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1. Subject of the Ph.D. Thesis

Creating girder constructions and operating them according to their aimed function require a unified approach of design, implementation and maintenance, in order to actuate our load bearer structures in more and more sophisticated ways in terms of economical building process, up-to-date maintenance and exact knowledge of their current state.

Describing the effective behaviour of the built girder constructions even more accurately, and feeding back the experiences on that behaviour into the data pool of the designing process, are the approved and accepted tasks of the theoretical, designer, executive and maintaining engineers. The present work intends to strenghten and to additionally form that unified approach.

Calculation of the reaction forces, intrinsic forces and movements of a particular structure is only possible through models. Accepting a model inevitably means accepting certain approximations in the same time. The structure itself is to be modelled, then the pattern and distribution of the loads are to be modelled, and the peculiarities of the building materials are also to be modelled. The models are to be simplified in order to become more accurately and simply describable mathematically. As of today, this simplification does not already necessarily result in models which may be worked out by being described using the methods of analytical geometrics, and by being inserted into the system of equilibrium requirements. Although the above geometrical definition is still necessary, the restriction in the amount of unknown quantities to be defined, and the analytical solution of the questioned statical and dynamic functions do not have to be aimed so strictly as before the application of computers. The same attitude applies to the summary description of those referring to the entire construction in each particular case, as it can also be done by computer softwares.

The possibility of breaking it down into a limited number of components, and that of defining the connections among those components as well as the relevant quantities in their connecting points through the processing of the calculation method, do not mean theoretical simplification. Indeed, they do result in a more exact modeling with either even fewer or even more accurate approximation, and in such definitions of strain, tension and drift of constructions, which do approach the reality more accurately. The so disengaged calculation capacity may be limited either by comprehension or by practical requirements.

Assuming that the theoretically deducted as well as practically and experimentally supported fact, that the modification of constructions unequivocally ifluence their dynamic behaviour, may meet the practical requirement of describing the current state of constructions in the simpliest and non-invasive way, without destruction.

This assumption is partly examined by the present work, considering also the possibility that theoretical confidence does not necessarily mean practical feasibility for several reasons, such as it might be either far too difficult to realize or far more expensive than the budget would allow, or simply the required workload would be disproportionately high compared to the importance of the result to be achieved. Detecting minor changes in construction industry would often require unobtainable and even unnecessarily high accuracy.

2. Materials and Methods of the Ph.D. thesis

Engineers focusing on design, implementation and maintenance, apply the general laws of technical mechanics routinely in their common work. From statical aspect, usually only those courses which are independent from time are to be examined with the methods of statics. Time-dependent kinetical courses are either less or not at all of a subject using statical methods, although these phenomena do include statical courses as well, where the time-variable have to be defined as zero. From the mathematical aspect, indeed, the partial derivative upon time of functions describing statical courses is zero.

Having described its behaviour upon time results in widely more detailed knowledge on a particular construction – the dynamic status is to be recorded in order to support that knowledge – since the analysis of that particular status makes possible to assay both the statical and the kinetic courses. The studied dynamic features – such as mode, eigenfrequency and damp – might not be the most valuable data carriers in themselves, at least for the civil engineering practice, but their changing pattern do, indeed, especially if the information carrier functions were recorded also formerly, in order to be able to detect their changes.

There have been certain measurings at several places around the world – including Hungary – since the sixties of the last century, aiming to describe the constructions even more accurately in order to benefit the above advantages, which results were analyzed and systematized focusing on the particular purpose of laying down the theoretical basics of dynamic monitoring of structures.

R. **Harnach** sais the demand for the dynamic monitoring of timber constructions increases significantly with a consequent increment in the number of measurings, as well as the eigenfrequency of timber structures is the highest compared to that of steel and concrete structures, given the same construction. The same paper discusses the dynamic features of timber constructions, emphasizing the importance of the rate of damping. In that case, a certain dynamic change due to a given structural change may be more characteristic in a timber construction than that is it in a steel or concrete construction, apparently.
Unfortunately, this suspicion could not have been verified in case of the studied constructions discussed in the present work, although the alterations in the dynamic behaviour are detectable, but not unambiguous, and the measuring and calculation results are hardly to be matched with each other.

The Ph.D. thesis traces through the procedure of laboratory data recording, identification and diagnostics, where – at least theoretically – also practically useful results can be concluded from the changes of the dynamic state.

The studied timber construction is variable in diameter, the intermediary approximately 70% of its beam is of a timber girder (Fig. 1). The differential equation of this particular construction is described by the author mainly upon the papers of **R. Heilig** and **R. Pischl** as well as upon the books of **F. Stüssi** and **S.**

Timoshenko, so that the deformations of the construction are able to be calculated. After having matched the measured and calculated data, the values characteristic to the behaviour could have been defined in nine particular states of the studied simple beam. Allocating the non-measured values of the matrices of rigidity makes possible to execute the dynamic calculations as well as to evaluate the changes.

The eigenfrequencies determined upon the measured vibration accelerations in each of the nine states of each of the four timber constructions result in the database which the thesis can be formulated by.
The dynamic calculations were executed by the author on an undamped structure, although the dampings and their changes were also determined in some of the states. Those have showed the behaviour of the structure to be non-linear.

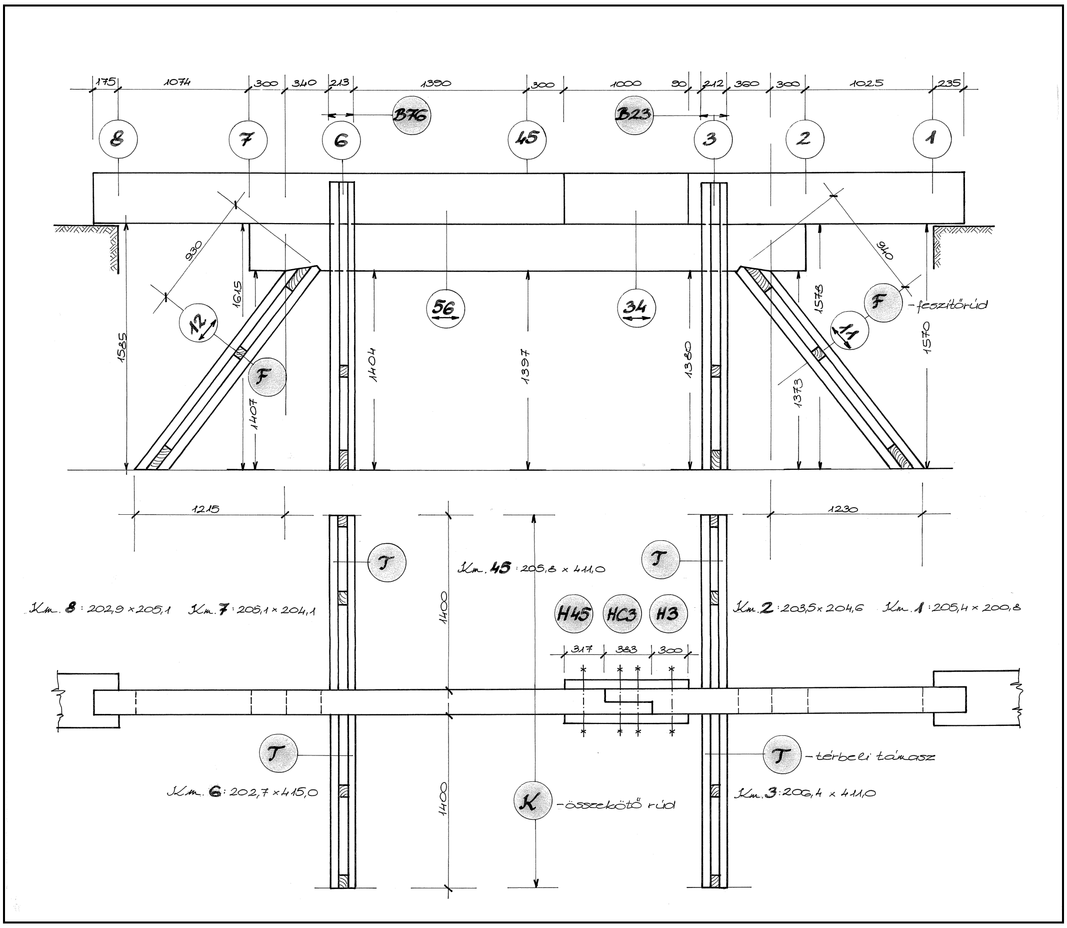


Fig.1

The set-up of the studied laboratory structure with the positioned sensors

Markers on the above figure:

- knots, cross sections and measuring positions:

  1, 2, 3, 45, 6, 7, 8
- the below symbols mark exclusively cross sections:

  B23, B76, H45, H3, HC3, F, K, T
- those marking exclusively measuring positions:

  11, 12, 34, 56

3. Laboratory measurings of the structure

An experimental timber structure with variable construction parameters has been designed by the author, with the advantage of being able to be gradually broken down by omitting certain structural elements, into each particular structure with specific features in short time.

By breaking gradually down the mounted structure it is possible to form several constructions in order to test the effect of the changes under different circumstances. This experimental structure has been manufactured without any special requirement, was made of sawn beams using the technique of local carpentry making timber constructions, just like a rack, a roof or even a wooden pedestrian bridge.

Fig.2

The setup in the laboratory of the experimental timber construction

Statical properties of the structures

Œ Cross spanning doubled truss
• Twin truss framework (Similar to Œ**,** but without cross spanning)
Ž Simple truss framework (Similar to • , but with only simple spanning)
• Simple beam

Theoretical dynamic properties of the structures

Each section of each structure is continuous in its mass-distribution, with a non-constant inertia along their axis. Their behaviour is presumably linear, with a negligible damping.

Variables are the

- the displacement and the rate of them in the two parts of the timber girder on each other. *(Imitating the reality, as the slipping of the joint bars on each other increases with time in the constructions, without usually knowing the rate of slipping)*;
- the upper beam is interrupted by a flexible knuckle, so that a relative rotation evolves in the joint of the upper beam due to its load. The joint is modeled as a flexible knuckle which resistance against rotation is expressed in rad/kNm. (*Timber connections either cannot provide rigid grip or the initial grip loosens in time making possible to evolve rotations*);
- the relative rotation between each cross spanning and the beam is variable in the cross section of the joint at both bars. *(There may evolve relative rotations at the cross spannings in time).*

Indeed, each of the above changes can be matched by an adequate practical structural alteration. Processing the entire series of experiments might have resulted in a register of failures, where the dynamic alterations are matched by structural changes.

The idea of creating that failure register of timber constructions was abandoned after the measurings had been executed and processed, as the observed and experienced dynamic changes were not characteristic.

4. Conclusions deducted from the results of the measurings

The external load, a concentrated force, was positioned in the middle cross section of the beam, with a monitored intensity adjusted between 5 and 35 kN.
The measurings of the timber construction aimed the following phenomena:

- the absolute and relative displacement of the two timber parts on each other;
- the deflections of the structure;
- autonomous vibration accelerations.

4.1. Statical examination

The values and the nature of the **slidings** allow to conclude the followings:

1. The sliding figures are not symmetrical, while the relative sliding figures are not antimetrical. (Both types of the phenomena are identical in terms of the deviation of the right and left sides of the curves from each other being uniform, in case of each loading force and in each state of the structure. The slidings on the left end of the timber girder section are smaller than that on the right end of the girder.)
   The extreme value points of the displacement curves are under the elongation of the upper beam. This is the point where the flexible knuckle is to be supposed, which makes possible to trace the non-symmetrical behaviour of the beam, as the inflections in point ƒ and point † are not

identical. If the symmetrical positioning of these points is assumed, then the deviation of the two inflections from each other has to be the consequence of the rotation in the flexible knuckle. The cross section of the extreme values of the sliding figures is under the elongation of the upper beam.

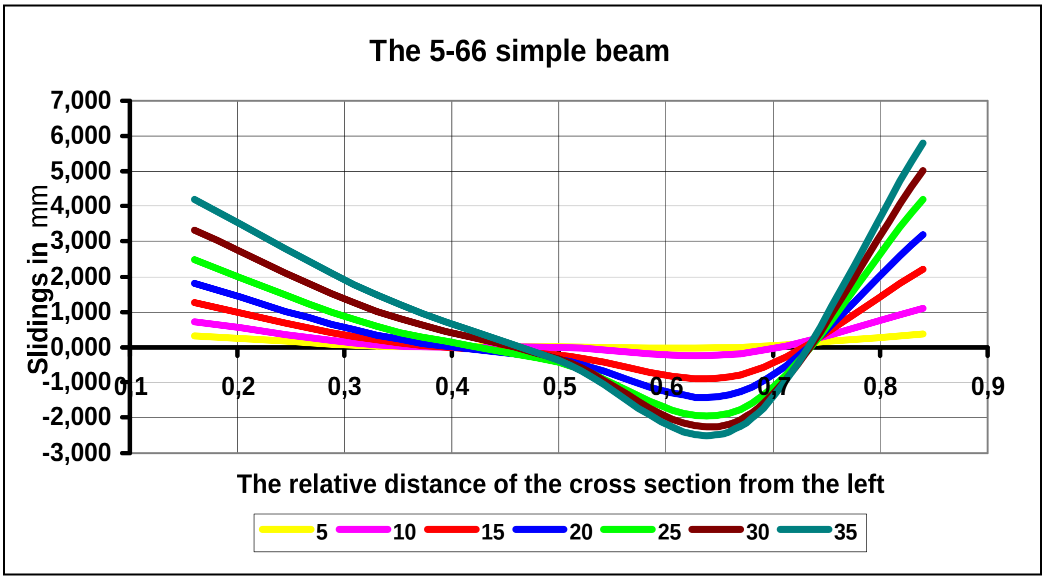


Fig.3

Measured absolute slidings represented along the axis of the structure

Extreme value points of the sliding figures	5-66	5-46	5-26
	0,663	0,654	0,655

The above numbers represent mean values upon each state, as the effective position cannot be defined. May the assumed position of the flexible knuckle be the mean value of the three above values: x_c=**0,658**

The knuckle is modeled by the concentrated bending momentum depending on the value of the unknown **k** vibration constant. It is to be observed that the left side sections of the curves are as good as paralel and proportional, while the difference among the slidings on the right side becomes disproportionately smaller with increasing the load. On this side, the curves intersect each other in a well-definable point.

2. The values of the relative displacement mark the zero positions of the curves showing the relative slidings in the below positions:

State	Loading						
	5 kN	10 kN	15 kN	20 kN	25 kN	30 kN	35 kN
5-66	0,510	0,531	0,538	0,540	0,542	0,545	0,543
5-46	0,523	0,538	0,540	0,542	0,544	0,547	0,548
5-26	0,529	0,541	0,544	0,548	0,551	0,552	0,553

The plus-minus sign changing position of the sliding forces is pushed to the right by 15mm to 85mm both by increasing the loading force and by decreasing the collaboration between the particular timber components, which can influence the resulting values while calculating the structure.

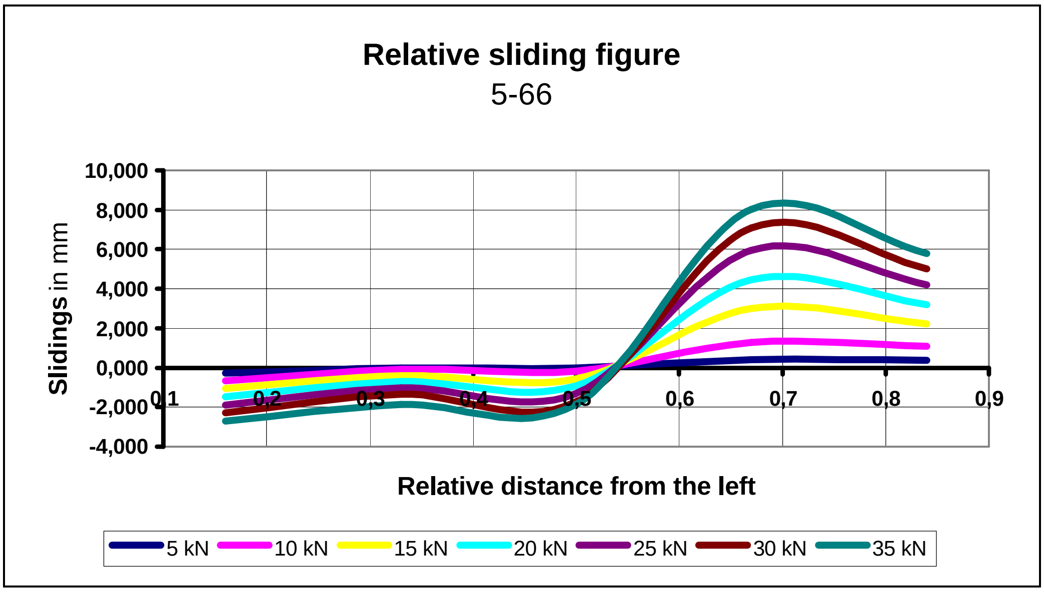


Fig.4

Measured relative displacement represented along the axis of the structure

3. Fundamental questions are the symmetry and the linearity of the structure. The author found the discussed load in the present case to be symmetrical and linear, as well as the applied materials to be of linear behaviour. The Young-modul of the applied materials is constant.

   The setup of the construction is not symmetrical. The measures, the supporting points, the joints between the surfaces of the timber girder in the intermediate section as well as the rate and the effectivity of their collaboration do change, but in no greater grade as they do in practical cases. (The **K** displacement modul and the g^2 displacement relation are not constant.) Not even the elongation of the upper beam is symmetrical, and a relative rotation is possible in the elongated section. The above setup is not unusual in the practice at all, and those inequalities do not play any role if the sizing is based on liminality. In the present case, indeed, since measured and theoretical data are to be matched, more sensitive theoretical considerations are needed and the deviation from symmetry results in circumstances which either make the efficiency of matching more difficult or require a multiparameter frame with insolvable complexity – the latter does not even make sense, as more general conclusions cannot be deducted in that case.

   A symmetrical model is to be set up, with the most possible properties to be considered. Data processing of displacement resulting from loads between 5 and 10 kN supports the statement that the structural behaviour regarding these loads is non-linear. Consequently, the connection between the force and the relevant sliding is not directly proportional and variable depending on the state of the structure and on the effective force.

However, linearity can be assumed in the case of 15, 20 and 25 kN loads, which has its particular importance when calculating the flexibility matrix. Namely, the elements of the matrix include inflections related load units, so either the inflections resulting from the applied loads are to be proportioned in order to form the middle bar of the matrix, or the calculations are to be done upon one load unit in order to define the elements in the two external bars of the matrix in the model with three degrees of freedom.

4. On the whole, upon the measured shifts and processed motions of the structure it may be concluded that a possibly succesful attempt can be made to answer the principal question of the present Ph.D. thesis, upon the statical and dynamic calculations of a construction which is linear in its material (flexible), symmetrical in its geometrics and structural setup as well as linear in its force inflection connection under loads over 15 kN. This key question is about the consequent alterations in dynamic properties resulting from structural changes. The **E** and **K** moduli have been approximately defined from the laboratory measurings, as well as the decision has been made regarding the basis of approaching the behaviour of the structure.

Examining the **deflections** of the model to be formed resulted in the same conclusions.
The statical model, which is oriented upon the above and is to be applied for the comparison of the measured and calculated results has the following properties:

- The structure behaves in a flexible way, i.e. the law of Hook applies. The effective slidings are proportional to the sliding forces, where the factor of proportionality is represented by the **k** spring constant, i.e. the sliding force needed for one unit of effective relative sliding;
- The rotations presented in the flexible knuckle formed by the elongation of the upper beam are proportional to the torque, where the factor of proportionality is represented by the **k** spring constant, i.e. the torque needed for one unit of effective rotation. The properties of the knuckle are not known, and alter upon the changes of the coaxial forces in the screws. The simpliest way to take its effect into account is to consider the increment of the **M** torque;
- The flexible behaviour means at least that the mathematical description of the deflections of the construction, using the methods of elasticity, results in practically acceptable conclusions;
- the measure of the **K** sliding modul and the **k** spring constant do not depend on the external load;
- the **E** and the **K** are constant along the axis of the structure. The cross section is also constant in each of the sections (in the simple beam section and in the timber girder section, too), as well as the setup of the structure is theoretically symmetrical, where the load is represented by one single concentrated vertical force in the middle cross section;

- The measure of deformation work resulting from the shearing forces is negligible, although it has been taken into account in order to be even more accurate;
- The following substance constants have been defined upon measures:

  E_h = 4400 N/mm^2; G_h = 220 N/mm^2 ($G_h \approx E_h/20$);

  The rate of sliding was barely influenced by the forces risen in the screws, therefore the γ varies between close marginal values:

  $$6{,}0 \cdot 10^{-4}\ \text{1/mm} < \gamma < 7{,}5 \cdot 10^{-4}\ \text{1/mm}$$

  The sliding modul is not constant, since the relative distance between the screws is not constant either; however, its mean value is as below:

  K = 8,83 N/mm^2

  The mean value of the resistance against sliding of the screws is the following:

  C = 3860 N/mm

The above premises suit the general practice as well as the standard yieldings. However, the model applied during the design and verification process does not have a checking control which could fit the measured and calculated results with each other, like in the case of the deflections in the present instance – which makes possible to define formerly unknown values. Consequently, the more simplified the calculation model is, the less adequate will the results regarding the **K** and **E** moduls be.

Taking all the above into account, the present Ph.D. thesis applies the differential equation upon the **N(x)** normal force risen in the mixed structures in the given circumstances. It also describes the function in the sections defined by the alterations of the bending momentum in the horizontal plane resulting from the **M(x)** external forces, along with its initial values and connecting conditions providing the smoothness:

$$\gamma^2 = \frac{K}{E} \cdot \frac{h}{I_1 + I_2} \cdot \frac{I_S}{S_S}\ [1/\text{mm}^2] \qquad \alpha = \frac{K}{E} \cdot \frac{h}{I_1 + I_2}\ [1/\text{mm}^3]$$

$$\boxed{\frac{d^2 N(x)}{dx^2(x)} - \gamma^2 N(x) + \alpha M(x) = 0}$$

$$\frac{dN(x)}{dx} = T(x) \quad \text{N/mm}^2 \qquad K \cdot \Delta u = T(x)$$

Representation of the **N(x)** and the **T(x)** functions. The effect of the changing torque resulting from the rotation in the flexible knuckle can be seen in the description of both functions.

4.2. Dynamic examination

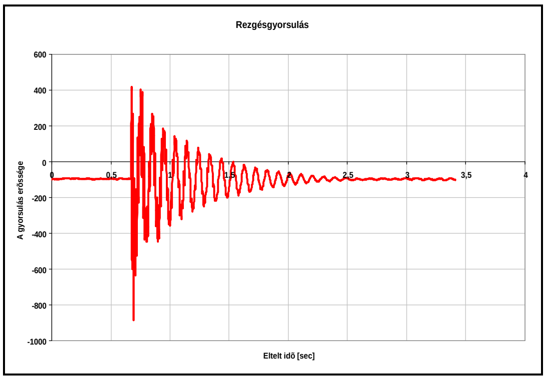
Upon the accurately defined statical framework in the given circumstances, the author determines the $\underline{\underline{\mathbf{H}}}$ flexibility matrix and the $\underline{\underline{\mathbf{K}}}$ rigidity matrix for nine different states of the examined structure. The dynamic features of the structure, which damping is regarded as being negligible, can be calculated upon the knowledge of the $\underline{\underline{\mathbf{M}}}$ mass matrix. The Ph.D. thesis determines certain eigenfrequencies and modes, as well as the vibration shape in one case, which is to be compared with the measured shape after having calculated the damped vibration shape, considering one single characteristic damping value determined upon the measured curves being constant.

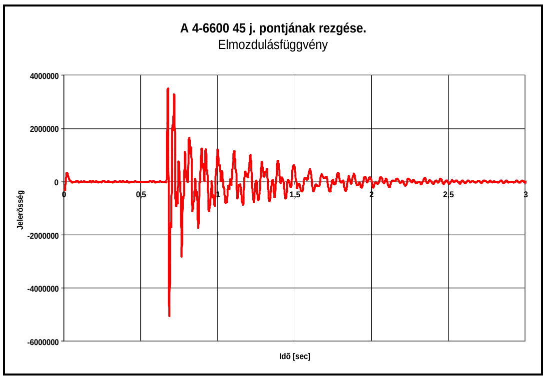
The frequency spectra have been determined in each state of each structure upon the measured vibration accelerations using the **catmanÒ** software made for processing the response signals of the measurings, which the eigenfrequencies have been selected from using the represented spectra. The conclusions enumerated under Thesis number 3 result from the changings of the individual values, from the comparison of the measured and calculated properties as well as from the dynamic examinations. The statements of the statical examinations are to be completed with the followings, after having processed the dynamic measurings:

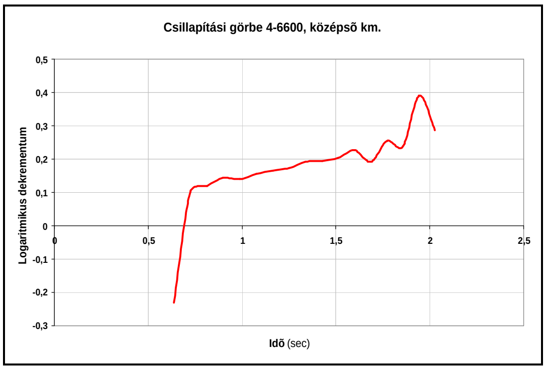
5. On examining the changings of the dynamic properties, it is to be decided whether two measurings done in different points of time are comparable – i.e. what the reason behind an occasional changing or even steadiness can be.
6. The dynamic examination of timber constructions results in less consequence than that of concrete or steel constructions, since the former are relative lightweighted and their joints are variable in their motions.

The dynamic examination means primarily the autonomous measuring of the four structures, secondly the dynamic calculations regarding the simple beam. During this work, the present Ph.D. thesis examined the following phenomena:

- recording the vibration acceleration of the four structures in 9 different states of each structure, always in 3 different points simultaneously and at least twice in each state. Calculation of certain damping curves and motions regarding the simple beam;







- calculation of the frequency spectra upon the vibration accelerations using the **catman®** software (simple beam 4, frequency – amplitude)

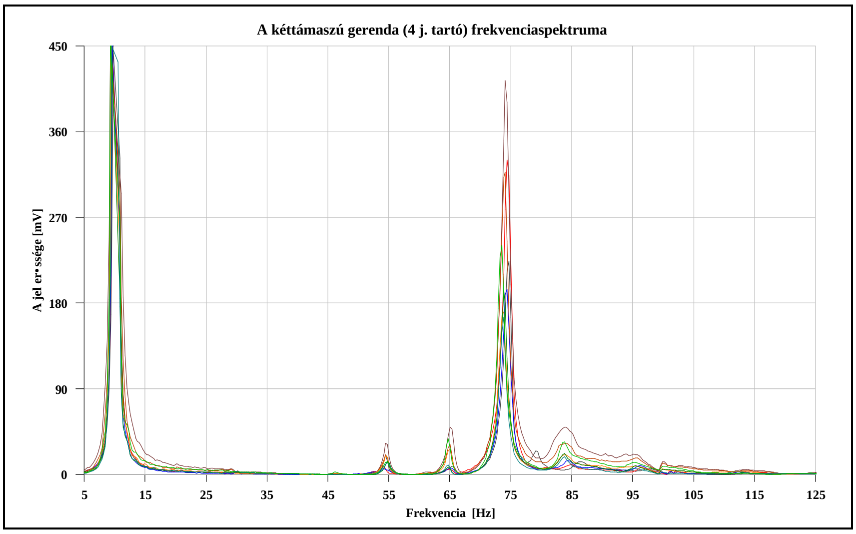


Fig.5

The measured and processed dynamic signs

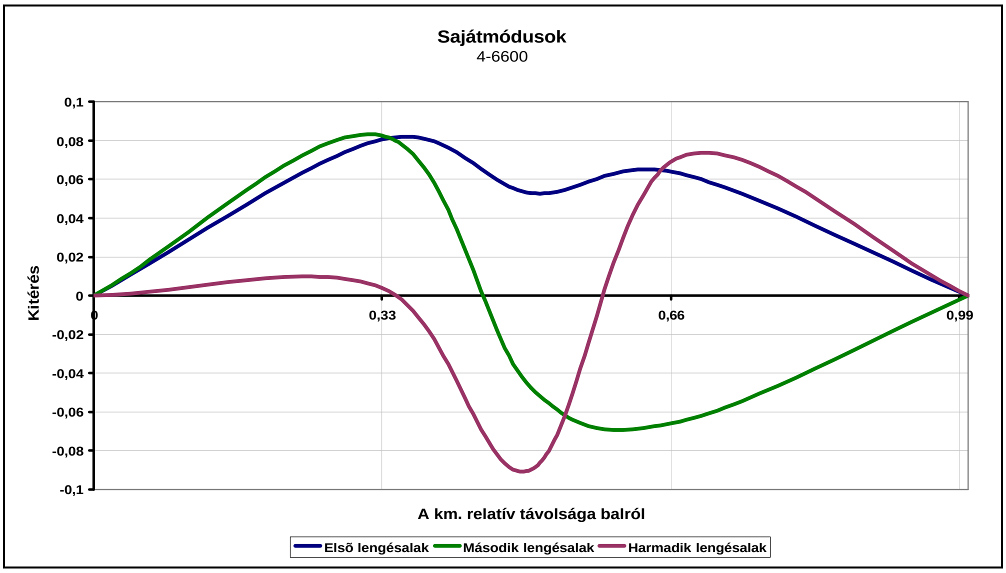
Determination of eigenfrequencies upon measuring results can also be applied in order to find out whether the dynamic examinations aiming to interpret the signs evoked by the changings are effective or do not make sense.
Since the flexibility matrices were known anyway, the dynamic properties of the simple beam have been determined also by calculation, in order to make the processing complete – such as the eigenfrequencies, the modes and the vibration profiles are as below:

- calculated eigenfrequencies

$f_i = \omega_i/2\pi$ [Hz]									
I	4-6600 j. tartó	4-6400 j. tartó	4-6200 j. tartó	4-4600 j. tartó	4-4400 j. tartó	4-4200 j. tartó	4-2600 j. tartó	4-2400 j. tartó	4-2200 j. tartó
1	10,368	10,098	9,977	10,141	10,081	9,941	10,010	9,842	9,719
2	21,991	21,682	21,270	21,997	21,821	21,447	21,856	21,469	21,074
3	39,672	38,534	37,777	36,417	35,839	35,108	35,543	34,704	34,416

The eigenvalues of the w_0 and the respective eigenvectors are to be determined upon the homogenous linear equation $(\underline{\underline{K}} - \omega_0^2 \cdot \underline{\underline{M}}) \cdot \underline{v} = \underline{0}$ of the undamped vibrations. Any solving other than trivial regarding the above equation is possible if the $\left|\underline{\underline{K}} - \omega_0^2 \cdot \underline{\underline{M}}\right|$ determinant takes up the value of zero. The eigenfrequencies can be deducted from the above homogenous equation. The dimensions of the **$\underline{\underline{K}}$** rigidity matrix and the **$\underline{\underline{M}}$** mass matrix are as 3 x 3 in case of three degrees of freedom, so the three primary eigenvalues can be determined.

- one of the calculated modes (**1**st, **2**nd and **3**rd mode, girder 4-6600, relativ distance from the left – deflection in *mm*)



- the vibration shift on calculated figure (assuming the initial shift to be 0,01 mm)

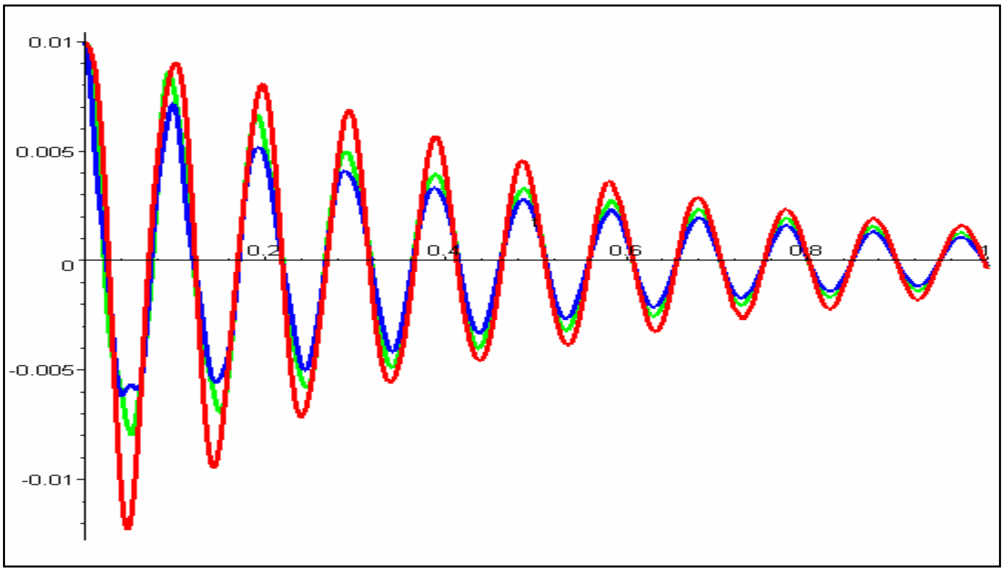


Fig.6
Calculated dynamic functions

5. Conclusions and results of the Ph.D. thesis

A timber construction has been designed and set up by the author in the laboratory. The construction was to imitate the time-induced alterations in a traditionally implemented timber structure.

The intermediate • I section of the 6.5m long beam of the examined timber construction is of a timber girder. The upper beam is extended in its lenght in one place using overlapped elongations strengthened by belt plates and penetrating screws. The sliding of the beams of the timber girder section on each other, as well as the rotation of the flexible knuckle formed in the elongated part were variable parameters. By breaking gradually down the mounted structure, it is possible to examine the below structures:

- cross spanning doubled truss
- twin truss framework
- simple truss framework
- simple beam

As it was outlined in the original conception, the statical and dynamic measurings have then been implemented by the author, aiming to determine the real behaviour of the construction. The measuring results were converted, systematized and described for further processing.

The Experiment protocol records contain the shifts measured in the construction, as well as the angular shifts and the vibration accelerations upon the below effects:

- statical load: concentrated force in the middle cross section, variable between 5 kN and 35 kN;
- excitation: impulse hammer.

The following results have been achieved by the author and the below statements can be concluded and formulated into thesis upon the implementation and processing of the laboratory measurings, the theoretical examination of the simple beam being partly a timber girder, and the comparison of the measured and calculated dynamic properties:

THESIS 1

Tracing the changing conditions of the compound timber construction by statical and dynamic laboratory measurings highlights the reason behind the practice of the discussed examination protocol, since the calculated results using the setup model and the measured results correspond to each other within a few percent of deviation range, altough this reatively accurate calculation model is based on a great number of measuring results done by the author. It is to be concluded that:

- the number of experimental and „in situ" measurings of timber constructions should be high on account of the wide scatter in properties of such structures;
- it is suitable to implement and process both statical and dynamic measurings simultaneously;
- a basic requirement for an accurate model is to determine by measuring many and several sort of quantities along the axis of the structure.

THESIS 2

The processing and representation of the measurings done on the setup model, the results of the calculations done on the model and the comparison of the measured and calculated results allow to conclude the followings:

- the measured displacement figures are not symmetrical due to the properties of the timber material and due to the the construction features, while the relative displacement figures are not antimetrical. The localization of the zero point of the displacement force is being shifted by increasing the load as well as by decreasing the cooperation of the single beams;
- the experimental and theoretical comparison proves that the localization of the extreme values of the displacement curves falls close to the elongation of the upper beam. The relative rotation formed in the cross section at the elongation makes the bending rigidity considerabely decreased locally, which influences the sliding in the questioned cross section;
- the law of Hooke as well as the proposition of Maxvell apply in the entire length of the structure which models the reality well, and the cross section and structural measures of the construction can be accepted as being symmetrical applying certain approximations. The behaviour of the construction at the joint of the two timbers is non linear due to the hectic changings of the **K** displacement modul, especially not in case of minor loads;
- the stoops arising from a single unit of force are to be calculated by proportionating the measured values with each other and by taking into account the torque changes due to the rotation of the flexible knuckle. The linear model can only be securely applied in case of extreme forces directly prior to resulting in irreversible damage;
- the approximations, the substance model, the material features, the statical framework, the measure and distribution of the tare and the chincks of the structures etc. all might raise the demand for applying a non-linear model, which would be definitely worthy to try.

THESIS 3

The measurings and the respectively done theoretical calculations proved the assumption of linear behaviour of timber constructions may lead to mistakes in case of numerous already built timber constructions. (In the present case, the absolute and relative displacement of the two timbers of the beam as well as the changing in the damping of the eigenvibrations showed the behaviour of the construction to be non-linear.)

Despite the above, the construction occasionally modified by executive failures (i.e. the quality of the timber material is lower than expected, or the formation of the joints is less accurate) as well as by time-induced structural alterations (i.e. the connections within the structure loosen with time, or unexpected motions spoil the cooperation), can be described using linear theories with the help of certain modifying factors. Consequently, the linear theoretics can be applied to structurally non-linear constructions, as well as the differental equation described to a construction with presumably linear behaviour can also be calculated (that are to be solved using initial values based on laboratory timber substance examinations), if the committed failures can be corrected by certain modifying factors based on measuring results, and the results can be verified.

It is advisable to evaluate the measuring results regularly right after having done the laboratory measurings, as long as the construction is able to be modified.
All values necessary to the theoretical calculations are to be measured, in order to decrease the inaccuracy resulting from the non-linear property. The rate of the occasional symmetry is to be verified by measurings, as well as it is to be decided whether it can be approximated.

THESIS 4

It is theoretically verified and also supported by measurings published in the literature (Illéssy, Cantieni, Flesch, Tilly, Jávor et al.) that the dynamic changing of bridge constructions is characteristic (e.g. the process of aging). Upon the present examination published in this Ph.D. thesis, it is also to be concluded that each individual changing is specific to the respective facility and to the construction itself, in the same way as it is it in the case of the sliding of the two timbers on each other.
It has been stated regarding bridges that the reduction in the primary proper swinging rate by one octave (i.e. to the half of it) indicates the end of the applicability of the bridge. (Although there are no many sorts of measuring protocols being able to determine the above, but such a high grade reduction in the primary proper swinging rate do predict the close exhaustion of the load-bearing capacity of the construction.)

The maximal changing range of the eigenfrequencies published in the present Ph.D. thesis falls between the 3% and 10% of the initial value, in the same way as the consequent increase due to the permanent weakening of the stoops (i.e. the decrease in flexibility) does. Since the reason behind the decrease in rigidity is known, the above mentioned rate of decrease in eigenfrequencies does indicate failures or structural changes. (The sliding between the two timbers and the rotation in the flexible knuckle increases, while the angle between the cross spannings and the beam decreases, i.e. the normal force in the supporting bar increases as its eigenfrequencies change.)
Analysing the effects of changings shows that:

- an approximate 1% changing in the eigenfrequencies is possible when measuring due to the modification of damping (e.g. occasionally more chinks are formed, alterations in humidity occur, connections loosen etc.), or when calculating due to ignoring the damping, therefore the above measure of changing does not allow to deduct any conclusion;
- being the primary eigenfrequency constant does not mean the dynamic properties (e.g. upper harmonics) are not influenced by time-induced effects. When doing dynamic observations, at least three – but better six – eigenfrequencies are to be detected. Minor changes are mostly indicated by the modified upper harmonics;

- an approximate 3% changing in the frequencies (primarily decrease) can already indicate a structural modification. The measure of changing in the eigenfrequencies depends on the character of the construction, on its spatial behaviour, on the direction of its spannings, on the occasional alterations in the formerly mentioned parameters as well as on the current mass distribution and on the proportion between the tare of the construction and its carried mass;
- the damping curve based on the response signals refers to whether the questioned construction is linear or non-linear. If either the damping calculated from the measurings or its character is constant, then the construction is practically linear;
- there might be such minor changes in the construction which are not accompanied by the decrease in bending rigidity (i.e. rotation, horizontal shift of a construction in the vertical plane, twisting of the supporting spannings etc.), which result in an increase in the eigenfrequencies, hereby being able to compensate occasionally the time-induced decrease in rigidity of the structure, or the increasing value remains.

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It is to be decided when examining the changings of the dynamic properties whether two measurings done in two different points of time are comparable, i.e. what the reason behind an occasional changing or even steadiness can be. For instance, how identical may the weight of the construction or even its carried weight be in case of two different examinations; whether any alteration influencing the structural damping (e.g. increased cracking, withering) did happen during the two examinations; whether the rigidity or flexibility of the construction did change (i.e. whether any knuckle pillar did not rotate, whether the gripped support did rotate, whether the effect of a support decreased or it even became flexible etc.).

Neglecting the damping means the consequent failure being under 1% in terms of the respective frequencies. Indeed, observing the process of damping means much more than the numerical value in itself. The quotient of the consecutive shifts is constant, since the T_0 period time concerning the respective frequency is constant as well. Therefore, the natural logarithm of those takes up a value close to this constant, the J logarithmic decrement, too.

Since timber constructions are relatively lightweighted in their substance as well as in their mass, and their joints are variable in their motions, their dynamic examination gives less direct quick result than that of constructions made of other substances.

The examinations on the spot are to be preceded by further laboratory measurings in order to assess the dynamic effects of the structural changes, or those are to be carried out paralel to the examinations on the spot. During the further examinations, special attention should be paid to the followings:

- the damping and logarithmic decrement of the structure are to be determined upon the measured dynamic response signals, irrespective of the fact that the practice occasionally does neglect the damping;

- there arise irreversible deformations from each statical load due to their non-linear behaviour. The dynamic measurings are to be executed after each loading in order to be able to relate the changings to the respective sort of load as well as to its measure;
- the timber girders and other structures made of more timber beams do react not only to the stress due to the applied loads, but also to the character of the specific load. Therefore it is suitable to execute the examinations using several sorts of load (i.e. one, two or three concentrated forces).
- An instructive and important phase in the dynamic examination is the comparison of the frequency spectra:
    - cross spanning doubled truss: 45,52,7,55,66 Hz;
    - twin truss framework: 18,16,52,44,66,21 Hz;
    - simple truss framework: 19,62,57,42,75,29 Hz;
    - simple beam: 10,25,20,21,29,88,54,42,65,62,74,70,86,42 Hz.

6. The applicability of the results

The present Ph.D. thesis is not of theoretical nature, therefore it does not aim to solve a calculation problem nor a subordinate question, does not contribute to answering any engineering question, does not discuss a formerly unknow even smarter mathematical approach, nor the related computed applications become easier.

Indeed, it does discuss how the calculations can approximate the reality, or how the measuring results can promote the accuracy of the calculations done on inevitably approximated models.

It does aim to be a humble contribution to be able to decide whether a model is accurate enough and to assess how accurate a model should be. It gives an example to show that despite the model is not perfectly suitable to solve the problem – as the beam and its description assume full linearity – how the same model can be corrected by knowing the measuring results and by determining the modifying factors applied also formerly.

The focus of the investigation of the Ph.D. thesis represents a real problem which is to be solved urgently. As it becomes clear from the present work, no detection method which could preserve the integrity of the examined object while recording its structural problems and discovering the reasons behind the changes may be generalized, at least not in the case of traditionally implemented timber constructions, mainly because of the structure-specific character of the changes.

The laboratory measurings executed when collecting data for the Ph.D.-thesis, their processing i.e. converting their results from machine units to *mm* and to *Hz*, the theoretical discussion of the structure with partially variable cross section, as well as the conclusions from having identified the measured and calculated results all primarily show the structural diagnostic examinations done by using dynamic methods cannot unequivocally become a frequent and usual investigation procedure, even if they may have the clearest theoretical background. The reasons behind that are the prerequisites of costly instrumentation and the legibility of the signs of dynamics, as well as the results have to be able to be reproduced by the user under the same circumstances.

It is also to be revealed in what conditions a specific change in the dynamic signs is significant, i.e. to decide whether and when it is to be taken into account or when might it be regarded as a consequence of the selected or given circumstances.

The term *required accuracy under the given circumstances* is to be defined case by case, i.e. how accurately a model is expected to match the construction in the reality. The changings might be so minor that they do not extend over the deviations resulting from the inaccuracy of the model, so even if they are determined, they do not allow to formulate any useful conclusion regarding the construction.

7. Further research

The Ph.D. thesis also documents the majority of the executed measurings, although they are not printed out for length reasons. Those constructions – that are slightly more compound than the statically definite simple beam – are also suitable for observing the dynamic changes, as well as their reasons behind and their courses. Processing the available and documented measuring results makes possible further elaboraton.

The measure of damping in the examined timber constructions falls onto the borderline between taking it into account and neglecting it. It would be suitable to procede with one of the elaborations by taking a $\underline{\mathbf{D}}$ damping matrix into account, since the measure of changing in the overtones in most cases is comparable with the measure of failure resulting from neglecting the damping.

Since the formerly setup beam does not exist anymore, a new construction will have to be built in order to be able to carry out new measurings, by taking into account the formerly collected experiences upon the then executed measurings and their processing. A couple of important considerations follows below:

- when formulating the task, it is to be examined more deeply whether and how well the construction to be investigated is able to be modelled, and whether such quantities can be expected to be determined based on the usual model, which do not allow to accurately describe the questioned phenomena due to their minor load, due to their less than laboratory accurate configuration or due to the uncertain qualities of their substance;

- on planning to observe minor changes, which may also be induced by the occasional modificaton in external conditions, it is to be questioned when the difference between the results of two different measurings may be regarded as being characteristic – as the damping of the construction, which accurate rate is indeterminable anyway, might have been changed during the period of time between the two examinations, not to mention the also unidentifiable modifications of the masses and rigidities;
- design regulations allow the substance of the designed constructions to fall securely into its borderline state when burdened with the determinative load, i.e. into the range of the upper limit of flexibility, a state which the construction is most linear in. (The model is being formulated in order to serve the secure setup of the constructions to be built, i.e. the setup of the construction based on the calculated values may only be more solid than required, but in no circumstances can it be less than that is necessary. In the same time, it is well known that the determinative load applies rarely, therefore the flexible behaviour is not certain. Consequently, those particular properties of the constructions which depend – also theoretically – directly on the bending rigidity of the cross sections, are inaccurate. The only question is the rate of that inaccuracy, as well as the measure of its effect.

  These problems do not exist when designing, except when the results measured and those calculated using models inevitably influenced by failures, are being compared with each other; i.e. for instance, in the case of the present Ph.D. thesis. Therefore the construction specifically built for this investigation, must have been examined and measured by starting with minor values and then by gradually increasing the load up to the borderline force.
  (The results of the measurings and those of the calculations would have more accurately matched each other without applying corrections, especially if larger loads would have been selected, too. The expected borderline load on the examined beam is at least 70 kN in the case of one single concentrated force attacking in the middle cross section, i.e. the marginal fiber tensions arising from the applied load do not achieve more than a half or one third of the standard borderline tension, so the flexible behaviour cannot be certain.);
- the dynamic excitation has to be executed in a way, where not only its effect, but also the excitation itself is fastened, and the input signal (such as the frequency, or the grade and the energy of the hit) is able to be reconstructed, which circumstances makes the processing easier and more accurate;
- as the changing of the dynamic properties is also specific to the particular construction, each one of the frequently applied structures are to be examined in order to be able to pay attention not only to the general conclusions deductible from the relevant theories anyway, but also to the minor changes, which may not be able to be mathematically formulated. Indeed, upper harmonics are being modified by them.

Dynamic construction analysis does have a future, although the data processing is costly and demanding in terms of the required instrumentation. The examinations make only sense when repeated on a regular basis, and the measuring results from each period are to be compared with each other, since the monitoring of the changes has paramount diagnostic value due to the construction-specific properties. Being only a question of organization, this is to be solved easily. Indeed, although rapid results can hardly be expected from this examination method, which preserves the integrity of the examined object (nondestructive method), but it is able to become the most accurate diagnostic procedure and structural follow-up method on the long run, especially when supported and refined by further focused research.

Gyõr/Hungary, March 2007

8. Publications

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The development of the Ph.D. thesis has been supported by the softwares below:

• **MS Word**	text, design
• **MS Excel**	plot, table
• **Maple V** és **Maple 8**	applied mathematics
• **catmanÒ 2.2R2** és **catmanÒ 5.0R3**	measuring and processing
• **FEM - Design 5.0 és 6.0**	static and dynamic calculations
• **AutoCADÒ LT 2.0**	plot, design
• **Allprojekt**	static calculations, plot