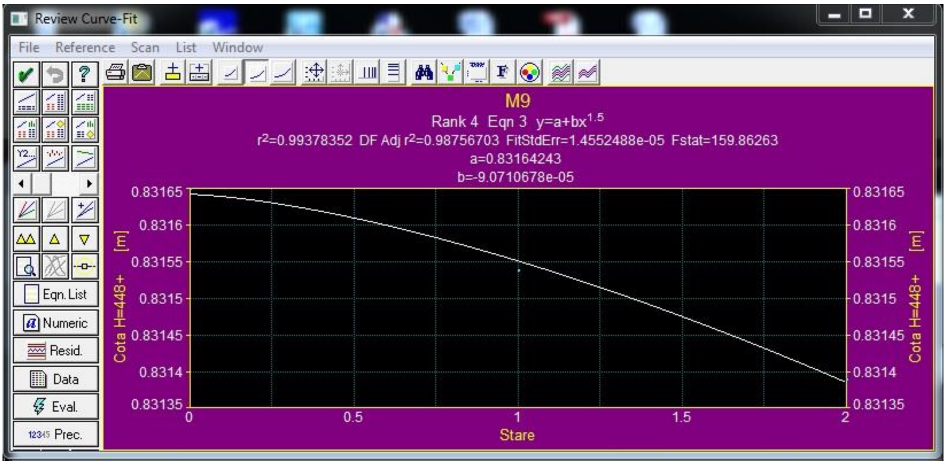

Fig. 5 The graph of the regression equation selected in the case of point M9

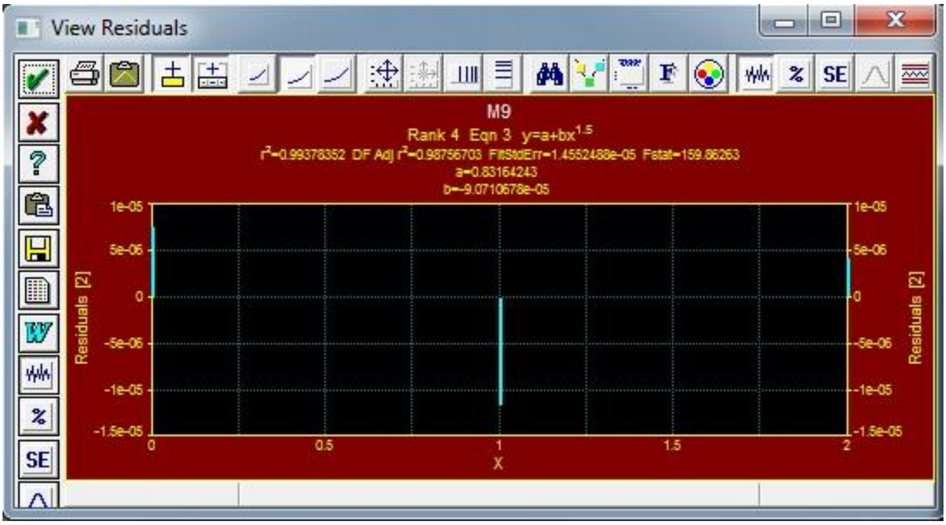

Fig. 6 Distribution of residuals for the selected equation in the case of point M9

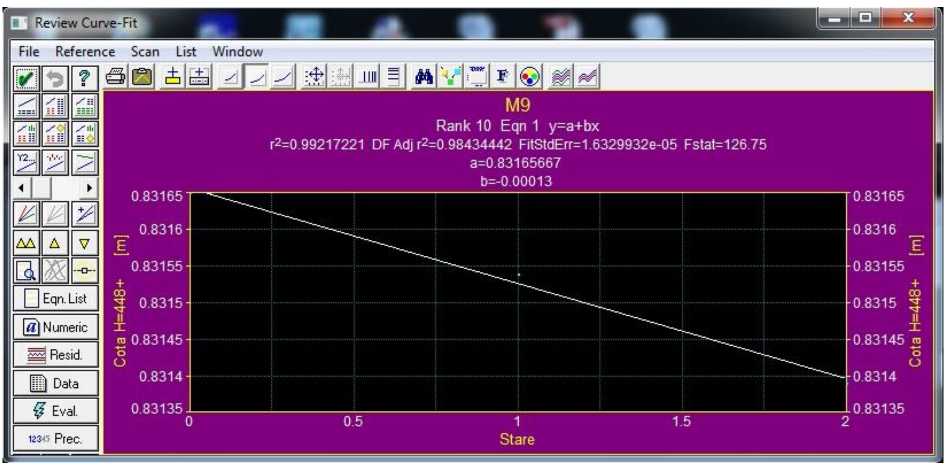

Fig. 7 The graph of the regression equation of rank 10 from the list of equations of point M9

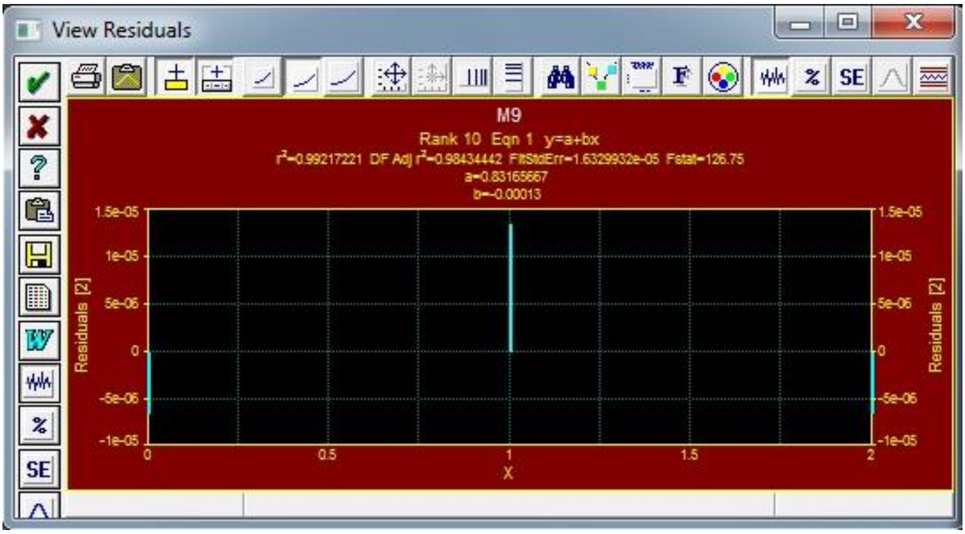

Fig. 8 Distribution of residuals for the regression equation of rank 10
from the list of equations of point M9

Table 2

The regression equations for the measured points

Point	Vertical Movement		Point	Vertical Movement	
	Regression equation Coefficient value: *a* *b*	Parameters: coefficient of determine. r^2 *F* statistical Standard deviat		Regression equation Coefficient value: *a* *b*	Parameters: coefficient of determine. r^2 *F* statistical Standard deviat
M1	$y=a+be^{-x}$ *a=0.683446765* *b=-0.0005723*	*0.9657865276* *28.22825221* *6.816296e-05*	M6	$y= y=a+bx^{3}$ *a=0.712213333* *b=-3e-05*	*0.9642857143* *26.999999994* *3.559026e-05*
M2	$y=a+be^{-x}$ *a=0.719306145* *b=0.000546538*	*0.9901553566* *100.57808259* *3.448526e-05*	M7	$y=a+bx^{2}lnx$ *a=0.75542* *b=-0.00018755*	*1.000000000* *9.841448e+12* *1.353406e-10*
M3	$y=a+be^{-x}$ *a=0.76181602* *b=0.00107898*	*0.9710799347* *33.578068483* *0.0001178285*	M8	$y=y=a+bx^{2}lnx$ *a=0.787895* *b=-8.1152e-05*	*0.932320442* *13.775510209* *4.949747e-05*
M4	$y= a+be^{-x}$ *a=0.816556965* *b=0.000498335*	*0.993763579* *159.348379* *2.498115e-05*	M9	$y=y=a+bx^{1.5}$ *a=0.831642426* *b = -9.0711e-05*	*0.9937835156* *159.86262636* *1.455249e-05*
M5	$y= a+be^{-x}$ *a=0.853385608* *b=0.001738393*	*0.9997063491* *3404.4036944* *1.885351e-05*	M 10	$y= y=a+bx^{3}$ *a=0.877654474* *b = 1.18421e-05*	*0.9868421053* *75.000000035* *8.429272e-06*
			M 9*	$y=a+bx$ *a =0.831656667* *b = -0.00013*	*0.9921722113* *126.7499999* *1.632993e-05*

The rank 4 equation was selected from the list, which simultaneously fulfills the three conditions:

- the value of the coefficient of determination r^2 greater than 0.95 (Fig. 4);
- the function graph as close as possible to the displacement graph (Fig. 5);
- the residuals distributed symmetrically with respect to the line of value 0 and the value close to 0 (the maximum value is $1x10^{-5}$) (Fig. 6).

In Fig. 4 it can be seen that a simple linear equation also appears in the list - the equation of rank 10, whose coefficient of determination r^2 is greater than 0.95 (lower by only 0.001611304 compared to that of the selected equation), but its graph (Fig. 7) is not similar to the result based on the measurements made (Fig. 3), and the residuals (Fig. 8) are higher than in the case of the selected equation (Fig. 6).

The regression equations selected for each of the measured points are presented in Table 2; the points are ordered on each side, and for point M9 the linear equation of rank 10 is also presented.

CONCLUSIONS

Establishing the degree of operational safety of a bridge is particularly important, given that most of these works of art were built more than half a century ago.

The specialized research done to identify the real conditions and parameters in which the bridge operates, provides information for the adoption of effective measures to ensure its safe operation.

Modeling the behaviour of the bridge under static load, based on data from topographical observations, offers the possibility of making predictions regarding the mode of operation of the bridge over time under operating conditions similar to those at the date of data collection. The appearance of disruptive external factors (tectonic accidents, earthquakes, corrosive agents, etc.), require the redetermination of the parameters and operating conditions of the bridge and the adoption of new measures, adapted to the new situation.

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