

RECENT INVESTIGATIONS AND TESTS WITH THE BBR WINDING SYSTEM FOR CIRCUMFERENTIAL PRESTRESSING OF CONCRETE VESSELS AND CONTAINMENTS

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1. INTRODUCTION

Prestressed concrete pressure vessels for nuclear power stations need post-tensioning systems of large capacity. For the circumferential prestressing, the continuous winding of prestressing steel has several advantages when compared to the use of large numbers of single tendons.

About 15 years ago Bureau BBR Ltd (Zürich) developed the winding system SW 8500. The further development work interrupted at that time for lack of immediate applications was resumed 4 years ago by Bureau BBR together with SUSPA on the ground of new projects being evaluated.

2. BBR WINDING SYSTEM SW 8500

The core of the winding system is the winding machine itself running on two rails fixed to the vessel wall. It winds 3/8" prestressing strand with a maximum force of 85 kN. Fig.1 shows a photograph of the prototype machine, Fig.2 shows the machine lay-out. With the winding machine it is also possible to retrieve the strand, for example for replacing.

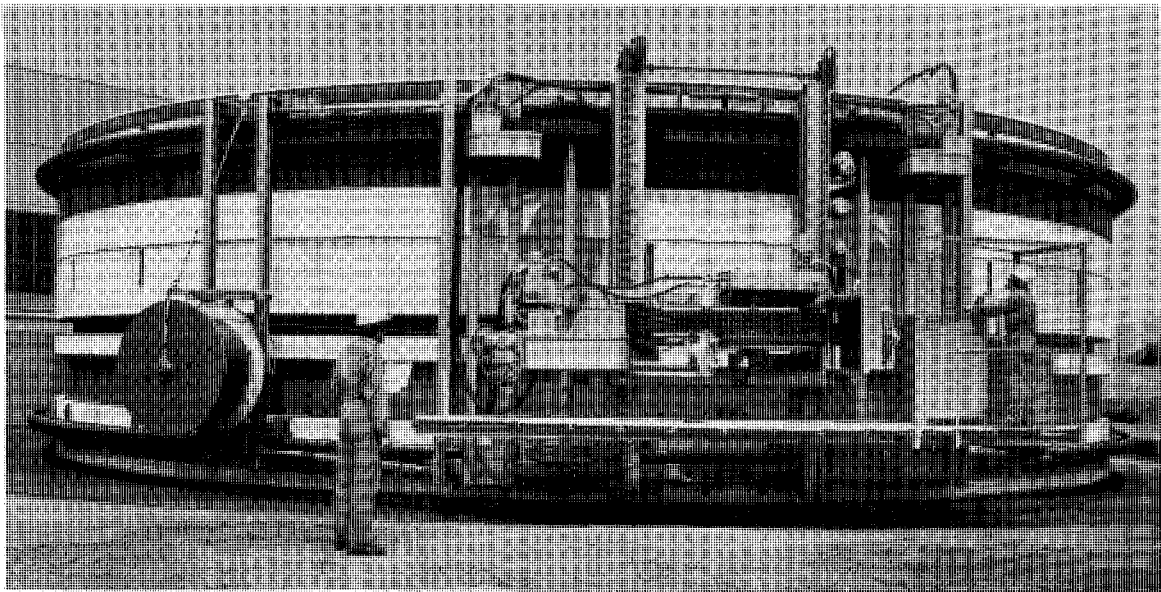


Fig.1: Prototype of the BBR winding machine SW 8500 on test ring

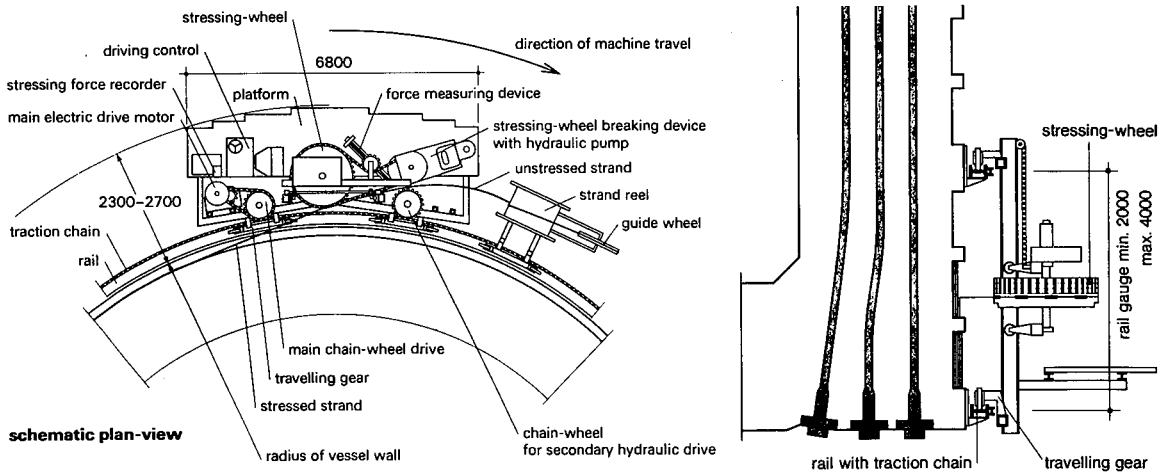


Fig. 2: Lay-out of the BBR winding machine SW 8500

The use of 3/8" strand decisively improves the efficiency of the prestressing operation in comparison with the 5mm diameter wire used by various system operators for tanks and silos as well as for some pressure vessels of the british AGR series.

The other essential feature of the system are the winding channels, the relative anchorages of the prestressing strands and the approach for the corrosion protection. Easy and well-tested handling procedures complete the system.

The strand is applied in layers spirally wound over the whole width of a channel. Layer on layer complete the total prestressing band in a particular channel. While winding the SW 8500 machine raises at each turn in correspondence of the spiral path, so that continuously the strand is placed in the grooves of the preceding layer. Each layer is anchored on both ends without intermediate fixation or joints. The anchorages are placed at the channel sides, the starting anchorage at the lower one and the end anchorage opposite at upper side. The channel dimensions are designed taking into consideration the winding procedure and the position of the rails with a constant gauge, the vessel dimensions and the prestressing demand. The formerly limiting condition about max. strand length is obsolete as 3/8" strand is now available in length beyond 15'000 m, which is definitely more than the length needed with well-designed channel widths.

A wound band of e.g. 36 layers and 1 m width has an ultimate carrying capacity of approx. 320 MN. Comparing this with a tendon application: the same capacity would need 30 no. of large BBR tendons of 162 7 mm diameter wires. The comparative space requirements are shown in Fig. 3.

The channel dimensions are subject to close tolerances in order to obtain a proper winding order. They may be formed by prefabricated reinforced concrete elements or by structural steel inserts.

The corrosion protection consists of plastic grease or wax that is easily placed as a grease layer on each strand layer. The following strand layer can be placed immediately without time interruption (as needed e.g. for a cement layer). Because of the plastic property the grease does not handicap the possible replacing of the strands by rewinding. Greases and waxes resisting the working temperature without any dropping and time dependent alterations were tested. After finishing the winding operations the channels are covered with steel plates to give mechanical and fire protection.

Before starting the winding operation the machine must be placed by crane on the rails of the respective winding zone comprehending more than one channel. At first the strand is fixed on the starting anchorage in the lower channel side. Then the winding machine runs with a working speed of up to 2 m/s around the vessel while the stressing wheel raises regularly with the strand diameter path. After reaching the upper channel side the strand is anchored by the end anchorage.

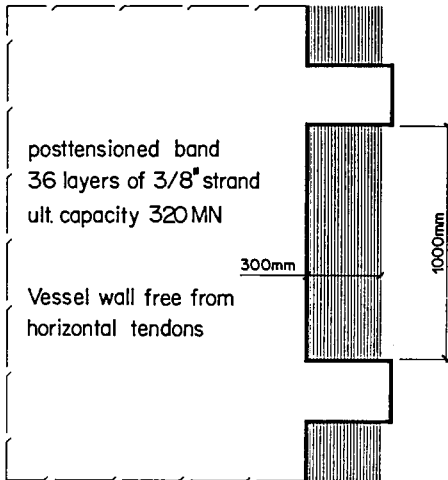


Fig.3a: Winding channel for
appr. 320 MN carrying load

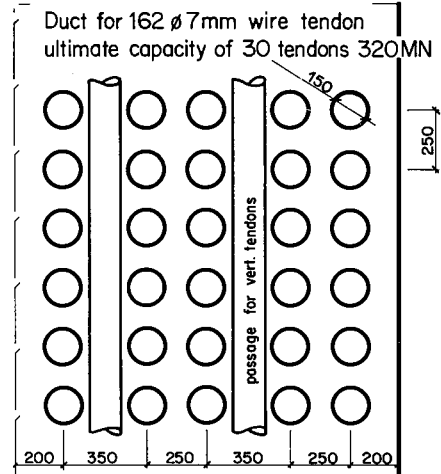


Fig.3b: 30 Tendons each of
10.5 MN carrying load

During the winding operation the prestressing force of the applied strand is measured and recorded continuously.

During surveillance the prestressing force of the whole strand package of a winding channel can be controlled by special lift-off devices (Fig.4): a hydraulic cylinder is inserted into the concrete wall of the vessel below and flush with the channel surface. The hydraulic system is only operated during the time of measurement so that fatigue of the system cannot occur. The hydraulic pressure and the piston displacement are measured by electrical gauges. The needed piston displacement is very small (ca. 0.3 mm) so that the measured force very well corresponds with the radial force of the strand package.

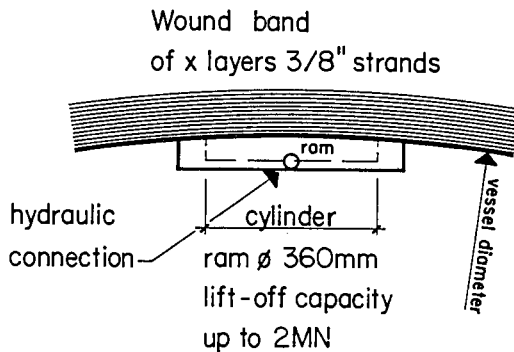


Fig.4:
Hydraulic equipment
for force measurement
of the whole strand
package

3. TESTS

Large tests have been carried out with an improved prototype of the winding machine running on a concrete test ring of 18 m diameter (shown in Fig.1). The carrying capacity of the test ring allowed the prestressing

of 13 strand layers in a channel of 30 cm width (total prestressing 25 MN). The tests confirming the performance of the system showed informative results.

Fig.5 shows as an example the wound strands of the layer no. 13. The order of the strands has been controlled by scanning of the layer shape for each layer. The principle is shown in the same figure.

In several test series the optimal distribution around the vessel circumference of the anchorages were investigated. The best results have been obtained by concentrating the anchorages of all layers in a common anchor block instead of distributed arrangements. An anchor block precisely prefabricated in steel is shown in Fig.6.

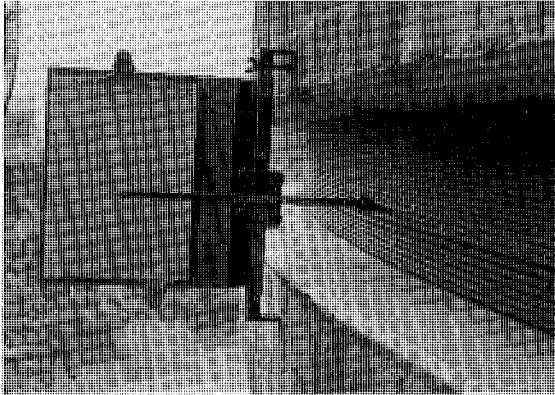


Fig.5: Winding channel with wound strands

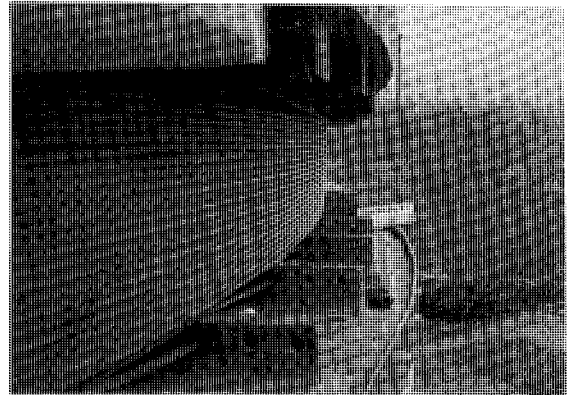


Fig.6: anchor block prefabricated in steel

As sites where such a winding system comes into operation, in particular nuclear pressure vessels, are very much dependent on a high performance guarantee in quality and timing the whole development work was oriented towards practical application basing on a given vessel design.

Therefore several tests have been performed for obtaining reliable procedure details and programme data under actual site conditions. It has been shown that the two anchoring operations of a particular layer required a time of max. 30 min. in addition to the winding time, which depends from the channel dimensions and the set speed of the machine. Placing the corrosion protection needed 3-5 additional turns of the machine around the vessel. Shifting the machine from one working position (embracing more than one channel) to the next, on preset rails, needs about 1 hour.

The force check of the whole wound band showed good accordance with the sum of the single strand forces continuously measured and added up during the winding operations.

4. WINDING LAY-OUT FOR HTR 500

The firm Hochtemperatur Reaktorbau GmbH (HRB) designed the prestressed concrete vessel for the HTR 500 [1]. The circumferential prestressing would be carried out by winding, particularly to get a short erection time. BBR and SUSPA together designed the winding lay-out. Fig.7 shows the dimensions and the arrangement of the winding channels as well as the rails on the vessel surface.

It is obvious that the winding machine cannot wind channel by channel in one procedure because of static reasons. The various working positions of the machine can be seen in the same figure. The wall regions where pipes go through obviously cannot be covered by windings.

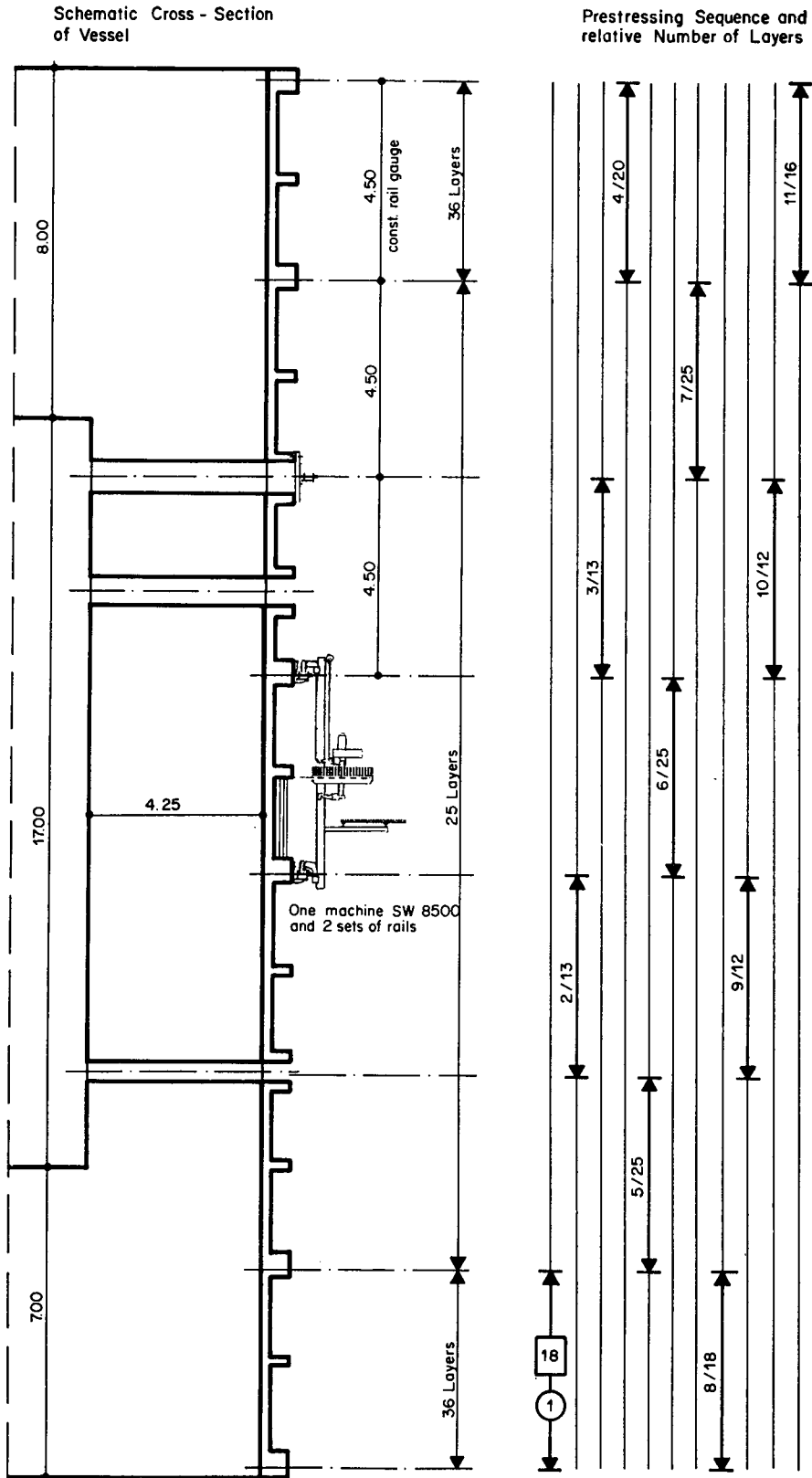


Fig.7: HTR 500 vessel with pattern of winding channels and rails

Fast performance is obtained by using two sets of rails, so that the machine can keep operating without wasting time for rail assembly. This principle has been applied in the case shown in Fig.7. It could even be advantageous to equip the whole vessel wall with rails for all working positions, as this arrangement may be used for any other needs of the vessel erection or operation.

The simultaneous use of two winding machines, which could be tempting for shortening the time needed for posttensioning, is not possible in order to avoid accidents in case of a strand failure during stressing.

The advantages shown for such a winding lay-out on a pressure vessel as compared to a tendon approach suggest further applications also for containments or other industrial vessels requiring large capacity horizontal posttensioning. Cost analysis show a positive result approx. over 300 to of steel per site.

5. FURTHER DEVELOPMENTS

A further development step was initiated by considering the use of prestressing steel strips instead of strands. In this case the winding machine does not raise vertically while running around the vessel because the strip is wound layer by layer in radial direction (Fig.8). The raising mechanism is only used to reach the new position. The advantage of this winding system is the simpler way of corrosion protection, an individual surveillance on each element and the replacement possibility of single packages.

Fig.9 shows 6 strip packages of 20 layers each, wound by a prototype equipment on a test ring of 5 m in diameter. Up to now prestressing steel strips with the needed cross section and length are not yet available for common use on a commercial scale. Therefore further developments are needed for practical use of prestressing steel strips.

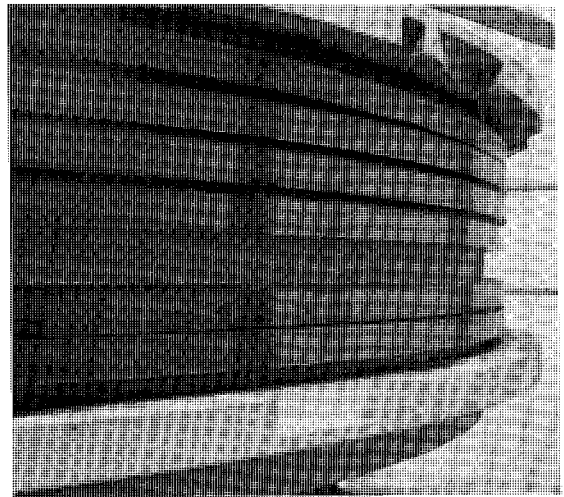
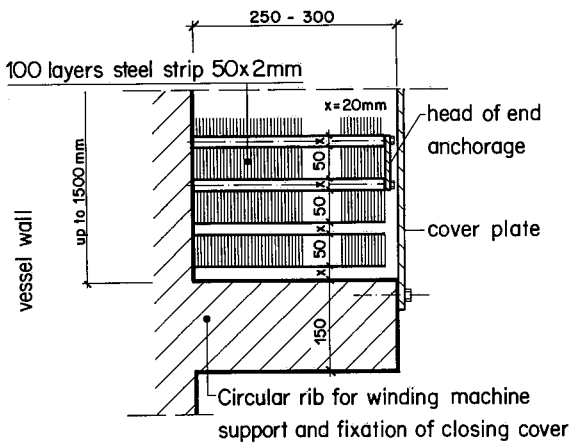


Fig.8: Pattern of packages of steel strips

Fig.9: Prestressed steel strips on the test ring

LITERATURE

[1] Elter, C.; Becker, G.; Weber, A., 1984. The HTR 500 Prestressed Concrete Reactor Vessel. Specialists Meeting on Vessel Concepts for Gas-Cooled Reactors, Lausanne, IAEA, Sum. Rep. pp. 85-96.