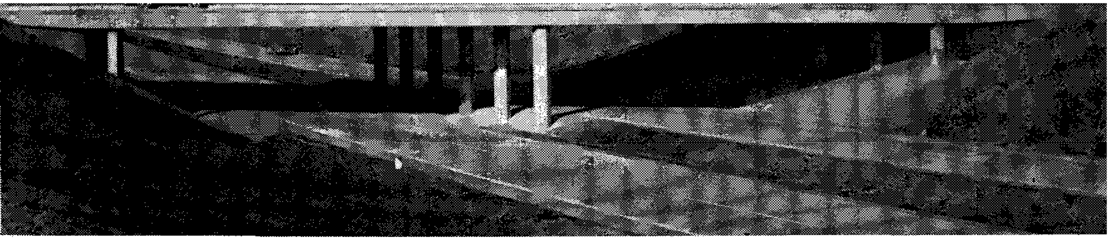

Fig. 1 Slab bridge over Danish turnpike (2 x 20m) with recessed abutments in order to increase visibility on the road.

Prestressed Concrete in Scandinavia

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I. Historical Review

One of the very first proposals concerning prestressed concrete was made by a Norwegian engineer, J. G. E. Lund, who in 1905 advanced the idea of using steel rods under tension (anchored with nuts) in reinforced concrete in order to avoid cracks in the concrete. He failed, however — as did many others later — due to the limited knowledge at that time of the shrinkage and creep of the concrete, and thus of the proper tension to apply to the rods.

In spite of this early attempt, prestressed concrete was not introduced to Scandinavia until 1942, at which time a "long line" factory was started in Stockholm. At about the same time a girder bridge was constructed in Sweden with a primitive sort of post-tensioning, using rods of steel outside the concrete, in order to attenuate the stresses in the reinforced sections of the main span of 72 meters.

It was, however, only after World War II that prestressed concrete became more used in Scandinavia. Long-line factories were founded in Denmark in 1947, in Finland in 1950 and in Norway in 1951. There are now (1957) about 10 of these factories in Scandinavia, the factory in Stockholm still being by far the biggest and only one in Sweden, whereas 4-5 factories of medium size are serving Denmark, which has a dense population compared to the other Scandinavian countries.

Prestressed concrete in the form of post-tensioning on the site was first employed in Denmark, where it was put at an early stage to many varying uses comprising of bridges, reservoirs, silos, industrial buildings, etc. The development in Sweden was at first confined to bridges, but is now spreading to the same fields as in Denmark, and the same is true, to a lesser extent, for Norway, whereas the use of post-tensioned concrete in Finland has been rather sporadic.

2. Scope of Activities

As outlined in the previous section, the scope of activity of prestressed concrete in Scandinavia has covered most normal fields of this building procedure. The most important of these fields are mentioned below illustrated by typical or outstanding examples.

A. Bridges

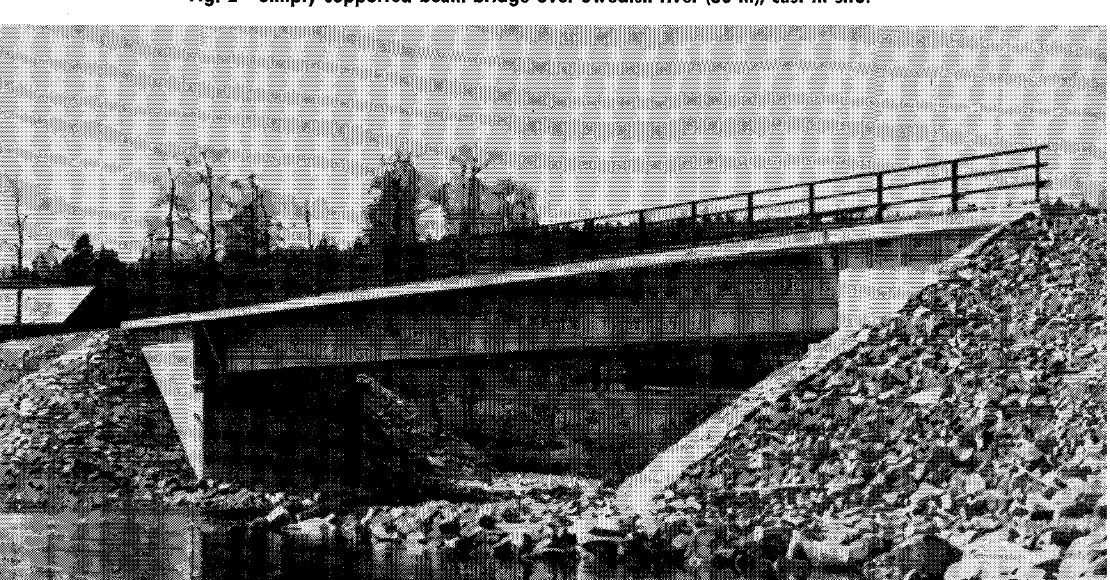
A large number of medium sized bridges have been built in prestressed concrete, especially in Denmark and Sweden. Characteristic for these bridges is that most of them have been cut in-situ, using as simple a form as possible, i.e., slab bridges for spans to approx. 20-25 m or slab-frames with abutments in normal reinforced concrete. For spans up to 40-45 m slab-beam bridges are used. Most of these beam bridges have been made with simple rectangular beams connected with the slab, the whole section working together. The reason why these simple forms are normally adopted is the rather high price of form work and the severe climatic conditions which prohibit the use of very thin webs in I-shaped beams.

As an example of a slab bridge, fig. 1 shows a bridge over a Danish turnpike (continuous over 2x20 m with a thickness of 0,6m), and fig. 2 shows a typical Swedish bridge over a river, constructed as simply supported beam (span 30 m, depth 1,9 m). Another typical Scandinavian application is to combine a prestressed slab or girder structure with normally reinforced abutments to a frame construction, as illustrated by fig. 3, which shows a Danish road-bridge (clear span 36 m, depth in the middle 0,75m); this type of structure is especially suitable where the construction-height is limited.

Large bridges are rare in Scandinavia, but some outstanding bridges in prestressed concrete with main spans of about 100 m have been built, or are under construction in Sweden, using cantilever construction without scaffolding. Fig. 4 shows one of these bridges especially suited to the rather broad and deep Swedish rivers where a strong current and ice make the building of a scaffolding hazardous and costly.

Bridges made of prefabricated elements are — as mentioned above — rather rare. Small bridges (with spans from 5-12 m), are often constructed in Denmark with inversed T-shaped beams made in a long-line factory. Apart from this use prefabricated and post-tensioned beams have hitherto only been employed where special conditions have favored this procedure. A bridge with a single span of 34 m over a heavily used railway has been constructed in the suburbs of Copenhagen, where I-shaped beams are

Fig. 2 Simply supported beam bridge over Swedish river (30 m), cast in situ.



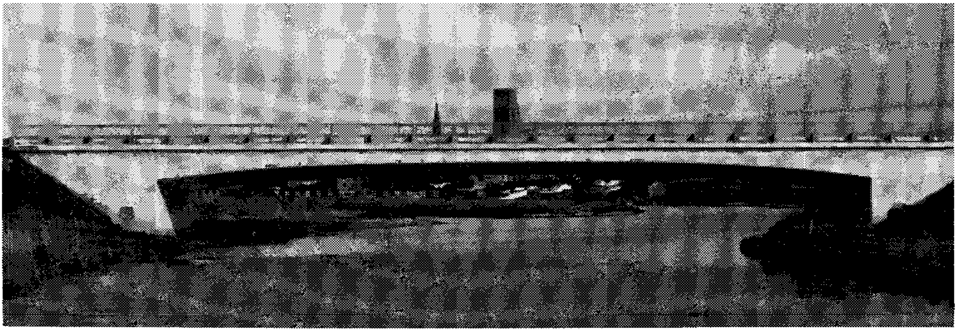


Fig. 3 Frame-bridge over Danish river (36 m) with prestressed superstructure fixed in reinforced abutments

assembled to a slab with a transversal prestressing. Fig. 5 shows another example, a part of the 500 m long approaches to Norway's largest bridge, where prefabrication of the main beams was advisable owing to the bad soil conditions which made scaffolding costly especially since the approaches rise to about 35 m over the ground level (spans 23 m, depth 2 m; the beams as well as the overlying slab were rendered continuous over about 8 spans by subsequent prestressing of the slab).

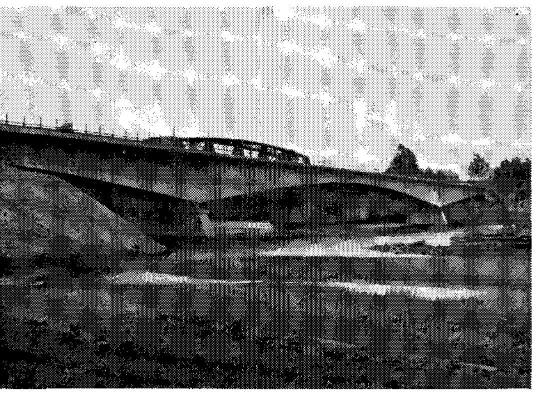


Fig. 4 Beam bridges over the Swedish river Tunsta (41 + 107 + 41 m) constructed by cantilevering without scaffolding.

B. Industrial and House-Building

Prestressed concrete has been used in this field especially for the roof construction of one story industrial buildings. In such structures large spans between the columns are very suitable, and prestressed concrete competes successfully with reinforced concrete under these conditions, and even with steel structures, as it is fireproof and demands much less maintenance. In Sweden, it is now almost the rule that roofings of this nature are constructed with beams of standardized type, produced in long-line factories. Fig. 6 shows a typical building of this type, and it should be mentioned that spans up to 25-30 m, made with prefabricated beams, are not a rarity. A similar development is taking place in Denmark, and has had a good start in Norway and Finland.

Post-tensioned members, too, are used for roof-structures, but to a lesser extent than pre-tensioned members, and especially where irregularities reduce the utility of the standardized pre-tensioned beams or where the spans are very large. An outstanding example is the roofbeams of a hangar in Helsinki Airport, with spans of 45 m, see fig. 7. The beams, which had the form of an arch-truss, were assembled from small prefabricated elements, using post-tensioning. Subsequently these 125 ton beams were lifted to their final position about 11 m over the pavement.

Prestressed multi-story buildings have not been constructed to any large extent in

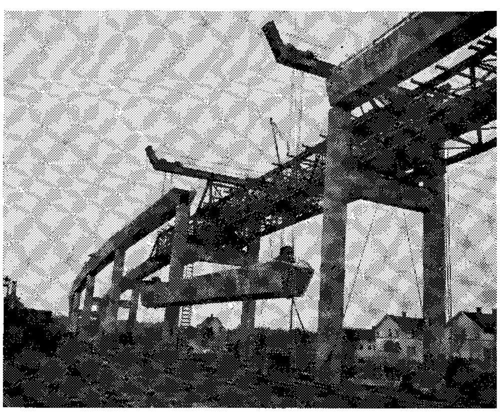


Fig. 5 Approaches for steel arch bridge over the Norwegian river Glomma (22 x 23 m), with main beams prefabricated and mounted up to 35 m (60 t). Columns made with sliding shutters.

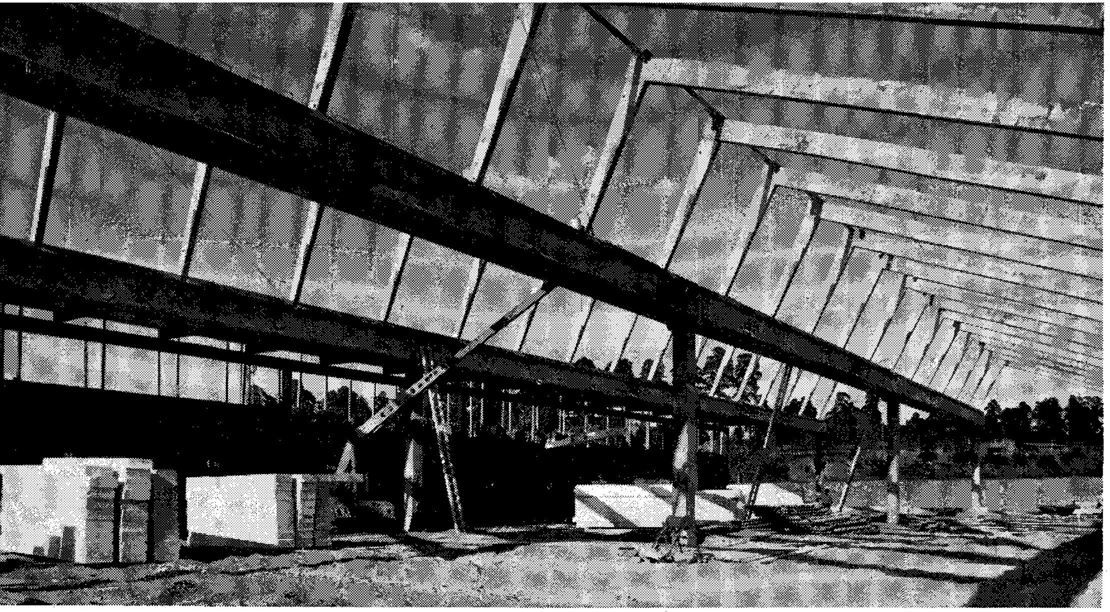


Fig. 6. Roof structure made with standardized prefabricated beams from long-line factory.

Scandinavia, but two interesting examples should be mentioned, a house building in Helsinki (fig. 8) and a factory building in Copenhagen (fig. 9). In both cases the prestressing was used to assemble rather heavy units (prefabricated outside the building site) to a rigid building frame, thus speeding up the construction on the limited area of the building site.

Prestressed shells have been used mainly in the form of spherical domes, comprising a prestressing of the edge beam for reservoirs and the like. Fig. 10 shows one of the biggest prestressed domes, covering a water reservoir in Stockholm (diameter 44 m, thickness 0,10 m).

Finally it should be mentioned that post-tensioned structures are not infrequently used to overcome a special problem in more conventional buildings erected in reinforced concrete. When such buildings are erected in city areas, a demand for large clear spans in the lower stories often arise in order to accommodate a service-station, a cinema or a department store. Prestressed concrete is in such cases a very powerful means of overcoming some difficulties since prestressing makes it possible to control the deformations of the beams and structures so that they can be kept within limits that will not damage the overlying structures. As an example, a garage can be mentioned in Stockholm where 20 m beams over the ground level carry several overlying stories bearing a heavy load (inter alia trams). The 30 beams necessary for this job were 1,8 m deep and 1,2 m wide.

C. Reservoirs and Silos

Concerning circular-cylindrical reservoirs and silos in prestressed concrete, Scandinavia has probably been leading in Europe; at any rate, the largest European water tanks, water reservoirs, cement silos, sugar silos and oil tanks of this type are to be found in Scandinavia, and other structures such as cement slurry basins, hot water tanks, etc. have so far only been constructed in Scandinavia.

All these structures have been prestressed with cables embedded in the wall, as the wire-winding systems are not favored in Scandinavia. This is due to the severe climatic conditions, which may injure the non-prestressed mortar protection of the wire-wound reservoirs, this being subjected to tensile stresses when the reservoir is full. Considerations of the same nature originating in the desire to lower the maintenance costs

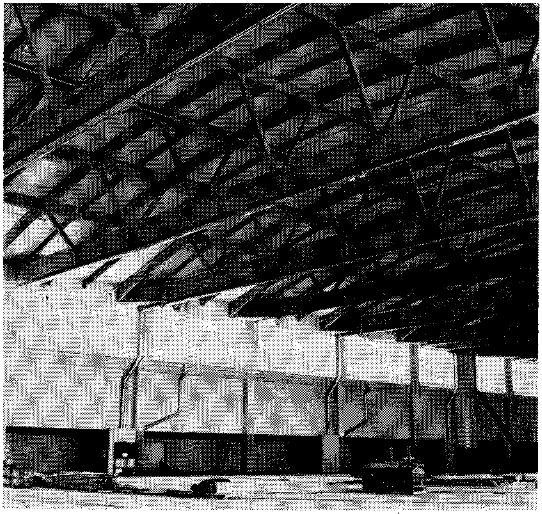


Fig. 7 Arch truss beams (45 m) covering hangar in Helsinki Airport, assembled in units on the ground and mounted 11 m (125 t).

have led to the avoidance of all moving joints between walls and footings, although this demands more skill of the designer, the contractor and the supervisor.

Moreover it should be mentioned that the procedure of sliding shutters has been combined with the procedure of prestressing with perfect success. Some of the most outstanding examples may be briefly considered.

Fig. 10. shows the interior of one of two water reservoirs in Stockholm, each holding 17,500 m^3 (diameter 44 m, water depth 11,5 m, wall thickness 0,25 m).

Fig. 11 shows a water-tower in Sweden, holding 8,500 m^3. It should be mentioned that the conical reservoir with a diameter of 50 m and weighing about 2,500 t. was cast at ground level and later mounted 40 m with hydraulic jacks.

Fig. 12 shows a silo plant for cement in Copenhagen comprising 5 silos, each holding 4,000 t. cement (diameter 13 m, height 25 m, wall thickness 0,20 m).

Fig. 13 shows two Swedish sugar silos, each holding 20,000 t. of white sugar (diameter 35 m, height 29 m, wall thickness 0,30 m). In addition 7 silos, with a total content of 60,000 t. white sugar have been constructed in Denmark.

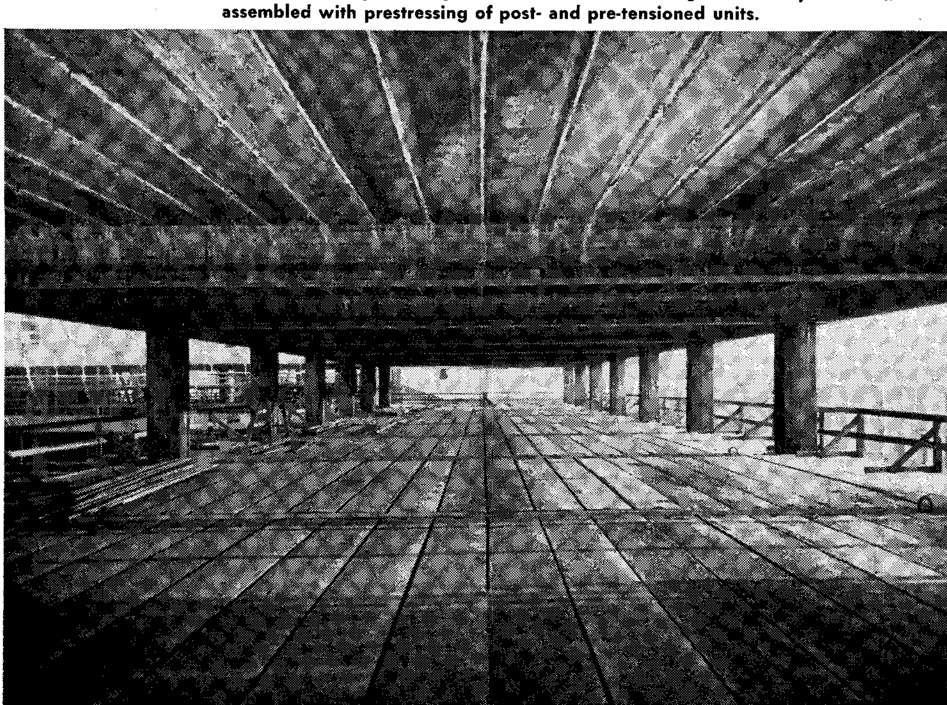
Fig. 14 shows a Norwegian 7,000 m3, tank for heavy oil.

As a special example of reservoirs should be noted swimming-pools, several of which have been constructed in prestressed concrete in Scandinavia. Fig. 15 shows the two swimming-pools, 50 m long and 20 and 17 m wide of an open-air bath in Oslo; each of the pools was entirely prestressed.

D. Miscellaneous Constructions

Outside the main fields of structural activities prestressed concrete has occasionally been used in Scandinavia for a fairly large number of other constructions. Without exhausting the list the following may be men-

Fig. 8 Prefabricated multi-story building in Helsinki (accommodating a University institute), assembled with prestressing of post- and pre-tensioned units.



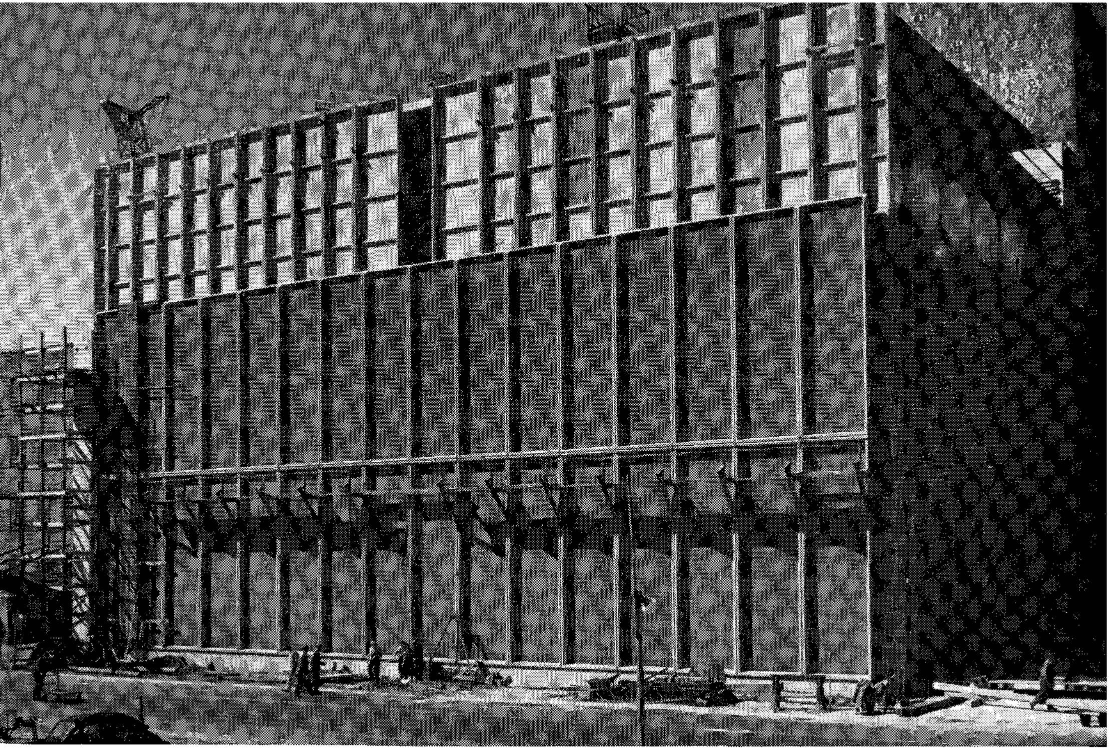


Fig. 9 Prefabricated multi-story building in Copenhagen (accommodating brewery cold storage tanks), assembled with prestressing of heavy, reinforced units.

tioned: special foundations (Norway and Sweden), water-tight chambers for hydro-electric plants (Norway), roofing over tunnels passing under existing buildings (fig. 16 shows an example from Stockholm), widening of existing bridges (Sweden and Denmark), grand-stands for sports-stadiums (especially in Denmark, see fig. 17) etc.

The record of prestressed activity would be incomplete without mentioning the comprehensive series of smaller elements which leave the long-line factories, comprising piles, poles, posts, joists, roof-slabs, frames for windows, safety-railing for highways, etc. Especially the Swedish production of prestressed tubes should be noted; they are made monolithically in one operation.

3. Scandinavian Trends in Prestressed Concrete

As may be gathered from what has been said, there is a trend towards simplicity in the Scandinavian use of prestressed concrete. A meticulous saving of materials is often sacrificed in order to achieve this simplicity, the two main reasons for this being the following:

a) the rather severe climatic conditions in the Scandinavian countries make conditions on the building-site rather difficult and prohibit the use of too thin and slender outdoor structures.

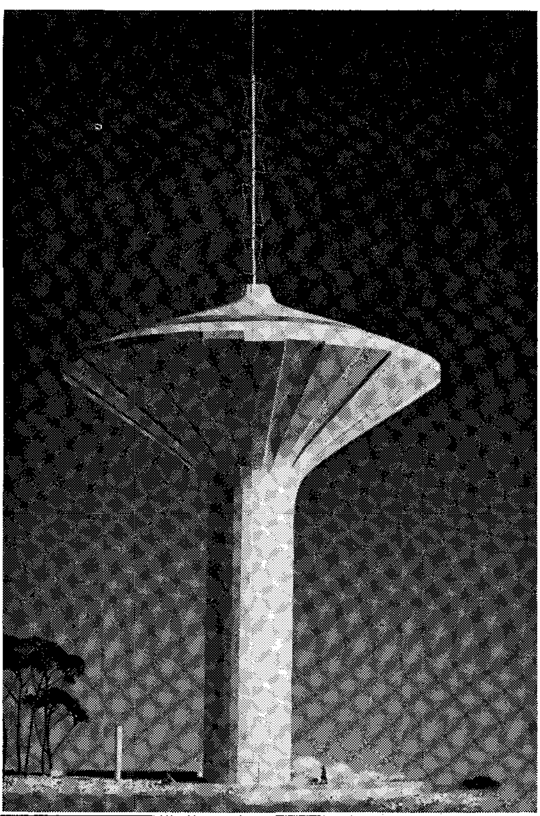
b) wages are rather high as compared to the cost of materials (thus resembling the conditions in the U.S.A.)

Thus solid slabs and beams of rectangular section are normally favoured instead of I-shaped beams and the like, and where continuous structures are concerned a solution is sought by means of cables running from one end of the structure to the other rather than a steel saving design with intermediate anchoring of the cables.

Another Scandinavian characteristic is a certain boldness in trying out prestressing on new types of structures in order to investigate its advantages and limitations.

Fig. 10 Reservoir in Stockholm, holding 17,500 m^3 water (diameter 44 m), with spherical dome-roof (0,10 m).

Fig. 11 Water-tower in Sweden, holding 8,500 m^3. Reservoir (2,500 t) was mounted on top of central tower (40 m) with hydraulic jacks after completion on ground.



The prestressing systems, hitherto used in Scandinavia are rather limited in number (as compared, for example, with Germany). The Freyssinet system was the first to be used, and is still the most general. Systems using bars, such as Dywidag, are increasing in use, and a special Scandinavian type has been developed (using rods produced in Sweden). The BBRV system has started rather successfully (especially in Sweden) and also the Gifford-Udall system. Finally, it should be mentioned that the Magnel system was used some years ago in Finland and that the Leonhardt-Bauer system has been used on one occasion in Norway. Fortunately most of the systems have been put on the market through firms independent of the contractors, so that free competition has been the rule.

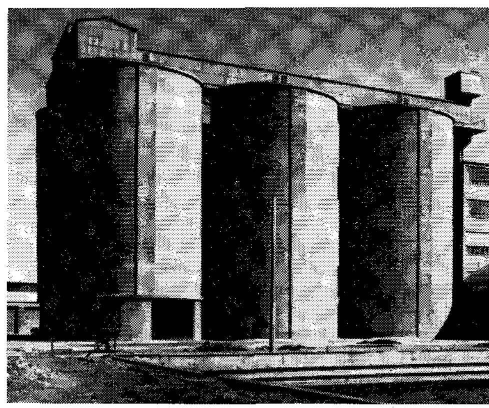


Fig. 12 Cement silos in Copenhagen, holding 5 x 4,000 t (diameter 13 m, height 25m) constructed with sliding shutters.

Original research work in Scandinavia on prestressed concrete has been confined to filling the gaps in the information obtained from abroad. The temptation of re-doing all the basic experiments has been avoided.

Research work has notably been done, and is still going on, concerning a problem of major interest for the Scandinavian countries: the effect of freezing on prestressed structures, especially the freezing of water or grout in the cable ducts. Means have been found to avoid the harmful effects of freezing, but research work is still going on to find a freeze-proof grouting mix. Other tests have been related to friction

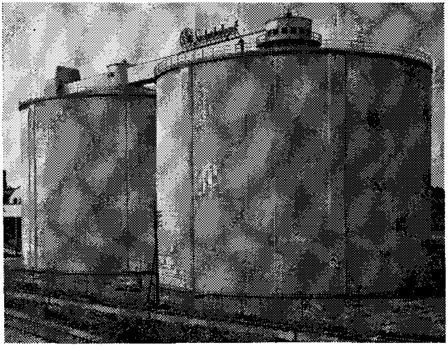
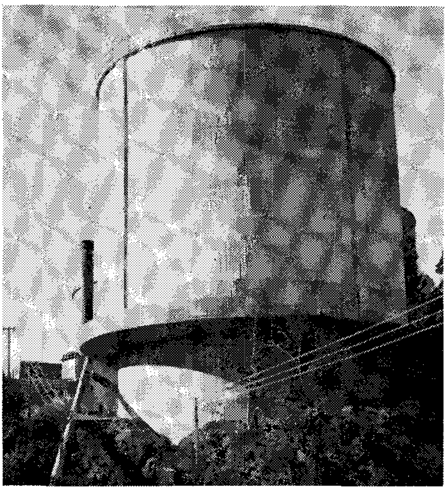


Fig. 13 Sugar silos in Sweden, holding 2 x 20,000 t (diameter 35 m, height 29 m).

Fig. 14 Norwegian 7,000 m³ tank for heavy oil.



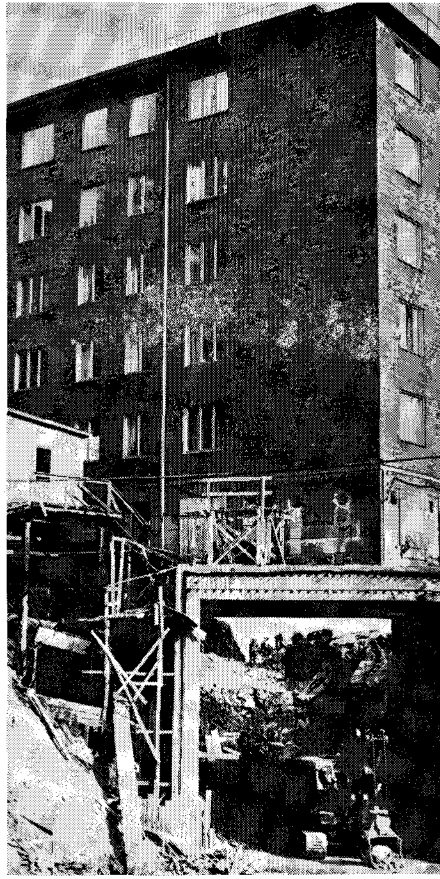
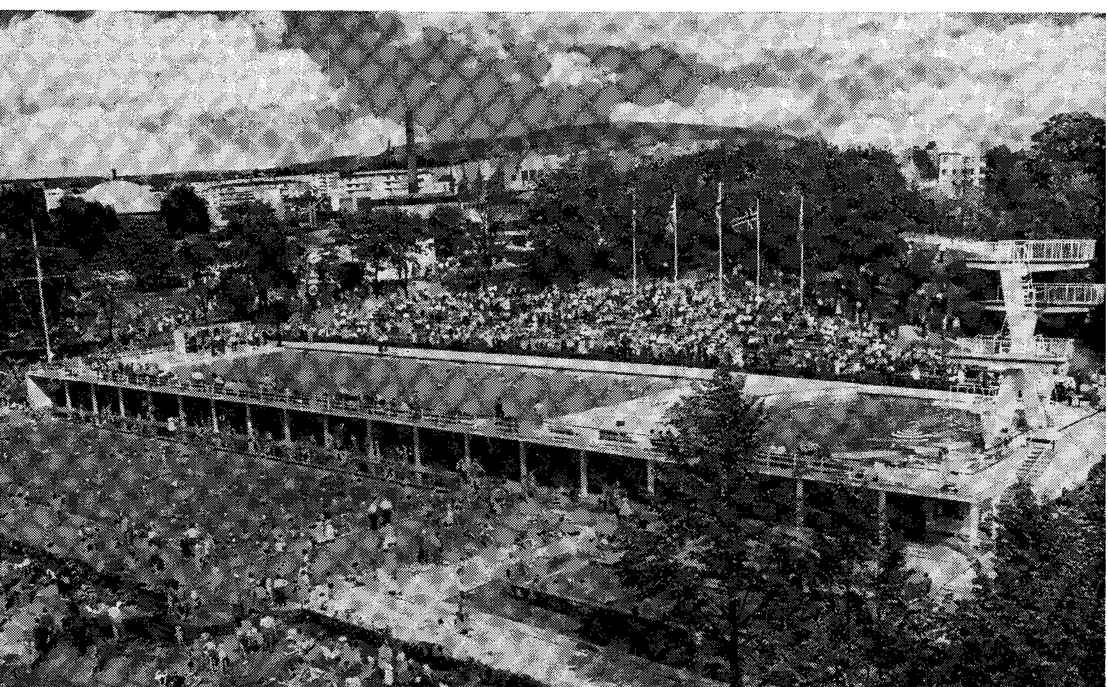


Fig. 16 Roofing for railway tunnel in Stockholm under existing building, constructed without moving the inhabitants (12 x 40 m).

Fig. 15 Swimming pools in Oslo, 20 x 50 m and 17 by 50 m



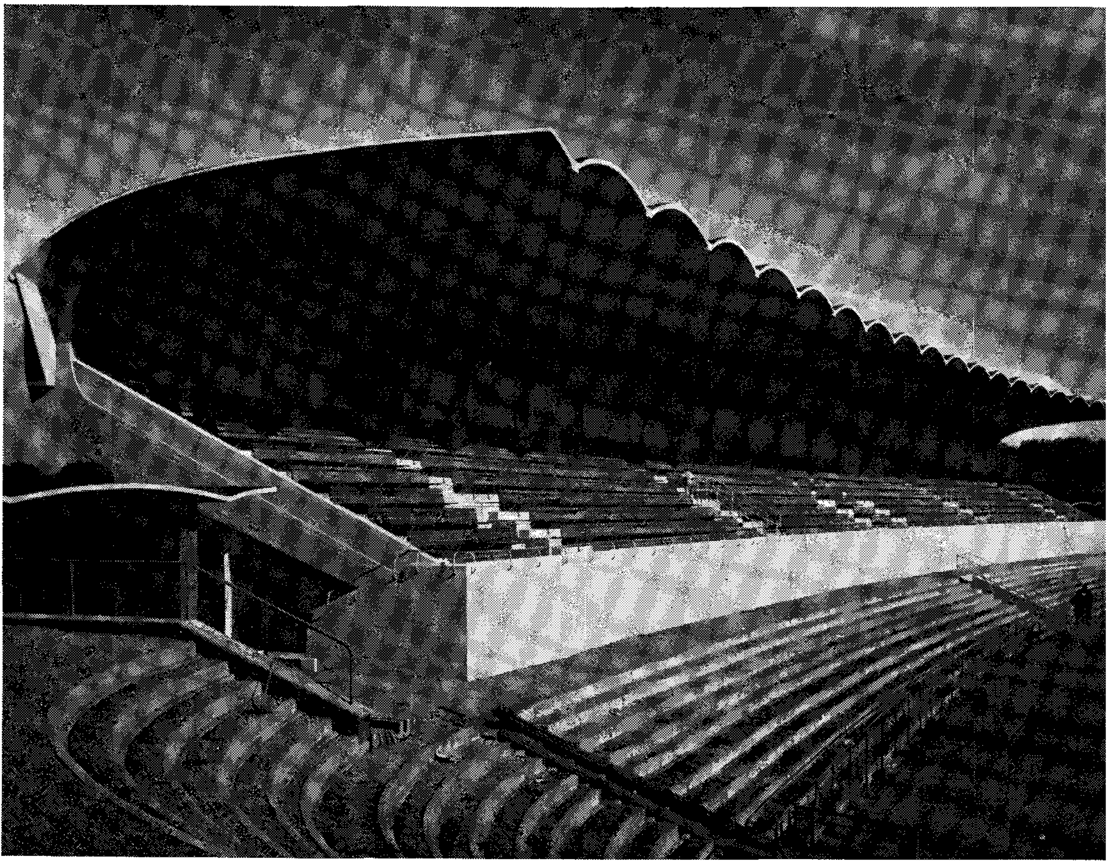


Fig. 17 Grand-stand at sport-stadium in Denmark, constructed with prefabricated U-shaped beams (12 x 95m).

in cables, resistance to fire and ultimate dynamic strength.

Congresses, with the aim of spreading knowledge of prestressed concrete, have been arranged by the Danish Society of Civil Engineers in Copenhagen in 1950 and by the Swedish Society of Civil Engineers in Stockholm in 1952. Engineers interested in prestressed concrete have formed associations in each of the Scandinavian countries, adhering to the International Federation of Prestressed Concrete. These associations have formed groups, which are carrying out further research and studies. Thus the Danish Society of Civil Engineers has formed a committee with a budget of 100,000 crowns for tests and research work on prestressed concrete.

Preliminary specifications for prestressed concrete have so far only been published in Norway. The general opinion in Scandinavia tends to consider it advisable to wait as long as possible with final norms, in order not to hinder the full development of prestressed concrete.