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Assessment of Existing Structures for their Rehabilitation

Evaluation de structures existantes en vue de leur assainissement

Beurteilung von Bauwerken und deren Instandsetzung

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SUMMARY

In situ non-destructive testing has become increasingly popular as a tool for assessment and re-evaluation, particularly in concrete structures. The main techniques of in-situ non-destructive testing are briefly analysed and their most common applications are listed. Their use is then illustrated with the analysis of two case studies.

RÉSUMÉ

Les essais non destructifs in situ son devenus de plus en plus populaires comme moyen d'analyse et d'évaluation spécialement dans les structures en béton. Les principales techniques de ce type d'essai sont analysées brièvement et décrites ci-après. Deux cas illustrent son application.

ZUSAMMENFASSUNG

Vorwiegend bei Stahlbetonbauwerken haben sich die in situ nicht zerstörenden Testmethoden als Mittel der Analyse und Beurteilung gut bewährt. Die wichtigsten Testverfahren dieser Art und deren häufigste Verwendung werden kurz beschrieben. Ihre Anwendung wird in zwei Beispielen aus der Praxis dargestellt.

1. INTRODUCTION

The increasing costs of building sites, the necessity of preserving the existing urban architectural image and natural or man-caused disasters are among the many factors contributing to the necessity of re-evaluating existing structures in order to widen its service life. There are many uncertainties connected with these studies: the nature of the ageing processes of the construction materials, its quality control in time, the way natural disasters affect the global behaviour of a structure, etc.. The analytical study of these problems is still under way and even the most up-dated state-of-the-art on this subject can not guarantee a reliable re-evaluation of existing structures relying only in mathematical models.

In this context, in-situ non-destructive testing (n. d. t.) is still one of the most effective tool for assessment and re-evaluation particularly in concrete structures. In this paper, the main techniques of in-situ n. d. t. are briefly analysed. Their use is then illustrated with the analysis of two case studies. One in which a fire of small proportions broke up inside a tunnel causing some severe localized damage. The second in which the in-service loads were to be increased in an existing structure for functional reasons.

2. THE NEED OF IN-SITU TESTING

Among other circumstances, in-situ testing is the best solution in the following cases [1]:

- If a structure shows signs of premature deterioration after some time in service - in particular, after having been subject to uncommon actions (earthquake, fire, explosion), the structure needs some analysing to make sure its reliability is still sufficient to fulfill the requirements of the codes. Structures in service for a long time may show signs of surface deterioration due to chemical attack, freeze-thaw cycles, alkali-silica reaction or other factors which may shed some doubts concerning its behaviour.
- When it is necessary to re-evaluate an existing structure - Very frequently, existing structures are asked to cope with in-service loads unforeseen in the original calculations. In-situ testing is the most effective way of knowing whether the structure is able to meet the new requirements without undergoing important changes and, if not, is a touchstone for a proper strengthening plan.

3. IN-SITU NON-DESTRUCTIVE TESTING

Very sophisticated new techniques of in-situ testing keep coming up but most of them are still very much laboratory bound. The most conclusive techniques for in-situ evaluation have been around for a while and have had a good deal of self-testing. They can be divided in two main groups: construction materials tests and structural tests.

The first group includes all the in situ tests in which the main result is some characteristic of the construction materials, usually a mechanical resistance. Among them, the most important are the ultrasonic pulse velocity test, the sclerometer test, the core test and the galvanic cell test.

The structural tests are the ones which study the structure as a whole regardless of the materials. The most well known are the full scale load tests and the dynamic tests.

Apart from the tests referred to, there is a high variety of others which will be listed in Table 1.

TEST	METHOD USED	MAIN RESULTS
Ultrasonic pulse velocity (concrete)	Determination of ultrasonic pulse propagation velocity	- Young modulus - Strength - Crack existance
X and Gama Rays (concrete and steel)	Radiographs	- Dimension and position of reinforcement - Cavities in concrete
Electrical methods (concrete)	Determination of overall capacitance or electrical resistivity	- Moisture content - Thickness of pavements
Dynamometer (steel)	Determination of magnetic permeability	- Reinforcement tension
Thermic methods (concrete)	Determination of maturity	- Strength
Galvanic cell (steel)	Measurement of an electrical potential	- Corrosion areas in reinforcement
Magnetometer (steel)	Measurement of a magnetic field	- Position of reinforcement
Acoustic methods (concrete)	Determination of the intensity of an acoustic emission	- Estimation of ultimate load - Crack existance
Sclerometer (concrete)	Determination of the surface hardness (rebound number)	- Strength
Penetration (concrete)	Determination of the resistance to the penetration of a probe	- Strength
Pull-out (concrete)	Determination of the pull-out resistance	- Strength
Cores (concrete)	Determination of the compression resistance	- Strength
Load Test (structure)	Determination of tensions and deflections	- Ultimate load - Behaviour under service conditions
Dynamic Test (structure)	Determination of the structure's response to dynamic excitation	- Dynamic characteristics

Table 1 [1] In-situ tests

4. RE-EVALUATION AND REPAIR OF A TUNNEL DAMAGED BY A FIRE

The tunnel inside which a fire broke consists of a reinforced concrete arch with a radius of 3 meters and a length of about 100 meters open at both ends. An accident next to one of the ends ignited the wooden formwork. Due to a chimney effect along the tunnel, the fire quickly propagated to all the wooden structure. The consequent high temperatures gave rise to significant deterioration of the gallery next to the formwork. The damage decreased in importance along the length of the tunnel.

Basically, four areas of different deterioration levels were defined:
Area A - no visible signs of deterioration.
Area B - the concrete cover had spalled in patches.
Area C - some of the reinforcement was visible but it was still adherent.
Area D - very high degree of concrete degradation, loose and twisted reinforcement (Fig. 1).

The visual inspection was complemented by an analysis of the materials strength.

Sclerometric tests were made along the total length of the gallery. They showed that superficial concrete in Area D (next to where the fire broke) had a lower residual resistance. To quantify more precisely the heat effect in depth, some cores were taken out and tested in compression (Fig. 2). The results varied between σ_{ck} = 30,6 MPa and σ_{ck} = 22,8 MPa in Area D for concrete not directly exposed to the fire. As all these values were superior to the one used in the initial design (σ_{ck} = 22,1MPa), it was considered that the existing concrete presented no safety problems for the structure.

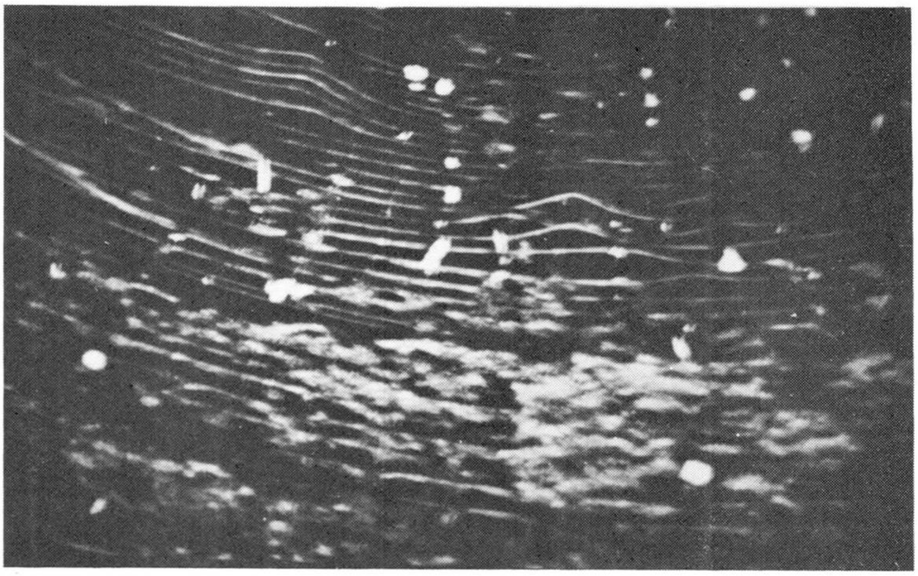

Fig. 1 [2] Damage in the cross-section of the tunnel (Area D)

Some steel cores from the various areas were also taken out and tested. Only the reinforcement in Area D showed some decrease in its mechanical characteristics ($f_{s0,2k}$ = 350 MPa < 400 MPa). As its residual extensions were substantial, the reinforcement was replaced. Adhesion tests were also performed before repair took place.

Taking into account these results, the following repair procedure was adopted:

Area A - the soot was removed.

Area B - the vault surface was pick-axed and subsquentely shotcreted in order to obtain the original cover.

Area C - the same as in Area B except that the concrete under visible reinforcement was also removed by pick-axing.

Area D - the reinforcement was replaced, about 3 cm of the surface concrete were removed and the cover was replaced by shotcreting. To efficiently verify the bond between old and new concrete, some cores were taken out and tested to quantify the bond strength of the joint. The ultimate shear stress was about 2,3 MPa, similar to that of 0,00the concrete used in the tunnel construction.

5. EXTENSION AND STRENGTHENING OF A BUILDING

The building occupies an area of 38.7 by 30.0 meters and its construction history is as follows:

- about 40 years ago, the ground floor and an intermediate floor consisting of a reinforced concrete slab resting on a beam grid were built up. The roof topwas a light steel structure.
- in 1961, a first extension of the building was concluded. It consisted of the replacement of the roof top by a pre-stressed small beams slab resting on reinforced concrete beams and of the building of a terrace with the same structural characteristics. These new pavements rested on columns on top of the initially built.

In neither case, was the structure conceived to withstand seismic actions and in both projects there was a remarkable deficiency in detailing namely concerning the reinforcement.

A second extension of the building was now needed in order to build a new floor. The in-service loads were also to be increased in all floors from the initial 3.0 KN/m^2 to up to 5.0 to 8.0 KN/m^2 . The seismic action according to the existing codes had to be considered in the new calculations.

The absence of proper reinforcement detailing for its characterization gave rise to the development of a scheme of structural inspection consisting of:

- groove making in concrete beams to determine the number and size of the reinforcement.
- non-destructive in-situ testing using X Rays to detect and identify the reinforcement in some slabs (Fig. 2). It proved to be efficient in the analysis of slabs up to 30 cm deep with the equipment used and the safety conditions imposed [3]. The radiographies showed the reinforcement layout and size.

According to the results obtained, it was not possible to guarantee analytically the safety factors in the dimensioning of the slabs with the new in-service loads. It was then decided to resort to a full scale load test of the slab with the least favourable conditions. The load consisted of water contained by a small wall specially built for the effect (Fig. 2).

The results showed a good behaviour of the slab with almost no visible cracking for the future in-service loads with a factor γ_f = 1,25. One of the main reasons for this was the good quality of the mortar layers used on top of the slabs that functioned monolitically with the concrete. There was then no need to strengthen the slab.

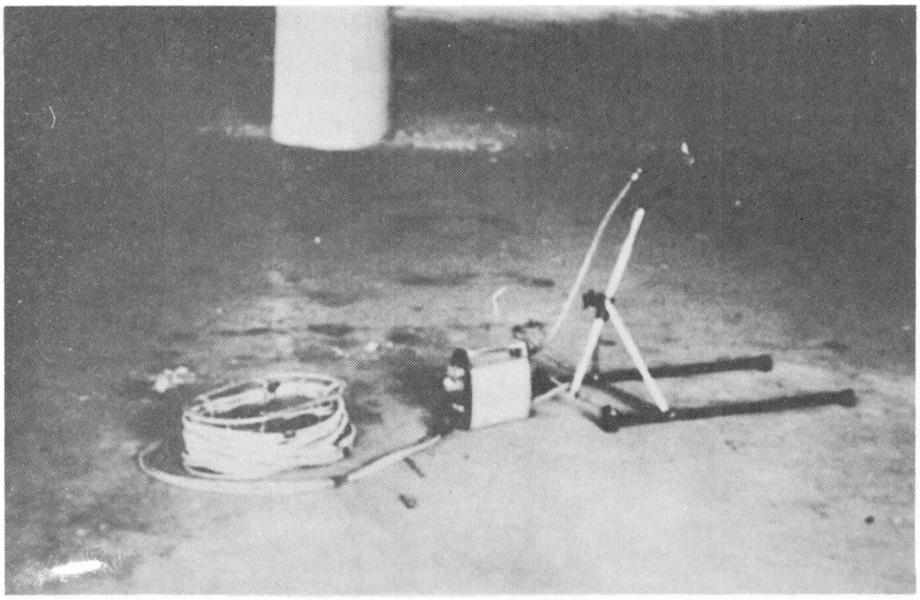

Fig. 2 X Ray equipment and full scale load test of slab

The remaining structure as a whole was strengthened to withstand a seismic action with a return period of a 1000 years according to the code. New shear walls and columns connected with the existing beams were built. Some of the beams were strengthened with new stirrups next to its bearings to guarantee an increased shear strength and improved ductility.

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