In 1977, researchers at the Norwegian Technical University (NTH), Research Institute for Cement and Concrete, developed and patented a method for in-situ determination of the flexural strength of concrete (2). Termed the 'Break-off Tester' the instrument was further developed during 1981-82 in co-operation with A/S Norcem. It has been accepted world-wide and has been approved as a test method in a number of national codes and standards (3, 4).

This paper presents a consideration of some practical aspects of the application of the break-off test in field situations together with some discussion of case histories of construction activities where the method has proven valuable.

EXPERIMENTAL

Figures 1 to 3 illustrate the principles of operation of the break-off test. A circular slit (Figure 1) is formed in the concrete in one of two ways depending upon whether the concrete is being placed or is part of an existing structure:

(a) In fresh concrete, plastic forms are placed into the concrete as it is cast and removed after curing;

(b) In hardened concrete, a diamond drill is used to cut the required slit (Figure 2).

Using the hydraulic testing device (Figure 3), a transverse force is applied to fracture the resulting core. The force required to rupture the core is taken as a measure of the flexural strength of the concrete and can be correlated with the compressive strength through the use of calibration charts. The small concrete core obtained during the test may also be taken to the laboratory for further examination

Since 1976, the Norwegian Institute of Technology, Cement and Concrete Research Institute (FCB) have been investigating the reliability of the break-off tester with different concrete mixes and for different curing conditions. Figure 4, shows a comparison of data from field and laboratory cured specimens taken over a 3 week period during the slip-form construction of a grain silo (5).

Table 1 illustrates the way in which the test data serve to monitor the strength development during curing and also shows the variability that can be experienced between individual tests on the same structure. These data were from tests performed on concrete from slip-formed shafts forming part of an offshore structure (Statfjord C).

PRACTICAL APPLICATIONS AND CASE HISTORIES

Developments in modern concrete technology are placing greater demands on the importance of strength control. Concrete required for marine exposure, use in chemical environments and under tough mechanical stress must be subject to close quality control. The growing use of new materials such as special cements, admixtures and curing control agents requires that their influence on the concrete in the structure be better known. In this regard, the break-off test has an important role to play and is particularly valuable in the following situations.

General In-situ Quality Control.

Traditional testing methods do not detect possible defects caused from faulty transportation, delivery, placing, workmanship or curing of concrete. The break-off test is especially useful to determine that concrete in place meets the required specifications.

Production Control.

In-situ tests are required during the production of concrete for the following reasons:

- To determine the time for safe form-removal during winter or when curing conditions are uncertain.
- To control the effects of curing aids such as plastic foil or chemical additives.
- To control the use of steam curing where there is a potential for variation in temperature throughout a curing chamber, along a pre-stressing bed or from floor to cover.
- To assist in the optimization of energy use when admixtures are employed to lower the curing temperature of concrete.

In all of these circumstances, the break-off test has proven to be a suitable method for in-situ monitoring of concrete production.

Control of Pre-stressing and Post-stressing of Concrete.

Both for reasons of economy, and to ensure that the product meets design criteria it is important to monitor actual concrete strength development when producing pre-stressed or post-stressed concrete. Such monitoring permits optimization of production cycles and of release-timing for the control of camber in pre-stressing plants and on cantilever bridge construction.

Examination of Existing Structures.

When structures have been subjected to environmental attack or when construction of extensions is planned, determination of the strength of the existing structure is necessary. Core drilling is time-consuming, costly and often difficult, in these circumstances the break-off test using a drill to form the core can be a simple, economical and practical means to determine concrete strength at the site where the investigator can immediately take further samples if the results suggest this to be necessary.

CASE HISTORIES

The break-off tester is used world wide for a variety of applications. The following case histories serve to illustrate some of the possible applications of this method to the practical field-testing of concrete.

Conventional Construction.

Because contractors are under pressure to "get there on time", progress plans and the concrete curing times are very important. For these reasons conventional construction is an area in great need of in-situ testing. The following three case histories illustrate the contribution of break-off testing in such applications.

CASE 1. In February 1982, a Norwegian contractor started the concrete work for the new "Bank of Norway" building in Oslo. On this site, the break-off tester was used to control the time for safe form-work removal and the curing control of concrete. Depending on the temperature and other curing conditions, compressive strength of this concrete varied from 14 to 23 N/mm^2 after 2-3 days. After 28 days of curing, the compressive strength was approximately 55 N/mm^2 (6).

CASE 2. The break-off tester is regularly used for curing control at early ages. A major Norwegian contractor has used the technique during the construction of 344 apartments outside Oslo. Rapid hardening cement and heated aggregates were used to make concrete on a 24 hour cycle. The strength was controled with the break-off tester after 16-18 hours curing and the results were used as the main basis for the decisions to remove the form-work. Concrete was made during both summer and winter under a great variety of curing conditions. The very rapid progress schedule used for the project made in-situ strength determination most important (7). Data from these tests are presented in Figure 5.

CASE 3. The break-off tester was used in Britain by a contractor on two sites during 1983:

- A Y.M.C.A development at Errol Street in London.

- A site in Reading.

In both cases plastic sleeves were placed in ground floor slabs (Figure 6), lift-shaft walls and first floor beams and slabs. After 7 and 28 days the sleeves were removed and the in-situ concrete strength was determined (8).

Slip-forming Operations

CASE 4. The company Norwegian Contractors have been responsible for building all of the offshore platforms that have been placed in the Norwegian sector of the North Sea oil-fields. Great demands are placed on these structures and stringent control of concrete quality is required. The break-off tester has been used in these structures to determine in-situ strength. During the shaft slip-forming for the "Statfjord c-Condeep", some 57 plastic sleeves for break-off testing were placed in the fresh concrete. As is shown in Figure 7 the sleeves were taped to a 5 cm thick polystyrene plate and tied between the reinforcement with steel wire (9).

In-situ testing of old concrete structures.

Two examples illustrate the use of the break-off test to examine the quality of ′old′ concrete.

CASE 5. A major civil engineering consultant in southern Norway has been using the break-off tester to examine concrete in some unusual situations. In one application, concrete exposed to high temperature (300-400°C) was drilled and the in-situ strength determined. Another application concerned the use of the equipment to test under-water concrete in bridge foundations and abutments.

CASE 6. Some of the concrete ships that were built during both World Wars are still in use as landing platforms along the Norwegian coast. To some extent they have been exposed to a sub-arctic environment for more than 50 years and are of interest with regard to the durability projections for off-shore oil and gas production structures presently being built in the North Sea. In 1978 F. Selmer A/S initiated a project to examine these old concrete ships. The break-off tester was used in addition to laboratory tests, and was considered useful in giving a more complete view of the condition of concrete subjected to this kind of exposure (10).

SOME FUTURE APPLICATIONS FOR THE BREAK-OFF TEST

Concrete Testing in Developing Countries.

Climatic conditions and the lack of qualified labour in some developing countries often causes variation in test results between actual placed concrete and the 'potential strength' based on mix proportioning. Also, concrete is being used increasingly at remote construction sites where distances to well-equipped laboratories are considerable. In both cases the advantages of using in-situ methods such as the break-off test are obvious. It is both cost- and time-saving and results in reduced risk of organisational errors. The site engineer is also able to more readily check any doubts that might arise during the construction.

Applications in Pre-cast and Pre-stressed Concrete Production.

Most pre-cast and pre-stressed concrete plants release their beds, remove components, clear the forms, reinforce and re-cast in 24 hours. To establish that the strength is appropriate, the concrete must be tested in the morning before the strands are released. These tests, performed according to traditional methods are time consuming and require that technicians get to the plant from 1 to 2 hours before the other workers in order that the tests are completed in time for work to start. The use of break-off testing routines make it possible to reduce the testing time to as little as 10 minutes in some cases (11).

ECONOMIC CONSIDERATIONS

Testing concrete in commercial laboratories by approved methods is expensive. Technicians must travel to the site and take concrete from the batch/truck/mixer and make cubes or cylinders that are tested at a later time in the laboratory. Most standards specify that testing should be after 7 or 28 days of curing, consequently substantial storage space is required. In Norway, normally a series of 4 cubes is cast at the site, tested in the laboratory and a report is prepared. The typical cost for this work is NOK 1320 (approx. $180.00(US)). If similar tests are performed by the site engineer with the break-off tester using 2 x 5 plastic forms, the total cost (including the time of the engineer) will be approximately $45.00(US). Costs for traditional testing at large construction sites will usually be less but the break-off test will still be less expensive.

A survey was made (12) in Norway in 1983 and showed the following cost ratios between break-off testing and conventional concrete laboratory tests:

	B-O Test:Laboratory
Cost at a small building site.	1:4
Cost at a pre-cast plant.	1:4.5
Time consumed at a small building site.	1:8
Time consumed at a pre-cast plant.	1:4.5
Equipment costs.	1:2 to 4
Weight of equipment.	1:20

CONCLUDING REMARKS

The original "Break-off Tester" has been in use for more than 6 years, and the more recently improved version of the equipment has been in service for the past 2 years.

The authors see a trend towards greater acceptance of the break-off test method in the field as the need for in-situ testing increases in the future.

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Table I

Data From Break-off Tests of Slip-formed Concrete

Curing Time (hrs)	Elevation (m)	Distance to test site (m)	B-O test Strength (MPa)
12	141.7	- 2.0	16.5
12	141.7	- 2.0	13.5
12	141.7	- 2.0	9.5
14.5	141.89	- 2.19	11.5
14.5	141.89	- 2.19	11.5
14.5	141.89	- 2.19	17.0
16	142.20	- 2.50	20.3
16	142.20	- 2.50	19.5
16	142.20	- 2.50	16.3
18	142.50	- 2.80	19.5
18	142.50	- 2.80	25.4
18	142.50	- 2.80	20.1
20	142.72	- 3.02	25.2
20	142.72	- 3.02	24.7
20	142.72	- 3.02	24.2
24	143.23	- 3.53	24.7
24	143.23	- 3.53	24.0
24	143.23	- 3.53	29.0

* Note: Initial concrete temperature 28^{o}C.
(from reference (5))

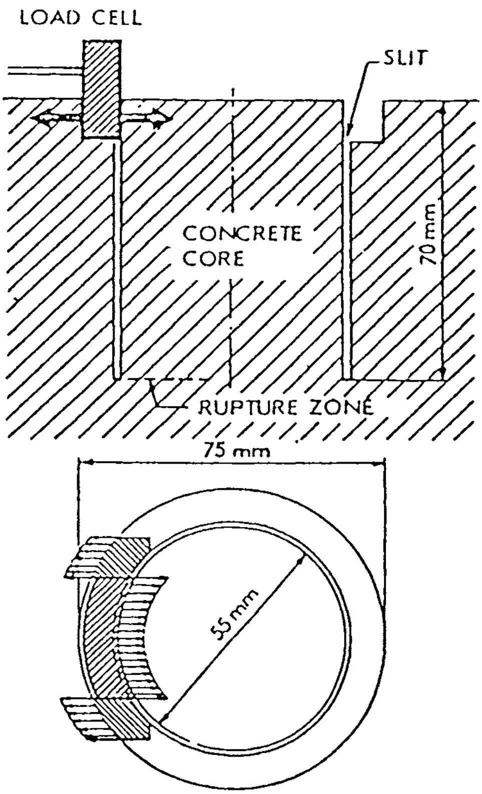

Fig. 1--Principle of operation of the break-off test

Fig. 2--Break-off tester drill in operation

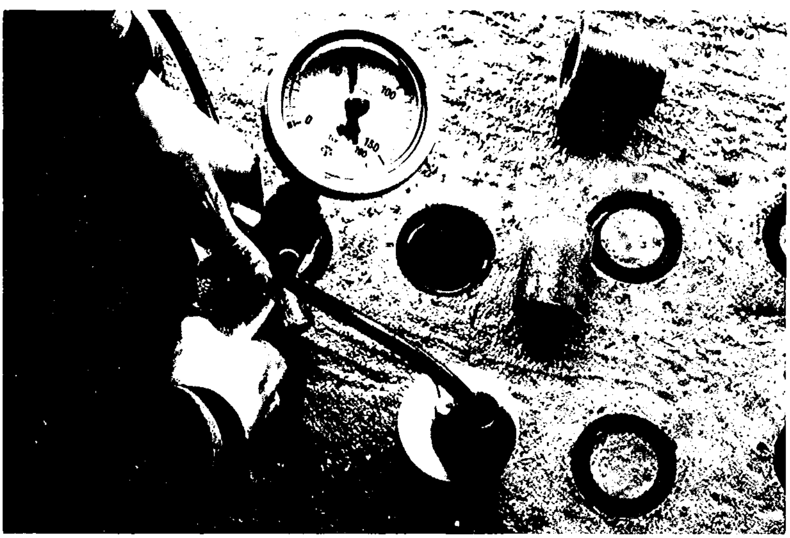

Fig. 3--Break-off tester in operation and one of the small cores obtained from testing.