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Autor: Brandes, Klaus

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Design of Reinforced Concrete Structures against Impact and Impulsive Loading

Projet de structures en béton armé sous l'effet de chocs

Entwurf von Stahlbetonkonstruktionen unter Stossbelastung

Klaus BRANDES
Dr.-Ing.
Bundesanstalt für Materialprüfung
Berlin, BRD

Klaus Brandes, geboren 1936, promovierte an der Technischen Universität Berlin. Nach vier Jahren Tätigkeit an der TU Berlin ging er an die BAM. Dort ist er vor allem mit bautechnischen Sicherheitsvorkehrungen für Kernkraftwerke beschäftigt.

SUMMARY
Reinforced concrete structures are suited in a particular way to withstand impact and impulsive loading. In contrast to static loads there may be considerable excedance of the limits of elastic behaviour. In addition to the strain limitations, deformation limits for the design have to be defined and determined. Gaps in our knowledge concerning this field have become obvious in recent years. The subject of this paper is a survey on how to succeed in closing these gaps.

RESUME
Les structures en béton armé sont très appropriées pour reprendre des chocs de haute intensité. Par opposition aux sollicitations statiques, des déformations au-delà de la limite élastique sont possibles. En plus de la limitation des contraintes, il faut également prescrire des limites aux déformations. Ces derniers temps sont apparus des manques de connaissances évidents dans ce domaine que cette contribution essaye de combler.

ZUSAMMENFASSUNG
Stahlbetonkonstruktionen sind in besonderem Masse geeignet, Stoss- und Impulsbelastungen hoher Intensität zu widerstehen. Im Gegensatz zu statischen Beanspruchungen dürfen dabei die Grenzen elastischen Verhaltens erheblich überschritten werden. Zusätzlich zu Begrenzungen der Spannungen müssen auch Verformungsgrenzen für den Entwurf definiert und festgelegt werden. Kenntnislücken auf diesem Gebiet sind in letzter Zeit offensichtlich geworden. Über Bemühungen, die Lücken zu schliessen und deren Erfolge wird kurz berichtet.

1. INTRODUCTION

Definitions in standards for the design of reinforced concrete structural members against impact and impulsive loading with high intensity differ from definitions established for static loads in such a way that besides the stress limits also limits for deformations have to be stated. This is still a rather new field and knowledge herein is imcomplete. Only in the past years relevant investigations - experimental and theoretical-numerical - have been performed; their results being the basis for an initial approach to set up rules. Further investigations are still necessary, especially experimental ones, to generalize the so far attained findings and place them on a broad basis.

2. PROBLEM DESCRIPTION

Reinforced concrete structures are well suited to withstand impact and impulsive loads of high intensity. They have a large mass and may reach, by an appropriate constructive design, large plastic deformations. The fact that the ability to strongly deform under short-term loading is essential, may be clarified by comparison of a simple reinforced concrete beam under static and short-term loading. With static loading, the deformation in the elastic range increases proportional with the load (fig. 1). When yielding starts in the cross-section, the deformation increases overproportional and after reaching the maximum value R_u of the force-deformation-curve (limit load), a point has been reached beyond with statical allowable conditions become impossible.

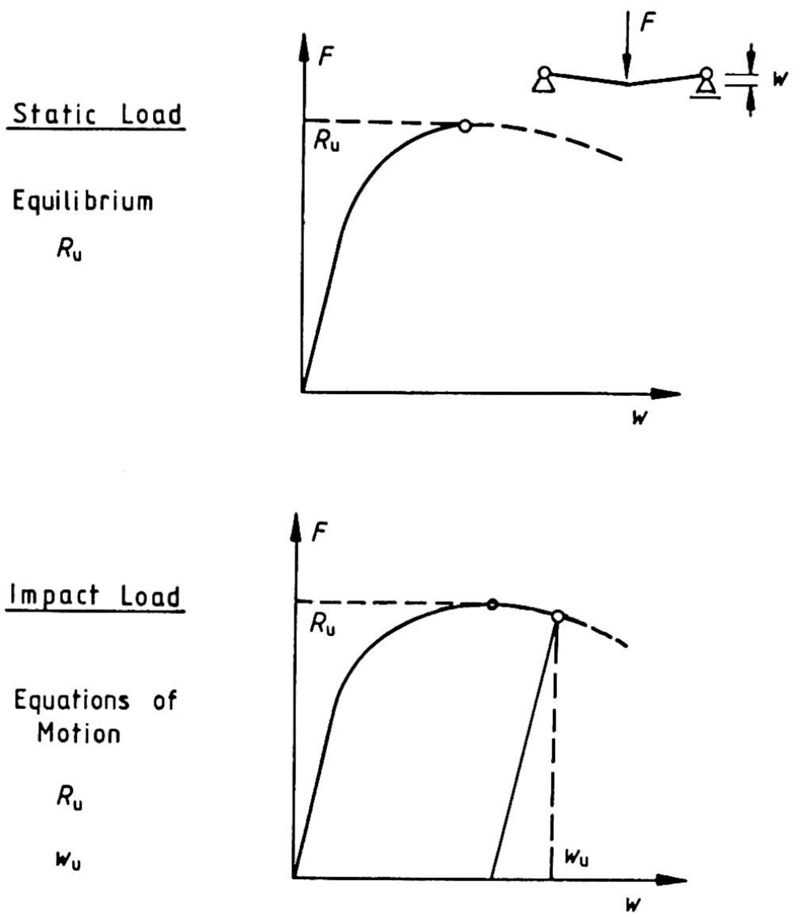

Fig. 1
Simply supported beam under static and under impact load. Load-deflection-diagram and characteristic values.

However, impact loads may exceed the value R_u (fig. 2). The structural member then follows the equations of motion.

The portion of the applying load F exceeding the value R = R(w) causes an accelerated deformation, mainly in the plastic range. Inertia forces, however, counteract this movement.

The plastic deformation is completed, if the impact force F drops below the actual value of R. To analyse the behaviour of the beam it is necessary that the curve R(w), and for a design formulation the value w_u (fig. 1) is known.

The solution of these problems is complicated insomuch as yield stress and tensile strength depend on the strain rate (fig. 3). Some results of the investigation confirm a similar dependence of the fracture deformation /1/.

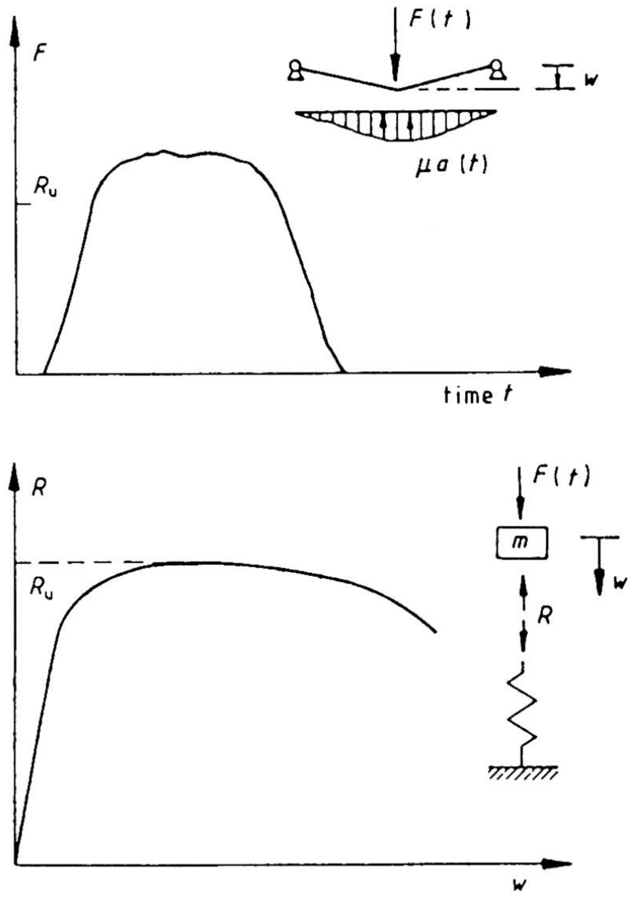

Fig. 2
Impact loaded beam. Impact force-time diagram, simple one-degree-of-freedom-system and resistance-deflection-curve.

3. INVESTIGATIONS, RESULTS, DEFINITONS

In the past years, extensive investigations, regarding a solution of these problems, were performed in the Federal Republic of Germany, also in Great Britain, France, Switzerland, the Netherlands and some other countries. A RILEM-symposium in 1982 also treated this topic in detail /2/.

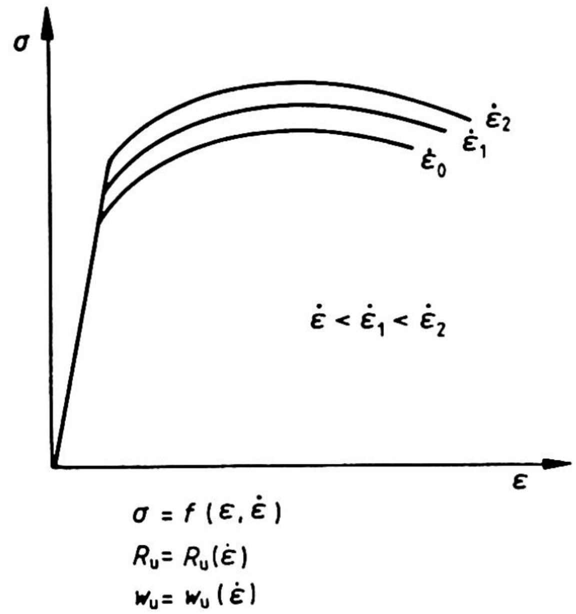

Fig. 3
Strain rate effect on reinforcing steel, schematical representation /6/

For impulsive loading and stresses due "soft missile impact", requirements on strain and deformation limits in plastic hinges can now be established, because of recent investigations. In the german nuclear code draft KTA 2203 /3/, the strain in the reinforcement, have been limited to 0.8-times that of the uniform elongation in tension tests (1.6 % ... 2.5 %). Regarding the rotational capacity θ_p of a yield hinge, the value from ACI 349-76 /4/,

$$\theta_p = 0.0065 \frac{d}{x} \leqq 0.07$$

was assumed for the limitation of rotation in plastic hinges, still requiring a re-examination. A survey on so far existing definitions is given in fig. 4.

The dependence of the material strength on the strain rate has been reflected in factors only by ACI 349-76. Investigations at the Federal Institute for Material Testing (BAM) confirm these statements /6/, fig. 5.

The safety assessment still has not been solved with stating these requirements, because safety factors were introduced for both stress limits and deformation limits whose coupling depends upon the overall system under consideration /7/.

4. SCOPE

First steps have been made to determine and define the properties of reinforced concrete structural members under impact and impulsive loading necessary for the engineer to design a structure. Further investigations, especially tests, are required to close the still existing gaps in knowledge. One question would, for example, concern the validity range of the meanwhile determined mathematical interrelationships describing the dependence of material characteristic values on the strain rate, but also the question regarding the influence of the strain rate history /6/.

Reinforced Concrete Structural Members / Reinforcing Steel

U L T I M A T E D E F O R M A T I O N

Design Values / Observed Values

CEB Model Code (8.3): Plastic Rotation (static load):

$$\vartheta_{p,u} = \begin{cases} 0.007 & \text{for } x/d = 0.6 \\ \vdots & \\ 0.040 & \text{for } x/d = 0.1 \end{cases}$$

ACI 349-76: Plastic Rotation (static and dynamic load):

$$\vartheta_{p,u} = 0.0065 \; d/x \leqq 0.07$$

KTA 2203 (draft 1983): Plastic Rotation:

$$(\vartheta_{p,u} = 0.0065 \; d/x \leqq 0.07)$$

Uniform plastic strain in reinforcement:

$$\varepsilon^{p}_{d,u} = 0.8 \; A_g \leqq 2.5 \; \% \; ^{*})$$

Observed Values (BAM - Investigation):

$$\vartheta_{p,obs,u} = \begin{cases} 0.19 & (\text{dyn.load, } f_y = 420 \text{ MPA}) \\ \vdots & \\ 0.08 & (\text{stat.load,} f_y = 1100 \text{ MPa}) \end{cases}$$

*) A_g uniform plastic elongation in tension test

Fig. 4 Requirements for deformation of plastic hinges or strain in reinforcemnet bars. Comparison of design values in several codes with observed values

$f_{y,o}$ N/mm^2	$f_{y,imp}/f_{y,o}$ ACI 349-76	BAM-Investig.
280	120 %	
350	115 %	
420	110 %	111 %
1100	100 %	100 %

Fig. 5 Strain rate dependent strength of reinforcing steel

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