II

Effect of Prestress on the Damping of Concrete

Influence de la précontrainte sur le facteur d'amortissement des oscillations dans les structures en béton armé

Einfluss der Vorspannung auf die Dämpfung von Betonkonstruktionen

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In the Structural Research Laboratory at the Technical University of Denmark some tests were carried out in order to investigate the effect of prestress on the damping properties of concrete. The research project was carried out by P. Haurbæk under the supervision of C. Dyrbye. The test results have not yet been published. A brief description will be given in the following.

Three different types of tests were made:

In our 10 Mp high frequency Amsler pulsating machine (Fig. 1) 18 cm long concrete prisms with a 6 by 6 cm square cross section were subjected to oscillating compressive stresses.

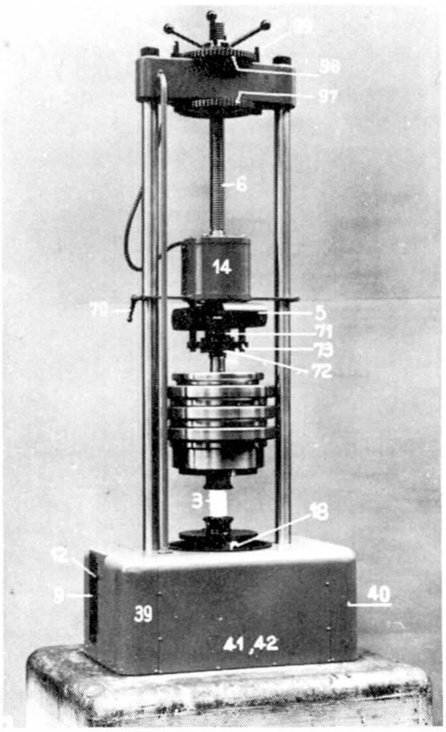


Fig. 1.

When the machine was stopped the free vibrations were gradually damped (Fig. 2). The relation between the imposed stresses and the damping is illustrated by the curves in Fig. 3. The ordinates indicate the damping

Fig. 2.

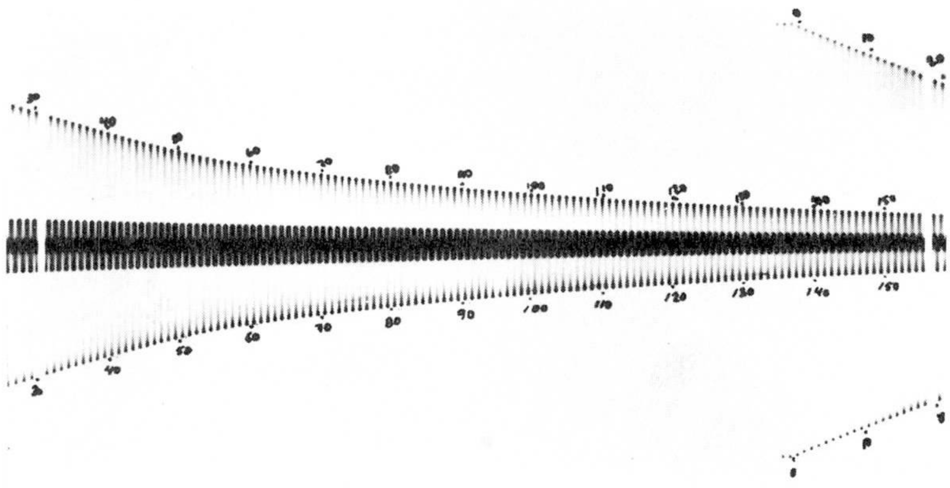
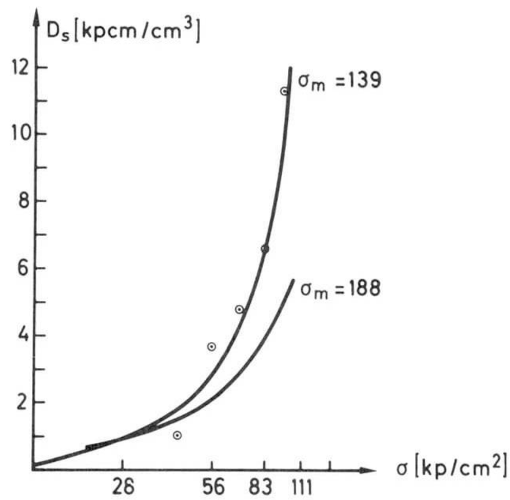


Fig. 3.



expressed by the dissipated energy per unit volume. The abscissas indicate the dynamic stress amplitudes. The average stress was 139 kp/cm^2 for the upper curve and 188 kp/cm^2 for the lower curve.

In the second test series 45 cm long concrete prisms with a 15 by 15 cm square cross section were tested in our low frequency Amsler testing machine (Fig. 4) and the damping of the forced vibrations was measured. The average stress was 139 kp/cm^2. The results correspond to the five points indicated in Fig. 3. Thus good agreement was found between the high and low frequency test.

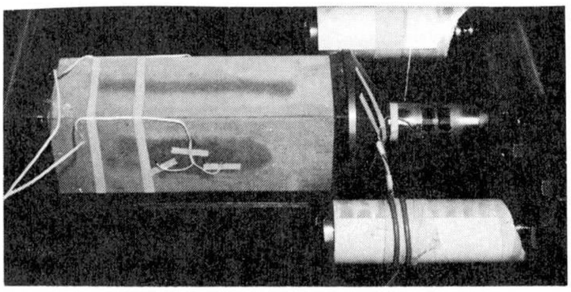
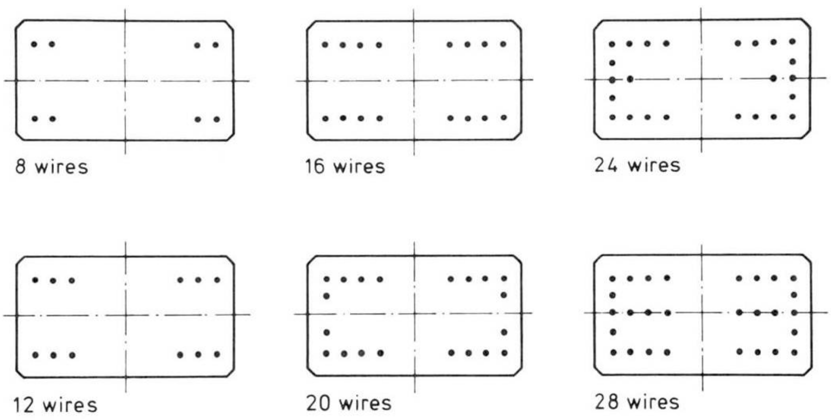


Fig. 4.

In the third test series twelve pretensioned beams were investgated. These beams were 6 meters long. The cross section had a depth of 13 cm and a width of 24 cm. The beams were identical with the only exception that six different levels of prestress were obtained by using different numbers of prestressing wires (Fig. 5). The beams were simply supported (see Figs. 6 and 7).

Fig. 5.



Cross sections of beams with different numbers of prestressing wires

Fig. 6.

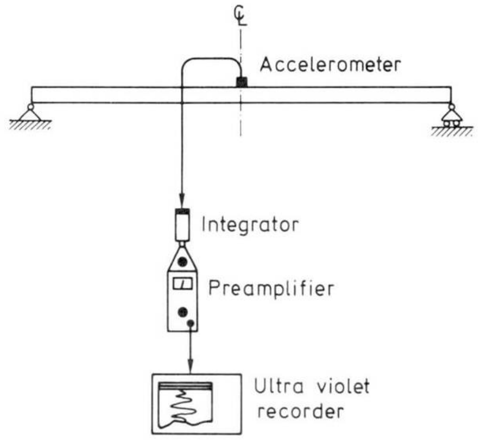
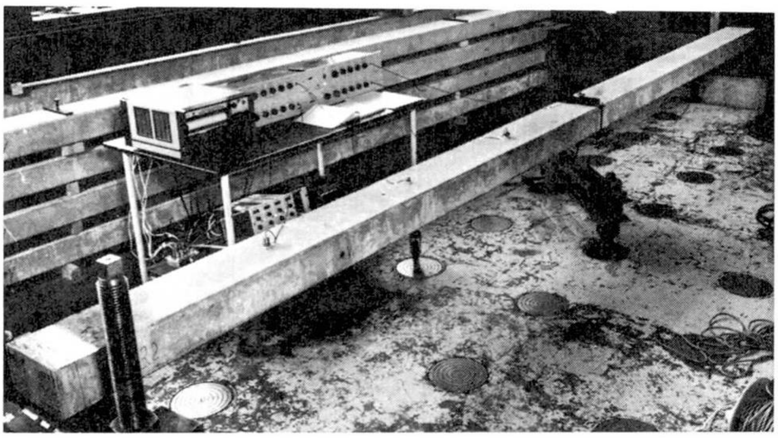


Fig. 7.



A static load was suddenly removed, and the ensuing vibrations were measured by means of an accelerometer (Figs. 6 and 8) and were recorded in diagrams as shown in Fig. 9. The damping characterized by the logarithmic decrement was calculated from these records. The results are illustrated in Fig. 10, where the abscissas indicate the dynamic stress amplitudes and the ordinates indicate the logarithmic decrement. The six curves represent the six different levels of prestress characterized by the number of prestressing wires. Except for the beams with 20 wires the results appear reasonable, but it has not been possible to give a satisfactory explanation of the apparent discrepancy of the results from the beams with 20 wires.

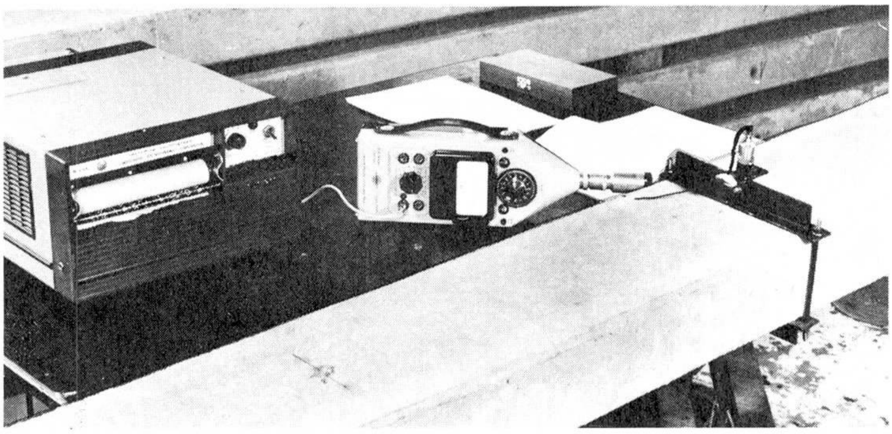


Fig. 8.

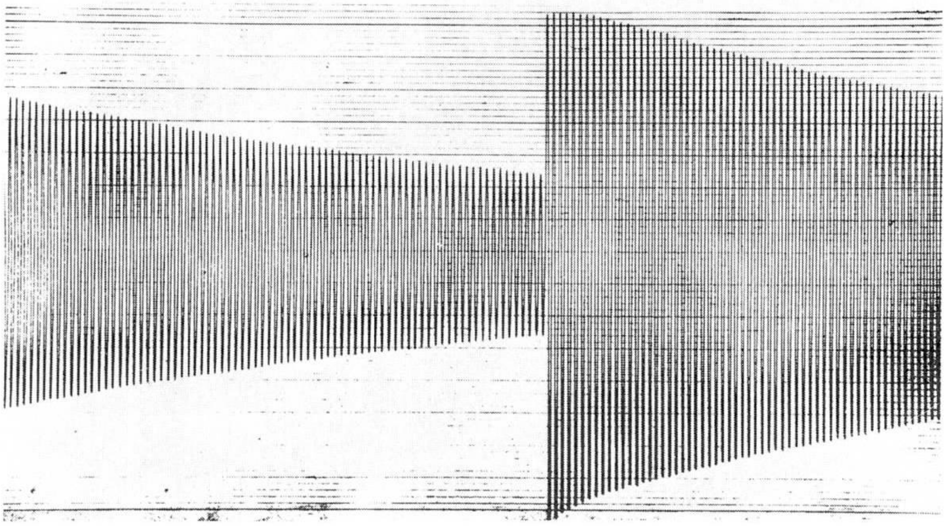


Fig. 9.

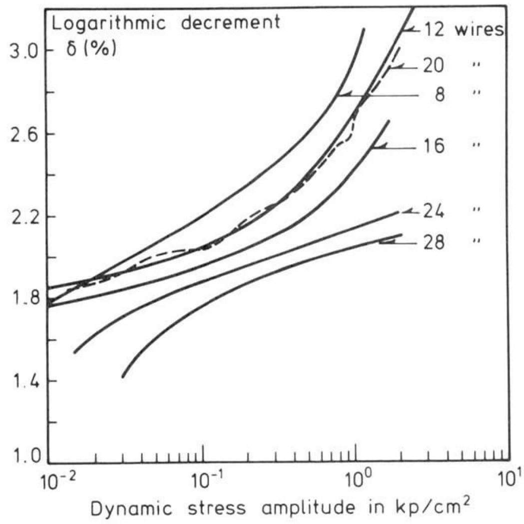


Fig. 10.

Conclusion.

The general tendency in all three test series is that the damping is reduced when the prestress is increased and when the stress amplitude is decreased.

SUMMARY

Test carried out at the Technical University of Denmark indicate that the damping of concrete structures is reduced when the prestress is increased and when the stress amplitude is decreased.

RESUME

Des essais effectués à l'Université Technique du Danemark montrent que le facteur d'amortissement des oscillations dans les structures en béton diminue avec l'augmentation de la précontrainte et avec la diminution de l'amplitude de contrainte.

ZUSAMMENFASSUNG

Versuche an der Technischen Hochschule Dänemarks zeigen, dass die Dämpfung von Betonkonstruktionen mit zunehmender Vorspannung und mit abnehmender Spannungsamplitude reduziert wird.

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II

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Vibration Damping of Structures

Amortissement de vibrations dans les structures

Dämpfung von Vibrationen an Tragwerken

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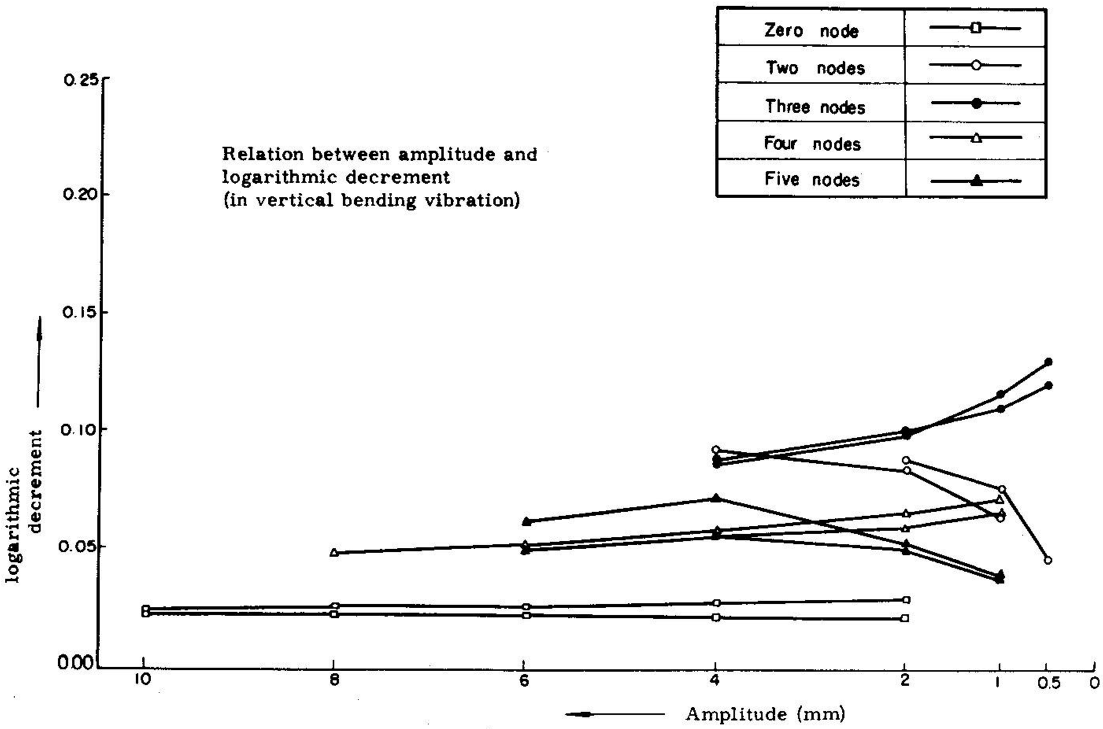
In their contributions in the Preliminary Report, Y. Yamada[1] and S. Mentel[2] reported that the damping constant increased with the increase of initial amplitude.

However, it should be noted that the above tendency reveals itself when the initial amplitude exceeds a certain critical value, beyond which friction damping or hysteretic damping seem to come into effect. An example[3] in the figure below and Figs. 5 to 7 in the paper by Mentel[2] show that the logarithmic decrement is almost independent on the initial amplitude when the amplitude is not large. But the general estimation of the critical initial-amplitude mentioned above is not



Relation between damping and initial amplitude
A truss-stiffened suspension bridge with a span length of 180 m. Data after Okubo and Narita, 1969.

clarified at the present stage.

Next, the writer should like to make a short supplemental comment on his contribution in the preliminary report. The logarithmic decrement is not always constant even in a particular oscillograph record of the free vibration test, and therefore, the values of logarithmic decrement referred in his contribution are the average value from many subsequent, usually ten to fifty, waves. In the range of small amplitude, the global value of logarithmic decrement seemed to be approximately constant, that is, the nature of damping was considered as viscous one.

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3) Okubo, T. and Narita, N.: An Experimental Study of Dynamic Characteristics of the Kompira Bridge, Tech. Note, ST-4, Public Works Res. Inst., Japanese Gov., Dec. 1969.

Die Ermittlung des Energieaufnahmevermögens von Konstruktionselementen aus Stahlbeton unter wiederholt aufgebrachter Belastung mittels der Methode der finiten Elemente

Calculation of the Energy Absorption Capacity of Concrete Structural Members acted on by Defined Repeated Loads by the Finite-Element-Method

La détermination de la capacité d'absorption d'énergie des éléments de construction en béton armé sous l'action de charges répétées au moyen de la méthode des éléments finis

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1. EINLEITUNG

Die Problematik einer theoretischen Ermittlung des Energieaufnahmevermögens ganzer Strukturen liegt in dem zum heutigen Zeitpunkt noch völlig unzureichend erforschten Last-Verformungsverhalten komplexer Tragwerksbereiche, die einer gegebenen wiederholten Belastung ausgesetzt sind, etwa den Verbindungspunkten von Balken und Stützen in Rahmenkonstruktionen. Die Fülle der hier noch offenstehenden Probleme lassen sich durch Versuche allein innerhalb eines kürzeren Zeitraumes nicht lösen. Es wird daher notwendig sein, Rechenverfahren, die besonders zur Feinstrukturanalyse geeignet sind, in verstärktem Maße zur Untersuchung des Energieaufnahmevermögens einer Reihe verschiedener Konstruktionselemente heranzuziehen.

2. METHODEN ZUR ERMITTLUNG VON LAST-VERFORMUNGSBEZIEHUNGEN

Eine Ermittlung von Last-Verformungsbeziehungen für einzelne Strukturbereiche einer Stahlbetonkonstruktion, im weiteren als Konstruktionselemente bezeichnet, kann entsprechend der in Bild 1 gegebenen Übersicht auf analytischem oder experimentellen Wege erfolgen. Für rechnerische Untersuchungen stehen im wesentlichen zwei Verfahren zur Verfügung, nämlich Rechenverfahren [1-5], denen weitgehend die Annahmen der Balkentheorie zugrunde liegen, und die Methode der finiten Elemente [6,8]. Die finite Elementmethode besitzt gegenüber allen anderen Berechnungsverfahren den Vorteil, allgemein ohne Einschränkungen anwendbar zu sein. Es lassen sich mit dieser Methode die Last-Verformungsbeziehungen sämtlicher interessierender Konstruktionselemente für jede gewünschte Wahl der Einflußparameter berechnen. Die bisher in diesem Zusammenhang auf theoretische Untersuchungen angewendeten Verfahren nach der Balkentheorie haben hingegen einen stark begrenzten Anwendungsbereich.

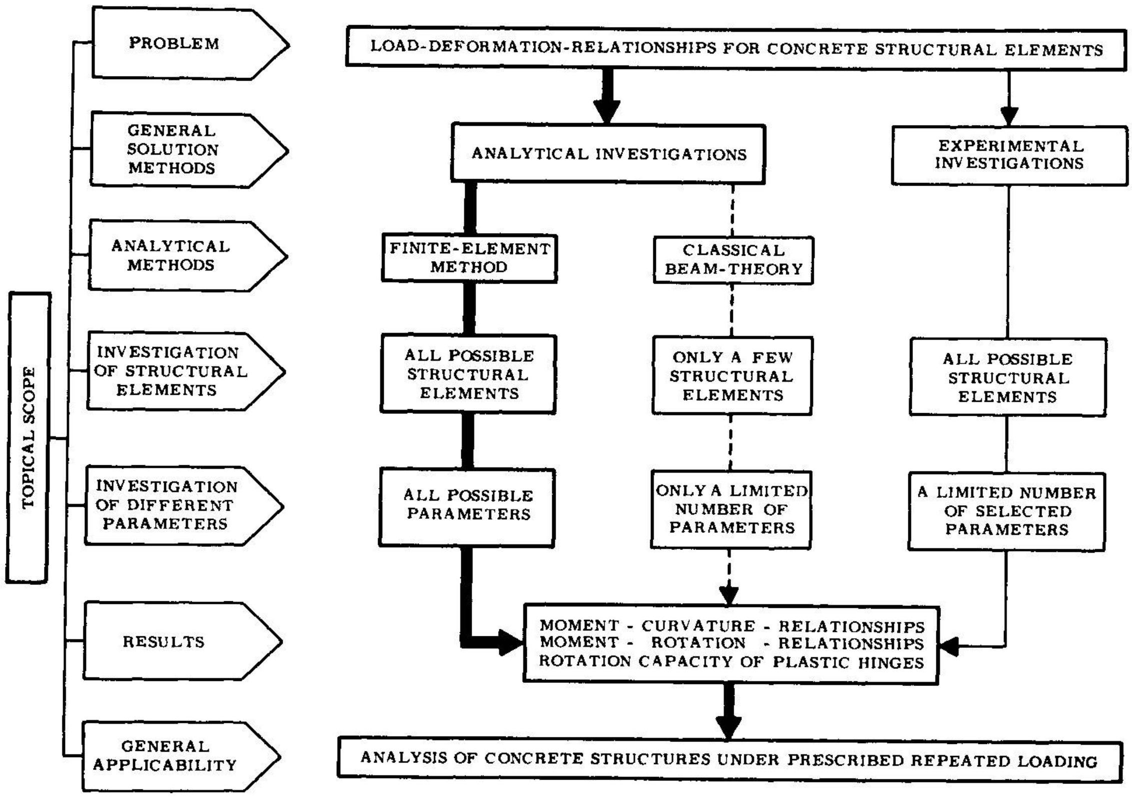

Bild 1: Methoden zur Ermittlung von Last-Verformungsbeziehungen

3. KRITERIEN ZUR AUSWAHL EINES GEEIGNETEN RECHENVERFAHRENS

Die Auswahl eines geeigneten Rechenverfahrens für die erforderlichen theoretischen Untersuchungen kann an Hand der in Bild 2 aufgeführten Kriterien weitgehend vorgenommen werden. Eine analytische Ermittlung des Last-Verformungsverhaltens wiederholt belasteter Konstruktionselemente kann nur zu wirklichkeitsnahen Resultaten führen, falls das zum Einsatz gelangende Rechenverfahren die im folgenden genannten Bedingungen weitgehend erfüllt.

Das einer Berechnungsmethode zugrundeliegende mechanisch-mathematische Modell muß eine wirklichkeitsnahe Spannungs-Verformungsberechnung des zu untersuchenden, im allgemeinen Fall räumlichen Konstruktionselementes ermöglichen. Ein durch geometrische Idealisierung gewonnenes Rechenmodell sollte dem Originalbauteil in allen wesentlichen Bestandteilen entsprechen. Die Spannungs-Verformungsermittlung von Konstruktionselementen, die bis an die Grenze ihrer Trag- oder Verformungsfähigkeit beansprucht werden, erfordert die Einbeziehung nichtlinearer Werkstoff- und Verbundgesetze in die Berechnung. Es muß weiterhin möglich sein, die Rißbildung und örtliche Zerstörung des Betons und des Verbundes durch die Rechnung zu erfassen.

Die Methode der finiten Elemente erfüllt die genannten Anforderungen weitgehend und ohne wesentliche Einschränkungen. Es kann daher mit diesem Verfahren eine realistische Ermittlung des Energieaufnahmevermögens komplexer Konstruktionselemente durchgeführt werden.

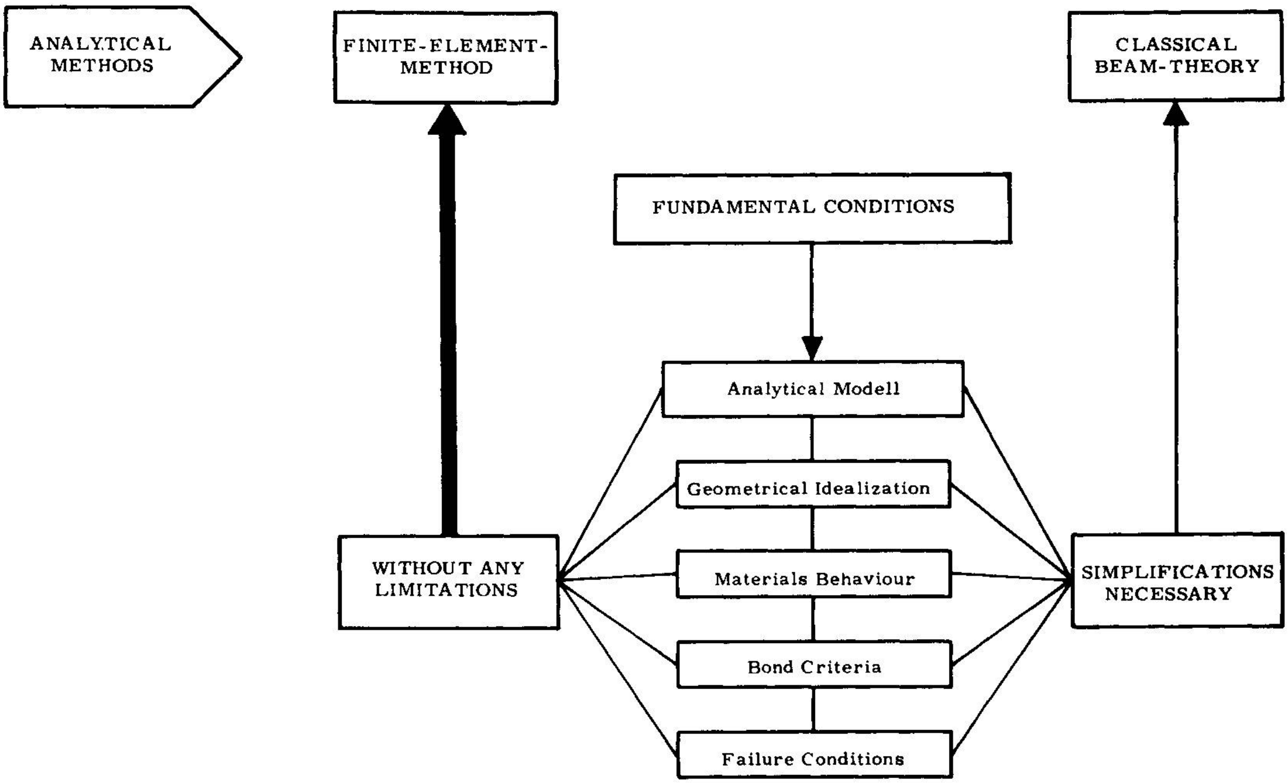

Bild 2: Kriterien zur Auswahl geeigneter Rechenverfahren

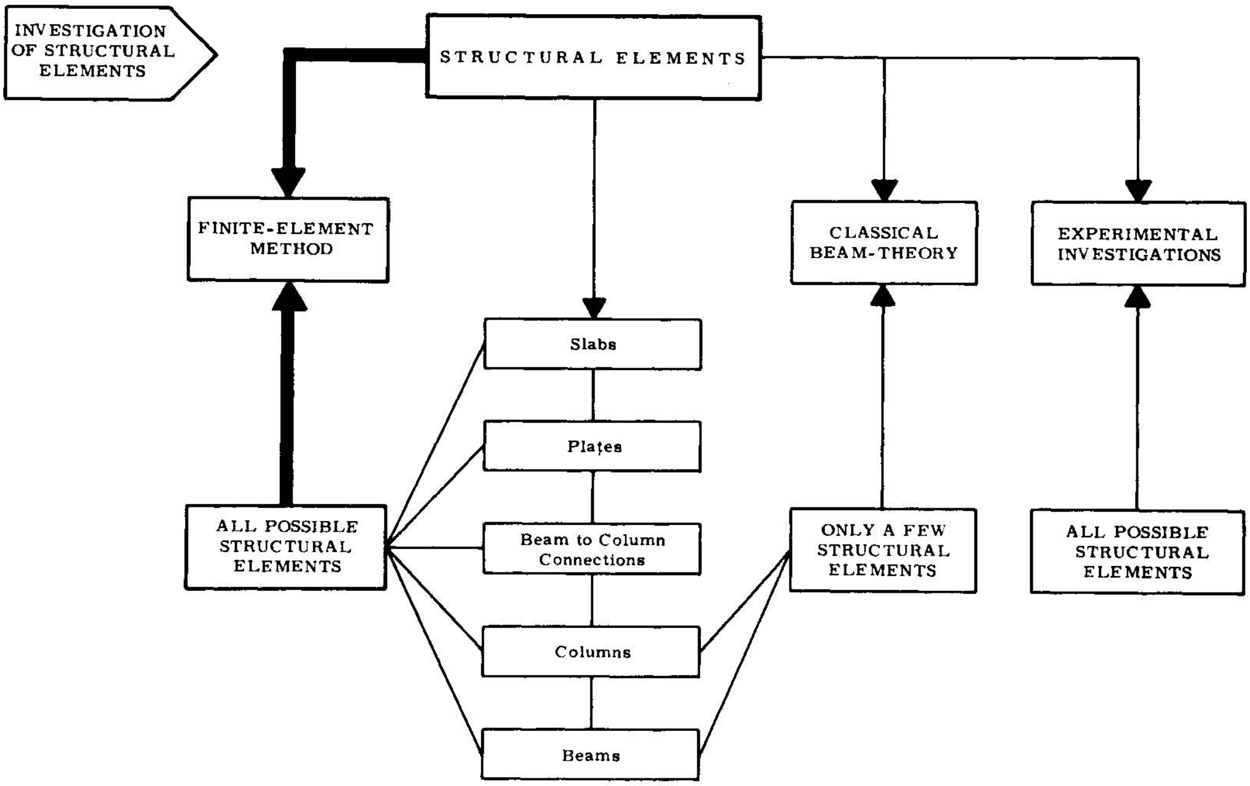

Bild 3: Untersuchung des Last-Verformungsverhaltens von Konstruktionselementen

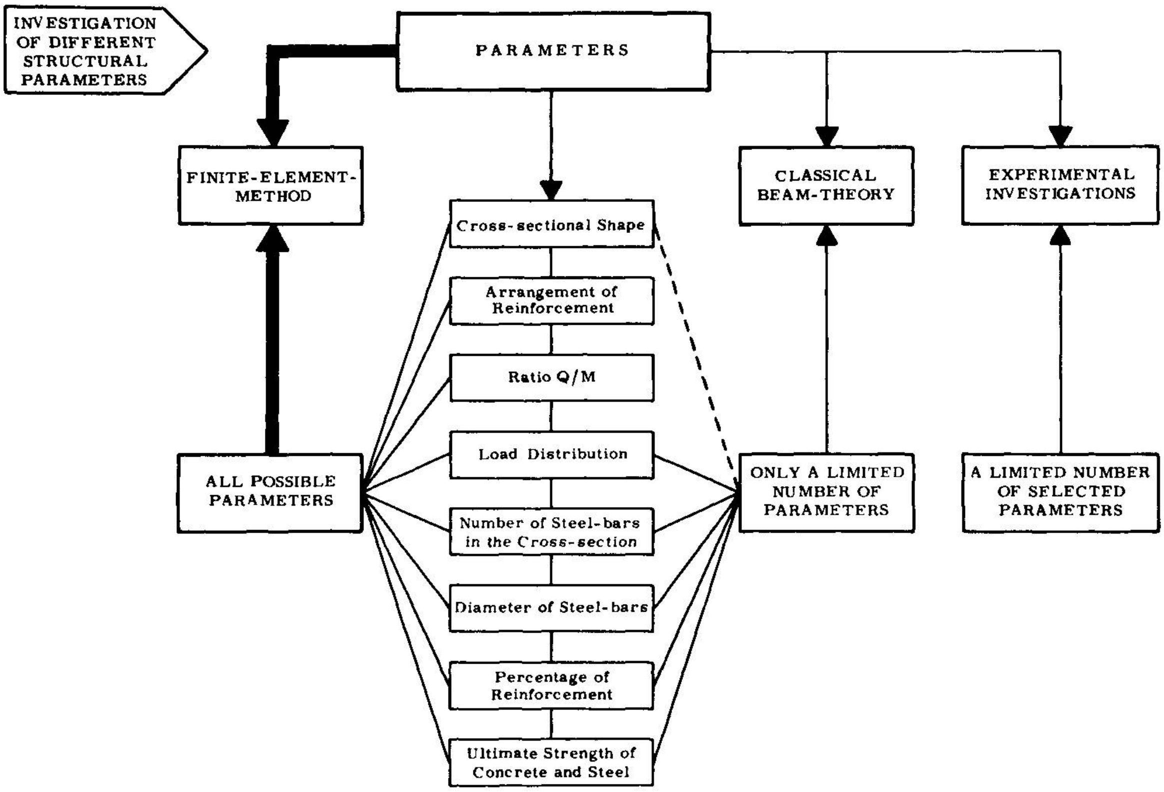

Bild 4: Untersuchung des Last-Verformungsverhaltens in Abhängigkeit verschiedener Einflußparameter

4. UNTERSUCHUNG VERSCHIEDENARTIGER KONSTRUKTIONSELEMENTE

Zu untersuchen ist das Energieaufnahmevermögen einer Reihe verschiedenartiger Konstruktionselemente, aus denen eine Stahlbetonkonstruktion zusammengesetzt gedacht werden kann. Aus Bild 3 ist zu entnehmen, daß hier die Methode der finiten Elemente universell einsetzbar ist, und insbesondere die Last-Verformungsbeziehungen räumlicher Kreuzungspunkte, z.B. die Verbindungsstellen von Unterzügen und Stützen in Rahmenkonstruktionen, untersucht werden können. Die Balkentheorie kann hier lediglich zur Ermittlung von Momenten-Krümmungsbeziehungen stabförmiger Bauelemente eingesetzt werden [1-5].

Verschiedentlich wurde die Methode der finiten Elemente bereits zur Erforschung grundlegender Zusammenhänge im Stahlbetonbau angewendet. Die Untersuchungen konzentrierten sich jedoch bisher im wesentlichen auf die Spannungs-Verformungsermittlung in Stahlbetonbalken und -Rahmen [7,9-12].

5. UNTERSUCHUNG VERSCHIEDENARTIGER EINFLUßPARAMETER

Für die verschiedenartigen Konstruktionselemente sind die Last-Verformungsbeziehungen abhängig von einer ganzen Reihe von Parametern, von denen die wichtigsten in Bild 4 aufgeführt sind. Bei der Durchführung der Untersuchungen mit der Methode der finiten Elemente kann eine Berechnung für jede beliebige Kombination dieser Parameter durchgeführt werden. Im Gegensatz dazu können bei einer Berechnung nach der Balkentheorie selbst bei der Betrachtung stabförmiger Bauteile wesentliche Einflußgrößen nicht in ausreichendem Maße berücksichtigt werden.

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ZUSAMMENFASSUNG

Zweck dieses Beitrages ist es, aufzuzeigen, dass eine theoretische Untersuchung des Energieaufnahmevermögens wiederholt belasteter Konstruktionselemente aus Stahlbeton ohne jegliche Beschränkungen mit der Methode der finiten Elemente möglich ist. Dieses Rechenverfahren ist in besonderem Masse dazu geeignet, das Last-Verformungsverhalten einer Reihe verschiedenartiger Konstruktionselemente - Balken, Stützen, Knotenpunkte usw. - in Abhängigkeit aller wesentlichen Einflussparameter - Belastung, Bewehrungsführung, Bewehrungsprozentsatz usw. - zu ermitteln.

SUMMARY

The purpose of this contribution is to show that the theoretical investigation of the energy absorption capacity of concrete structural members acted on by defined repeated loads can be well performed by the Finite-Element-Method.

The load-deflection behavior of various structural members - beams, columns, beam to column connections etc. - which is depending on essential influencing parameters - load-distribution, arrangement of reinforcement, percentage of reinforcement etc. - can be calculated by this method.

RESUME

La présente contribution a pour but de démontrer la possibilité de mener une étude théorique sans aucune restriction par la méthode des éléments finis concernant la capacité d'absorption d'énergie d'éléments de construction en béton armé soumis à des charges répétées.

Cette technique de calcul se prête particulièrement à la détermination du comportement charges-déformations d'une série d'éléments de construction différents - poutres, appuis, assemblages etc. - en tenant compte de tous les paramètres d'influence essentiels tels que charge, position des armatures, pourcentage d'armature etc.

II

The Dynamic Effects on Prestressed Concrete Bridges Built without Falsework

Effets dynamiques sur les ponts en béton précontraint construits sans échaffaudage de montage

Die dynamischen Einwirkungen auf im Freivorbau gebauten Spannbetonbrücken

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In course of recent years at the construction of large span bridges the method of construction of prestressed concrete bridges without falsework was generally used. Those are structures of cantilever type mostly continuous with several spans often with various type of hinge connection at the centre of span of single spans.

Theoretic solution of the problem of dynamic effects of vehicles upon larger span bridges is often considered as a beam with an elastic layer over which passes a system with two degrees of freedom. In the case of a simple beam this brings about a system of three simultaneous linear differential equations with varying coefficients, two of them usually being of the second order one partial of the fourth order at "x" and of the second one at "t". As external force we consider the force harmonically variable and we assure the rigidity for vehicles as periodically variable over the whole beam length. In the case of a task it is necessary to define exacting initial and boundary conditions. The entering quantities of the majority of constants depend upon many factors. These parameters, therefore, are idealized but solutions are known for which this task in the case of a simple beam are solved by means of 20 principal and 4 auxiliary entering parameters.For continuous structures the task are still more exacting. That was the principal reason for our decision to examine the bridges built without falsework in an experimental way from the point of view of various parameters which act in a most expressive way upon structure vibration and fatigue.

The quantities obtained experimentally were examined from the point of view of the most often used dynamic parameters of bridge structures such as:

- dynamic deflection coefficient δ_w, relative deformation δ_ε, or stress coefficient δ_σ

- the natural frequency of the unloaded $/f_0/$ or even of the loaded $/f_1/$ bridge
- the natural circular frequency of the unloaded $/\omega_0/$ or loaded $/\omega_1/$
- the logarithmic damping decrement ϑ
- the circular damping frequency $\omega_b = \vartheta . f_o$
- the damping coefficient $D = \frac{\omega_b}{\omega_o}$
- the damping frequency $f_b = \frac{\omega_b}{2\pi}$
- the critical speed „C"

The results of the examination of dynamic effect at the prestressed concrete bridges erected by the cantilever construction method in Czechoslovakia have shown that these larger span structures have high dynamic coefficients, slow vibration damping and are eysily brought into some oscillation conditions. The most disadvantageous effects arise at the outer spans at the inner spans occurring a certain damping owing to the connection with the outer fields. It will be necessary to augment the influence of the hinge connection of two cantilevers in the middle of the span.

On the average for the spans and kinds of constructions examined by us we recommend to consider the following coefficients of deflection increase δ_{w}:

- the inner spans of bridges concreted without falsework provided with steel hinges δ_{w}= 1,35
- the outer spans of bridges concreted without falsework provided with steel hinges δ_{w}= 1,50
- the medium spans of bridges concreted without falsework provided with a reinforced concrete hinge δ_{w}= 1,45
- the outer spans of bridges concrete without falsework provided with a reinforced concrete hinge δ_{w}= 1,70
- the medium spans of frame-type bridges without hinge δ_{w}=1,60
- the outer spans frame-type bridges without hinge δ_{w}= 1,85

At the same time it is necessary to secure a smooth roadway surface on the bridges and for the region in front on and behind the bridge as the unevenness of the pavement considerably increases the dynamic effects upon the bridges.

It is obvious that relatively high dynamic coefficients for bridges not always mean harmful effects from the point of view of the bridge structure bearing capacity as the design moment for which the bridge is considered is always far more higher. The loads capable of bringing about the design moment required may be attained only with a greater number of vehicles which abolish their mutual effects which means that dynamic effects in this case are much more lower and within the standart limits. It was the reason why we carried out our dynamic tests of the bridges erected by a cantilever construction method by means of vehicles with a wheel and not caterpillar undercarriage for which irregularity and larger caterpillar surface moderate dynamic effects. It was shown also for other frame and other type bridges.

From the above it follows that the dynamic coefficients of bridges become only orientation values and in the future it will be necessary to consider the constructions of this type dynamically at the design. The importance of the examination of dynamic effects consists also in possibility of considering the bridge as to fatigue. This is permitted by cognizance of the natural bridge frequency and of statistic data on transport density.

Very important but often neglected factor is also an estimation of biologic and psychologic effects of strong bridge vibration upon pedestrians not acquainted with the statics, but primarily upon motorists in vehicles travelling across the bridge. On the base of a research in the USA according to Janeway and Oehler the safe limit to a still discomforting oscillation is given by the relation $a.f^3 = 2$ for frequencies of 1 through 6 cycles p.s. and $a.f^2 = 1/3$ for frequencies of 6 through 12 cycles p.s. where „a" is the amplitude in inches and „f" the natural frequency of bridge.

From what was said it follows that the bridges of larger spans we examined from the point of view of biologic action of bridge structure vibration upon man for dynamic effects acting on the bridge are discomforting. For instance in the case of the Kollárovo bridge /fig.1/ at the 2nd span during the passage of one vehicle weigting 20 t the $a_{dyn} = a_{sts} . \delta_{sr} = 0{,}585$ cm . $1{,}35 = 0{,}312$ i. for $f = 2{,}56$ c/s. Then $af^3 = 5{,}22 > 2{,}0$, i.e. the structure may have infavourable effects from biologic and psychologic point of view upon the driver. It might lead to a breakdown especially in the case of an adequate resonance during the passage of two vehicles moving against each other. It will be necessary to solve this problem for the design of modern subtle bridge structures.

Fig.1 The 5-span bridge concreted without falsework across the river Váh at Kollárovo during testing

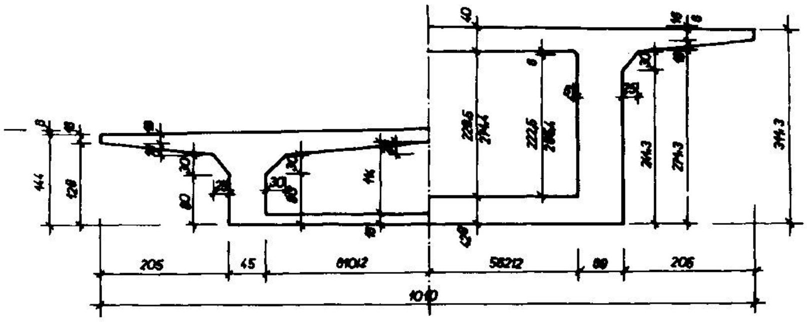

Fig.2 A scheme of cross-section of the bearing structure of the bridge Kollárovo.

SUMMARY

The results of the examination of dynamic effects at the prestressed concrete bridges erected by the cantilever construction method have shown that bridges with larger span have high dynamic coefficients and slow vibration damping. A very important factor is also the estimation of biological and psychological effects upon the drivers travelling across the bridge.

RESUME

L'analyse des effets dynamiques effectués sur ponts en béton précontraint construits en encorbellement a permis de déceler la présence de coefficients dynamiques considérables ainsi qu'un amortissement de chocs trop lent pour les ouvrages de grande portée. Un problème très important est l'évaluation des effets biologiques et psychologiques sur le conducteur.

ZUSAMMENFASSUNG

Die Prüfungsergebnisse der dynamischen Einwirkungen an im Freivorbau gebauten Spannbetonbrücken haben bei grösseren Spannweiten grosse dynamische Beiwerte und langsame Dämpfung gezeigt. Sehr wichtig ist auch die Abschätzung der biologischen und psychologischen Einwirkungen auf den Fahrzeuglenker, welcher die Brücke benützt.

II

Comments by the Author of the Introductory Report

Commentaire de l'auteur du rapport introductif

Kommentar des Autors zum Einführungsbericht

Minoru WAKABAYASHI
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First, Messrs. Mazilu and Sandi who could not attend the symposium presented a method to formulate the damping capacity based on the linear rheological models, introducing different types of mathematical models. They also summarized the quantative results of the damping capacity of structures.

The damping behavior of the existing bridge superstructure was thoroughly discussed by Messrs. Ito, Katayama and Nakazono. They derived the average values of damping factors of bridge superstructures deducing a number of test data gathered, and discussed the effects of mode, mass, flexural rigidity, amplitude, supporting condition and interface friction on damping factors, that were found from the model tests.

The damping due to mechanical friction at the structural connection was discussed by Professor Yamada who could not attend, introducing the behaviors of welded and riveted beams under vibration test as an example. He showed the theoretical assessment on friction damping of cantilever beams with splice joints as well as the test results of cantilever and simple beams with one or two splice joints, and concluded friction damping increased with vibration amplitude.

Another set of test results on structural damping was reported by Dr. Mentel who was also absent. He tested a number of single I beams with stiffners and double I beams with several floor beams under different supporting conditions. Discussed in his paper were the effects of supporting conditions, number of floor beams, stiffness of floor beams, and skew angle of floor beams. He concluded in some cases the effect of structural damping in bridge structures can be the dominant one.

Three examples of the application of the damping device on the real structure were introduced by Messrs. Bobrowski and Cramer. They were a cantilever roof with heavy judge box at its tip, a roof supported by suspension cables, and a shell type roof. The most effective place of damping device was studied and a great deal of saving in the cost provided by the application of the damper was emphasized, comparing with the rigid high density design.

Following the presentations of the prepared discussions, Messrs. Brondum-Nielsen, Ito, Plauk, Javor and Ciolina presented their free duscussions on several problems concerning the damping and energy absorption of structures.

Unfortunately, the author had a feeling during the session of the symposium that the hysteretic damping of the structure had been scarcely discussed, to which more attention should be paid from the author's opinion.