	Cobrimento, Corrosão e Durabilidade Primeiras pesquisas sobre corrosão das armaduras no concreto armado - 1912 - USA	Prof.. Eduardo C. S. Thomaz Notas de aula

1 - Artigo da Revista Brasileira de Engenharia / 1926, sobre Cobrimento, Corrosão e Durabilidade no Concreto Armado.

Esse artigo faz referência às pesquisas:
https://ia800308.us.archive.org/1/items/actionofsaltsin191212bate/actionofsaltsin191212bate.pdf
do Bureau of Standards / USA, do ano de 1912.

2- Resumo dessas pesquisas do Bureau of Standards:

ACTION OF THE SALTS IN ALKALI WATER AND SEA WATER ON CEMENTS , *do Bureau of Standards / USA / 1912*

https://ia800308.us.archive.org/1/items/actionofsaltsin191212bate/actionofsaltsin191212bate.pdf

contendo as pioneiras experiências feitas por

- ***P. H. BATES, Chemist***
- ***J. PHILLIPS, Assistant Chemist***
- ***RUDOLPH J. WIG, Associate Engineer Physicist***

sobre corrosão do concreto e das armaduras no concreto armado.

3- Desde o início do uso do Concreto Armado, nota-se a preocupação com a corrosão das armaduras e com o ataque dos sulfatos aos concretos.

Eduardo Thomaz

1926 - Cobrimento, Corrosão e Durabilidade

REVISTA BRASILEIRA DE ENGENHARIA

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1926

ANNO VI — TOMO XII — N.º 3 — SETEMBRO DE 1926

SUMMARIO

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1926

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DIRIGIDA POR J. PANTOJA LEITE

(PROFESSOR CATHEDRATICO DA ESCOLA POLYTECHNICA DO RIO DE JANEIRO)

ANNO VI — SETEMBRO DE 1926. — TOMO XII — N.º 3

SUMMARIO

A corrosão das Armaduras Metallicas mergulhadas no Concreto

As construcções em concreto armado constituem hoje, mais do que nunca, objecto de estudos e investigações. A sua resistencia á acção do tempo tem, principalmente, merecido attenção especial.

Como disse um engenheiro especialista em concreto, «In the early days, the general opinion was to the effect that concrete in general was as permanent as the Rock of Gibraltar. Then we found that certain agents attack concrete. Now we are studing earnestly to find what ones do not.»

Alguns engenheiros eminentes, cuja competencia no assumpto dispensa qualquer prova, são hoje de opinião que as construcções de concreto armado não são duraveis, salvo nos casos em que tenha sido feito um acurado estudo de todos os factores que nelle possam ter influencia, e, além disso, se tenha tido o importante cuidado de escolher os materiaes a empregar, entre os mais aptos a concorrer para a efficacia do conjuncto.

De accôrdo com os estudos até agora feitos, póde-se, com plena autoridade, affirmar que o concreto, em geral, é bastante poroso, permittindo a penetração da humidade, e, portanto, a sua acção sobre o metal de reforço. Considerando que a ferrugem tem um volume sete vezes superior ao do ferro que contribuiu para a sua formação, torna-se evidente a extraordinaria gravidade que a porosidade do concreto representa. Principalmente nas peças em que a porcentagem de ferro é importante, as acções dessa natureza são muito de temer.

Está provado que a pressão exercida pela ferrugem formada no interior da massa de concreto é sufficiente para fazel-a estalar, mesmo que as armaduras se achem protegidas de uma espessa camada de argamassa; e as fendas assim produzidas tornarão mais facil a penetração da humidade, apressando a deterioração das armaduras.

Em um relatorio sobre «A Ferrugem no Concreto», publicado no numero de Abril de 1926, dos «Actos da Sociedade Americana de Engenheiros Civis», ficou provado que, em determinados concretos, bastante porosos, a penetração da humidade póde perfeitamente attingir o centro da massa. Diz mais o referido relatorio, que isso já se tem verificado varias vezes na pratica, e que, dentro de 10 ou 20 annos, devido, provavelmente, ao grande incremento que tem tomado a industria do concreto armado, se constatará um grande augmento nos estragos produzidos pela ferrugem, em obras desse genero.

Em uma publicação intitulada «The Corrosion of Steel, It's Cause and Prevention», Maximilian Toch tratou desse assumpto em um artigo, especialmente dedicado ao concreto armado. Segundo esse autor, é um erro acreditar que o concreto evita a ferrugem. Constatou elle que, uma mesma armadura de aço póde não soffrer nenhum ataque mergulhada em uma argamassa de cimento e areia na proporção de 1:1, e ser completamente corroida si a mergulharmos em um concreto do traço 1,5:2,5:5.

O mesmo engenheiro já citado, Maximilian Toch, em um trabalho intitulado «Chemistry and Technology of Paints», diz, á pagina 279, no capitulo «Electrolytic Corrosion of Structural Steel», que o ferro mergulhado no concreto, ou mesmo em cimento puro, não se póde libertar da acção electrolytica, salvo quando isolado electricamente da massa que o cerca. Depois de citar varias experiencias, diz: «O resultado de toda esta série de experiencias serve para provar concludentemente que a corrosão electrolytica das armaduras de aço embebidas em concreto ou areia se dá sómente no anodo, e com grande violencia; e, ainda mais, que o cathodo é protegido pela corrente electrica. A crença popular de que o concreto é um protector contra toda a sorte de corrosões, é errada. O anodo não sómente se oxyda muito violentamente, como augmenta de volume a ponto de fazer estalar a camada de concreto.»

Em um trabalho technico (Nº 3) do *Bureau of Standards, chamado «Test of the Absortive and Permeable Properties of Portland Cement Mortar and Concrete together With tests of Damp Proofing and Water-proofing Compounds In Material»*, lê-se o seguinte: «In large or exposed work it is practically impossible to prevent some cracks.»; e ainda, que as fendas são geralmente devidas á acção e tambem a dilatação e contracção do concreto, causadas pelas mudanças de temperatura.

Estas fendas são quasi inevitaveis em peças sujeitas a grandes variações de temperatura e de trabalho mecanico, como, por exemplo, os conductos forçados.

Qualquer que seja a localisação da fenda, a humidade entrará por ella, até alcançar a armadura metallica; e si a natureza desta permittir a corrosão sob fórma tubercular, como, por exemplo, o aço, a força de expansão da ferrugem em breve determinará a formação de novas fendas, annullando completamente a protecção representada pela camada de concreto que cobre a armadura.

Outra contribuição importante para o esclarecimento da questão em estudo é o trabalho technico pøblicado sob o numero 12 pelo *Bureau of Standards*, trabalho esse intitulado: «*Action of the Salts and Alkali Water and Sea Water on Cement*». Relatando uma experiencia realisada em telhas de concreto, diz que, praticamente, todo o metal que fôr introduzido uma pollegada para dentro na superficie cylindrica, é mais ou menos corroido, e mostra casos em que elle é corroido por completo. Os peritos que procederam a esta experiencia, chegaram á conclusão de que é arriscado deixar o reforço metallico a menos de duas pollegadas da superficie do concreto, mesmo no caso de não haver fendas, e de se manter a mais completa uniformidade na mistura dos ingredientes.

1912 / 1926

VER REFERÊNCIA NA PRÓXIMA PÁGINA

CONCLUSÃO

É conveniente ter em vista que todas as autoridades citadas nas linhas acima são faforaveis ás construcções em concreto armado, aconselhando, porém, as maiores precauções no seu uso, pois cada vez mais se constata a facilidade com que as suas armaduras se deterioram pela ferrugem. Devido á sua grande superioridade, sob innumeros pontos de vista, o emprego do concreto armado se torna vantajoso em grande numero de casos; mas é evidente que, para salvaguardar da ferrugem as suas armaduras, inevitavelmente sujeitas á humidade, deve-se escolher material apropriado, que apresente em menor escala os inconvenientes decorrentes da deterioração da peça pela farrugem.

A ferrugem do aço é do typo concavo, tubercular e expansivo, isto é, cada camada de ferrugem que se fórma é naturalmente expulsa, continuando sob ella a acção dos agentes que a determinaram. A ferrugem do ferro puro, ao contrario, é um oxydo impermeavel, protector, portanto, e se fórma em camadas tão finas que a sua acção expansiva é muito pouco pronunciada.

NBR6118 - 2019

2019

Tipo de estrutura	Componente ou elemento	Classe de agressividade ambiental (Tabela 6.1)			
		I	II	III	IV [c]
		Cobrimento nominal mm			
Concreto armado	Laje [b]	20	25	35	45
	Viga/pilar	25	30	40	50
	Elementos estruturais em contato com o solo [d]	30		40	50

1912

Technologic Papers

of the

Bureau of Standards

S. W. STRATTON, Director

No. 12

ACTION OF THE SALTS IN ALKALI WATER AND SEA WATER ON CEMENTS

DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 12

ACTION OF THE SALTS IN ALKALI WATER AND SEA WATER ON CEMENTS

1912

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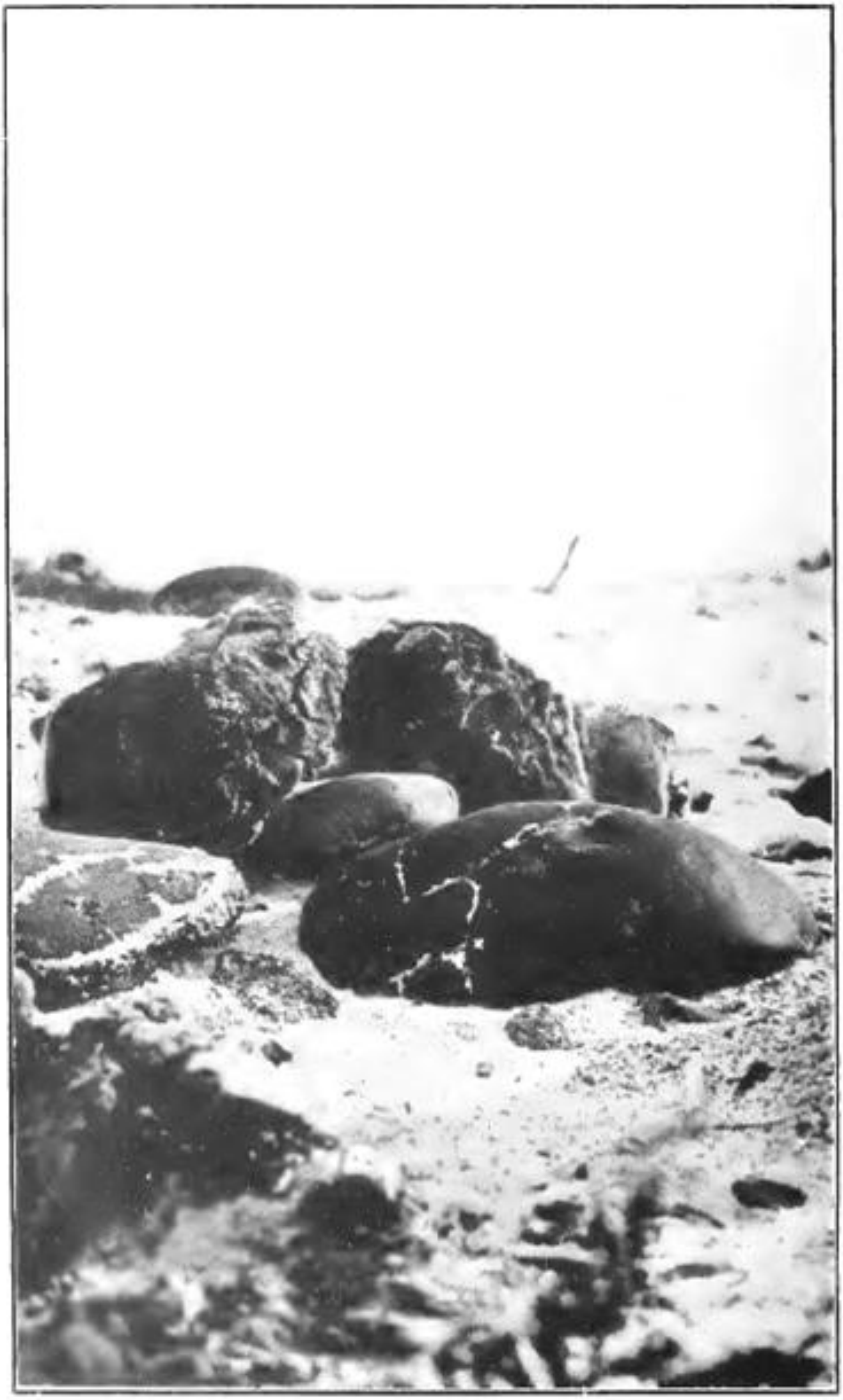
Bureau of Standards

[NOVEMBER 1, 1912]

WASHINGTON

GOVERNMENT PRINTING OFFICE

1913



Disintegrated concrete and bowlders, showing alkali in crevices, at Lateral "W," Shoshone Project, Wyo.

weeks to two years. The results of these tests are given in Tables 22 and 23 (p. 142).

The concrete for the test pieces reported in Table 22 was made in the proportion of 1 part Portland cement to 1 part sand to 5 parts gravel, which was found by test to be the mixture which gave the maximum density for these materials where the ratio of cement to aggregate was 1 to 6. Practically all of the metal

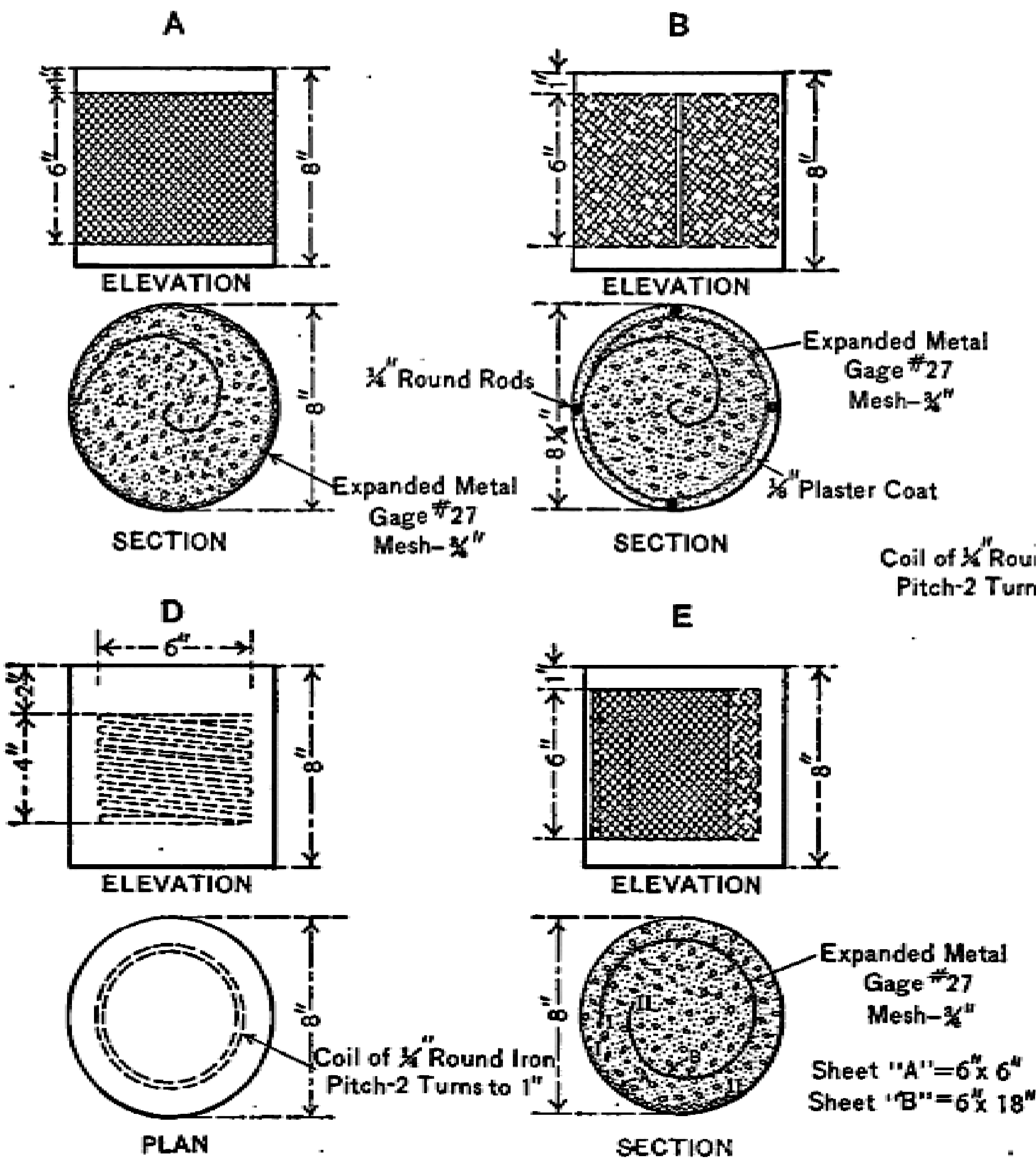
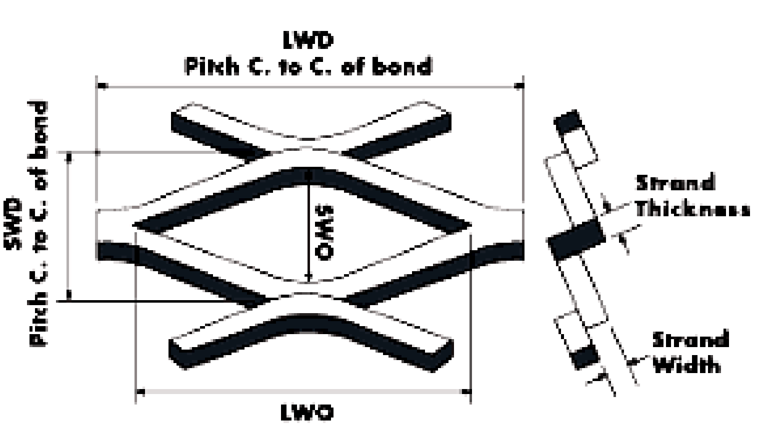


Fig. 30.—*Diagram of metal corrosion test pieces*



EXPANDED METAL

embedded within an inch of the cylindrical surface is more or less corroded. Where the metal was placed as shown in Fig. 30a, it is corroded somewhat to the depth of about an inch from the cylindrical surface, and in some cases the entire metal is corroded. In the case of the spiral reinforcement, which was embedded within about an inch of the cylindrical surface, it was practically all more or less corroded. While the 1:1:5 proportion gave the maximum density for these materials, undoubtedly a mixture containing a greater percentage of fine material would have been more efficient in coating and protecting the metal.

All of the metal embedded 2 inches or more from the surface is practically clean, and there seems to be no difference in the condition of the metal whether the concrete was immersed or placed between tides.

From the results given in Table 23 (p. 144) it will be observed that, although the metal in the interior did not extend to the outer surface, the metal within an inch of the surface was in most cases somewhat corroded, while that 2 inches or farther from the surface was practically clean.

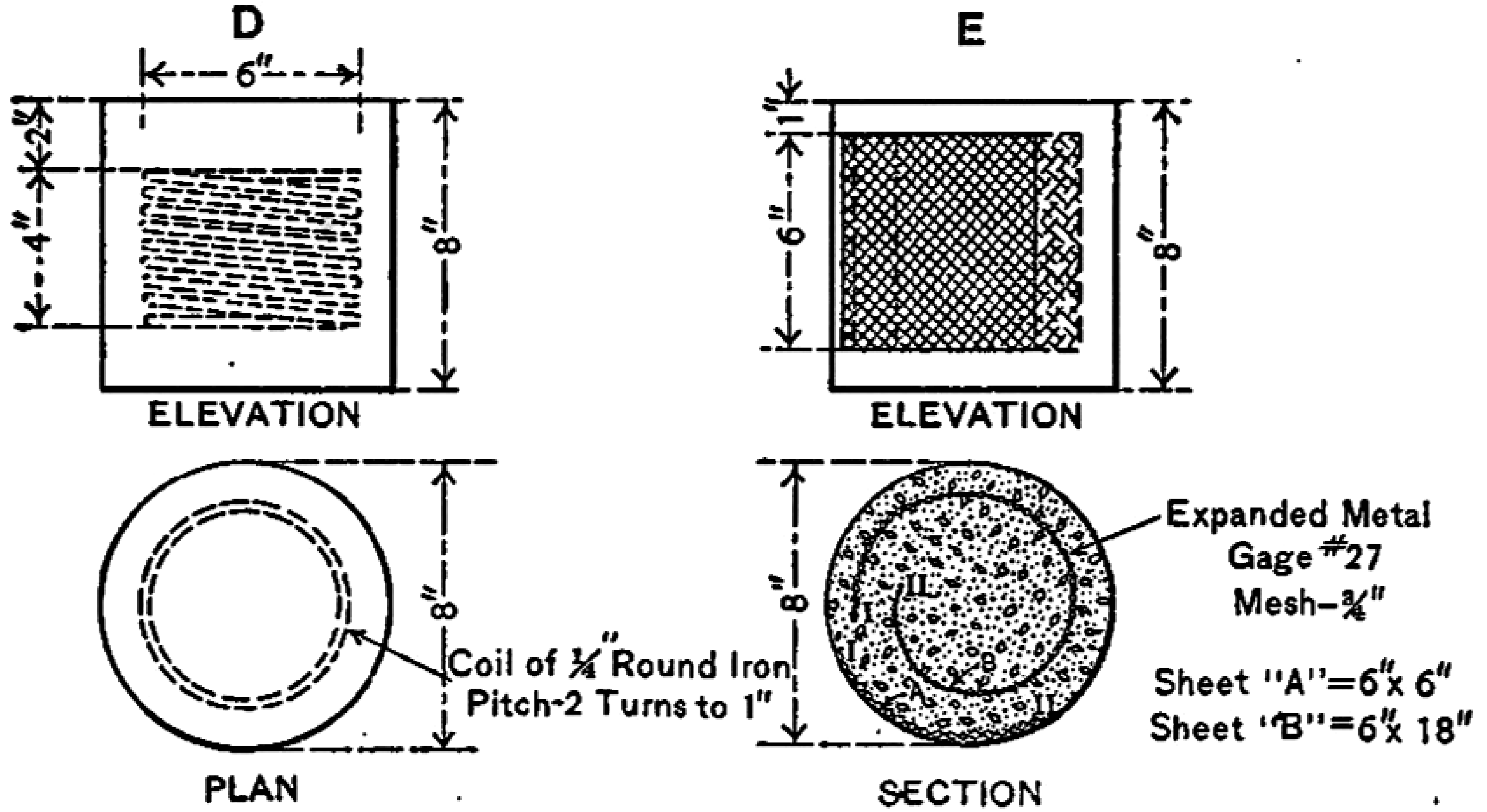


Fig. 30.—*Diagram of metal corrosion test pieces*

SULFATO DE MAGNÉSIO É MUITO AGRESSIVO.

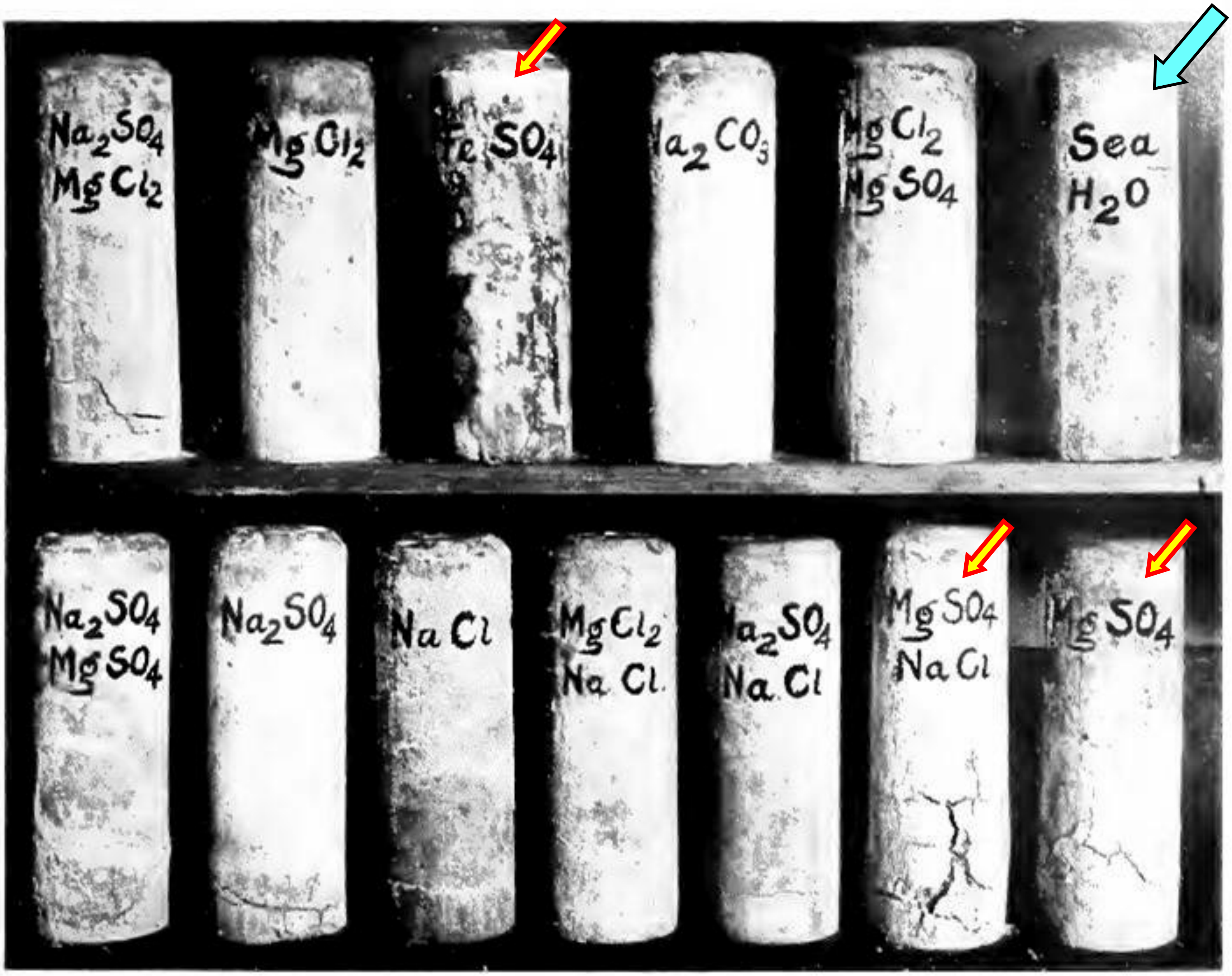


Fig. 1.—*Hollow cylinders composed of one part Portland cement to two parts sand after exposure to various solutions*

"As a rule it was noticed at the projects visited that with increasing amounts of magnesium sulphate disintegration was greater, although this was not always the case. As it had been previously found in sea water, this action occurs at the water line, extending from the low-water line to a few inches above the high-water line, caused no doubt by the concentration of salts at this point from the evaporation of the water."

SULFATOS DE MAGNÉSIO E DE SÓDIO SÃO MUITO AGRESSIVOS AO CONCRETO.

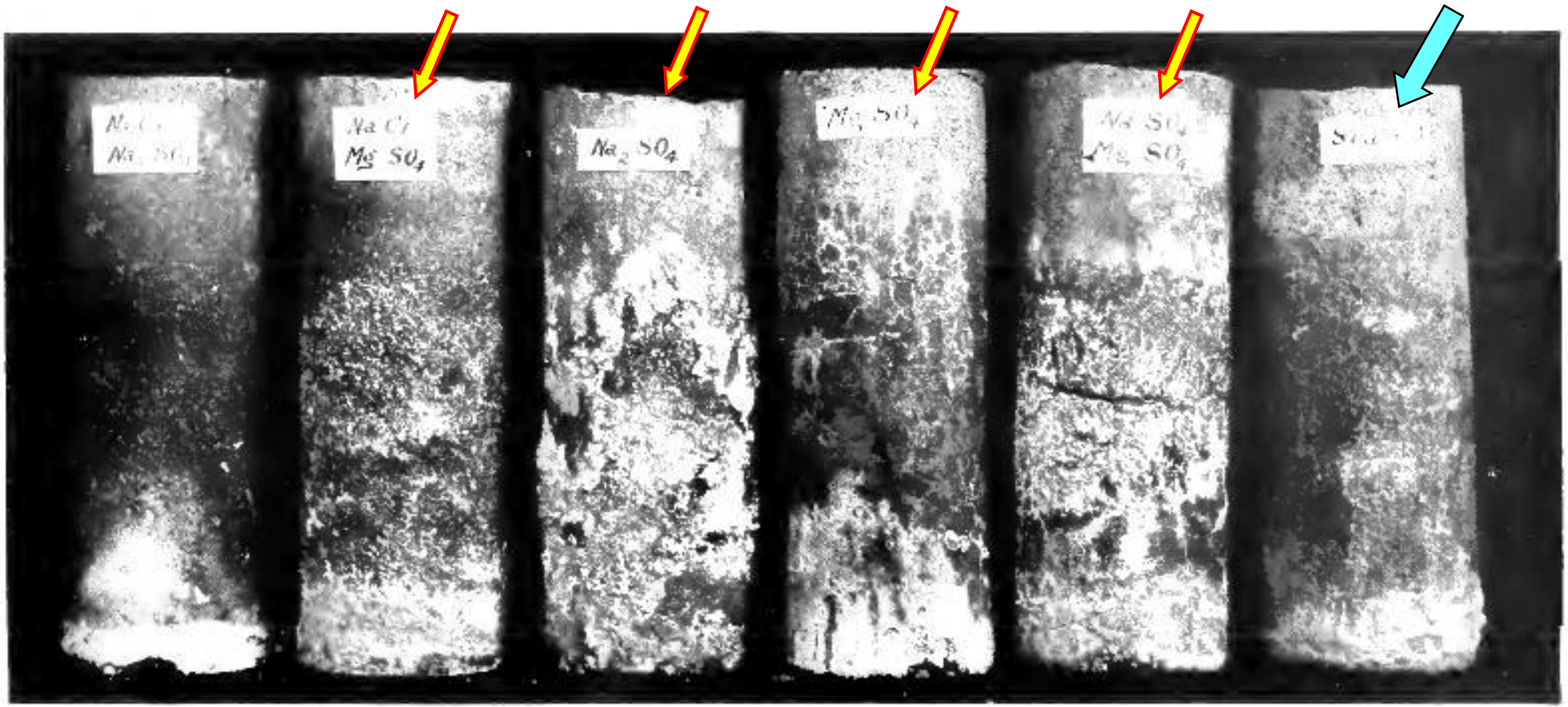


Fig. 2.—*Hollow cylinders composed of one part Portland cement to three parts of sand after exposure to various solutions*

Fig. 19.—*Crate with concrete test pieces before placing in sea water*

ANTES

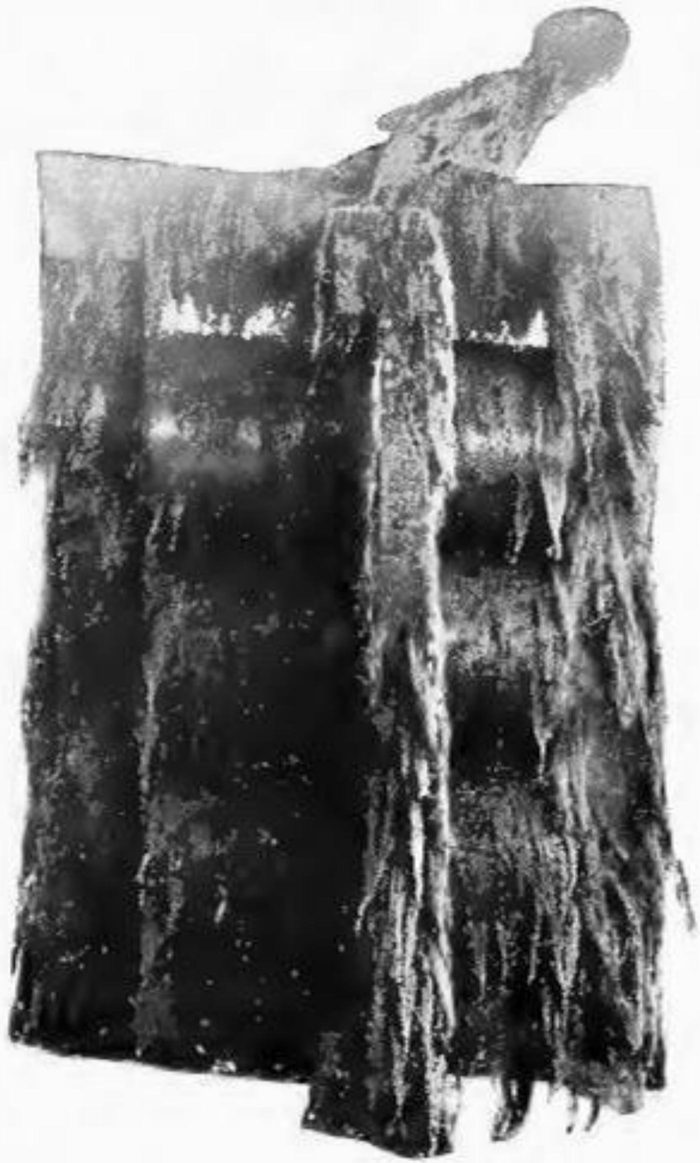


Fig. 20.—*Crate with concrete test pieces after storage in sea water*

DEPOIS

OBS. : REAÇÕES QUÍMICAS NO ATAQUE AO CONCRETO PELOS SULFATOS

2001 - DURABILIDADE - ATAQUE POR SULFATOS

***Joana de Sousa Coutinho* - FEUP - Faculdade de Engenharia da Universidade do Porto**

http://www.deecc.ufc.br/Download/TB819_Patologia_e_Recuperacao_de_Estruturas_de_Concreto/ATAKSulfato.pdf

Em geral o ataque por sulfatos incide sobre o aluminato tricálcico do cimento hidratado.

$3CaO.Al_2O_3$ (designação simplificada C_3A).

Em ambientes químicamente agressivos, a degradação resultante do ataque por sulfatos, para uma determinada dosagem de cimento, depende claramente do teor de C_3A (aluminato tricálcico) desse cimento, dependência que vai sendo menos notória à medida que a dosagem aumenta– Figura 2 (Gonçalves, 2000).

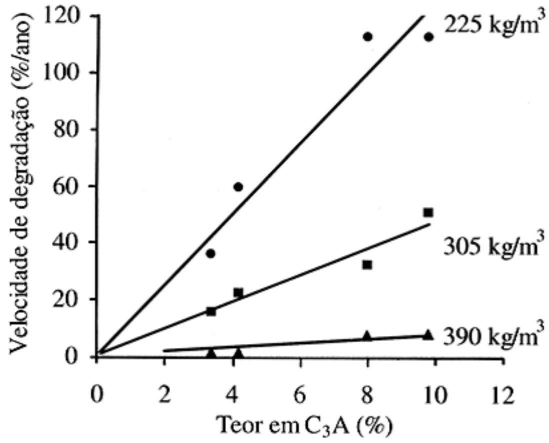


Figura 2 – Influência da dosagem de cimento e do seu teor de C3A na resistência do betão ao ataque por sulfatos (Gonçalves, 2000)

Todos os sulfatos levam à deterioração do betão de cimento Portland mas o mecanismo e grau de ataque dependem do tipo de sulfato presente.

Sulfato de cálcio e sulfato de sódio

Enquanto que o sulfato de cálcio apenas reage com o aluminato de cálcio hidratado para formar sulfoaluminato de cálcio, o sulfato de sódio reage com o hidróxido de cálcio livre, formando-se sulfato de cálcio que por sua vez reage com a aluminato.

Reacção com sulfato de sódio:

$$Ca(OH)_2 + Na_2.SO_4.10H_2O \longrightarrow \underset{\text{gesso}}{\underline{CaSO_4.2H_2O}} + 2NaOH + 8H_2O \qquad (1)$$

Reacção com sulfato de cálcio:

$$\underset{\text{aluminato}}{\underline{4CaO.Al_2O_3.19H_2O}} + 3(\underset{\text{gesso}}{\underline{CaSO_4.2H_2O}}) + 16H_2O \longrightarrow \underset{\text{etringite}}{\underline{3CaO.Al_2O_3.3CaSO_4.31H_2O}} + Ca(OH)_2 \qquad (2)$$

A reacção (1) prossegue enquanto houver condições para tal. Por exemplo, em água corrente com fornecimento constante de sulfato de sódio e remoção do hidróxido de sódio formado, a reação prosseguirá até ao fim. No entanto se o hidróxido de sódio se acumular, atingir-se-á um equilíbrio dependendo da concentração de sulfato de sódio.
Por exemplo, para uma concentração de 5% de sulfato de sódio só cerca de um terço do trióxido de enxofre é depositado como sulfato de cálcio quando o equilíbrio é atingido e para uma concentração de 2%, cerca de um quinto.

Sulfato de magnésio :

O sulfato de magnésio tem uma ação mais devastadora do que os outros sulfatos pois decompõe os silicatos de cálcio hidratados e reage com os aluminatos e hidróxido de cálcio. (como os ensaios do Bureau of Standards já mostravam em 1912, ver acima)

$$3CaO_2.SiO_2\ aq. + MgSO_4.7H_2O \longrightarrow 3(\underset{\text{gesso}}{\underline{CaSO_4.2H_2O}}) + 3Mg(OH)_2 + 2SiO_2 aq.$$

LABORATÓRIO NO MAR

Fig. 17.—*Laboratory at Atlantic City, N. J.*

TABLE 23

Corrosion Tests of Metal Embedded in Concrete Cylinders Immersed in Sea Water

[Expanded metal to be placed as per Fig. 29e]

Number of test piece	Materials in aggregate and proportions. 1 part Portland cement to—	Age of test pieces, in weeks	Actual placing of metal: Thickness of concrete covering, in inches: Sheet A: End I	Sheet A: End II	Sheet B: End I	Sheet B: End III	Actual placing of metal: Distance of metal from top surface, in inches: Sheet A: End I	Sheet A: End II	Sheet B: End I	Sheet B: End III	Depth of penetration of sea water in from surface, in inches	Description of extent of corrosion of metal: Sheet A	Description of extent of corrosion of metal: Sheet B	Remarks
37	6 parts pit run gravel No. 55.	8	½	1/16	1	1½	1¼	1¼	¾	¾	Damp to depth of Sheet A.	Very slight corrosion	Brownish tinge near top.	Sheet A was entirely covered.
38		13	3/16	¼	½	2 1/16	⅝	⅞	¾	¾	½ inch	Heavy corrosion where exposed; light corrosion where covered.	Light corrosion especially at top.	Section 2 inches square of Sheet A near top was exposed.
39		26	½	¼	½	2 1/16	1 1/16	1¼	½	¾	Entirely through	Coating of rust on both surfaces of metal, being heaviest where exposed.	Lightly rusted along edges.	Section of Sheet A 4 by 1 inches exposed.
40		52	⅛	1/16	1 1/16	2½	1¼	1⅜	⅝	1¼	½ inch	Slightly rusted in places	Light rust near edge at End I.	Sheet A entirely covered; one rust spot on cylinder.
41		78	1/16–½	3/16–¼	⅝	1⅝	1¼	1¼	1 1/16	1¼	Entirely through	Badly corroded where exposed; heavy rust where covered.	Light rust along edge, especially at End I.	Section 2 by 5 inches of Sheet A was exposed by flaking off of concrete.
42	1 part gravel No. 55 below ¾-inch sieve and 5 parts gravel No. 55 above ¾-inch sieve.	8	* 3/16	* 3/16	⅜	2⅛	2¼	1¼	4⅝	⅞	½ inch	Heavily corroded in spots	Brownish tinge near top.	Sheet A protected only by thin skin of cement.
43		13	3/16	1/16	⅞	2¼	1¼	¾	⅝	1¼	1 inch	Heavy corrosion where exposed.	Very light corrosion in spots.	Sheet A exposed in spots.
44		26	3/16	1/16	⅞	2¼	¾	¼	1 1/16	⅞	Entirely through	Outside surface covered with a medium light coating of rust in places; inside surface covered with light coating of rust.	Light surface rust in two places.	Sheet A exposed in places.
45		52	....	....	¼	2⅜	1¼	1¼	1¼	1¼	do	Badly corroded where exposed; both surfaces heavily rusted.	Metal perfectly clean.	Sheet A exposed near top and bottom of cylinder.
46		78	3/16	1/16	½	2⅜	1 1/16	1 1/16	1¼	⅝	2 inches	Badly corroded where exposed; both surfaces coated with heavy rust.	Light rust near End I.	Sheet A exposed in one place.

TABLE 23 (CONTINUAÇÃO)

47		8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] inch	Very slight rust in spots	Slight brownish tinge.	Sheet A completely covered. Rust spots on cylinder surface.
48	2 parts gravel No. 55 below [illegible]-inch sieve and 4 parts gravel No. 55 above [illegible]-inch sieve.	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1[illegible] inches	Rusted slightly on both sides.	Lightly corroded in few spots.	Do.
49		26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Entirely through	Outside surface medium heavy coat of rust; inside surface light coat.	Slight surface rust near edge.	No metal exposed.
50		52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	do.	Both surfaces medium heavy coat of rust.	Metal perfectly clean.	Sheet A exposed in four places. Rust spot on cylinder surface.
51		78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	do.	Outside surface covered with heavy rust, slightly heavier than inside.	Lightly rusted near End I.	No metal exposed. Rust spot on cylinder surface.
52		8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1 inch	Heavy corrosion in spots	Very slight brownish tinge.	Do.
53	3 parts gravel No. 55 below [illegible]-inch sieve and 3 parts gravel No. 55 above [illegible]-inch sieve.	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1[illegible] inches	Heavy uniform surface rust.	Medium heavy surface rust at ends.	No metal exposed.
54		26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Damp throughout	Outside surface practically clean; inside surface covered with medium heavy coating of rust.	Lightly rusted near edges.	Do.
55		52	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	1[illegible] inches	Both surfaces coated partially with light rust.	Lightly rusted in few spots.	Do.
56		78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Entirely through	Both surfaces coated with heavy coat of rust, outside surface being coated heavier.	Light rust near End I.	Sheet A exposed in one place.
57		8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] inch	Heavy corrosion only where exposed.	Slight brownish tinge (due to mixing water).	Sheet A exposed in spots.
58	1 part gravel No. 55 below [illegible]-inch sieve and 5 parts gravel No. 55 above [illegible]-inch sieve.	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1 inch	Heavy coat of rust; inside surface coat heavier than outside.	Light corrosion in spots.	Sheet A covered only with thin skin of cement.
59		26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2 inches	Both surfaces covered with heavy coat of rust.	Lightly rusted near End I.	A section of sheet A 1 inch wide extending from top to bottom of cylinder, exposed.
60		52	....	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1[illegible] inches	Both surfaces coated with medium heavy rust.	Perfectly clean	Sheet A exposed in one place.
61		78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2 inches	Coated with a very heavy rust.	Light coat of rust near End I.	No metal exposed.

* In some places.

DESPLACAMENTO DO CONCRETO

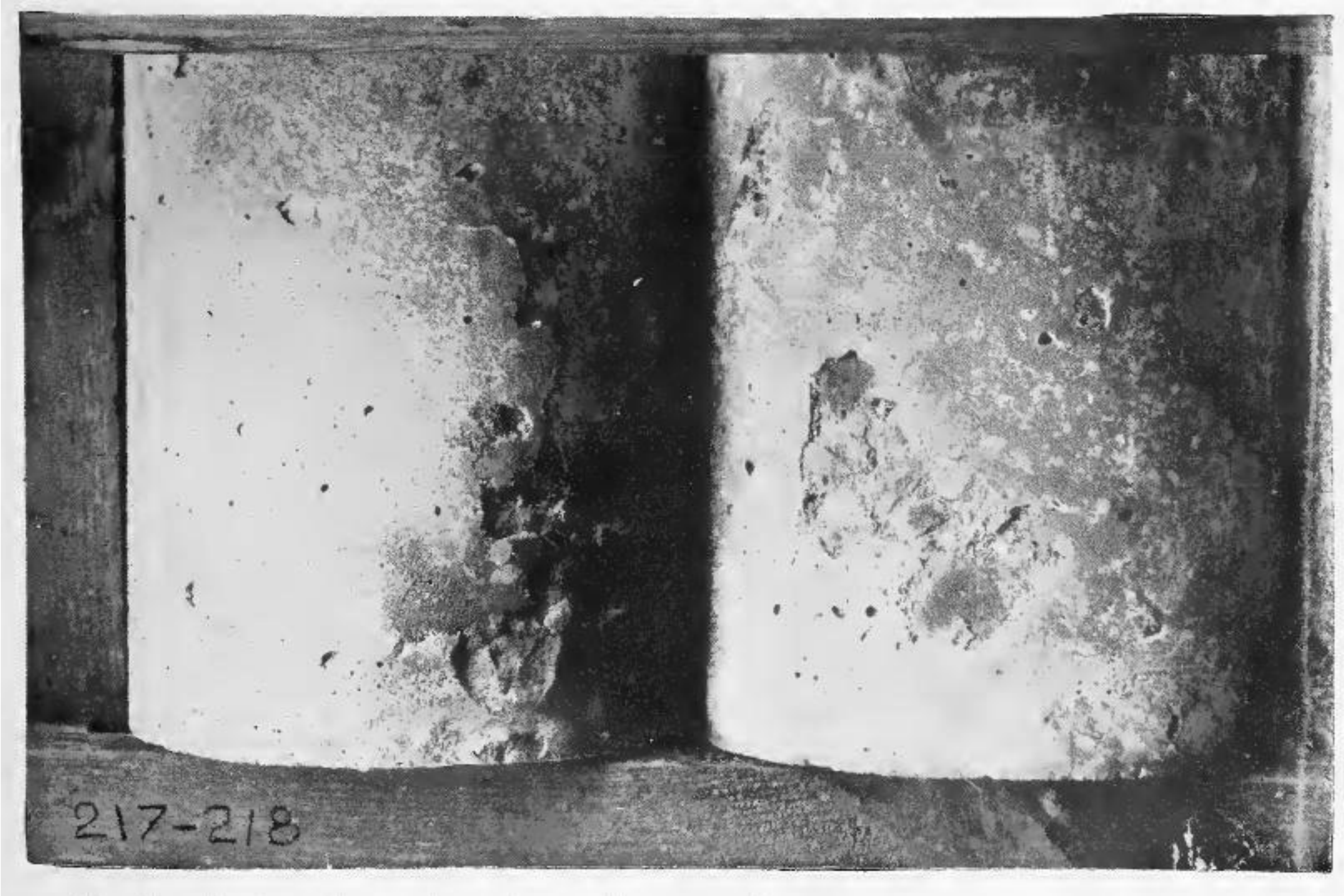


Fig. 25.—*Portions of concrete specimens after one year's exposure to sea water, showing cracked surface and layer flaking off*

XI. SUMMARY

The conclusions must be limited by the scope of this investigation and since the physical tests reported cover a period of exposure not exceeding $3^1/_2$ years the conclusions should be considered as somewhat tentative.

1. Portland cement mortar or concrete, if porous, can be disintegrated by the mechanical forces exerted by the crystallization of almost any salt in its pores, if a sufficient amount of it is permitted to accumulate and a rapid formation of crystals is brought about by drying ; and as larger crystals are formed by slow crystallization, there would be obtained the same results on a larger scale, but in greater time if slow drying were had.

Porous stone, brick, and other structural materials are disintegrated in the same manner.

Therefore in alkali regions where a concentration of salts is possible, a dense nonporous surface is essential.

2. While in the laboratory a hydraulic cement is readily decomposed if intimately exposed to the chemical action of various sulphate and chloride solutions, field inspection indicates that in service these reactions are much retarded if not entirely suspended in most cases, due probably to the carbonization of the lime of the cement near the surface or the formation of an impervious skin or protective coating by saline deposits.

3. Properly made Portland cement concrete, when totally immersed, is apparently not subject to decomposition by the chemical action of sea water.

4. While these tests indicated that Portland-cement concrete exposed between tides resisted chemical decomposition as satisfactorily as the totally immersed concrete, it is felt that actual service conditions were not reproduced, and therefore further investigation is desirable.

5. It is not yet possible to state whether the resistance of cements to chemical disintegration by sea water is due to the

28 - In service the concrete extends from the sea bottom to a point above high tide, where the wall or pile would always be exposed to the atmosphere. With this condition the sea water could be drawn up the wall by capillarity, the moisture evaporating and leaving the salts, which would become concentrated, and thus possibly cause disintegration, especially if mixture is porous. An additional series of tests is now being made in which short piles 7 feet in length are being placed in sea water so that 2 feet of the center portion will be exposed to the atmosphere. After various periods of exposure the piles will be sawed and the various sections tested for elastic properties and compressive strength.

superficial formation of an impervious skin or coating, which is subsequently assisted by the deposition of shells and moss forming a protective coating, or by the chemical reaction of the sea salts with the cement forming a more stable compound without disintegration of the concrete, or by a combination of both of these phenomena.

6. Marine construction, in so far as the concrete placed below the surface of the water is concerned, would appear to be a problem of method rather than materials, as the concrete sets and permanently hardens as satisfactorily in sea water as in fresh water or in the atmosphere, if it can be placed in the forms without undue exposure to the sea water while being deposited.

7. Natural, slag, and other special cements tested in concrete mixtures showed normal increase in strength with age both in sea water and in fresh water.

8. In the form of neat briquettes most of the Portland cements of high iron content, several of the cements of high or normal alumina content and one special slag cement did not show any marked difference in tensile strength whether exposed to fresh or sea water for all periods up to two years. Other cements of various compositions showed signs of disintegration after a few weeks.

9. All cements resisted disintegration in sea water better in mortar mixtures than in the form of neat briquettes. In most cases the mortar briquettes had normal strength up to 2 years exposure.

10. The physical qualities of the cement, which depend essentially upon the method of manufacture, would seem to determine its resistance to decomposition when brought into intimate contact with the sulphate and chloride solutions.

11. Contrary to the opinion of many, there is no apparent relation between the chemical composition of a cement and the rapidity with which it reacts with sea water when brought into intimate contact.

12. Tricalcium-sulpho-aluminate could not be formed, and therefore disintegration could not result from this cause.

13. In the presence of sea water or similar sulphate—chloride solutions

(a) The most soluble element of the cement is the lime. If the lime of the cement is carbonated it is practically insoluble.

(b) The quantity of alumina, iron, or silica present in the cement does not affect its solubility.

(c) The magnesia present in the cement is practically inert.

(d) The quantity of SO3 present in the cement up to 1.75 percent does not affect its solubility, but a variation in the quantity present may affect its stability by affecting its rate of hardening.

14. The change which takes place in sea water when brought into intimate contact with the cement is as follows:

(a) The magnesia is precipitated from the sea water in direct proportion to the solubility of the lime of the cement.

(b) The sulphates are the most active constituents of the sea water and are taken up by the cement. Their action is accelerated in the presence of chlorides. No definite sulphate compound was established.

(c) The quantity of chlorine and sodium taken up by the cement is so small that no statement can be made as to

the existence of any definite chloride or sodium compound formed with the cement.

15. The SO3 added to a cement in the plaster to regulate the time of set is chemically fixed so that it will not go into solution when the cement is brought into intimate contact with distilled water.

16. Metal reinforcement is not subject to corrosion if embedded to a depth of 2 inches or more from the surface of well-made concrete.

Washington, November 01, 1912.

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