Spiral Ramps for Parking Structures — The Prefabricated Solution

The New Parking Facility at Fornebu Airport, Oslo, Norway

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As air traffic keeps increasing, the demand for parking spaces at airports continually grows. In order to solve the parking problem at Fornebu Airport, Oslo, it was necessary to create a parking area of about 54,000 m^2 (580,000 sq ft).

To meet this challenge, it was decided to build a main parking structure (see Figs. 1a and 1b) with overall dimensions of approximately 81.5 x 96.0 m (270 x 315 ft) comprising six levels of parking. In addition, there is a wing with three levels of parking, roughly 48 x 48 m (155 x 155 ft).

Experience has shown that it is advantageous to move the transportation ramps outside the parking structure when the size exceeds a certain number of parking spaces. Otherwise, the traffic becomes too congested in the parking areas. Consequently, it was decided to use spiral ramps located outside the main structure to bring the traffic in and out of the parking facilities.

For the detailing of the structure, our firm used the recommendations in the PCI publication "Survey of Precast Prestressed Concrete Parking Structures," Research Project No. 7. This publication provided answers to many questions that arose and is highly recommended.

The author presents the design, production and erection features of a precast prestressed concrete parking structure recently completed at Fornebu Airport in Oslo, Norway. A key element in the design of the facility was the use of prefabricated spiral ramps.

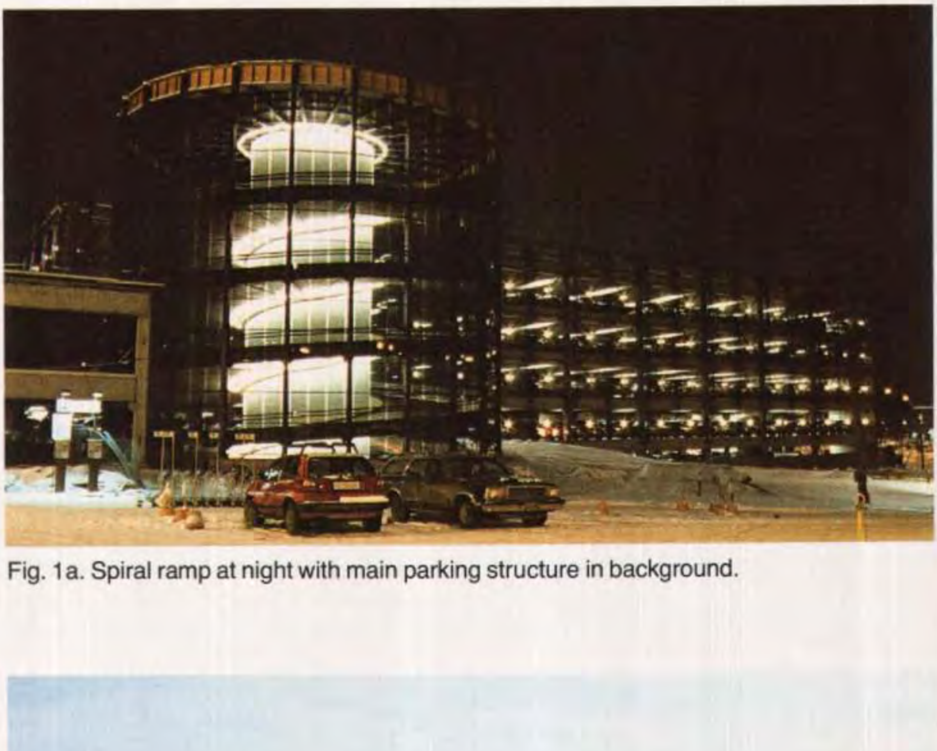

Fig. 1a. Spiral ramp at night with main parking structure in background.

Fig. 1b. Overall view of parking structure on a winter day.

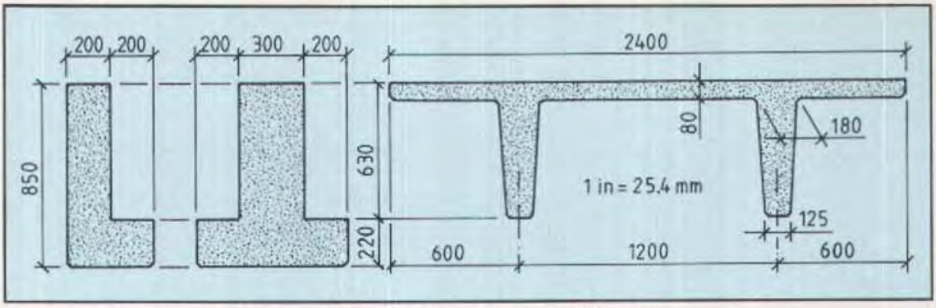

Fig. 2. Typical cross sections of ledger beams and double tees.

The Main Parking Structure

The basic grid for the main structure was chosen to be 16 x 7.2 m (52 ft 6 in. x 23 ft 7 in.). To obtain the necessary slopes for drainage, the foundations for the columns were lowered in every second tier, thereby maintaining identical columns on the entire structure. This configuration did not create any problems for the general contractor on site, but was a major simplification in the production, transportation and erection of the columns.

The frame consists of prefabricated columns, ledger beams and double tees. The cross section of the interior columns in the five-story main structure is 500 x 500 mm (1 ft 7⅝ in. x 1 ft 7⅝ in.), while the facade columns and the columns in the two-story wing is 400 x 400 mm (1 ft 3¾ in. x 1 ft 3¾ in.).

The columns in the main structure were prefabricated in one piece without field splicing for a total height of 16.15 m (53 ft). The cross sections of the ledger beams and double tees are shown in Fig. 2. The ledger beams span approximately 6.4 m (21 ft), and the double tees have a span of about 15.5 m (51 ft).

In order to keep the torsion in the ledger beams within acceptable limits, two methods were used:

1. For the outer beams, with support ledge on one side only, the ribs of the double tees were welded to the ledge, and a wedge was put between the top flange of the double tee and the side of the beam. This is a steel wedge which is welded to the beam only. The support detail is shown in Fig. 3. This entire support welding was carried out while the double tee was still hanging from the crane cable, just barely touching the beam. The welds on the support for the double tees, and the anchorages of the steel plates are designed to transmit the horizontal force necessary to counteract the torsion induced in the beam by the total dead load of the slabs, plus that of the live load they carry. All cast-in steel units are corrosion protected, and all welds were treated with corrosion resistant paint.

2. For the interior beams, with support ledges on both sides, it was possible to avoid steel wedges and the welding. This was done by making sure

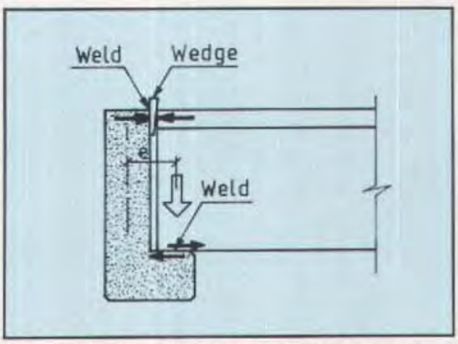

Fig. 3. Support detail on spandrel beam.

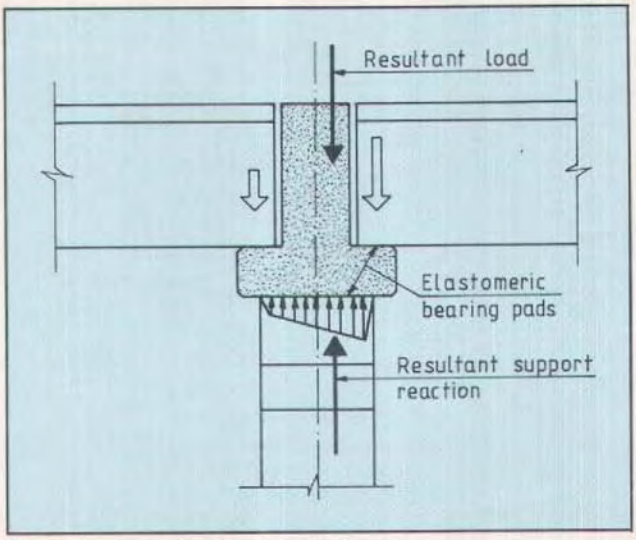

Fig. 4. Support detail on interior beam.

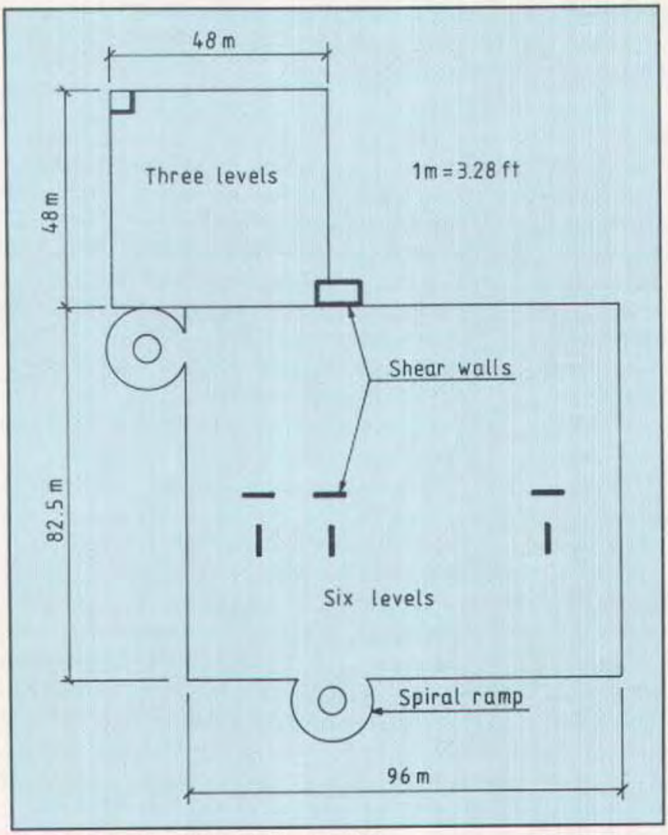

Fig. 5. Plan, location of shear walls.

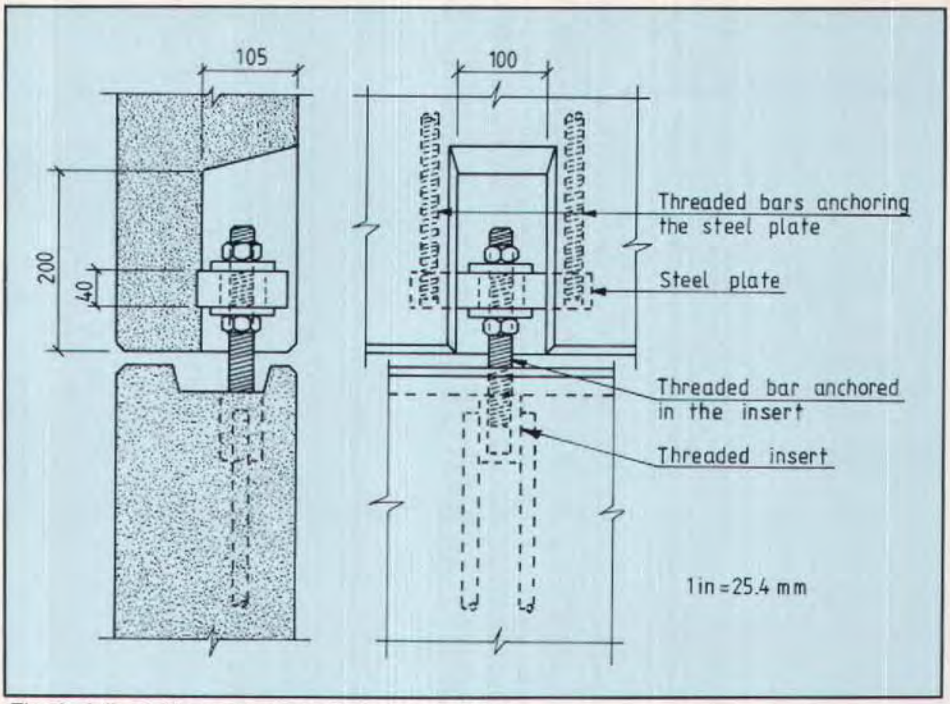

Fig. 6. Adjustable connections in horizontal joints.

the torsional moments could be carried by the supports for the beam with acceptable deformations of the elastomeric bearing pads. Consequently, it became principally a matter of the geometry of the ledges relative to the geometry of the supports. The torsional moments were, of course, only due to lack of symmetry of the live loads, for — during erection — dead load of slabs on one side only. The arrangement is shown in Fig. 4.

The double tees were cast with an additional flange thickness. Normally, the flange is 50 mm (2 in.), but on this project the thickness was increased to 80 mm (3¼ in.) This was done for structural reasons, and eliminated the need for concrete topping. Consequently, a less expensive wearing surface could be used. This will be elaborated upon later.

The stability of the structure is achieved by means of relatively few shear walls, strategically located. The chosen location of the shear walls eliminated the need for expansion joints, which are both expensive and might be potential problem areas. The locations of the shear walls are shown in Fig. 5.

For the shear walls crossing the direction of the beams, the columns were cast as an integral part of the shear wall. The shear walls in the direction of the beams were placed between the columns, but with relatively heavy welded connections to the columns, the columns were activated as part of the stabilizing structure. The inherent advantage with this solution is that the dead loads of the building will be utilized in stabilizing the structure, thereby reducing the demand on all other connections in the shear walls.

In the horizontal joints of the shear walls, a conventional bolted connection was used. The connection facilitates the adjustment of the elements during erection, and will transfer both compressive and tensile forces. This connection is shown in Fig. 6.

In summary, the main part of the parking facility is a rather traditional type of structure. However, the interesting elements are located outside the building, namely, the prefabricated spiral access ramps, one for traffic entering and one for traffic leaving the parking facility. Although spiral ramps have been used before, to our knowledge they have never been used in precast concrete construction.

Why Prefabricated Spiral Ramps?

In the current building industry in Norway, there is an acute labor shortage. This situation may not last, but at the time the parking facility was being bid, the general contractor was not sure whether such a facility could be built as a cast-in-place structure. The only recourse left was to use prefabrication which was probably correct as far as the main structure is concerned. However, it took some time before the concept of prefabricating the ramps was fully accepted. In hindsight, we can say emphatically that prefabrication not only solved the labor shortage problem, but also provided significant savings both in construction time and direct costs.

A comparison of the expenditures shows that the total cost of the ramps with the prefabricated solution was about 70 percent of the cast-in-place scheme. There were three major concerns that were important in the choice of this solution, namely:

1. Cost
2. Time
3. Resources

As far as time is concerned, it is estimated that a total savings of between 3 and 4 months per access ramp was attained. This means that the parking structure can be put into service between 6 to 9 months earlier. The economic implications of this earlier usage is evident.

Fig. 7. Erection of spiral ramp.

The Spiral Ramps

Fig. 7 is a picture taken when the erection of one spiral ramp was nearing completion. The central core is 6 m (20 ft) in diameter, with an outside spiral ledge. The total circumference of the central core is divided into four precast segments, each covering one-quarter of the circle. The thickness of the core segments is 300 mm (12 in.) and the ledge section is 200 x 250 mm (7⅞ x 9⅞ in.). The main dimensions of a central core segment are shown in Fig. 8.

The spiral deck part of the ramp is made of warped, wedge shaped panels, each unit covering 15 degrees of the circle. The ledge on the central core and the deck panels are, of course, horizontal at the entry to each level of the parking structure. These solid deck panels

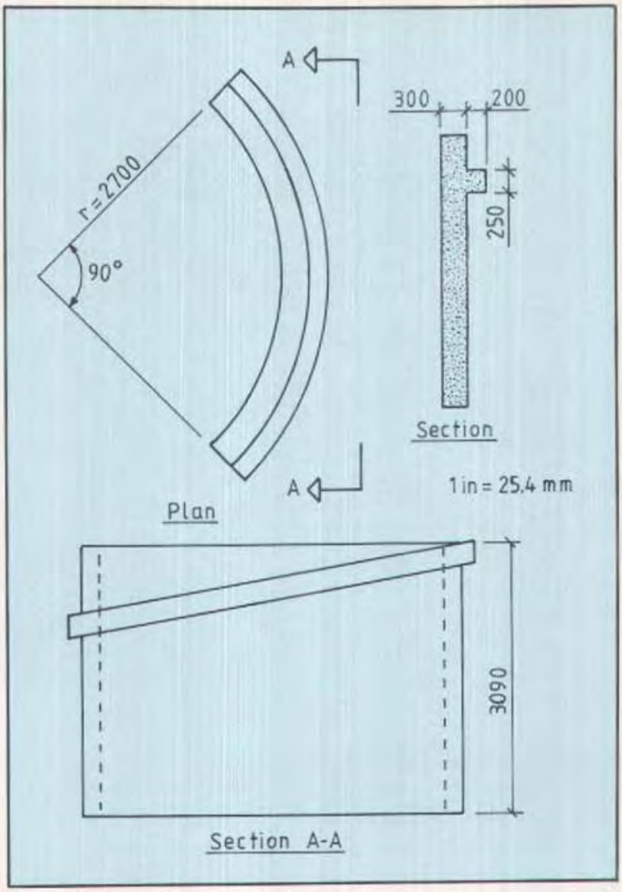

Fig. 8. Segment for central core.

span approximately 5.8 m (19 ft) and have a thickness of 240 mm (9½ in.). A stack of panels is shown in Fig. 9.

The outer supports for the spiral deck slabs are at this project a steel structure. The slabs are supported on steel beams following the spiral curvature of the access ramps.

Originally, the wedge shaped deck panels in the spiral ramps were planned as flat slabs, with the difference of elevation in the joints to be evened out with a concrete topping. However, as the geometry of the spiral was more closely examined we found that the geometry of a spiral deck is actually rather simple, as all radial lines are hori-

Fig. 9. Stack of panels.

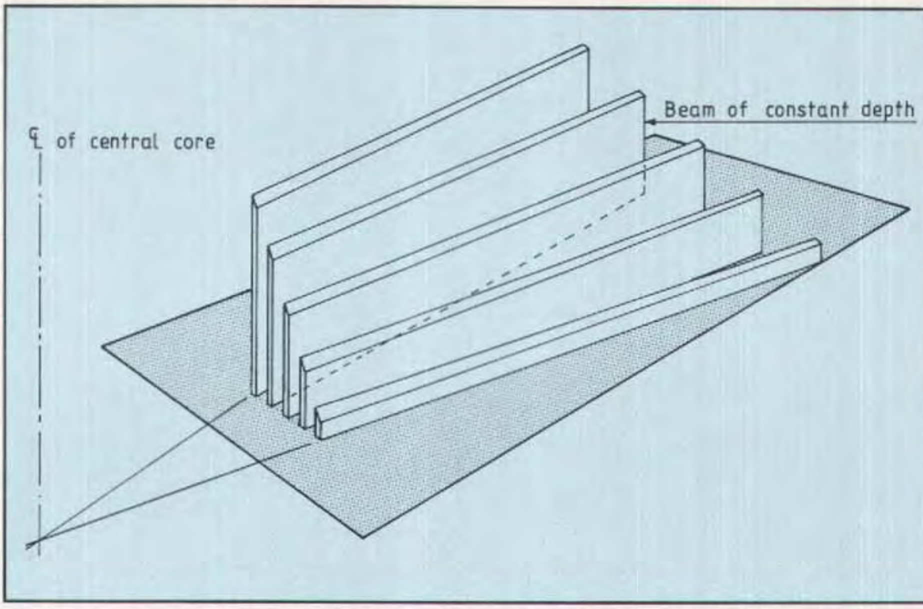

Fig. 10. Framework of form for warped deck panels. Beams of variable depth were laid out in a fan-like pattern on a horizontal surface.

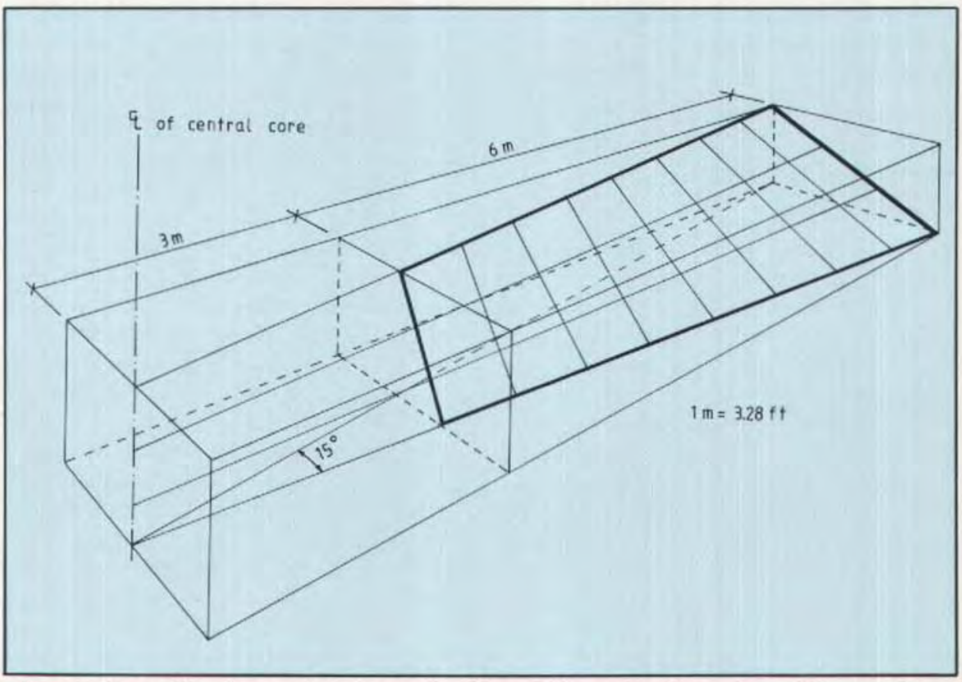

Fig. 11. Geometry of warped deck panels. Although the underside surface of the panels was developed by straight lines, the actual surface was curved.

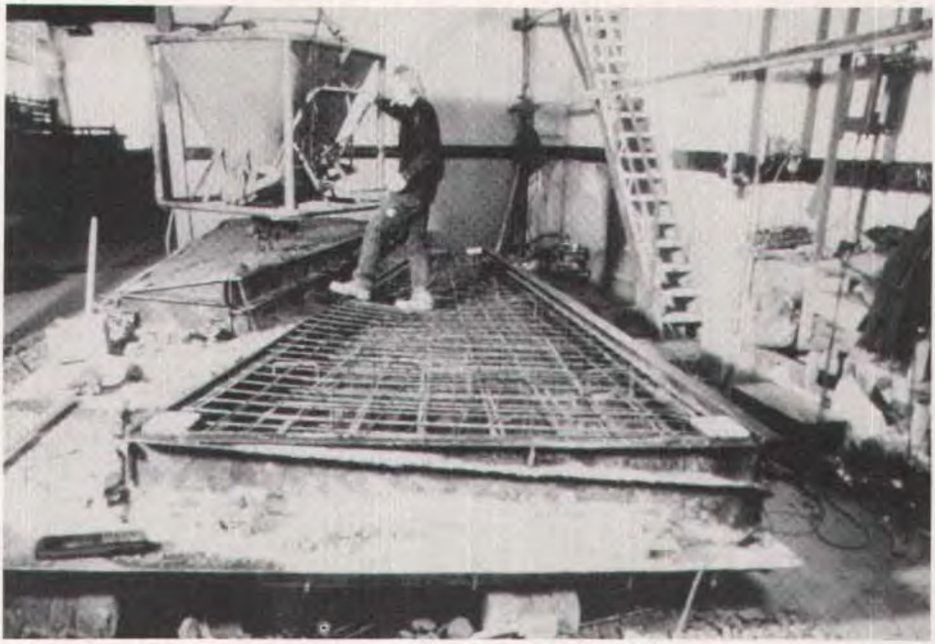

Fig. 12. Casting of prefabricated panels.

zontal. Similarly, when unfolding the cylindrical central core, the spiral ledge becomes a straight line, which can easily be transferred to the curved mold.

Considerations for Mold Design

Because the geometry of the spiral ramps was relatively simple, the mold for the warped panels could easily be produced by constructing the framework for the bottom of the form with beams of different depths being laid out on a horizontal surface in a fanned pattern, as shown in Fig. 10. These beams were then covered with a 4 mm ($^3/_{16}$ in.) thick steel plate, flexible enough to follow the curvature created by the beams. Thus, the underside of the deck panels assumed a smooth surface of an apparent warped shape, but actually consisted of straight lines in the pattern shown in Fig. 11.

The warped deck panels had to have a "right" and a "left" twist, due to the differences in direction of the two spiral ramps. However, it was not possible with one form to find a practical way to reverse the twist. Consequently, a mold was made for the "right" twist, and one for the "left" twist. The choice of two forms also made it possible to meet the delivery schedule with only one casting in each form every day. Fig. 12 shows the two forms in use. They were built on a tilt table that was slightly raised during production in order to get the average slope of the concrete surface as flat as possible.

For the central core it was just as simple. As mentioned before, when the cylindrical central core was unfolded, the spiral ledge became a straight line, as illustrated in Fig. 13. The bottom of the form was then constructed as one-quarter of a cylinder, laying on its "back." The measurements to the spiral ledge, determined as the distances to the straight line on the unfolded central

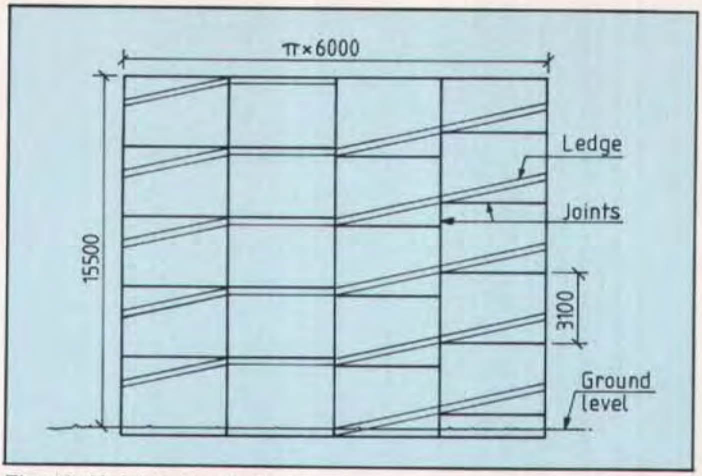

Fig. 13. Unfolded central core.

core, could then be transferred to the cylindrical form.

Both spiral ramps should be curving left, one going up and one going down. Since the recess in the mold forming the ledge was a fixed part of the mold, this was achieved by extending the form on both sides of the recess, and then during production switching the top and bottom limitations of the mold from one end to the other. The ledge then changed direction from up to down.

In order to facilitate all the variations needed, the horizontal joints were staggered. The ledge could then be at the bottom of the element, curving up, or at the top and curving down. The elements that should have the ledge horizontal were produced with the recess for the ledge being built outside the end of the form. The stagger of the joints is shown in Fig. 13.

Thus, only one form was needed to produce all the elements for the central core of the spiral ramps. In actuality, all 48 elements for the two central cores were produced in this one mold during 51 working days, allowing a few days for the necessary changes in the form.

The fabrication of the mold and the casting operations were executed very smoothly.

The Joints

The horizontal forces acting on the spiral ramps were relatively small, since the ramps were not considered contributing to the stability of the main parking structure. Consequently, the central core only had to take care of the stability of the spiral ramp itself. For the sake of simplicity, though, the same connection device was used in the horizontal joints as in the shear walls in the main parking structure (see Fig. 6).

The transfer of shear forces in the vertical joints is accomplished by welded plates combined with a friction contribution from the grouting of the joints.

The connection between the warped deck panels and the central core, including also the connection to the steel frame on the outside, was not required to transfer forces of any significant magnitude. Bolted connections were considered, but the necessary inserts and bolts complicated the production process, and also placed considerable demands on the accuracy of the production and erection operations. Consequently, welded connections were chosen, with steel plates cast in both the central core segments and the warped deck panels.

Fig. 14. Proud foreman showing perfect fit of components of spiral ramp.

Unfortunately, the welded connections created some additional finishing work. Therefore, it is suggested that on future projects bolted connections be used since they are structurally superior and safer than welded connections.

Erection Time

The erection of the ramps proceeded very smoothly. The curved elements of the central core were erected at a rate of about six per day. The erection of the steel structure (which was done by others) took some time, but the net erection time was about 2 weeks for one ramp. In the beginning, we erected the panels at a rate of about fifteen per day. The total erection time for one spiral ramp, five stories high, then became approximately 5 weeks. This time period can probably be reduced as experience is gained. In Fig. 14 a proud erection foreman is showing how perfectly all the elements fit.

Cost of Spiral Ramps

As mentioned earlier, the method of prefabricating the spiral ramps not only solved the problem of labor shortage, but also provided significant savings in time (3 to 4 months per five-story ramp). From an economical viewpoint, a comparison of the bids with the actual construction cost shows that the cost of the prefabricated spiral ramp is about 70 percent of the cost of a cast-in-place solution.

The basic dimensions of one spiral ramp is as follows:

Diameter of central core: 6 m (20 ft)
Diameter of outer steel frame: 18 m (60 ft)
Width of traffic lane: 6 m (20 ft)
Story height: 3.1 m (10 ft 2 in.)
Total height: 16.4 m (53 ft 9 in.)

The total cost of one such access ramp, including the central core, the deck panels, the steel structure at the outer perimeter, all produced, transported and erected, but excluding the foundations, the wearing surface in the traffic lanes, the railing and the roof structure, was approximately NOK 2,100,000 ($325,000). This amounts to NOK 1.850 per sq m of access road, or $26.50 per sq ft.

The use of a concrete frame instead of a steel frame at the outer perimeter would not change this figure significantly. Fig. 15 is a graphical presentation of a cost analysis comparing prefabricated and cast-in-place spiral access ramps.

Wearing Surface

As mentioned earlier, the double tees were cast with an additional flange thickness. This was done for structural purposes to avoid a concrete topping. As a result, it opened up the possibility to use mastic asphalt as a wearing surface.

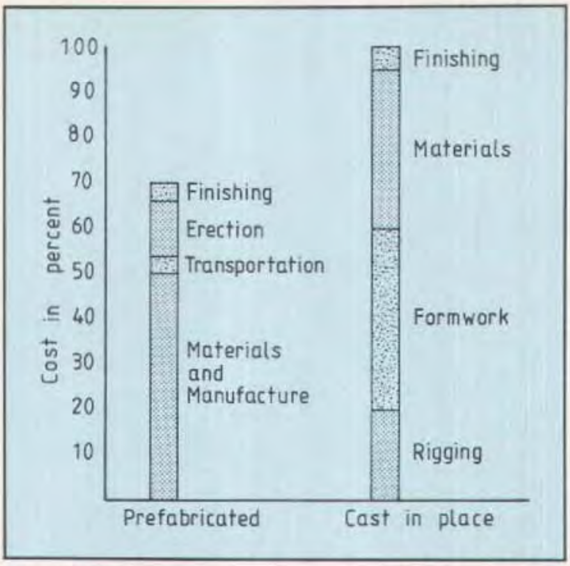

Fig. 15. Cost comparison for prefabricated and cast-in-place solution of spiral ramps.

The use of mastic asphalt wearing surface is actually rather common in Norway, and over the years the material has performed quite well in our rather frigid climate, where the use of steel studded tires is common on all cars for about 6 months of the year.

The standard procedure for installing mastic asphalt wearing surface consists of a bottom layer of 10 to 15 mm (about ½ in.) thick asphalt concrete which serves the purpose of a gas releasing layer (nonadhering) and mastic asphalt layer of 30 mm (1¼ in.). This method is used for all levels except the roof parking deck. There the bottom layer is as

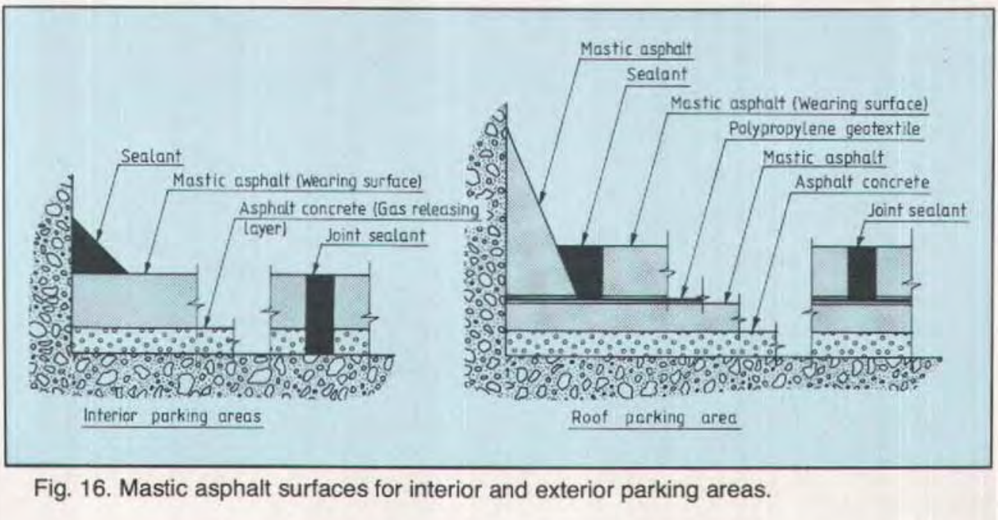

Fig. 16. Mastic asphalt surfaces for interior and exterior parking areas.

Fig. 17. Erection of spiral ramp.

Fig. 18. Closeup of spiral ramp.

Fig. 19. Shot of spiral ramp and main parking structure on a winter night.

Fig. 20. Overall view of spiral ramp and main parking structure nearing completion.

described above, then follows a mastic asphalt membrane of 15 mm (¼ to ¾ in.), then, as a drainage layer, a nonwoven polypropylene geotextile, and finally the mastic asphalt wearing surface. The installation of mastic asphalt in the traffic lanes in the ramps is similar to that of the interior parking levels, except that the wearing layer is placed in two operations. Each layer is less than 25 mm (1 in.), but the two layers added are a little more than 40 mm (1½ in.). Sections through the two types of mastic asphalt are shown in Fig. 16.

The mastic asphalt membrane has a maximum aggregate size of 10 to 6 mm (⅜ to ¼ in.), a filler content of about 40 percent and a binder content of about 11 to 12 percent. The bitumen is at straight run 40/50 penetration. The mastic asphalt wearing layer has a maximum aggregate size of 10 mm (⅜ in.), about 30 percent filler and a binder content of 7 to 8 percent.

The mastic asphalt in the membrane as well as the wearing course has no voids and is waterproof. The wearing layer has joints for every 350 to 600 m^2 (3763 to 6452 sq ft) in order to take care of temperature differentials. Between the double tees and before the asphalt is laid, the gap is sealed with a strip of asphalt felt. The mastic asphalt is laid by a beam paver and by hand at a temperature of about 220°C (428°F).

The use of mastic asphalt eliminates costly joint details in the concrete slab. Other advantages are wearing resistance, flexibility and skid resistance. Any large uneveness of the concrete surface must be smoothed out with concrete or ordinary asphalt before applying the mastic asphalt.

The cost of a mastic asphalt surface, adding the cost of the increased flange thickness of the double tees is approximately NOK 140 per sq m ($2 per sq ft). This is 5 to 10 percent less expensive than a concrete topping with joints. The main advantage, however, is the elimination of complicated joint details that are potential problem areas. Normally, the only maintenance required is adding new top layers as the old surface is worn down by traffic. In the access ramps deterioration can be expected between 5 to 10 years but in other parts of the garage the life expectancy of the surface is considerably longer.

Figs. 17 through 20 show various construction phases of the spiral ramp and main parking structure.

Conclusion

We believe that the new parking structure at Fornebu will serve its purpose efficiently and economically by providing a safe facility with a durable and long life. In the main structure no new techniques have been tried. The prefabricated spiral ramps, however, were new to us. The geometry and production concept presented a challenge, but that is now behind us, as the ramps have been erected. The solution of prefabricating the spiral ramps is not unique, and can be adapted to any parking structure. We are confident of the success of this structure, both for the airport authorities and public and for us as the producer.

Credits

Owner: Civil Aviation Administration (Luftfartsverket), Oslo, Norway.

Architects: Nansen and Eskeland, Engh and Seip, Oslo, Norway.

Consulting Engineer: Taugbøl and Øverland A/S, Oslo, Norway.

Project Administration: Construction Management A/S, Oslo, Norway.

General Contractor: A/S Veidekke, Oslo, Norway.

Mastic Asphalt: A/S Spesialdekker, Kjeller, Norway.

All the prefabricated concrete elements were designed, manufactured, transported and erected by Østlandske Spennbetong A.S., Hønefoss, Norway.

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Note: Discussion of this article is invited. Please submit your comments to PCI Headquarters by December 1, 1988.