DATA FOR DISCUSSIONS.

SECTION (2)

REINFORCED CONCRETE AND CRACKS.

Contributed by R. Kneale.

Ordinary M.S. breaking stress = 64,000 lbs./sq. in.

At about half this stress, say 32,000 lbs./sq. in., it stretches or yields. In ordinary practice a factor of two on the yield point is often used, or a working stress of 16,000 lbs./sq. in.

To exclude possibilities of concrete cracking to permit of water penetration it is desirable that the concrete shall not be stressed in tension to such a degree as would crack it—actually to have no stress applied in tension.

Good concrete can be considered as having a working stress in tension of about 60 lbs./sq. in.

Up to the point when the concrete cracks, the concrete and steel act together, the steel, however, taking fifteen times as much stress as the concrete owing to its higher elastic modulus. Thus the relationship is so adjusted in good design that the steel elongates or contracts the same as the concrete surrounding it.

If concrete is under stress for only short periods of time strain is proportional to stress and recovery after the load is removed is almost complete. Under sustained load, however, the strain increases without increase of stress, and this additional amount of strain remaining after the stress is removed.

This residual strain is termed "creep" or "plastic yield," and the amount may be much greater than the elastic strain; for this reason the modulus of elasticity (or ratio of stress to strain) is taken at a much reduced value, and is the method in computations of taking care of creep or plastic yield.

Concrete breaks in tension when it is stressed somewhere below 240 lbs./sq. in. Therefore, with the steel stressed to 16,000 lbs./sq. in. the concrete will definitely have cracked in tension, and is therefore incapable of resisting tensile stress. Hence the steel is designed to carry the whole tension, receiving no assistance from the concrete.

Cracks do exist, even though not seen by the naked eye. They are generally so fine that they cannot be detected, as may be readily calculated as follows:—

The elongation of the steel in 12 inches, if stressed to 16,000 lbs./sq. in., is:—

$$ e = \frac{12 \times 16,000}{30,000,000} = .0064 \text{ inch.} $$

= about \frac{1}{60} of an inch.
Cracks nearer than 12 in. would be proportionately less, and those further apart than 12 in. proportionately greater.

Cracks open and become visible to the naked eye when the steel yields badly at about half its ultimate stress. The relationships on which strength calculations are based are then completely upset, and failure soon occurs. A reinforced concrete structure designed for a factor of safety of four generally stands loading or stressing up to twice its designed load without serious cracks, and fails under anywhere between two and three times the designed loading (or stressing).

Cracks are most likely to occur at construction joints where a good bond between new and old concrete has not been secured by a thorough cleansing and scabbling of the old surface, etc.

Bituminous joints (or others allied) may be used to keep the structure watertight or for total exclusion to penetration of water.

Referring generally to cracks and as applicable to a chimney stack—

When concrete contracts, hair cracks occur if the length of concrete is great or if the ends are restrained.

Reinforcement does not prevent this taking place, but distributes the cracks over the area concerned and makes them so frequent that none of them is of any importance. If, however, cracks appear which are easily visible to the naked eye, it is obvious that the amount of reinforcement is deficient, design faulty, and the structure generally may become a danger.

If a reinforced concrete chimney is properly designed and protected from high temperatures, superficial cracks only should occur, and any cracks within the limits of the elongation of the steel, when stressed within safe limits, could be treated with waterproofing materials; etc.

It can be deduced that conspicuous horizontal cracks would give suspicion of faulty design and a warning of the reinforcement being over stressed with relative instability; while vertical cracks would introduce the question of expansion of the concrete circumferentially due to unduly high temperatures. Vertically this expansion is free, but circumferentially it is locked up and can force open cracks, such cracks not revealing an undue weakness of stability relative to height, but rather a detriment owing to penetration of water. Where these vertical cracks appear it would be a precaution to fill them with some suitable plastic waterproofing material.

The linear contraction of concrete due to shrinkage when under construction is generally from 0.0003 to 0.0004 of the length, about 0.0001 occurring in the first month. This is
generally considered during the construction period by prevention of quick drying out, and thus such shrinkage is reduced.

The cracking subsequently occurring is due to high temperatures, and is relative to the coefficient of linear expansion of concrete, which is about 0.000006 per deg. F.

Coeff. of exp. for steel = .0000063.

Considering a chimney of diameter 14 feet, circumference say 44 feet, temperature 200° F., and having four vertical cracks.

Eleven lineal feet would represent—

\[ 132 \text{ inches} \times 0.000006 \times 200 = 0.1584 \text{ width of crack.} \]

With faulty design and under excessive stress due to high wind pressure prevailing, failure could be sudden or just about to happen. If stressed almost at the limit of safety, a return to temporary stability could be established when wind subsided, and would remain only during calm weather.

Subsequent inspection by an expert may prove fruitful in warning being given of dangerous over-stress taking place. This condition of a stack would prove dangerous design, etc. Foundation design has not been taken into account for the purposes of the matter under consideration.

It is important to note that the above data and opinion do not include consideration of essential design relative to circumferential stress and stability as a reinforced concrete unit, but only data influencing cracks and height stability, etc.
NOTES ON SECTION (2) REINFORCED CONCRETE AND CRACKS.

Contributed by J. G. M. Gough.

I have read with much interest Mr. Kneale's valuable contribution on the question of reinforced concrete and cracks, and also have just heard Mr. Michaelson's remarks.

Whilst both these gentlemen have told us with much detail how cracks develop, nothing has been said regarding the cure of them. In other words, "If we have to lock the stable door after the horse has bolted," it should be locked to such an extent that no further trouble in this connection should take place. It is therefore proposed to deal briefly with a practical means of restoring to its original strength at least, or in many instances more than the original strength, any concrete structure which has developed faults of the kind pointed out by Messrs. Kneale and Michaelson.

Some years ago, about 1911 I believe, an appliance known as the "Cement Gun" was patented and marketed in U.S.A., and its main purpose was the spraying, by means of compressed air, a mixture of Portland cement and sand with water as the dehydration agent. The word "Gunit" was subsequently coined to describe the sand-cement product, and has been universally used ever since. Briefly the machine and process could be described as follows:

The machine consists of two vessels integral known as the top and bottom chamber. The machine is operated by compressed air, and the materials which have been previously mixed dry, are introduced into the upper chamber, which alternately is under pressure and free from pressure, and thence flow into the lower chamber which, during operation, is always under pressure.

The mixture, by means of a feed wheel driven by an air motor, is introduced into a pocket at the point of outlet where compressed air, about 80 lbs. per sq. inch, carries it dry through a hose to the nozzle. Water is added at the nozzle in the form of a series of fine jets, resulting in hydration coincident with deposit. Incidentally, the mixture can be transported through the material hose up to 500 feet along the level and vertically to a height of 80 to 100 feet.

The theory of deposit simply means that the mixture hydrated at the nozzle is driven by the compressed air with considerable force on to the surface to be treated, the nozzle being held 3 to 4
feet from the work, as near as possible to right angles to it. Providing the surface of the work is clean and previously wetted the first grains of sand will rebound, but in doing so they act as a hose of miniature tampers and drive into the most miniature pores and cracks a volume of cement. Then some of the smaller grains of sand adhere and are also tamped well in by the larger grains of sand and very rapidly the surface builds up, resulting in a densely packed uniform mixture of sand and cement. As an example of the adhesion between Gunite and the surface against which it is applied, being stronger than the material of that surface, a very simple experiment can be carried out. To the clean surface of an ordinary brick Gunite is applied—then, after a few days' curing, an attempt is made to break away the Gunite from the surface of the brick, and a thin veneer of brick adheres to the surface of the Gunite at the point of cleavage.

A test was carried out at the University of California in connection with the design of supporting Gunite collars to be used in underpinning a building. In such test the load was applied on the top of the sample columns and was continued until the concrete was forced through itself. The Gunite bond remained unbroken. This shear value of the concrete was 600 lbs. per sq. in., proving that the adhesion value of the Gunite was greater.

Regarding the deposit of Gunite, this is due to the method of application, the material being transported in a relatively dry state to the nozzle, where water is added at the instant the mixture is propelled against the surface to be covered. The density and imperviousness of Gunite is proved by many tests of reservoirs and similar structures lined either over old surfaces or directly against earth.

In connection with strength, the method of placing Gunite results in the production of a material having a proven ultimate compressive strength averaging more than 5000 lbs. per sq. in., and modulus of elasticity approximates 4,670,000 lbs. per sq. in.

Time does not permit me to deal further with the properties of Gunite. Therefore, I would like just to conclude my remarks by quoting some typical applications made here and abroad.

One of the most notable repair jobs carried out was the part relining of main outfall sewer at Werribee, of Melbourne and Metropolitan Board of Works. Some years ago this main outfall sewer had gradually deteriorated to the extent that on the sides between high water and low water mark, the cement rendering and concrete underneath it had become spongy, so much so that a nail could be pushed in from the surface to a depth of about 3 inches (in some very bad instances up to 5 inches) and
considerable spalling had taken place, thus exposing a fresh surface of comparatively good concrete to further deterioration. I might add that some hundreds of lineal yards of the sewer walls were affected. The method of repair adopted was as follows:

The Cement Gun with its mixing equipment, being of the semi-portable type, was stationed on the surface convenient to a manhole. The material was transported down the manhole and to the point of contact by means of the material hose, water also being transported by the same means through rubber hose. Staging for the operator was carried on floating pontoons controlled by mooring ropes. Quick drying cement was used with clean sand in proportions of three (3) parts sand to one (1) part cement, and, after chipping the defective concrete from the surface to be treated, and the wetting of same with clean water, the Gunite was applied when the sewer contents had reached the extreme low water mark. The initial set took place very quickly, and, although rising water covered the Gunite within two to three hours after shooting, there were no deterrent effects, and gradually the whole condemned portion of the sewer was treated by this means and, it is understood, has never given any trouble since.

Another application was the Moorabool Viaduct, at Geelong, which developed very serious cracks. These were chipped out and Gunite applied, in bad instances with reinforcement, but in most cases without reinforcement. Perfect bond took place, and permanent repairs were effected. This can be understood when it is realised that the cracks occurred probably through excessive stressing of the structure due to settlement of the foundations, and when the Gunite was applied permanent settlement had taken place.

One other application should, perhaps, be mentioned, although actually speaking it is not by way of repair or rendering of a concrete structure. It is an application by lining with Gunite Steel Bunkers at Newport "B" Power House, recently put into service by the State Electricity Commission of Victoria. The Bunkers were lined with an average of 3 in. Gunite reinforced by mesh, and the most interesting features to note are, firstly, the Cement Gun was on ground level, and the mixture transported to about 80 ft. above ground level, which means that the total length of hose employed was in the region of 150-175 feet; secondly, the extreme density of the Gunite when placed, it being almost impossible to chip by means of a cold-chisel.

Dealing with applications abroad, I can only state that it is possible to mention only one or two examples, as literally thou-
sands of jobs have been carried out in America, England, and many parts of Europe. In England, perhaps the most notable example was the part lining of the Mersey Tunnel at Liverpool. Altogether an area approximating 23 acres was Gunited, thicknesses varying from 1/4 in. to 4 in., and the main reason for using Gunite in this instance was water proofing.

In America some of the largest tunnels in connection with the Great Boulder Dam, and many notable hydraulic electric schemes use Gunite very extensively. Then again, in steel works it is common practice to recondition concrete chimneys, and it is interesting to note that steel chimneys which have reached the stage where normally they would have been scrapped, are successfully reconditioned by coating inside and outside with Gunite reinforced heavily at the base, with gradual taper towards the top and progressively lighter reinforcement.

In view of Mr. Kneale’s remark concerning effective heat on concrete structures, it is interesting to note that practically all the chimneys treated by Gunite, in the manner mentioned, have the base coated on the inside by Gunite, consisting of a mixture of ground fire-brick, fire clay, and other refractory materials.

I am afraid that to a large extent I have departed from the subject matter, i.e., reinforced concrete and cracks. If so, I trust it will be understood that the main reason for mentioning Gunite was to point out that, if there is a valuable concrete structure which for any reason has developed defects such as cracks, Gunite if properly applied will in most instances permanently cure such trouble, and with the experiences gained abroad, there are numerous examples where Gunite, with reinforcement, is preferred as a casing to beams, columns, linings, etc., to reinforced concrete placed by the ordinary methods.
Mr. E. J. Michaelson contributed the following notes:—

Cracking of concrete can be the outcome of:

(a) Faulty design.

(b) Improper selection of aggregate and placing of concrete in position.

(c) Curing conditions.

In the design of a concrete structure four main points are to be considered.

1. The compressive strength of the concrete.
2. The tensile strength of the steel.
3. The bond between the concrete and steel.
4. The shearing strength of concrete.

The proportions and the position of the steel in the concrete to give maximum efficiency have been deduced by mathematical analysis, which has shown that the relative positions of the centre of area of the steel and concrete about the neutral axis are dependent on their relative compressive and tensile strengths.

Testing has shown that concrete is capable of sustaining fairly high stresses in compression, but that its tensile strength is negligible. Now, as steel is capable of resisting tensile stresses, if the two materials could be combined to form such a member that the compressive stress only could be taken by the concrete, while the tensile stress was taken by the steel, a satisfactory material of construction could be obtained.

Research has proved that several physical properties must be considered in the design of a concrete structural member that will resist failure. The failure of a concrete member is first perceived by cracks forming on the outside when the failure is due to tensile weakness, and flaking on the surface when the failure is caused by insufficient compressive strength.

The bond stress has a critical value depending on the surface area of the steel reinforcing unit. If this value is exceeded, the steel will be pulled from the concrete, and therefore fails to take the tensile stress, and the concrete cracks and ultimately fails.

Concrete has also a definite shearing strength, and in a simple uniformly loaded beam the shear is a maximum at the points of supports. The resistance to shear in the concrete member may be augmented by the addition of steel rods known as stirrups.
Having designed the structure with the use of well-known formula, the results are scheduled, and this information passed on to the field. It should include proportion of stone, sand, cement and water, which are to comprise the concrete mixture. Poor sand is the most common cause of defective concrete. The presence of organic matter such as vegetable loam is the most objectionable, for it prevents the concrete from hardening satisfactorily. It is essential to carry out a grading test of the sand, inspection not being sufficient.

Excessively fine sand is most unsuitable for concrete and must be rejected. The average size of the grains must be coarse.

Concrete is often seriously injured by the excessive use of water. The strength is reduced and the wearing qualities lessened. Cracking and crazing of the surface are increased. The concrete aggregates, together with the water when confined, are solids. The concrete takes its initial set quickly, and the water, by capillary action and evaporation, gradually leaves the concrete, and the position in the concrete previously occupied by the water is left as voids.

To obtain good and lasting results strict supervision must be paid to the mixing of concrete. Suitable measuring equipment should be used to ensure exact proportions, and the time set and adhered to for the mixing process in the mixing machine.

The careful computation and schedule drawings prepared by the designing engineer are often nullified by unskilful placing of the reinforcements or displacement of reinforcements during pouring of concrete. Cracking of concrete members is frequently caused by lack of rodding the concrete during placing, thus leaving air voids in the body of member. Air pockets are frequently found at the end of beams where solid concrete is most necessary for shear for this reason. The concrete is poured into the beams, and where the negative rods and stirrups intercept portions of the concrete the air pockets must be relieved by tamping.

During the transportation of the concrete from the mixer to the placing position, the large aggregates tend to sink to the bottom of the conveyor, and the water and fine aggregates rise to the top. Concrete should always be placed on a board and remixed prior to being placed in forms.

It is the human element responsible for the concrete to this stage, and unless care is taken in all operations a defective structure and cracking will result.
In the curing of the concrete further defects may occur if the structure is not protected from excessive high and low temperatures.

Having outlined the possibilities of defective concrete, and consequent development of cracks due to design and defective workmanship, I will leave it to others to develop the subject further with such details as they consider they are able to contribute.
MR. WM. DOBSON contributed the following notes on the

EFFECTS OF INDUSTRIAL GASES, ETC., ON CONCRETE

Industrial gases of different kinds have to be considered where concrete work is used, as in some cases their effect can reduce the strength to about 40 to 50 per cent.

Blisters or deep cracks where deterioration may start should be investigated if any doubt exists.

Gases known to be detrimental are:
1. Sulphuretted Hydrogen.
2. Bisulphide of Carbon.
3. Oxysulphide of Carbon.
4. Carbonyl Chloride
5. Phosgene.
6. Anhydrous Sulphurous and Sulphuric Acid.

1. Sulphuretted Hydrogen has been the subject of laboratory research, and it has been shown that even a very small percentage in moist air will destroy 10% to 15% of the initial resistance of a concrete structure in less than a year.

2. Anhydrous Sulphurous and Sulphuric Acid on absolutely anhydrous surfaces will be resisted by concrete for a very long time, but on a moist surface brown or dark spots appear, which are difficult to detect when in a dirty atmosphere. These dark spots are considered to be an indication of the decomposition of the calcium ferrate contained in the cement. These spots are often found to be the centres of radial fissures due to the formation of iron salts, and it is not long before they spread rapidly, with destructive effects on the structure.

Other gases, Bisulphide and Oxysulphide of Carbon, Carbonyl Chloride, Phosgene, etc., seem to cling to the dust on structures, which in turn absorb moisture, the resulting corrosive liquid rapidly attacking the concrete.

Bituminous or other suitable paints would appear to be a good method of protecting the concrete under such conditions.

When concrete is immersed in water containing rotting vegetation, Humic Acid is formed, which, especially in tropical districts, rapidly destroys much of the strength of a structure by penetrating through minute cracks to the reinforcing steel.
Lactic Acid, formed through bacterial activity in the gummy constituents of decaying roots and stalks, is also troublesome. At first the surface of concrete becomes glossy, then follows a crystallising effect, leading to cracking off of small splinters. Unless checked by some protective film this action will eventually destroy the structure.

Dry Carbon Dioxide does not act on concrete, but solutions of even weak concentrations are harmful, especially when high temperatures prevail. Surface treatment with silicate of soda or potash is recommended, but must be used with caution, as a crystallising action can cause cracking and eventual further trouble.

Calcium, aluminium, iron, magnesium and sodium sulphites are important causes of slow damage.

When concrete is left to harden before being immersed in water containing calcium sulphate in solution, the action is less harmful than if cast in situ.

Although sodium chloride (common salt) is not harmful to it, concrete frequently washed by brackish water is frequently attacked.

J. Basso, Chief Chemist, Asland Cement Co., Spain: Research has proved that sugar has a favourable effect on white lime mortar, but has an injurious effect on Portland cement mortar.
Author/s: 
Kneale, R. F.

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