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IDENTIFICATION OF PARAMETERS FOR DYNAMIC MODELS OF TOWER STRUCTURES WITH ADDITIONAL AXIAL LOADS

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1. Introduction

Chosen problems concerning dynamic identification of building structures were presented in the authors' previous papers (cf. Kawecki (1978), Ciesielski and Kawecki (1987)). Identification is understood here, as a process in result of which a physical and mathematical model of the object, describing the behaviour of the object in a satisfactory way, is obtained. One of the stages of the identification process realization is the experiment carried out on the object.

Kawecki (1978) considered the problems of dynamic identification of tower structures of guyed mast type and introduced there determination of three ranges of identification: α, β and γ. The first one includes identification of structure and parameters of the model, the second one - identification of parameters at a simultaneous assumption of an a priori adopted structure and the third - consists in choosing such one from the considered models, which describes best the investigated object. The problem put forward in this paper was solved realizing the process of identification in the range β. The conceptional scheme of the identification process was presented in fig. 1.

A tower structure with a great capacity tank for liquid located on it is considered. Hence, it is an object loaded, as a rule, with a great compressive force in place of tank location. Identification consists here in determination of parameters of the model which can be applied for solving dynamic problems and stability of this type of engineering objects.

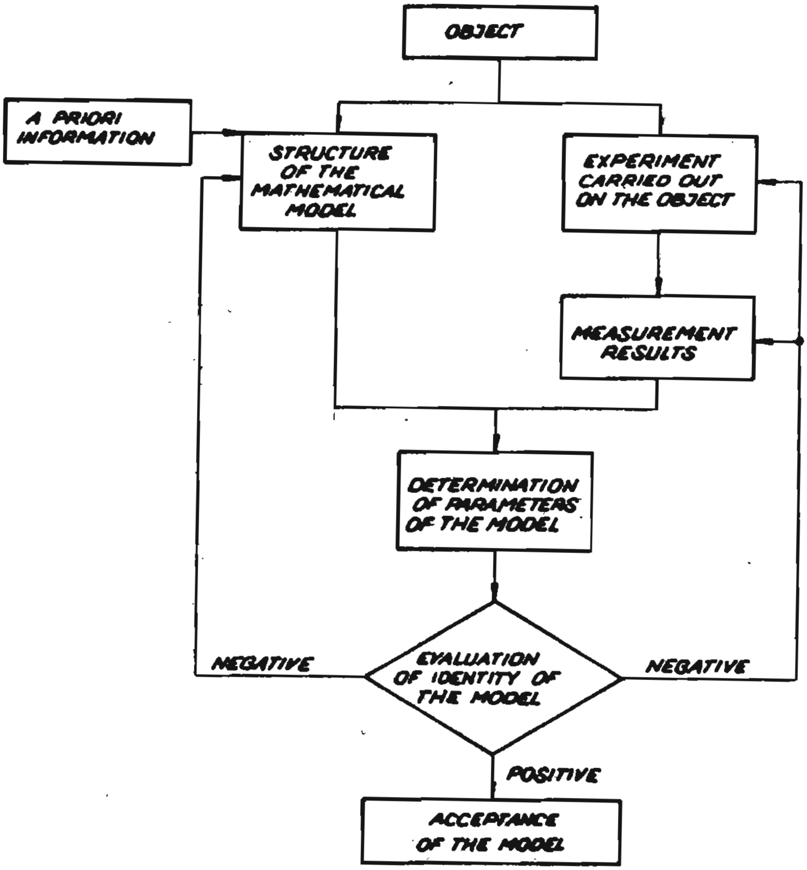

Fig. 1 Scheme of identification process realization.

2. Adoption of a structure for a mathematical model

It is assumed that the considered dynamically loaded (e.g. wind load) object works in a lineary-elastic range. The structure of a mathematical model of such an object can be described with the following equation of motion (cf. Gawroński et al. (1984))

$$\mathbf{M}\,\ddot{q} + \mathbf{C}\,\dot{q} + (\mathbf{K} - \mathbf{K}_G)\,q = p\,, \tag{2.1}$$

where: M - matrix of inertia, C - matrix of damping, K - matrix of stiffness, K_G - matrix of geometrical stiffness, q - vector of generalized displacements and p - vector of loads.

It is usually assumed also that matrix C can be given in the form:

$$C = A\,(K - K_G) + B\,M\,, \tag{2.2}$$

Hence, the model was assumed to be linear. In further considerations it was assumed that the compressive force resulting from the dead weight of the tower structure exerts an insignificant influence on dynamic properties of the structure and this influence can be neglected.

3. Experimental examination of the structure

Experimental examination carried out on the structure are an essential stage of realization of the identification process. Proper planning of the experiment must preceed investigations. Among others, the character of the experiment (active or passive), techniques of the experiment (choice of apparatus, way of results recording, and their analysis), as well as conditions of the experiment are to be determined.

The basic frequency of free vibrations of the engineering objects under consideration can be qualified to low and very low frequencies. The apparatus applied for measurements should permit recording vibrations of very low frequencies.

From among measurement sets applied by the authors the measurement system of Bruel-Kjaer production could be recommended. In the course of measurements the following equipment was used: accelerometer-piezoelectric gauge 8306, electric feeder 2805, normalizing load amplifier of charge 2626 and four track tape-recorder 7003. The dynamic response of the structure at chosen measurement points is recorded on a type recorder, that makes analysis of measurement results much easier.

Results of experimental examinations should be presented in such a form as to make determination of the structural model parameters possible.

Parameters of the model of the structure can be determined on the basis of dynamic characteristics of the building object; into them the following can be included e.g:

a) the set of successive free vibration frequencies ω_i, corresponding to them forms of vibrations A_{ik} and the values of damping coefficients β,
b) the matrix of transmittance moduli of elements $|H_{ik}|$ and the matrix of phase of elements Θ_{ik}.

The above characteristics can be obtained subjecting the results of the active experiments to proper analysis. During this experiment vibrations of the structure can be excited by a vibrator of an adoptable revolution number (cf. Dietze (1966)) a rocket engine (cf. Bata and Plachy (1987)), or a relatively easily realized jump forcing (cf. Kawecki (1978)). In the last of the mentioned ways forcing is realized by sudden release of a previously tensed guy fixed at a chosen level of the structure. Fig.2 gives a scheme of the way of realization of the experiment.

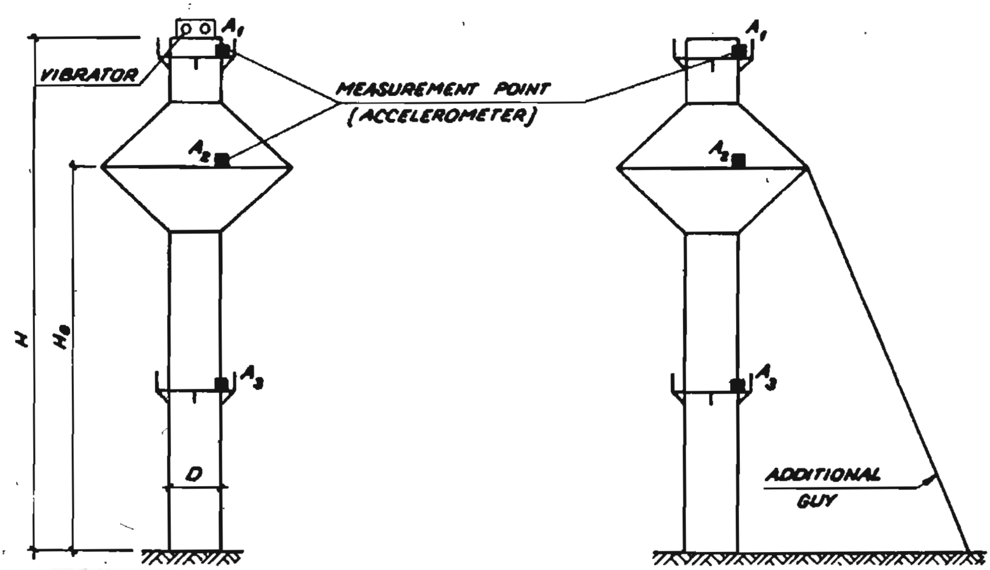

Fig.2 Scheme of realization of experiments.

Dynamic investigations have been carried out at various situations of the tank fill. The effect of motion of the liquid on vibrations of the structure will be eliminated only when the tank is divided into separate compartments which can be filled up independently on one another. The situation of the tank fill (α) is determined by the relation of the volume of the liquid in the filled up compartments of thank (V) to the whole volume of the tank (V_c). Investigations carried out on the object concern chosen situations of filling i.e. from the situation corresponding to an empty tank (number 0 what corresponds to α=0) to complete filling of all the tank compartments (number 1 = 1, what corresponds to α = 1,0).

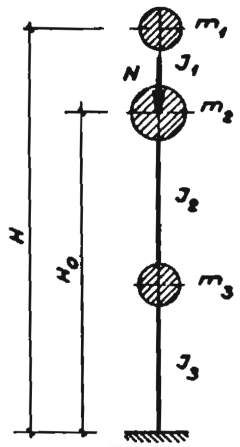

Fig.3. The adopted physical model of the structure.

Filling of the chosen compartments of the thank makes the structure loaded with an axial force of considerable (but known) value. The effect of this force on the change of the dynamic characteristics will be noticeable. E.g. decrease in the basis free vibration frequency will result partly from increase in the value of concentrated mass and partly from the effect of the compressive axial force (cf. fig.3).

4. Determination of parameters of the mathematical model

The results of examinations carried out on the structure can be presented in form of the matrices of amplitude-frequency and phase-frequency characteristics. Elements of these matrices are functions of vibration frequencies and can be presented in form of diagrams. These diagrams - with regard to the required accuracy of modelling (use is to be made of the object in engineering evaluation of structure behaviour at wind load) - must be given in such a frequency interval in which three successive frequencies of free vibrations should find place ω_1, ω_2 and ω_3.

Flaga et al. (1979) described the possibilities of making use of frequency characteristics for determination of dynamic properties of building objects. Later in Kawecki (1981) a procedure of application of amplitude - frequency characteristics for determination of the linear parame

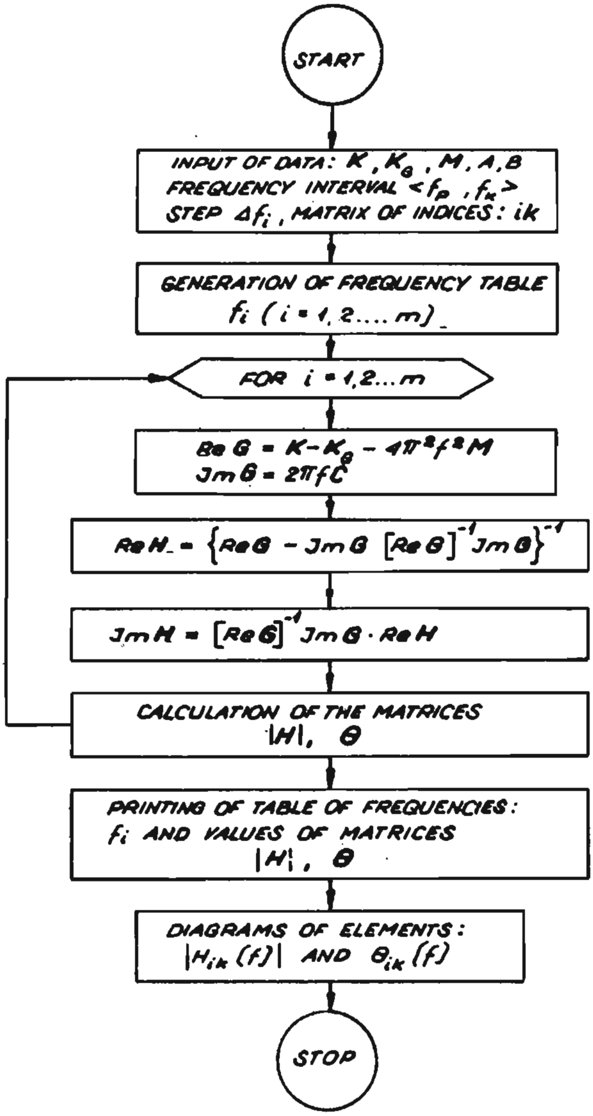

Fig.4 System flow chart of calculation $|H_{ik}|$.

ters for a mathematical model of a tower structure was presented. Making use of the given formulae matrices K^o, M^o, and C^o corresponding with an empty tank (l=0) can be determined. Subsequently matrices K^l, M^l, C^l and K^l_G corresponding to l-th situation of tank fill are determined. For this purpose use is made of dynamic characteristics presented as the result of the analysis of results examinations carried out at successive situations of tank fill. Moreover, it may be assumed that the matrix M^l results from adding to the matrix M^o in a proper element the mass corresponding to the liquid fill of the tank and that the matrix K^l should be equal to matrix K^o.

In each of the analysed situations of the tank fill the parameters of the model are determined using only part of the information contained in the set of dynamic characteristics. The rest of information is used for evaluation of identity of the determined model with the object. Equation (2.1) of previously determined parameters can be, thus, used for calculation of any characteristics $|H_{ik}|$ and the diagram obtained in result of calculations, can be compared with the diagram constituting the results of dynamic investigations of the object. The calculation procedure $|H_{ik}|$ was presented in fig.4 after Flaga et al. (1979).

If in result of the carried out comparison of diagrams the model was accepted (differences in ordinates of the diagrams do not exceed the assumed accuracy), then it may be, used in further analysis e.g. for determination of the value of the critical force $N_{1,cr}$.

5. Determination of the foreseen value of the basic critical load

The matrices of geometrical stiffness K_G differ in dependence on the situation of the tank fill l. The values of elements of this matrix depend on the compressive force N^l (weight of the liquid fill of the tank). The tank fill influences the change of frequency of free vibrations of the structure in consequence of: a locally occurring increase in concentrated mass (change of matrix of inertia M^l) and increase in compressive force on the tower shaft (N^1).

For examination of the effect of compressive force N^1 on the change of basic frequency of free vibrations of the structure ω_1^1 the modified value of reference frequency $\omega_{1,o}^1$ should be calculated first. It corresponds to the model in which no compressive force N_1^1 occurs, but the matrix of inertia is the matrix M^1. The value $\omega_{1,o}^1$ is found from equation:

$$M^1 \ddot{q} + K \overset{1}{q} = 0 \,, \tag{5.1}$$

The known values of free vibration frequencies ω_1^1 and $\omega_{1,o}^1$ can be used for determination of the expected basic value of critical force $N_{1,cr}$. The following, approximate relation between ω_1^1 and $\omega_{1,o}^1$ can be adopted after Nowacki (1961) in compressed bars vibrating laterally:

$$(\omega_1^1)^2 \approx (\omega_{1,o}^1)^2 \left(1 - \frac{N^1}{N_{1,cr}^1}\right) . \tag{5.2}$$

Basing upon investigations on the object the value ω_1^1 can be obtained in every situation of the tank fill. From calculations of the model (5.1) the value $\omega_{1,o}^1$ can be obtained. One point in the coordinate system corresponds to every situation of tank fill: $(\omega_1^1/\omega_{1,o}^1)^2$ and N^1. Points corresponding to all considered situations of tank fill should lie on a straight line described by equation (5.2). As shown in fig.5 the value $N_{1,cr}$ can be determined by extrapolation.

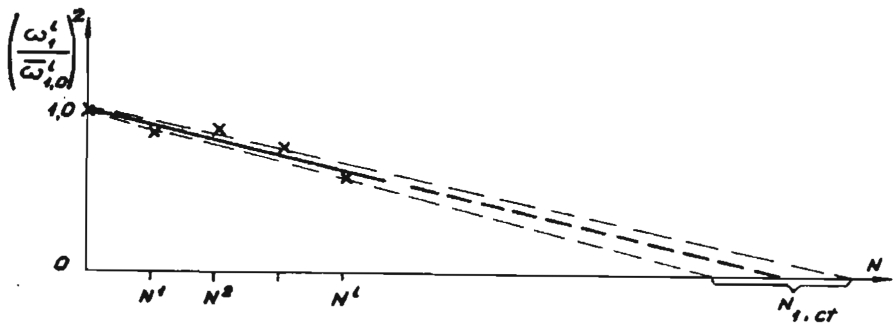

Fig.5 Application of investigation results for determination of the basic critical force N (x-from measurements, - - - border lines considering accuracy of the method).

6. Recapitulation

The described procedure of identification of parameters for a tower structure with additional axial load is based on identifications of models of other tower structures (masts, chimneys). An additional factor which is constituted by a great vertical axial load complements the description of the model structure. In this type of engineering structures the problem of general stability plays an important role (determination of the value of the basic buckling load). The above described procedure which makes use of investigations of the object in natural scale permits determination of an approximate value of the basic critical force.

The so planned experiment can be carried out only after the realized object of this type has been made accessible.

Evaluation of accuracy of identified parameters and sensitivity of the model to disturbances has not been presented in the paper. This problem requires a seperate elabolation.

References

Bata,M.Plachy,V. (1987): Analysis of dynamic effects on engineering structures, Elsevier Science Publishers.

Ciesielski,R. Kawecki,J. (1987): Application of experimental investigations for dynamic identification of towerstructures, *Selected Works in the Field of Civil Engineering-Monograph* No 56, Technical University of Cracov; 25-39.

Dietze,F. (1966): Vibration measurement on anchored masts,Symposium Book, IASS, Bratislava.

Flaga,A. Kawecki,J. Kucwaj,J.(1979):Frequency characteristics in the description of dynamic properties of engineering structures (in Polish), *Arch.Inż.Ląd.* 25(4),593-609.

Gawroński,W. Kruszewski,J. Ostachowicz,W. Tarnowski,J. Wittbrodt,E. (1984): Finite element method in dynamics of structures (in Polish), Warszawa, Arkady.

Kawecki,J (1978): Dynamic identification of engineery object of the guyed masts type (in Polish), *ScientificPublication - Civil Engineering*, Technical University of Cracov, 56(5).

Kawecki,J, (1981): Application of experimental investigations in modelling of tower structures (in Polish), 20thSymposium: Modelling in Mechanics - Proceedings, Gliwice- Wisła, 231-241

Nowacki, W. (1961): Dynamics of structures (in Polish),Warszawa, Arkady.

Summary

IDENTYFIKACJA PARAMETRÓW MODELI DYNAMICZNYCH BUDOWLI WIEŻOWYCH Z DODATKOWYMI OBCIĄŻENIAMI OSIOWYMI

Zagadnienie identyfikacji rozwiązano w zakresie β (por. Kawecki (1978)). Po przyjęciu struktury modelu wg (2.1) wykorzystując wyniki badań przeprowadzonych na obiekcie podano procedurę wyznaczania parametrów modelu. Rozważono budowlę wieżową z umieszczonym na niej zbiornikiem na ciecz o dużej objętości dającym dodatkową siłę osiową. W tego typu konstrukcjach inżynierskich ważnym zagadnieniem jest wyznaczanie wartości podstawowej siły krytycznej. Opisana procedura wykorzystująca wyniki badań na obiekcie w skali naturalnej umożliwia wyznaczenie przybliżonej wartości podstawowej siły krytycznej.