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Observation of the Personality of Concrete

Observation de la personnalité du béton

Beobachtung der Betoneigenschaften

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Introduction

Design starts from experience - experience both of desirable objectives to be achieved and of the means of fulfilling the particular functions embodied in those objectives. And experience comes initially from interpreted observation although, of course, one can gain much experience by learning from others who have made deductions from their own observations. Thus, the interpretation of new observations in the light of existing experience is an essential part of improved design.

Observation relevant to structural design may consist of a simple visual inspection of an existing structure or of the measurement of some behaviour of it; or it may be the result of some experimental or theoretical simulation of an aspect of structural behaviour based on certain assumptions. All these forms of observation have made notable contributions to the skill with which we can now design structures. But there appears to have been undue emphasis on the experimental and theoretical approach, and comparatively little prominence has been given to the less sophisticated observation of concrete structures in their normal existence. It is from such observation that one obtains an overall assessment of the factors which appear to be the most significant in particular situations and checks the validity of the assumptions made in the other type of work.

However, there is a growing awareness that there are some aspects of the personality of concrete which we do not know or, if we do, we have found it expedient to ignore them. This symposium is evidence of the need that has become apparent for a better appreciation of creep, shrinkage and temperature changes which hitherto have tended to be relegated to a secondary place in the design of many structures. The old attitude may well have been justified in the past because observation of our structures had led us to the conclusion that these characteristics were of little significance. Perhaps this was generally true as long as we were concerned primarily with the danger of collapse of structures. But there has been ample experience to suggest that structures have not always been fulfilling other desirable functions and that these "failures" could often be attributed to a lack of appreciation of the effects of creep, shrinkage and temperature changes on the part of the designer.

A failure is here intended to imply any aspect of design which has not been adequately fulfilled, either as deliberately intended or hopefully wished for. The commonest failure, related to the movements occurring in concrete, is visible cracking which occurs when there is an excessive restraint on the attempted movement. Cracking may not be objectionable - indeed the art of the designer is to produce as many cracks in concrete as possible so that they are all so small that they will not be noticed and hence be accepted as part of the "personality" of concrete! (They will be micro-cracks within concrete itself.) The larger cracks are undesirable because they may indicate impending danger, may lead to deterioration or may simply be unsightly; and it is these that would constitute a failure.

Failures of this type have generally occurred because designers have thought of the material as being dead and inanimate whereas, in reality, it exhibits many characteristics similar to those of living people. No one is perfect, but at some stage action has to be taken to deal with personalities which exhibit gross departures from social conformity; acceptable standards are continually changing.

A design concept

It is possible to apply the limit state philosophy to the design of structures against failures which are due to the effects of changes in the temperature and humidity of the environment and to creep - i.e. one can think in terms of selecting a probability that failure will not occur in the structure during its useful life. Indeed, with the present lack of experience, this is perhaps the only sensible way to think about these problems even though there may be little numerical data for computation, and hence the probability will be far from precise. But engineering intuition can be applied provided it is based on a reasonable concept of the personality of concrete.

To apply this intuition, a designer has first to assess the environment in which the concrete structure will exist. Not only will he be concerned with the extreme levels of temperature and humidity of the surrounding atmosphere but also he should consider such factors as their rate of change with time and differences which occur in different parts of the structure at the same time. Other factors which may also have to be taken into account include the effect of heat generated internally in concrete in its youth by the hydration of the cement, the effect of heat transmitted to or from the structure by radiation, fluctuations in the level of temperature or humidity which induce "fatigue" effects, characteristics of the atmosphere that may affect rates of evaporation of water from the concrete, or condensation into it, and the effect of atmospheric carbon dioxide on the shrinkage of the concrete.

As examples, a structure for the storage of liquified gases may have to withstand very low temperatures, and one adjacent to a furnace very high temperatures; any building may be subject to an "accidental overload" in respect of high temperatures if a serious fire occurs in it. Horizontal slabs of concrete exposed to a clear sky, such as roads or roofs, may be subject to a rapid change of temperature from daytime to night - perhaps up to 60°C in about 12 hours. Large differences of temperature may exist between the inside and the outside of cladding to a building and between members in sunlight and shade. Fluctuations in atmospheric conditions appear to cause appreciably greater creep than would be expected at constant values corresponding to the average. Potential rates of evaporation of water from concrete are affected by the temperature and relative humidity of the air, the difference in temperature between concrete and air and the wind speed, and the actual rate is limited by the rate at which water can migrate through the concrete. Carbonation, and its associated shrinkage, is insignificant if the concrete is saturated or absolutely dry, but occurs most if the cement paste is in equilibrium with air at an R.H. of about 55 - 60%.

Having assessed the environment to the best of his ability, the designer should then consider the partial factor of safety appropriate to the uncertainty of his decisions.

Next, the designer has to assess how the structure, which he has conceived as a general idea, will respond to the various levels and changes of environment; he will need to consider the structure as a whole, one member relative to another, different parts of any one member and even the different constituents of the concrete within a member. Changes of either temperature or relative humidity may produce significant changes in dimension; but a short-term rise in temperature of the atmosphere, which would tend to cause an expansion of concrete, will generally be accompanied by a decrease in relative humidity of the air, which would encourage drying shrinkage of the concrete with some compensating effect. Apart from temperature changes arising from the hydration of the cement and from some very specialised curing techniques (such as electrical curing and infra-red radiation), temperature changes occur first at the outside of the concrete, and the material towards the middle responds accordingly; temperature gradients, and hence expansion gradients, are therefore set up across the section. Frequent changes in moisture distribution occur because of changes in the atmosphere at the surface of the concrete, but changes of temperature and load can also result in some internal redistribution of moisture.

Aggregate and cement paste react differently to these changes so that significant stresses may be set up by the restraint between the bonded materials; this effect will vary with the maturity and type of concrete, because the response of the hardened cement paste will vary with its age and with the properties and proportions of the constituent materials. Reinforcement to which the paste is bonded will also influence the development of internal stress: reinforcement is usually provided to control the development of cracks in a plane perpendicular to its axis, but it is also a potential cause of cracks in planes perpendicular to its surface.

There is considerable interaction between these effects because creep may operate beneficially to relieve internal stress which is not induced too quickly; or creep may have the adverse effect, of which most designers are aware, of increasing deflection. Creep is usually measured on concrete under compression, but creep under tension may well play a significant part in the limitation of cracking or the increasing deflection of members in flexure. In making the assessment of the effects of these environmental changes, it may be important to distinguish between true creep - long term displacement occurring only as a result of the continued application of given loads - and differential shrinkage which will produce similar characteristics even though no external load, as normally considered, is applied. The reinforcement near the bottom of a simply supported beam or slab restrains the long-term shrinkage of the concrete in the lower part while the concrete near the top, where there is no reinforcement, is free to shrink; the member would deflect as though by creep under load as it dries out even if it were not subject to either dead or imposed loads. The relative amounts of true creep and differential shrinkage will vary with several factors, such as the proportion of reinforcement and the shape of the section of the member, so there would appear to be little point in trying to express long-term deflection as a proportion of the instantaneous deflection, except for clearly defined limitations.

The designer how has to use his intuition to arrive at a suitable partial factor of safety to cover the uncertainty with which he can forecast what will happen, in each of the various cases to be considered, if the structure is subjected to the assumed environmental conditions.

And he must then consider whether the partial factors for materials and workmanship, as used when designing for other purposes, can also be applied to these problems. Included in this assessment, however unconsciously, may be the point of view that, if deficiencies appear, the designer can blame them on the materials or workmanship being faulty, as though it were not part of his responsibility to ensure that they conformed to his assumptions. Failures must be the moral responsibility of the designer because he is engaged to supervise the schemes he has prepared and ensure that materials and workmanship are as he intended.

The prospect of formalising limit state design procedures using precise numerical data for dealing with the types of failure envisaged is formidable, although serious attempts have been made to do so for structures which may be critically dependent upon freedom from failure, such as nuclear reactor pressure vessels. However, for the majority of structures, poor techniques to account for temperature, shrinkage and creep have not resulted in danger to life - only inconvenience - and until recently there has been little incentive to devote more effort to the improvement of design methods. Hence, the simple observation that the deficiencies of design, though undesirable, can generally be tolerated by society has led to the common belief that design for other criteria, or acceptance of simple codified design rules, is sufficient to meet our needs.

Concrete is a likable character, without expensive tastes, and we can suffer its foibles!

Visual observation of plain concrete

A great deal can be inferred about the character of structural concrete from the simple visual observation in service of the behaviour of concrete which is neither reinforced nor prestressed. The stress patterns observed may guide the designer to the better positioning of the steel when detailing his structural work.

Cracking occasionally occurs in horizontal slabs of concrete, when only a few hours old, as a result of a form of shrinkage. This "plastic cracking" may be the result of excessive extraction of water from the cement paste by evaporation, by absorption into aggregates which were dry before mixing or by hydration of the cement; these effects are aggravated if the mix is too harsh to flow (or creep) thus relieving the stresses. If designers are keen to reduce the creep of hardened concrete in structures they may also have to be much more careful to reduce the causes of concentrations of stress otherwise there will be more cracking.

Precast kerbs, made by vibrating concrete in moulds, have suffered from a lack of durability in several situations in the U.K. Careful observation of many examples over several years has shown that failure was not progressive, but that individual kerbs would disintegrate within a year after being sound for many years. The interpretation of this and other experience is that concrete has a skin which provides a measure of protection provided it is not broken; the kerbs only disintegrated after their surface had been damaged in some way: usually this was by spalling at the end of a kerb as a result of thermal expansion of a line of kerbs. Structural concrete exposed to severe environmental conditions may be expected to deteriorate similarly if it is not designed to remain free from skin defects.

The curling and cracking of screeds and granolithic floor toppings has provided ample evidence of the response of concrete to differential shrinkage across the section, especially when the moisture gradient is aggravated by a thermal gradient resulting from underfloor heating. The danger of cracking in these toppings and in pavement slabs is much reduced if the length of the bay is not more than about $1\frac{1}{2}$ times the width, if the size is limited and if there are no re-entrant corners or openings with sharp corners to generate concentrations of stress from which cracks are easily initiated. This experience is directly applicable to the design of structural concrete in suggesting how reinforcement can be placed to compensate for differential shrinkage or to relieve concentrations of stress.

Unreinforced concrete masonry walls have been observed to crack for a variety of reasons. Again, the size and shape of the panel and the presence of openings are important factors. But walls have often cracked because of the loads imposed on them by the deflection of adjacent structural frameworks, steel or concrete, due to load or thermal and other movements. It has not normally been necessary to calculate the strength required of a wall to withstand these loads: instead, the wall is built with a gap between the frame and the end or top, sufficient to accommodate any movement that can be anticipated, and then filled with a suitable resilient material. There are many other situations in which it is unnecessary to know precisely the amount of creep, shrinkage or temperature movement likely to occur; but it is necessary to allow for some movement, and a rough guess, based on a little experience, is adequate.

Crazing of concrete is often accentuated by carbonation of the cement paste near the surface, especially if this concrete is of poor quality or the surface is porous because of poor curing. Carbonation is accompanied by shrinkage, and the differential shrinkage, due to both carbonation and drying, between the concrete at the surface and away from it induces sufficient tension at the surface to cause cracking. This phenomenon is a caricature of what can happen in structural concrete. Similarly, concretes made with aggregate particles which exhibit changes in volume on wetting and drying provide examples of deterioration which illustrate the stresses set up between cement paste and aggregate particles when they are subjected to differential changes of volume resulting from loading, shrinkage or temperature changes. Experience of structural concrete made with shrinking aggregate(1) has also made engineers much more aware of the need to design all concrete structures to take account of creep and moisture and temperature changes.

The simple cartoon can often emphasise our features or character better than would a more sophisticated or formal study.

<u>Visual observation of structural concrete</u>

The effects of temperature movements and shrinkage often become manifest in the behaviour of structural concrete at very early ages. Although the concrete itself is very pliable for an hour or two, it soon begins to have a mind of its own - but it may crack before it is strong enough to withstand the strain of tension. For example, prestressed I-beams have been damaged by the differential thermal expansion of steel moulds and concrete, during or after steam curing, if the moulds have not been released soon enough. In the early stages of steam curing the outside of the concrete is hotter than the inside, but after a few hours the heat generated internally by the hydration of the cement causes the internal temperature to exceed the surface temperature, and this, in turn, will be above the atmospheric temperature. Even in a saturated atmosphere some evaporation of water will then occur, but the rate will tend to increase during the cooling period as the difference in temperature between the surface of the concrete and the atmosphere increases.

Not only will this evaporation cause tension to develop at the surface relative to the interior of the concrete but the effect will be greatly aggravated by the differential thermal contraction between the inside and the surface and by the restraint on internal contraction imposed by any reinforcement away from the surface. Many examples of this feature have been noted in reinforced concrete walls, even without the use of steam curing: the temperature differential generated by the heat of hydration of the cement has been sufficient to cause cracking. While attention is generally paid to the temperature rise occurring in large masses of concrete, such as gravity dams and turbine foundation blocks, it is not always realised that walls cast from moderately rich mixes, using cement with a rapid development of strength, may need similar consideration even though the wall thickness is no more than about 200 or 250 mm, particularly if the formwork provides a high degree of thermal insulation. The danger of cracking is greatly increased if, on removing the formwork, cold water is applied to the hot surface in a mistaken attempt to reduce contraction caused by drying shrinkage.

The occurrence of cracking in this type of construction is greatly influenced by the detailing of reinforcement. Quite often the main vertical bars are placed as near the surface as is possible, without encroaching on the cover required to ensure adequate protection of the steel, to obtain the maximum structural effect, and any horizontal distribution steel is placed inside. As a result, the horizontal bars, instead of reinforcing the surface against tension developed across vertical planes, as they should do, restrain the relatively small amount of shrinkage of the interior concrete and increase the shrinkage gradient. Furthermore, the larger diameter bars, nearer the surface, induce still further the tension in the surface concrete across vertical planes through them because it is trying to shrink on to them. The danger of cracking is greatly reduced by placing the horizontal reinforcement, consisting of small diameter bars at close spacing rather than fewer larger bars, outside the vertical reinforcement as shown in Fig. 1; the cover should be adequate for durability but not excessive. The vertical bars on opposite sides should be staggered.

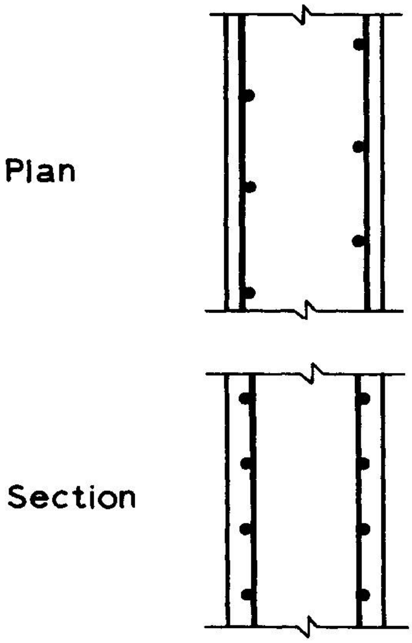

Fig. 1 Reinforced concrete wall

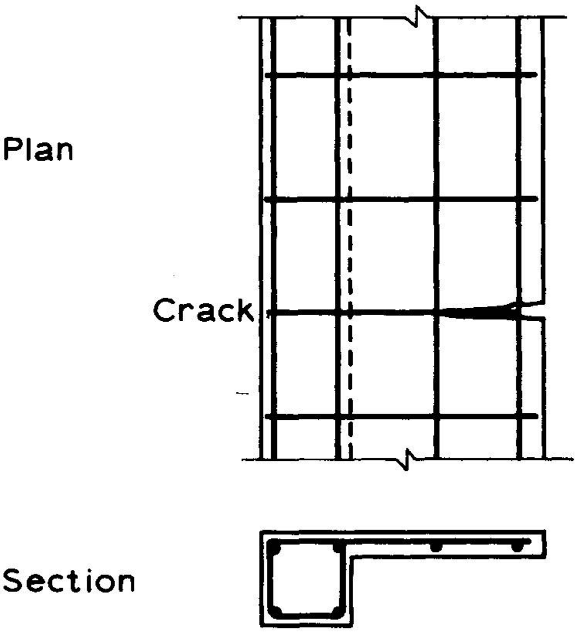

Fig. 2 Reinforced concrete sill

Cracking has also been observed in concrete units which have abrupt changes in cross section. For example, the ledge of a precast concrete window sill had a high surface to volume ratio projecting from a square section with low surface/volume ratio as shown in Fig. 2; the concrete in the ledge was able to shrink more rapidly than that in the other section so cracks developed in from the edge because there was insufficient reinforcement in the ledge parallel to the length of the unit. Such structural sections will also be subject to differential thermal movement, inducing tension in the cooler parts, when the temperature of the environment changes. In another example, an in-situ concrete culvert which consisted of a circular opening through a block of square cross section, cracked along the top of the opening through the thinnest section as shown in Fig. 3; the failure was probably aggravated by curing the outside top surface with a pool of water, while air was allowed to circulate through the opening.

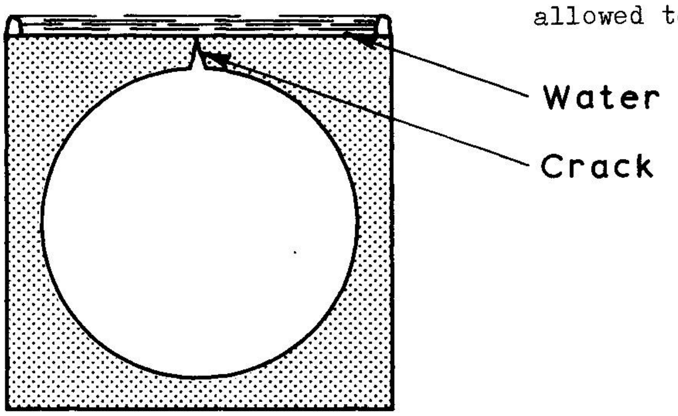

Fig. 3 Reinforced concrete culvert

Long-term differential shrinkage induced by reinforcement has been observed in the curling of a roof slab approximately 6 in x 3 in sufficient to lift the ends off the supporting wall as shown in Fig. 4. There are several examples of precast concrete cladding units being damaged because they were fixed rigidly to a frame and the designer had made inadequate provision for accommodating the stresses set up by restraint preventing the relative movement which would have occurred if the joints had been free. Nibs, on columns, supporting beams have been damaged by spalling at their ends because of the concentrated load resulting from deflection of the beams as shown in Fig. 5.

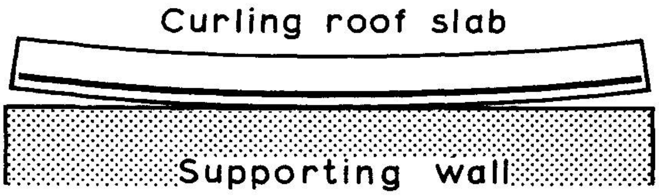

Fig. 4 Curling of roof slab

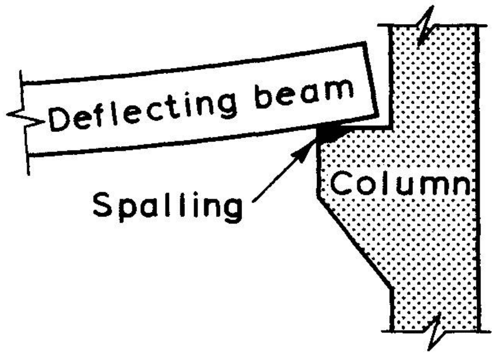

Fig. 5 Spalling of nib

The loads exerted by structural concrete as it deflects under the influence of changes of temperature and humidity can obviously be very great. For example, the diurnal change in temperature of a roof slab to a framed building only about 10 m wide (i.e. two spans of 5 m) can deflect the tops of the outer rows of columns sufficiently to damage infilling panels. Although the resulting stresses set up in these columns may not jeopardise the safety of the structural frame when using our present load factors, continuing progress towards more refined design techniques may demand that, in critical cases, more serious account will have to be taken of the imposed loads arising from changes of temperature, moisture distribution and creep.

The new British draft code of practice for structural concrete(2) makes specific reference to dead load, imposed loads and wind loads, and notes that the partial safety factor for loads is intended to cover, among other things, "inaccuracies in assessment of effects of loading and unforeseen stress redistributions within the structure". Furthermore, it states that the effects of creep, shrinkage and temperature may be ignored when considering the limit state of collapse; but for the limit state of local damage, where the effects are "greater than those known from past experience to be inconsequential, the resulting internal forces and their effects on the structure as a whole should be considered in design".

Recommendations relating to movement in concrete structures, drawn from 42 standard documents produced in 18 countries, have recently been reviewed.(3) The British draft code has introduced new features relating to the control of deflections in reinforced concrete structures; the basis for the proposed empirical relations, which includes observation of the performance of structures, has been reported separately.(4) The draft code states that for the limit state of deflection "the effects of temperature, including temperature gradients within the members, should be considered when they are greater than those effects known from past experience to be inconsequential". The code places a responsibility on all designers to do what many have always done - to observe the behaviour of structures already erected in accordance with their designs, and to improve their techniques for the construction of new work.

Thus, designers should watch the development of their children as they grow so that those born later may benefit from the experience.

Measurement of movements in structures

For some design purposes, visual observation of behaviour is inadequate, and attempts have been made to measure the movements which occur in different parts of a structure under the natural conditions in which it exists. These investigations are beset by many difficulties: the work is expensive in terms of staff and equipment; instrumentation during construction complicates the building process and sensitive equipment may easily be damaged; continued recording of data over a long period of time may interfere with the client's use of the structure; and, probably, most disconcerting, the interpretation of any data obtained is far from easy. A further problem is sometimes the flagging of interest because of the long delay before the results are available for application in future work.

Simple techniques for the measurement of movements in structures have been used, e.g. taut wire reference lines and adjustable staffs, but uncertainty attached to the reproducibility of the results obtained over a period of time has given rise to doubts in the interpretation of the measurements. More sophisticated techniques include the use of demountable strain gauges and even acoustic gauges buried in the concrete at the time of casting. Observation of climatic conditions has not always received the same attention, but temperatures have been measured by thermometers in sockets in the concrete (which can lead to some error) or by casting thermocouples into the concrete at various depths from the surface; this latter technique is particularly desirable with the thicker members so that it is possible to observe the effects of the delay in transference of heat through concrete subjected to fluctuating surface temperatures. A method for estimating stresses in concrete bridges by imposing identical strains on companion test specimens has recently been reported(5); it reduces the uncertainty which arises in the estimation of stresses from measured strains because of doubt about an appropriate value of the modulus of elasticity.

Several investigations have been made to determine the relative movements occurring between different parts of structures and the strains developed in concrete at various times after casting under normal constructional conditions. A record of the testing of several structures by the Building Research Station was given at the Concrete Society symposium on "Design for movement in buildings"[6]; similar studies of road bridges have been made by the Road Research Laboratory[7]; and other individual investigations have been reported, ranging from the apparently simple retaining wall[8] to complicated pressure vessels[9].

The conclusions to be drawn from this type of work are many and varied: perhaps the most interesting one, expressed during the discussion at the symposium, was simply that movement was observed to occur when it was not expected and did not occur when it was expected! If this were to be general experience our theories and assumptions must be in need of considerable revision, or perhaps the number of factors influencing our measurements are so numerous, complicated and inter-related that it is impracticable to derive a procedure which will enable us to forecast precisely what will happen in a particular situation. It would seem that the measurements made on actual structures serve best to high-light those of the many factors that are likely to be of most significance in particular situations.

Several of these investigations have led to the conclusion that temperature variations are more important than shrinkage or creep; as would be expected, changes in temperature assume greater importance the larger the mass and the older the concrete. It seems that in many of these investigations the observed movements have been less than would have been expected from the data provided in British codes of practice. However, the stresses developed in concrete have probably been much higher than might have been expected with the result that local damage has occurred. In one contribution to the discussion of the study of retaining walls[8] it was suggested that, in a large number of instances, stresses induced by heat of hydration will be the largest ever experienced by the structure. On the other hand, measurements on one building[6] have shown that, because of the structural interaction of the beams and the floor slabs, the lower flanges of the beams, although designed to act in tension, were in compression because the shrinkage of the concrete induced compressive stresses greater than the tensile stresses due to small service loads.

In order to avoid some of the practical difficulties associated with the long-term testing of actual structures some development work has been done on full-scale units under normal atmospheric conditions. While these investigations do not necessarily embrace all the factors that may have to be taken into account in design, they can form a useful link between the results of experiments made under controlled laboratory conditions on small specimens, and corresponding measurements on structures.

The Cement and Concrete Association has examined the response of reinforced concrete road slabs[10] and walls to changes of environment from the time of casting; and the long-term deflections of precast prestressed concrete slabs have been measured while they were carrying constant load and stored under cover but subject to the changes of temperature and relative humidity of the outside atmosphere[11]. Work simulating pavement construction early in the day, when the weather is hot with clear skies, has shown that an unprotected top surface becomes very much hotter than the lower surface during daytime; but during the following night the temperature gradient will be reversed causing the slab to warp or even to crack at the top surface. Tests on a simulated in-filling panel with the reinforcement anchored in the end "bays" and cast using concrete at a high temperature of about 50°C suggested that the movements resulting from temperature changes at early ages may have caused a break down of bond between the steel and the concrete over a considerable length away from the joint. The deflection of the freely-supported prestressed slabs has tended to be independent of temperature changes and to be concentrated into short periods at particular times of the year with little increase the remainder of the time.

It seems that for this type of member, having clearly defined characteristics, it will be possible to make reasonably accurate forecasts of long-term deflection, but that the important factors will not necessarily be those studied in laboratory investigations.

At this stage of development it appears that the measurement of movements in structures under service conditions or in development projects is unlikely to lead to a simple theory for estimating the magnitude of movements based on an extension of laboratory work. Its value lies in indicating the scale and direction of movement, absolute or differential, that results from the interaction of the many factors already indicated by visual observation of the behaviour of concrete and hence in suggesting the ways in which precautions should be taken to prevent undesirable consequences. The best use of this information is admirably summarised in another of the papers to the Concrete Society symposium[12]: "The problem of movement in building construction is not so much the determination of the absolute value of any particular movement but more that of achieving a compatibility of movement between parts. Without this, cracking and other disturbances are inevitable and are likely to recur even after repair. In such cases, the accurate assessment of movement serves little purpose."

A person approaching a state of severe distress may benefit from psychoanalysis, but for most of us our personality is expressed by our general reaction to stress and frustration.

Conclusion

The author's experience of looking at examples of poor design may tend to be reflected in a morbid review of the present ability of engineers to design concrete structures to accommodate the effects of creep and changes in temperature and humidity. However, a similar view seems to be shared by a practising designer[12]: "To the engineer, movement of a structure under applied load and changing environment is an important consideration in ensuring that the structure is safe and will satisfactorily fulfil its purpose. In important structures special care will be taken to allow for such movement, but in general building construction the problem is rarely considered in depth and, indeed, it is often overlooked or totally ignored."

If this is a valid assessment, the lack of attention to the problem may well be due to a lack of appreciation of the real character of concrete as a genus and to the particular traits of individual members of the family. If we are to bring out the best in people, we need to know them well. Perhaps there is a close analogy with the design of structural concrete: there is some hope for improvement in the servicability of our concrete structures the more that designers become acquainted with the total personality they try to exploit.

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Summary

Improved standards for the design of structures require that more attention be paid to the effects of changes in the temperature and humidity of the environment and to the creep of the materials. Observations of the performance of concrete in service and measurements of the movements occurring in structures are interpreted to provide an appreciation of the way concrete responds to varying conditions; an analogy is drawn between the behaviour of concrete and human personality.

Résumé

L'amélioration des normes pour l'étude des structures vise à ce que l'on prête plus d'attention au fluage des matériaux ainsi qu'aux effets des variations de température et de degré d'humidité du milieu ambiant. Les observations des performances du béton utilisé et les mesures des mouvements survenant dans les structures sont interprêtées pour fournir une estimation de la façon dont le béton réagit dans des conditions diverses; on esquisse une analogie entre le comportement du béton et la personnalité humaine.

Zusammenfassung

Verbesserte Normen für den Entwurf von Tragwerken verlangen, dass den Wirkungen von Temperatur- und Feuchtigkeitsänderungen der Umgebung sowie dem Kriechen von Baustoffen grössere Beachtung geschenkt wird. Beobachtungen des Verhaltens des Betons im Gebrauch und Messungen der bei Tragwerken auftretenden Bewegungen werden zur Beurteilung der Reaktionsweise des Betons bei wechselnden Verhältnissen ausgewertet. Der Verfasser vergleicht das Verhalten des Betons mit der menschlichen Persönlichkeit.