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Design of base slab structures for fast construction on "Cold Sites"

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1. Scope

The owner of any construction project aims at short construction times. This aim is especially applicable for power plants with high investment costs and cash flow benefits associated with the start of generating electricity

For isolated construction sites it is generally important to reduce the man-hours required. This assumption is particularly valid for the time critical man-hours on cold climate sites where weather conditions, in principle, may prevent work during more than half of the year. For a wind power plant, the final erection of tower, nacelle and blades must be carried out prior to the seasonal occurrence of snow, ice and low temperatures. On the other hand this work can be completed within a few days only. The site-specific work of the base slab can start at the end of springtime. The on site construction works must be finalized within just a few months.

2. Major Design Criteria

There are 2 major load conditions for the structural design of the base slab:

-Ultimate Limit State (ULS) for dimensioning wind loads including partial safety factors
-Service limit state (SLS) for fatigue effects of wind loads

The design for ULS is made as for any civil engineering structure. The design could be made completely according to the valid codes (In Sweden 2012 = Eurocode 2 for concrete structures)
The design in SLS for fatigue should be made with more than use of codes. Engineering thinking is needed! My own judgment is that for fatigue, the designer should give special consideration to shear stresses. It is favourable to counteract cracking effects of fatigue loads by introducing pre-stressing compression forces into the structure

3. Design principles for fast construction

3.1 Prefabrication

The obvious answer to the cold climate site requirements is to prefabricate the base slab in an intelligent manner. I define "prefabrication" as:
- Option 1: Prefabrication of formwork elements and re-bar units for a slab poured on site
- Option 2: Concrete elements prefabricated in a factory or on site adjacent to (but not on) the front-line for the site works

Option 1: Prefabrication for slabs poured on site.
For sites close to a concrete batch plant it might be preferable to procure the concrete from such a plant. The reinforcement might be made as large units assembled either in a workshop or on site. (Site work with reinforcement can be done also in cold weather, however with a reduction of productivity)

Option 2: For sites "far away" from concrete batch plants, the main part of the concrete structure should be prefabricated as elements with the weight and dimensions as limited by the road conditions and/or hoisting capacity on site. The splicing of the elements is made on site during "summer conditions". My personal opinion is that the central part (defined as the area within 1-2 metres outside the radius for the embedded ring below the tower) should be poured on site. This pour would comprise a concrete volume in the order of 50 -100 m3. With regard to fatigue, the designer should consider post-tensioning of the central parts.

3.2 Time critical works on site

3.2.1 Time critical works for solid base slabs poured on site

For a base slab designed as a solid slab (typical diameter 15-20m and typical height 2-4 m) the pouring of concrete can be made during some few days only. The concrete pouring is not time critical. The formwork area (outer edge) can be made within 1 week. The construction of formwork is not time critical.

Thus, the works with excavation and with reinforcement (typical 50-100 tonnes) are time critical. (In the present paper I do not deal with excavation issues. I interpret "cold sites" as cold but without permafrost)

For the reinforcement works, a crew of 10 skilled rebar workers would need a calendar time of the order of 1 month.

The design of the reinforcement should aim at a simple and robust structure. My personal point of view as a civil engineering designer is to use post-tensioned tendons in order to reduce conventional reinforcement. The use of post-tensioning might be (but not for sure) more expensive than the alternative without post-tensioning. However, the use of corresponding mild reinforcement would be time critical.

The mild reinforcement should be prefabricated as cages and meshes, preferably in a special reinforcement workshop. The costs for placing re-bars at cold remote site are considerably higher than the direct material costs. For "nasty" bars the construction costs might be 5 times the material costs (or even more). The prefabrication of reinforcement reduces time critical man-hours at the front-line on site. Thus, one should not fear the transportation costs. One option is to prefabricate the rebar cages adjacent to the site, i. e. not at the front-line for the site works.

The reinforcement works are simplified if the geometry of the structure is simple. I judge that circular base slab should be avoided and replaced with octagonal slabs. Then hoop re-bars can be avoided and replaced with straight bars which are easy to store, to place and to splice with overlapping only. In order to avoid hoop re-bars it would be required to place the upper face re-bars in horizontal layers. For the drainage it is necessary to provide a slope on the upper concrete surface. Thus, the upper concrete face should be provided with increased concrete cover at the central parts of the base slab.

When post-tensioning is used the designer should put priority to constructability and not to direct material costs. In order to avoid collision between post-tensioned tendons and the embedded ring for the tower, the tendons should be placed outside the ring. The compression force of the tendons results in a reduction of the horizontal bars both at the lower face and at the upper face. The design for shear is simplified. Maybe vertical shear reinforcement can be omitted completely, at least in the outer parts of the base slab. Savings of front-line man-hours! As a spin off effect, the structural behaviour for fatigue is improved considerably as "compression" means less cracking and could be used to reduce the change of re-bar stresses for fatigue loads.

3.2.2 Time critical works for base slabs constructed as prefabricated concrete elements
A prefabricated base slab with measurements inside a diameter of 20m should be made with 8 corners (octagonal), 12 corners or with 16 corners (hardly more), i .e the outer part of the slab should be made with 8-16 beam elements in radial direction combined with 8-16 slab elements between the beams+ 8-16 elements at the outer face of the slab structure.
Thus, several "tricky" reinforcement details are made in a factory and not on site. The placing of < 50 elements could be made within some days.
The joints towards the central part of the slab are challenging, especially for the fatigue design.
As mentioned previously, my personal conclusion is that the central part should be poured on site. Although the re-bar works and pouring of the central part takes some time, it is probable that the prefab option is less time consuming than the option with a solid base slab poured on site.
With this option the dead weight of the concrete structure would not be sufficient to stabilize the tower. Ballast between the beams would be required!

4. Transport and hoisting capacity

For the option with solid base slabs poured on site, the requirements on transportation capacity and hoisting capacity are low. There is in principle no difference between cold sites and "conventional" sites. Winter problems might postpone the start of the works in springtime but they will not prevent the feasibility of the works. The transport and hoisting of the embedded ring for the tower will probably be dimensioning for the construction period prior to the hoisting of the steel tower
For the option with prefabricated concrete elements, the roads must have a capacity for weights of 20-30 tonnes. The same applies to hoisting capacity on site

5. Personal conclusion

After comparing advantages and disadvantages, I have arrived at the conclusion that (in general) cold sites do not cause other problems than conventional sites. The general problems can be tougher on cold sites but they can be solved with general engineering approach. My personal conclusion is that the start option for any site should be:

Solid base slab with prefabricated reinforcement and with post-tensioning

Certainly sites will exist where this option is not the most favourable one. Then, use prefabricated elements!

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