

PRESTRESSING WITH HIGH-TENSILE STEEL STRIPS

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High stress resistant steel can be obtained by quenching. The efficiency of the process depends on the thickness of the steel. The thinner the material, the more efficient the process becomes. As a consequence, quenching is equally efficient on a wire as on a somewhat thinner, but wider steel strip.

Such high-tensile strip exists commercially and is available from different mills. The range of thicknesses and widths varies with the supplier, but 0.04 in. by 10 in. wide strip (0.1 x 25 cm.) is very common, sold in more than 1500-ft. (450 m.) coils. Ultimate stress is above 200,000 psi (14,000 kg./sq.cm.) and ultimate elongation is more than 2.5 percent. Elastic limit is higher than 160,000 psi (11,300 kg./sq.cm.).

The advantage of a steel strip post-tensioning system lies in simplified construction due to simple anchoring devices and in easy tensioning techniques. The system promises to offer advantages especially for the construction of pres-

sure vessels where prestressing forces are very large.

CIRCUMFERENTIAL PRESTRESSING

General. The future of prestressed concrete primary and secondary nuclear containment vessels is closely linked with the availability of high capacity tendons, because conventional tendons are too weak for the overall forces to which these structures are subjected. Thus, an entirely new approach to post-tensioning circular vessels was developed.

It might be useful to quote a few figures concerning the prestress required as an example. A pressure vessel designed to withstand a service pressure of 1400 psi (100 kg./sq.cm.), with internal and external diameters of 30 and 60 ft. (9 and 18 m.) respectively, must withstand a prestressing force of the order of 2000 tons per linear foot of cylinder; the cross section of each prestressing ring must therefore exert a service force of 10,000 tons, with rings at 5 ft. (1.5 m.) on centers.

This paper describes the potentials and features of a post-tensioning system which uses thin, high-strength steel strips as tendons. Its primary realm of application is in prestressed concrete pressure vessels. The system can be used with radial jacking or with a tensioning-by-winding technique. Tests to destruction of an 800-ton capacity tendon are described in detail.

Preliminary project studies carried out by the French Commissariat à l'Energie Atomique and Coyne & Bellier, Consulting Engineers, Paris, France, have revealed the important advantages of moving all prestressing cable to the outer face of the vessel, in the form of independent high-tensile steel rings which, once tensioned, compress the concrete wall.

The main advantages of external rings are:

1. Greater ease of concreting
2. Minimum volume of concrete and reduced external diameter
3. Homogeneity of stresses in the concrete since there are no overlapping cables
4. No bulky and costly steel bearing plates and anchorages
5. Ready access for visual inspection
6. Savings in construction time and labor

Design and prestressing methods for external rings. Tension rings are formed by winding high-tensile steel

strip around the vessel. If coil length is insufficient, a second coil is started before the first one is completely wound around the vessel, so that the ends overlap, and winding continues with the second coil. This operation can be repeated indefinitely until the required ring strength is reached. It is also possible to wind two or more strips simultaneously provided they begin and end on different turns. No welding is needed.

Whatever the details of the process chosen to build the ring, there always remains the outer end of the strip which has to be fixed to prevent it unrolling when tensioned. The best way consists of forcing the last turn against the preceding ones with an elastic force not exceeding an average value of a few tons per circumferential foot. The resulting frictional resistance allows the extremity of the last turn to withstand the pull of the prestress.

Tensioning by radial jacking. One

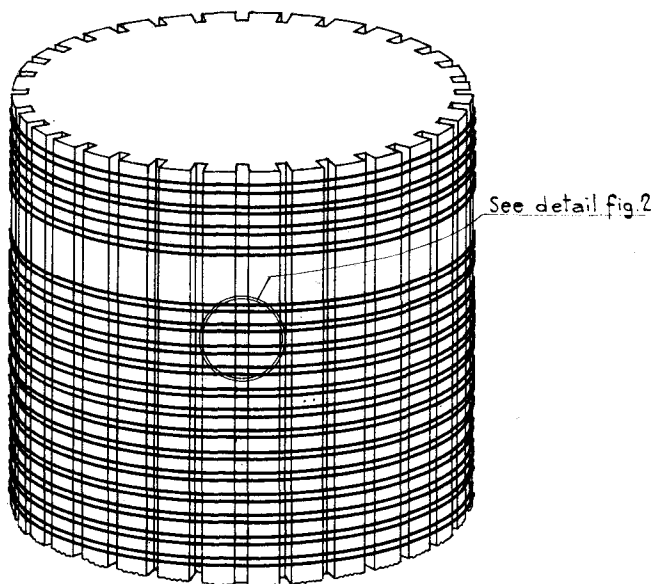


Fig. 1. Schematic view of post-tensioned vessel

method of tensioning the above described ring is to place jacks bearing on the walls of the vessel and to displace the ring radially outwards. The head of the jack pushes on a bearing plate whose surface is curved to limit secondary stresses in the strip. All the jacks of one ring act simultaneously. After tensioning, the ring has a curved polygonal shape. Once the ring is tensioned, its tension force is locked in by wedges (Fig. 2). With this method losses of tension are negligible and it is easy to check or correct ring tension at any time.

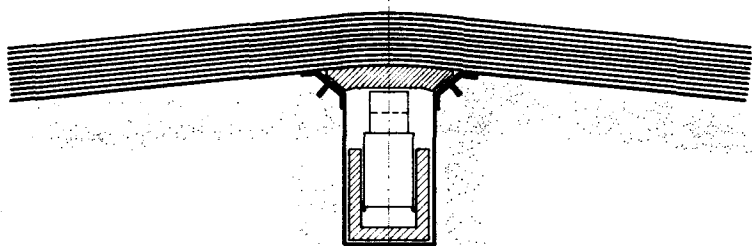
Tensioning by winding. This process is similar to the Preload system, the difference being that the force applied to a high-tensile strip is greater than the force applied to a wire. Furthermore, the strip is rolled on itself while wire has to be wound around like thread on a

reel. In the tensioning machine the strip is pressed without sliding between pairs of rollers, these rollers being braked in order to tension the strip to its nominal value. Due to the winding force each turn is pressed upon the underlying one. The inner end of the strip has to be partly or totally anchored when winding begins. This can be done by welding or with a friction anchoring device.

Comparison of the two tensioning methods. Radial jacking allows checking or readjusting tension at any time, whether by using the set of jacks used for tensioning or by placing cast iron blocks supporting the tensioned ring upon a dynamometer system. Tensioning by winding under tension is usually more economical since no supports are needed.

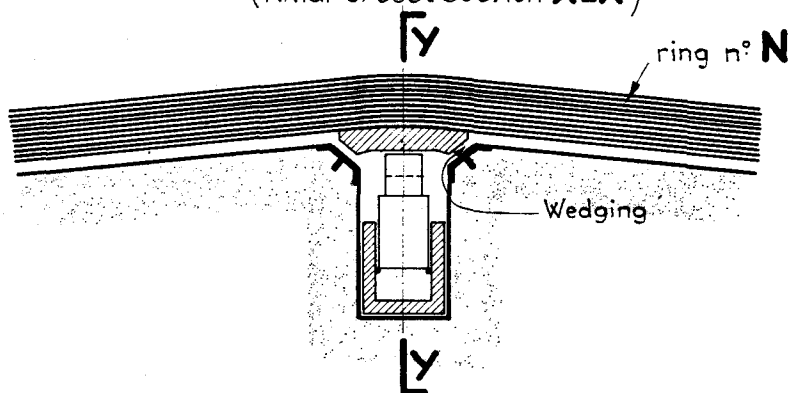
The tensioning systems listed

position of the jacks before tensioning.
(Axial Cross-Section)



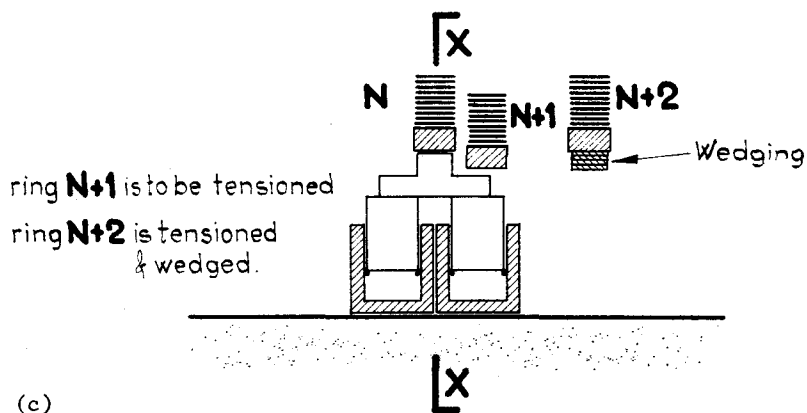
(a)

position of the jacks during tensioning ring n° N
(Axial cross-section X-X)



(b)

Transverse Cross-Section Y-Y



(c)

Fig. 2. Position of a radial jack under a ring to be tensioned

above are not the only ones possible. The choice of a system depends on the design itself and on the design criteria.

TEST OF A TENSION RING MODEL

General. A brief description of a ring test run by the French Atomic Energy Commission at the Marcoule Centre in France is given. The results have been extensively reported at the Euratom Conference held in Brussels in November 1969.

The test was primarily aimed at proving that high-tensile steel strip has similar tensile properties as strand or wire. Other objectives were concerned with the ring system itself:

1. Problems which may arise

from the installation of the strip

2. Friction anchorage of the outer end

3. Behavior when stress in the steel exceeds nominal pre-stress

4. Uniformity of jack lift.

Cost considerations led to 16 jacks of 500 tons capacity being used for tensioning. The strip width of 10 in. (25 cm.) was greater than would be used on any prototype. It was assumed that any defects and their possible consequences would be more visible with wide rather than narrow strip of 4 to 6 in. (10 to 15 cm.), while the installation and anchorage of the outer turn would be more difficult.

The test, thus being severe, was



Fig. 3. Model of concrete ring and high-tensile steel strip tension ring

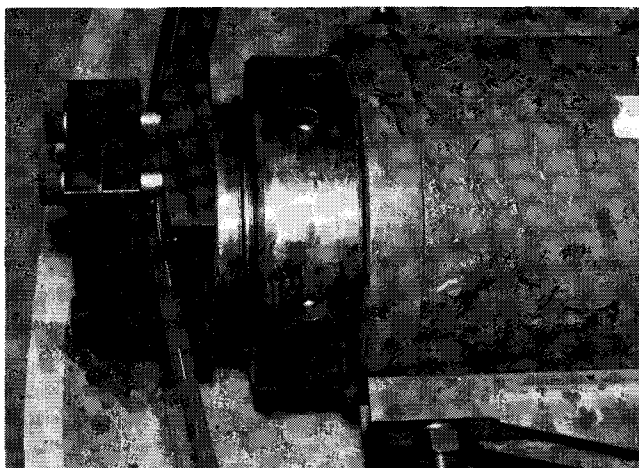


Fig. 4. Radial jack with bearing plate and friction bracket

supposed to reveal any possible difficulty that could be encountered with the use of the high-tensile steel strip system.

Test arrangement. The concrete ring, as shown in Figs. 3 through 5, is 2 ft. 2 in. (65 cm.) high. Its inside diameter is 6 ft. 5 in. (2 m.), with a 0.2 in. (5 mm.) thick liner anchored to the concrete. The outer face is a 16-sided polygon inscribed in a circle of 12 ft. 10 in. (4 m.) diameter.

The sixteen jacks acting radially, fixed in position with bolts embedded in the concrete, are shown in Fig. 3. Their nominal rating is 500 tons, lift of 8 in. (20 cm.), and outside diameter of 16 in. (40 cm.). The piston area is 93 sq. in. (600 sq. cm.). The ram pushes a bearing plate whose face in contact with the strip is a cylindrical surface of radius 20 in. (50 cm.).

Fig. 4 shows the exterior bracket plate which is to develop the friction needed for holding, and thereby

tensioning, the outer end of the strip. This plate is fixed to the bearing plate by means of four bolts with spring washers so that a clamping force of about 8 tons can be exerted.

The high-tensile strip material is a 0.75 percent carbon steel, hot and cold rolled and tempered:

Elastic limit = 190,000 psi (13,500 kg./sq.cm.)

Breaking strength = 225,000 psi (16,000 kg./sq.cm.)

The strip is 0.04 in. (1 mm.) thick and 10 in. (25 cm.) wide with slit edges, and is supplied in coils of 14 in. (35 cm.) internal diameter and 28 in. (70 cm.) external diameter. Each coil weighs about 1350 lbs. (600 kg.) and is sufficient for about 18 turns on the concrete ring.

The strip was simply installed by carrying the coil around the concrete ring, imposing a slight tension on the strip during unwinding. The profile obtained was a regular curvilinear polygon.

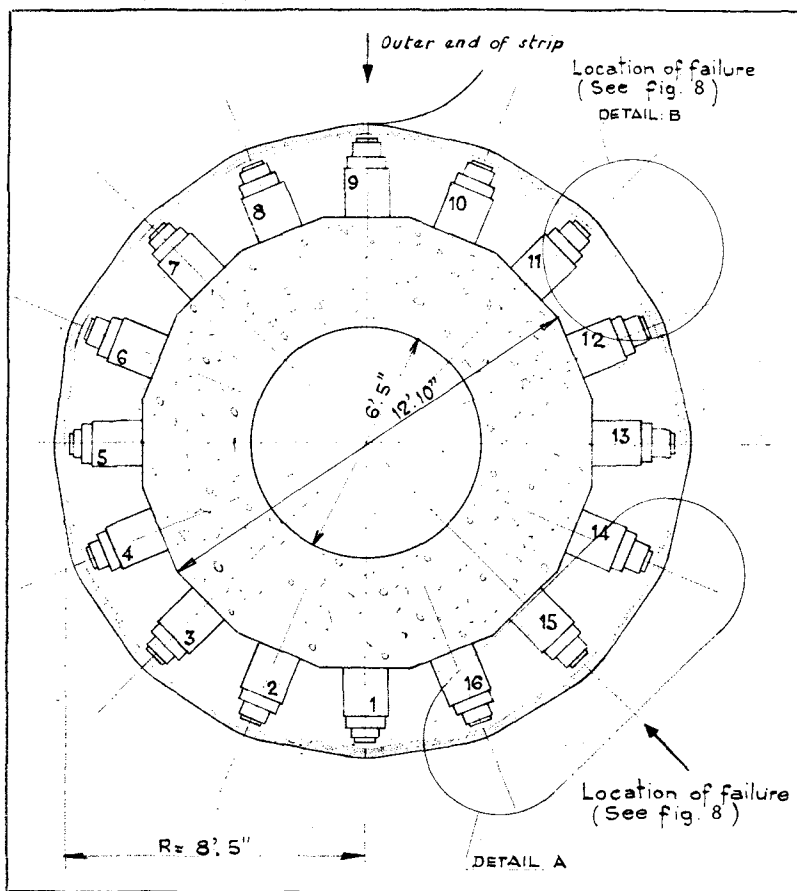


Fig. 5. Schematic view of tension ring tested to destruction

Execution and evaluation of the test.

The test was divided into two parts because of the limited capacity of the jacks. In the first phase, the ring was made up of two coils of strip as described above, making a total of 37 turns of strip forming the ring. The maximum force applied to the ring reached 925 tons, i.e. a mean stress of 142,000 psi (10,000 kg./sq/cm.), which is within the elastic range of the steel used.

During the second phase, the ring

was made up of 18.5 turns, i.e. using only one coil. In this case it was possible to carry the test to failure with the jacks available. The force applied to the ring at failure was 750 tons. Measurements were made by strain gauges bonded to the inner and outer faces of the steel ring. Readings were compared with stresses deduced from the forces applied by the jacks and from displacements.

The friction force exerted on the

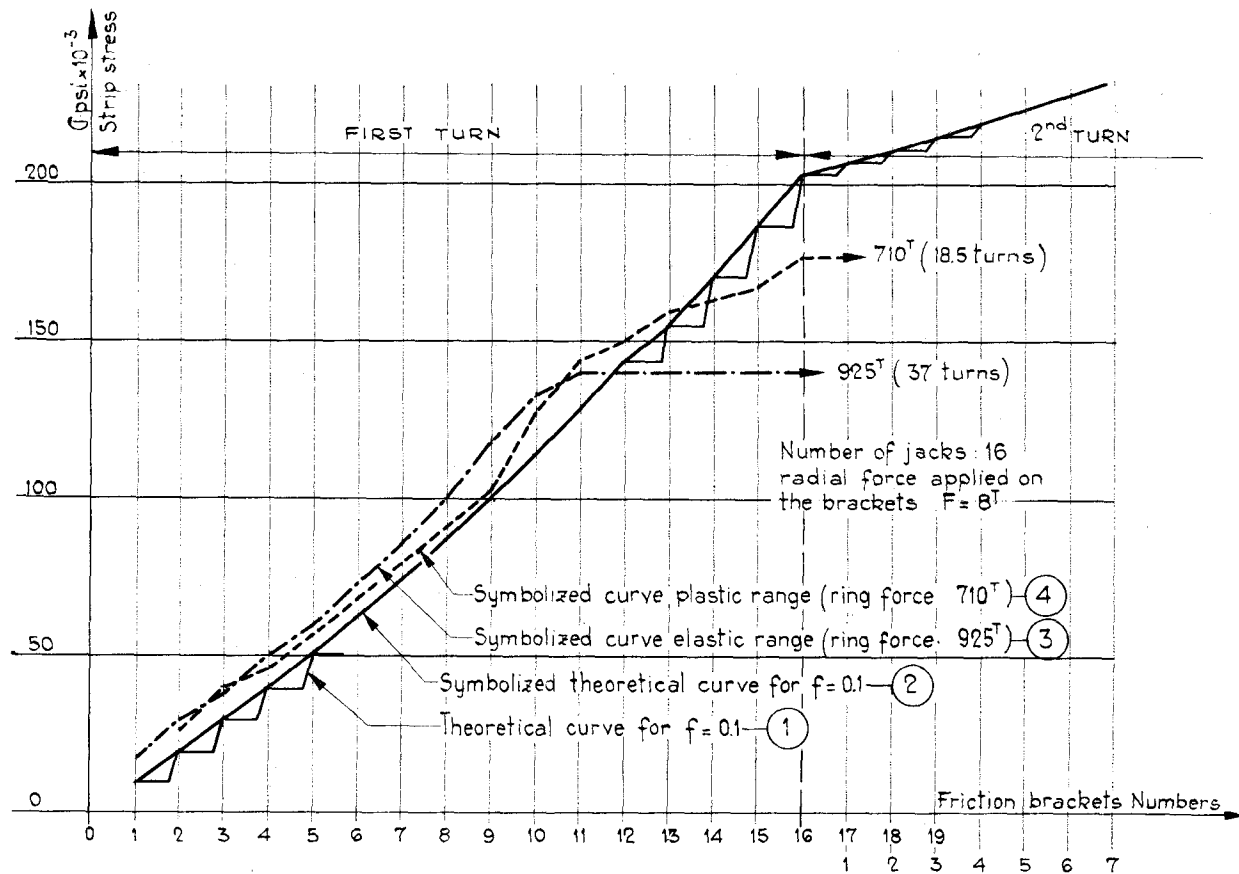


Fig. 6. Number of friction brackets vs. ring tension stress

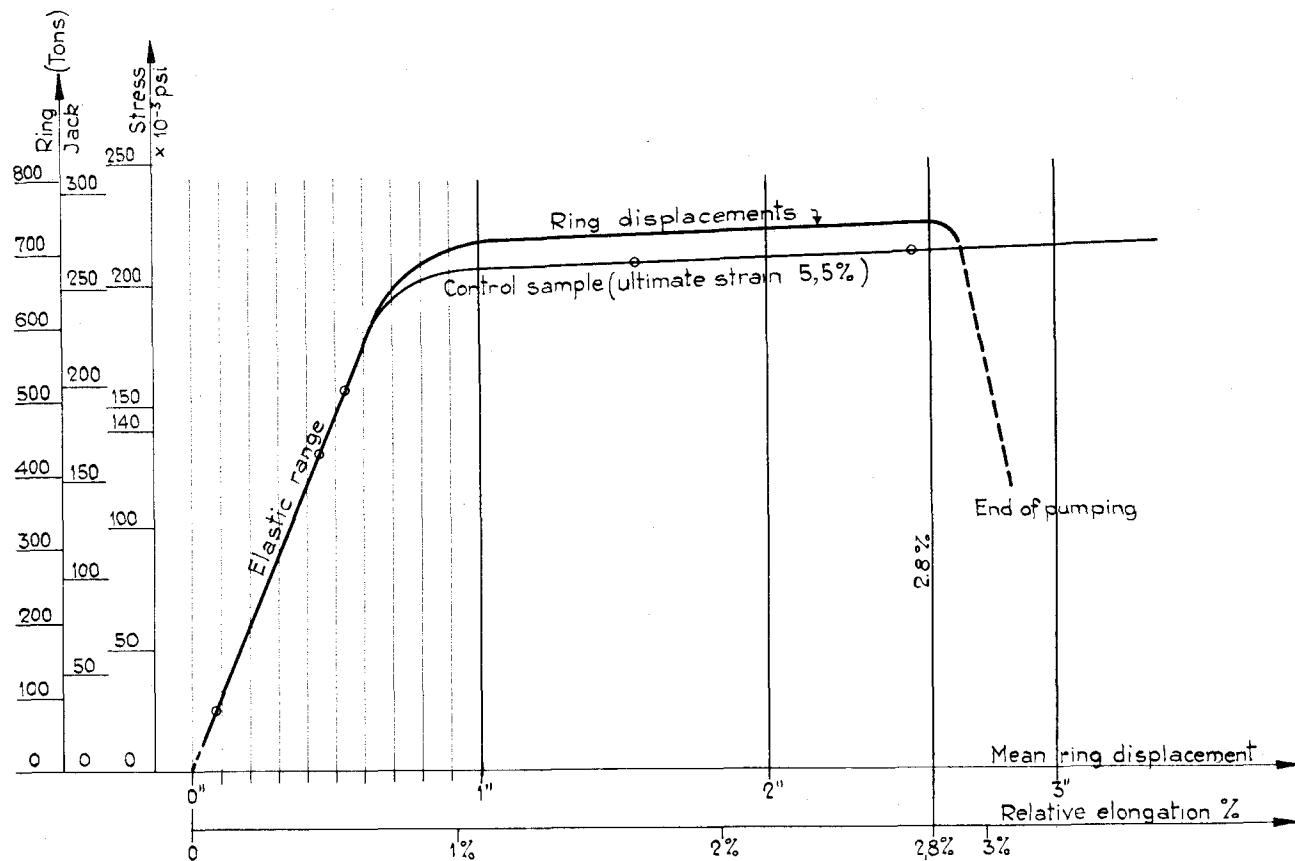


Fig. 7. Stress-strain curve for test of ring to failure

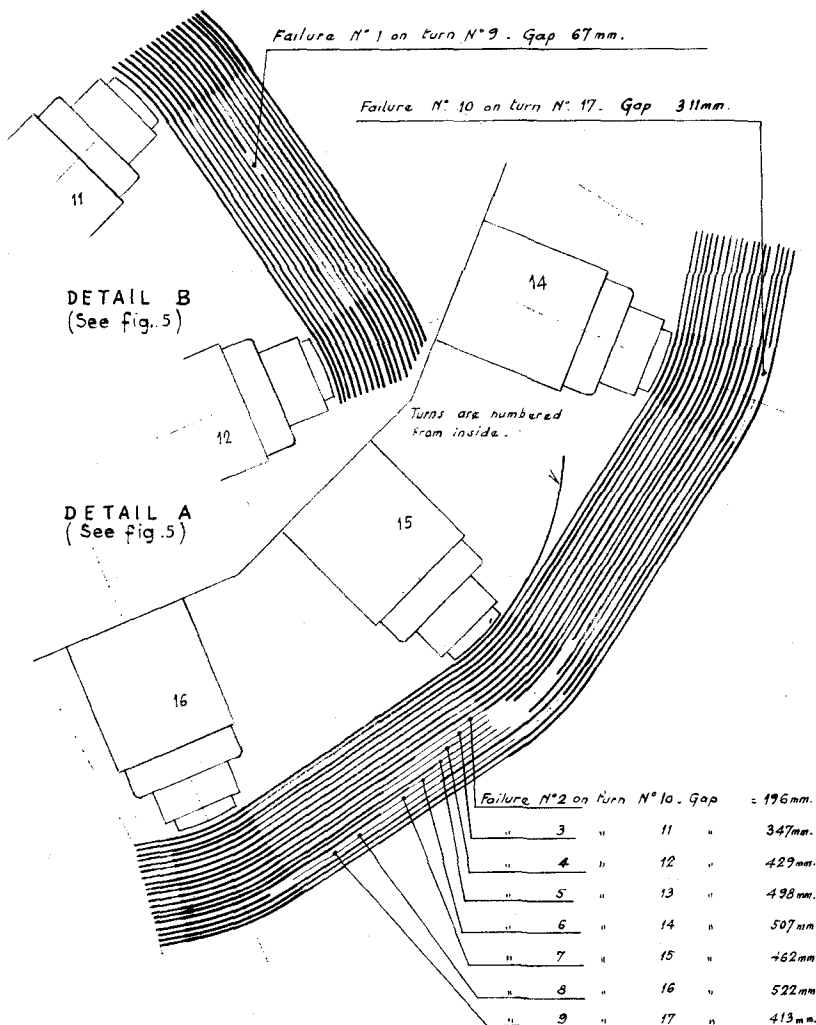


Fig. 8. Failure mode of steel strip ring

outer turn by the clamping brackets (Fig. 4) can be calculated by counting the number of brackets on which sliding occurs and by knowing the tensile stress prevailing in the ring. This relation is illustrated in Fig. 6 for a coefficient of friction, $f = 0.1$. The curves show theoretical and ex-

perimental results.

The strain gauges showed that tension in each cross section of the ring between adjacent jacks was uniform in the elastic range. Due to plastic deformation near failure some irregular stress distribution between jacks developed. In general,

however, it can be stated that within the test elastic range (37 turns), correlations between the forces applied by the jacks and those deduced from calibrated strain gauges were very good.

Concerning the test to failure (18.5 turns), the results are summarized in Fig. 7. This graph shows the stress-strain curve derived from ring force and displacement measurements, and the curve obtained from the calibrated strain gauges. The first curve lies approximately 5 percent above the latter, which can be explained by the friction between jack rams and cylinders induced by uneven lateral displacement. Jack friction is negligible only when the jacks act perfectly radial.

The ultimate elongation was 2.8 percent whereas 5.5 percent was obtained on samples. This discrepancy is similar to results obtained with other post-tensioning material.

Failure was progressive. Fig. 8 shows the two points where the strip failed. No failure occurred elsewhere.

STRIP TENDONS

The use of high-tensile steel strip is not restricted to tension rings. The following outline deals with their application to tendons. A tendon differs from a ring by the fact that it has two ends. The major problem, therefore, is how to anchor the individual strips. Theory and experience prove that if a cable is clamped externally, the cable's ultimate load decreases because of the clamping force. It appears, therefore, advantageous to use a friction anchorage device which has no notching effect on the strip material.

One possibility of making a tendon out of high-tensile strip is shown

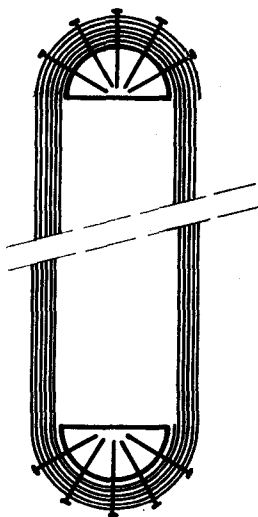


Fig. 9. Strip tendon with jacking heads

in Fig. 9. The semi-circles act as anchoring heads and can be jacked. This arrangement might be advantageous when the linear portion can be located outside the concrete.

A U-shaped cable can be developed from unequal lengths of strip as shown in Figs. 10 (a) and (b). The two free ends of the cable are interlocked around a half-cylinder like playing cards and anchorage is ensured by interface friction, which can be increased by applying a force radially to the cable.

Another way of anchoring the strip ends is shown in Figs. 11(a) through (d). The principle consists in forcing each layer of strip, A, against an adjacent layer or a friction plate, B, so that their load is transferred by friction. The friction plates can be stacked in the same way as the layers of strip and a single normal compressive force, N , can anchor as many strip layers as feasible.

The friction plates can be split up longitudinally into several elements to give an anchorage of smaller transverse area but greater longitudinal length, Fig. 11 (d). In this case, the friction plates are supported on the shoulders of the mild steel box. The box walls have threaded holes for bolting on a thick steel cover plate forcing the whole assembly together by means of an elastic device precompressed with a given pressure

In general, it can be stated that strip tendons differ from other tendons in that safe and compact anchorages can be provided for high-

capacity tendons of several thousand tons. Such friction anchorages, in addition to their compact size, allow applying a corrosion protective coating to the strip steel before it leaves the mill, which will eliminate the need for additional corrosion protection of the tendon at the site.

CONCLUSION

It has been shown how high-tensile steel strips can be used in post-tensioning, either as tension rings or as tendons. Their assets lie primarily in simple anchorage

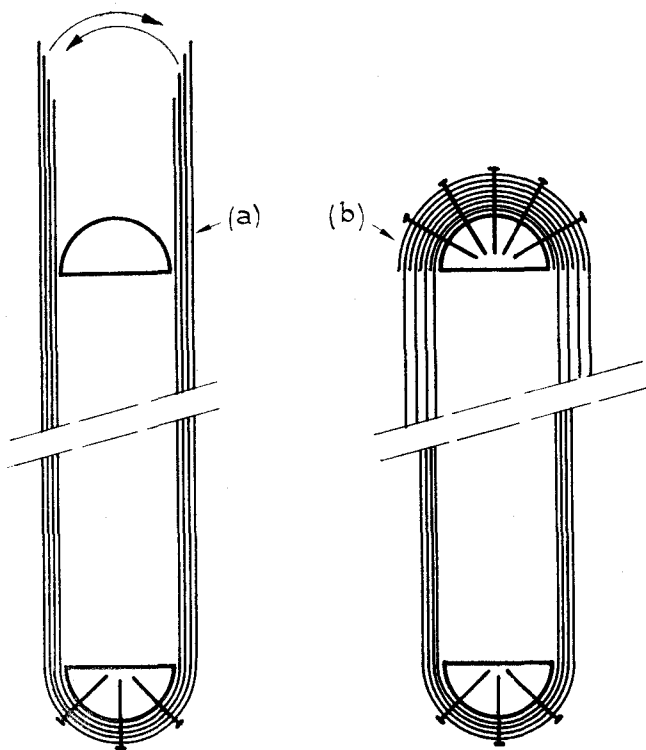


Fig. 10. Strip tendon with lapped splice

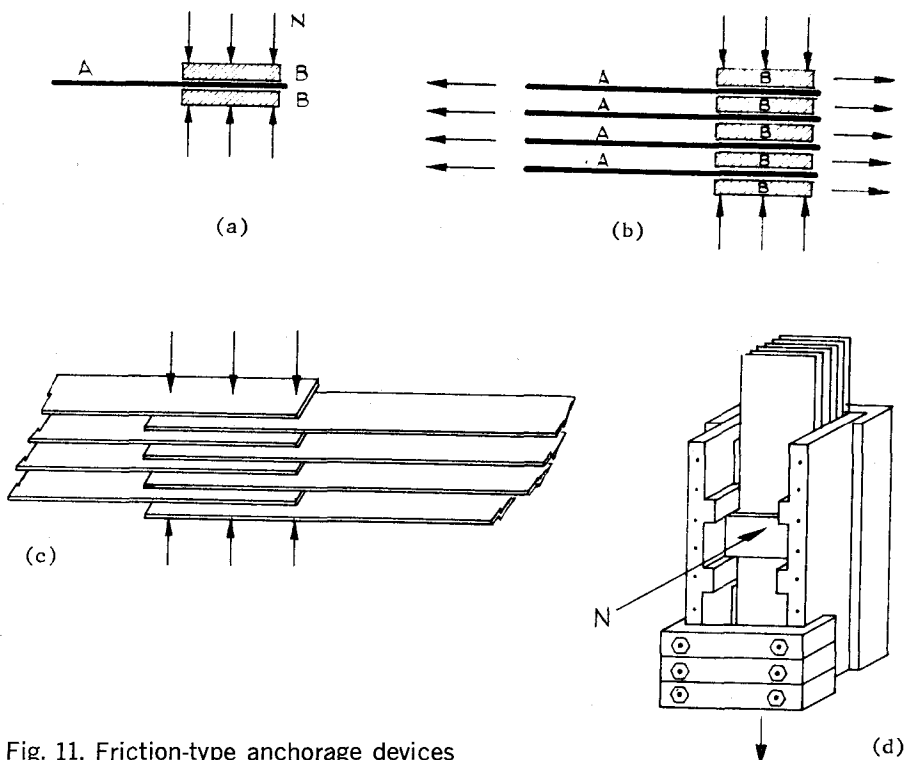


Fig. 11. Friction-type anchorage devices

devices due to the large area available for developing friction without notching.

In continuous strips, as used for tension rings of post-tensioned pressure vessels, the anchorages are

eliminated entirely. This and the possibility of tensioning by radial jacking or by winding make high-strength steel strip tendons an efficient system for post-tensioning pressure vessels.