CONCRETE IN DENMARK
1905 - 55

NIELS MUNK PLUM

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THE DEVELOPMENT OF

CONCRETE IN DENMARK

By NIELS MUNK PLUM

This article is reprinted from the

Fiftieth Anniversary Number

of

"Concrete & Constructional Engineering"

JANUARY, 1956

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By NIELS MUNK PLUM

Director, Danish National Institute of Building Research.

Introduction.

When we try to picture a long period of development the background is distant, relatively unknown, and hazy, and we never fail to get an impression that very much has been achieved during the period. If, however, we try to see the period from the level of the knowledge and skill that existed at its beginning, the view may be clearer because the differences between now and then become less pronounced. To get a fair view of the period it must be looked at from both ends. The backward look is easy, but it may be deceptive. Our system of education and the newspapers often praise new developments in such an extravagant manner

Fig. 1.—Reinforced Concrete Bridge built in Copenhagen in 1894.

that few will hesitate to judge the last fifty years as a period of vast improvement. To maintain a sound balance I have therefore, as far as possible, tried to judge the period by a forward look from 1905. Born in 1911 and graduating in civil engineering in 1934, this has not been easy, but as a result of studying a vast number of old technical periodicals and papers I hope that I can visualise the early years of the century as objectively as an older man, because memory is very imperfect and often deceives. In this connection one must thank the technical periodicals, and among them "Concrete and Constructional Engineering", for making this possible.

Documentation.

In 1905 only five periodicals of importance concerned wholly or partly with one or more of the many aspects of concrete were issued in Scandinavia, and by 1955 the number had grown to twenty-one. A bibliography of their contents has just been issued by the Danish Institution of Civil Engineers, and from this it has been possible to prepare *Fig.* 2.

The articles printed in these journals are divided into the following nine

* Reprinted from the Fiftieth Anniversary Number of "Concrete & Constructional Engineering", January, 1956.

of materials; 624, Civil engineering; 625, Road and railway engineering; 627, Harbour and waterworks; 629, Transport engineering; 666·9, Cement and concrete industry; 666·94, Cement manufacture; 666·977, Precast concrete; 690, Building (methods and design); 691, Building (materials and components); 693, Building construction (execution of work).

The number of articles published in Scandinavian journals in each five-years' period from 1900 to 1954 is given in *Table* 1. It is seen that while the number

Table 1.

Five years ending	1904	1909	1914	1919	1924	1929	1934	1939	1944	1949	1954
Number of articles	54	103	137	210	175	265	289	378	418	626	803

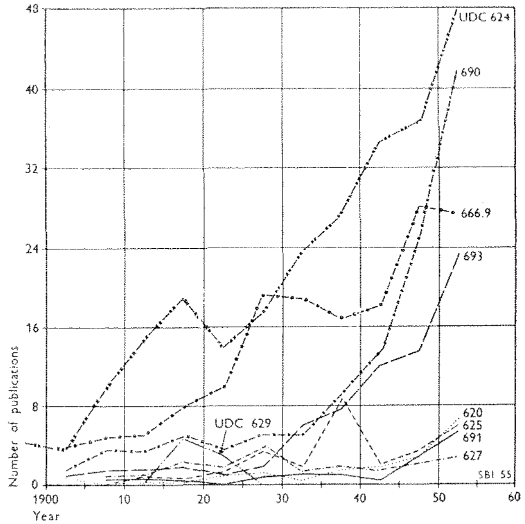


Fig. 2.—Articles published in Scandinavia, 1900–1955.

of periodicals increased about four times from 1900 to 1954, the number of articles contained in them increased about sixteen times; this is an average annual growth of 5·7 per cent., which corresponds favourably with the other developments mentioned later. Apart from the interruption of the two world wars and the depression in the early 1930's, which are apparent in all the curves, other characteristic trends are visible which will be commented upon later.

Concrete Construction.

Danish civil engineers and contractors followed with great interest the rapid development of reinforced concrete on the Continent since Hennebique and Coignét in France in 1892 got their first patents for reinforced concrete, and in 1894 the first reinforced concrete bridge in Denmark (*Fig.* 1), designed by Professor A. Ostenfeld, was constructed by the contractors Schiøller & Rothe. This bridge for a live load of 500 kg. per square metre (100 lb. per square foot).

In the years immediately following, the use of reinforced concrete spread rapidly and new contracting firms specialising in concrete and reinforced concrete were founded. The most important of these was Christiani & Nielsen, which was founded in 1904, and by 1907 had an annual turnover of about 1,000,000 kr. (about £50,000). The writer worked with this company from 1935 to 1947 and would particularly mention one of the co-founders, Mr. Aage Nielsen, who was a technically and practically gifted contractor with the intuition that brings the explorer safely through a jungle of new and unsolved problems. His presence was an inspiration to every employee, from responsible engineers to labourers on the site, and it is mainly due to him that the company, and later many other contracting companies started by engineers who had been trained by this firm, met with success throughout the world.

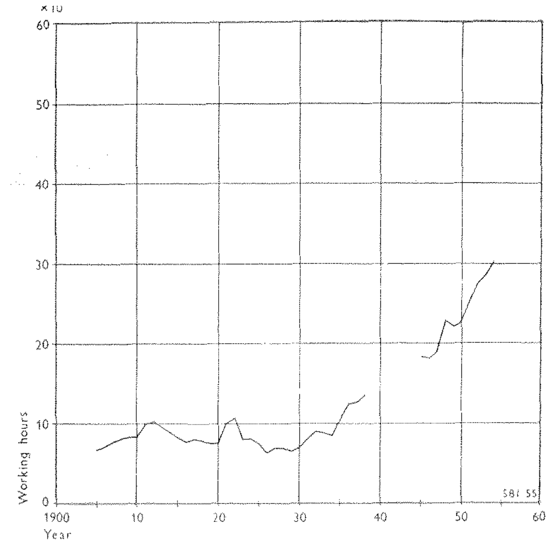
An idea of the total volume of concrete construction can be obtained from the curves in *Fig.* 3, in which (*a*) shows the total number of man-hours worked by employees of members of the Contractors' Association, (*b*) the cement produced per year, and (*c*) the accumulated cement consumption per year. These curves show declines due to the wars and trade depression, and an average annual growth of $3\frac{1}{2}$ per cent. and $4\frac{1}{2}$ per cent. respectively. Considering the increase in mechanisation during the period, the figures are a reasonable guide to the increase in structural and civil engineering. It is of interest to compare these percentages with the growth of 5·7 per cent. in the number of technical papers and articles published, as this illustrates the importance of the technical periodicals and contradicts the view that engineers are reluctant to pass on the results of their experience to others.

During the early years attention was concentrated on new methods of design and construction. There were early wage disputes, and in 1907 a section of the Contractors' Association was formed, comprising contractors who specialised in concrete, to negotiate with the Concrete Labourers' Union; an agreement was reached that ensured an average hourly wage of 40 to 45 Danish øre (5*d*. to 6*d*.) per hour. This agreement permitted piece-work, which had previously been considered to be inconsistent with good workmanship. The piece-rate system has proved very useful to contractors in preparing estimates, and the savings so obtained are generally believed to outweigh the difficulties of applying piece-work rates to new materials and equipment. In Denmark to-day from 50 to 60 per cent. of concrete work is paid for by piece-rates in the metropolitan districts and 30 to 40 per cent. elsewhere.

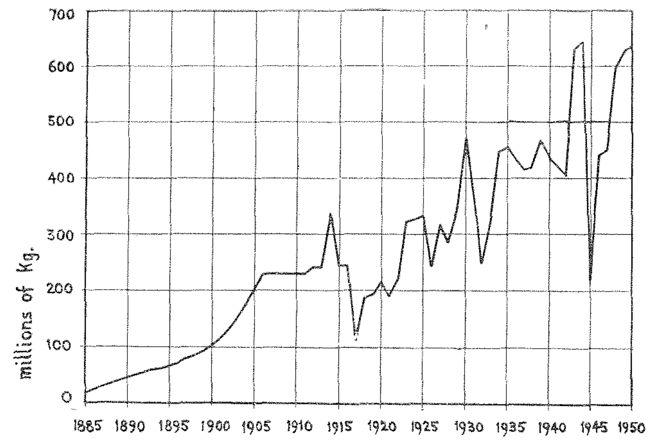
Some Early Structures in Denmark.

As already mentioned, in 1894 the first bridge (*Fig.* 1) was built. A second bridge (*Fig.* 4) was built in 1906 by Christiani & Nielsen, and this also is still in service. In the same year this firm designed and constructed two quay walls of the type shown in *Fig.* 6; this design, which originated in Denmark, is now used the world over.

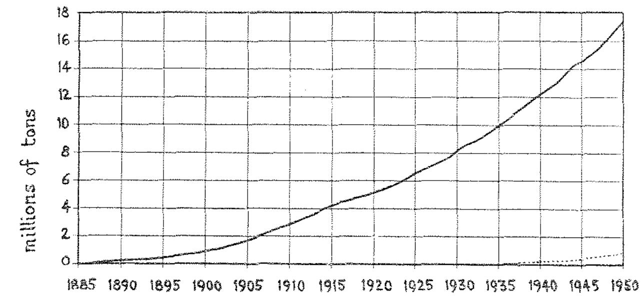
In 1905 Captain N. F. Møehl, an engineer of Danalith Ltd., patented the precast tee-beams shown in *Fig.* 5, and these were used in 1907. In 1910 a concrete chimney was cast in sliding forms, also developed by Captain Møehl. A cross



(*a*) Labour Employed on Concrete Work, 1906–1955 in Millions of Man-hours.



(*b*) Annual Cement Consumption, 1885–1950.



(*c*) Cumulative Cement Consumption, 1885–1950.

Fig. 3.

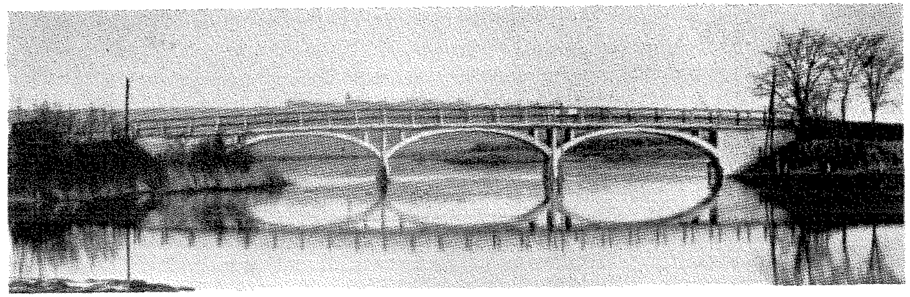


Fig. 4.—Road Bridge at Randers. Built in 1906.

section of the bottom (*Fig.* 7) consists of three identical circular rings drawn apart to form a clover-leaf. At the top of the cone-shaped chimney the three rings come together to form a circular cross section. Chimneys of this type, though slightly modified, are still being constructed as is seen in *Fig.* 8, which shows a chimney built by Danalith Ltd., for the National Portland Cement Co., Pty., Ltd., in Cape Town in 1939.

Many bridges have been built, especially of the bow-string type, and these illustrate the progress in design and in the quality of concrete. Compare, for example, *Fig.* 9, a bridge with a span of 54 ft. built in Germany in 1910 by Danish contractors, with the bridge with spans of 265 ft. built in Sweden by Danish contractors in 1934 shown in *Fig.* 10. Two bridges, with lengths of 1178 m. (3600 ft.) and 3211 m. (9600 ft.) respectively, were built in the early 1930's across the Lillebelt (*Figs.* 11, 12 and 13) and the Storstrøm (*Fig.* 14). The concrete foundations and approach spans of both these bridges presented new and interesting problems which were skilfully solved by the contractors, Monberg & Thorsen and Christiani & Nielsen. The steel superstructure of the Lillebelt bridge was built by Gruen & Bilfinger, Krupp, and Eilers, of Germany, and the steel superstructure of the Storstrøm bridge by Dorman Long & Co., Ltd., of England.

During the first world war the construction of concrete vessels aroused considerable interest everywhere, but it was relatively short lived. A ship of 1800 tons deadweight built for the Danish merchant navy behaved well at sea, was easy and cheap to repair, and remained in service for several years (*Figs.* 15 and 16).

In 1929 concrete and reinforced concrete were at last allowed for the construction of houses and dwellings and here, as elsewhere, a tremendous development

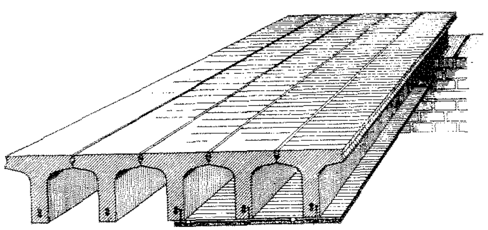


Fig. 5.—Precast Floor Beams used in 1906.

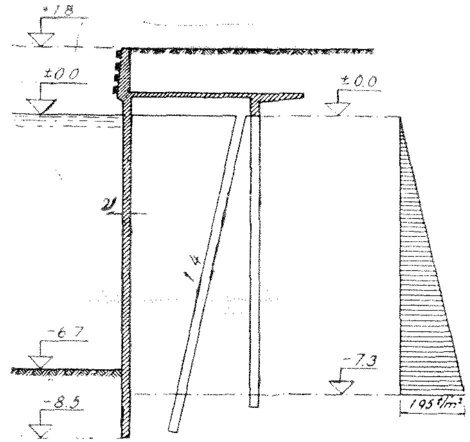


Fig. 6.—Cross Section of Quay Wall at Assens, built in 1906.

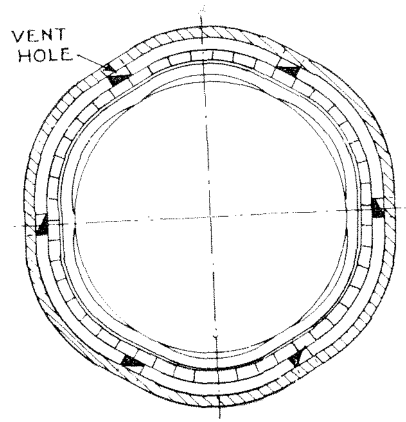


Fig. 7.—Cross Section of Bottom of Chimney. Built in 1910.

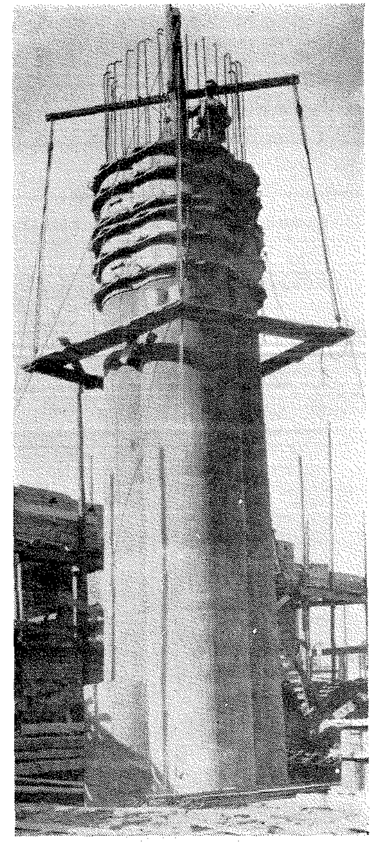


Fig. 8.—Chimney built in Cape Town in 1939.

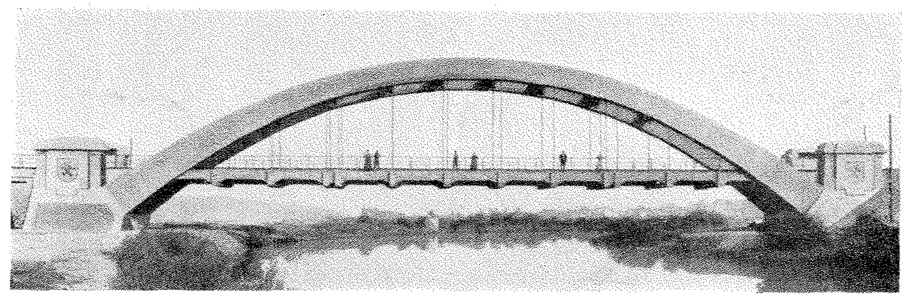


Fig. 9.—Railway Bridge, Thuringen, Germany. Built in 1910.

stressed and precast elements, and *Figs.* 17, 18, and 19 give an idea of the development. *Fig.* 17 shows a military hospital at Copenhagen, with precast columns, built in 1953 by Messrs. Larsen & Nielsen. *Fig.* 18 is a block of flats fifteen stories high built in Copenhagen by the same firm, who also built the factory with precast columns and beams shown in *Fig.* 19. The load-carrying structure is normally of ordinary concrete, whereas generally the walls are of cavity or lightweight concrete blocks with a density of 40 lb. to 50 lb. per cubic foot. In the

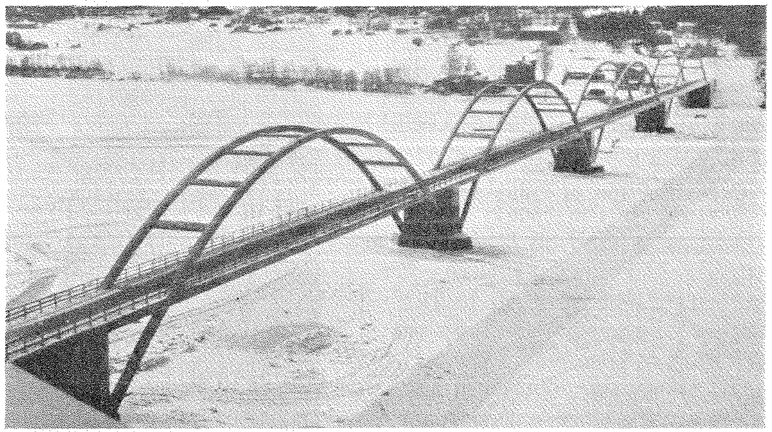


Fig. 10.—Road Bridge at Hammar, Sweden. Built in 1910.

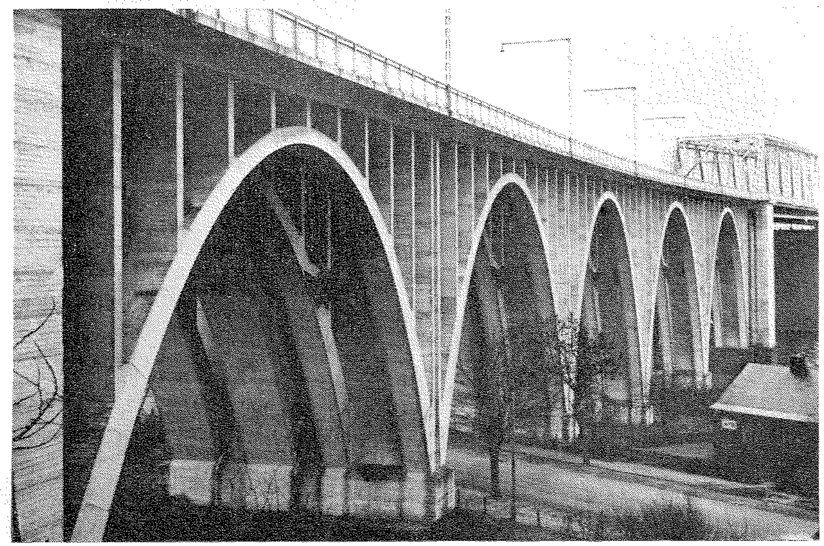


Fig. 11.—The Approach to the Bridge over the Lillebelt.

construction of the walls (whether load-bearing or not) of houses, lightweight blocks and slabs, which are now being precast the full story height, have largely displaced clay bricks.

Just before the second world war much interest was taken in concrete roads,

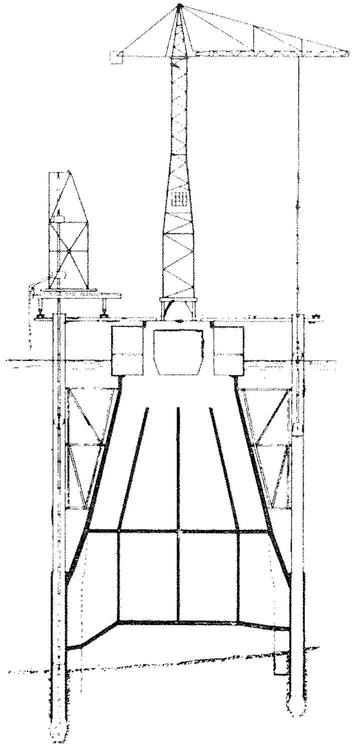


Fig. 12.—Bridge over the Lillebelt: Pier at Mid-stream during Construction.

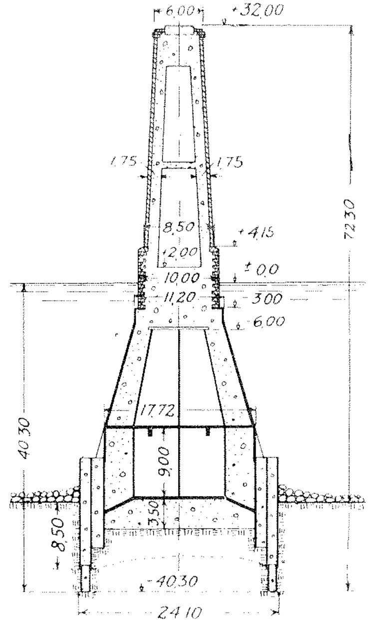


Fig. 13.—Bridge over the Lillebelt: Cross Section of Pier.

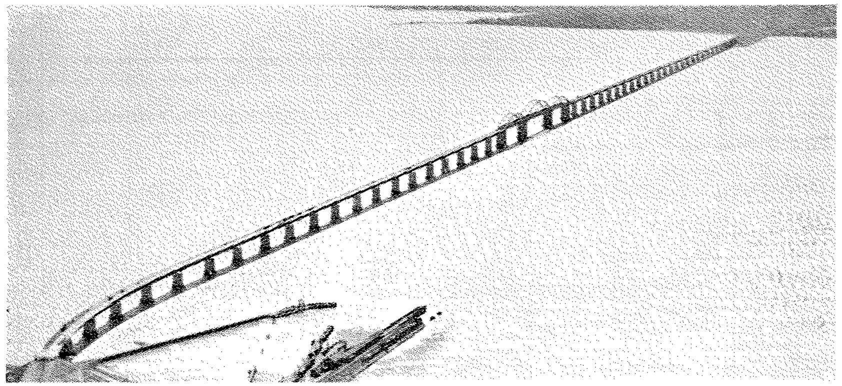


Fig. 14.—Storstrøm Bridge.

roads to be built again after the war.

Danish Work Abroad.

Engineering skill and contracting experience are very suitable for export, and Danish civil engineers and contractors were quick to seize the chance. Before the first world war companies affiliated to Danish concerns were established in ten countries, and during the past fifty years work has been done in about fifty countries. The international character of Danish civil engineering may be seen from *Fig.* 20, which shows that about half of the Danish civil engineering graduates in the period 1905 to 1942 worked or studied more than one month

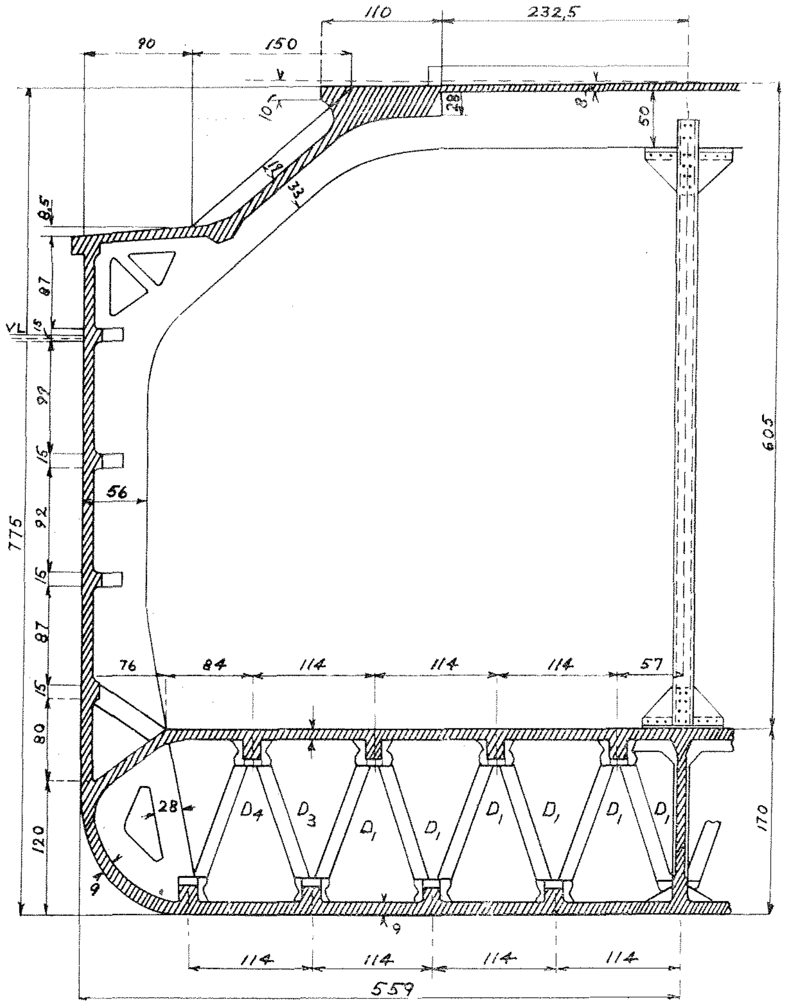


Fig. 15.—Cross Section at Midship of Concrete Ship.

tunately the collection of this information was discontinued in 1942 and has not yet been completed, but the writer believes that the proportion is steadily increasing. Precise information is not available of the amount of work done by Danish contractors abroad, but it is likely that Danish firms have built abroad about 7000 structures at a cost of about 5 billion kroner (£250,000,000); to-day the rate is about £20,000,000 a year. Some photographs of recent works are shown in *Figs.* 21, 22, and 23. *Fig.* 21 shows a bridge at Lisbon built in 1950 by

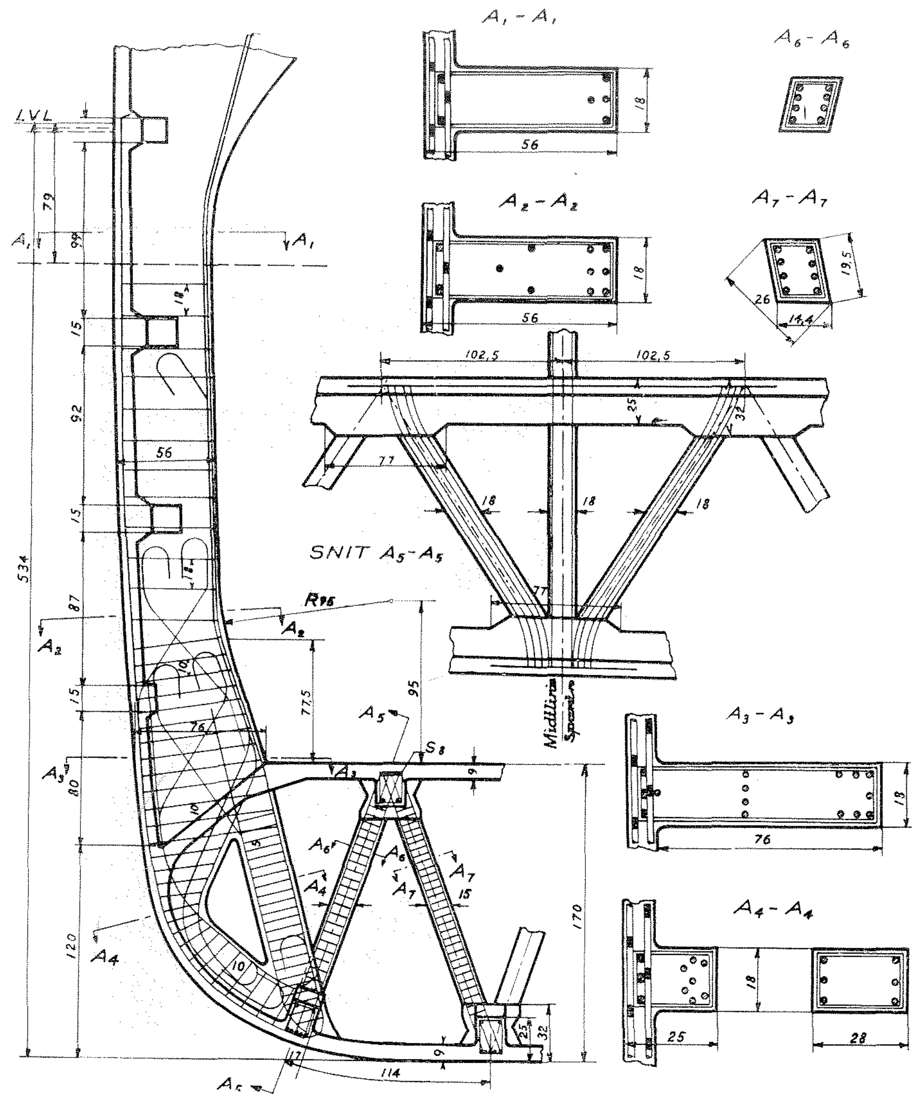


Fig. 16.—Details of Reinforced Concrete Ship.

Fig. 23 is the Owen Falls dam in Uganda built in 1953 by Messrs. Christiani & Nielsen.

Durability of Concrete.

From 1900 to 1905 Danish engineers were confident of reinforced concrete as the result of tests already made in other countries. The early advocates of the new material emphasised the importance of its resistance to fire and to decay, as well as the saving in construction time and the decrease in the dead load compared with other permanent building materials. To-day the picture has changed. Fire resistance and resistance to decay are accepted as facts. With regard to savings in construction time the picture is even reversed, for nowadays concrete cast in place may be considered a relatively slow process compared with prefabricated construction. Also the higher strength of the concrete made to-day

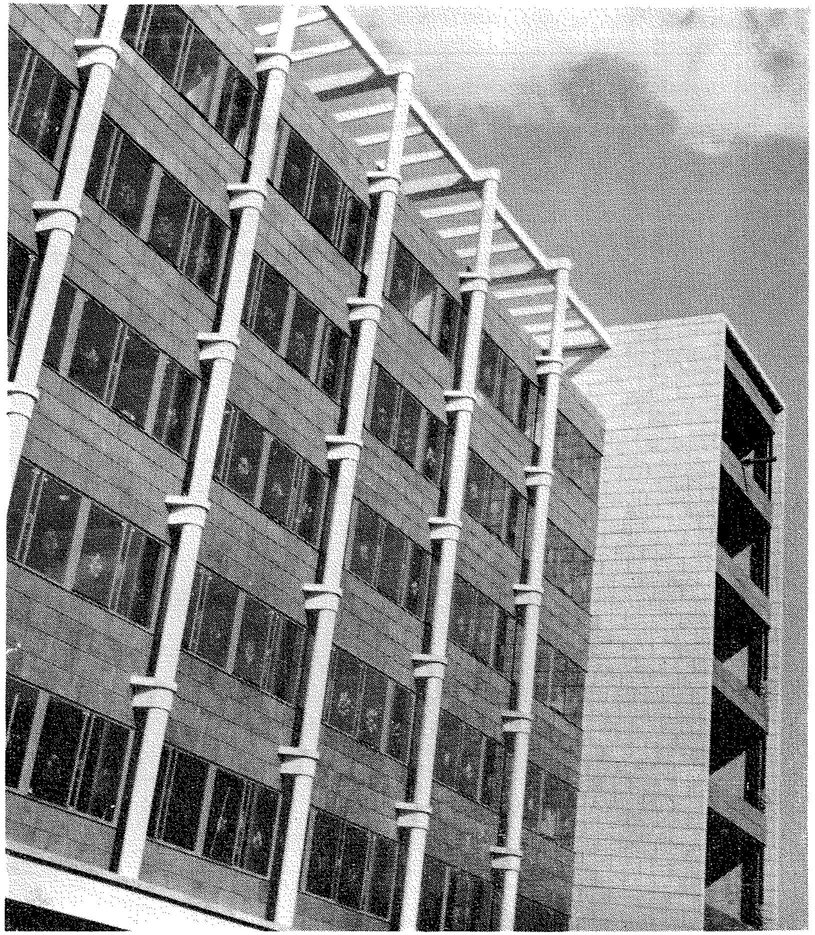


Fig. 17.—Military Hospital, Copenhagen. The Columns were Precast.

appear rather clumsy. Engineers and contractors of fifty years ago were extremely optimistic about the future of concrete, and their expectations have in some respects been fulfilled. Concrete and reinforced concrete have been put to more uses than could possibly have been foreseen, and if no new and revolutionary materials appear this development will continue.

It is surprising how little attention was given to the durability of concrete in the early period. Because concrete is composed mainly of natural stone and has a strength almost equal to that of natural stone, it is not difficult to understand why its durability was not doubted. The engineers of those days would, however, have been very surprised had they known how some of their structures would deteriorate. Apart from the reasons that led them to believe that concrete would last for ever, it is not difficult to understand why durability in general has become a problem only recently. *Fig.* 3*c* gives an approximate idea of the total amount of cement used in plain and reinforced concrete structures. The area under the curve is proportional to the accumulated total, and in general has the

Fig. 18.—Fifteen-story Block of Flats at Copenhagen, built with Sliding Shutters.

yearly volume of about 6 per cent. If the time that elapses without serious and visible deterioration of normal concrete under average exposure is assumed to be, for example, 20, 30, 40, 50, and 60 years, the percentages of damaged structures at various times can be calculated as in *Table* 2. From the table it is obvious that, if the durability of concrete is, for example, fifty years, failures would not become a serious problem until after that period, and in 1955 only about 8 per cent. of the structures built in 1905 would be more or less damaged. This corresponds rather well with experience in practice, and indicates that a life of about fifty years is reasonable for structures built early in this century; the last two

Fig. 19.—Factory with Precast Columns and Prestressed Beams.

lines of the table suggest that the problem will be very serious indeed as more of these early structures reach the age of fifty years.

TABLE 2.—PERCENTAGE OF DETERIORATED STRUCTURES.

Year.	Period before deterioration takes place (years).				
	20	30	40	50	60
1925	26	9	0	0	0
1930	36	12	2	0	0
1935	41	18	5	0	0
1940	44	24	12	1	0
1945	46	28	12	3	0
1950	46	30	17	6	1
1955	46	31	19	8	2
1960	46	31	20	11	4
1965	46	31	20	12	5

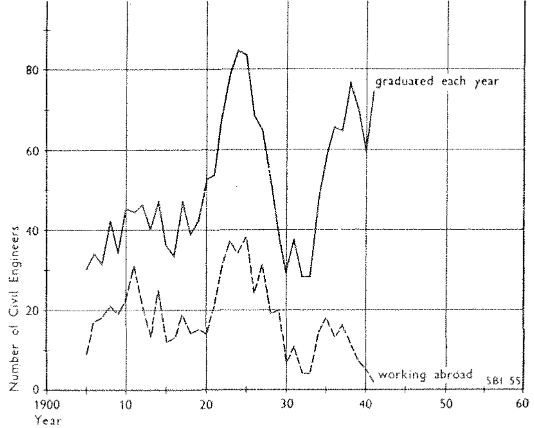


Fig. 20.

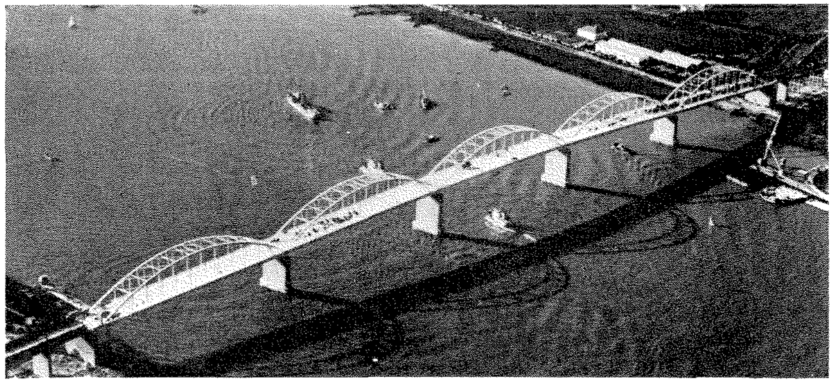


Fig. 21.—Bridge at Lisbon.

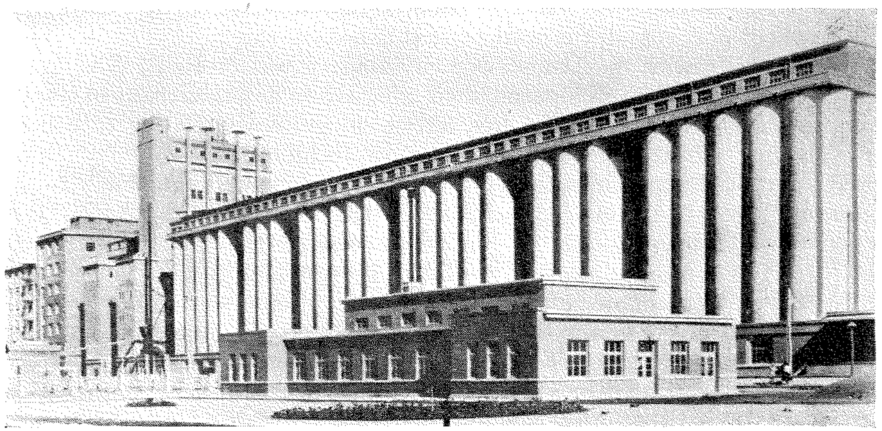


Fig. 22.—Grain Silo at Teheran, Iran.

that have a comparatively short life or to improve the concrete. Much research is now devoted to improving quality, but our predecessors cannot be blamed for leaving the problem unsolved, because the relative values of the life of a building and the cost of better concrete could not be assessed without the practical experience of recent years as expressed, for example, in *Table* 2.

Research.

As mentioned earlier, research on concrete is as old as concrete itself, and besides the professional curiosity in the early days of reinforced concrete it was no doubt necessary to have some research data to persuade more conservative clients and authorities to use the new material. In Denmark official research on cement began with the creation of the State Testing Laboratory at the Danish Technical University in 1896 under the auspices of the Institution of Danish Civil Engineers, which was founded in 1892. The work in this laboratory increased steadily, and in 1909 it came under the ægis of the Ministry of Commerce. At present the Laboratory has an average annual budget of 800,000 kr. (£40,000), most of which is paid by industry for routine testing, among which cement and concrete play an important part.

More research was begun in 1904 when E. Suenson, after two years' study of new materials in other countries, was charged by the Danish Technical University with the creation of a new laboratory for testing building materials. Suenson early concentrated most of his interest on concrete and, by his brilliant laboratory work and the gifted presentation of his findings, did more to forward concrete than anyone else in Denmark. In 1916 Suenson was appointed Professor at the University, and from then until 1948, when he retired, devoted his time to research and the education of a whole generation of Danish civil engineers. Suenson's work won high international reputation, and he has continuously produced books and papers since, in 1907, he published his first textbook on reinforced concrete.

Almost since its establishment in 1882 the F. L. Smidth Co. has undertaken research on cement, but most of their findings were, especially in the earlier years, for commercial reasons kept secret. Such secrecy appears to the writer to be a short-sighted policy, and it is noted with satisfaction that in 1934 the Technical Information Bureau of the Danish cement industry was created. This bureau has for twenty years actively disseminated information and the results of research on improving concrete by giving free advice on problems relating to concrete and by issuing a quarterly bulletin " Concrete Technique ".

About 1885 the consumption of cement in Denmark was negligible. In 1896 production was 35,000 tons, in 1914 about 180,000 tons, and in 1955 about 800,000 tons. From *Fig.* 3(*c*) it can be calculated that the average annual increase in the consumption of cement has been about 4½ per cent. As the average annual increase of the rate of building has been about 3½ per cent., and the strength of concrete during the period has increased from about 200 to 550 kg. per square centimetre (2800 to 7700 lb. per square inch), or about 2½ per cent. per year, it is obvious that concrete has been used to a relatively greater extent, no doubt at the cost of other building materials.

The Danish Institution of Civil Engineers has initiated and sponsored research The first standards for concrete and reinforced concrete were issued in 1908. They have since been revised five times, and the current standards DS411 were issued in 1940. In 1946/7, on the suggestion of Mr. Søren Rasmussen, consulting engineer, and the writer, more intensive work was started, and the Concrete Section now issues the periodical " Beton & Jernbeton " and pamphlets and books, and arranges classes for engineers, site superintendents, and others.

Some of the activities of the Concrete Section, especially on research, were, however, taken over by the Danish National Institute of Building Research, which was founded in 1947 and has an annual budget of 2,500,000 kr. (£125,000). The importance placed by the Institute on research is seen from the fact that slightly more than a quarter of the hundred or so publications issued so far by the Institute deal with concrete, reinforcement, or shuttering. Many of these publications are in the English language or have extensive summaries in English. In some circles there seems to be an impression that too much research is being done on concrete and reinforced concrete. The curve 666·9 of *Fig.* 2 referring to cement and concrete shows, however, that this is apparently not so. In the 1920's the subject attracted much attention, and a closer study of the curve shows that one-third of these papers dealt with the improvement of concrete, another third with the proportioning and production of concrete, and the other third with lightweight concrete, other special concretes, and precast concrete. The average annual increase in the number of papers in this group from 1900 to 1929 is as high as 6½ per cent. Apparently the depression of the early 1930's affected the interest in these subjects, and interest was not resumed until the years immediately after the second world war. The interest this time was again surprisingly concentrated and short, and was followed by a decline during the last five years, which is in great contrast to the rapidly-increasing interest in all other subjects. The average annual increase in the number of papers between 1900 and 1955 was only 4 per cent.

The conclusions that can be drawn from the curves in *Fig.* 2 are limited, and the ratio between the amount of research and the number of publications in the different categories is not known. It may, however, be concluded that those who think that too much research is being done on concrete should base their opinion on conditions five to ten years ago. The relatively decreasing trend in the publication of articles on concrete in Scandinavia in recent years is, however, noteworthy, and if the tendency is continued an investigation should be made to see if additions are necessary to our present research.

During recent years we have, as have others, concentrated particularly on the durability of concrete, and Denmark is one of the few countries in Europe where much deterioration can be definitely traced to cement-alkali reactions. A considerable sum has recently been appropriated to a special research group under the auspices of the Danish National Institute of Building Research and the Danish Academy of Technical Sciences jointly to study the question, and it is hoped soon to determine the sites of these aggregates and the extent of the danger. Work has also been started, in collaboration with the Technical University, to develop methods of neutralising reactive aggregates, and we are further in close contact with the research that is going on at the Building Research Station in England on this question.

In evaluating the development described in the foregoing it is tempting to use superlatives to describe the increase in size and numbers of concrete structures. Quantitatively the development has been impressive, and I would emphasise that the figures are given in terms of the use of concrete and are not influenced by the inflation of money values. It is, however, an open question whether much improvement in quality has taken place during the period 1905 to 1955. It seems to me that the answer is almost in the negative, for the following reasons. First, nearly all the principal inventions were made before 1900, and the developments since have been refinements and improvements only of these principles. Secondly, no radical change has taken place in the quality of concrete. In spite of the increase in the strengths of cement and concrete, we have not yet produced a material as strong and durable as hard natural rock. Experience during the period has, on the contrary, made us more doubtful than our predecessors about the possibility of doing so.

So far as the writer can see, much of the present research therefore takes the form of improving a partly obsolete material and partly obsolete methods, and I believe that, if very basic and radical changes in the quality of cement and concrete are not soon made, the next fifty years may see the eclipse of concrete and reinforced concrete by new materials. Concrete as it is now known is not enough for really permanent structures, and unless it can be made either much cheaper or much better it will be in serious competition with cheaper or more durable materials.

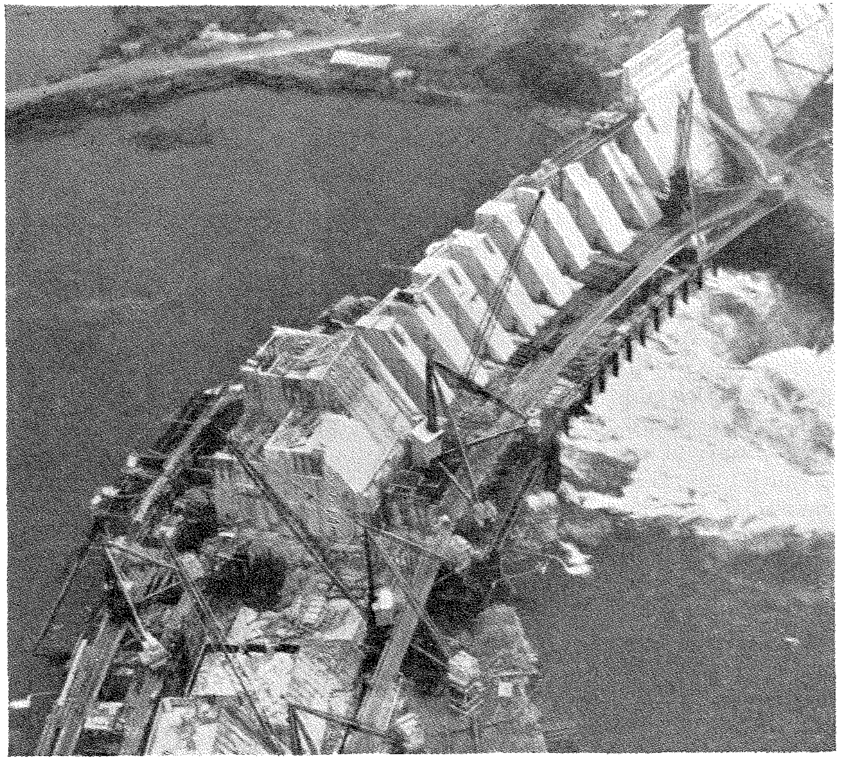


Fig. 23.—Dam at Owen Falls, Uganda.

In studying the literature of the last half-century it is surprising to see how many of our current problems were present in 1905 to 1910, and to see that our knowledge has so little improved during the period. It seems common nowadays, especially in larger countries, to approach the problems of research by making extensive and expensive tests with perhaps little previous thought and statistical planning. The result is dismaying. Tremendous amounts of test data are accumulating which may give some immediate help in practice but which cannot be scientifically explained, and these primitive results are often reached at a cost many times more than the cost of well-planned research where testing is only the least part of the project. Thanks to the concrete periodicals, which give a very close picture of the history of concrete and the mistakes that have been made, the writer is able to conclude with some suggestions for the future of concrete research. Before entering on a new project, practice, or research, much time and money will nearly always be saved if the following suggestions are adopted.

(1) Read the literature—it will save repeating previous mistakes, and enable a much more accurate aiming at the target. It is quite fantastic to see the amount of repetition of the same tests that has taken place because of an ignorance of what has been already done.

(2) Think before starting actual experiments. From existing knowledge, it is frequently possible, by calculation of the physical and chemical processes, to reach the goal without tests, or to get so near to the truth that tests are needed merely to verify or to state arithmetically what is conceived by the mind.

(3) If and when tests are necessary, simulate the actual conditions of exposure in practice as closely as possible, even if this entails considerable complications, and record as many test conditions and test results as possible. The number of accelerated standard test procedures that are poorly correlated with actual conditions in practice is overwhelming, and presents a problem of high importance to national economy. Economic conditions must mainly be based on the degree of safety under service conditions, but at present this degree of safety has little connection with the results of accelerated tests. Further, a valuation of test results will be frequently complicated by lack of data which at the outset are considered irrelevant, and some extra data will often, when kept on record, render many later tests superfluous.

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