UPUS® Ultrasonic load measurement for prestressing bars

Bernard Basile[1)], Eric Le Bis[2)], Bruno Lancia[3)]

1) Technical Manager, Advitam, Paris, France
2) Technical Manager; Advitam, Washington DC, USA
3) Technical Manager, Freyssinet, Paris, France

ABSTRACT

Many items of equipment are attached to structures by anchorages consisting of short prestressing bars. The safety of such equipment calls for a minimum tensile load being maintained in these bars. The only known and reglementary method of verifying the value of this load is by overstressing the bar and deducing its value from the "unseating" graph of the anchorage. This is the principle of LIFT-OFF.

This article describes the UPUS® system which can determine, during the first and only LIFT-OFF, an ultrasonic characteristic of the bar which, when associated with the LIFT-OFF results, then allows one to calculate the load by simple measurement of a time of propagation of an ultrasound from one end of the bar to the other. The initial measurements as well as those taken afterwards are automatically processed for calculation of the required values, not only to provide a written report on the operation but also for analysing the behaviour during the initial tension. The computer which processes these data and measurements also contains the database of the bars.

A description is given of a UPUS® on the French nuclear network, highlighting the gain in time and precision achieved.

The traditional method of measurement of the residual load in a prestressing bar is calculated traditionally by the lift-off (or "weighing") method as prescribed in Fascicle N° 65 A of the French Ministry of Transport and Equipment. The principle is based on showing up, with the aid of the load/displacement curve, the change in state which corresponds with the moment when the prestressing load is reached and then exceeded : the first part represents the stiffness of the extra length and the second the entire bar.

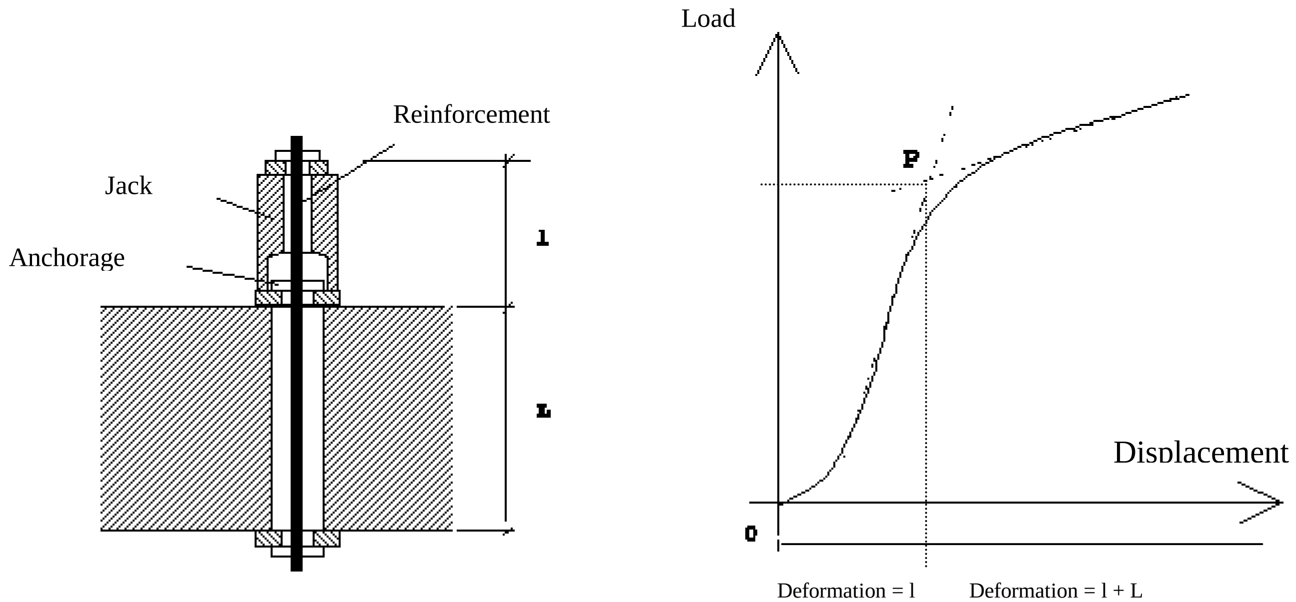


Fig 1: Extract from fascicule N°65 A, principle of retensioning a short prestressing tendon

More often than not, the points on this load/displacement curve are obtained at pressure stages, are few in number and more or less precise depending upon the methods of measurement. Following this, calculation is performed manually or using a spreadsheet while seeking the most suitable lines passing through these points and calculating the ordinate of their intersection.

This leads to a load determination which cumulates these various imprecisions but which may, nevertheless, be adequate for the purpose.

Furthermore, each time one wishes to know the load in a bar, one must implement this entire method, which in particular means installing the load application apparatus and retensioning the bar i.e. incurring the risk of rupture or plastic deformation of the steel.

UPUS® was developed in order to overcome this drawback.

Improvements and innovations of UPUS®

The first lift-off is performed in the traditional manner, but a certain number of improvements are introduced. Its purpose is to determine the prestressing load precisely and to obtain an in-situ calibration of the bar which thus allows considerable simplification of the ulterior measurements.

Two patents protect the principle and methods of UPUS®.

Continuous measurement

Continuous measurement of the parameters of the operation ensures achievement of a curve with a wealth of points and greatly improves determining and understanding of the different phases of tensioning.

A pressure captor ① is connected to the hydraulic circuit of the jack and allows one to determine the load applied by the latter with just a correction for loss by friction. One option consists in interposing a load cell ② above or below the jack in order to obtain direct measurement.

A displacement captor ③ measures the movement of the extremity of the bar in relation to the structure. This value represents the elongation of the bar. The latter two combined values give the classic LIFT-OFF curve.

For the UPUS®, two extra captors are associated with those mentioned above. A probe ④ measures the temperature of the bar at its extremity. An ultrasonic transmitter/receiver ⑤ on the end of the bar allows measurement throughout the entire operation time of the return course, from one end to the other of the bar, of an ultrasonic wave.

The entire group of these values is entered on a site computer ⑥ which also contains the ultrasound processing card. The relevant software which complements all this and which is incorporated in the overall UPUS® computer programme automatically detects the echo of the end of the bar and monitors it automatically during the tensioning operation.

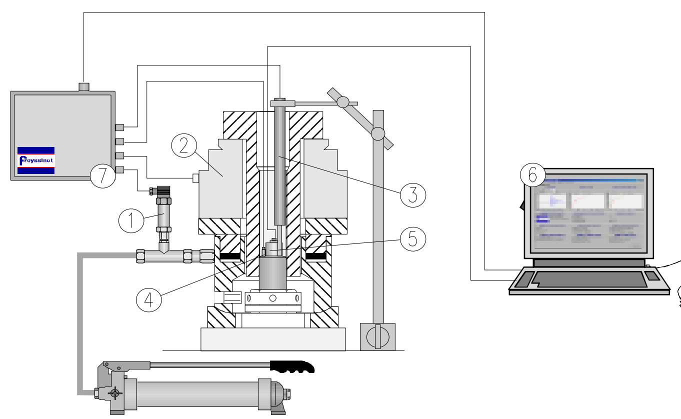
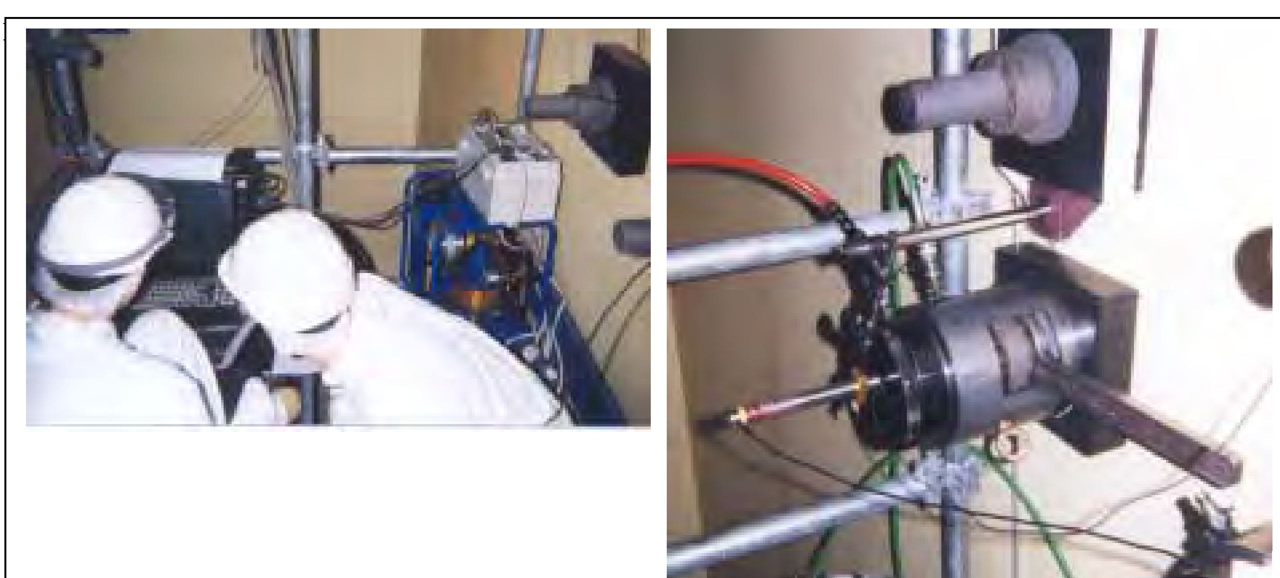


Fig 2: Assembly

In order to avoid problems of environmental interference on the signals, the analogical measurements of the captors are immediately digitalised by an intermediary module ⑦.



Analysis in real time and assistance with selection

The identification of the bar, apart from its univocal location on the structure, also contains its mechanical and dimensional characteristics : module, diameter, tensioned length, extra length. These data are used for calculating and drawing on the screen before the operation, the theoretical straight lines, of which the stiffnesses are represented by the slopes and the expected load the intersection. This function gives the operator a very clear vision of behaviour during tensioning as compared with expected behaviour and allows him to optimise the operation and detect any singularities. Furthermore, calculations of behaviour in real time are made and can give rise to anomaly messages by comparison with a model or a variation.

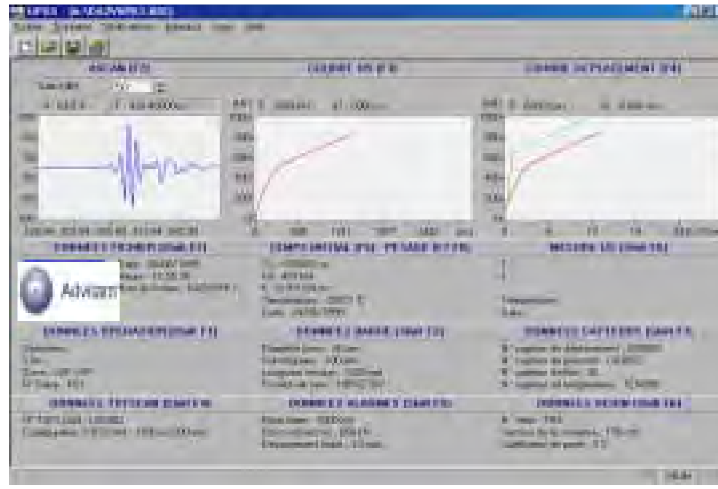


Fig 4 : View of the screen during the operation

Propagation period of the ultrasounds.

The principle of force measurement by the period of propagation of an ultrasonic wave is widely used on bolted assembly lines in the automobile industry for example. It uses the fact that the variation in time T is directly proportional to the variation in force F through the cumulated effect of the variation in length and the variation in speed of propagation. These two effects are linear in the same direction and the general formula is of the type F=K T.

In the case of these assemblies, the factor K is determined by a preliminary calibration of a representative sample, then the variation of force is calculated as from a zero force ; the formula is written simply as F=K T.

This principle for the measurement of force in bars already in place comes up against two unknowns : the time representing a zero force has not been measured initially, the factor K has not been determined.

Processing of measurements

Analysis of the curves recorded during the UPUS® lift-off allows one to find these datas and then to calculate the force by measurement of the time.

Firstly the force in the bar is calculated by fine analysis of the curve representing the force expended in the jack/elongation of the bar. It is "fine" in the sense that takes account of the true behaviour of the bar during tensioning, in particular the first part is not linear and expresses a variation in the tensioned portion of the extra length. Furthermore, as the support of the bar is not infinitely rigid, the part of the bar which is generally tensioned begins to elongate right from the start of the operation.

A calculation algorithm which takes this behaviour into account is incorporated in the software programme. It allows one, at the end of the operation, to determine precisely the force required.

An identical calculation is carried out, this time considering the expended force/variation in time of propagation. In fact it appears that this curve is similar to the preceding one thus exposing the fact that the variation in time is directly related to the variation in length. An identical algorithm is applied and gives the same result. Tests carried out have however shown that there is greater precision in the second case as there is less parasitic effect (settlement or bending of the bearing) likely to affect the ultrasonic measurement which concerns the bar alone.

Fig 5 : Acoustic stiffness

It is therefore possible to determine the force in the bar by examination of the expended force/variation in time of propagation curve. Nevertheless, the UPUS® retains the displacement measurement, as there may occur, in the course of the operation, an "interruption" in the monitoring of the ultrasound echo. Should both processes be possible, the determination by ultrasound is taken into account.

Prior to the operation, the propagation time is measured. This time therefore corresponds to the calculated force**.**

Another calculation algorithm uses the expended force/variation in time for determining the K factor.

One may note that these curves show the behaviour of two parts of the bar, neither of which is the part normally subjected to the force. The slope at the origin of the first part corresponds to the factor Ka which ties the variation in time to the variation in force in the extra length, the slope in the second par corresponds to the factor Kb which ties the variation in time to the variation in force in that part of the bar between the jack grip and the opposite anchorage.

It has come to light that a simple combination of these "acoustic stiffnesses" (just as one would do with mechanical stiffnesses) allows one to obtain the acoustic stiffness of the part normally tensioned.

Finally, measurement of the temperature in the bar, corresponding to the values obtained by this calibration, us used to compensate the time of ulterior propagation for the effects of a variation, by the normal formula for correction.

The product of the operation is therefore: the identification of the bar, knowledge of the force, knowledge of the associated time, knowledge of the relation of variation between time and force, the measurement parameters. A written report on the operation is automatically delivered by a printer connected to the computer.

Simplified ulterior measurement

Thus, it suffices thereafter to measure the time and temperature of the bar to know the force. The time is corrected for temperature variation between calibration and measurement, the variation in time is multiplied by the factor K and then this result is added to the initially determined force. The computer contains all the data relating to the barwhich are automatically recalled by identification of the latter.

The ultrasound transmitter/receiver associated with the temperature probe are placed on the end of the bar; the calculations in accordance with the above principle are carried out and the result is filed away in the database of the bars.

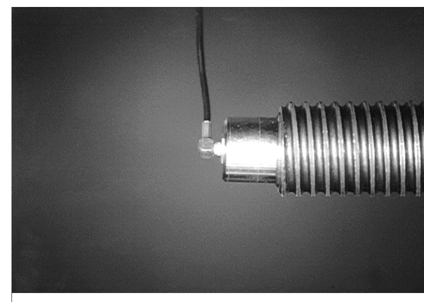


Fig 6 : Ultrasond transmitter/receiver

Precision

Very many tests on different configurations of bars have shown that the initial incertitude with regard to the determination of the force is less than 2% when using the curve force/displacement and less than 1% when using the curve force/variation in time. Then, determination of the force by simple measurement of time leads to an incertitude of under 4%, which is close to the common value of 5% admissible with a traditional LIFT-OFF.

Applications

The first applications of the UPUS® were carried out on anchorage ties on the French nuclear network where operations of surveillance are under way.

During the years 70 to 80, the tensioning techniques for anchorage ties were not always very efficient and there existed no other reliable method of guaranteeing the residual tension. Thus, within the scope of a maintenance programme, EDF (the French electricity authority) asked FREYSSINET, in partnership with FRAMATOME, to verify the residual tension in the anchorage ties of the high voltage lines of the primary and secondary circuits and to retension them if necessary.

This operation mobilises extensive human and equipment resources, often in controlled zones, and thus involves high costs.

The advantage of the UPUS then becomes obvious, as it will allow the production authority to learn, after several years have passed, the residual tension in these anchorage ties by a simple Ultrasonic measurement. The operation is rapid and calls for just one technician. Moreover, should retensioning be necessary, this can be limited to the deficient ties alone. The cost of maintenance is thus enormously reduced.