Application and experimental verficiation of advanced mechanics in reinforced concrete

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Application and Experimental Verification of Advanced Mechanics in Reinforced Concrete

Exemples d'application et vérification par expérimentation des nouvelles méthodes utilisées en mécanique des structures en béton armé

Anwendungsbeispiele und experimentelle Bestätigung neuer Verfahren im Stahlbeton

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SUMMARY
By more or less arbitrarily chosen examples of applications and their experimental verification it is attempted to show the significance of these advanced numerical methods for reinforced concrete structures. Still existing restrictions as well as very promising possibilities in new fields of applications are indicated.

RESUME
Des exemples d'application et leur vérification par expérimentation illustrent l'importance de nouvelles méthodes utilisées en mécanique des structures en béton armé. Les réserves encore à faire ainsi que quelques champs d'application spéciaux et prometteurs pour l'avenir sont indiqués.

ZUSAMMENFASSUNG
Anhand willkürlich ausgewählter Anwendungsbeispiele und deren experimenteller Bestätigung wird versucht, die Bedeutung dieser neuen Verfahren für Stahlbetonkonstruktionen zu veranschaulichen. Noch bestehende Einschränkungen und einige spezielle, vielversprechende Anwendungsgebiete in der Zukunft sollen aufgezeigt werden.

1. INTRODUCTION

The behaviour of one-, two and threedimensional reinforced concrete structures under load or imposed deformations is governed by highly nonlinear differential equations, which in general cannot be treated by analytical methods. Therefore at a time where electronic computers had not been available approximations based on the theory of linear elasticity had been used for the predictions of structural behaviour in design work as well as for research purposes.

While in case of one- or twodimensional bending members these methods proved rather satisfactory in other cases as e.g. ultimate limit states or stability problems they gave poor or improper results.

Now during the last 15 years in close connection with the growth of digital computers new powerful numerical procedures have been elaborated, which allow to treat cracked concrete structures in a more realistic manner, provided that nonlinearities resulting mainly from compatibility and constitutive equations of reinforced concrete are available. Intensive experimental research has been undertaken to create this basis.

By these means new results have been gained already, while the full effectiveness of these methods - a generation of faster digital computers has been announced - probably will be proved in future.

A broad range of possible applications for these advanced numerical procedures exists.

2. FIELDS OF APPLICATIONS

Let me begin with an example of practical experience which demonstrates the need for such methods as well as the difficulties still involved in its application:

In an office building (fig. 1) one bearing floor, which was to carry secondary floors by tensile members resp. columns, should be clamped to four towers. The whole dead- and liveload of this 137 m high building were to be transferred by four joints which consisted of an outer prestressed ring, a layer of plain concrete or mortar and the inner tower wall. There is no doubt, that from a structural point of view it seemed justified to investigate this most important detail extensively.
As the load carrying capacity depended highly on the stiffness of the mortar layer, the prestressed outer ring, and the deformation of the rather thin inner ring - conditions which could not be changed - the assumption of elastic behaviour was unsuited and could be dangerous. So it was decided to try an investigation, taking the realistic behaviour of cracked concrete into account.

In 1976 it took several month to find someone who was willing to overtake these task within the given time limit of a few month. The costs were extremely high. At last after some trials because of the problems which arose from organizing tedious calculations over great distances, from misunderstanding and communication difficulties between participants the design was rejected. Only due to a general scientific interest of the contractor the most significant computations could be finished later on [1, 2].
The gained experience may be generalized as follows. These new methods demand a high standard of theoretical knowledge as well as a sound know-how concerning constitutive relations and the experimental behaviour of steel and concrete, if the gained results are to reward the invested amount of work. Important decisions, which are still necessary to solve practical problems, such as e.g.

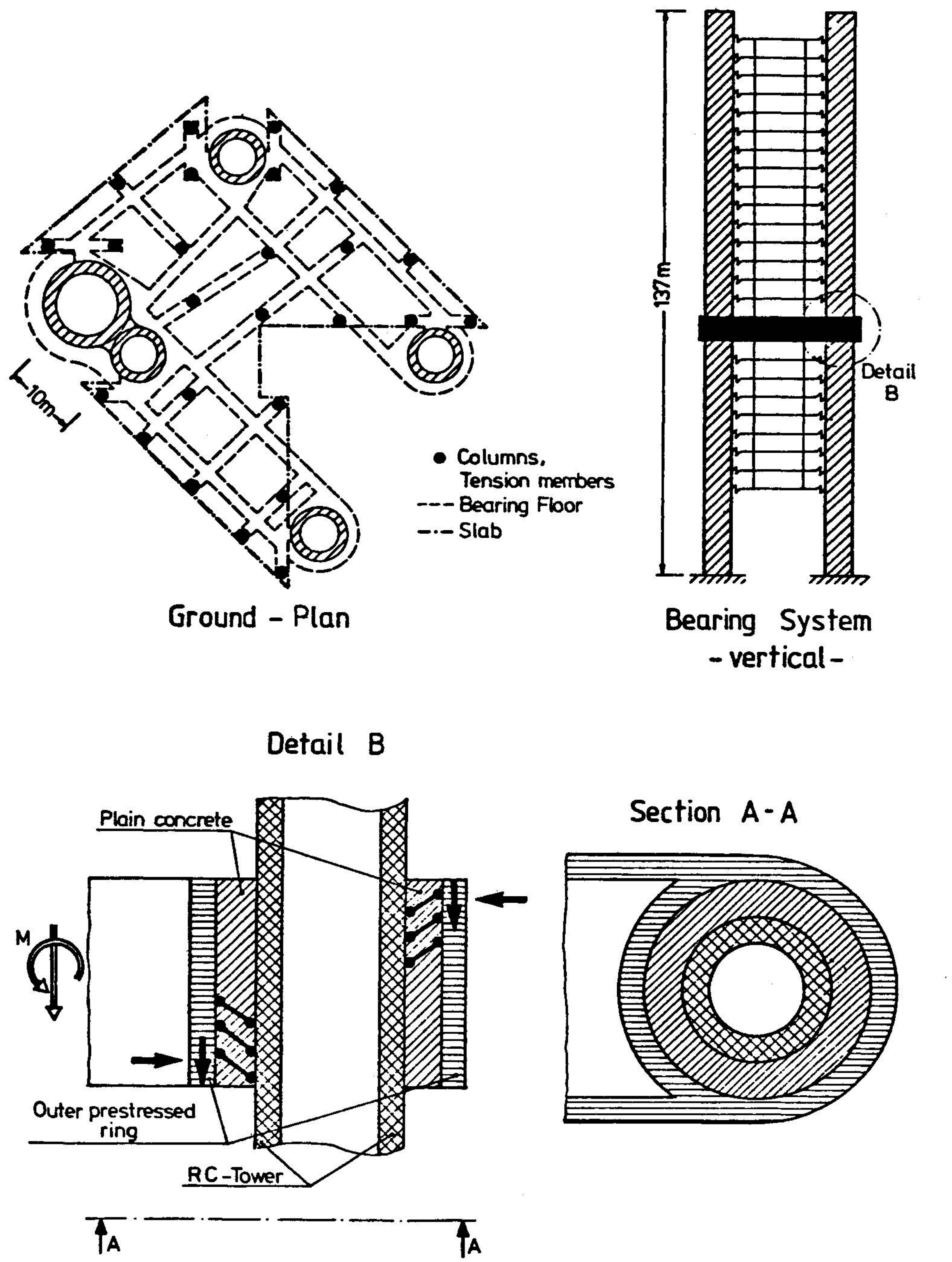


Fig. 1 (according to [2])

the discretisation of the structure, the modelling of the tension behaviour between cracks, the incorporation of the bond characteristics or the use of three- resp. twodimensional models, can only be made by experienced engineers who in many cases are not very familiar with highly sophisticated numerical methods. From here problems for practical use arise. As long as the following difficulties

- communication problems in modelling the structure
- the amount of time for communication, computation and
- the resulting costs

are not overcome, application in design work will be hindered to a great extent.

So to the author's opinion for the n e a r future the application of these special methods in practice is restricted to rare cases, where the necessary amount of time and money will be repaid by the structure. In all other cases available numerical procedures based on the linear theory of elasticity will suffice to solve even rather complicated systems.

Making these more advanced methods applicable for design calculations also further simplifications within the method are necessary. Possible aims of appropriate studies could be

- to determine the limits were complicated biaxial concrete behaviour in case of slabs with low percentage of reinforcement could be avoided [3]
- the evaluation of cases where bond in greater detail may be neglected
- an appropriate modelling of tension-stiffening corresponding to the exactness of practical needs
- the consideration of the scatter of test results when methods are refined just to reach a better data-fit at one single and arbitrarily chosen experimental example.

The Comité Euro-International du Béton (CEB) decided to make its contribution by publishing agreed constitutive laws, so that engineers not so familiar with specific problems may find a basis for their work.

Nevertheless the main field of application will be in research. There these newly developed methods will show their full effectiveness, but only, if they are extensively applicated in connection with tests. That means that in all possible cases s y s t e m a t i c parameter variations have to be done by simulated experimental investigations. The fact that practical oriented engineers very often do not yet appreciate these new methods stems from their experience that in many cases computer programs have been written, tested at a simple and often used test-example, published and never used.
Accompaning experiments for calibration which are still necessary to the author's opinion may be omitted one day, when sufficient knowledge of material parameters entering computations have been gained. The fact that a priori known experimental results, especially load-deformation relations can be described after the experiment has taken place, should not be overestimated. Everybody doing such calculations knows how many parameter changes are possible and sometimes done to gain such a data-fit.
In research the already mentioned hindrances as communication problems or the necessary amount of time are of secondary importance and may be overcome much more easily.
Admitting all these still valid restrictions frankly does not mean to reject this powerful tool, which is only at its beginning, as will be carried out in the following chapter.

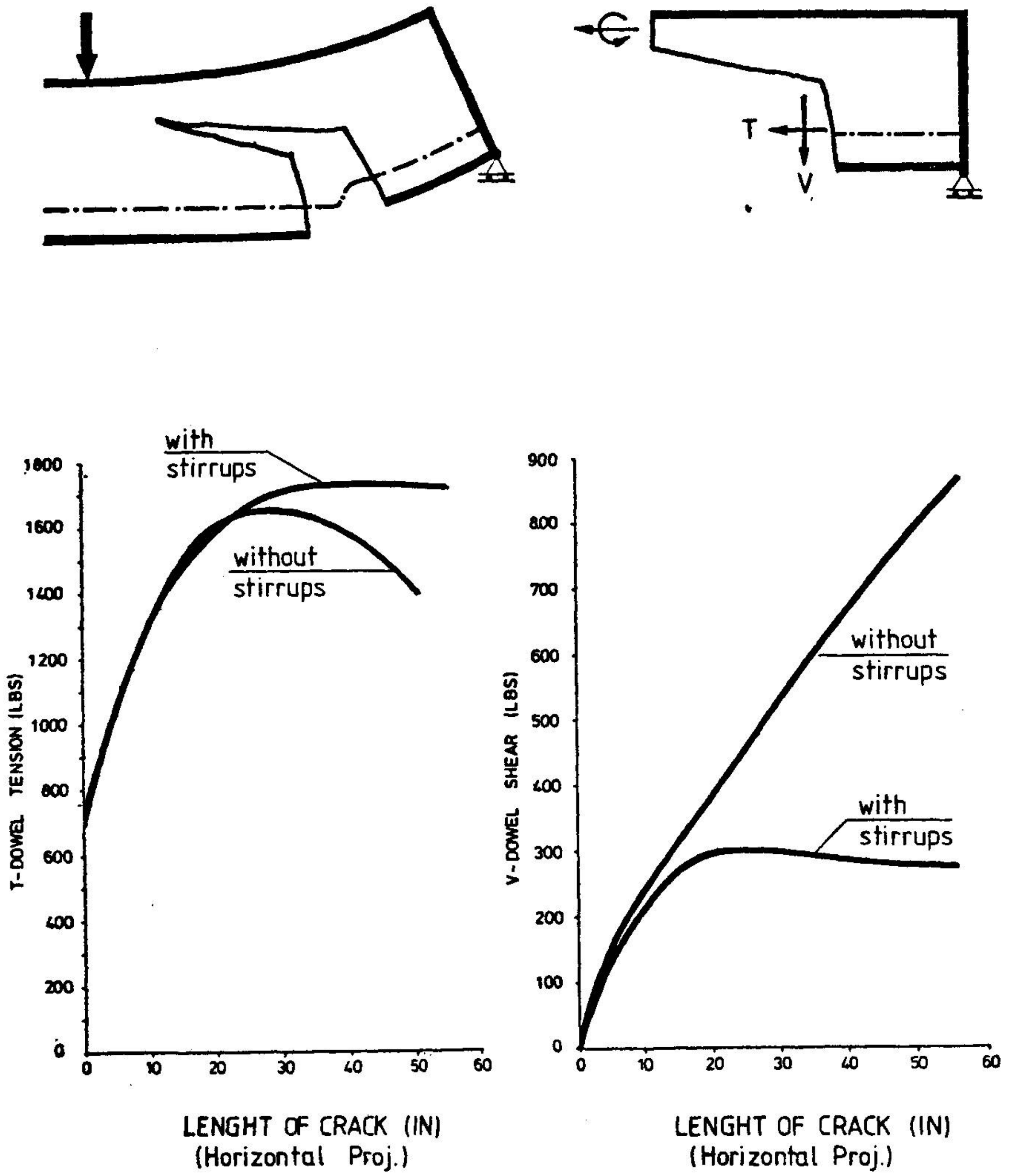


Fig. 2 Investigation of Shear- BEAMS [4]

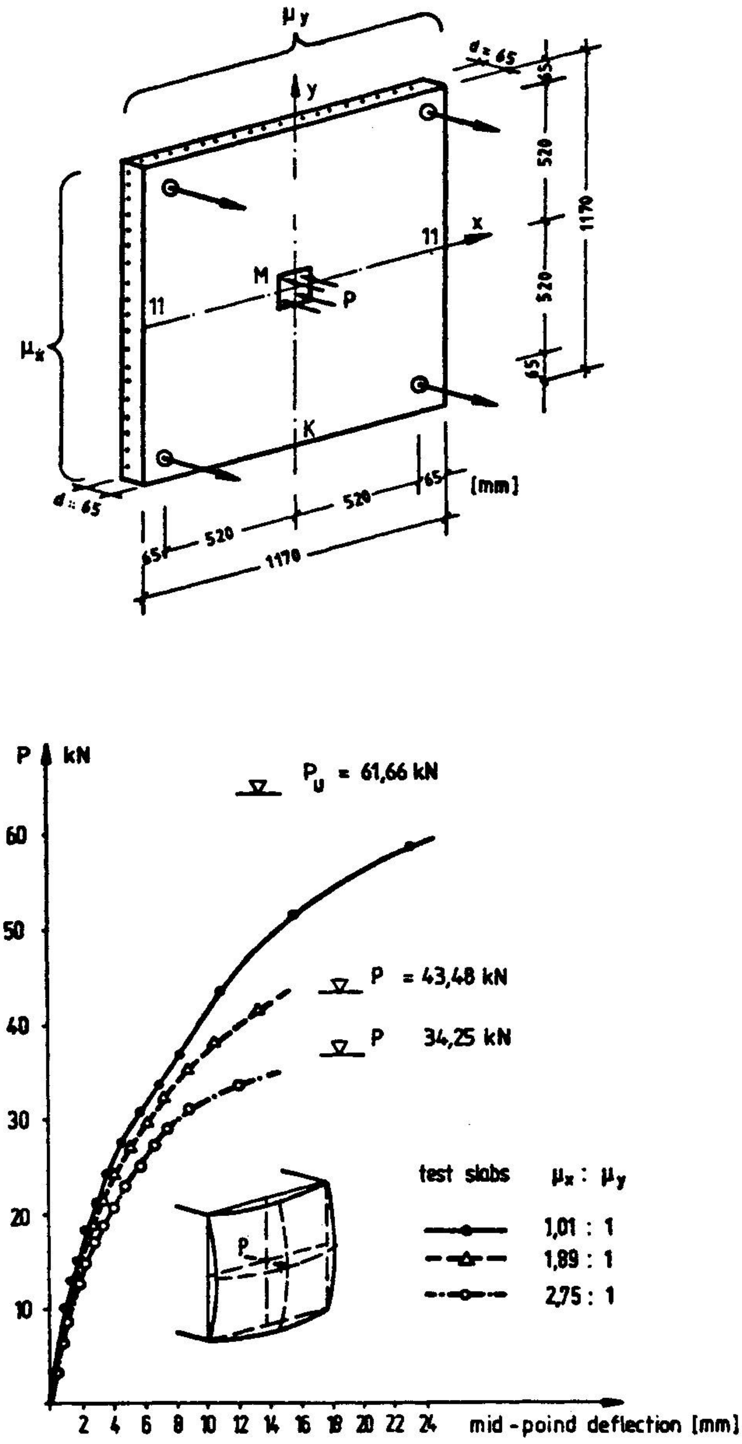


Fig. 3 Deflection Curves- Slab Tests [19]

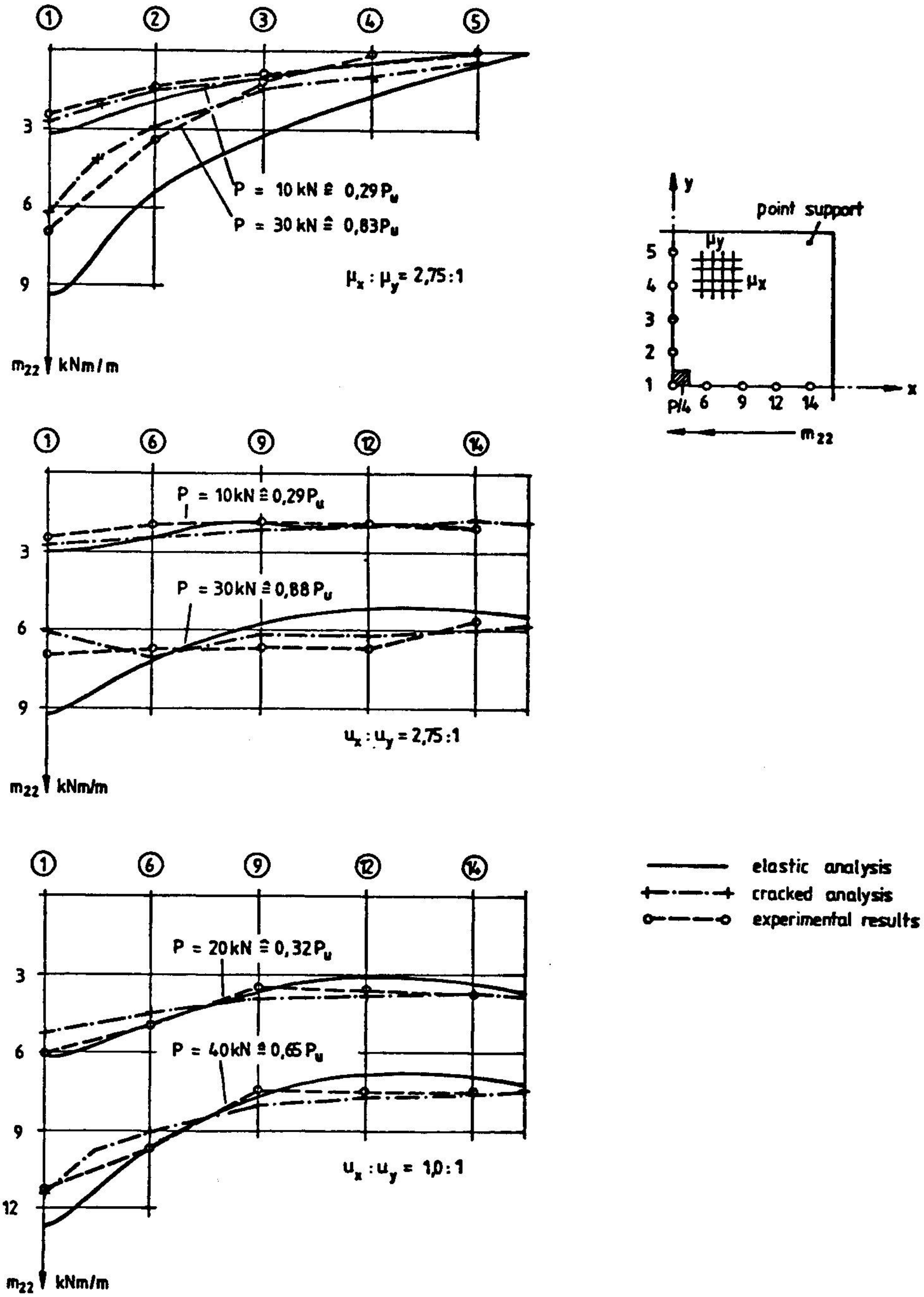


Fig. 4 Experimental and Analytical Distribution of Moments m_{22} in Axes of Symmetry [19]

For the near future the author predicts a rare application in practical design work, but a steadily increasing use in many fields of research.

3. EXAMPLES OF APPLICATIONS

Discussing now some examples where advanced mechanics have been applied the author does not strive for a complete representation of what has been done in the past as already given in earlier publications (e.g. [24].

There are many well known studies and applications which are often quoted in the relevant literature, as e.g. by NGO/SCORDELIS [13], SCORDELIS/NGO/FRANKLIN [14], NILSON [5], FRANKLIN [6], CEDOLIN/DEI POLI [7], JOFRIET/McNIECE [8], BELL/ELMS [9], BERG et al. [10] CERVENKA [12], WEGENER et al. [11], HAND/PECKNOLD/ SCHNOBRICH [18], SCHIMMELPFENNIG [15], EBBINGHAUS [16], GRÜNBERG [17], and last not least by ZIENKIEWICZ et al. and ARGYRIS et al. to mention some arbitrarily chosen authors. A more complete historical rewiew has been recently given by SCORDELIS [4].
Problems of cyclic loading as well as studies treating time dependent creep behaviour will be discussed by other reports.
For a great number of successful special applications in reactor technology even in cases of threedimensional structures the reader is referred to reports published on occasion of SMIRT (STRUCTURAL MECHANICS in REACTOR TECHNOLOGY) -conferences.

In the following only such investigations are shortly mentioned, which have been published recently, are not so well known or by which some special trends may be shown. Completeness cannot be reached.

Of general interest for reinforced concrete research are investigations of SCORDELIS (chapt. 4 in [4]) (fig. 2) which are very helpful in discussing the shear-failure of RC-slabs without stirrups, a problem which has been treated for a long time within the Comité Euro-International du Béton (CEB) when the Model Code was made. An even more enlarged systematic study would be very desirable.

Also of great practical importance are investigations as done by DUDDECK et al. [19] (fig. 3. 4) where the service-ability of concrete slabs with different meshes of reinforcement are studied by test as well as computation. As in most European countries slabs are designed according to their ultimate limite state, not much care has been taken to watch the cracking behaviour, possible corrosion and maximum deflection under service loads. Damages in several countries brought this subject to discussion again.

With these advanced mechanics under considerations probably the greatest practical success has been gained by the computation of slender columns taking into account second order effects. Very effective work has been done by KORDINA in Germany and during the last years by MENEGOTTO in Italy.
In the CEB-Manual "Stability" a selection of 503 experimentally tested columns is compared with corresponding calculations giving a median $N_{test}/N_{cal} = 1,06$ with a coefficient of variations 0,136.

At the author's institute an investigation by KESTING [20] (fig. 5, 6) has been carried out by means of layered elements and dynamic relaxation to study the stability of prefabricated wall panels. Here in contrary to columns and plates the modelling of tension-stiffening as the stabilizing effect proved decisive for the bearing capacity [28]. This latter results probably may be generalized for other kinds of twodimensional structures as e.g. for hyperbolic cooling towers and cylindrical shells endangered by second order effects.

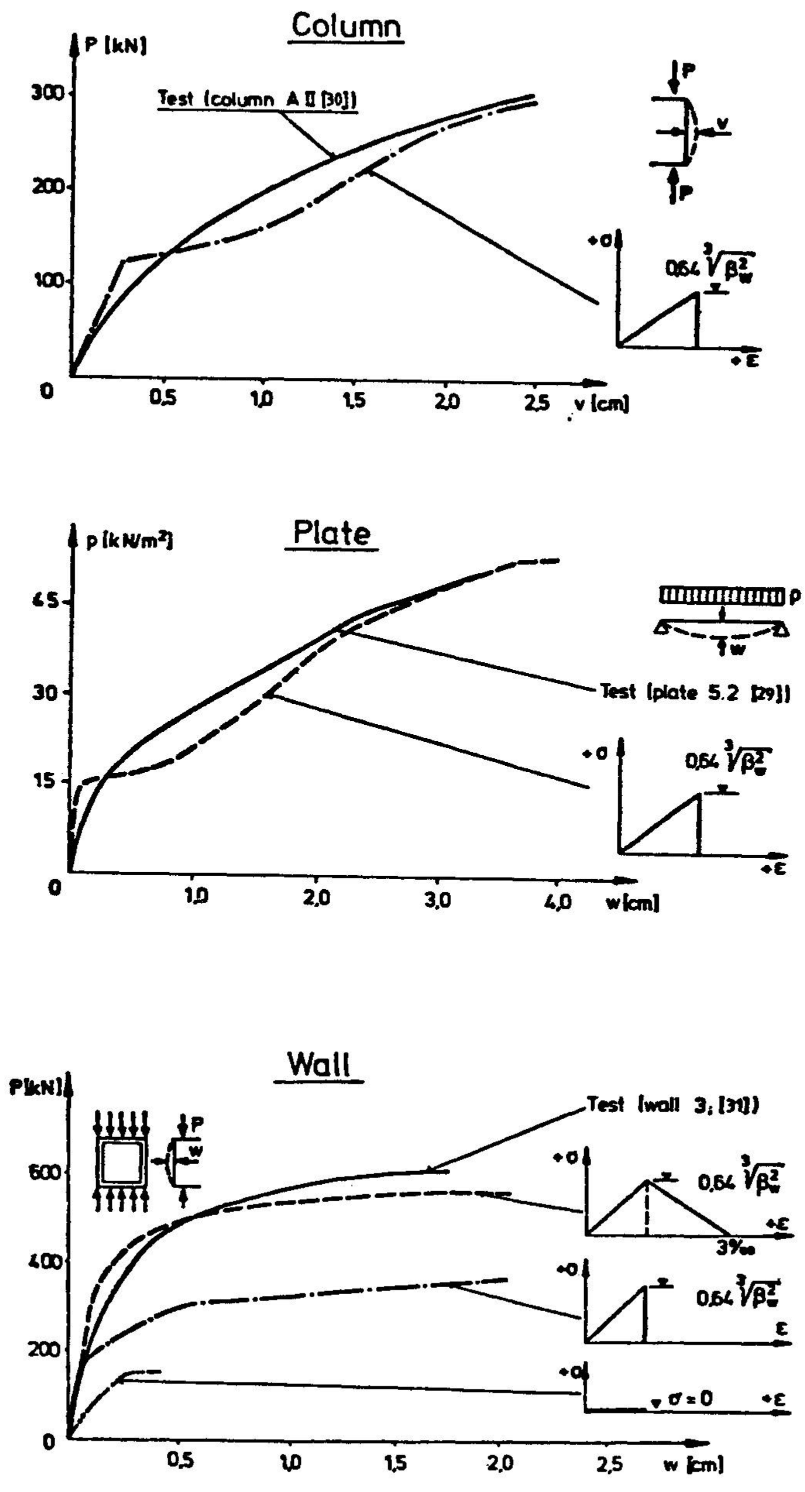


Fig. 5 Comparsion- Calculations with Different Assumtion for Tension- Stiffening [28]

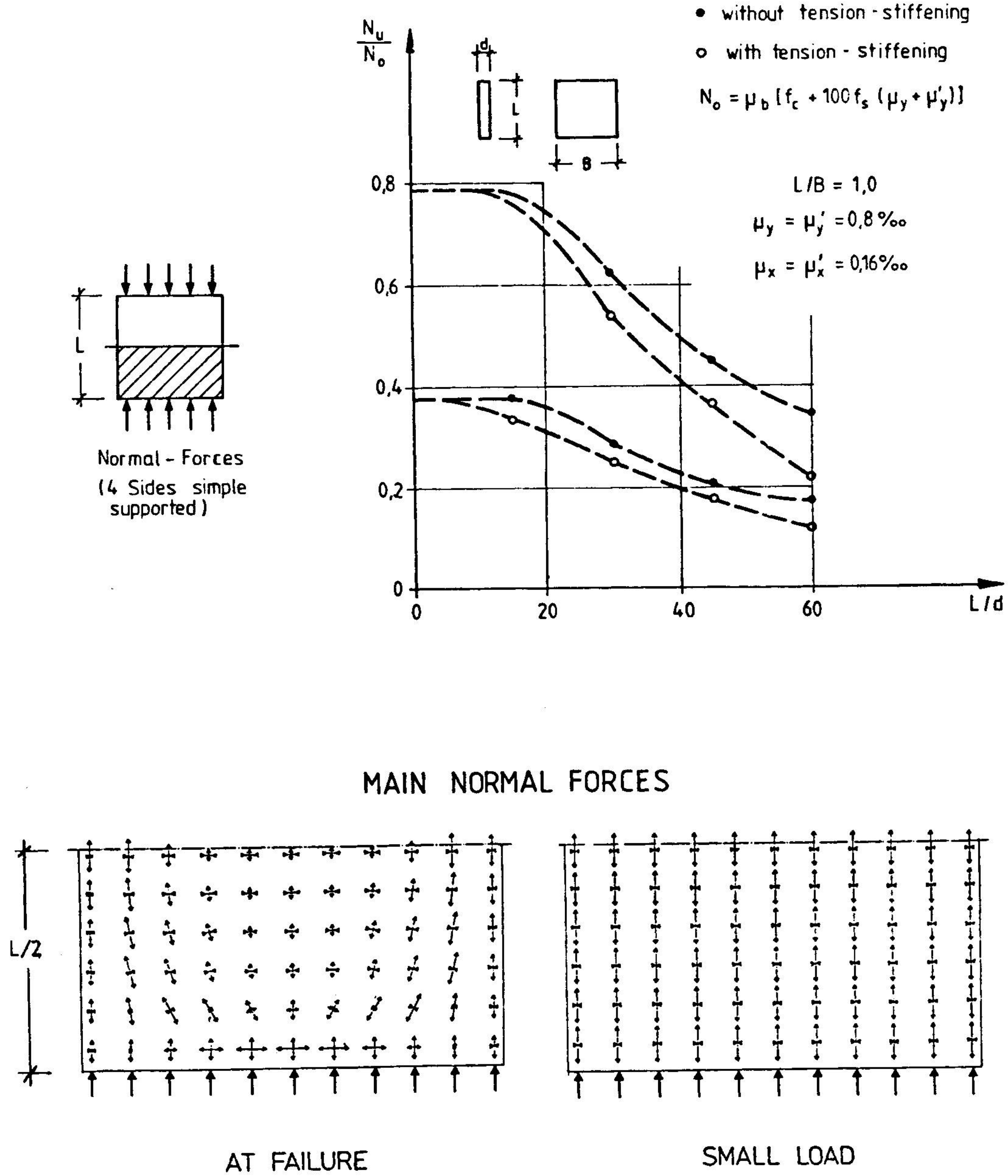


Fig. 6 Bearing Behaviour of RC- Walls Including Second Order Effects [28]

Interesting investigations by CRANSTON et. al [32] to study these tenson-stiffening effects experimentally in greater detail are still under progress in the United Kingdom (fig. 7).

Principle calculations similar to [20] have also been done by KRISTJANSON [21] and earlier by BERGAN [22]. In [21] also results for skew slabs are given showing that with an encreasing number of cracks a significant change of the bearing behaviour occurs which is important for practical design work (fig. 8).

The fact that modern numerical methods may be a great help in analyzing shells has been confirmed among others by MÜLLER/KABIR/SCORDELIS [23] recently, who investigated a hyperbolic paraboloid as a gable-, saddle- and inverted umbrella shell including creep and shrinkage.

New and important impact problems have been put forward in connection with nuclear power plants and offshore platforms.
So a study of contact problems has been published recently by NILSON [25] (fig. 11). The fact that his theoretically gained results do not agree very well with experimental values may also be due to the fact that thermal effects have been abandoned. Own experiments show that there is a remarkable heating of material surfaces under high velocity impact.
Problems of spalling and penetration of RC-slabs under high impact loading can only be explained in a consistent manner if the dispersion of impact waves and the resulting stresses are computed. The threedimensional problem may be simplified in many cases to a simpler twodimensional problem, because of rotational symmetry. Fig. 12 shows some results calculated by SÜPER [26] for concrete slabs, similar to elasto-plastic solutions gained already by KAWAI [27] and others, which seem to be in rather good agreement with own tests carried out.

Interesting calculations of stresses due to temperature caused by cement hydradation, which are to be compared with measurements at a bridge still under progress, have just been finished by ZEITLER [33].

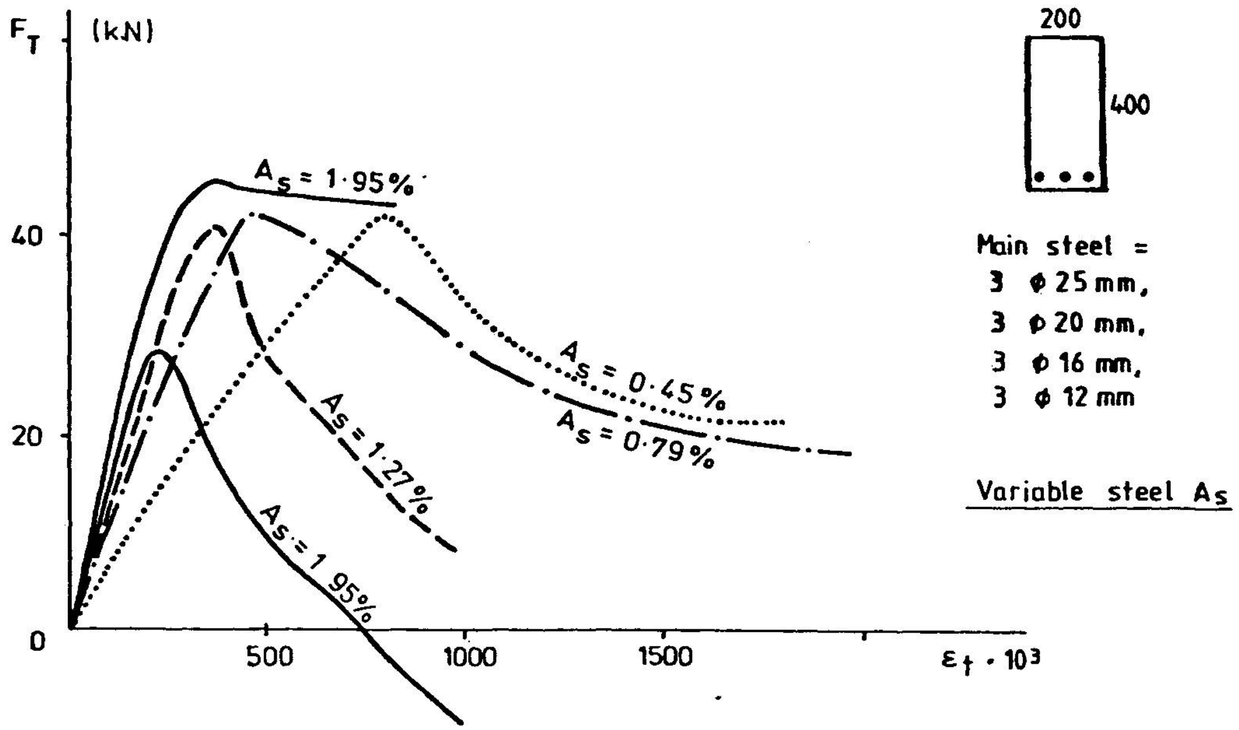
4. FUTURE APPLICATIONS - PROBLEMS TO BE SOLVED

In the following chapter the author wants to represent a few quite arbitrarily chosen two- and three-dimensional problems which to his opinion offer wide and fields of application for the methods in discussion:

Two-dimensional RC-problems

As prefabrication becomes more and more important - not only because of economical reasons but also because of a lack of skilled craftsmen in developed countries - high strength concrete and therefore slender structures endangered by stability-failures have to be studied. This statement is true for panels and slabs, high girders as well as for special frequently used shell-structures cast in situ such as cooling towers e.g. Realistic stability experiments where necessary deformations are not hindered and conservative or nonconservative loads are imposed in agreement with reality are very difficult and expensive. So experimental research must be restricted to a small number of carefully carried out tests. Here advanced numerical methods should be used to extend our knowledge by varying necessary parameters.

Another interesting and still discussed technical problem is combined bending and shear in the webs and flanges of T-beams. Although further tests are necessary especially for cases where failure is due to exceeding compressive stength, F.E.-methods based on realistic RC-behaviour could be very helpful.



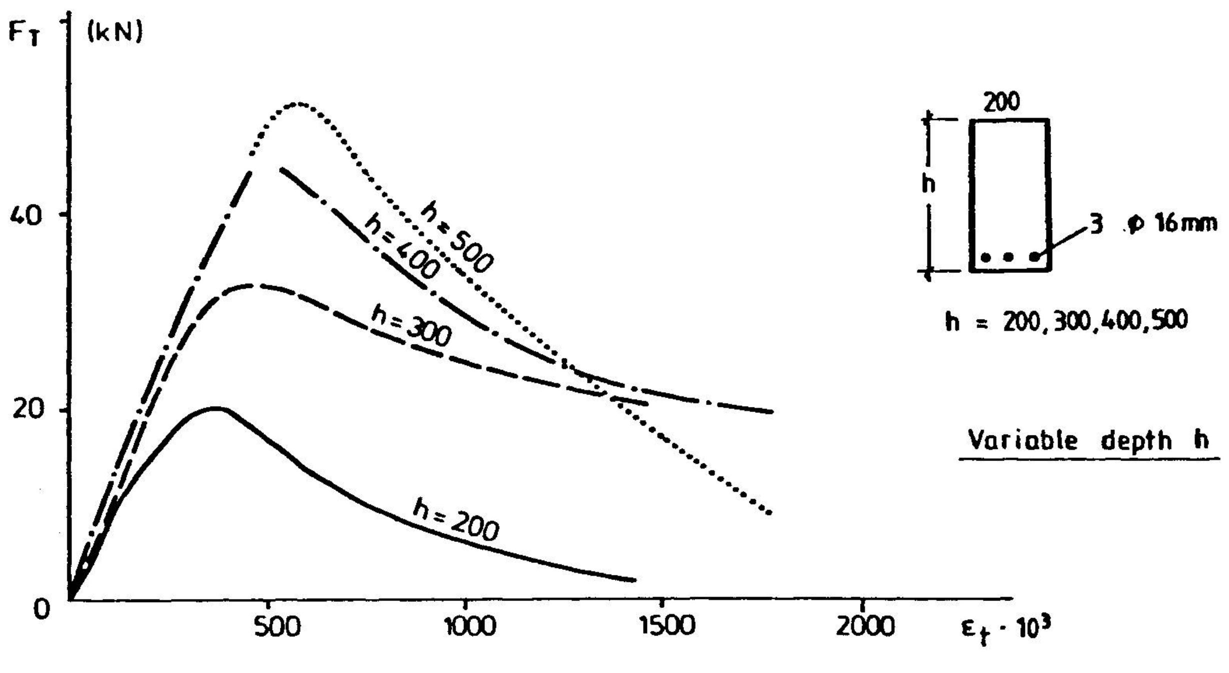
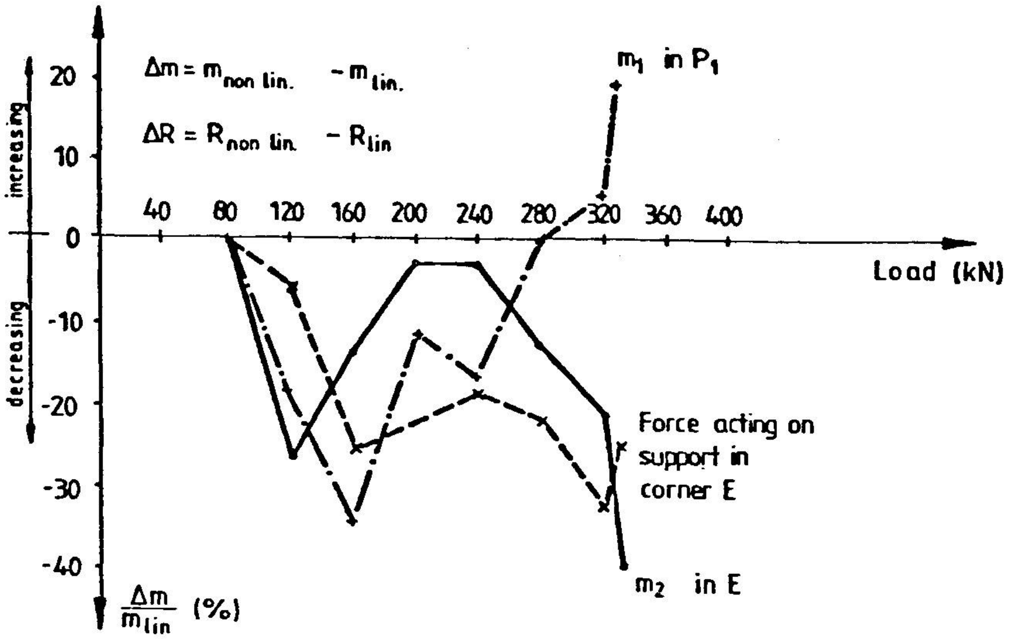


Fig. 7 Tension Force Versus ε_t According to Experiments [32]



m1 , m2 main moments

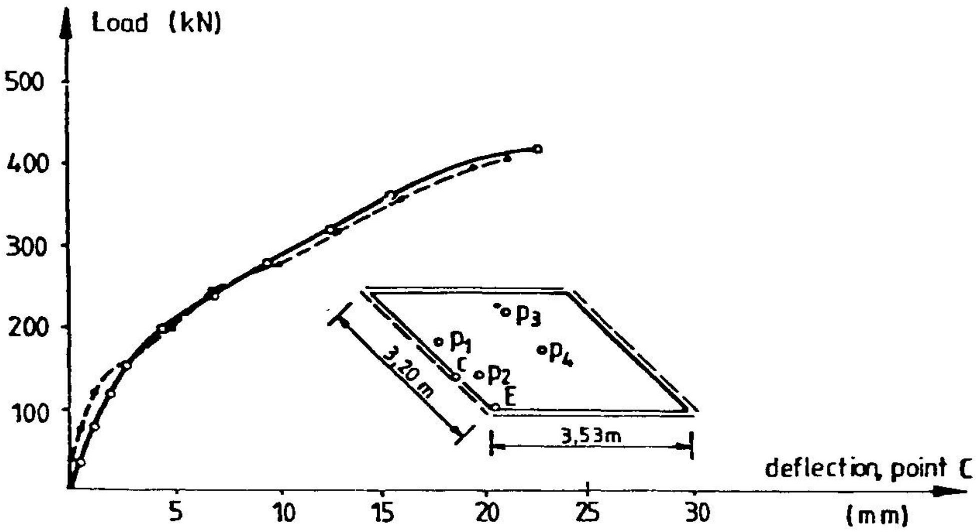


Fig. 8 Bearing Behaviour of Skew Slab [24]

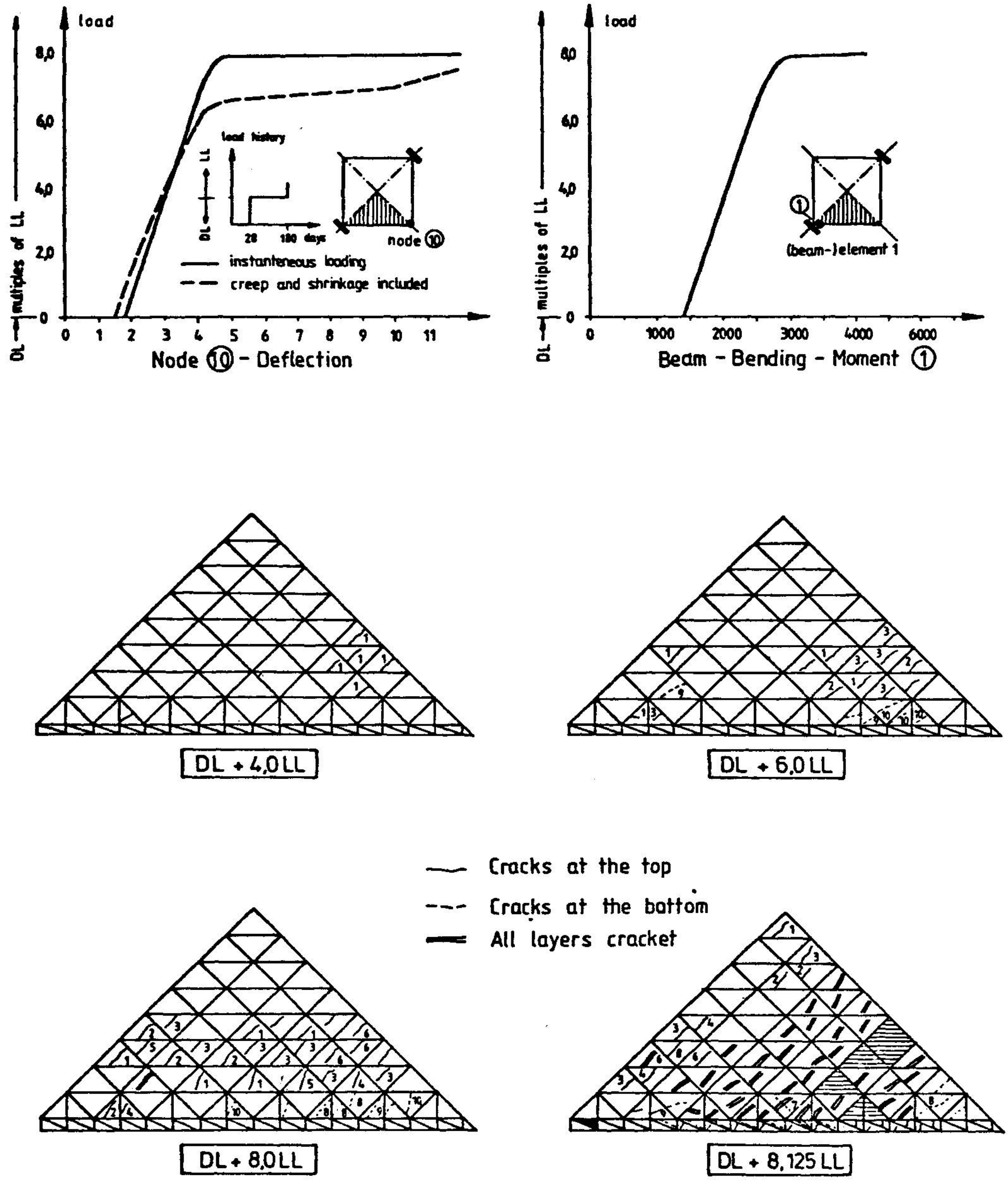


Fig. 9 Resuluts for Saddle Shell [23]

Corbels as shear members belong to the same category of possible tasks.

For frequently used shell containments nearly no results are available concerning their behaviour under imposed deformations due to temperature effects or due to settlements. While some structures are very insensitive to these kind of "loading" there are other structures endangered by stability-failure where cracks and therefore reduced stiffness is of decisive inportance, not to mention corrosion problems which right now become of major importance at least in the author´s country.

In many structures being built to guarantee sufficient energy-supply such as off-shore platforms, LNG(Liquid Natural Gas)-containers and especially nuclear reactors impact problems are of major concern. With the latter it may be stated that impact loading in many cases determines the concrete-thickness of containment walls and the necessary reinforcement and therefore to a high extent the building costs of a nuclear power plant. Own experimental and theoretical studies show that there is a real need for more advanced numerical procedures in this field.

That simple cases of vehicle impact caused by trucks and locomotive are still of interest has been shown by a number of latest accidents, where collapsing bridges killed and injured people.

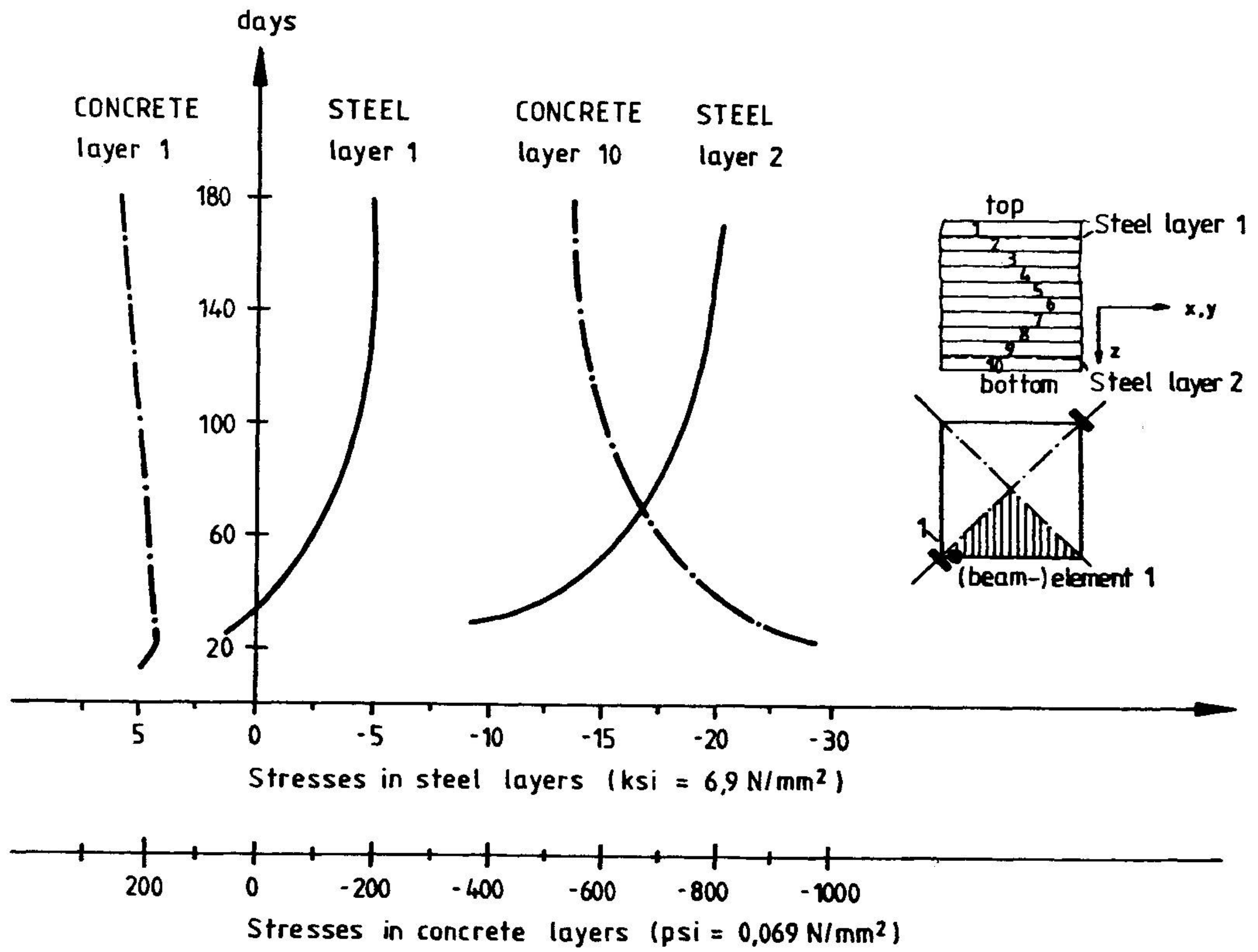


Fig. 10 Stresses Redistibution in Beam (Element 1)

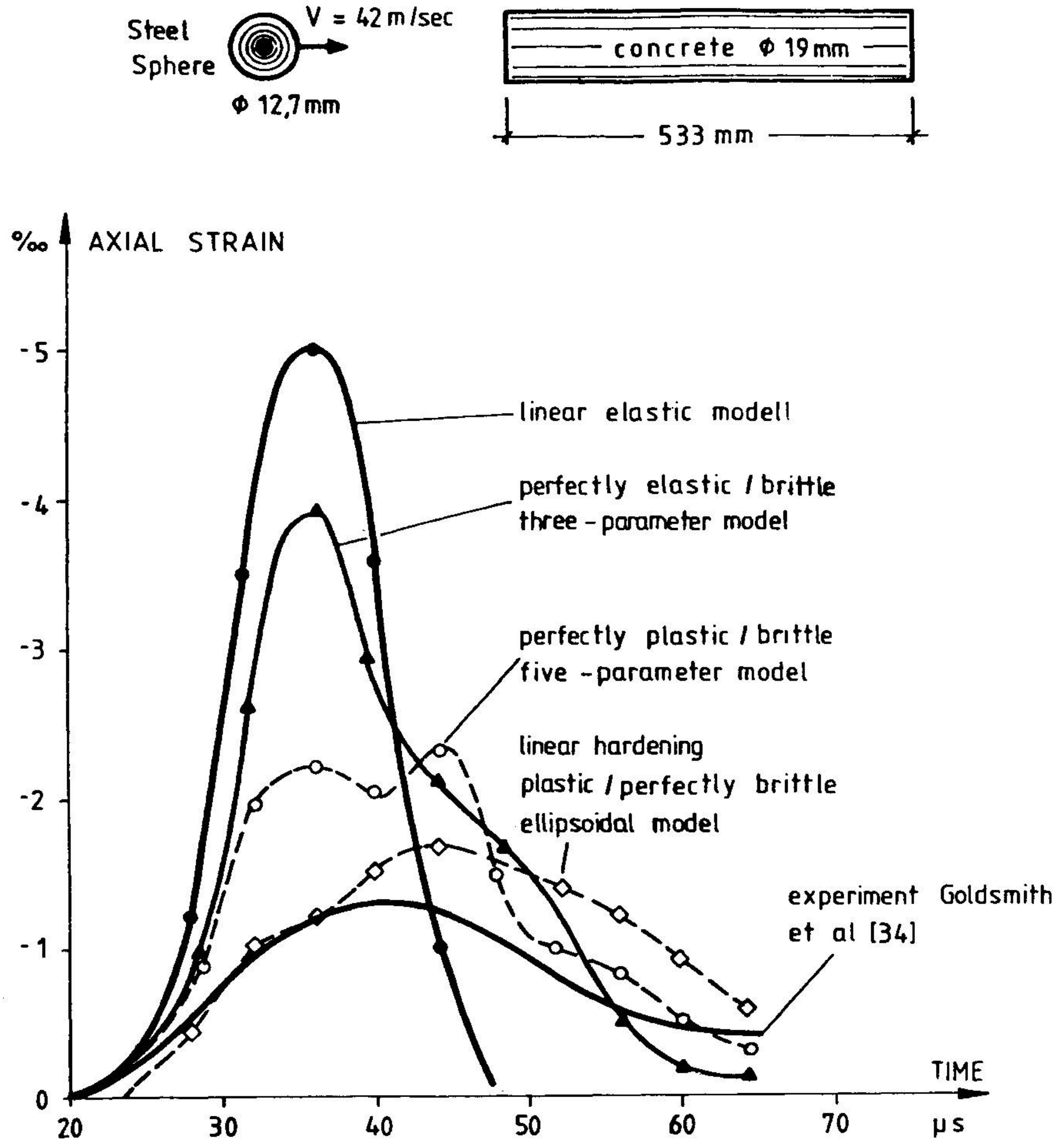


Fig. 11 Contact Problem- Different Constructive- Laws [25]

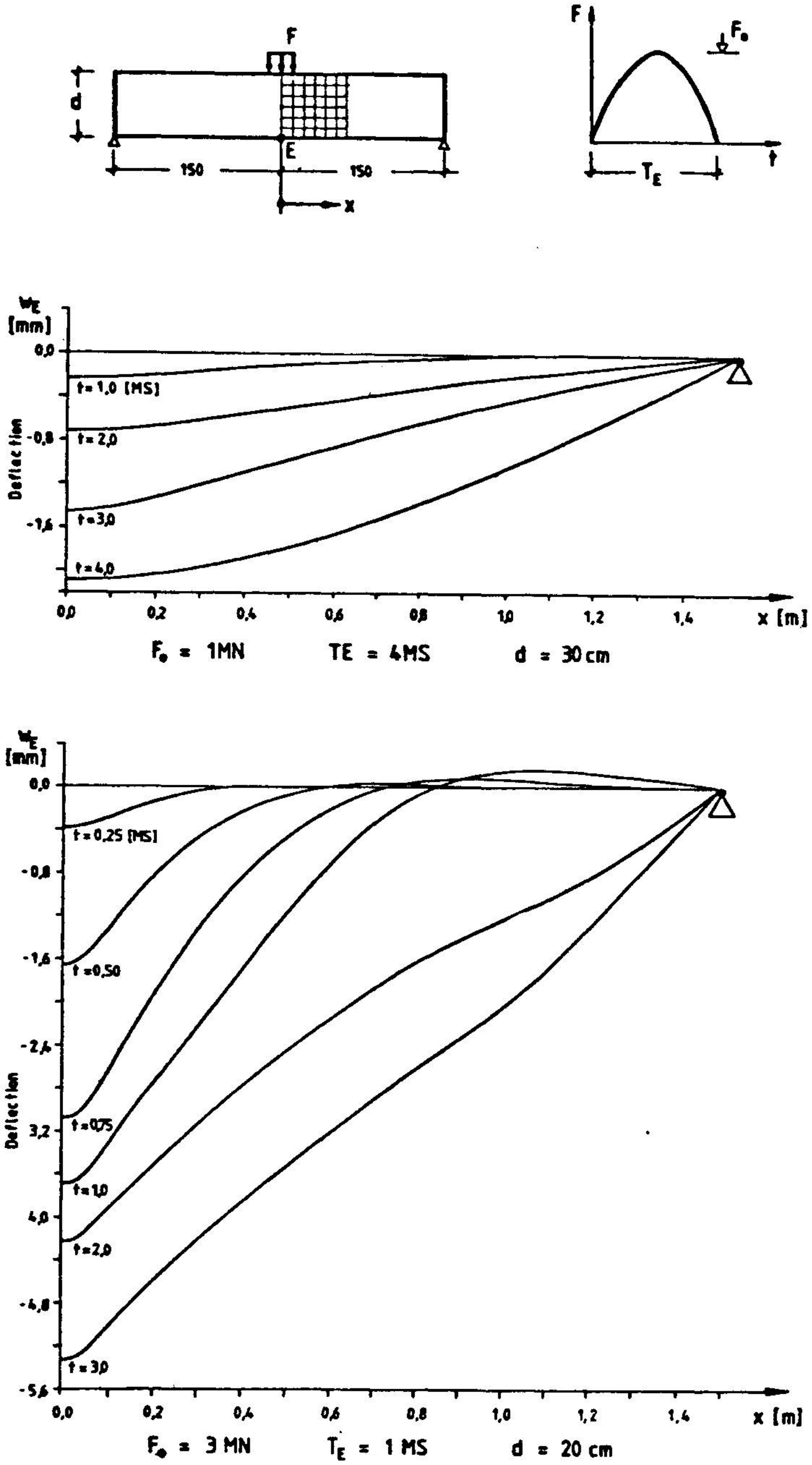


Fig. 12 Midpoint E- Deflection of Thick Slab Under Impact [26]

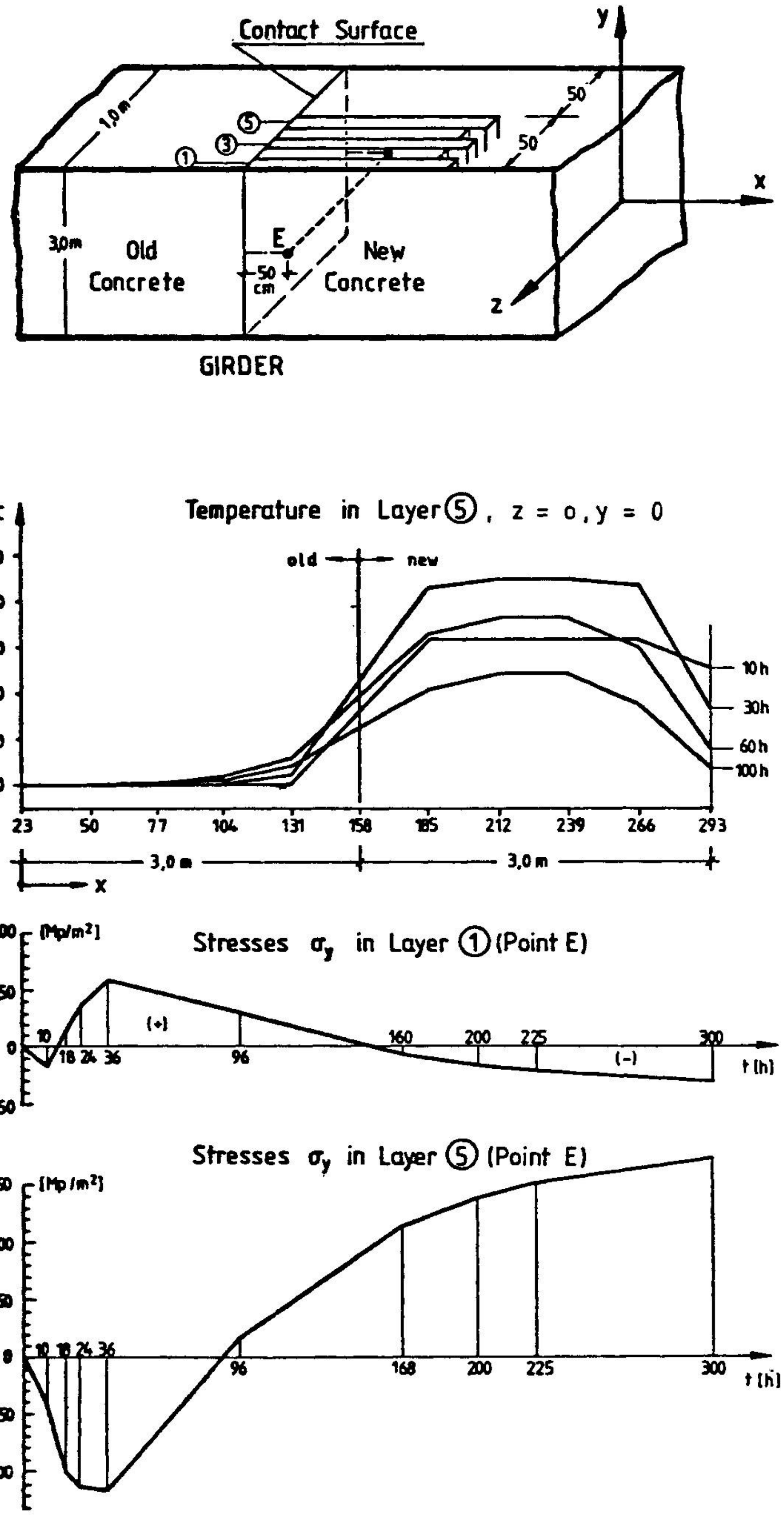


Fig. 13 Stresses in The Web of a Bridge- Girder Due to Hydration of Concrete [33]

- <u>Three-dimensional RC-problems</u>

  There are rather simple and commonly used structures such as flat slabs and their punching behaviour which demand reasonable threedimensional investigations. Especially flat RC-slabs prestressed without bond, which are increasingly used for office buildings and factory halls raise new discussions.

  Also in many cases where edge beams support slabs or shells the torsional stiffness of the beams require threedimensional treatment. E.g. near the supports of bridge-superstructures which consist of a double T cross-section without any further web connection because of the manufacturing process these effects are of great importance for an economic solution.

The fact that there is a great need for such methods with all thick threedimensional structures e.g. for reactor containments is well known and must not be emphasized. Here more complex investigations including temperature, time and even moisture are desirable.

5. NECESSARY RESEARCH

As there are other reports on necessary research there is no need to treat this subject here in greater detail. The author just wants to mention some problems where from the applications point of view, intensified research is desirable. These are

- A realistic investigation of the descending branch of the concrete-constitutive law including the rotational capacity of RC-slabs and RC-beams eventually at high strain rates.

- Constitutive laws for concrete including more complex loading histories than unidirectional monotonic loading. Even cyclic loading - though not sufficiently explored - is still a rather restricted loading process.

- Tension stiffening because of its great importance for the bearing capacity of structures endangered by stability-failure.

- An experimental verification of threedimensional creep laws possibly under varying temperature.

The first item is important in all cases where realistic collapse loads are to be calculated. As for impact and dynamic loading the energy absorption is decisive the rotational capacity has to be taken into account in a realistic manner.

The second problem needs clarification with respect to safety considerations. After a complex history low safety-factors for a special favourable multiaxial compression-situation can only be allowed if the real behaviour including this history is known.

The last two subjects are of great importance for all structural systems where the bearing capacity is endangered by second order effects. Here a realistic simulation of stiffness is decisive.

6. CONCLUSIONS

From my statements the following conclusions should be drawn:

- The newly developed methods are well apt to be used in research and may be a great help in exploring reinforced concrete behaviour. In many cases, as shown, the agreement between experimental and calculated results seems to be better, than justified by the scatter of concrete characteristics.

- Besides further research investigations should be done striving to simplify gained knowledge.

- Written computer programs should be really a p p l i e d in simulated experiments.

- Communication problems between theoretically drained and design engineers, which are not to be underestimated, have to be overcome.

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