would allow the employment of lighter structural members. It might in fact be quite possible, as suggested by Mr. Wing, to install ventilators that would ensure a definite reduction of internal pressure, and that would be a distinct novelty in design. Such ventilators would require to have ample ventage-area and to be of such a shape and location that the internal pressure could be reduced to some predictable value. It was suggested that ventilators almost flush with the roof-covering would be the most suitable type for transmitting the external manometric pressure to the interior. The values given in *Fig. 17* would seem to indicate that the centre of the roof would be a suitable location for the ventilators. The suction on that line was more or less independent of the direction of the wind. The effect of the ventilators should, of course, be checked by experiment.

Paper No. 5202.

"The Deterioration of Concrete in Contact with Sewage." †

By SOLOMON SIMON MORRIS, B.Sc., Assoc. M. Inst. C.E.

Correspondence.

Mr. E. J. Guild observed that there might be a possibility of condensation from the sewage forming on the upper parts of pipes or tanks. Such a condensate would have all the corrosive effects of distilled water, as well as those due to any dissolved gases evolved by decomposition of the sewage. What would be the *p*H-value of such a condensate, what *p*H-value would be most favourable to the growth of *Spirrilum desulphuricans*, and what would be the most inhibiting value ?

Mr. R. H. H. Stanger was particularly impressed by the implication that the corrosion of the concrete was due to the formation of sulphuric acid formed by the bacterial reduction of sulphates. In his experience, soluble mineral sulphates had a much greater corrosive effect on concrete than had sulphuric acid. If that were agreed, any method of prevention of corrosion which aimed at the prevention of the bacterial reduction was of little use. It was the action of the sulphates themselves which had to be prevented.

† Journal Inst. C.E., vol. 13 (1939–40), p. 337 (February 1940).

*** **Mr. L. C. Woolley** observed that the extract from the Author's communication to The Institution represented to a large extent a Report on a preliminary investigation into the deterioration of concrete in the sewerage system of Cape Town carried out by him in March 1931, and *should not be taken as representing the true position to-day.* From the observations then made certain conclusions were drawn and remedial measures were proposed and carried out. Mr. Woolley wished to show which conclusions had been proved to be correct by subsequent investigation, by commenting on the results of the remedial measures carried out. He would also mention that reference to the subject had been made elsewhere.*

The very brief description of the physical characteristics given in the Paper might be misleading to those who had not become acquainted with the phenomenon. Corrosion, so far as investigations in Cape Town indicated, was confined to materials or structures in which cement or lime was an ingredient. Glazed sewer-pipes and bricks were unaffected. Concrete and the jointing of bricks or tile-work were the materials affected, and corrosion took place only when the materials were not continuously submerged.

Above high-water mark the initial visible stage of corrosion of both the concrete and the jointing was the formation of a white powdery deposit similar to efflorescence. In the case of concrete that deposit thickened, became continuous, and formed bulky flakes which had no strength or coherence and consequently broke away under their own weight, leaving a soft spongy surface exposed. Corrosion continued at an increased rate owing to the porosity of the exposed surface, and further flakes and pieces of coarse aggregate became detached from the structure. In the case of

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*** Mr. Woolley's contribution has been abstracted from a lengthy communication describing additional tests and giving details of the chemical analysis of the mechanism of corrosion; the MS. and illustrations may be seen in the Institution Library.—SEC. INST. C.E.

* R. F. Goudey, " Odor Control by Chlorination." California Sewage Works Journal, vol. 1 (1928), (December 1928). [Reprinted in *Western Construction News*, San Francisco, vol. 4 (1929), p. 16 (10 Jan. 1929).]

It was stated that the 26-mile trunk outfall sewer was badly affected in Orange County, Cal., and that chlorination eliminated corrosion.

A. F. Pistor, " Effects of Sewage Gases on Concrete." *Sewage Works Journal*, vol. 7 (1935), p. 697 (July 1935).

At Canton, Ohio, in 1934, an interceptor constructed from vitrified tile failed owing to corrosion of the joints.

E. G. Studley, " Experimental Ventilation of the North Outfall Sewer of the City of Los Angeles." *Sewage Works Journal*, vol. 11 (1939), p. 264 (March 1939).

It was described how the disintegration of the 55-mile north outfall sewer of the City of Los Angeles was held in check by forced ventilation.

F. M. Lea, " Deterioration of Concrete owing to Chemical Attack." Journal Inst. San. E., vol. 39–40 (1935–36), p. 185.

L. H. Enslow, " Sewage Chlorination for the Protection of Masonry Sewers against Deterioration." *Water Works and Sewerage*, vol. 67 (1920), p. 306 (September 1920).

the jointing, the second stage was a swelling of the joints owing to the increased volume of the corrosion-product. That expansion might take place outwards, in which case the swelling reached a certain point and then broke away under its own weight, leaving a soft putty-like substance in the joint. If the expansion took place sideways as well as outwards, sufficient pressure was set up to shear off the faces of the adjoining bricks.

Corrosion also took place between the levels of high water and low water, and under certain conditions corrosion at, and immediately below, high-water mark was extremely severe. During low water, corrosion occurred between high-water level and low-water level, and when the sewage flow increased the corrosion product was washed away. That corrosion and subsequent erosion resulted in removal of the matrix, causing exposure and final breaking away of the aggregate. The characteristic appearance showed the coarse aggregate protruding from a soft dirty-white putty-like substance. The actual corrosion was, on that area, often masked by a deposit of slime and organic matter from the sewage. When a short peak flow occurred at long intervals the portion of the structure immediately below high-water level showed the greatest corrosion, but when the peak flows were of longer duration, and occurred more frequently, maximum corrosion occurred above high-water level.

After the submission of the Report covered by the Paper, further examinations confirmed in general the previous observations, but in addition revealed that :—

(*a*) pneumatic ejectors were a distinct improvement on pumping-stations, as no signs of attack were found at any of the discharge-pipes where they entered the interceptor, although some had been in operation for more than 30 years ;

(*b*) in every case where reduction in velocity of flow occurred in the reticulation, causing deposition of silt, corrosion occurred ;

(*c*) corrosion did not occur where ventilation was sufficient to maintain unsubmerged portions of the structure free from condensed water.

In order to study the corrosive action further, a series of tests was inaugurated, the first of which consisted of the test-patches in the pump-well of the main pumping-station mentioned in the Paper. The other tests were :—

(i) Approximately 16 square yards of surface on the east wall of the pump-well were chiselled out and 3 : 1 Ciment Fondu plaster ½ inch thick was added. That was coated with "Inertol." A strip approximately 12 inches wide and 8 feet long was chiselled out and plastered on the west wall opposite the above-mentioned area, and left unpainted.

(ii) A series of test-slabs were hung in the interceptor, for observation both before and after chlorination.

(iii) Three specially-made pipes were placed in the 24-inch gravity main taking tank-effluent at the Athlone disposal-works. They were fitted with multiflex joints so that each pipe could be removed and inspected periodically. Pipe No. 1 was made of type-4 mix * Ciment Fondu. Pipe No. 2

* 2 parts of stone, 2 parts of sand, and 1 part of cement.

was a Portland-cement pipe with a Ciment Fondu lining. Pipe No. 3 was a Portland-cement pipe which, after curing, was treated with paraffin wax.

Physical examination of the 12-inch square test-patches at the main pumping-station, after that described by the Author, confirmed the superiority of Ciment Fondu over some other cements, but indicated that wire-brushing the surface before application did not give a satisfactory bond. Sand-blasting had been used extensively in America for ensuring a good bond between old and new concrete, and it was suggested that that method might be used with advantage in removing corroded concrete before re-plastering.

Physical examination of the two "Inertol"-coated Ciment Fondu strips indicated that less corrosion had taken place on the painted surface than on the unpainted surface. Microscopic examinations of samples of the deposits on the uncoated Ciment Fondu showed them to be mainly

TABLE II.

	Pipe No. 1.	Pipe No. 2.	Pipe No. 3.
Material.	Ciment Fondu 2:2:1 mix.	Portland cement, lined with 2:2:1 Ciment Fondu.	Portland cement, impregnated with paraffin wax.
Maximum corrosion after 14½ months' use: inch	$\frac{9}{64}$	$\frac{13}{64}$	$\frac{7}{64}$
Life of pipe, based on first 14½ months' service: years	10·5	7·9	15·2
Maximum corrosion after 2 years' use: inch	$\frac{18}{64}$	$\frac{17}{64}$	$\frac{31}{64}$
Life of pipe, based on corrosion during last 9½ months of test: years	7·5	16·4	3·1
Life of pipe, based on corrosion during entire 2 years of service: years	9·1	10·3	5·8

gypsum, whilst the deposits on the coated Ciment Fondu consisted of sulphur and gypsum. Bacterial threads resembling *Beggiatoa* were observed, as well as numbers of bacilli and vibrios. Chemical analysis, in conjunction with microscopic examinations, showed that a high percentage of free sulphur was found on "Inertol"-coated Ciment Fondu; whereas the deposit on the uncoated Ciment Fondu contained more than 90 per cent. of gypsum. That confirmed the physical observation that less corrosion had taken place on the "Inertol"-coated strip.

Table II gave the extent of maximum corrosion occurring in the three test-pipes, and also the computed life of each pipe, based on the corrosion occurring during the period that the pipes were under observation. From examination of pipes which had failed, and from a study of the aggregate used in the concrete, it was assumed, in computing the life of a pipe, that failure would occur when the thickness of the pipe was reduced to $\frac{1}{4}$ inch.

It was of interest to compare those computations of the life of the pipes with computations based on the corrosion of concrete in the sewers of the Cairo main drainage scheme. In Mr. A. O. W. D. Pinson's Paper*, the average depth of corrosion in $7\frac{1}{2}$ years, scaled from the diagrams, was $3\frac{3}{4}$ inches, giving an average corrosion-depth of $\frac{1}{2}$ inch per year. The "Hume" pipes at the Athlone disposal-works were $1\frac{1}{2}$ inch thick, and thus would have a life of only 3 years under those conditions.

The results indicated a slight advantage in favour of Ciment Fondu as a material, but taking the measurements as a whole, the Ciment Fondu pipe No. 2 was definitely superior. The corrosion of $\frac{13}{64}$ inch occurred at only one point in the section of No. 2 pipe, and was probably due to a porous patch of cement; the subsequent corrosion occurring in the second year might represent more accurately the resistance of Ciment Fondu. No. 3 pipe stood up very well during the first period, but during the second period the resistance of the paraffin wax broke down and excessive corrosion occurred. That ruled out paraffin wax as a protective coating for concrete against that form of corrosion.

At the time of the second examination the conditions under which the pipe-line operated were altered. The outlet was changed to allow free discharge, and at intervals of 50 feet the pipes were replaced by open channels 7 feet and 2 feet in length. In addition, an 18-inch cast-iron pipe-line was laid to relieve the load on the concrete pipe-line.

Examinations carried out recently had shown that slight corrosion occurred at each open channel following a 2-foot opening. In other words, an opening of 2 feet in a length of 100 feet did not give sufficient ventilation to prevent corrosion. Where there were 7-foot openings in a length of 100 feet the pipes appeared sound.

From consideration of the observations in the light of the mechanism of corrosion, the following represented a summary of the important factors relating to the corrosion of concrete :—

(A).—*Factors causing and aiding corrosion.*

(1) Retention in pump-wells.
(2) The deposition of silt and organic matter in sewers.
(3) Seeding of fresh sewage with stale organic matter.
(4) Agitation.
(5) Condensation on unsubmerged portions of the structure.
(6) Summer conditions, including higher temperatures, lower flows, and longer retention-periods.

* "Cairo Main Drainage Extensions." Minutes of Proceedings Inst. C.E., vol. 231 (1930–31, Part 1), p. 130.

(B).—*Factors preventing or retarding corrosion.*

(1) The use of pneumatic ejectors.
(2) The total exclusion of air.
(3) Complete access to the air.
(4) Increased ventilation.
(5) Chlorination.
(6) The use of Ciment Fondu.
(7) The use of "Inertol," or some other bituminous coating.

A careful survey of the sewerage-system was made to ascertain whether any changes in operation could be effected to prevent or to retard corrosion. As a result of trials, the following alterations had been made in regard to the operation of the system. Sumps at sub-pumping stations were cleaned out twice weekly instead of weekly; the permissible flow to the disposal-works was increased, and one of the storm-water tanks was utilized as a balancing-tank to prevent back-flooding, enabling the sewer to be cleaned out; and at the disposal-works the sedimentation-tank effluent carrier was altered to give free discharge, and large openings were provided every 50 feet. Attention had also been directed to means of preventing corrosion. A chloronome was installed on the Maitland sewer to feed chlorine at a point immediately after the discharge of the rising mains from the sub-pumping stations, and badly-damaged structures connected with that sewer were reconstructed, Ciment Fondu being used throughout. Recent examinations indicated that some of the reconstructed work showed no sign of attack after approximately 2 years' service. The sumps of the main pumping station were reconditioned throughout with Ciment Fondu, coated with "Inertol." Later, a chloronome was installed, primarily to counteract odours at the station and at the disposal-works; it also had the effect of retarding corrosion. An inspection of the sump of the main pumping-station carried out in 1940 indicated that the improved operation of the sub-pumping stations, the prevention of back-flooding in the main sewer, and chlorination, had retarded corrosion to a considerable extent. The upper portions of the sump were sound, and corrosion to the extent of approximately ¼ inch was observed only between high- and low-water level. That indicated that hydrogen-sulphide production had been reduced to such an extent that the amount of gas present was below that necessary to saturate the sewage, and that consequently no appreciable liberation of hydrogen sulphide had taken place. The reconstructed work appeared sound, except for certain points, strangely enough between high- and low-water level, where the bond was not good.

Similar measures had, however, failed at the Muizenberg pumping-station, put into operation in 1934. On account of odour-complaints, attempts to provide adequate natural ventilation had had to be abandoned, and in view of the apparent resistance of the "Inertol"-coated Ciment Fondu test-strip at the main pumping-station, the Muizenberg sump was given two coats of " Inertol." Owing to lack of ventilation in the Muizenberg sump, however, the painting having been done after the station had been put into operation, it was impossible to get the walls thoroughly dry before applying the " Inertol." Examination in 1935 showed that there was very little bond between the " Inertol " and the " Ferrocrete," and that the concrete of the sump had corroded slightly. In 1938 a further examination was carried out, and two 12-inch by 6-inch cement test-slabs of 3 : 1 Portland cement were placed in the sump ; one was suspended so as to be nearly always submerged, whilst the other was suspended at such a level as to be submerged only at high water. After 3 months and after 11 months slight corrosion was observed, but during the subsequent 12 months the action appeared to have become intensified. The slab which was submerged most of the time was sound, whilst the other slab was considerably corroded. At the last inspection, in January 1940, the walls of the sump showed the typical flaking putty-like deposit, and had softened to a depth of 1 inch in places.

The observations on that station indicated that the use of resistant materials was no safeguard against that form of corrosion, unless in addition the cycle of happenings leading to the formation of sulphuric acid was broken or retarded by one or more of the means previously mentioned.

Mr. Woolley would like to acknowledge the collaboration of Mr. A. Abbott, B.Sc., Assistant Chief Chemist at the Athlone disposal-works, with whom he was closely associated, by courtesy of the City Engineer, Cape Town, for the greater part of the investigation described.

The Author, in reply, wished first to thank Mr. Woolley for his observations. The purpose of the Paper had been to demonstrate to engineers the fact that sulphur bacterial action could be counteracted, but it had given only a very brief outline of the problem. The Author considered that a most authoritative and valuable contribution had been made by Mr. Woolley to the scanty literature on the subject.

He was particularly indebted to Mr. Abbott for assistance in replying to some of the queries raised in the Correspondence.

Mr. Guild's observation regarding condensation forming on and attacking the concrete had been actually borne out in practice. Such condensation was mentioned by Mr. Woolley on p. 533, *ante*, and on p. 535, *ante*.

Corrosion occurred on the upper parts of sewers or appurtenant works whenever the ventilation, whether forced or natural, was inadequate to maintain those parts completely dry. Condensation alone, however, was not enough to precipitate corrosive action. It was essential that hydrogen sulphide be present, and it was through the secondary solution of hydrogen sulphide that the final changes which led to corrosion actually took place. Attempts to eradicate corrosion by ventilation had failed when due cognizance had not been taken of that important factor. Such an instance had been recorded in the abortive efforts to reduce corrosion in the main drainage of Cairo in 1918[1], where one large fan had been installed to exhaust sewer-air from a trunk sewer about 8 miles long, only one air inlet being provided at the head of the sewer. That was inadequate to prevent condensation in such a length of drain, whilst the reduction in pressure in the sewer caused the liberation of a constant stream of hydrogen sulphide, which, coming in contact with the condensate on the upper portion of the sewer, set up an ideal combination for corrosion.

The final process of corrosion was the formation of sulphuric acid in the thin film of condensed moisture which contained the dissolved hydrogen sulphide. The main agents responsible for that essential part of the process of decay were considered to be sulphur bacteria.

Generally, however, owing to its relatively small quantity, the action of such a condensate would be slight and it could hardly be compared with the action on concrete actually submerged in distilled or chemically pure water.

The *p*H-value of that condensate would depend upon several variable factors difficult to determine, of which the nature of the gases in the sewer, the extent of sulphuric acid production, and the consequent action on the concrete were some of the most important. Actually no definite *p*H-value could be laid down.

The organism *Spirrilum* or *Vibrio desulphuricans* developed strongly at *p*H-values between 6·9 and 7·5, and presumably the optimum *p*H-value for that particular bacterial development lay between those two values.

There was, however, no question of *Spirrilum* or *Vibrio desulphuricans* acting in the condensate on the upper parts of sewers or tanks, since that organism, which reduced the sulphates to hydrogen sulphide, functioned only under anaerobic conditions below the surface of the sewage itself.

Mr. Stanger's contention that soluble mineral sulphates had a corrosive effect upon concrete greater than that of sulphuric acid would be true only when the sulphuric acid solution was of a considerably weaker concentration than the sulphate solution. In equal concentrations the corrosion due to sulphuric acid would exceed by far that induced by a sulphate solution. In any case, the deterioration of concrete in contact with sewage was definitely not brought about by the direct action of soluble sulphates. Chemical analysis indicated that it was due ultimately to sulphuric acid produced by sulphur bacterial action. The quantity of soluble sulphates present in sewage was usually too small to cause direct corrosive action. The highest sulphate-content encountered in Cape Town sewage was less than 20 parts per 100,000, or 0·02 per cent. Most authorities agreed that before concrete pipes would be attacked the sulphate-content in solution would have to exceed between 0·05 and 0·1 per cent.

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[1] A. O. W. D. Pinson, "Cairo Main Drainage Extensions." Minutes of Proceedings, Inst. C.E., vol. 231 (1930–31, Part 1), p. 114.

Actually, in the case of cements immersed in sulphate waters, the expansion and disintegration were caused by the formation of gypsum ($CaSO_4.2H_2O$) and of calcium sulpho-aluminate, which crystallized with the formula $3CaO.Al_2O_3.3CaSO_4.31H_2O$. The latter salt was not found to form under the acid conditions existing in the corrosion under discussion. Moreover, conclusive evidence that the corrosion was not produced by sulphates in solution was provided by the fact that distintegration took place on those portions of the sewerage systems which were either entirely or intermittently unsubmerged, and never on those portions which were continually under water.

The Author wished to thank Mr. W. S. Lunn, Assoc. M. Inst. C.E., City Engineer, Cape Town, for permission to publish the Paper, and he hoped that by bringing the problem of sulphur bacteria, its action, treatment and prevention to the notice of engineers throughout the world a step had been taken towards the complete eradication of that costly and highly-virulent agent of destruction.

CORRESPONDENCE

ON PAPER PUBLISHED IN MARCH 1940 JOURNAL.

Paper No. 5217.

"The Dragline Excavator." †

By William Barnes, M. I. Mech. E.

Correspondence.

Mr. C. B. Bailey observed that he was concerned with the larger types of excavator, but unfortunately the majority of digging that his firm had to meet was of such a nature that dragline excavators could not face it; much had been made of the recent developments in draglines tending towards the handling of heavier rocks, but he thought that it would be generally accepted that such rocks had to be expensively blasted before the dragline type of machine could deal with them.

† Journal Inst. C.E., vol. 14 (1939–40), p. 8 (March 1940).