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CONSIDERATIONS ON LOADS TRANSMITTED BY THE BRIDGE INSPECTION INSTALLATION ON SUPPORT STRUCTURES

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Abstract

The inspection of bridges is an essential activity to maintain the viability and safe operation of these structures. The inspection process shall be carried out by visual means using special equipment called bridge inspector. The equipment is similar in design to mobile crane installations – crane lorries, with the rotating part in the form of a boom at the end of which is the work platform for personnel and tools. The structure of the arm has the shape of a lattice girder or beams with closed section (caisson); regardless of the type of construction there is at least one telescopable section. During use, the installation is positioned on the superstructure of the bridges, supporting it by means of folding or telescopic outriggers.

Starting from the determination of the loads on the supports of a crane, loads necessary to ensure the stability, in the case study presented in the paper, the authors identify for bridge inspection equipment the value of the loads transmitted through the support system for different positions of the telescopic arm. These values are of interest when, due to space or omission, the outriggers of the installation are positioned on sidewalks or degraded structures and may cause loss of stability leading to technical damage (of the installation and the bridge) but also possible injuries to workers.

Keywords: bridges, cranes, bridge inspector, outriggers.

1. INTRODUCTION

The bridge - concrete construction meant to ensure the connection of a communication route over an obstacle, also called a work of art, bridges are in fact constructions that connect people. Starting from these concepts, it is self-evident the importance of each phase that contributes to the creation and maintenance of a bridge in operating conditions from the yet design, construction and maintenance phase in order to maintain its corresponding technical parameters and service life.

In Europe and beyond, bridges inspection is organized at network level to ensure that structures are safe and can be maintained in good condition by maintenance work. Manner in which the monitoring and evaluation of the viability of the bridges is carried out are established by norms and laws specific to each nation, not being a unitary standard adopted at Community level (UE). The unification of standardization in Eurocodes for new constructions has been achieved and is adopted by all EU member states. Thus, in Eurocode 2 (concrete), 3 (steel) and 4 (composite structures), materials used in the construction of bridges, part 2 of each of them focuses on the evaluation of new bridges [8].

In Romania, the inspection is carried according to the Methodology contained in document AND 522-2017, the type of works being established based on the normative AND 554 - 2002. Along with the main purpose of these bridge inspection operations, based on global regulations, the requirement to update the BMS (Bridge Management System) database is also identified, the inspections being performed at fixed intervals, but also after the occurrence of important events at the structural level or natural disasters.

2. BRIDGE INSPECTION

2.1. Literature review

The current methodology for inspecting bridges is visual, with specialized personnel and using measuring equipment: portable laser rangefinder, indoor-outdoor thermometer, etc. and control: cracking meters, lead wire, concrete mixer, Turner-sclerometer, as a result of which defects and / or degradation of the structure are identified. Access to lower part of the bridge is made with a special

vehicle, called a bridge inspector, equipment designed to carry workers during inspections, but which is also used for light maintenance work, such as cleaning and painting operations. Although it is a safe method, the implications on costs, specialized personnel, access difficulties but mainly the fact that the identification can be done only after the degradation reaches the surface of the construction elements, extensive research programs dedicated to modern concepts to optimize maintenance and intervention have been developed worldwide [6].

The research direction focused on several criteria such as the creation of new systems such as SHM (Structural Health Monitoring), monitoring and inspection operations in which the influence of the human factor to be minimized, but also the possibility of integrating new technologies in performing inspections (robotic equipment, computer systems and unmanned aerial vehicles -UAV). In the work [14] the robotic inspection system proposed by the authors consists of three main components: a custom truck, a mobile robot mechanism that takes pictures with the entire area of interest and software that automatically associates these images with the CAD model of the bridge. The result of the inspection is generated by the software in the form of a report describing the technical parameters at the time of the inspection, the intervention requirements and an overview of the inspections carried out so far with it.

T. Whitley et al. in [15] presents the level of development of a UAV, intended for bridge inspection, equipped with a hardware system and which includes laser rangefinders, optical flow sensors and live video telemetry, the advantages of their use being documented in [7] by S. Dorafshana and M Maguireb. The authors' remark is that the potential for using UAVs for bridge inspections and that can work automatically will improve with the development of location and mapping solutions in a location without GPS signal, with the possibility of combining the sensors used with different types of algorithms, navigation, as well as the application of data fusion techniques in the processing of collected data. Specifically, the use of UAVs for inspections at bridges depends on solving three fundamental problems: mapping, location and route planning.

2.2. Bridge inspector structure

The equipment for inspecting bridges, Figure 2.1, consists of a movable arm 1, auto chassis 2, superstructure 3, outriggers 4 and work platform 5. The car is a motor vehicle, which meets the requirements for traveling on public roads; equipment for inspecting bridges mounted on a road-machine must be in dimensional and energetic accordance with it, so that in the transport position it falls within the permissible dimensional limits and in the working position to ensure safe operation. The mobile boom is a metal construction made up of sections, with the structure shape in the form of a lattice girder spatial or beams with closed section (caisson) type construction, with hydrostatic drive. The superstructure is fixed on the chassis, supporting the drive and rotation mechanisms, and at the bottom are mounted the four outriggers. The outriggers aim to ensure a good stability of the whole installation, so that during function the stresses on axles, suspensions and tires are as low as possible. The stabilization system can be telescopable or folding, constructive solutions that ensure the increase of the dimensions of the support polygon in order to improve the stability in use of the installation.

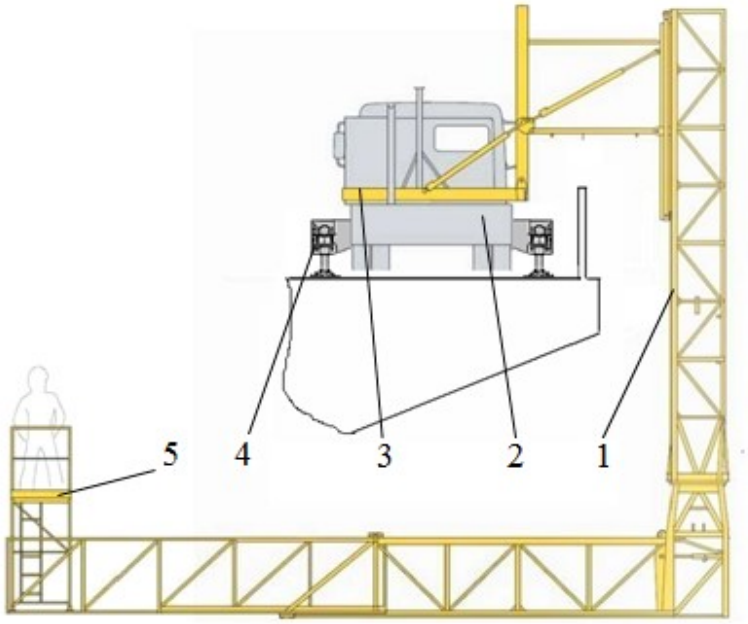


Figure 2.1. Bridge inspector equipment [17]

3. DETERMINATION OF SUPPORT LOADS

The equipment for inspecting bridges is similar to the mobile crane. While at lifting installations, knowledge of the loading on the supports is necessary for calculating and the sizing of the supports but and for checking the support holder, at equipment for bridge inspection knowledge of these charges is useful to personnel when working on a bridge that has supporting structure degradation or structure whose load resistance for load bearing is reduced such as sidewalks.

Referring to the lifting installations, these being equipment that are part of a field regulated by specific laws (which also includes the bridge inspector) due to the high potential to cause accidents with adverse consequences by loss of stability (human losses, materials, time resources, etc.), we encounter a rich literature as a result of research conducted around the globe. As a result of this research, multiple computer programs were created to choose the optimal version of the crane, based on a lifting plan prepared by specialists, so that the installation meets all safety criteria in operation, including in terms of stability.

Thus, in the paperwork [13] the authors present the improvement of the previously developed program in which the load values of the stabilizers are automatically determined based on algorithms that perform simulations for all types of cranes introduced in the program from the existing range on the market. The developed program automatically analyses the maximum ground contact load of the stabilizers, determining its necessary characteristics, of the support plates of the outriggers to ensure the stability of the crane but also the load-bearing capacity necessary for the ground for a certain an installation.

In the analysed works [10], [16] regarding the calculation of stability for mobile cranes (mobile cranes, truck-mounted cranes) the distribution of loads on the support of the rigging is conventionally adopted, according to the scheme in figure 3.1., distribution being at a slope of 1: 1.

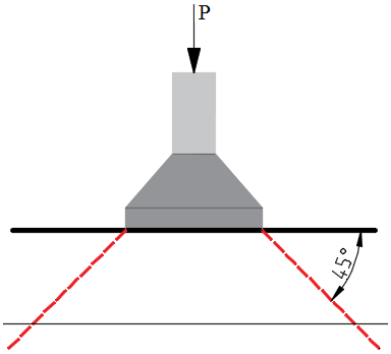


Figure 3.1. Distribution of concentrated loads in stabilizers

Also, the size of the loads in the stabilizers depends on the mass of the basic machine, the arm, the load and the angle of orientation of the arm. By rotating the arm, changing the position of the centre of gravity will vary, also the load on the supports coming from the vertical forces. Horizontal forces (wind action, inertial forces) are creating a moment of overturning M_H acting in the vertical plane of the arm and which can be broken down into two components. Regardless of the size of the loads on the supports, the stabilizers must not be supported directly on the ground. For contact with the ground, wooden supports (wooden sleepers) or steel plates are used. In order to determine the dimensions of the support made of wooden sleepers, the calculation is performed in stages, starting with the adoption of the number of sleepers which results in the width of the support (the section of sleepers is known) [2], [5]. The pressure applied to the soil q is determined by the relation (3.1.).

$$q = \frac{P}{b \cdot c} \tag{3.1.}$$

Thus, considering the known load-bearing capacity of the soil, the minimum area of the support that must satisfy the relation is determined (3.2.).

$$A_{\min} = \frac{P}{q} \tag{3.2.}$$

The result is the length of the support sleepers:

$$c = \frac{A_{\min}}{b} \tag{3.3.}$$

The wooden cross members are checked at the bending and shearing request, because the timber sleepers can be exfoliated at transverse stresses. The bending moment of a timber crossbar is calculated with the relation:

$$M_{\hat{i}} = \frac{qba^2}{2} \tag{3.4.}$$

For a number of *n* sleepers, the bending stress is calculated with the relation:

$$f_{\hat{i}} = \frac{3qa^2}{d^2} \tag{3.5.}$$

The dimensions of the support are satisfactory if $f_{\hat{i}} \leq f_{ad}$ of the support material (timber). Otherwise, the support is resized so that the bending and shear stresses are checked. Shear stress is calculated by the expression (3.6.)

$$\tau = \frac{1.5qa}{d} \tag{3.6.}$$

where: P – maximum outrigger load;

a – distance from the edge of the outrigger to the edge of the sleepers in the longitudinal plane

b – the width of the support;

c – the length of the sleepers;

d – the height of the sleepers.

Just as for the bending moment, the calculated shear stress $\boldsymbol{\tau}$ must be less than the permissible shear stress of the material used for the support (timber). Similarly, if $\boldsymbol{\tau}$ exceeds the allowable shear stress, the support should be resized.

Steel plates can also be used for stabilizer supports. Since the width $\boldsymbol{b}$ of the support in the case of a steel plate is not limited by a minimum, the bending stress must be checked in the two main directions using the equation (3.4). Equation (3.5.) shows that the moments in both directions will be equal and that the maximum design efficiency will be obtained when $b = c$ (square section). The shear strength shall not be checked in the case of steel plates. The maximum allowable bending stress may be the flow resistance value.

Determining the load on the four stabilizers is a statically undetermined problem, so to solve it is considered the absolutely rigid base frame and the transmission of moments is done by maintaining the flat shape.

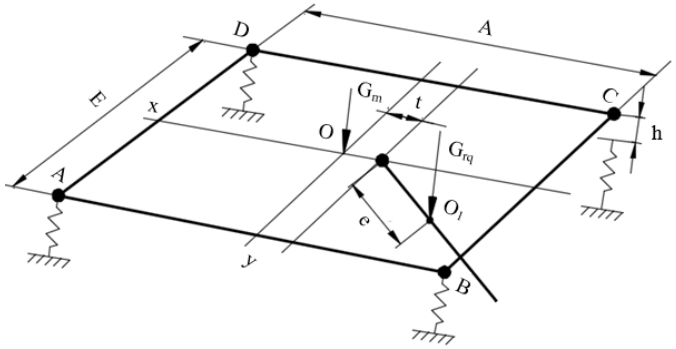


Figure 3.2. Scheme for calculating the loads on the supports of a crane [3]

The calculation for the determination of the loads on the outrigger, are made based on figure 3.2., uses the hypothesis that all the supports are elastic and under the action of the loads they are deformed, and one of the supports no longer in the same line as the other three [3], this being displaced by distance h against the horizontal plane of the other 3 outriggers.

The equation system of the 4 vertical loads under external forces are composed of 3 equations that can be identified in the plane of the outriggers and one compatibility equation determined based on elastic displacements. The compatibility equation is (3.7):

$$V_A + V_C - V_B - V_D = -\frac{h}{k} \qquad (3.7.)$$

in which

h – displacement of an outrigger the others' plane;

k –elasticity coefficient of the outrigger.

The elasticity of the outriggers is considered through the elasticity coefficients ($k = k_c + k_m$, k_c being the roadway elasticity coefficient, and k_m is the elasticity coefficient of the equipment's frame). the elasticity coefficient represents vertical elastic deformation under unit force.

The condition for keeping the planar shape of the frame is:

$$kV_A + kV_C - kV_B - kV_D = h$$

Based on this presumption, the calculation for vertical loads is given by the relations (3.8.):

$$V_A = \frac{G_m + G_{eq}}{4} + \frac{G_{eq}}{2} \cdot \left(\frac{e}{E} \cdot \sin\varphi - \frac{e}{A} \cdot \cos\varphi - \frac{t}{A} \right)$$

$$V_B = \frac{G_m + G_{eq}}{4} + \frac{G_{eq}}{2} \cdot \left(\frac{e}{E} \cdot \sin\varphi + \frac{e}{A} \cdot \cos\varphi + \frac{t}{A} \right)$$

$$V_C = \frac{G_m + G_{eq}}{4} - \frac{G_{eq}}{2} \cdot \left(\frac{e}{E} \cdot \sin\varphi - \frac{e}{A} \cdot \cos\varphi - \frac{t}{A} \right) \qquad (3.8.)$$

$$V_A = \frac{G_m + G_{eq}}{4} - \frac{G_{eq}}{2} \cdot \left(\frac{e}{E} \cdot \sin\varphi + \frac{e}{A} \cdot \cos\varphi + \frac{t}{A} \right)$$

where:

$V_A; V_B; V_C; V_D$ - loads on the four supports, respectively A, B, C, D; G_m – the weight of the basic machine acting in the centre of the bearing surface; G_{eq} – weight of revolving part (boom) and load; t – the position of the rotational axis relative to the centre of the support surface; e – the position of the centre of gravity of the rotating part (boom) and the load in the platform; φ – the orientation angle of the rotating part; A – horizontal distance between outriggers - wheelbase; E – transverse distance between outriggers – track gauge; h – the vertical displacement of a support relative to the plane of the. The additional load on supports given by the moment M_H has the expression (3.9):

$$\Delta V = \pm \frac{M_H \cos\varphi}{2 \cdot A} \pm \frac{M_H \sin\varphi}{2 \cdot E} \qquad (3.9.)$$

The „±” marks correspond the moment signs $G_{eq} e \cos\varphi$, respectively $G_{eq} e \sin\varphi$.

According to the mentions in the specialized literature, as well as from the above relations, it is observed that the value of the loads on an outrigger is directly proportional to the position of the boom, fact illustrated in the gaff in the figure 3.3. The graph was made for a value of the angle of orientation of the boom between $\varphi = (0...2\pi)$ on the stand in the laboratory of Lifting Machinery of the Faculty of Technological Equipment.

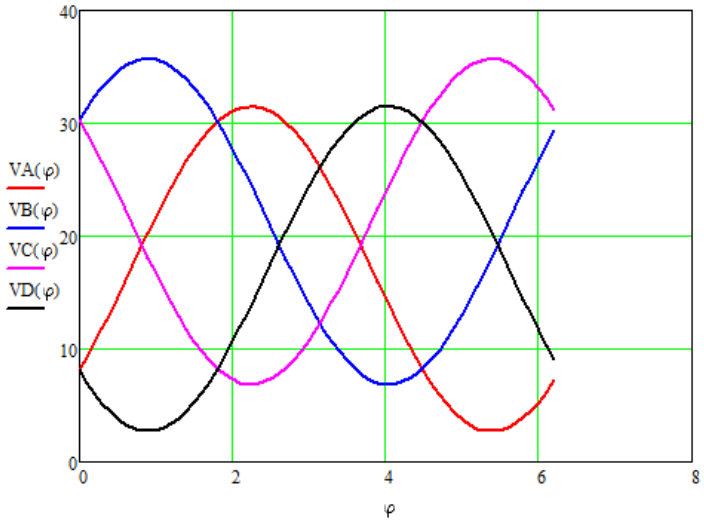


Figure 3.3. Graph of variation of loads on crane supports

4. CASE STUDY. DETERMINATION OF LOADS ON THE OUTRIGGERS OF A BRIDGE INSPECTOR

At the place of use, the bridge inspector is put into working configuration starting with the extension and securing of the stabilizers and the installation. Normally, the positioning is done on the road, this desideratum being dependent on several aspects: dimensions of the boom section and dimensions of the road. Many times, when the traffic way is narrow, the positioning of the stabilizers is on the pavement, which could pose a safety problem for workers and also for these structures, with additional concentrated demands being introduced. The case study will be performed using the working configurations of a bridge inspector, based on which the loads calculation schemes on outriggers are established, figure 4.1.

In order to perform the calculation, the following hypotheses were adopted:

- the mass of the boom for the two sections (vertical and horizontal) is evenly distributed along the length;
- loads of the action of the wind are neglected;
- inertial forces are neglected;
- the values of the loads given by the vehicle are taken into account without dynamic coefficient, this being at rest.

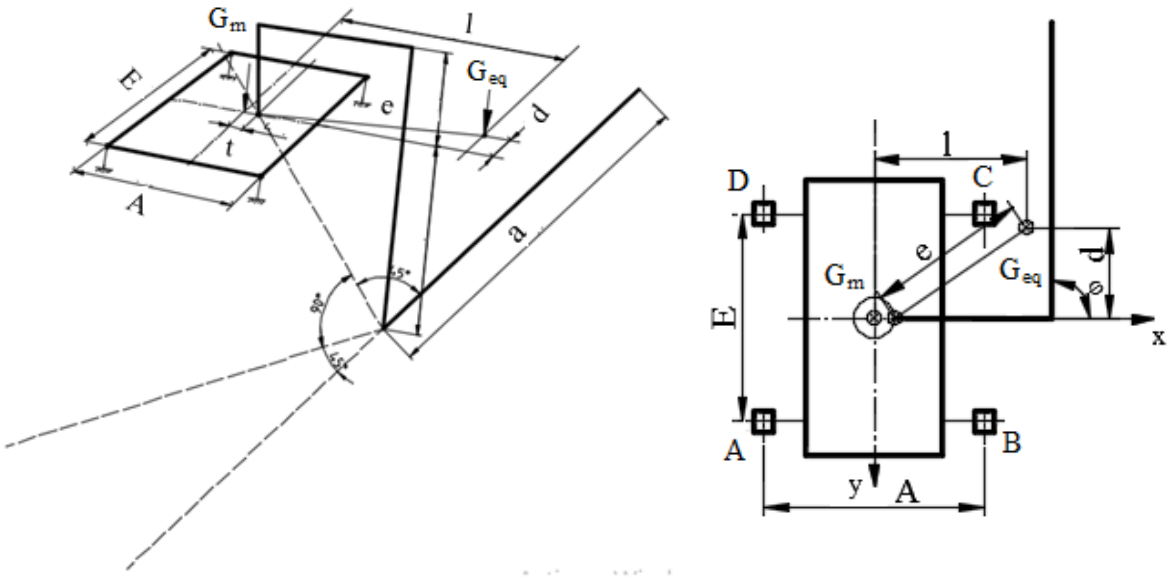


Figure 4.1. Scheme for calculating loads on outriggers

Geometrical and load bearing characteristics of the bridge inspection equipment for the case study are:

a = 18,0 m – Horizontal maximum reach;

b = 8,7 m – Maximum inspection reach in relation to the bridge platform;

c = 2.5 m – Occupied distance by the equipment on the bridge;

d = 2,5 m – Max distance to the bridge traverse – width of the sidewalk;

e = 3,5 m – Height over the sound barriers

G = 300 000 N – total weight of the equipment composed of:

$G = G_m + G_{eq}$ where G_m is the machine weight, and G_{eq} inspection equipment weight, including the 2 operators in the nacelle. Calculated values in the study are determined based on the presented hypotheses giving the following values:

G_m = 230 000 N

G_{eq} = 70 000 N

The positioning of these loads on the diagram is represented in the centre of mass determined for the machine, respectively for the inspection equipment (figure 4.1.)

The results obtained for the loads in the outriggers of the bridge inspector, for different positions of boom orientation are given in the table 4.1.

Table 4.1. Loads value at outriggers

Loads at outriggers	Boom orientation angle φ		
	$\varphi = \frac{\pi}{2}$	$\varphi = \frac{3\pi}{4}$	$\varphi = \frac{5\pi}{4}$
V_A	39980 N	43240 N	90690 N
V_B	116200 N	61310 N	108800 N
V_C	112000 N	108800 N	61310 N
V_D	35780 N	90690 N	43240 N

It is easy to see that the most loaded outriggers are the ones on which the arm is oriented and also transfer the load to the sidewalk of the bridge.

5. CONCLUSIONS

The calculation values obtained by using the methodology for determining the outriggers loads of the lifting installations confirm that the calculation hypothesis is also valid for the installations for inspecting bridges. The obtained results show that the most requested supports are those on which the arm is oriented. These values may be of interest when the positioning of the bridges is done on the sidewalks of the old bridges, given the calculation loads used in the design of these structures.

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