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ANALYTIC MODEL OF THE ROTATING HALF BRIDGE BELONGING TO A CIRCULAR SETTLING TANK

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The paper presents an analytic model of a rotating half bridge which is a complex structure under a complex state of loads. The theoretical model considers the rotating arm as a straight bar loaded by various forces which are bending the structure. The evaluation of the loads uses a computer based approach which is a fast, flexible, reliable and reusable calculus method. There were conceived several methods to verify the accuracy of the model using 'in situ' experimental measurements. Once the analytic model is calibrated, the according information regarding the supports, loads and material may be used to develop a numerical model of the rotating half bridge, which is already in progress.

Keywords: modeling, simulation, hybrid model, accuracy verification.

1. Introduction

The research topic is included in the set of problems which must be solved in the Constanta region which influence the Black Sea ecosystem, [1], the structure under investigation being operated at Constanta South Wastewater Plant. Studying the problems in this field, one can notice that advanced models were developed in order to explain the phenomena and to optimize the wastewater depollution processes [2], [3]. Moreover, the fluid mechanics phenomena regarding the flow of the wastewater and the separation in gravitational sedimentation tank were also studied using advanced models [4], [5]. Valuable information regarding the equipment employed for the wastewater treatment were also published, [6].

However, computer based modeling can offer a broader perspective regarding the interaction between the various effects involved in the analysis of the phenomena. Moreover, the creation of some computer based investigation

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instruments, [7], may lead to a more accurate model and they be developed to become automatic design instruments having artificial intelligence features. In addition, the same set of input data may be used for both analytic and numeric modelling. The knowhow behind this approach is presented in the following sections.

2. The structure to be investigated

The circular settling tank is an open basin employed for the gravitational separation of the sludge (at the bottom) and of the clarified water which is discharged in the launder which is mounted at the periphery of the tank - 2, fig. 1. In order to extract the sludge, a rotating bridge - 10, fig. 1, is employed to sweep the sludge to the middle of the basin and to vacuum and sent it to the central collector - 8, fig. 1. According to the main hypotheses employed in structural studies, the rotating arm has the length larger than the other dimensions, so it can be modelled using the beam theory.

Fig. 1. Components of a circular settling tank and the rotating bridge

As it can be noticed in the above figure, there may be identified several categories of loads. First we can notice the concentrated forces generated by the weight of: the set of scrapping blades – 3, the suction pipes – 4, the local sludge collecting chamber – 5, the sludge transporting horizontal pipes – 7. Next we notice the forces generated by the loads on the access bridge – 11 and by the Archimedes' forces produced by the floating barrels – 6. The weight of the main bridge – 10, may be considered an equally distributed force which loads the equivalent beam which models the rotating bridge. Other forces may be also considered, but in a first approximation let us consider only these types of forces.

3. The analytic model

The rotating bridge may be modeled according to the calculus scheme in the figure above, as a straight beam loaded by several concentrated forces and by equally distributed forces.

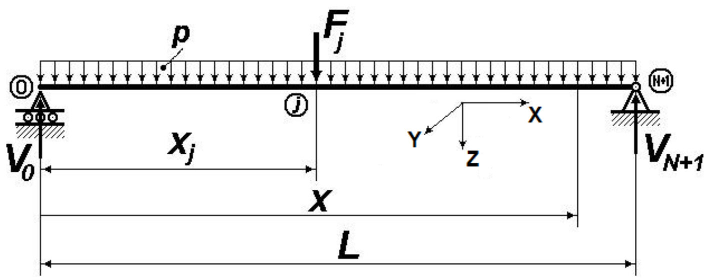

Fig. 2. Calculus scheme of the equivalent beam

All the F_j forces may be calculated using computer based geometrical models based on calculus schemes similar to those presented in the figure below.

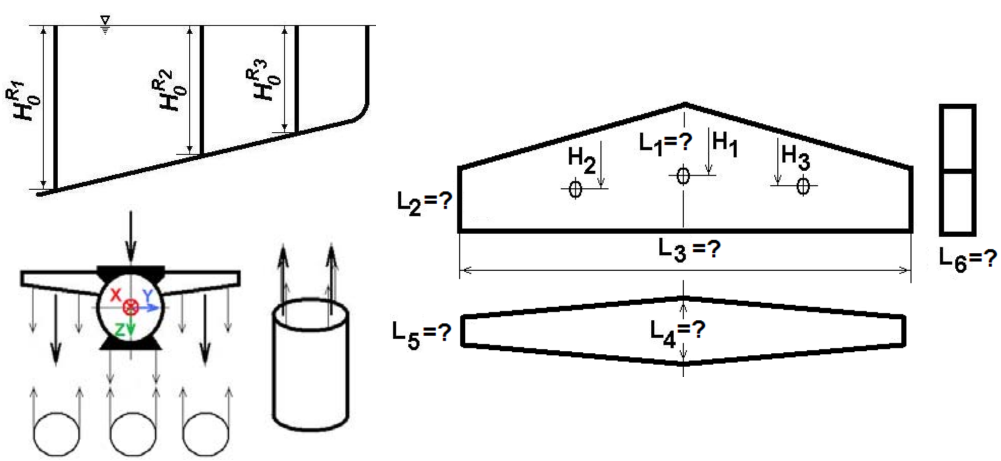

Fig. 3. Calculus schemes based on parameterized dimensions

The geometrical computer based models are very flexible because the dimensions are parameterized and connected one to the other, so we have a small volume of input data. Moreover, the input values are verified according to a certain range of values associated to each dimension: thickness of a metal sheet, diameter, aso.

The calculus scheme in fig. 2 may be used to calculate the reactions and the displacement along the beam using the method of initial parameters. Let us consider Heaviside's function expressed as:

$$H\left(x-x_j\right)=\begin{cases}0, \ x<x_j \\ +\dfrac{1}{2}, \ x=x_j \ , \ \forall x_j \\ +1, \ x>x_j\end{cases} \quad (1),$$

which can be used to express the laws of variation of the shear force and of the bending moment:

$$T_Z(x)=V_0\cdot x^0\cdot H(x)-p\cdot x\cdot H(x)-\sum_{j=1}^{N}F_j\cdot\left(x-x_j\right)^0\cdot H\left(x-x_j\right) \quad (2),$$

$$M_Y(x)=V_0\cdot x\cdot H(x)-p\cdot\frac{x^2}{2}\cdot H(x)-\sum_{j=1}^{N}F_j\cdot\left(x-x_j\right)\cdot H\left(x-x_j\right) \quad (3).$$

The differential equation of the neutral fiber in bending under the influence of the vertical forces is:

$$\frac{d^2u_Z(x)}{dx^2}=\frac{d\varphi_Y(x)}{dx}=-\frac{1}{E\cdot I_Y}\cdot M_Y(x) \quad (4),$$

which has the equivalent form

$$\left(E\cdot I_Y\right)\cdot\frac{d^2u_Z(x)}{dx^2}=\left(E\cdot I_Y\right)\cdot\frac{d\varphi_Y(x)}{dx}=-M_Y(x) \quad (5).$$

We integrate two times the above mentioned differential equation and it results the law of variation of the displacement along the beam:

$$\left(E\cdot I_Y\right)\cdot u_Z(x)=\left(E\cdot I_Y\right)\cdot u_{Z\,0}\cdot x^0\cdot H(x)+\left(E\cdot I_Y\right)\cdot\varphi_{Y\,0}\cdot x\cdot H(x)-$$
$$-V_0\cdot\frac{x^3}{6}\cdot H(x)+p\cdot\frac{x^4}{24}\cdot H(x)+\sum_{j=1}^{N}F_j\cdot\frac{\left(x-x_j\right)^3}{6}\cdot H\left(x-x_j\right) \quad (6).$$

where $u_{Z\,0}$, V_0 and $\varphi_{Y\,0}$ are the unknowns of the problem.

We set the following boundary conditions

1. $x=0 \ \Rightarrow \ u_Z=0 \ \Rightarrow \left(E\cdot I_Y\right)\cdot u_Z(x=0)=\left(E\cdot I_Y\right)\cdot u_{Z\,0}=0 \ \Rightarrow$

$$u_{Z\,0}=0 \quad (7);$$

2. $x=L \ \Rightarrow \ M_Y=0 \ \Rightarrow \ M_Y(x=L)=0 \ \Rightarrow$

$$V_0=\frac{p\cdot\dfrac{L^2}{2}+\displaystyle\sum_{j=1}^{N}F_j\cdot\left(L-x_j\right)}{L} \quad (8);$$

3. $x=L \ \Rightarrow \ u_Z=0 \ \Rightarrow$

$$\varphi_{Y0} = \frac{1}{(E \cdot I_Y) \cdot L} \cdot \left[V_0 \cdot \frac{L^3}{6} - p \cdot \frac{L^4}{24} - \sum_{j=1}^{N} F_j \cdot \frac{(L - x_j)^3}{6} \right] \quad (9).$$

This method also allows us to calculate the position of the section where the maximum displacement may be found, by solving the equation:

$$\varphi_Y(x) = 0 \quad (10),$$

which is basically a third order polynomial equation:

$$C_3 \cdot x^3 + C_2 \cdot x^2 + C_1 \cdot x + C_0 = 0 \quad (11),$$

the according coefficients being

$$C_3 = \frac{p}{6} \quad (12),$$

$$C_2 = \frac{1}{2}\left[\sum_{j=1}^{N} F_j \cdot H(x - x_j) - V_0 \right] \quad (13),$$

$$C_1 = -\sum_{j=1}^{N} F_j \cdot x_j \cdot H(x - x_j) \quad (14),$$

$$C_0 = \frac{1}{2}\sum_{j=1}^{N} F_j \cdot x_j^2 \cdot H(x - x_j) + (E \cdot I_Y) \cdot \varphi_{Y0} \quad (15).$$

The solution of equation (11) must be verified to be included in the current interval for which the equation was solved.

4. Design of the experimental study

First of all, it is important to evaluate the usefulness of an experimental study. As mentioned before, the theoretical studies have strong points, such as simplicity, relevancy of the quantities involved in the analysis, possibility to be easily implemented, possibility to be linked to other types of studies, and others. We must also admit that the theoretical studies are based on various simplifying hypotheses which generate errors. To avoid the apparition of the inaccurate results there must be used information given by the real behavior of the structure in order to accordingly adjust the theoretical model, [8]. Several variants of experimental studies were evaluated in terms of appropriateness, basically being a problem of weighting of a structure on wheels, [9]. Beside the strain gage technology, the capabilities of other experimental methods were also evaluated, [10], being finally decided that the strain gage technology is the most appropriate for ‘in situ’ measurements in running conditions.

We consider that the rotating arm is working in steady state conditions, being important that the experiment not to modify the real running conditions. Other objective is to have minimum costs of the experimental study, in this way being useful to use a minimum number of strain gages.

There were evaluated several possible locations of the strain gages. Finally it was decided that the measurement of the V_0 reaction, theoretically calculated using (8), is the best choice. Moreover, the measurement of the reaction may be done in static conditions using a hydraulic jack and in running conditions using a weighting platform which is placed between the wheel and the concrete border of the tank, fig. 1.

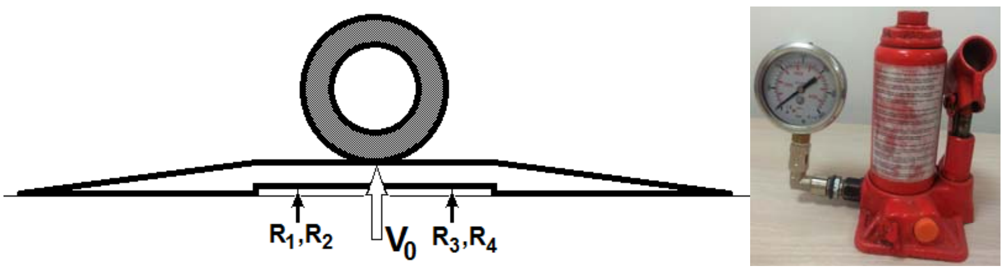

Fig. 4. Weighting device for measurements in running conditions and an original hydraulic jack for static measurements

The set of strain gages are located on the down most horizontal surface of the central plate, in this area being not reached by the moving wheel.

A condition formulated by the professionals who operate the equipment is that the height of the platform should not be over 40÷50 mm in order not to perturb the normal running conditions.

We consider that the central plate has the height h, width b, length L and the V_0 reaction is located in the middle section. In these conditions the both reactions are $0.5 \cdot V_0$, and the according bending moment which loads the plate is $M_Y = 0.25 \cdot V_0 \cdot L$.

In order to have a correct calibrated platform, suitable for the range of the V_0 reactions we consider that the measured signal is in a convenient range of values and we have to perform a reverse calculus in order to dimension the thickness of the measuring platform. Moreover, the platform must be loaded strictly in the elastic range of the stress-strain curve. Thus, the normal stress generated by the V_0 reaction is $\sigma = \frac{M_Y}{W_Y} = E \cdot \varepsilon$, where $W_Y = \frac{b \cdot h^2}{6}$ is the section modulus. Accordingly, the height of the central plate is: $h = \sqrt{\frac{3}{2} \frac{V_0 \cdot L}{b \cdot E \cdot \varepsilon}}$. Let us consider that the significant range of strains is 100-300 με, and for various values of L and b there may be computed the according values of the height h, with respect to V_0 which may be measured in static conditions using a hydraulic jack fitted with a pressure gauge. We are able to measure the dimensions of the hydraulic jack, i.e. 'D', the diameter of the piston on which the pressure is applied and the according force is $F = p \cdot \frac{\pi \cdot D^2}{4}$. The measurement of the V_0 reaction in static conditions should be done several times in order to have a trustful range of values.

There were performed several calculi, [8], and it results that $h \approx 25\ mm$ is an appropriate value for the measured strains are in the range $\varepsilon \in [100 \ldots 300]\ \mu\varepsilon$. However, for a theoretical mass of 2000 kg the according strain is about ~500 με, that is not a large value.

There must be noticed that there may be a larger range of values depending on the level of the water in the tank, the position of the floating barrels which apply the Archimedes' forces on the structure, the density of the wastewater, the temperature and others.

Taking into account these sources of inaccuracy it is rational to use the appropriate features of the parametric design in order to conceive the weighting platform. In this way we chose NX as the basic CAD application to be used for the design of the weighting platform. The main dimensions of the platform are declared 'parameters', as it is presented in the following figure. These parameters are related so the entire design may be modified by changing a few 'independent', so-to-say, parameters. The parameters are stores in 'csv' text files[5] which is a neutral format which can be used by various spreadsheet applications, including Excel. Moreover, being a text file any text editor may be used to modify the 'csv' file. However, our main objective is to modify the parameters according to an intelligent software application which computes the dimensions of the platform.

We have defined the following main parameters:

- the height of the central plate, h, is defined as the P8 parameter;
- the length of the plate, L, is defined as the P12 parameter;
- the width of the central plate, b, is defined as the P30 parameter.

Using the CAD model presented in the following figure it will be created a finite element model which will evaluate the analytic model of the platform.

[5] Comma separated value

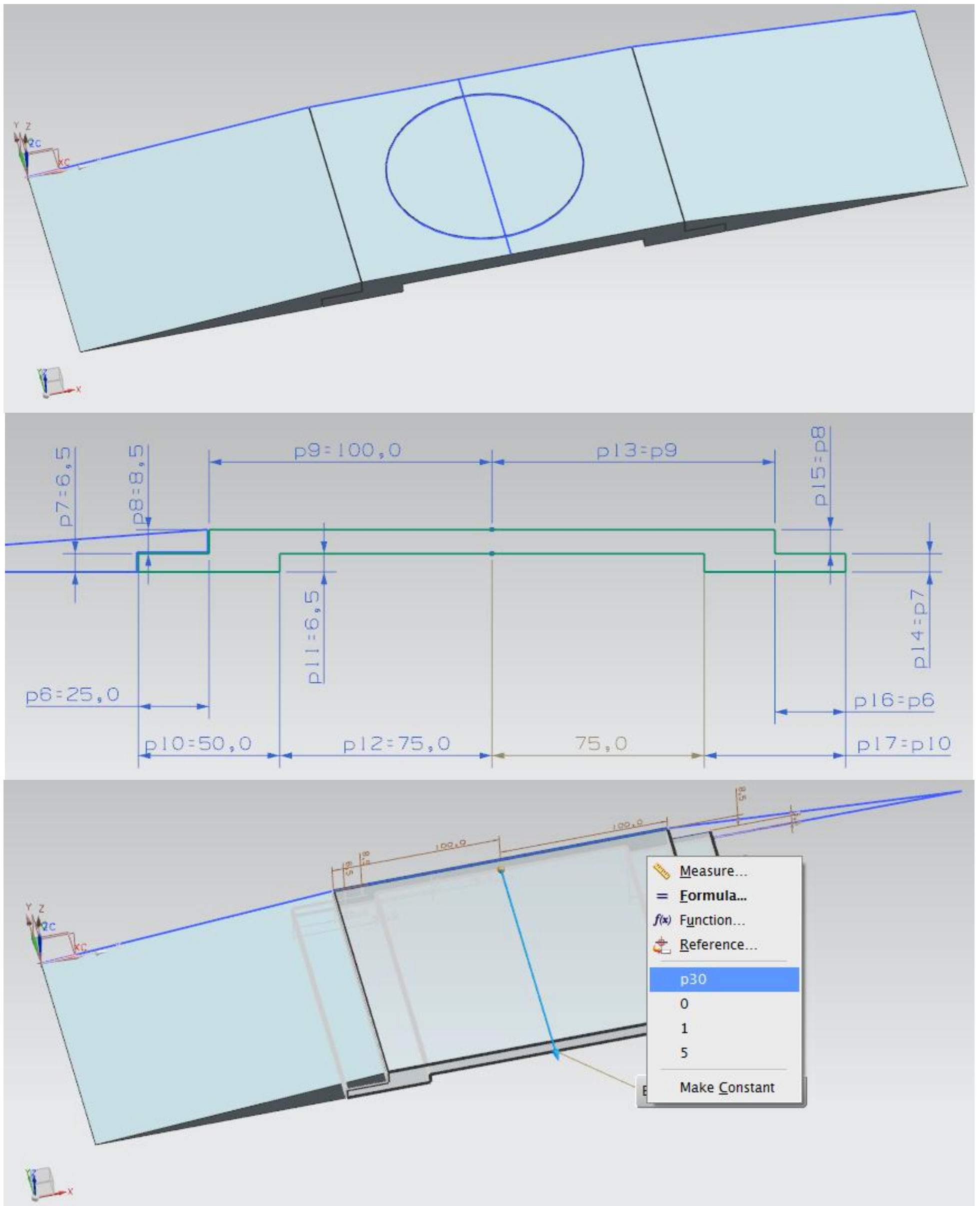

Fig. 5. Parametric design of the weighting device in NX

The results of the finite element model may be also used to establish correlations with the measured strains using experimental methods, and the real V_0 relation.

Last but not least, once the problem is solved, there may be also computed the stresses in the elements of the structure, in this way being useful the algorithms presented in [11], based on analytic approaches, which were already implemented, tested, upgraded and generalized.

6. Conclusions

The paper presents a series of original results, at different levels: conceptual, theoretical-algorithmic, theoretic-numeric, experimental. The knowhow presented in the paper may be used to create a software application for the automatic design of rotating half bridge structures, by including the software already developed in a series of loops which finally offer relevant sets of dimensions of the various parts of the structure, together with remarks regarding the possible side effects. In this way a new version of a rotating half bridge may be just at a few clicks away.

Moreover, along the evolution of this science project the studies belonging to various field, analytic, numeric and experimental, may be integrated using computer based methods in higher level hybrid model. In this way there may be reached an important level of relevancy of the results.

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R E F E R E N C E S

[1]. *L.I. Vuta, G.E. Dumitran*, "Assessment of water quality at the romanian Black Sea shore", Scientific Bulletin, University Politechnica of Bucharest, Series D, Mechanical Engineering, ISSN 1454-2358, vol. 75, iss. 2, 2013.

[2]. *C.R. Mocanu*, "Wastewater pretreatment in the sewage system", Scientific Bulletin, University Politechnica of Bucharest, Series D, Mechanical Engineering, ISSN 1454-2358, vol. 75, iss. 3, 2013.

[3]. *I.C. Moga, G. Petrescu, B. Nasarimba and D. Robescu*, "Aeration efficiency for a leachate treatment plant", Scientific Bulletin, University Politechnica of Bucharest, Series D, Mechanical Engineering, ISSN 1454-2358, vol. 76, iss. 4, 2014.

[4]. *E. Iatan, R.M. Damian*, "Numerical modeling the diminution of transverse section of a sewer pipe for sediments transported as bed load", Scientific Bulletin, University Politechnica of Bucharest, Series D, Mechanical Engineering, ISSN 1454-2358, vol. 75, iss. 3, 2013.

[5]. *I.I. Panaitescu, A.A. Scupi and D.N. Robescu*, "Flow modeling and simulation of a sand and fat tank from a wastewater treatment station", Scientific Bulletin, University Politechnica of Bucharest, Series D, Mechanical Engineering, ISSN 1454-2358, vol. 76, iss. 4, 2014.

[6]. *Robescu Dan, Szabolsc Lanyi, Robescu Diana, Constantinescu Ionel, Verestoy Attila*, Tratarea apelor uzate (Wastewater Treatment), Editura Tehnica Bucuresti, 2001.
[7]. *Lazaroiu Gheorghe*, Sisteme de programare pentru modelare şi simulare (Programming systems for modelling and simulation), Editura POLITEHNICA PRESS, ISBN 973-8449-78-2, 490 pg., Bucureşti, 2005.
[8]. *E. Oanta, G. Lazaroiu, C. Panait, T. Axinte and A.E. Dascalescu*, "A method to calibrate the analytic model of the rotating half bridge belonging to a circular settling tank", CIEM2013 Green and smart energy – International Conference on Energy and Environment, November 7-8, 2013, 'Politehnica' University of Bucharest.
[9]. *E. Oanta, C. Panait, G. Lazaroiu, A. Raicu, T. Axinte and A.E. Dascalescu*, "Conceiving a Hybrid Model of a Weighting Device", ATOM-N 2014 - The 7th edition of the International Conference "Advanced Topics in Optoelectronics, Microelectronics and Nanotechnologies", 21-24 August 2014, Constanta, Romania.
[10]. *E. Oanta, C. Panait, M. Barhalescu, A. Sabau, C. Dumitrache and A.E. Dascalescu*, "Original Computer Method for the Experimental Data Processing in Photoelasticity", ATOM-N 2014 - The 7th edition of the International Conference "Advanced Topics in Optoelectronics, Microelectronics and Nanotechnologies", 21-24 August 2014, Constanta, Romania.
[11]. *E. Oanta, A. Nita*, An Original Method to Compute the Stresses in Applied Elasticity, Journal of Optoelectronics and Advanced Materials - Rapid Communications (OAM-RC), Editor in-chief: Prof. Dr. Mihai A. Popescu, ISSN: Print: 1842-6573, Vol. 3, No. 11, November 2009, pp. 1226-1230.