CONSTRUCTION POSSIBILITIES FOR MONOLITHIC CONCRETE SPAR BUOY SERIAL PRODUCTION

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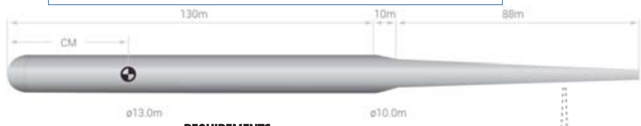
CONSTRUCTION



REQUIREMENTS

- Watertight structure of excellent quality
- Durable under harsh offshore conditions
- Cost-efficient construction
- Post-tensioning equipment
- Minimal handling of finished structure
- Smooth transition construction-transport

CONCRETE PLACEMENT SCHEMES:

GENERAL RECOMMENDATIONS

- Ensure continuous supply of concrete
- Use steel standard form panels
- Back-up equipment and quick response plan in the event of failure
- High-rate placement systems (>100 m³/h) like boom pumps, tremies, conveyor belts
- Maximize reuse of forms
- Enable repetition of operative cycle to maintain smooth workflow
- Evalue the risk of joints appearing during all construction stages
- Enhance productivity and minimize delivery time

HORIZONTAL

Coastal facilities like dry-dock . Launching of structure into the sea also possible using sliding/skidding system.

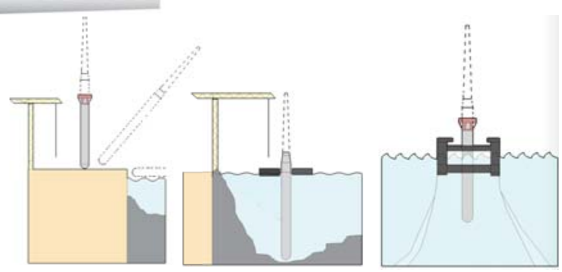
- ✓ Cluster all construction works on land
- ✗ Unfavorable concreting direction for slipforming

SPECIFIC RECOMMENDATIONS

- Around-the-clock pouring of concrete
- Use self-propelled formwork systems that slide on temporary service tracks and with the ability to retract-collapse
- Prioritize use of commercial products from the tunnel industry
- Use vibrating form panels
- Mechanize form erecting, stripping, cleaning and treating
- Use inner concreting train(s)
- Use self-propelled devices for removal of inner forms
- On-site steel welding workshop for form panel fabrication and repair and rebar welding.

VERTICAL

- ✗ Unpractical handling
- ✓ Vertical slipforming



ON-LAND

- ✗ Unpractical handling
- ✗ Incompatible transport

SHELTERED WATERS

- ✗ Large water depth required
- ✗ Only feasible at very specific locations (fjords)

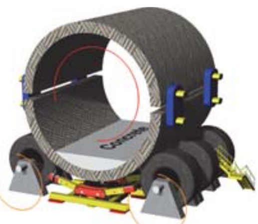
OFFSHORE FACTORY

- ✓ Minimum transport
- ✗ Logistic difficulties
- ✗ Extremely expensive

Production directly at sea is an ambitious solution (design & construction of remote concrete plant, transport of raw materials, unstable working conditions). The idea becomes somewhat more viable by recycling and adapting an obsolete O&G platform due to be de-commissioned. It would allow an interesting space for collaboration between Wind and O&G industries and increase the residual value of old platforms.

SEGMENTAL

CENTRIFUGE



Compactation by centrifugation is a technique typically limited to ϕ 1-2m, arguably applicable to a ϕ13 m of the tower. Plus, spinning the 200-m long structure, if at all possible, results in unprecedented up-scaling in terms of equipment and energy and presents unreasonable execution risk (many spinning devices perfectly synchronized). Centrifuging discrete segments is the only realistic option but results in a non-monolithic structure.

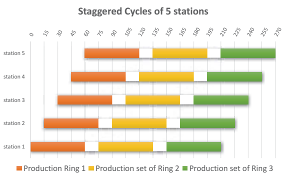
Tolerating a certain number of joints may result in a cheaper construction process. The cost reduction in construction by allowing joints in a segment approach will need to be compared to the costs of high-quality sealing of these joints, the increased maintenance costs and the impact on the life-time of the structure.

- ✓ High quality of centrifuge concrete
- ✓ High-production speed
- ✓ No need of inner core
- ✗ Non-monolithic
- ✗ High energy requirements to spin
- ✗ Increase of maintenance due to the presence of joints.

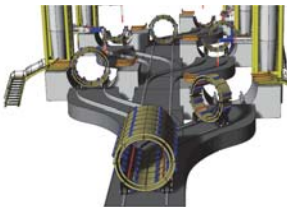
SEGMENTS JOINED IN FRESH

ASSEMBLY-LINE

Several identical "casting stations" operate in staggered cycles with a fixed lag time t_{lag} (e.g. 15 min between the start of two consecutive stations) and produce identical rings. It takes each station a time $t_{production}$ to complete a ring. Once a given ring has been completed its transported to the assembly line where it 'waits' in place during $t_{waiting} = t_{lag}$ before the next ring produced at the consecutive station is ready to be connected.



A Gantt Diagram is shown corresponding to the 3 first cycles of 5 identical stations with $t_{lag} = 15$ min and $t_{production} = 60$ min. After 270 min the total number of rings produced is 5×3 = 15 rings. When Station No. 5 completes its first ring (min. 120) Station No. 1 is close to completing it's second ring. (min 135). From that point on stations can connect rings for as long as required. As soon as a station has finished producing a ring it will re-start its operative cycle to fabricate another ring



As long as $t_{waiting} \ll t_{setting\ concrete}$ joints between rings will not form. To ensure bonding, extra concrete can be pumped radially at the interphase of a completed ring while waiting for the next ring to be connected. Train-like bogies and rail tracks allow swift transport of freshly filled molds.

- ✓ High-production speed
- ✗ Risk of cold-joints occurring
- ✗ Very time-sensitive
- ✗ High execution risk

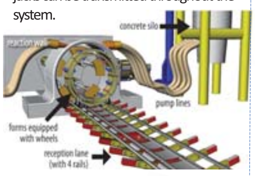
INCREMENTAL LAUNCHING

Based on adaptation of pipe-jacking techniques. Instead of using hydraulic jacks to push prefab concrete segments into the soil, a circular arrangement of jacks will 'launch' previously filled molds into a reception lane. A new set of forms are then interlocked with the previous, filled with fresh concrete and launched again. All concreting operations are located at a fixed location

Hydraulic jacks retracted to make room for cranes to assemble a new set of forms

Hydraulic jacks in pushing position 'extrude' the cross-section

Forms must interlock so action force of jacks can be transmitted throughout the system.

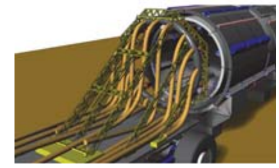


Forms are equipped with 4 sets of wheels matching rails on reception lane.

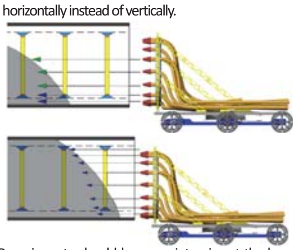
- ✓ High-production speed
- ✓ Use experience from pipe jacking
- ✗ High-jacking forces on form panels
- ✗ Loads exerted on panels lead to buckling and early replacement of forms

CONTINOUS

CONCRETE CROWN

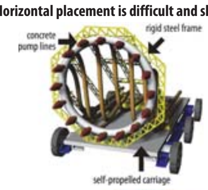


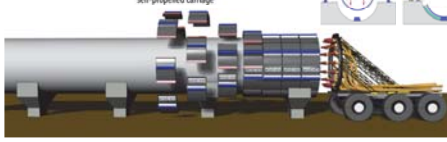
Comparable to slipforming in the sense that concrete is introduced axially, perpendicular to the cross-section of the tower into previously erected forms. The fundamental difference is how concrete is placed, linked to the fact that the device moves horizontally instead of vertically.



Pumping rate should be more intensive at the lower part to create a concrete slope within forms so concrete placed at higher levels has a base to fall on. Slope angle must be such that freshly pumped concrete does not slide off. Pumplines must be extendable and can rest on reinforcement bars not yet reached by concrete. New forms must be in place before the previous are completely filled whilst pouring never stops. The device slides backwards as construction progresses.

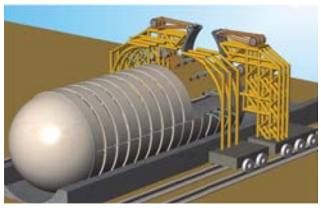
- ✓ Create value through new technology
- ✓ Highly automated
- ✗ Uncertain outcome
- ✗ Unproven and requires research
- ✗ Horizontal placement is difficult and slow



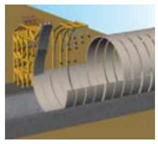


ARCH-TRAVELLERS

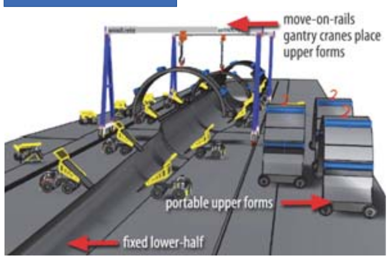
Highly-specialized travelers that move on rails parallel to the structure on both sides, they lower forms in place with a pulley system and then release them. A carriage supporting concreting equipment then follows while the Arch travelers are fed new forms and move on to the next section to erect. Different carriages should slide on separate rails to avoid interference between equipment



- ✓ Quick delivery
- ✓ Optimized form-handling
- ✗ Large up-front costs to design and build traveler

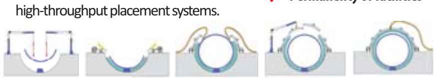


GIANT RE-USABLE MOLD



The giant re-usable mold, in which the bottom half is fixed and spans the entire length of the structure while the top half are a series of removable arch-forms. This method allows simultaneous pouring of the whole structure with directly discharging dumpster trucks and other high-throughput placement systems.

- ✓ High throughput
- ✓ Technological simplicity
- ✓ Low execution risk
- ✗ Large up-front costs to manufacture massive mold
- ✗ Permanency of facilities



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