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Autor: Parrott, Leslie

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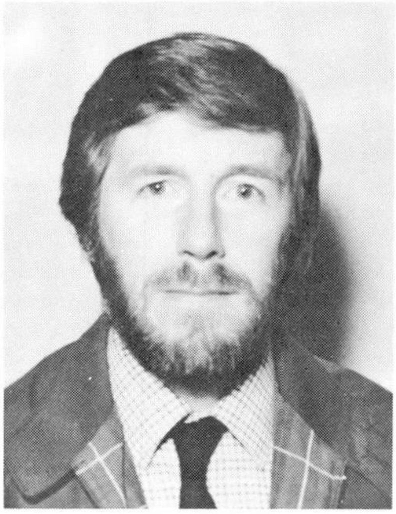
A 12 Year Case Study of a Reinforced Concrete Building

Une étude de cas d'une durée de 12 ans concernant un bâtiment en béton armé

Eine 12 Jahre umfassende Fallstudie eines Stahlbetongebäudes

Leslie PARROTT
Research Engineer
British Cement Assoc.
Slough, UK



Leslie Parrott received his Bachelor and Doctor degrees in civil engineering from London University. His research on various aspects of concrete performance, including internal moisture, deformation properties, carbonation, durability and high strength, has resulted in about 80 published papers.

SUMMARY

Shrinkage and stress-induced strains in a two-storey office building were measured using vibrating wire gauges embedded in the roof and intermediate floor. The floor dried more quickly than the roof. This contributed to tensile stresses in the floor, differential movements and associated cracking of glazed panels and internal block wall. The bituminous membrane on the flat roof deteriorated after 7 years and water leaked through the carbonated concrete roof slab. This case study shows that service behaviour is greatly affected by concrete moisture conditions.

RÉSUMÉ

Le retrait et les déformations dues aux contraintes dans un bâtiment à deux étages ont été mesurés à l'aide de jauges à fils vibrants noyées dans le toit et le plancher intermédiaire. Le plancher a séché plus rapidement que le toit. Cela a entrainé des efforts de traction dans le plancher, des déplacements différentiels et une fissuration du vitrage et du mur interne en parpaing. La membrane bitumineuse du toit plat a été détériorée après 7 ans et l'eau s'est infiltrée à travers les dalles de toiture en béton carbonaté. Cette étude de cas montre que l'entretien ets largement affecté par les conditions d'humidité du béton.

ZUSAMMENFASSUNG

Mit Hilfe vibrierender, im Dach und in der Gebäudedecke eingebetteter Messstreifen wurden Schwinden und durch Beanspruchung verursachte Verformung in einem zweistöckigen Bürogebäude gemessen. Die Decke trocknete schneller als das Dach. Dies trug zu Zugspannungen in der Decke, Differentialbewegungen und damit verbundenem Platzen von Glasfassadenplatten und innerer Blockwand bei. Die bituminöse Schicht auf dem Flachdach war nach 7 Jahren schadhaft und Wasser drang durch die karbonisierte Betondachplatte. Diese Fallstudie zeigt, dass die Haltbarkeit in starkem Masse von den Feuchtigkeitsbedingungen des Betons beeinflusst wird.

1. INTRODUCTION

Investigations of in-situ movements in concrete structures were initiated by the British Cement Association in the mid-1970's as part of a programme on the prediction of concrete deformation properties. The reported investigation of a two-storey office building has been continued because it is providing valuable information relating to long-term moisture conditions, carbonation and durability in reinforced concrete.

2. DESCRIPTION OF BUILDING

A diagram of the two-storey office building is shown in Figure 1. There are twelve bays each 5.4m long with a stairway at the ninth bay providing some longitudinal restraint. The 4.4m wide offices are accessed by 1.3m wide corridors on the ground and first floors. The longer portion of the building between the stairway and an old stone tower can move longitudinally by virtue of a movement joint at the interface of the tower and office corridors. At this interface and for one bay the width of the structure is reduced to that of the corridor and the walls are fully glazed. The continuous floor and roof slabs were cast in-situ on precast concrete cross beams that were supported by a frame of precast columns and longitudinal beams.

The in-situ and precast concretes were made with lightweight coarse aggregate and a natural sand. 100mm cube strengths at 7, 28 and 182 days were 35.9, 42.4 and 55.0 MPa respectively. The mix constituents per cubic metre were 170kg free water, 350kg Portland cement, 730kg zone 2 sea dredged sand and 600 kg of lightweight aggregate plus about 100kg of absorbed water.

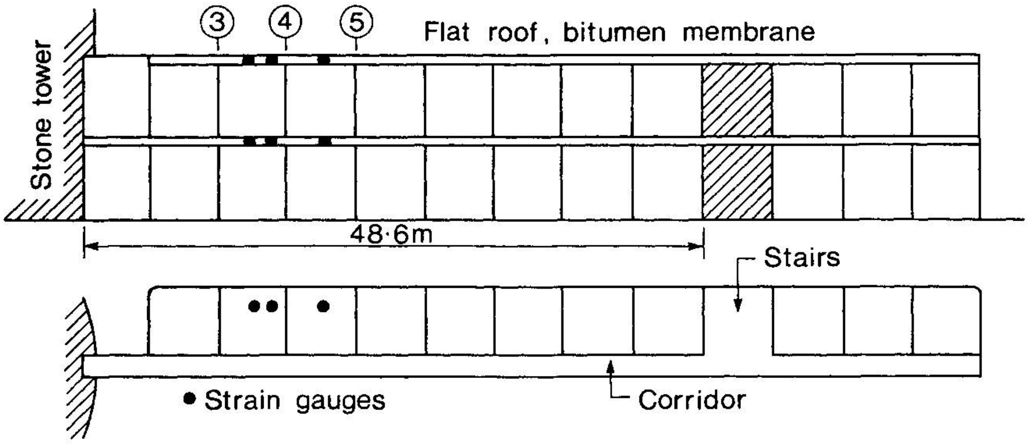


Fig. 1 Elevation and plan of two-storey office structure

3. MEASUREMENT METHODS

The 165mm deep floor and roof slabs in bays 3-4 and 4-5 were instrumented at mid-span with embedded vibrating wire strain gauges set at three depths above the neutral axis. Bays 3-4 of the floor and roof were also instrumented near the neutral axis at quarter-span (i.e. where stresses were expected to be small). The strain gauges were installed horizontally in orthogonal pairs with the longitudinal gauge parallel to the length of the building. This arrangement of gauges permits separate calculation of shrinkage and stress-induced strains [1].

A small correction was made (2.5 microstrain/^{o}C) to allow for the difference in thermal expansion of the concrete and the steel wire in the strain gauge and was based upon in-situ temperature measurements. The shrinkage and stress-induced strains (Esh and Est) were calculated from the longitudinal and transverse strains (El and Et) using the relations Est = (El - Et)/1.18 and Esh = El - Est. The factor 1.18 derives from the assumption that Poisson's Ratio is 0.18 for short and long-term loading [1]. Contraction and extension are regarded as positive and negative strains, respectively.

Prisms measuring 100 x 100 x 290mm were cast from the in-situ concrete for various site and laboratory tests.

4. RESULTS AND DISCUSSION

4.1 Concrete prisms and measured strains

Six prisms were stored beneath the roof for long-term measurements of shrinkage and weight loss. The shrinkage results in Figure 2 suggest that approximate moisture equilibrium was reached after about 3 years and this was consistent with the weight loss measurements: thereafter the small increase in shrinkage was accompanied by a slight gain of weight that was indicative of carbonation [2].

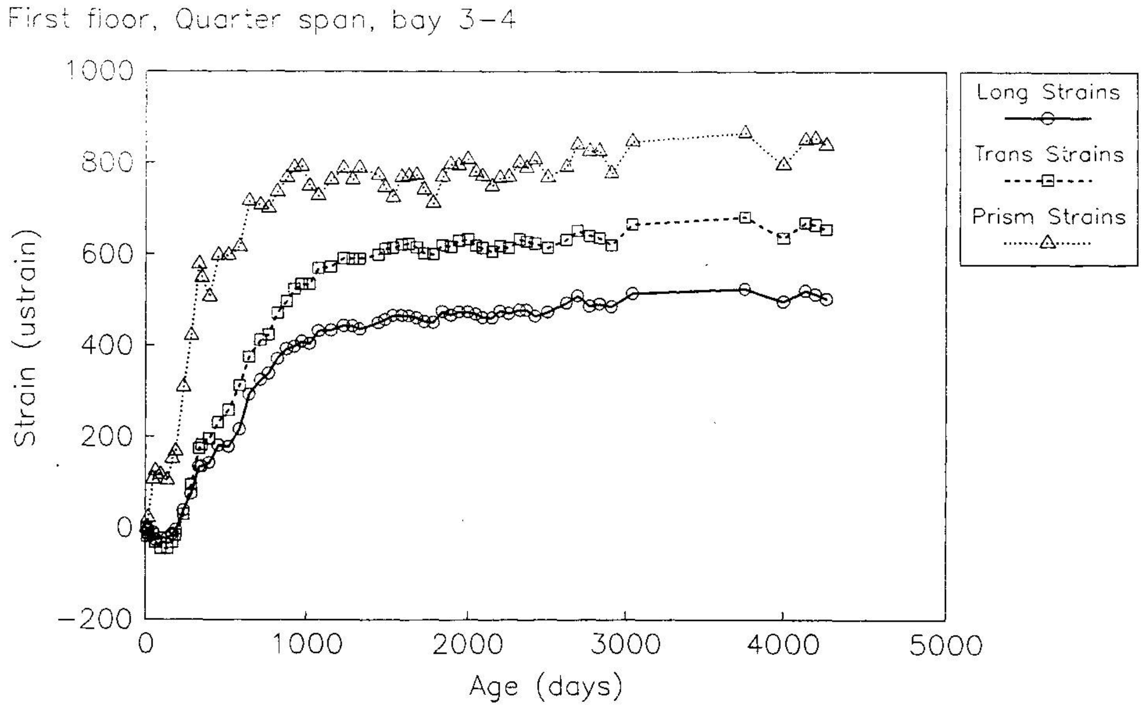


Fig. 2 Strains in prisms; longitudinal and transverse strains at quarter span, bay 3-4 in floor.

Figure 2 shows that initially longitudinal strains are slightly larger than transverse strains at quarter-span in the floor. This is consistent with the expected, small flexural stresses. After about 250 days the transverse strains exceed the longitudinal strains and this indicates that axial tensile stresses develop at later ages. Similar patterns of transverse and longitudinal strain were observed at mid-span in bays 3-4 and 4-5 of the floor.

4.2 Shrinkage and stress-induced strains

The calculated strains for bay 4-5 of the floor slab are shown in Figure 3. There were only small differences in shrinkage between the three instrumented sections. The shrinkage of the floor slab developed more slowly than the prism shrinkage (Fig 2) and appears to be stabilizing at a smaller, final strain. These effects are attributable to differences in drying path length [3]. The stress-induced strains exhibit the expected pattern for flexural loading but they are superposed by the development of tensile strains.

The calculated strains for the roof slab in Figure 3 show that shrinkage developed more slowly than that in the floor. Although the roof slab was similar in thickness to the floor slab drying was retarded by the waterproof layer on its upper surface. The stress-induced strains exhibit the expected pattern for flexural loading but they are superposed by the slow development of small tensile strains. The tensile strains in the roof develop more slowly than those in the floor.

The strain patterns in Figure 3 suggest that longitudinal drying shrinkages of the floor and, to a lesser extent, the roof are restrained and thus cause the development of longitudinal tensile stresses. This is consistent with the similarity in shape and period of occurrence of the shrinkage versus age and stress-induced strain versus age curves. Restraint may have derived from the columns, longitudinal beams, internal block walls and the foundation.

4.3 Movement and cracking

Qualitative corroboration of the more rapid drying shrinkage of the floor compared with the roof and foundation was provided by visible movement between the building and the adjacent stone tower. Furthermore, several glazed panels in the corridor next to the tower cracked at an age of about 5 years due to the shearing action of the floor movement. Cracking of internal block walls provided additional evidence of the relative movement of the floor. The replacement glazing has not shown any sign of distress. A mastic-filled joint was provided between the block wall and the structural components of the building: this has prevented any further cracking of the walls.

4.4 Roof leakage and carbonation

Solar radiation caused local expansion and deterioration of the bituminous roof membrane after 7 years, in spite of a surface layer of white, reflective stone chippings. Consequently the central drainage gully did not function properly and after rainfall it acted as a reservoir for water leaking through the roof slab. Continued deterioration of the roof membrane and leakage of water over a period of five years caused damage to internal finishes and raised the question of reinforcement corrosion. Measurements on a prism stored beneath the roof suggested that the roof slab may be carbonated to a

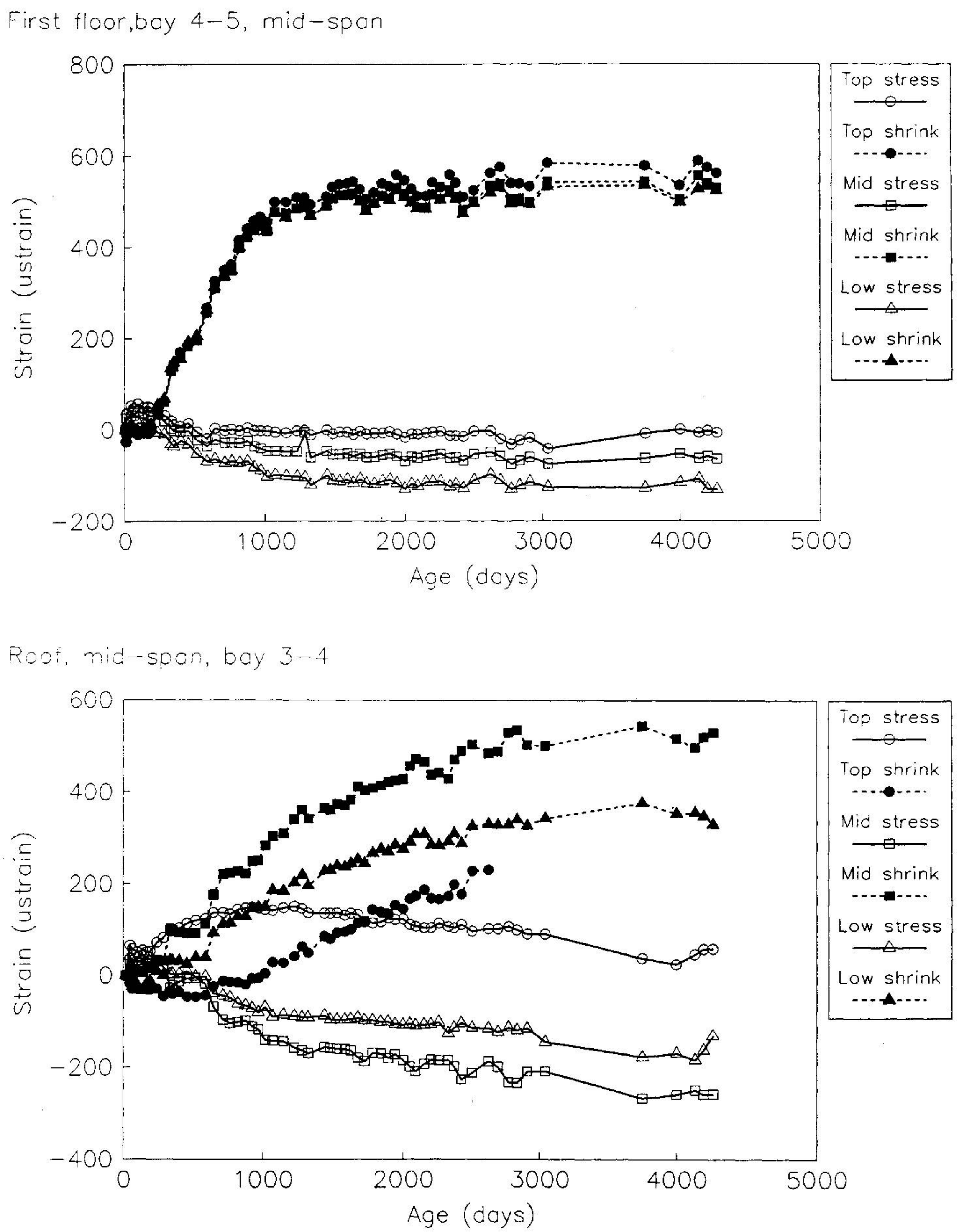


Fig. 3 Shrinkage and stress-induced strains in floor(upper) and roof(lower).

depth of 12mm (standard deviation = 3mm). The specified depth of cover was 20mm and with the standard deviation typically in the range 5 to 15mm [4] there is a risk that some of the reinforcement may be corroding[2]. Further inspection for signs of corrosion is planned.

5. CONCLUSIONS

The reported long-term case study of a two-storey office building showed that moisture conditions can have an important effect upon the service performance of a concrete structure; they can affect building movements, component stresses and durability.

Restraint of drying shrinkage caused the development of an axial, tensile component of stress in the floor and, to a lesser extent, in the roof.

It seems advisable to use carbonation-resistant concrete for flat roof construction to minimise the risk of reinforcement corrosion in the event of leakage.

ACKNOWLEDGEMENT

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