

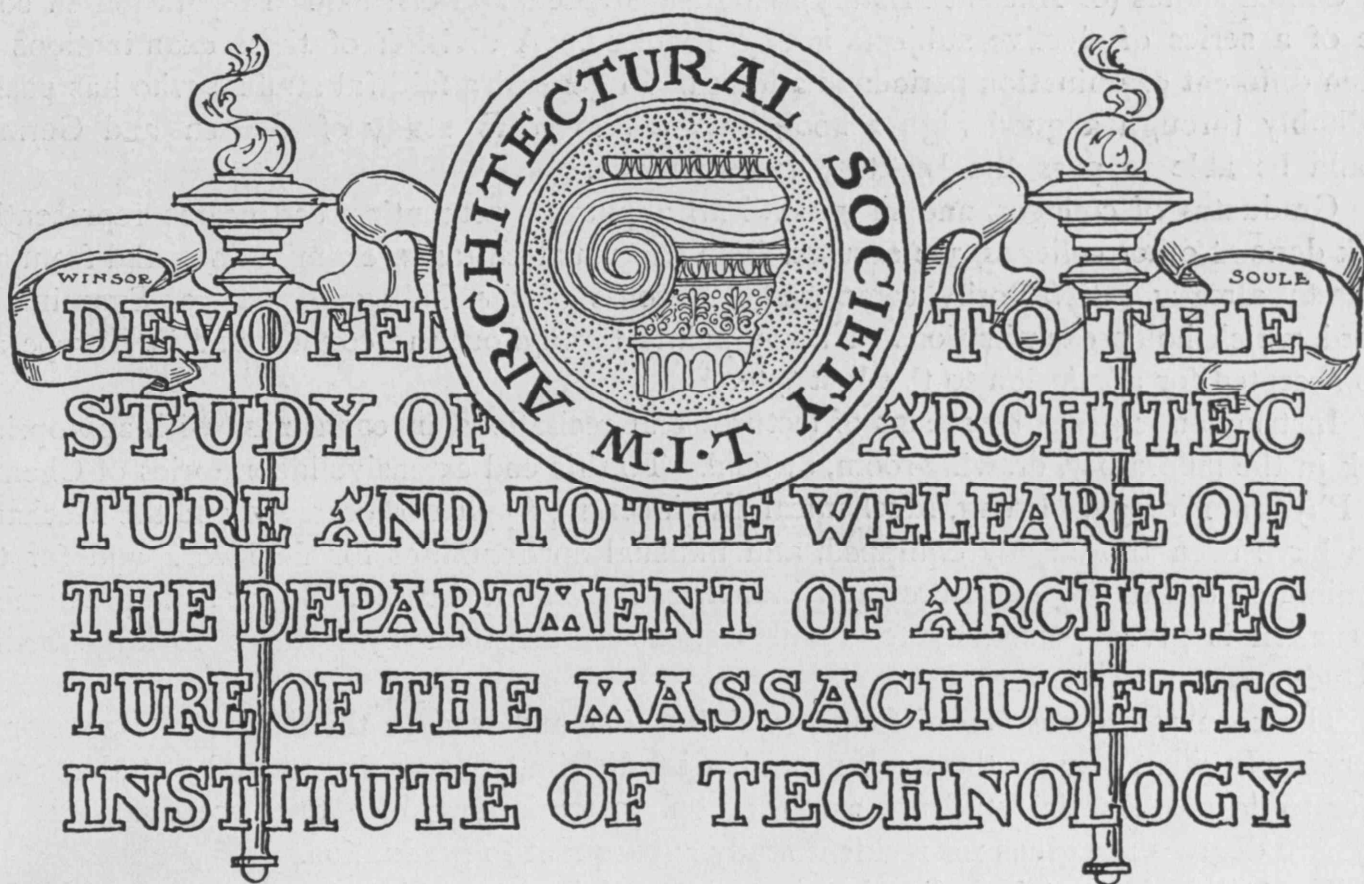
CORROSION OF STEEL IN REINFORCED CONCRETE

Investigations by the Research Laboratory of Applied Chemistry, M. I. T.

VOL. 3. NO. 3

JUNE. 1910

THE TECHNOLOGY ARCHITECTURAL RECORD



PUBLISHED QUARTERLY BY THE
M.I.T. ARCHITECTURAL SOCIETY

THE
Massachusetts
Institute of Technology
BOSTON, MASS.

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The instruction in Option 2, a specialized course in Architectural Engineering, includes advanced courses relating to Applied Mechanics, the Theory of Structures, and practical problems in Structural Design.

The department offers opportunities for one or more graduate years of advanced study, to be spent in professional work, and leading to the Master's degree.

The student is strongly advised to spend part of the summer in an architect's office, for this practical experience is a great aid to him in the clearer understanding of his school work.

The Bachelor's degree of the Institute admits the holder to candidacy for membership in the American Institute of Architects, without the examination ordinarily required of candidates for membership.

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IONIC CAPITAL, FORUM OF TRAJAN, BY A. RECOURA, Grand Prix de Rome

The original of this plate is in the
Gallery of the Department of Architecture

The Technology Architectural Record

Vol. III

June, 1910

No. 3

\$1.00 per Volume

Single Copies, 35 Cents

Published by the Architectural Society of the Massachusetts Institute of Technology.

The proceeds of this publication are devoted to a Scholarship Fund, founded by the Architectural Society for students of the Department of Architecture of the Institute.

At the recent meeting of the Académie des Beaux-Arts, Paris, Professor Despradelle was elected, on the first ballot and by a large majority, Membre Correspondant de l'Institut de France. The Académie des Beaux-Arts, which is one of the five sections of l'Institut de France, is composed of a limited number of architects, painters, sculptors, and composers. Its members are elected for life.

Through the generosity of Mr. Guy Lowell, '94, in again contributing the sum of five hundred dollars, the Executive Committee of the Institute is able to offer the 1910 Traveling Fellowship of one thousand dollars. Nine students entered the competition, which closed May 26. The problem is a Museum-Library, and the successful design will be published in our next number.

On Friday and Saturday, March 25 and 26, delegates from the architectural societies of Cornell, Harvard, Pennsylvania, and Technology met in New York to discuss matters of interest and importance in architectural education. As a result of the conference it was deemed advisable for the societies of the various institutions to join the Architectural League of America. Furthermore, in order to promote the interchange of ideas and advance the interests of architectural education, the Intercollegiate Architectural Federation was formed. Its purpose is to unite all organizations interested in architecture which are established at the various schools in America.

This Federation should be able to do much to advance architectural education, and to this end has already made plans for intercollegiate competitions. It aims also to institute a traveling exhibition of the work of the various schools, in much the same spirit in which the intercollegiate exhibition was held recently here in the Department.

Among the gifts lately received by the Department library, and of which we desire to express grateful appreciation, are some fifty valuable books and a considerable collection of photographs formerly belonging to the late Alfred Greenough, and presented by the heirs of Mr. C. H. Parker; a number of photographs and prints from Mrs. William B. Rogers; three large books on ornament, with elaborate plates, from Mrs. Joseph Stone; a copy of Shaw's "Civil Architecture," from Professor W. A. Johnston; a copy of "Bricklaying System" by Frank B. Gilbreth, the gift of the author; and two hundred plates of

artistic interiors of American homes, with descriptive text, the gift of Mr. John L. Batchelder, Jr., '90.

Since our last number the following Tech men have distinguished themselves in their profession: Mr. F. M. Chace, '04, associated with Mr. W. W. Cook, won the first prize of \$500 in the *Brickbuilder* Competition for a Public Bath and Gymnasium Building. Mr. F. A. Colby, '01, associated with Messrs. F. Wilson and C. Heber, won the Avery prize in this year's competition.

On Tuesday evening, May 3, the monthly dinner of the Boston Society of Architects was held at the Art Club. It was the occasion of announcing the winner in this year's Rotch Traveling Scholarship Competition and awarding the prizes offered annually by the Society to the students of the fourth-year class at the Institute. J. McGinniss, '08, who since leaving the Institute has been in the office of Codman & Despradelle, was awarded the two-year traveling scholarship, and G. Fox, '09, from the same office, was given the second prize of \$75. To R. D. Johnson was awarded the prize of \$50 offered to the regular students; and J. E. Kelley, the same amount offered to special students. Their prize designs are published in this issue of the RECORD. During the remainder of the evening Mr. I. K. Pond, of Chicago, president of the A. I. A., spoke most appropriately on the subject of traveling scholarships in architecture. He gave his views of the methods to be followed by a student in order to gain the greatest benefit from a year's study abroad. He was followed by Mr. J. H. Freedlander, of New York, and Mr. Samuel J. Elder, of Boston.

As the result of the preliminary competition for this year's Paris prize, F. J. Robinson, '08, and K. E. Carpenter, '09, were admitted to the second competition. In the latter, Carpenter was one of the five selected for the final competition. The preliminary sketch for the final competition was held in New York on May 14; the competition closes July 18.

The preliminary competition for the Prize of Rome in Architecture, offered by the American Academy in Rome, was held on May 6. The problem was a Building for the Department of Fine Arts in Washington. As a result of this competition H. D. Bounetheau, '09, was selected as one of the four for the final competition, and W. B. Kirby, '07, as a substitute.

The Department will offer, as usual, its summer courses in Second and Third Year Design and Shades and Shadows. They will begin July 5, and be of eight weeks' duration. A six weeks' course in Mechanical Drawing and Descriptive Geometry will also be given. Circulars giving more complete information can be obtained by addressing Professor A. L. Merrill, Secretary of the Institute.

Owing to lack of space in this issue, the department devoted to the Architectural Society and the list of mentions awarded in the second term of Design have been omitted. They will be published in the September number.

Architectural Engineering

Corrosion of Steel in Reinforced Concrete

By WILLIAM H. WALKER, Ph.D.
Professor of Industrial Chemistry, M. I. T.

Investigations by the Research Laboratory
of Applied Chemistry, M. I. T.

THERE is an old saying that a chain is no stronger than its weakest link, which, if we might paraphrase, would read, a building is no stronger than its weakest part. Since the calculation as to strength of material made by the architect, upon which the stability of a structure depends, is of value only so long as the assumed strength of material remains constant, the importance of providing against a decrease of this strength is apparent.

The fact that modern buildings of great size depend for their life upon the durability of the steel framework employed in their construction makes the study of the deterioration of steel necessary from an architectural engineering standpoint. There are, however, but two factors which enter into this deterioration; namely, the fatigue of the steel and its corrosion. The former is seldom of importance, so that it is only the latter which will be considered in this paper, in which we will endeavor, first, to state, as briefly as possible, the fundamental conceptions involved in the electrolytic theory of the corrosion of iron and steel, and, second, to point out some of the practical applications of this theory to the problems of corrosion as met with in architectural practice.

While a tendency to corrode is a property inherent in iron and therefore always present, yet from the fact that under identical conditions of service some samples corrode much more rapidly than do others it is evident that there is something other than the iron itself playing an important part in the phenomenon. The commercial material which we term iron is unique in that it is never in reality the pure metal (as copper, for example, is), but always a mixture of iron and certain alloys of iron with other elements with which it unites during the process of its manufacture. These alloys or compounds, moreover, when present even to a very minute extent, have a controlling effect upon the physical properties of the resultant product. When the iron is first reduced from its ore these impurities are present in relatively large quantities, and are removed by refining processes, which if carried on with the iron in a plastic condition result in what we term wrought iron; while if during the process of refining the mass is continuously held in a molten condition the material known as steel is produced. The iron of fifty years ago was made by the first process, and it cannot be denied that such material resisted corrosion better than much of our modern iron or steel.

There has been an endeavor on the part of some manufacturers who now use processes essentially the same as that formerly used to attribute the value of the old product to the process, and to assert that the output of a puddling-furnace, for example, must be the more valuable because

it was made in such a furnace. But while a product is in general a function of the process used in its making, it does not follow that the process alone can insure the value of the product, and that wrought iron will necessarily resist corrosion because it is wrought iron. Hence the futility of the discussion which has been going on for the last few years as to the relative merits of wrought iron and steel as to this particular property. We have plenty of good steel and bad wrought iron, and also bad steel and good wrought iron. Had the energy and time spent in this useless wrangle been devoted to a sincere endeavor to determine the factors controlling the rate of corrosion the problem would now be nearer solution.

The substance rust is a combination of oxygen and iron, usually associated with more or less water. Oxygen will not unite directly with metallic iron except at a high temperature, when it forms a dense magnetic mass such as mill-scale. In order for the union to take place at ordinary temperatures the iron must pass into solution in a way common to all metals with the formation of what are known as metallic ions.

IONS AND THE ELECTROLYTIC DISSOCIATION THEORY.

In order to explain certain important and well-established facts,—such, for example, as the electrical conductivity of salts dissolved in water, the abnormal lowering of the freezing-point and the raising of the boiling-point of water by the presence of dissolved salts, abnormal osmotic pressure, etc.,—there has been proposed and almost universally accepted what is known as the electrolytic dissociation theory. In accordance therewith, when a salt dissolves in water a certain proportion of the dissolved molecules are regarded as dissociated or broken up by the water into component parts called ions. These ions act in the phenomena just mentioned, and in many others, just as whole molecules do. These parts of molecules may be made up of a single atom, or a group of atoms, but as individuals differ from real atoms in that they carry relatively large charges of electricity. Thus common salt in water solution furnishes two ions—the sodium ion carrying a positive electrical charge, and the chlorine ion carrying an equivalent negative charge. Water itself is somewhat dissociated into two ions oppositely charged—the positive hydrogen ion composed of one atom of hydrogen, and the negative hydroxyl ion composed of one atom each of oxygen and hydrogen.

ELECTROLYTIC SOLUTION PRESSURE.

Every metal when placed in water, or under such conditions that a film of water may condense upon it, tends to dissolve in the water; or, in other words, to pass from its atomic or metallic condition into its ionic condition. This escaping tendency of the metals varies from that shown by sodium or potassium, which is so great as to cause instant and rapid decomposition of the metal and water, to gold or platinum, where such tendency to dissolve is zero. Between these two extremes we find the other common metals, including thereunder the element hydrogen, which may be considered as a metal. As the atom of metal passes into the water it assumes a positive charge of electricity, leaving the metallic mass from which it separated charged negatively; this property or escaping tendency of the metal is termed its solution pressure. It is obvious, however, that this action can continue for only a short time; owing to the fact that the mass of metal and solution are of opposite polarity, the electrolytic tension becomes so great that no more atoms can escape to the ionic state, and the solvent

action ceases. This condition was first described by Helmholtz, and called by him an electrolytic double layer. If now there be in the water ions of another metal which has a smaller solution pressure than the one under consideration, the action as above described will be reversed and the ion with the less solution pressure will pass back to the metallic state, plating out on the first metal and giving up its charge of electricity. At this point the first metal will be charged positively, and the solution in the immediate vicinity negatively, and there will tend to be set up a second electrolytic double layer opposite in polarity to the first. The result is, a current of electricity flows from the metal to the solution at the point where the metal passes into solution, through the solution to the metal at the point where the ions of the second metal are plating out, and back through the first metal to the starting-point again. The electrolytic double layers are thus destroyed, an electric current passes, and the solvent action of the water on the first metal continues.

This phenomenon and its relation to the corrosion of iron are clearly exemplified in the well-known Daniel or gravity cell.

In the case of pure iron in water a perfectly analogous condition is found to exist. Water itself is dissociated to a small but perfectly definite extent into its ions, hydrogen (H) and hydroxyl (OH). When a strip of pure iron comes into contact with water it sends into the water iron atoms in the form of positively charged ions. Hydrogen as a metal has a much smaller solution pressure than iron, and hence an equivalent number of hydrogen ions plate out on the iron strip (leaving the free hydroxyl ions with their negative charges to balance the iron ions with their positive charges), and an electric current flows from the iron by means of the iron ions to the solution, and by means of the hydrogen from the solution back to the iron again, thus completing the circuit. But here comes an important break in the analogy of the film of copper in the Daniel cell. Deposited copper is a good conductor of the current, and offers no resistance to its flow from the solution to the iron on which it is attached. The reverse is true of the deposited hydrogen; here we have a high insulator — a film of gas which offers a great resistance to the flow of the current. Hence, although in the case of the iron strip in water all the conditions for continuous solution are present, owing to the resistance offered by the deposited hydrogen film (called polarization) the action must cease.

Just as in the case of iron in a copper sulphate solution the rapidity of the action depends upon the number of copper ions present in the solution, so here the solution of the iron, in the first instance, depends upon the number of the hydrogen ions present. This number of hydrogen ions, or the concentration of these ions, is increased by the addition of any acid. So weak an acid as carbonic increases the number, but to a relatively small amount; while a strong acid, like hydrochloric or sulphuric, adds to the number to such an extent that the solvent action becomes violent and the deposited hydrogen comes off as a stream of gas.

Water is composed of, or breaks up into, two ions,—hydrogen, which carries the positive charge, and what is termed the hydroxyl ion, which carries an equivalent negative charge. It happens that there exists a very delicate test for the presence of the iron ion in the fact that potassium ferricyanide solution immediately forms therewith a bright blue color; while, on the other hand, there is an organic substance known as phenol phthalein, which be-

comes intensely red in the presence of hydroxyl ions. If, therefore, a piece of iron be placed in a water solution containing potassium ferricyanide and phenol phthalein, and which, to prevent convection currents, is thickened with a little ordinary gelatine, there should be formed a bright blue color at those points on the iron bar at which the iron is passing into solution, and a bright red color on those portions on which the hydrogen is plating out, leaving in the solution at that place an equivalent number of hydroxyl ions. These conditions are easily realized, and an experiment is shown in Fig. 1, where some ordinary wire nails have been placed in such a jelly. The dense portions are the blue zones at those points where iron is passing into solution and reacting with the ferricyanide, and the deeper portions are the red of the phenol phthalein where separating hydrogen has left the free hydroxyl ions.

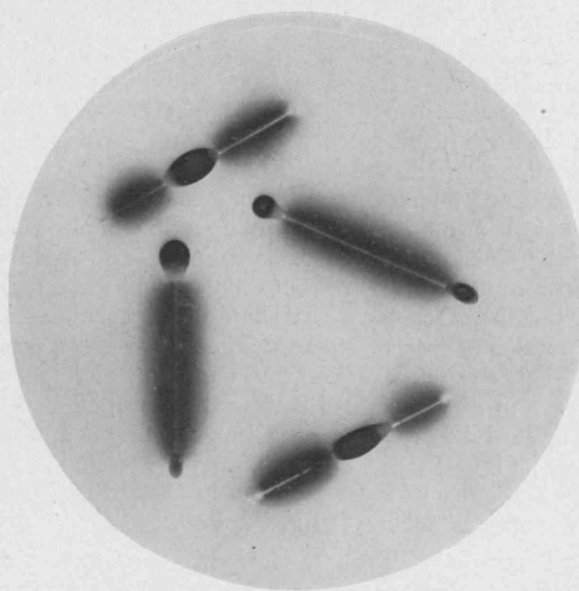


FIG. 1.

Since the presence of the polarizing film of hydrogen arrests the further solution of the iron, it is obvious that in order for the reaction to proceed this hydrogen must be removed. The destruction of the hydrogen film in ordinary corrosion is accomplished by the oxygen of the atmosphere which is dissolved in the water. The action here taking place is a simple union of the hydrogen on the iron and the oxygen dissolved from the air, with the reformation of water. It follows from this that any substance which dissolves or reacts with hydrogen should accelerate corrosion. This is found to be in fact the case.

It was formerly thought that the action of oxygen as a factor necessary in corrosion was simply to oxidize the iron ions thrown into solution, and to precipitate them as rust. While it is true that this reaction does take place, and is indeed the most striking function that oxygen performs, it is in reality a secondary one, simply incidental to corrosion and not a necessary part of the action. Its real accelerating effect is due to the fact that it depolarizes the hydrogen which is set free by the reaction and separates out on the metallic iron.

Having now a conception of the mechanism by which iron corrodes, some important conclusions may be drawn. Since corrosion can take place only when the deposited

hydrogen film is continually destroyed, it follows that any agency that will increase the speed of the reaction by which the hydrogen plating out on the iron and the oxygen dissolved in the water will unite will in turn accelerate the corrosion. It is well known that the union of the oxygen and hydrogen takes place at ordinary temperatures much more rapidly upon a surface of platinum than on copper, on copper much more easily than on iron, and on iron more easily than on zinc. To use a modern phrase, these metals catalyze the reaction. Hence if a piece of platinum or copper be united electrically with a piece of iron the hydrogen will be liberated on the platinum and the iron will be free to pass into solution over its entire surface. This is shown in Fig. 2. A piece of platinum wire is seen at the center of the plate, and is without action. A nail is also seen corroding at the ends and setting free hydrogen upon its central portion. A second nail is connected to a piece of platinum wire; the red of the phthalein is seen around the wire, while the nail is corroding very much faster than the unconnected nail. Many substances occurring in modern iron and steel—such, for example, as manganese oxide and magnetic oxide—act in this respect just as platinum does. Their presence in the iron furnishes small points upon which the hydrogen set free can easily be liberated, and thus form the cathode pole of an exceedingly small electric couple, thus setting up a flow of electric current and forming a center of corrosion. In proportion as the iron contains many of these centers will the rate of its corrosion increase. Hence we should expect that the speed of corrosion of iron or steel would increase in accordance with the percentage of impurities present, and it should decrease in accordance with the care bestowed upon the iron or steel during its manufacture to prevent a segregation of its impurities. The simplest way, of course, to insure an absence of segregation is to eliminate altogether those materials not needed in the iron.

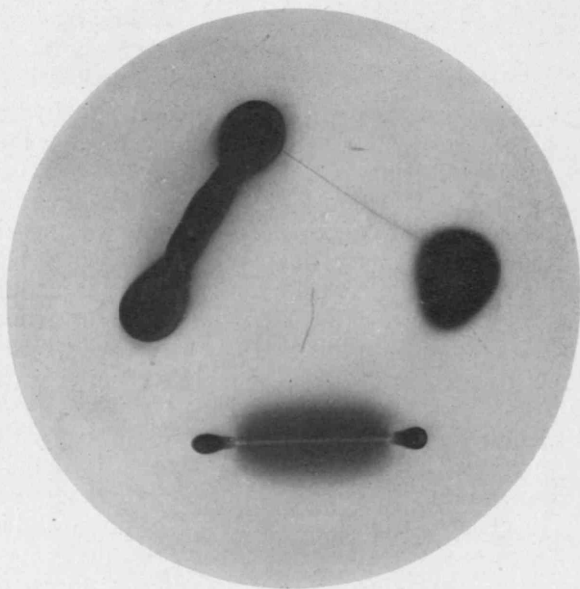


FIG. 2.

Since iron can pass into solution only by assuming the ionic form, and having at the same time an equivalent amount of hydrogen pass from the ionic condition to the gaseous state, the speed of the reaction will depend upon

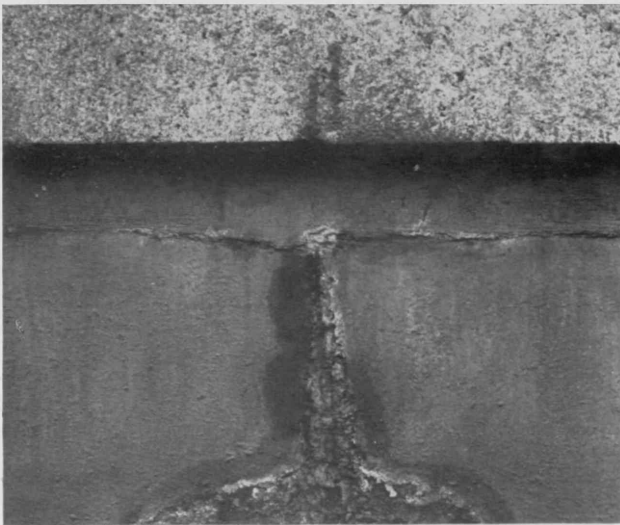
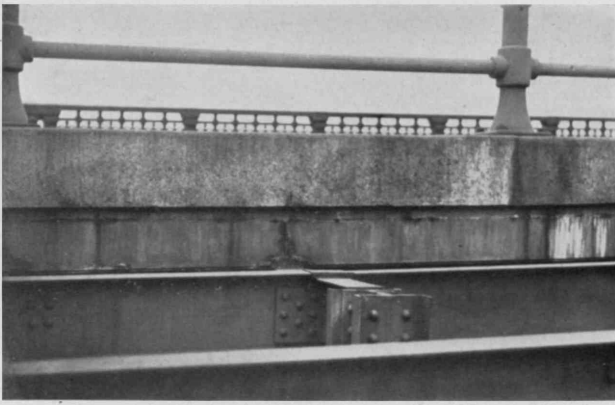
the number of hydrogen ions present in the solution. If this number be enormously increased, as can be done by adding some strong acid, the reaction will be accelerated to such an extent that the hydrogen may be seen passing off the iron as a stream of bubbles. If this concentration of hydrogen ions be but slightly increased by the addition of such weak acids as the carbonic acid of the atmosphere, or the carbonic and sulphurous acids resulting from the combustion of most fuels, corrosion will again be accelerated, though to a less noticeable extent. The presence of any material (such as alum or magnesium chloride) which when subjected to pressure, or other materials which by hydrolysis, will form an acid, will also accelerate corrosion. This explains why boiler feed-water should be free from magnesium chloride, for example. This salt hydrolyzes in the presence of water at temperatures above 120°C to produce the highly dissociated muriatic acid and the weak base magnesium hydroxide, and a rapid corrosion of the boiler due to increased hydrogen-ion concentration results.

If, on the other hand, the hydrogen-ion concentration be reduced, the corrosion of the iron will also be decreased. Such a condition may be most easily realized by adding to the water a strong alkali, which, owing to the presence of a large number of hydroxyl ions, decreases thereby the number of the hydrogen ions. Iron will not rust, therefore, in a solution of soda ash, lime-water, or any material (such as sodium phosphate) which when present in water will by hydrolysis decrease the number of hydrogen ions.

This fact has an important bearing upon the question which has been lately much discussed, as to whether concrete will protect iron from corrosion. Inasmuch as Portland cement, when it sets or hardens, liberates a large quantity of caustic lime, which is a strong alkali, and since good concrete is therefore saturated with this strong alkali, the answer to the question must be in the affirmative. Iron or steel will not corrode when embedded in concrete. But caustic lime is soluble in water, and poorly made concrete is not impervious to water. Therefore, if iron be embedded in concrete through which water at any time be allowed to percolate, this calcium hydrate will be slowly but surely dissolved and washed away, and with it will disappear the inhibiting action of the concrete, and iron embedded therein will surely rust. To insure absolute protection of the reinforcing members of concrete construction, therefore, such concrete must be sufficiently dense and carefully made to render it practically water-proof. This is not an impossible condition.

The solvent action of water which may percolate through a pervious concrete upon the soluble calcium hydrate formed by the setting of the cement is well shown in the new East Cambridge bridge. The water which passes from the pavement finds its way out at different points along the structure of the bridge, noticeably at the joints of the supporting steel structure. This strongly alkaline water has saponified the paint upon the ironwork with which it comes in contact, and, after being neutralized by the carbon dioxide of the air, these exposed portions of the iron members rapidly corrode. This is seen in the accompanying illustrations, which show one of the many points where the seepage from the pavement is destroying the steelwork. So soon as caustic lime has been leached out of the concrete forming the pavement protection of the steel structure supporting the pavement will be destroyed, and this portion of the structure will then also corrode.

By electrically connecting a piece of iron with a bronze



or copper structure the latter will be protected from corrosion, because, owing to the fact that the iron passes into solution, hydrogen will be liberated upon the bronze or copper and its solution will thus be prevented. Employing the same reasoning, we find that any metal with a greater tendency to dissolve than iron — for example zinc, on which the hydrogen is liberated with more difficulty than on iron — should protect the iron at the expense of this other more positive metal. This action is shown in Fig. 3. A piece of zinc is seen at the center corroding slightly from the ends, and showing the red due to the separating hydrogen ions at the center. Zinc ferricyanide is white and hence the same reagent demonstrates the separation of zinc ions, just as it does the iron ions in the plate already considered. The nail which has been connected to another piece of zinc is not corroding, but is protected by the separating hydrogen. The zinc thus connected, however, is seen to be rapidly dissolving. This is the explanation of the well-known use of zinc in boilers for the prevention of pitting; and it is but necessary to maintain an electrical connection between the zinc and the iron to insure the complete protection of the latter for a distance which depends upon the electrical conductivity, or purity, of the water in which the two are immersed. In perfectly pure water zinc will protect iron for a distance of but one half inch or so; but if salt or any other electrolyte be added thereto the area of protection is increased to twenty inches or more.

The fact that the presence of a metallic iron surface accelerates the corrosion of zinc has an important bearing upon the protection of such structure where both iron and zinc surfaces are exposed. In making barbed-wire fencing,

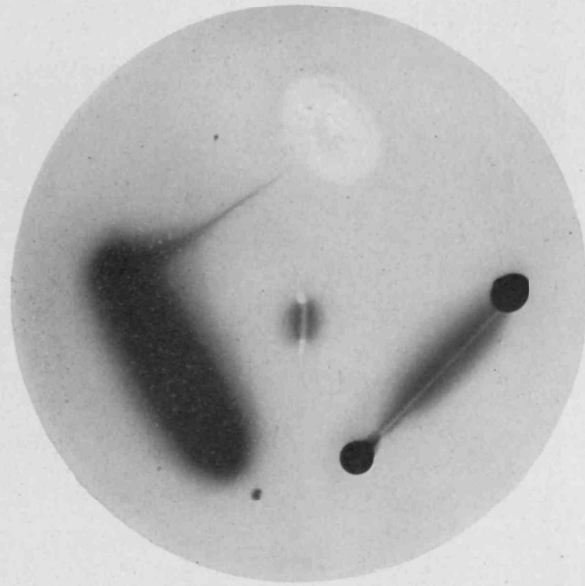


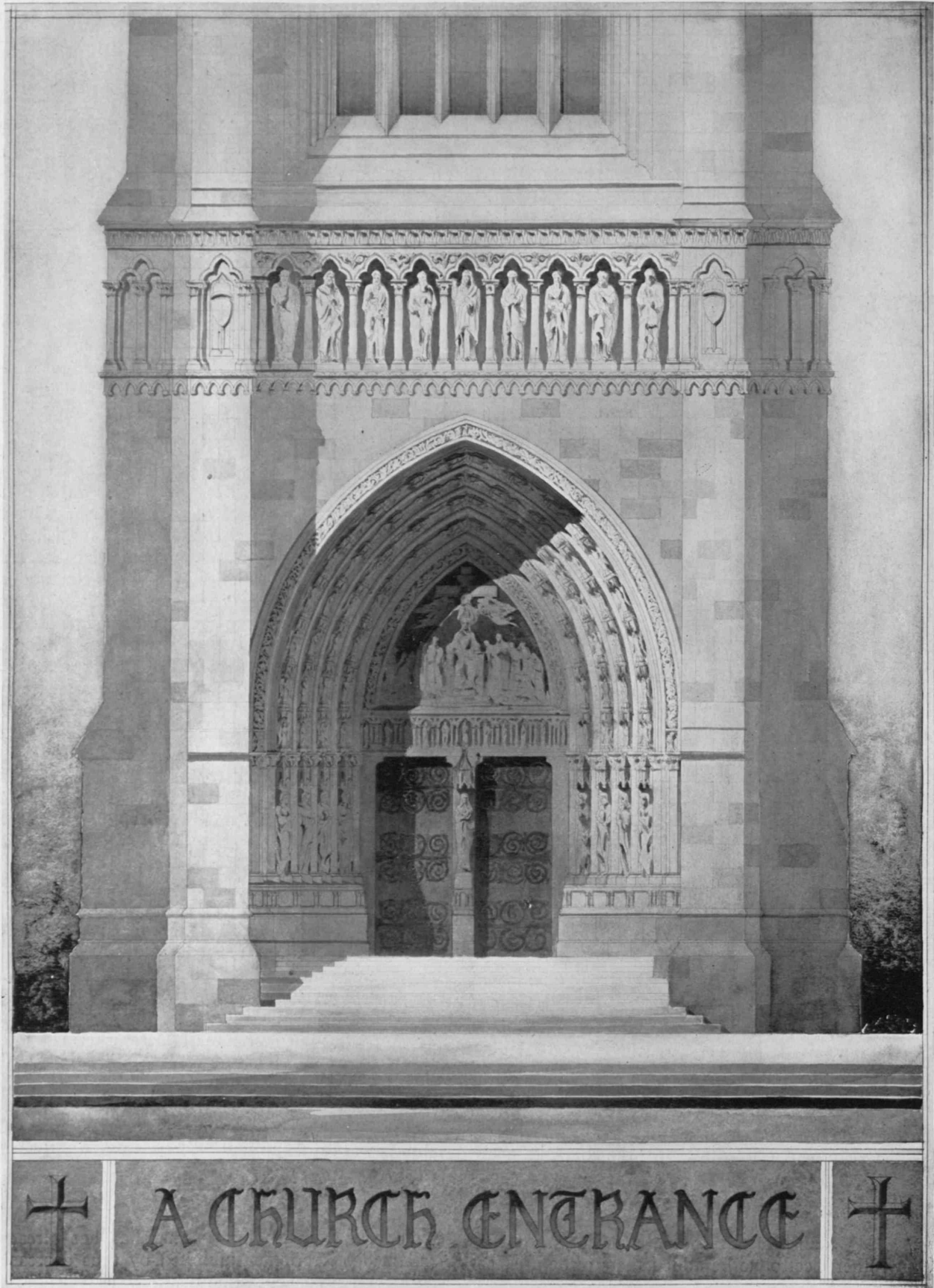
FIG. 3.

for example, the wire is first galvanized and then wound into fencing, the cross-wires forming the barbs being cut at an angle in order to make a pointed barb. This freshly cut surface of iron is thus exposed, and so furnishes just the surface required for depolarizing the zinc surface, and thus greatly increases the rapidity with which the zinc coating will corrode. As the zinc coating recedes from the iron surface the latter rusts, on account of the low conductivity of the water-film on the two; hence the explanation of why deterioration of a barbed-wire fence always starts at the barbs and travels from there along the strands. It also shows the necessity of protecting those places on a galvanized structure from which the zinc, for whatever cause, has been removed.

Since oxygen is necessary to insure the continuous removal of the hydrogen film, it is obvious that if no oxygen be allowed to reach the iron through the water no corrosion can take place. This fact teaches us much regarding the corrosion of boiler shells and tubes. Pitting may be entirely avoided if the air be removed from the feed-water before its introduction into the boiler. This may best be done by the employment of an open feed-water heater, or, what is better still, a feed-water heater connected to the dry vacuum-pumps of the condenser. If such treatment is not possible, the air may be removed from the feed-water by drawing the water through a closed box containing scrap iron; the oxygen in the water is used up in corroding the scrap iron instead of the boiler-tubes. Or, the oxygen in the water may be absorbed by feeding into the boiler with the water a very small quantity of an alkaline solution of a tannin material. Such a solution of alkaline tannate will break up under the pressure and temperature of the boiler, with a formation of a pyrogallate of the alkali, and this rapidly absorbs the oxygen. Soda ash, or rather alkali, is of course useful, but not because of its effect upon the oxygen content, but because, as has already been explained, corrosion is inhibited by thus decreasing the hydrogen-ion concentration of the water.

The author has already shown that "mill-scale," or magnetic oxide of iron, is strongly electro-negative to iron.

(Continued on page 75)

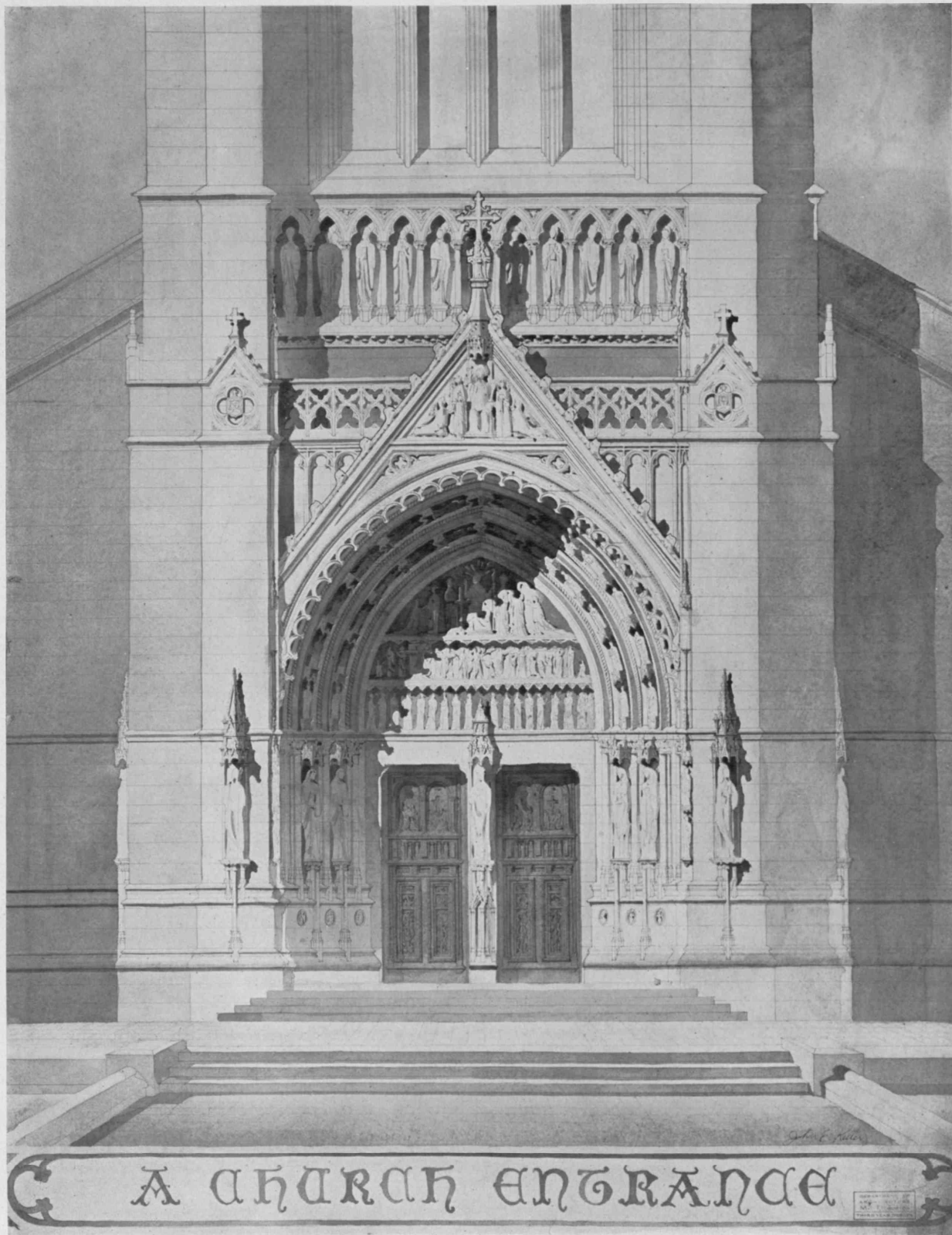


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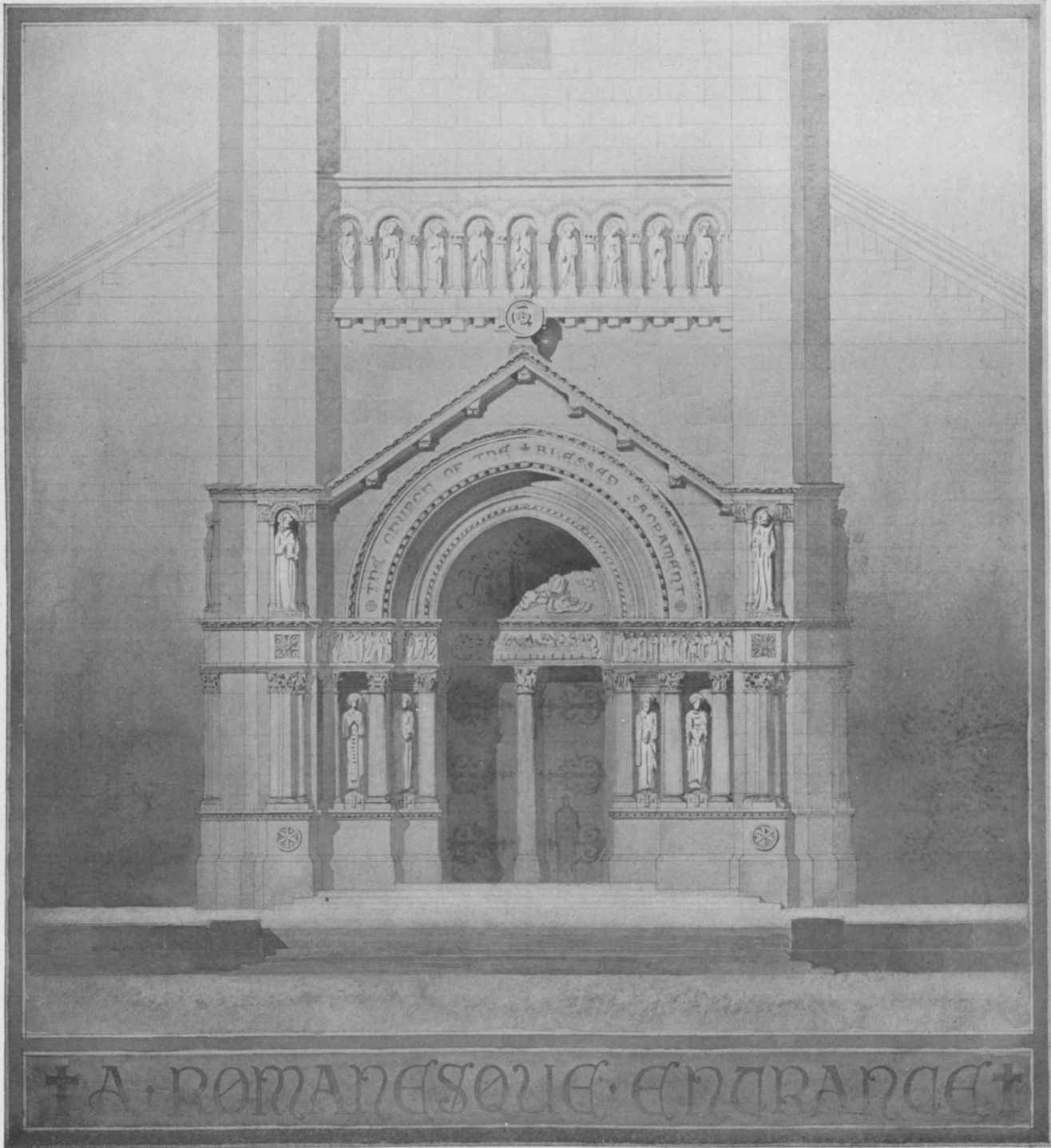


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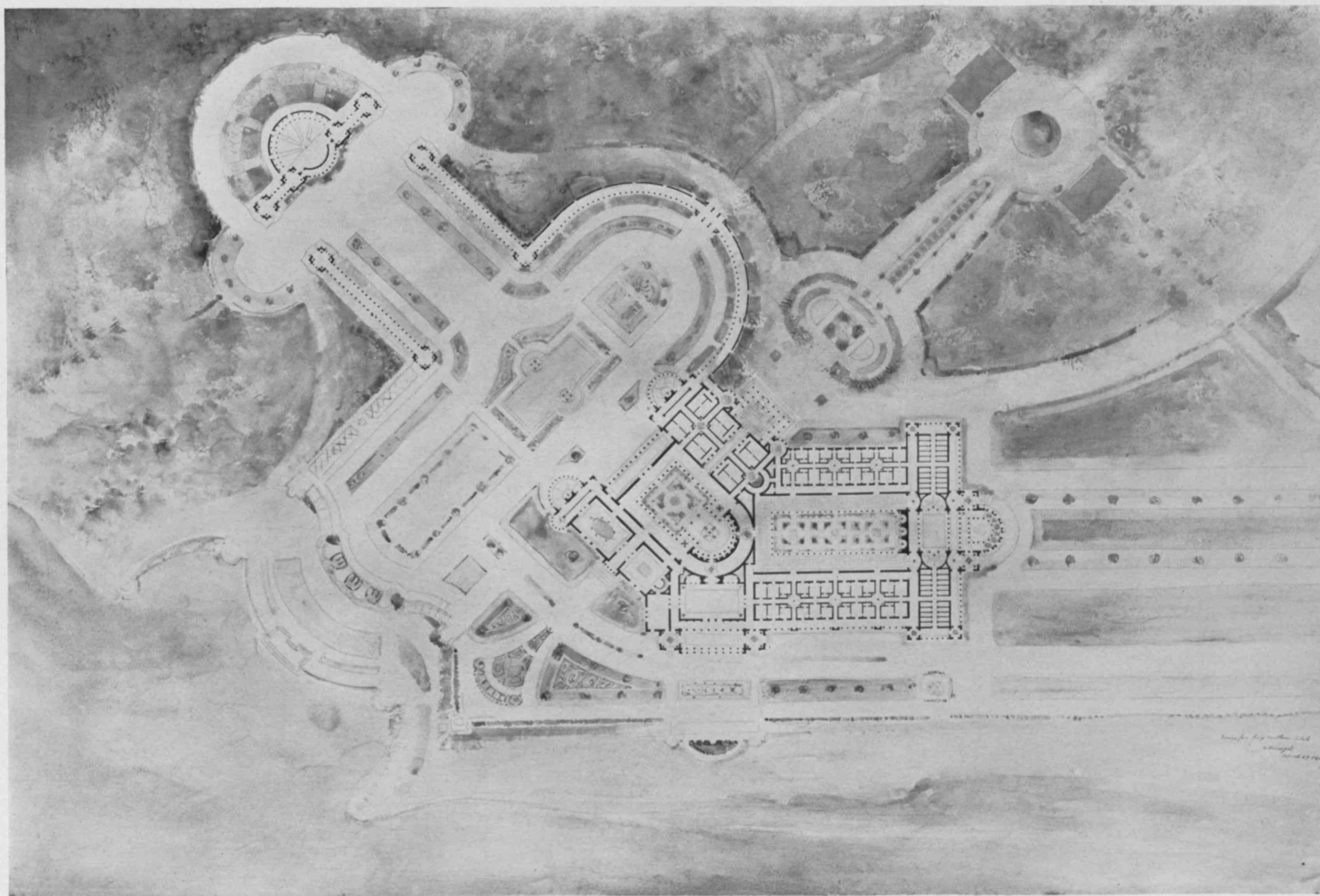


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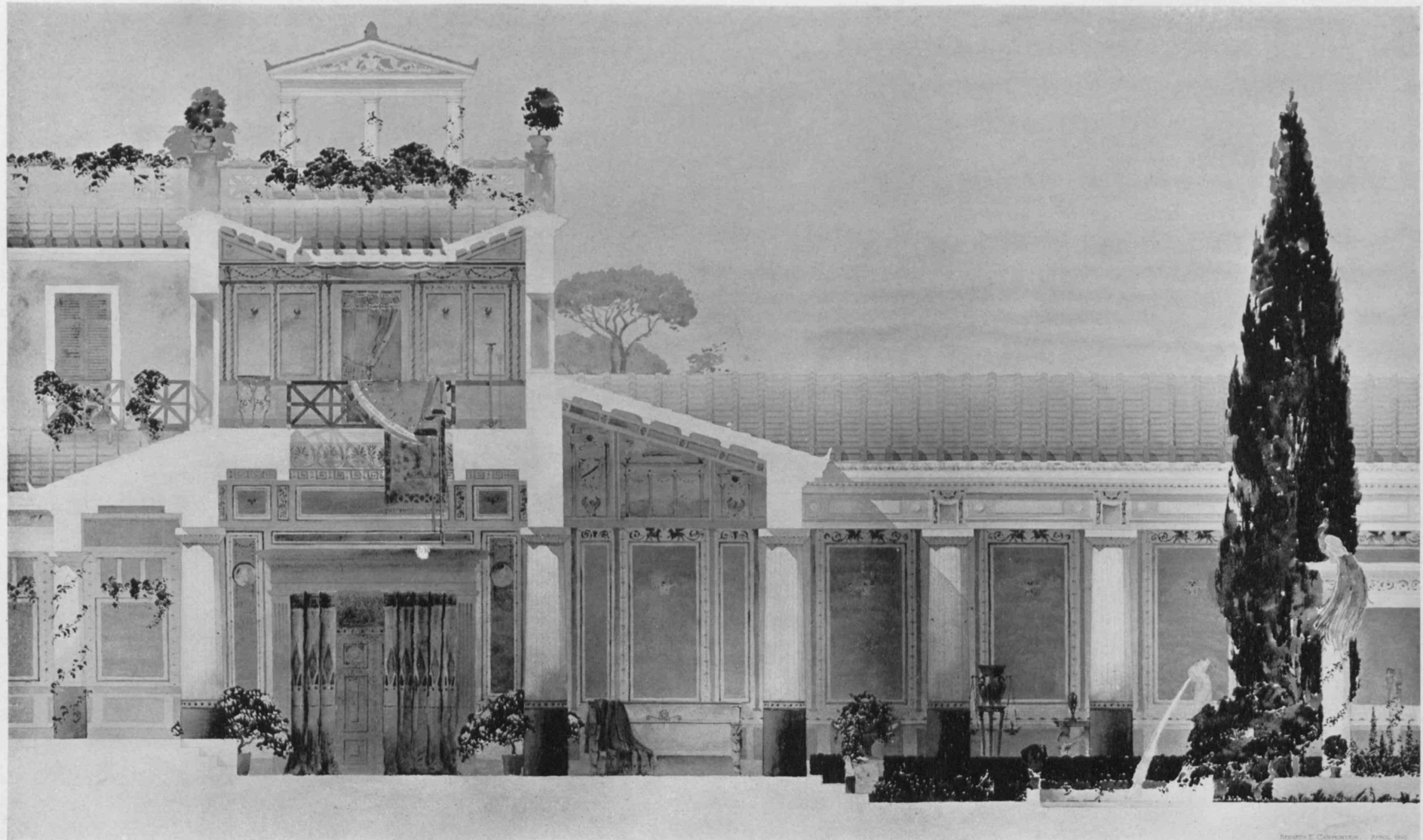
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PLAN OF A LARGE SOUTHERN ESTATE

K. VONNEGUT

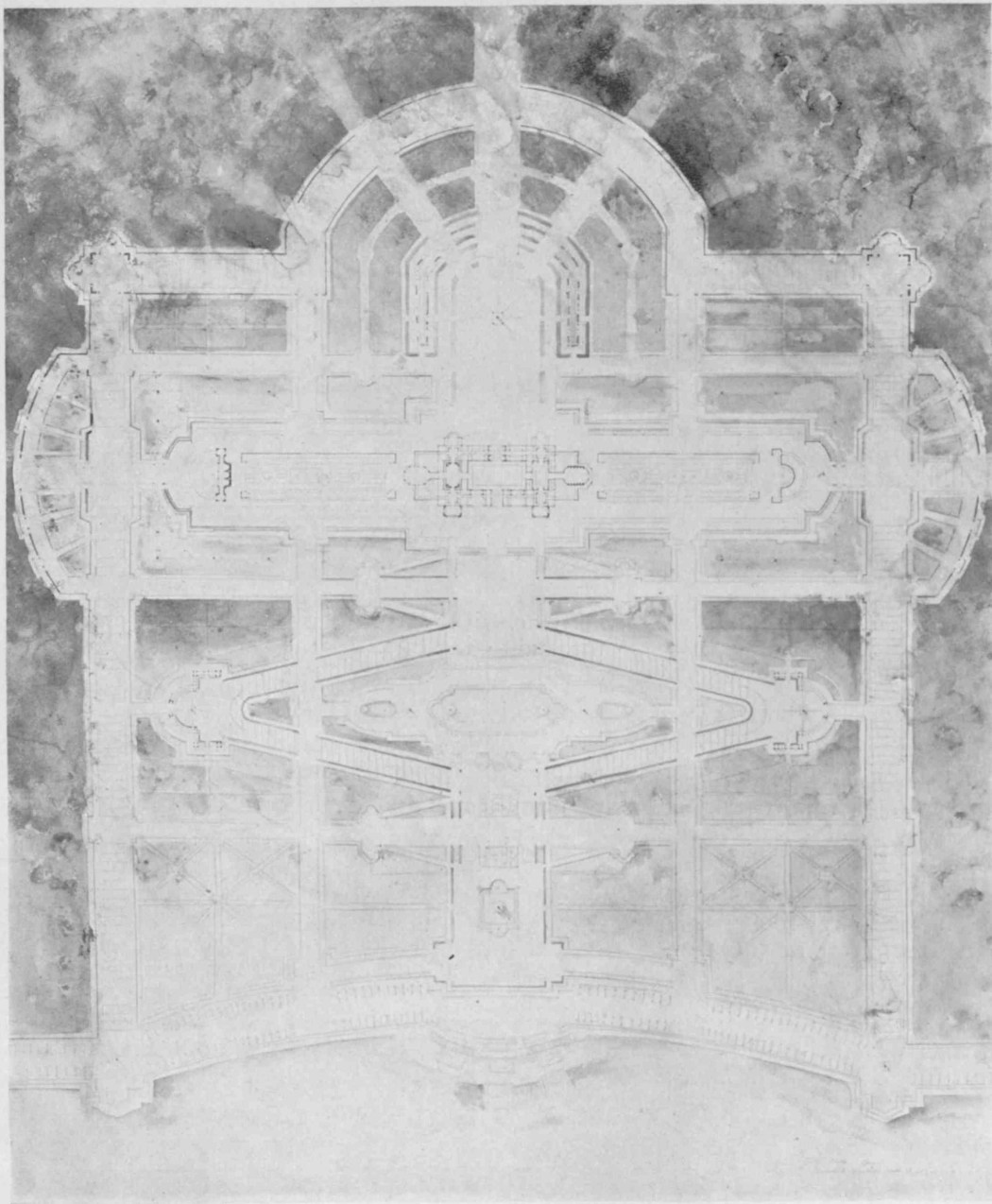
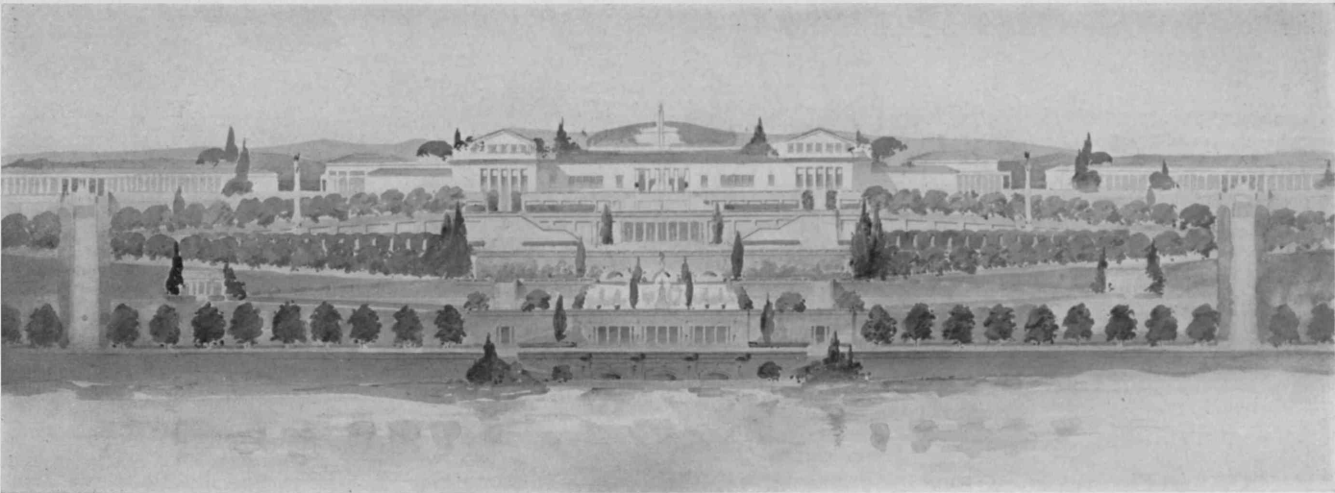
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(Continued from page 65)

Since mill-scale is insoluble in water and cannot of itself enter into the reaction, its only function must be analogous to that of platinum or other insoluble conductor of this kind; viz., to furnish a surface on which the hydrogen liberated by the dissolving iron can separate and be catalytically oxidized to water again. This is also true of the black oxide protective coatings sometimes used upon iron and steel, as, for example, that of the Bower-Barf process. Just as is the case in mill-scale, these coatings are very serviceable so long as the whole coating is intact. But so soon as a portion of the metallic iron is exposed this portion corrodes all the more rapidly on account of the presence of the surface of scale on which the oxidation of the hydrogen and consequent depolarization can go on. Fig. 4 shows the influence of mill-scale on the speed of corrosion of a wire nail. A piece of scale is seen at the center, and on the outside a free nail and also one connected with another piece of scale. The accelerating effect is obvious. The inevitable result is that a pit forms at the exposed point and grows deeper and more marked in proportion as the scale is dense and closely adherent to the iron surface. Hence, if it were possible to remove the mill-scale entirely from steam-boiler tubes, for example, pitting would be largely eliminated, and the life of the tubes prolonged.

Inasmuch as both moisture and oxygen are necessary in order that corrosion may proceed, it can easily be seen that the duty of a protective paint is to exclude both of these elements. It is well known that a linseed-oil film is an excessively porous structure, acting somewhat as a sponge toward moisture and freely allowing the passage of oxygen. The function of the pigments employed in paint is therefore at least threefold: first, the more obvious one of imparting a color thereto; second, the most important one of filling up the pores of interstices in the oil-film, thus rendering it as little pervious to moisture and air as possible; and third, to aid the composite film in drying or oxidizing to a compact, impenetrable covering. Very little work has as yet been done upon paints from this point of view; but with a clear conception of the factors involved in the corrosion of iron an intelligent study is made possible, and valuable results can be predicted with certainty. The porosity of paint-films containing no linseed oil, but composed of bituminous materials which may be adapted for the purpose, may also be studied with profit, with a view to increasing their moisture and oxygen excluding properties.

Although, as I have tried to point out, the corrosion of iron and steel is an electrolytic phenomenon occasioned by the passage of an electric current from one point on the metal to another, it must not be confounded with what is known as "electrolytic corrosion" or "electrolysis due to stray currents." While the action both chemically and physically is in each case identical, it differs in this important respect. The current flowing in the first instance is limited to the very small electromotive force produced by the difference in the solution pressure of hydrogen and iron, retarded more or less by the resistance of the external circuit. In the second case, however, the current may have any strength and is limited only by the difference of potential existing at the two poles of the generating system. The first case may be compared to the abrasions caused by a quietly moving stream through a comparatively level country where the banks are slowly worn away, being deposited somewhere else as silt. The second case is like a leak in a hydraulic main in which water has been placed under a high pressure, and is capable of producing the same action as in the first case, but greatly intensified. The first mode of corrosion is dependent upon the purity of the iron and the other conditions already noted, while the second has been artificially brought about and can to a greater or less extent be controlled.

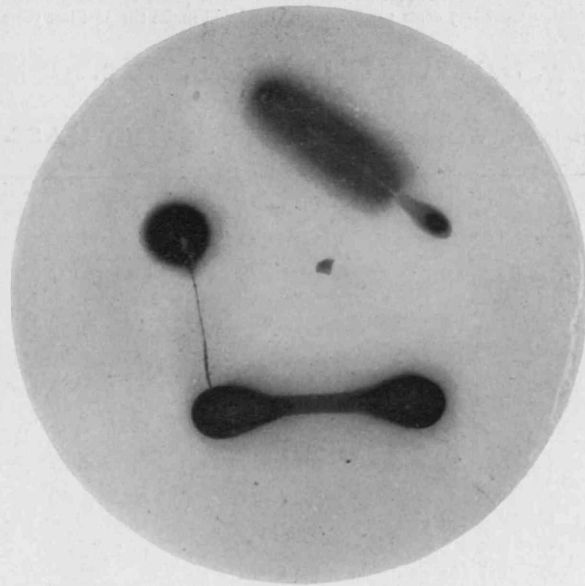
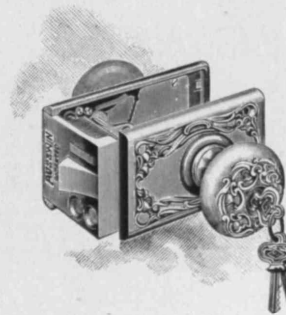


FIG. 4.



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Building-Materials

(Continued from Vol. III, No. 2)

Limes, Cements, Mortars, and Concretes

[These notes were prepared for the students in the Department of Architecture, to serve as a text in a short course of instruction in the classroom. Many authors have been consulted and often copied literally; and as a list of the most important will be given at the end of this article, it has not seemed necessary always to make direct mention of them in the text.—ED.]

CONCRETE. Concrete is a lime or cement mortar in which is thoroughly imbedded a coarse material such as sand gravel, broken stone, shells, etc., thus making a sort of rough rubble masonry. The mortar in this compound is usually called the matrix, or gang; and the coarse materials, the aggregate. As originally accepted, when the matrix was simply lime the mixture was concrete; but when the matrix was cement or otherwise possessed hydraulic energy it was *béton*.

Now the word "concrete" covers any form of this artificial compound, whether the matrix is lime or cement, but a wholly lime matrix is rarely used. It is a wise rule to use Portland cement for nearly all concretes. It is more uniform and therefore more reliable, and its strength is so much greater than that of Natural cement that its ability to carry a larger proportion of aggregate will often give better results at less cost than if Natural cement were used.

The general rule for proportion of matrix to aggregate is that the former shall be somewhat in excess of the voids of the aggregate, to insure each particle being covered by it and also as a precaution against imperfect manipulation. The simple way to find the contents of these voids is by measuring the quantity of water that can be poured into a vessel of known size that has been filled with the aggregate. The aggregate should be of different sizes to reduce the amount of voids, thereby requiring less cement and at the same time making a stronger concrete because more compact.

The object should be for a concrete to contain as much broken material and as little mortar as possible. It is usually specified that the largest of the broken stone or other material shall pass in any direction through a ring measuring two inches in diameter, because large pieces cause straight joints in the mass, weakening its strength to bear strains. The mass of the material should be as homogeneous as possible. A rough, porous stone makes a better aggregate than a hard, smooth one, as the mortar sticks to it better.

PROPORTION FROM PRACTICE. In general practice today a concrete in direct compression, such as the construction of footings, foundations, and basement walls, heavy machinery supports, etc., is specified to be mixed in the proportion of one part Portland cement, three parts sand, and six parts broken stone,— 1 : 3 : 6. This should carry safely a load of twenty-three tons per square foot. In reinforced concrete the proportion becomes 1 : 2 : 4.

A proportion easy to be remembered to be used for ordinary purposes is: Natural cement, one part; sand, two parts; pebbles, three parts; broken stone, four parts,—

1 : 2 : 3 : 4. Such a concrete ought to stand ten days after deposition a load of sixteen to twenty tons to the square foot.

In a portion of the Washington aqueduct extension the proportions for concrete were: Rosendale cement, one part; sand, two parts; broken stone, four parts,— 1 : 2 : 4. At Croton Dam, New York, the proportions for concrete were: Rosendale cement, one part; sand, two parts; broken stone, four and one-half parts,— 1 : 2 : 4½. Some of the same work which was deposited under water had six parts of stone, and at the end of a year had become so hard that it was found necessary to drill and blast a portion that had to be removed.

General Casey tested a concrete made of Portland cement, one part; sand, two parts; pebbles, three parts; broken stone, four parts. It was 138 days old, and showed the first crack at 125 tons, and crushed at 155 tons per square foot. This mixture was used for enlarging the foundations of the Washington Monument.

COQUINA CONCRETE. Perhaps the most interesting application of concretes in this country, at least to the architect, is in the Coquina concrete constructions in St. Augustine, Fla. The proportions of cement, sand, and shell were varied in accordance with the strain to which the concrete was subjected. The greater part of the shell passed through a one-half inch mesh. When a crushing-stress only was to be endured, as in the walls, the proportions were: cement, one part; sand, three parts; shell, three parts; but when a tensile strain was to be sustained, as in the case of lintels, the proportions were: cement, one part; sand, two parts; shell, three parts; and in some instances where unusual strength was required the proportions were: cement, one part; sand, one part; shell, two parts.

The massive walls of the Ponce de Leon Hotel were built upon a foundation of water-packed sand without piling. It was an extreme test of the quality of concrete construction to evenly distribute a load, but the result fully sustained the architects in adopting this bold plan. The cement used throughout the operation was the "Hanover Portland." This cement was selected as a result of comparative tests made in New York previous to the work. Crushing-strain, sustained by blocks of concrete six-inch cube, was equal to seventy tons to the cubic foot, the age being thirty days, and the proportions of the mixture being: cement, one part; sand, three parts; shell, four parts.

During the operation there were 300,000 barrels of this cement used. The engineer in charge made daily tensile tests to detect any possible falling off in the quality of the cement; and although the quality remained generally good, the value of precaution was shown in many instances.

The daily capacity of the concrete mixers was four hundred barrels of cement, making about three hundred cubic yards of concrete. This concrete was taken in barrows to powerful elevators and the barrows themselves hoisted to the different levels, from whence the concrete was dumped through canvas tubes to where it was to be used. It was then spread in six-inch layers, and a first gang of men rammed it with iron rammers six inches square. A second gang followed with rammers eight inches square; and a third gang with still broader rammers completed the course. The men kept up this regular routine round the building until the day's work was done. The final operation on each layer was to roughen its surface with a rake, to receive the next layer. The greatest height accomplished in one day was ten feet, though the average was five. The



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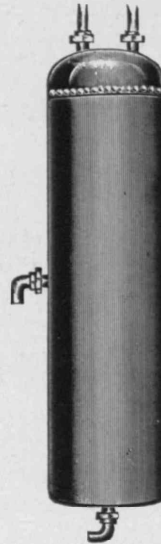
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work was carried on so skilfully that each successive layer could be placed before the set of the preceding one took place. The wooden molds were usually removed twenty-four hours after the placing of the cement, but sometimes sooner.

The walls of the Ponce de Leon were in some cases ten feet thick, and the external walls were never less than two feet thick. The interior walls were also built of this concrete, from eight to twelve inches thick. The concrete laid cost about \$8.00 per cubic yard: the material, mixing, and placing costing about \$2.00 of this.

BETON COIGNET. Béton Coignet is a mixture of Portland cement and lime with large proportions of sand. No gravel or broken stone is used. The proportions vary according to the work the mixture has to do. A stone made of this resisted 100 to 150 tons per square foot three months old, and 240 to 400 tons in two years.

MIXING CONCRETES. The usual method of mixing when done by hand is to first make the cement and sand mortar as already described, which is then spread on a plank floor in an even bed. The broken stone is thoroughly drenched to remove all dust or dirt, and to allow it to absorb all the water it will in this way instead of from the mortar. This wet stone is then spread evenly on the mortar not more than six inches in depth, and the whole is then thoroughly mixed together by turning with shovels.

Sometimes the broken stone is spread first, the smaller pieces at the bottom, and the mortar spread as evenly as possible over this, and then all the materials are thoroughly mixed together with the shovel.

The strength of a concrete depends principally upon the matrix, but also upon the thorough mixing of all the ingredients together so that each part of the aggregate shall be encased in the matrix, and also that there shall be no voids in the mass; to accomplish which this thorough working over is necessary.

Concrete should be made only in such quantities as can be used in less than two hours. Any excess should be condemned.

LAYING. When the concrete is thoroughly mixed it should be at once wheeled to where it is to be used, and gently tipped into place, so that the mass shall remain uniform and the heavier stones not sink to the bottom. It should be slightly rammed in layers from six to nine inches thick. This ramming compacts the mass and so increases its strength.

A slow-setting cement should be used for large work and the layers should follow each other before the last one has time to set. In this way all the layers are well bonded together. If each layer is allowed to set before the next one is laid the upper surface should first be thoroughly wet and roughened with a pick.

When concrete begins to set, on no account must it be disturbed by ramming or walking over for twelve hours. Hence a quick-setting cement should not be used for large work; but if used, should not be rammed. All work in process of hardening should be protected by a temporary plank covering, and should be allowed at least twelve hours to set before anything is laid on it.

The authors in the following list are among those who have made a most thorough study of this subject in bringing it up to date. Many of their works have been consulted and often copied literally in the preparation of these notes.

Report of Board of Engineer Offices on Testing Hydraulic Cements, with Specifications for the Several Classes Used by the Engineer Department. (Professional papers of the Corps of Engineers, U. S. A., No. 28.)

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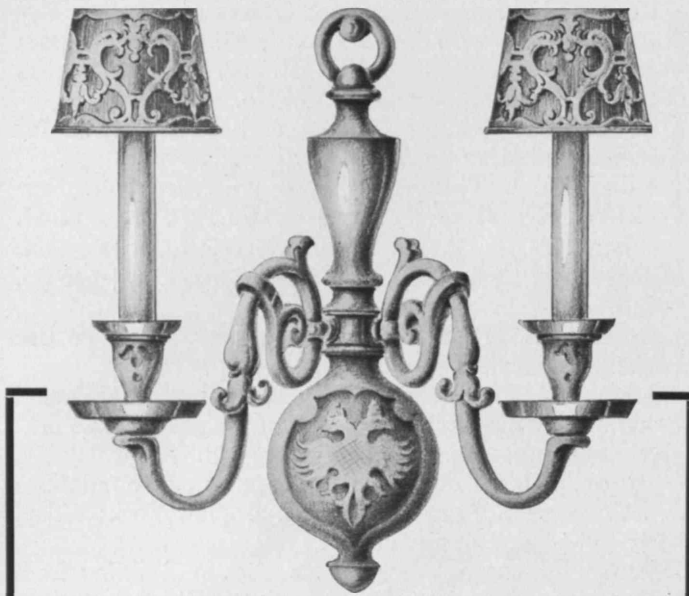
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Thompson, S. E. Reinforced Concrete Chimneys. Philadelphia: Assoc. Amer. Portland Cement Mfr., 1908. 43 pp. O.



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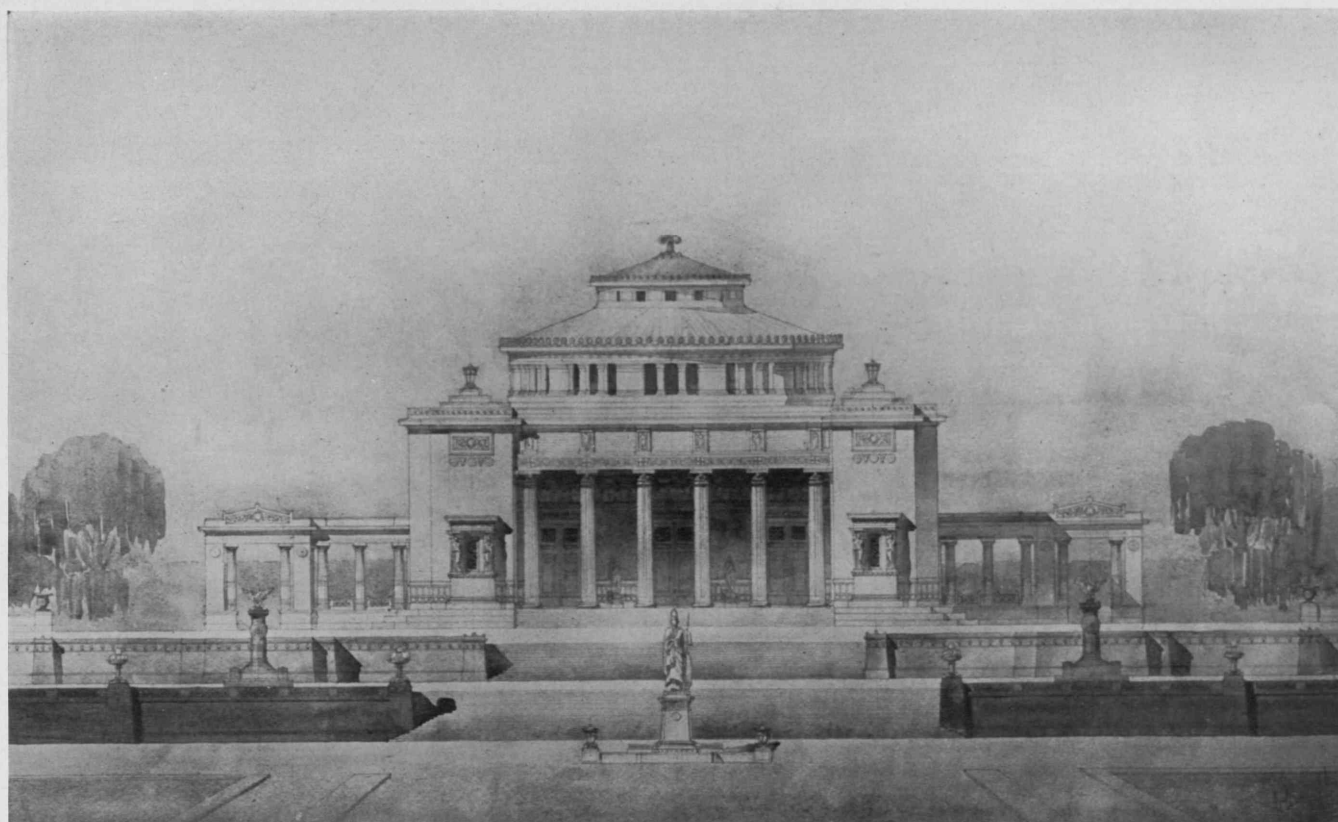
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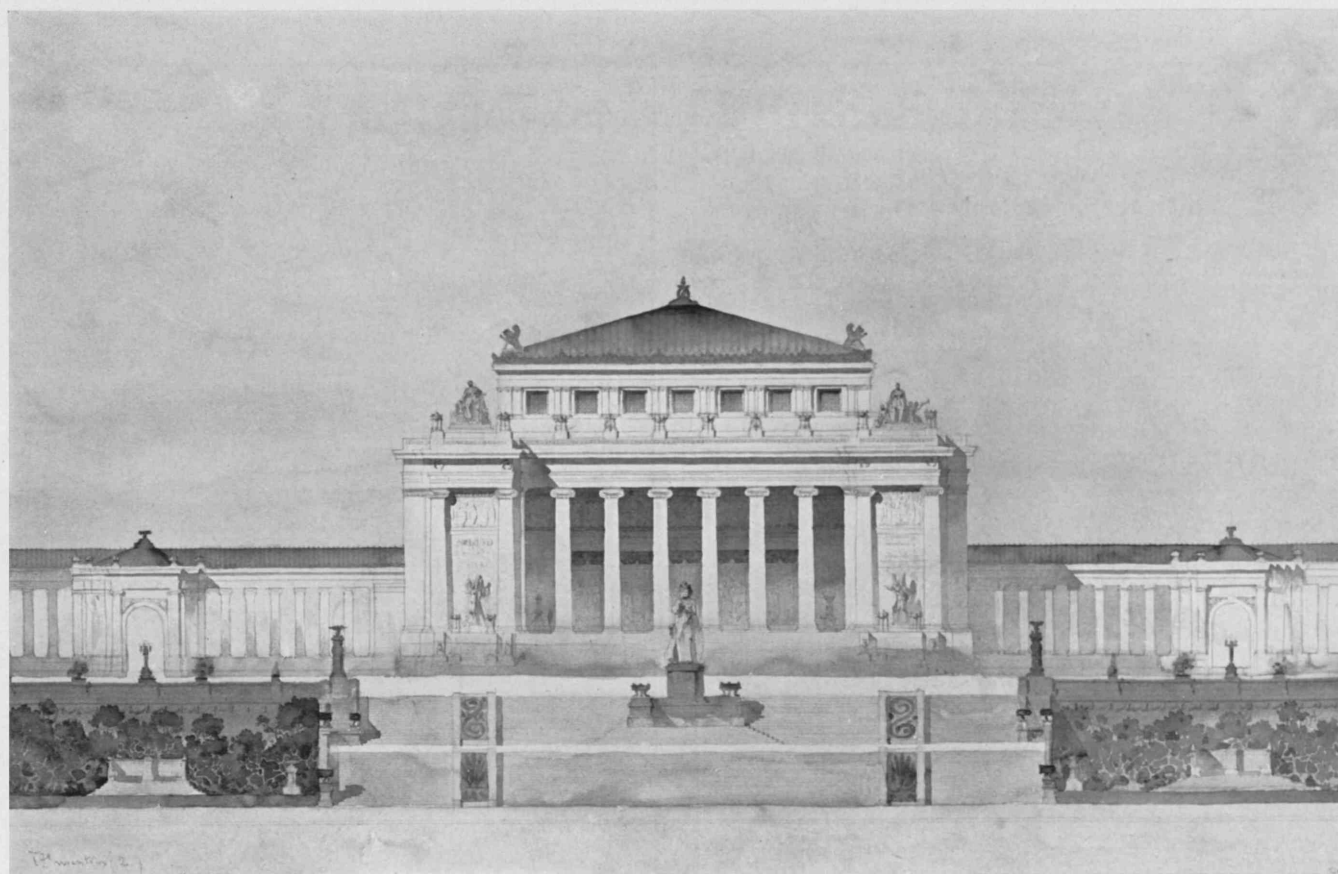
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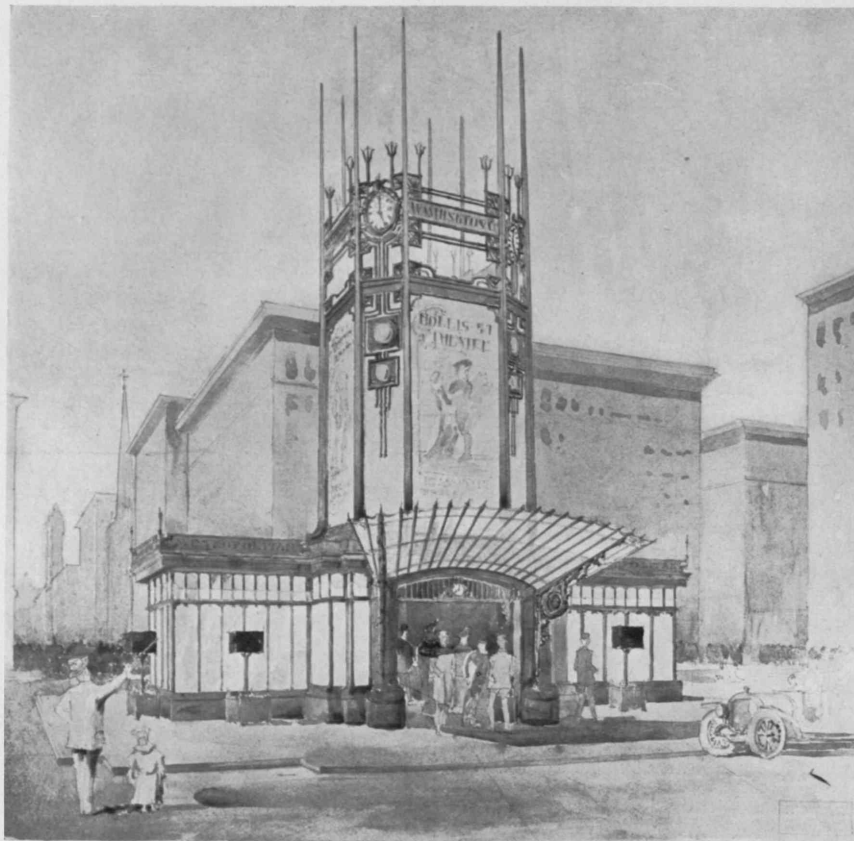
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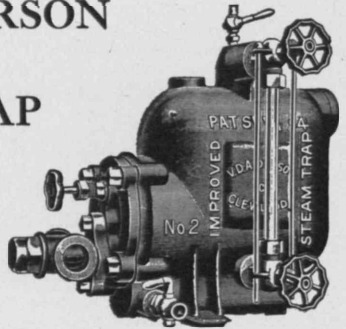
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Alumni Notes

The department is in receipt of many applications from architects and others for assistants. We have no information as to whether our alumni are satisfied with their present positions and prospects, consequently many opportunities for Institute men are doubtless lost.

The Secretary of the Institute will send application blanks to any of our former students who wish to register their names with the view of making a change whenever a suitable opportunity occurs.

T. H. Atherton, Jr., '09, is with Carrère & Hastings, New York City.

In the recent examinations for a license to practise architecture in the State of Illinois, J. C. Bollenbacher, '09, and S. A. Marx, '07, were among the twenty-two successful applicants. Sixty-three men tried the examinations. Bollenbacher is with Lowe, '05, & Ingram, Chicago, Ill., as structural engineer. Marx is in partnership with F. C. Lebenbaum, '06, in Chicago, Ill.

F. A. Burton, '09, and A. F. Menke, '09, will return to the Institute next fall for advanced work.

N. L. Coleman, '09, is with L. R. Bedell, Los Angeles, Cal.

T. G. Machen, '09, is with Wyatt & Nolting, Baltimore, Md.

Miss M. K. Babcock, '08, announces that she has opened an office at 104 Washington St., Wellesley Hills, Mass., and is prepared to undertake the laying out of country estates, playgrounds, suburban places, and other landscape work. At the annual meeting of the Hills and Falls Village Improvement Society of Wellesley on April 23 Miss Babcock gave an informal illustrated talk entitled "Some Suggestions for the Improvement of Suburban Home Grounds at Small Expense."

S. O. Clements, '08, is in the office of W. W. Bosworth, '89, New York City.

R. G. Crane, '08, is in the office of Cass Gilbert, New York City.

R. T. Hyde, '08, who left the Institute in 1907 to go to Paris to study painting, has recently returned to this country. He hopes, however, to go back to Paris within a year.

Thomas Owings, '08, is in Paris.

C. F. Baker, '07, has returned from his trip abroad, and is again in the office of Holabird & Roche, Chicago, Ill. He writes, "I enjoyed my trip to the fullest extent, and feel that I gained much along many lines, but I am glad to be at work again."

W. A. Gates, '07, is an engineer and superintendent for Layton, Smith & Hank, Oklahoma City. He writes, "This whole country is developing very rapidly, and I think it has a great future. Oklahoma City in particular seems destined to be a large city. Two years ago there was not a building over three stories. Now they are building ten and twelve story buildings so fast that some of the streets are impassable. The larger buildings are mostly first-class construction; but the smaller ones, particularly residences and flat buildings, are marvels of flimsiness. I am getting used to it now, but when I first came out here I expected to see some of them fall down before they were completed."

W. B. Kirby, '07, has returned to the Institute to take part in the 1910 Traveling Fellowship Competition.

E. S. Campbell, '06, who since 1907 has been instructor in architecture at the Carnegie Technical Schools, has been advanced to the rank of associate professor, and granted a year's leave of absence for study in Europe.

J. J. Donovan, '06, has opened an office at 437 Fifth Ave., New York City.

A. W. Hertz, '06, formerly of Kansas City, is now in New York.

S. T. Strickland, '05, who has been studying in Paris most of the time since graduation, has returned home, and anticipates locating in Chicago, Ill.

L. C. Clarke, Jr., '04, has gone abroad.

G. Neville Wheat, '04, is now located in Houston, Tex.

F. H. C. Garber, '02, of the firm Garber & Woodward, '02, Cincinnati, O., is planning for the near future a six-weeks' trip to Northern Italy to study Italian terra cotta and brickwork.

The marriage is announced of W. T. Aldrich, '01, and Miss Dorothea Davenport, of Boston, on March 28.

E. F. Lawrence, '01, formerly of MacNaughton, Raymond & Lawrence, may be found at 613-615 Lewis Building, Portland, Ore., where he will continue the practice of architecture. He will also maintain an office in the Ransom Building, Walla Walla, Wash., and has associated with himself in that office Mr. J. J. Burling.

J. Lovell Little, Jr., '01, has illustrations of three plaster houses in the November number of *The Architectural Review*.

H. H. Saylor, '01, formerly on the staff of *Country Life in America*, is now editor of *House and Garden*.

W. P. Rand, '00, is engaged in designing structural work for buildings in the office of F. A. Burdett, Consulting Engineer, New York City.

E. L. Gerber, '99, and wife sail, June 11, for Europe, returning in February, 1911.

Bliss, '95, & Faville, '96; Guy Lowell, '94; Rankin, '90, Kellogg, '87, & Crane, '90; E. P. Whitman, '92; Wood, Donn, '91, & Deming, are among the twenty-five architects invited by the municipal authorities of Oakland, Cal., to submit plans for the new one-million-dollar city hall. J. G. Howard, '86, is the consulting architect for the Board of Public Works in this competition.

E. C. Klipstein, '94, is in partnership with W. L. Rathmann, with offices in the Chemical Building, St. Louis, Mo.

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Biscoe, '93, & Hewitt, '99, of Denver, Col., have in the March issue of *The Architectural Record* a design for the proposed civic center of Denver.

Coolidge, '92, & Carlson, '92, have removed their offices to 89 State St., Boston, Mass. Mr. Carlson gave a talk to the fourth-year students, recently, on "How an Architect's Practice Grows."

Current Work of the Alumni Illustrated in the Magazines

AMERICAN ARCHITECT.

- January 5, Kilham, '89, & Hopkins, '96, House, Bristol, R. I.
 " 5, O. C. Hering, '97, House, Abington, Penn.
 " 5, J. Purdon, '96, House, Leominster, Mass.
 " 12, Coolidge, '92, & Carlson, '92, Squash Court, No. Easton, Mass.
 " 12, C. H. Johnston, '80, Dormitory, University of Minnesota, Minneapolis, Minn.
 " 12, Wheelwright, '78, & Haven, Boston Opera-house, Boston, Mass.
 " 26, Davis, '92, & Brooks, Schoolhouses, New Britain and Willimantic Conn.
 " 26, Davis, '94, McGrath & Kiessling, Schoolhouse, Leonia, N. J.
 February 2, Rankin, '90, Kellogg, '87, & Crane, '90, Government Building, Philadelphia, Penn.
 " 23, Tallmadge, '98, & Watson, Garage, Riverside, Ill.
 March 9, Kilham, '89, & Hopkins, '96, Recent Work of
 " 30, Rankin, '90, Kellogg, '87, & Crane, '90, Barracks in Philadelphia Navy-yard.
 April 6, G. Lowell, '94, Building for Music, House, Bar Harbor, Me.
 " 13, Elzner, '87, & Anderson, House, Cincinnati, O.
 " 13, Foote, '80, & Headley, House, Rochester, N. Y.
 " 13, J. W. Lavalle, '87, House, Brookline, Mass.
 " 13, J. Purdon, '96, House, Dover, Mass.
 May 3, Foote, '80, & Headley, House, Rochester, N. Y.

ARCHITECTURAL REVIEW.

- October, Wood, Donn, '91, & Deming, Y. M. C. A. Building, Norfolk, Va.
 November, J. L. Little, Jr., '01, Houses near Boston, Mass.
 December, Shepley, '82, Rutan & Coolidge, '83, Three Plaster Houses.

ARCHITECTURAL RECORD.

- February, Hill & Woltersdorf, '94, Commercial Buildings, Chicago, Ill.
 " Schmidt, '87, Garden & Martin, Commercial Buildings, Chicago, Ill.
 March, H. V. Shaw, '94, Commercial Buildings, Chicago, Ill.
 April, H. V. Shaw, '94, Commercial Buildings, Chicago, Ill.

ARCHITECTURE.

- January, Hoppin, '89, & Koen, Police Headquarters, New York City.
 " G. Lowell, '94, Museum of Fine Arts, Boston, Mass.
 " W. C. Zimmermann, '81, House, Chicago, Ill.
 February, Parker, '95, Thomas, '95, & Rice, '91, Hotel Belvedere, Baltimore, Md.
 March, Parker, '95, Thomas, '95, & Rice, '91, Union Boat Club, Boston, Mass.
 " Davis, '94, McGrath & Kiessling, House, Glen Ridge, N. J.
 " Shepley, '82, Rutan & Coolidge, '83, Old Colony Trust Co. Building, Boston, Mass.
 " Wheelwright, '78, & Haven, Harvard Lampoon Building, Cambridge, Mass.
 April, Fernekes & Cramer, '96, House, Oconomowoc, Wis.
 " Wheelwright, '78, & Haven, Harvard Lampoon Building, Cambridge, Mass.

BRICKBUILDER.

- January, Green & Wicks, '76, State Fair Buildings, Syracuse, N. Y.
 " Harding, '89, & Seaver, '97, Schoolhouse, Pittsfield, Mass.
 " Tallmadge, '98, & Watson, House, Riverside, Ill.
 " Wheelwright, '78, & Haven, Boston Opera-house, Boston, Mass.
 February, F. M. Chace, '04, & W. W. Cook, 1st Prize Design, Brickbuilder Competition for a Public Bath and Gymnasium.
 " W. F. Dolke, Jr., '08, Submitted Design in Competition.
 " M. Lichtenstein, '06, Submitted Design in Competition.
 March, Hunt & Hunt, '82, House, New York City.
 " C. H. Johnston, '80, State Prison, Stillwater, Minn.
 " Parker, '95, Thomas, '95, & Rice, '91, Union Boat Club House, Boston, Mass.
 " Stratton & Baldwin, '92, Bathhouse, Detroit, Mich.
 " Wheelwright, '78, & Haven, Harvard Lampoon Building, Cambridge, Mass.
 April, W. W. Bosworth, '89, Country Club House, Schenectady, N. Y.
 " Davis, '92, & Brooks, Country Club House, Farmington, Conn.
 " Elzner, '87, & Anderson, Country Club House, Cincinnati, O.
 " Foltz & Parker, '89, Country Club House, Indianapolis, Ind.
 " Garber, '02, & Woodward, '02, Country Club House, Wyoming, O.
 " A. Garfield, '96, Country Club House, Cleveland, O.
 " Green & Wicks, '76, Country Club House, Buffalo, N. Y.
 " H. E. Hewitt, '94, Country Club House, Peoria, Ill.
 " Mauran, '89, Russell & Garden, Country Club House, Clayton, Mo.
 " Meade, '89, & Garfield, '96, Country Club House, Cleveland, O.
 " J. Purdon, '96, Country Club House, York Harbor, Me.
 " H. V. Shaw, '94, Country Club House, Flossmore, Ill.
 " Tietig, '98, & Lee, '98, Country Club House, Cincinnati, O.
 " H. L. Walker, '00, Country Club House, Atlanta, Ga.
 " A. F. Rosenheim, '81, Church, Los Angeles, Cal.



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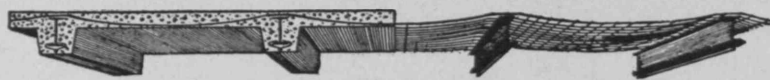
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