Rock anchors - state of the art
Part 3: Stressing and testing

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Acceptance testing of production anchors
SHORT-TERM ACCEPTANCE tests on all production anchors highlight potential difficulties pertaining to service behaviour and provide measured safety factors related to the design working load. These tests are associated with the initial stressing operation and permanently include quality control observations over a period of up to 24 hours.

As a first priority, the testing procedure must yield a measured safety factor of 1.2 times the stressing load for a short period. Such overloads, however, must be compatible with the allowable stresses and safety factors permitted in the country concerned. The relevant details are disposed of in Part 1—Design (Table XV), and these suggest an encouraging trend towards standard safety factors throughout the world at the present time.

In the case of prestressed anchors, a measure of performance against that predicted by calculation, it is essential that a load-extension graph be plotted for each anchor, in the manner discussed in Part 3—Stressing. In addition, an attempt should be made on either preliminary test anchors or on early production anchors to obtain an indication of fixed anchor movement, since this information allows the analyst to assess a degree of movement, in addition to the increment in displacement which in turn permits a reasonable estimate of the degree of debonding, if any.

Finally, it is necessary to ensure that the service load locked-off after stressing is stable. The alternative methods employed in practice are monitoring loss of prestress with time, and monitoring creep displacement of the anchor with time.

Acceptance testing of temporary anchors in Geyerssteg (DIN 4125 (1972). This standard concentrates solely on soil anchors but it is considered relevant to describe the recommendations in this view—since the tests are rigorous and have been carefully devised. In addition, important principles are introduced which may well be stipulated for rock anchor testing in the future, particularly in the case of highly weathered materials, or fractured rock masses.

Each production anchor is subjected to an initial load $T$, equivalent to 0.1 $T$, $T =$ yield strength of the tendon, assumed to be the 0.1% proof load which is equivalent to 83.5% (fp) after which it is stressed to one operation to 1.2 $T$, ($T$ = specified working load) and held for at least 5 minutes in non-cohesive soils, and 15 minutes in cohesive soils, whilst tendon extensions are monitored at the top anchor, (Type I test).

Where the spacing between grouted fixed anchor zones is less than one metre, a check on interaction may be necessary. This will involve several adjacent anchors being loaded simultaneously.

For the first ten anchors, and thereafter one in ten of all subsequent anchors, a slightly more rigorous approach is taken and the extensions must be monitored from a fixed datum at load increments equivalent to 0.4 $T$, 0.8 $T$, 1.0 $T$, and 1.2 $T$, due account being taken of strand slippage (Type II test). At the maximum test load the observation times are as stated for the Type I test, and on dismounting to the initial load ($T$), an indication of the permanent extension is provided. In the case of prestressed anchors, the working load is subsequently applied and locked-off.

For loads in the non-cohesive range, the results are plotted as shown in Figs. 13 a & b and at 1.2 $T$ (Point X) where unloading is first carried out, the elastic component ($\Delta e$) and permanent component ($\Delta p$) of the extension plotted on the load-extension graph can be distinguished. The curve, $T$, $X$, in Fig. 13b is taken as an approximate path for the elastic displacement.

It is further specified that at least 5% of the anchors must be tested up to 1.5 $T$, bearing in mind that the maximum test load cannot exceed 0.9 $T$ (Type III test). At the maximum test load the observation times are as stated for the Type I test.

In general, the acceptance regulations are met for Type I tests, when at a load of 1.2 $T$, the displacements stabilise within the observation time, and when the elastic extension curve lies between two boundary lines plotted on the load-extension graph.

The upper boundary line (a) corresponds to the tendon extension equivalent to the free length plus 50% of the fixed anchor length, or 110% of the free length in the case of a fully decoated tendon with an end plate or nut. The lower boundary line (b) corresponds to 80% of the free length of the tendon. It is important to emphasise that account should be taken of sources of error as already described in Part 3—Stressing, and generally it is merely recommended that the observed load-extension line should be compared with the calculated theoretical extension due to the elastic extension of the free length of the tendon.

The permanent displacement, calculated with the aid of the approximate elastic extension line $T$, $X$, should conform closely with the results of the basic test but the permanent displacement ($\Delta x$) must not be greater than that observed for the basic test over the load range 0.4 $T$ to 1.2 $T$ (see "Special test anchors").

For Type II and III tests, the acceptance conditions are met when at maximum test load the creep displacement stabilises within the observation time, and when the free length of the tendon and permanent displacement have been proved in a similar way to the Type I test, through back-analysis of the observed extensions.

In the case of permanent anchors, generally regarded as having a service life in excess of two years, current thinking in Germany is illustrated in the Draft DIN 4125 (1972), which has been published for comment. In this document, it is suggested that each anchor should be tensioned from the initial load $T_w$ to 1.5 $T_w$, with a preliminary reading at $T_w$. The anchor is then unloaded to $T_w$, the permanent elongation is measured, after which the anchor is retensioned to $T_w$.

For the first ten anchors, and thereafter one in every ten, the test load is to be applied in stages at 0.4 $T_w$, 0.8 $T_w$, 1.0 $T_w$, 1.2 $T_w$ and 1.5 $T_w$. Unloading then occurs in the same stages to $T_w$, before $T_w$ is reapplied.

The displacements occurring at 1.5 $T_w$ should be measured at 2, 3, 5, 10 and 15 months after lock off. The specified observation period of 15 minutes should be extended if displacements occurring between 5 and 15 minutes are greater than 0.5mm, and monitoring should be continued until a clear estimate of the creep rate is possible. An observation period of 5 minutes is considered sufficient in frictional soils, provided that the displacements are smaller than 0.2mm.

The results of these measurements compare favourably with test anchor results, and a comparison of elastic extensions and the creep rates is usually sufficient. The acceptance test is considered to be satisfactory if the elastic extensions fall between the two boundary lines (a) and (b) previously described. Further, the creep should be less than 2mm at a load of 1.5 $T_w$ (see "Special test anchors").

With regard to acceptance testing in France, Bureau Securitas (1972) states that overloads of 1.2 $T_w$ and 1.3 $T_w$ should be applied to temporary and permanent production anchors, respectively. In the case of permanent works, where anchors are in service for more than 18 months, it is further suggested that 5% of all anchors could be tested to 1.5 $T_w$. No maximum permissible stress is specified for the steel tendon, but the Bureau warns that great vigilance is required when the elastic limit is exceeded (83.5% (fp)), and normally the test would be stopped if the extension reached 150% of the extension at the 0.1% proof stress.

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Accurate estimation of load losses e.g. through friction, is emphasised when plotting load-extension data, and an accuracy of not less than 3% is stipulated for manometers. Tensioning by stages starts at $0.15 - 0.20 T_e$ and at least five stages are recommended in order to draw accurately the load-extension diagram. In frictional soils the test load is held for 1-2 min. During this time the displacement should not exceed 1 mm and the observed free length of the tendon, based on back analyses of the load-extension diagram, should lie between the theoretical free length and the theoretical free length plus 50% of the fixed anchor length. For anchors with a working life less than nine months, an observed free length equivalent to 90% theoretical free length is accepted. If these tests are satisfactory the service load is lock-off, plus an allowance for losses.

In cohesive soils, the test load is held for five minutes, and the curve of displacement with respect to time should compare closely with the performance of anchors subjected to creep tests (see “Special test anchors”), in addition to complying with the extension criteria described above.

In Czechoslovakia the draft standard for prestressed rock anchors (Klein, 1974) stipulates the test loading of all temporary anchors to $1.2 T_e$ in cycles as shown in Fig. 14: (a higher test loading for permanent anchors is expected but yet to be specified). The maximum permissible stress in the steel tendon is the 0.2% proof stress which is equivalent to 87% fpu. The observed displacements are separated into elastic and permanent portions and the observed elastic displacement at $1.2 T_e$ should lie between the boundary lines (a) and (b) as specified in DIN 4125 (1972). The permanent displacement is due to the increase in load from $T_e$ to $1.2 T_e$ should not exceed by more than 10% the permanent displacement obtained in the basic anchor test over the same load range (see "Special test anchors"). With regard to creep under a constant service load, it is stipulated that the displacement should not exceed 0.135 mm/m of free tendon for every tenfold increase in time. To simplify measurements on production anchors, the draft Code suggests that constant time intervals should be chosen for the observations, and that changes in displacement must not increase in these time intervals. For these specific time intervals in Fig. 15, the displacement must be less than 0.02 mm/m of free tendon, and for acceptance testing, the total period of observation must be at least ten minutes. Finally, the creep displacement is compared with the results from basic tests.

On every site, it is specified that the first three production anchors and 5% of the remainder should be subjected to a more rigorous test loading to $1.4 T_e$ and $1.5 T_e$ for temporary and permanent works, respectively. A service life of less than two years is considered temporary.

The FIP final draft (1973) suggests that the tensile stress in the tendon must never exceed $0.9 T_e$ (75% fpu, assuming $T_e$ is equivalent to the 0.1% proof stress) and all production anchors should be tested to $1.2 T_e$ and $1.3 T_e$ for temporary and permanent works, respectively. A service life of less than two years is considered temporary.

Details of the acceptance test are shown in Fig. 16 and extensions are monitored at load increments equivalent to $0.15 - 0.20 T_e$. For soils and rocks not susceptible to creep the test load is held for 2.5 min., and the anchor is accepted if:

(i) no noticeable displacement (approx. 1 mm) is observed during the period of observation, and

(ii) the measured total displacement at the top anchorage is in reasonable agreement with the results of the “extended acceptance” test (see below).

For soils and rocks susceptible to creep, the observation period at constant test load must be long enough to enable the relationship between creep displacement and time to be ascertained, and a minimum period of five minutes is specified. The anchor is locked off at the required service load if the measured total extensions and creep displacements conform closely to those of the “extended acceptance” test.

At the beginning of a contract, it is recommended that between three and ten production anchors should undergo an “extended acceptance” test. The stressing programme is shown in Fig. 17 and this test is applied to approximately 10% of the production anchors constructed thereafter.

In this test the anchor is accepted if:

(a) the displacement of the anchor under test load has stabilised within the observation period,

(b) the measured elastic tendon extension corresponds to the calculated elastic extension.

In connection with (b), the calculated free tendon lengths based on the observed elastic extension of the tendon must not exceed the free tendon length plus 50% of the fixed anchor length or 110% of the free length, or be less than 90% of the free tendon length.

Current practice in Italy has been re-
vealed by Arcangeli and Tomiolo (1975) of Rodio. From an initial seating of 0.10 Rak (Rak = characteristic tensile rupture stress of steel), extensions are recorded at 0.15 Rak intervals up to 0.85 Rak. This load is applied usually for 10-15 minutes until creep losses in the steel are negligible (less than 0.1mm in 5 min.). Therefore, following destressing down to 0.3 Rak in 0.15 Rak increments, the anchor is restressed to 0.85 Rak before locking off at the required load.

All anchors are tested in this way to provide a measured safety factor of 1.3 and to compensate for frictional effects and lock-off losses the procedure of Fenoux and Portier (1972) is used. In general the results from each site or geotechnically distinct anchor area are analysed and compared statistically to verify the service conditions of the installations.

In the United States, PCI (1974) suggests the test loading of every anchor to at least 1.15 Tw. During the test loading the prestressing load in the tendon should not exceed 80% fpu. The maximum test load is usually applied for up to 15 minutes, and extensions should not diverge by more than 10% from the calculated values, otherwise an investigation is required. For temporary anchors in rock (up to three years where there is no apparent danger of corrosive attack) it would appear that extension measurement is not usually required. With reference to losses of prestress during service, PCI states that meaningful lift-off checks can be carried out after 24 hours and that in most cases of rock anchors the primary time dependent loss is steel relaxation.

In Britain, CP 110 (1972) permits tensile testing to 80% of the characteristic tensile strength (fpu) of the steel tendon and the authors’ recommendations on safety factors related to acceptance tests are reaffirmed in Table V.

The above recommendations are gradually being adopted in Britain, but for temporary and permanent anchors the most common method in current practice consists of test loading in increments up to 1.25 Tw with a minimum observation period of five minutes at this maximum test load. The anchor load is then reduced to zero before restressing in increments up to a lock-off load of 1.10 Tw (Littlejohn, 1970). Tendon extensions are monitored but since the movement at the top anchorage during the initial loading stage may comprise fixed anchor displacement, tendon extension, wedge pull-in, bearing plate and structural movement, the interpretation and analysis of the data are usually restricted to the load-extension graph obtained during the second loading cycle.

The observed extension should compare closely with the value estimated from the free length of the tendon and the permissible discrepancy on any site varies, the value often being directly related to the accuracy of the measurements and parameters used in the calculation.

In order to give some insight into service behaviour of anchors in Britain, emphasis to date has been placed on monitoring loss of prestress with time, which is a simple alternative to the German and French practice of measuring creep displacement. A lift-off check is carried out immediately after lock-off to measure the actual residual load in the anchor. This residual load, which is usually 1.10 Tw, is then checked after 24 hours. Bearing in mind the errors in measurement referred to in Part 3 “Stressing”, a loss of up to 5% is acceptable in practice. If the load is less than 0.95 Tw, the anchor should be replaced or otherwise dealt with as agreed with the Engineer.

Where the anchor load lies between 0.95 Tw and 1.05 Tw, the tendon should be retested to 1.1 Tw, and retested after a further period of 24 hours. If the anchor, after three such tests, still fails to retain a load of 1.05 Tw, the anchor should be replaced or, agreed with the Engineer. In the former case it is recommended that the load be reduced until no pre-stress losses are observed, over a period of at least one week, based on daily readings. A safe working load may then be established equal to 62.5% and 50% of this reduced stable load for temporary and permanent applications, respectively (see Table V).

If a component of a multi-unit tendon fails during the stressing stage, a reduced anchor capacity, in proportion to the number of components left, may be agreed with the Engineer, unless the individual components have stresses in service which are below the limits specified. In this situation it may be possible to upgrade the load in each component to compensate to some extent the loss of the redundant component. For example, a tendon consisting of 10 No. 15.2mm Dyform strands might be required in Britain for a permanent anchor with a working load of 1,400kN. In this case each strand would be resisting only 140kN (46.7% fpu) and could therefore be upgraded to 50% fpu (150kN) to give a safe working load on the anchor of 1,350kN if the same approach may be applied if gripping wedge failure occurs and fresh wedges cannot be fitted.

In South Africa the Code of Practice “Lateral Support in Surface Excavations” (1972) stipulates a test load of 1.25 Tw for every prestressed anchor. This load is maintained for a period of not less than ten minutes to test the anchorage, and is then removed.

Between 24 and 48 hours after lock-off, the tendon is retensioned until the anchor block just lifts off the permanent load bearing plate, and the residual load at this point is recorded. If this residual load is greater than 0.80 Tw but less than 1.05 Tw, the tendon should be retensioned to 1.10 Tw and then retested 24 hours later. If after three such retests at 24 hour intervals, the tendon fails to maintain the load at the working load it should be condemned and replaced, or derated as approved by the Engineer.

In the case of tendons which are to be permanently protected against corrosion by grouting, they may be grazed out after the 24.48 hour test but not later than seven days after this test. Such fully bonded tendons are not subjected thereafter to further tests.

In this connection Parry-Davies (1968) emphasises the advantages of leaving the tendon ungrouted over a period of, say, 12 months in order to facilitate tests.

A further reason for removing the working strain in the tendon is only a small fraction of the ultimate strain, a generous safety factor against “catastrophic collapse” is provided. Since a small extension of the tendon supporting a basement excavation, for example, will relieve excess forces.

<table>
<thead>
<tr>
<th>Item</th>
<th>Temporary (Life &lt; 2 years)</th>
<th>Permanent</th>
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</thead>
<tbody>
<tr>
<td>Design or working force (T&lt;sub&gt;w&lt;/sub&gt;)</td>
<td>62.5% fpu</td>
<td>50% fpu</td>
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<tr>
<td>Test force (T&lt;sub&gt;t&lt;/sub&gt;)</td>
<td>78% fpu</td>
<td>75% fpu</td>
</tr>
<tr>
<td>Measured safety factor</td>
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<td>1.5</td>
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</table>
which may build up, the safety of the sys-
tem lies not so much, therefore, in the
ratio of actual stress in the tendon to uti-
mate stress, but in the ratio actual strain
to ultimate strain.

Removal

The value of overloading an anchor to
give a measured load safety factor and to
impose a stress history which can improve
subsequent behaviour, is widely ap-
preciated.

With reference to the interpretation of
load-extension data, however, important
differences in acceptance criteria are ap-
parent, and clearly use of boundary lines
which reflect permissible discrepancies
must not be employed inflexibly or with-
out a basic understanding. For example, an
anchor with negligible fixed anchor move-
ment but which has apparently debonded
along half of its length might be judged
acceptable. An anchor in which only 80% of
the applied load has seemingly been
transferred to the fixed anchor zone might
also be considered satisfactory. These two extre-
me situations are considered use of the
extension criteria could be misleading
and potentially dangerous especially when
considering the corrosion risk (debonding
at tendon interface) or the overall stability
(inadequate load beyond potential failure
plane).

It is suggested that while load-extension
boundary lines are favoured in practice, care
and attention is required in interpre-
tation. To avoid the appearance of im-
plications authors recommend that all pro-
duction anchors should be subjected to at
least one stage of cyclic preloading. The
analyst should then concentrate on the
load-extension characteristics of successive
load cycles, from which most of the
initial non-recoverable movements have been
evened out as plateau "bedding-in".

In the case of anchors, the theoretical and observed distributions should
be apparent, easing the analysis of anchor performance.

If discrepancies are still considered sig-
nificant, on-site discussions are necessary to dispose of anchor, which may
lead to acceptance, derating or re-
placement of the anchor, depending on the cir-
cumstances and the consequences of fail-
ure.

Long-term monitoring of selected production anchors

Long-term monitoring over periods in ex-
cess of 24 hours checks service behaviour
and acts as a control to verify that anchor performance is satisfactory. Further-
more, the collection of data relating loss of
pre-
stress or creep displacement to time, type of
rock, and anchor load and geometry,
will improve understanding of the service behavior of anchors and could well lead to
future refinements in design. In the short
term, such data establish whether over all
load-off, are adequate and realistic.

Long-term changes in the anchor are
due to a combination of steel relaxation and
anchor creep (see "Service behaviour of
production anchors"). The relaxation char-
acteristics of prestressing steel are well
known to be variable from manufacturer
to manufacturer. Less is known about creep in rock
anchor systems largely because basic in-
formation regarding the magnitude and dis-
tribution of stresses in the fixed anchor
zone is not available. Nevertheless, in
weathered rock or fractured rock with clay
infill, creep losses may be significant and an
estimation of the amount to be expected
should be gauged from test anchors instal-
led well in advance of full-scale production.

Where test anchor results are not avail-
able and the rock is of poor or variable
quality, it has been recommended in Britain
that production anchors should be checked
be carried out on production anchors as follows:

(i) The load in all anchors should be
checked 24 hours after stressing to provide
an early warning of load loss or, if any. This check applies to
primary and permanent anchors.

(ii) On a large contract where the con-
sequences of failure are severe, the first test should be checked
weekly for one month, then monthly
for the next three months.

(iii) Subject to satisfactory results after
four months, 5% of all production
anchors should be checked at six
months, and again at 12 months.

The permissible variation in anchor load
is usually ± 0.1 Tcr and restressing is only
carried out after careful consideration. For
example, in the case of a retaining wall
failed back by several rows of anchors in-
stalled in a weak sheave, loss of pre-
stress due to consolidation of the sheave in
the fixed anchor zone may be observed without accompa-
nying movements of the retaining wall.
In these circumstances remedial mea-
sures may not be required.

Bureau Securitas (1972) considers
that although the ground anchor tie-back system
is now a satisfactorily tried and tested method, it is absolutely
necessary to plan a monitoring or control procedure
which will detect possible failures in time.
As a result, periodic monitoring of perman-
ent anchors is generally carried out at least ten
years is compulsory in France.

During the first year, monitoring takes
place at intervals of three months, at six
month intervals in the second year, and
thereafter at intervals of one year. As already
indicated, the Bureau classifies anchors ac-
cording to basic geometry and type of
ground at the fixed anchor. In each cate-
gory, the minimum number of anchors to
be monitored is as follows:

10% of production anchors (total installed,
1-50)
7% of production anchors (total, 51-500)
5% of production anchors (total installed,
over 501)

The Bureau further states that the con-
trol apparatus must be reliable, simple, and
have an adjustable sensitivity; it need not
be a measuring device, and a limit device
capable of detecting load losses of between
15 and 25% is adequate. In this connection
the authors would add that the control
apparatus should also be capable of moni-

toring pre-stress loss in clays, a theory in the

case of anchors for retaining walls.

In selecting the production anchors
for observation, the FIP Draft Recommenda-
tions (1973) indicate that for "extended acceptance"
tests, an initial number of
3-10 anchors should be monitored, followed
by a percentage of all others—usually 10%.
It would seem that the South African
Code "Lateral support in surface excav-
ations" (1972) recommends the most rigor-
ous approach at the present time, namely
that each anchor should be tested at the follow-
ing intervals after stressing unless it is to be permanently protected against cor-
rosion by galvanizing:

(i) Not less than 24 hours and not more
than 48 hours.

(ii) Seven days if the 24/48 hour test is
satisfactory.

(iii) One month if the 7 day test is satis-
factory.

(iv) Monthly intervals for the first six
months and thereafter at three monthly
intervals if the first monthly test is satis-
factory.

After 12 months, all tendons remaining
in service should be tested at intervals laid
down by the Engineer; in no case should
such intervals exceed 24 months. In an alternative to the measurement of
loss of prestress, creep displacement may
be monitored since test results in Germany
and France have indicated that, under con-
stant load, the sum of the checked on the
tendon, the fixed anchor, and the
ground in the vicinity of the fixed
anchor proceeds linearly, when displace-
ment increments Δ are plotted against the
logarithm of time. Whether displacement and
remain increase with increase of load and
when the stresses at the fixed anchor
interface approach the ultimate strength of the ground the displacements
accelerate in relation to time on a semi-
logarithmic scale.

On the basis of these observations cer-
tain authorities clearly consider that the
displacements may be considered stabi-
lised when, for a constant applied load, the
displacements are zero or such that
they do not increase more than linearly
when plotted on a semi-logarithmic scale
against time (see "Special test anchors"
in Germany).

In current practice where an attempt
is made to gauge the long-term perfor-
ance, this commonly consists of one
light-off check but the time of observation varies
considerably e.g. at 24 hours (Buro, 1972,
Mitchell, 1974), 72 hours (Australian Stan-
ard, 1973), 7 days (Gosschalk and Taylor,
1970, and Chen and McMullan, 1974) or 28
days (Morrison and Garrett, 1966). Certainly
few production anchor checks are as thorough as those by McLeod and
Hoadley (1974), all anchors being
checked at 3, 7 and 21 days, and 100 out of
1,800 by load cell each day for six
months.

Removal

For economic as well as operational reasons the time involved for the stressing
and control of anchors on a construction site
should be minimised. The question remains: whether all is as simple as possible, to judge the long-term load hold-

ing capacity of the anchor on the basis of a
short-term test. Although prestress losses due to lock-off, friction and steel relaxation are predictable, the creep behaviour
of different types of rock due to anchor load-
ing is largely unknown. Field experience
indicates that such losses may be signif-

cant in heavily weathered rock, or fractured rock with clay infill. A

A prestress loss of up to 5% in 24
hours or a creep displacement of up to
4mm in 72 hours has been used as an
upper threshold of acceptability in practice,
but these figures are rather arbitrary and
should be regarded as provisional.

Only when creep losses are monitored
over long periods for a variety of anchor
loads and geometries, and for a wide range of classification rocks, will an ac-
curate predictive capacity be available.

In the meantime, therefore, it is recom-

mended that periodic checks of anchor stress or creep displacement should be carried out on anchors whenever possible, but further effort should be made to publish the field
data obtained in the form of case histories.

(To be concluded)