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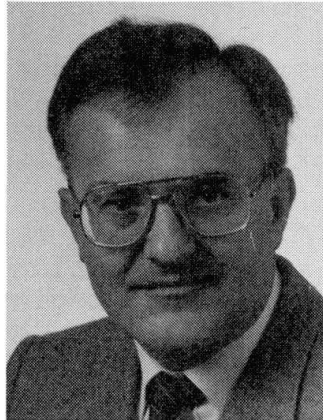
Role of Experiments in a Consistent Dimensioning Concept

Rôle des expériences en vue d'un concept de dimensionnement

Experimentelle Prüfung von Stahlbetonbauteilen

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SUMMARY

The present paper deals with the possibilities and limitations of experiments in the field of structural concrete elements. With the background of the rapid development of computer, and simulation techniques, an attempt is made to define the importance of experimental tests both for past and future research in structural concrete.

RÉSUMÉ

L'article traite des possibilités et des limites de l'expérimentation dans le domaine des structures en béton armé. Dans le cadre du rapide développement des moyens informatiques, il s'agit de définir quelle a été l'importance des essais et expériences passées et quelle sera leur importance pour la recherche future.

ZUSAMMENFASSUNG

Der vorliegende Beitrag beschäftigt sich mit Möglichkeiten und Grenzen der experimentellen Prüfung von Stahlbetonbauteilen. Auf dem Hintergrund der sich stürmisch entwickelnden Rechen- und Simulationstechnik wird versucht, den Stellenwert der experimentellen Untersuchungen bisher und für zukünftige Forschungen auf diesem Gebiet zu umreißen.



1. INTRODUCTION

The present subject is tempting according to the given formulation to switch in a black and white mentality. On one hand there are practical engineers for which nothing than an experiment is better to confirm a constructive idea. On the other hand there are the computer specialists, becoming more and more numerous, which raise the impression to be able to simulate almost each experimental test. Encouraged by more and more powerful computers they propagate to replace each experiment by calculation.

I followed this development within the last 25 years with the eyes of an experimentator, therefore I am certainly a bit prepossessed. Nevertheless I believe that this activity allows to derive essential arguments for the role of experiments in the field of structural concrete.

I decided to restrict my argumentation to technical aspects. Therefore only some words at the beginning concerning financial problems. They are characterized by the situation in Stuttgart and therefore not completely transferable to other institutions.

Due to the separation of research and testing in two different organizations the costs for testing are expenses which have to be paid according to the fees of the testing institute. They concern mainly technical staff who is in general working without any personal interest in the research project. The theoretical and numerical work on contrary is performed by young engineers who were specially motivated by the task and are working more intensively therefore. Additionally only the immediate personal costs for this academic staff arise while their general costs are financed by the public budget. This unequal treatment of costs leads to an unbalanced comparison and should be taken into account in a realistic analysis of costs for economical research.

2. MATERIAL TESTING

Now I want to continue with the technical part of the problem. The material properties are essential for the design of structural concrete. Besides the physical capacities more and more the thermal and environmental influenced properties become important. In this field experimental investigations are necessary to determine fundamental properties as

- coefficient of expansion
- conductance
- penetration of gases and liquids.

Already at this point it is necessary to emphasize that usable test results are only possible together with well founded theoretical investigations. For example test concerning the absorptive capacity of concrete are almost useless without accompanying calculations

concerning the chemical and physical correlations to this problem (Fig. 1).

Except quality control tests for reinforcing steel there are no tests necessary to determine the strength properties. That is different for the ductility. Modern manufacturing processes may change properties as geometry of ribs, ductility and sensitiveness against chemical attack. So the practicability of these bars is influenced by reduced bond quality, moment redistribution and increased concrete cover (Fig. 2). Instead of the well established tensile test we need specific tests for characterizing these properties.

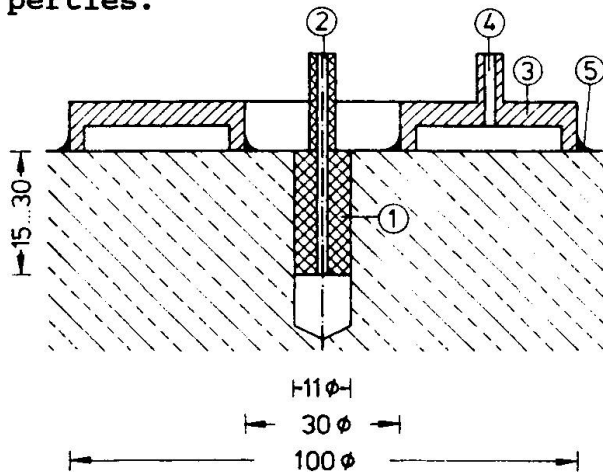


Fig. 1 MEASUREMENT OF PERMEABILITY ON CONCRETE SURFACES

- 1 Injection-packing
- 2 Gas-inlet
- 3 Gas-collector
- 4 Gas-outlet, to flowmeter
- 5 Sealing

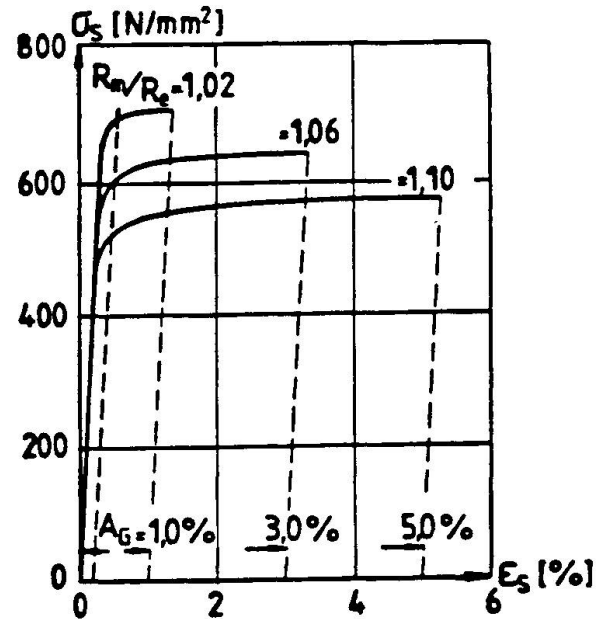


Fig. 2 SCATTER OF STRESS-STRAIN-RELATIONSHIP FOR WELDED WIRE-MESH

This necessity for specific tests is much more pronounced for concrete. Without regarding the problem of cube- or cylinder-strength there are only some words important concerning the tensile strength. Presuming their existence it is necessary to determine amount and scattering on the background of the different parameters. On the basis of statistical and probabilistic concepts these values have to be adopted by dimensioning concepts.

The correlations become even more complicated concerning the bond qualities of re-bars. In the first approach bond stress-slip-relationship, determined on pull-out-test were used for a realistic modelling of bond. Meanwhile the test specimen and the accompanying results became much more sophisticated according to the local situation near cracks (Fig. 3). This approach already indicates the problem of modelling for test specimen. How close to the real element should the model be designed, covering then only a narrow part of application? On contrary, if the model comprises a wide practical applicability are then the test results enough evident? These material properties are the tools for the designer to calculate the dimensions to carry the internal forces. There is no feed back to the determination of these material properties.

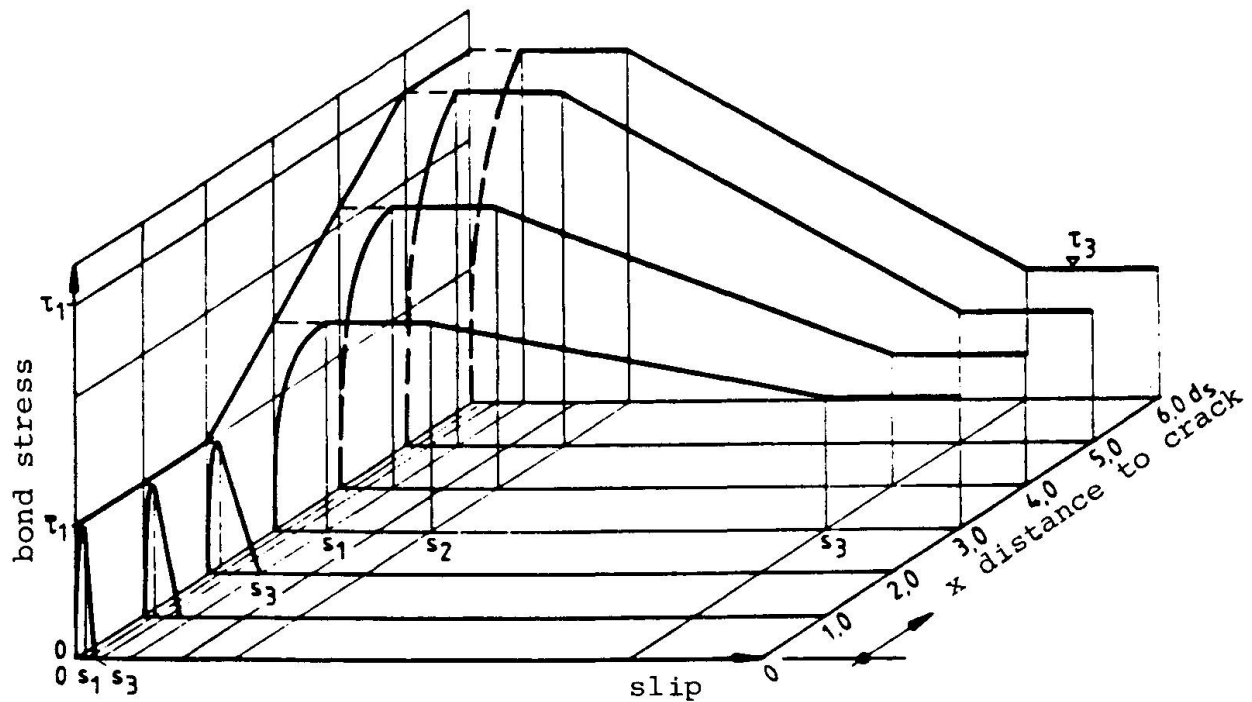


Fig. 3 BOND STRESS-SLIP RELATIONS

3. TEST ON STRUCTURAL ELEMENTS

3.1 General remarks

The main part of this article concerns tests on structural elements. This means all experimental investigations, where simple and complicated structural elements are modelled to test specimen in order to find out and explain the flow of the internal forces. Examples for such tests are:

- capacity of lapped splices;
- punching resistance of flat slab-column-connection;
- moment redistribution for beams and plates;
- indirect supporting and loading;
- combined loading of moment, shear force, torsion...;
- capacity of columns and long term loading;
- tensile stiffening of concrete;
- determination of restraint forces;
- combined action of loads and restraint forces;
- test on complete structures.

In the beginning of the application of reinforced concrete already the confirmation of theoretical research activities by experimental tests was quite usual. Especially Stuttgart was well known by the close cooperation between Morsch and Graf.

The influence of the above mentioned experimental investigations on the existing codes and dimensioning concepts are evident and it is not necessary to explain this in detail. But at least from today's point of view it is worth to ask if these results could also have been achieved with other methods and if future problems should be solved with more appropriate tools.

3.2. Some Remarks to conventional testing techniques

A critical review concerning the conventional testing techniques is pointed out on 3 elements:

- designing of test models
- choice of appropriate measurements
- limits of validity for the rest results.

A suitable designed test model should be idealized from the real element so that secondary structural effects are excluded consciously to emphasize the specific subject. Unintentional restraints and mainly the concrete tensile strength are the most important disturbing factors. The tensile strength can not always artificially be excluded although it is neglected for almost all dimensioning concepts.

The second problem concerns the measurements. During planning of tests it has to be judged responsibly which kind of measurement are appropriate without disturbing the internal flow of forces in an unacceptable way. Remembering the fact that each measurement includes a disturbance either these measurements have to be reduced to a minimum or the amount of disturbance should be checked realistically.

Furthermore the time for taking the measurements should be realized. Improvement of measurement-equipment (strain-gauges, LVDT, load-cells...) and modern computer controlled multi-switches have solved many problems. Quite modern methods as Laser, Holographic and Photogrammetric techniques are also working rapidly and guarantee a quick taking and storing of experimental data.

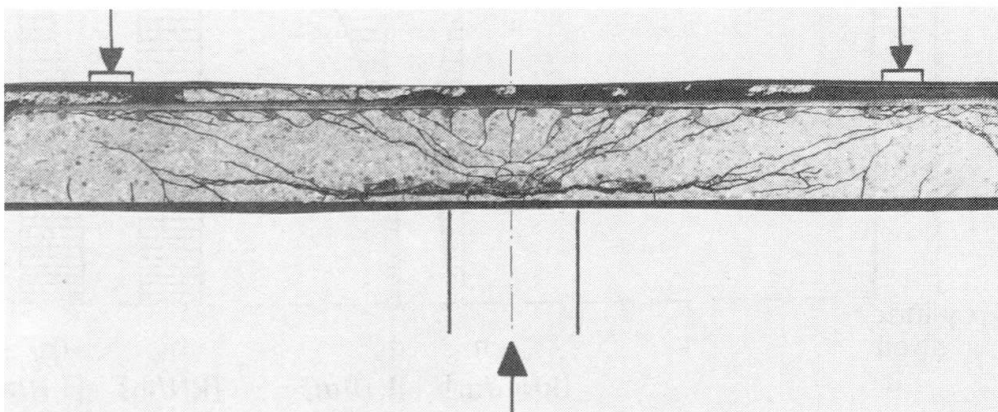


Fig. 4 CRACK PATTERN WITHIN A FLAT SLAB AFTER PUNCHING



Only crack measurements are a major problem in spite of the fact, that crack pattern represents a fundamental key to understand the internal flow of forces in structural concrete elements. There are existing some optic-electronic methods to take the crack pattern of visible concrete surfaces. But almost no method exists to determine pattern and crack width inside the test models. There is in general only one way to saw the test specimen after the test (Fig. 4). This is not only quite expensive but gives also severe problems in analysing the load-depending crack pattern and crack width.

The third remark concerns the evaluation of the test results. A single tensile test on a reinforcing bar out of a specific lot gives single results. Together with the well known scatter of this results the responsible engineer is able to classify this results. In case of doubt he has to test additional specimen. This judgement is not so easy for test results on structural elements. The purpose of such test mainly is to point out a specific aspect by means of different measurements without knowing the scatter of such measurements. Very often the interdependence of the different aspects are not well known during planing of the tests. This means, that not always the appropriate measurements were performed compared to the final stage of knowledge. Also secondary effects as loading or deformation rate, testing time for visco-elastic effects, restraint effects... remain unknown. Very often people are forced to publish numerous test data to demonstrate expensive experimental work. In this field the computer specialist is in a much better situation. Inopportune results of calculations may easily disappear in the waste paper box to be replaced by a new course of calculation.

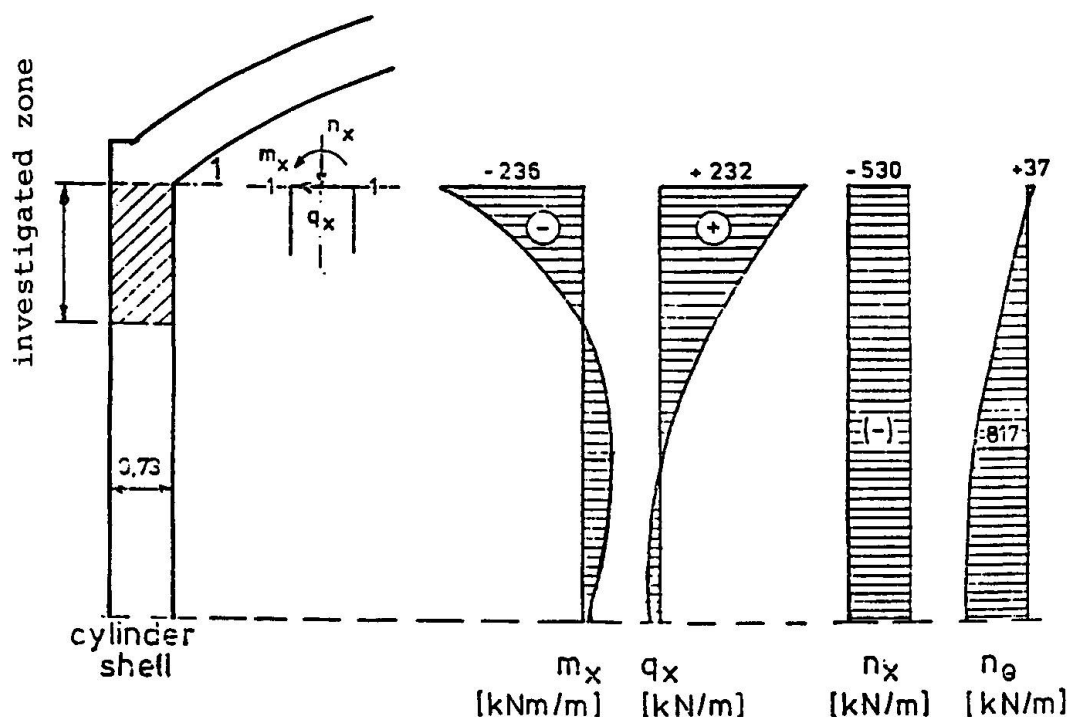


Fig. 5 DISTRIBUTION OF FORCES IN THE CYLINDER SHELL

3.3. Example

It is obvious that each example presented at this place will be criticized heavily and of course there will be more arguments if the tests of this example are carried out by the author in Stuttgart. In spite of this facts I want to present this example since only fruitful criticism will help to overcome old way of thinking and helps to find better solutions.

Starting point of this research project was the problem of shear transfer at the intersection between cylindrical shells and cones or domes, which is often used for Off-Shore platforms (Fig. 5). Linear elastic calculations produced high shear forces at this corner; the required shear reinforcement was so high, that there was no practical solution to install this reinforcement. The aim of the theoretical and experimental work was to demonstrate

- that the bearing capacity of such high stresses regions are higher than given by present code and resp. or
- that the peak values of the shear stresses according to the elastic calculation were reduced due to the redistribution of the internal forces after cracking of the shells.

The experimental work for this project was done in three steps.

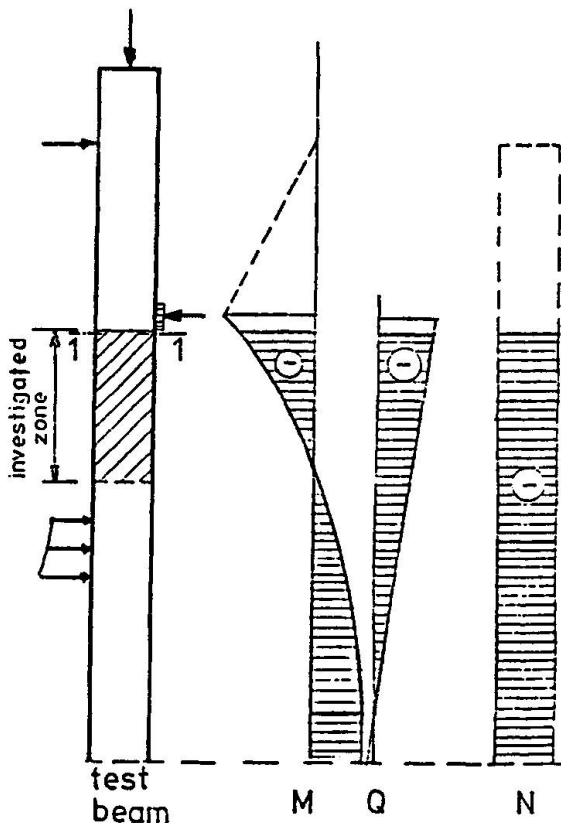


Fig. 6 FORCES FOR THE BEAM-CANTILEVER SPECIMEN

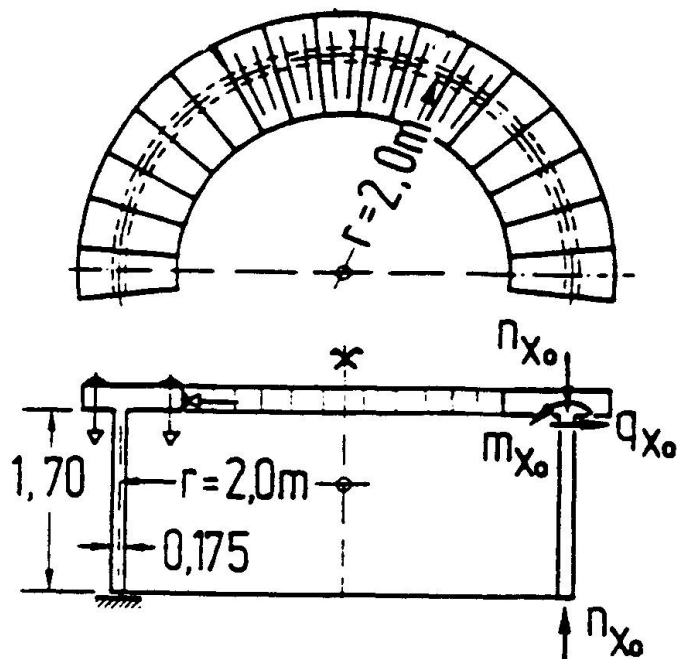


Fig. 7 CYLINDRICAL SHELL SPECIMEN FOR UNIT FORCES



- Step 1) Loading tests on wall-strips under the combined action of moment, shear- and axial force (Fig. 6).
- Step 2) Loading tests on cylindrical shells under unit forces acting at the edge of the shell (Fig. 7).
- Step 3) Loading test on a complete structure of a cylindrical and a conical shell (Fig. 8).

It is not the right moment to explain the numerous measurements and their results but I would like to explain some ideas which were predominant for the chosen solution of the test models.

Within step 1 the spherical problem should be linearized by neglecting the hoop action. By a realistic variation of the moment-shear-ratio the capacity of this corner should be determined. For the chosen test specimen the part of the conical shell was folded in the surface of the cylinder. So the test specimen was a single span plate strip with a cantilever arm.

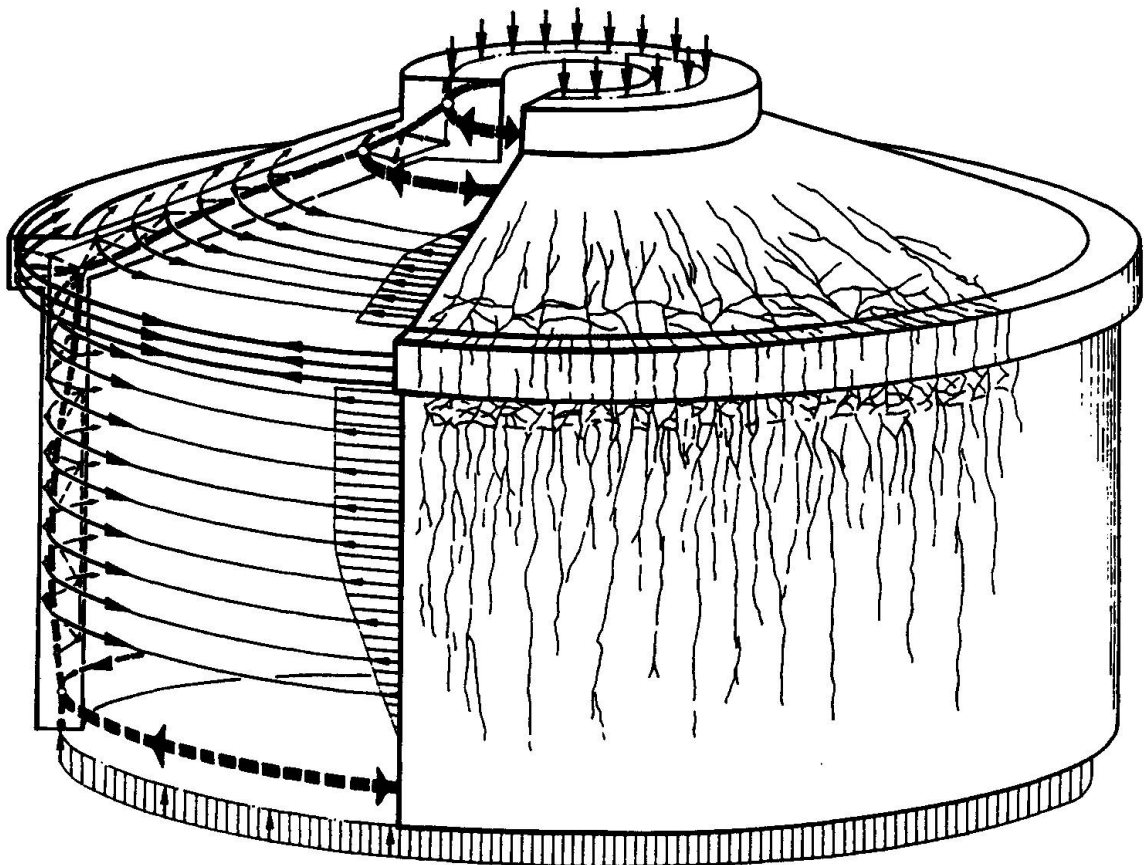


Fig. 8 CYLINDRICAL AND CONICAL SHELL-STRUCTURE

In step 2 besides meridian forces also hoops forces were produced. For this reason cylindrical shells were loaded with edge-forces. The three forces

- bending moment in meridian direction
- shear forces in radial direction
- normal meridian forces

could be applied either separately or in realistic combinations.

The final test step 3 demonstrated the load-deformation behaviour of a complete structure where par example the edge forces and their distribution into the different elements could develop according to the actual stiffness after to cracking.

From a distance of several years since we performed these tests it is quite difficult to judge if the former decision to carry out this kind of tests was correct or not. There are no indications concerning the economical alternatives to the choosen solution to have objectiv arguments for this judgement.

4. SUMMARY AND OUTLOOK

During the pioneer time of reinforced concrete structures and also during the huge application after the second world war tests on structural concrete elements were necessary but also most expensiv to show the flow of internal forces in order to draft realistic codes and dimensioning concepts. Quite a lot of these results were taken over without critical review. Many of this test can now be simulated by computer programs. Some of this test results and their interpretation seem to be problematic today.

For further problems there remains the question how to achieve new knowledge and which will be the range of experimental investigations. Obviously there are some main fields of activities.

- Stressing of structural elements not only caused by forces (temperature, environment, chemical...).
- Replacing of common materials by new materials.
- Better and more economical use of available materials including improved methods for calcuations and designing.
- Industrialisation of the building process.

It is unbelievable for me that all research activity which is necessary for these fields can be simulated by computers. There must be performed additional experimental work to do fundamental research and to confirm other results.

The numerical checking of test results has indicated the weakness of some kind of experimental work. For the future it is therefore necessary to combine both research methods to achieve optimal results.



There are three main fields for this cooperation:

1. Simulation of the behaviour of model specimen and real structural elements under realistic loading conditions.
2. Computer aided testing to comprehend complicated loading and deformation conditions.
3. Experimental testing of structural elements as a spot check of numerical calculations.

The testing institutes have to devote themselves to this dual job, either by establishing a own group which is specialized for simulation problems or they have to look for partners for such a cooperation.

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