

# Inherently Flawed: Carbonation-Induced Cracking in Reinforced Concrete Structures

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## Abstract

Concrete was considered an everlasting, permanent material from its expanding use at the end of the 19<sup>th</sup> century until the early 1900s. In the 1910s and 20s scientific research on concrete failure began, a response to the inevitable cracks and deterioration that began to plague concrete structures. Today cracks are recognized as an inevitable symptom of the deterioration of concrete structures. Early-age cracking is often due to improper rebar cover and carbonation-induced corrosion. This thesis explores some aspects of the cracking of reinforced concrete structures caused by carbonation-induced corrosion, and historical approaches to conservation repair and treatment, from the use of early cementitious patching and crack stitching in the 1950s to modern conservation materials, such as injectable crack fillers, sealers, and penetrating silane water repellents. This thesis has attempted to clarify the understanding of conservation treatments for reinforced concrete structures.

## Acknowledgements

I would like to thank the many professors who have helped me develop this topic, and supported my innumerable research excursions, including Jorge Otero-Pailos, and Theo Prudon, and my thesis advisor Norman Weiss. Thank you especially to my diligent readers, Marjorie Lynch and Helen Thomas-Haney, for your encouragement and direction. I am also very grateful to Brooke Young Russell and Leo Schmidt for sharing their experiences with the conservation of the Berlin Wall panels in New York and Berlin. And finally a large thank you to my family, to Lauren Bennett, and to Chase Ries.

“Entropy: the degradation of matter and energy in the universe to an ultimate state of inert uniformity. This definition is ultimately the subject: how to retard, inhibit or correct the ineluctable degradation of the materials of which our buildings are constructed. All physical materials, including the nominally obdurate stones which we employ in architecture, are subject to this degradation. Under the law of entropy as we now understand it, there is no such thing as a “permanent” or “everlasting” material, though each undergoes change at a different rate. The process begins the day the building is completed. It cannot be prevented; it can never be reversed; its rate can only be slowed down.”

*James Marston Fitch, “Conservation of historic masonry; the social and technical parameters, Durability of Building Materials” (1988).*



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# Introduction

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Concrete's durability was ascribed almost mythical significance during its expanding use at the end of the 19<sup>th</sup> century.<sup>1</sup> There was little change in this enthusiasm into the early 1900s. In 1927, *The Atlas Handbook on Concrete Construction* advised clients on the advantages of concrete. "Concrete is permanent—It does not rot or decay; therefore, it requires no repairs and does not involve expense for painting or other upkeep. Concrete is strong—and grows stronger with age."<sup>2</sup>

It was at about that same time that scientific research on concrete failure began—structures that were once considered ageless had inevitably succumbed to cracks and deterioration. Today cracks are recognized as an inevitable aspect of deterioration of concrete structures. Does this understanding of the material reflect a century of research? Or, do modern applications of concrete crack more quickly than historic concrete? This thesis specifically explores cracking associated with carbonation-related corrosion of reinforcement, and discusses the treatment options for dealing with those cracks.

Carbonation is a natural process and will occur in all Portland cement-based concrete over time. A discussion of carbonation is in Chapter 3, which also considers factors such as mix design, environment, and placement of reinforcement with respect to the concrete surface.

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<sup>1</sup> New York Stone Contracting Co, *Beton Coignet system of constructing and repairing railway and other structures*. (New York Stone Contracting Co, product brochure, 1885).

<sup>2</sup> Atlas Portland Cement Company, *The Atlas handbook on concrete construction*. (New York: The Atlas Portland Cement Company, product brochure, c1927).



The conservation of historic structures presents a unique set of problems for the concrete repair industry. In 2014, The Getty Conservation Institute's Conserving Concrete Heritage Experts Meeting examined key issues affecting the conservation of modern concrete architecture, particularly the apparent friction between the concrete repair industry and the dictums of conservation management. Conservators Alice Custance-Baker and Susan Macdonald noted that "Industry-driven methods and materials do not take into account the usual conservation demands of minimum intervention and retention of the original fabric, and can have a significant impact of the appearance and materiality of the concrete, which in many cases is core to architectural expression."<sup>3</sup>

While early repairs were improvised by filling cracks with cementitious material, today, due to our improved understanding of concrete, repair materials have expanded to include a range of treatment options and compatibility parameters.<sup>4</sup> Conservators should be wary of marketing materials and industry misnomers during treatment selection: products are commonly sold as *enduring*, *waterproof*, *permeable*, and/or *invisible*. With a proper understanding of the problems affecting concrete structures, conservators should be able to develop treatment strategies and implement durable repairs. Among the products discussed in Chapter 4 are crack fillers, water repellents, and migrating corrosion inhibitors.

My interest in the phenomenon of early-age concrete cracking began after visiting the Memorial for the Murdered Jews of Europe in Berlin in 2015 (Figure 1) . The memorial opened

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<sup>3</sup> Alice Custance-Baker and Susan Macdonald. Conserving Concrete Heritage Experts Meeting. (Los Angeles: The Getty Conservation Institute, 9-11 June 2014), 1-3.

<sup>4</sup> New York Stone Contracting Co, *Beton Coignet system of constructing and repairing railway and other structures*. (New York Stone Contracting Co, product brochure, 1885).

to the public in 2005. Today 80% of the 2711 concrete stelae are cracked. Cracks were recorded on the stelae as early as seven months after the memorial opened to the public. The smooth concrete surface of the blocks is central to Peter Eisenman's design for the memorial, but the cracking of the concrete makes the site unsafe for visitors, who enjoy the interaction with the monument. By 2014, 420 of the stelae were secured with steel ties to prevent expansive cracking. The memorial encouraged me to research philosophical questions posed by conservators; such as how do we preserve sites of recent and modern heritage? And, what is the difference between a construction defect and a conservation issue?



*Figure 1: Images of the Memorial to the Murdered Jews of Europe, 2015, student photos. Photos show signs of cracking; the image on the bottom right shows steel collars reinforcing the concrete pillar.*



# Understanding cracking

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Cracking is a very visible mode of deterioration affecting the appearance of the concrete. English Heritage described cracking as a natural feature of concrete structures, which provide “important indications of the response to applied loads, the construction and maturing of the concrete, and the development of deterioration”.<sup>5</sup> Proper identification and causes of cracking are important for conservation treatment and repair. By understanding patterns of cracking, a conservator can begin to develop a treatment that impedes the deterioration of the concrete.

## A. Historical discussions of cracking

In the early 20<sup>th</sup> century, concrete cracking was primarily discussed by civil engineers studying steel reinforced concrete. Early sources in this discussion expressed ambivalence toward the use of concrete instead of steel for structural framing.<sup>6</sup> In 1908, the American Society of Civil Engineers recommended against the use of reinforced concrete for railroad bridges precisely because the constant vibration from the rail lines could cause concrete to crack, and “separate the reinforcement from the concrete”.<sup>7</sup> The American Society of Civil Engineers also advised against the use of concrete where conditions “would be favorable to the rusting of

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<sup>5</sup> English Heritage. *Practical Building Conservation: Concrete* (London: Ashgate, 2012), 71-102.

<sup>6</sup> American Society of Civil Engineers. *Transactions of the American Society of Civil Engineers* 38 (1908): Nineteenth Century Collections Online.

<sup>7</sup> Ibid.

steel...unless cracking can be prevented”. This early insight understood that ultimately, concrete cracking can expose the reinforcement to water and oxygen, causing rust formation.

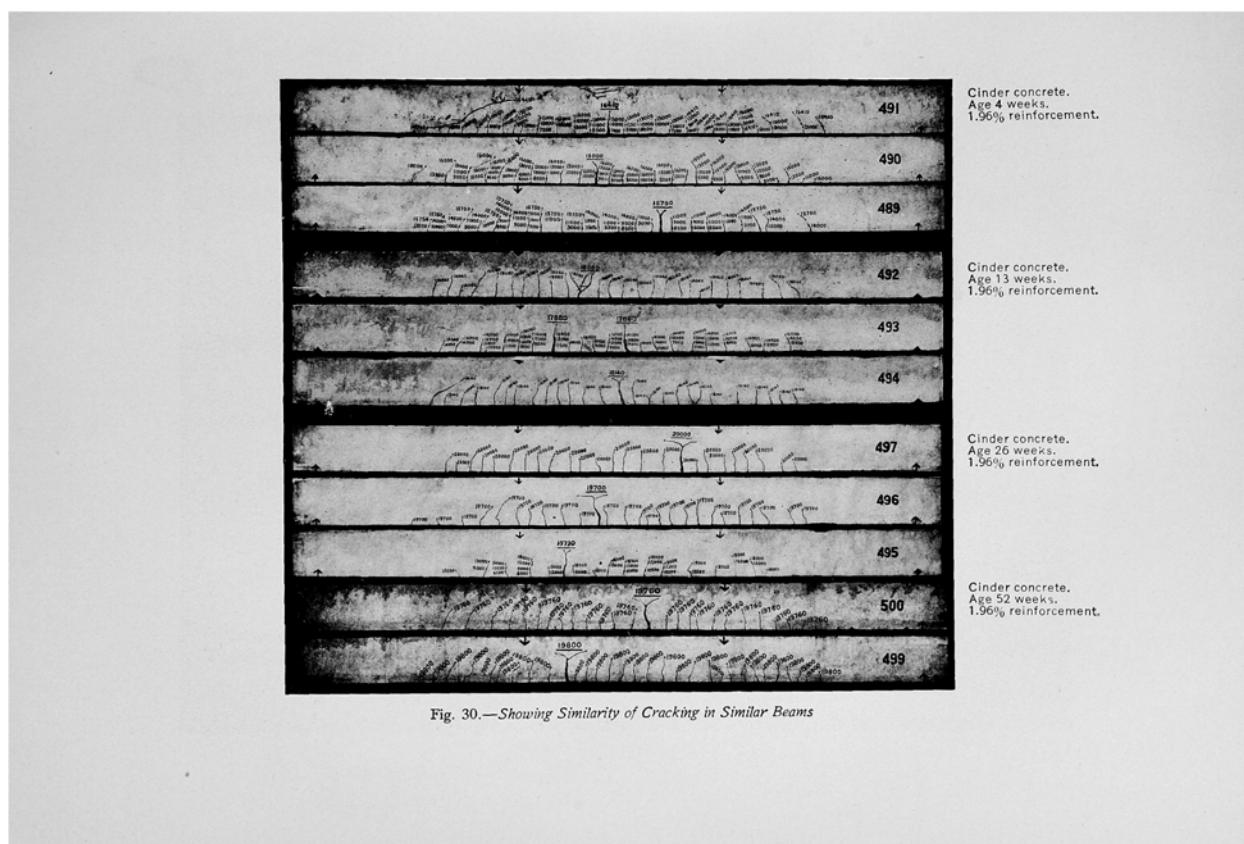


Fig. 30.—Showing Similarity of Cracking in Similar Beams

Figure 2: *Technologic Papers of the Bureau of Standards*, 1912. Figure shows similarity of cracking in similar concrete beams with 1.96% reinforcement at various ages.

A 1908 discussion led by the American Society of Civil Engineers also found that “high stresses are always accompanied by cracking of the encasing concrete, with the involved likelihood of rust and of becoming a source of incipient failure by diagonal tension”.<sup>8</sup> In 1912, researchers for the Bureau of Standards indicated high stress as a reason for concrete cracking (Figure 2).<sup>9</sup>

<sup>8</sup> American Society of Civil Engineers.

<sup>9</sup> Richard Lewis Humphrey, Louis H. Losse, and Burndy Library. *Technologic Papers of the Bureau of Standards*. (Washington: Government Printing Office, 1912): Nineteenth Century Collections Online.

In 1925, Constantine Kenneth Smoley described in detail the risk of cracking for reinforced concrete in a book published by the International Library of Technology, intended as instruction papers for students of the International Correspondence Schools.<sup>10</sup> Smoley instructed students to test for soundness before any application of Portland cement using the steam test.<sup>11</sup> Testing revealed inferior cement by evidence of “distortion, checking, cracking or by entirely disintegrating”.<sup>12</sup> As Smoley instructed students, “If any cracks appear, they must be carefully studied; for while some cracks indicate unsoundness and poor material, ordinary shrinkage cracks are entirely harmless” (Figure 3).<sup>13</sup>

## TYPES OF CRACKS



Fig. 3.1

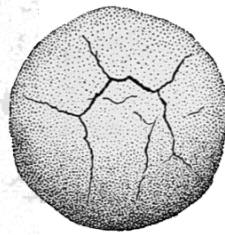


Fig. 3.2

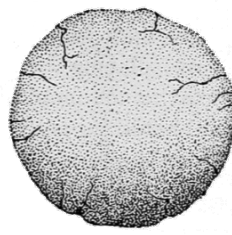


Fig. 3.3



Fig. 3.4



Fig. 3.5

Figure 3: Constantine Kenneth Smoley and Burndy Library. As described by Smoley: “Figs. 1 and 2 illustrate shrinkage cracks, and Figs. 4, 5, and 6 show progressive development of disintegration cracks.”

<sup>10</sup> Constantine Kenneth Smoley and Burndy Library. *Stone, Brick, and Concrete: Prepared under the Supervision of C. K. Smoley*. (Scranton, Pa.: International Textbook Co., 1925): Nineteenth Century Collections Online, 16-33.

<sup>11</sup> From Smoley: “Conical pats about 3 inches in diameter at the base,  $\frac{1}{2}$  inch thick at the center, and tapering to a thin edge, are formed on clean glass plates from a cement paste of normal consistency. These pats are allowed to remain in moist air for 24 hours and are then tested. They are placed on a wire-screen support 1 inch above boiling water, and kept in an atmosphere of steam at a temperature between 98 and 100 degrees Celsius for 5 hours. A good cement will not be affected by this treatment and pats will remain firm and hard.”

<sup>12</sup> Smoley, 16-33.

<sup>13</sup> Ibid.

For added protection of concrete surfaces, Smoley suggested coating the concrete with a waterproof paint or with asphalt applied with a brush while boiling hot, or a pure cement wash or rich mortar, and substances used for waterproofing mortar. However, the waterproofing coatings Smoley described were also recommended as a cheap alternative to lime washes that are prone to crack with the concrete, or separate from the concrete and peel off.<sup>14</sup>

David Snader led the first thorough investigation of concrete cracking at Columbia University's Civil Engineering Research Libraries as early as 1920.<sup>15</sup> Snader's interest in the cracking of concrete dams subject to considerable water pressure spurred his research on cracking circa 1927.<sup>16,17</sup> Snader confronted the presumed superiority of concrete in his 1937 doctoral dissertation, "The Deterioration of Concrete in Normal Service", in which he wrote:

In recent years it has become increasingly clear that the older slogan of 'concrete for permanence' is only relatively true. In brief, concrete is an artificial stone, and as earlier experience with natural stone would have indicated, the forces of nature, particularly the action of water, cause deterioration even in the most compact and hardest rocks be they natural or artificial.<sup>18</sup>

The scope of Snader's investigation was of course limited to the use of concrete from 1870-1930. Since concrete was used under widely varying conditions of service, Snader speculated that concrete was not always used in the correct application:

The economic use of concrete under these differing conditions, as well as its improvement in quality so as to render it a more reliable and even more widely applicable

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<sup>14</sup> Smoley, 16-33.

<sup>15</sup> David Levi Snader. "Investigation of the deterioration and disintegration of concrete structures". (Masters thesis, Columbia University, 1926), 3-42.

<sup>16</sup> Approximate date from text: "In this investigation, begun some ten years ago, the attempt has been made to study both of these phases of the problem."

<sup>17</sup> Snader, 3-42.

<sup>18</sup> Ibid.

## PLATE VIII

CONCRETE IN EARLY STAGES OF DISINTEGRATION.



FIG. 1

SECTION OF A RETAINING WALL



FIG. 2

PART OF BALUSTRADE OF A CITY BRIDGE

Figure 4: David Levi Snader, 1937.: "Plate VIII, Fig. 1, shows part of a retaining wall several hundred feet in length, at a section where disintegration has occurred in particular in the top of the wall. Fig. 2 shows part of the balustrade of a bridge in a large city. The structure is of modern design, has pleasing lines, and probably was built under modern engineering conditions.

In both structures a characteristic network of veins and cracks has developed, which are more than simply surface cracks. They show a condition of the concrete which usually leads to the breaking up and falling away of the outer, harder, more carbonated shell, variable in thickness, and thereby exposing the interior mass to further attack both from within and without."



material, requires a careful consideration of both its structural characteristics and properties as well as its resistance to deterioration. All materials have certain inherent qualities and characteristics, and unless these can be modified or changed through improved methods of preparation or manufacture, these qualities become limitations to proper use if desired results are to be obtained.<sup>19</sup> (Figure 4)

Due to gaps in knowledge at the time concerning the correct use and in-service environment for concrete, Snader concluded that concrete will inevitably begin to crack and deteriorate. Snader also emphasized the propensity for concrete to crack due to freeze-thaw and water. What these cracks had in common was the stability of the cement paste. Snader wrote, “Cracking due to freezing is believed to be generally secondary in importance to the more or less continuous breaking down of the internal structure of the cementing medium, which occurs where water finds entrance into the concrete under usual conditions of service”.<sup>20</sup>

Snader’s investigation did not consider corrosion of steel or defects occurring from design and construction. In 1943 the Engineering Division of the Association of American Railroads studied electrolysis of steel in concrete under the direction of Random Ferguson, electrical engineer, and G.M. Magee, research engineer. The researchers and supporting committee reached significant conclusions, “Increasing the thickness of concrete covering around reinforcing steel reduced the rate of electrolytic corrosion but did not effectively eliminate it to prevent cracking of the concrete”.<sup>21</sup>

Magee continued the study of electrolytic corrosion with the engineering division of the Association of American Railroads in April 1944. Magee’s paper was presented at the Fifth

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<sup>19</sup> Ibid.

<sup>20</sup> Ibid.

<sup>21</sup> A.E.Archambault, et. al. “Investigation of Electrolytic Corrosion of Steel in Concrete”. (progress of Committee 2, Electrolysis, Electrical Section, Engineering Division, Association of American Railroads, In *Railways Mechanical Engineering*, January, 1946), 1-18.

Annual Conference of the National Association of Corrosion Engineers (NACE) in Cincinnati in April 1949. Magee's experiment followed an inspection of deteriorated steel footings on the Cleveland Terminal. The anchor bolts on the footings corroded and "the resulting expansion due to this increased volume of the rust cracked the concrete, which permits water to contact the steel, further accelerating the deterioration".<sup>22</sup> Magee's experiment was developed to study the controlled conditions affecting various factors on the electrolytic corrosion of steel embedded in concrete.<sup>23</sup> He concluded that the use of stainless steel would lessen the corrosion and resultant cracking of the concrete. Magee also stated that the use of sulfate-resisting cement is of utmost importance to prevent deterioration of concrete.

Following World War II, studies on concrete cracking became increasingly specialized. A general understanding of concrete cracking can be gleaned from repair manuals and texts published by the National Bureau of Standards (NBS) in this period. In 1956, NBS structural engineering laboratories and A.P. Clark of the American Iron and Steel Institute's Research Fellowship studied the cracking of loaded concrete beams and slabs. The specific aim of the test was to provide a resource for controlling the spacing and width of cracks for new construction. The study considered the formation of tensile cracks in flexural members with conventional, non-prestressed reinforcement unavoidable due to concrete's low extensibility.<sup>24</sup> NBS considered two types of cracks: (i) those barely wide enough to be visible were a risk only because of appearance, while (ii) cracks of greater widths were dangerous because of "the

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<sup>22</sup> G.M.Magee. "Electrolytic Corrosion of Steel in Concrete". (paper presented at the Fifth Annual Conference of the National Association of Corrosion Engineers at Cincinnati, Ohio, April 11-14, 1949) 1-5.

<sup>23</sup> Ibid.

<sup>24</sup> National Bureau of Standards. "Control of cracks in reinforced concrete". (The Aberdeen Group, 1956).

possibility of corrosive agents attacking the steel reinforcing bars”.<sup>25</sup> Wider cracks were also attributed to leakage of water and soluble chemicals into the concrete, depending on the in-service environment.

S. Champion distinguishes between chemical and mechanical deterioration in his 1961 book *Failure and Repair of Concrete Structures*. Champion divided cracks into two categories: solitary and pattern cracking. Solitary cracks were considered due to an overstressing of the concrete due to either load or shrinkage, which indicated the understanding that concrete by itself is relatively weak in tension. Pattern cracking described cracks that had occurred more or less at the same time, which included repeat solitary cracks, random cracks, and progressive cracking, in a regular or random pattern.<sup>26</sup>

In 1969, concrete was still considered a superior building material by NBS, with the disclaimer, “All materials, of course, deteriorate in some measure from the ravages of time, exposure to the elements and the effects of wear and tear; All factors considered the performance of concrete compares favorably with other structural materials”.<sup>27</sup> In this report, there was a new distinction made between cracks that are considered active, and cracking that is dormant, similar to Champion’s classification of cracks as solitary or pattern. Active cracks appear and continue to develop after the concrete has hardened. Dormant cracking is caused by a factor that is not expected to occur again, such as plastic cracks, temporary overload cracks, movement of machinery, or random cracks caused by construction.<sup>28</sup>

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<sup>25</sup> National Bureau of Standards, 1956.

<sup>26</sup> S. Champion. *Failure and Repair of Concrete Structures*. (London: Contractors Record Limited, 1961), 2-19.

<sup>27</sup> Ibid.

<sup>28</sup> Ibid.

In the 1969 study, NBS considered concrete cracking a symptom rather than a fault, which is another way of defining cracks as a result of a deterioration.<sup>29</sup> NBS detailed specific types of common concrete cracking to assist in repair selection; including: alkali-aggregate expansion, caused by a chemical reaction between some aggregates and alkalis in Portland cement, resulting in map-cracking. NBS also recognized that there are too many types of cracking to discuss in a single report, and advised to refer to the pattern of the cracking, location, depth and width of the cracks to determine which factors caused the cracks to form.

Champion's book and the 1969 NBS report reflect an understanding of historic concrete cracking similar to modern perceptions. These are early articulations of a "cause-symptom repair" approach.

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<sup>29</sup> S. Champion, 2-19.

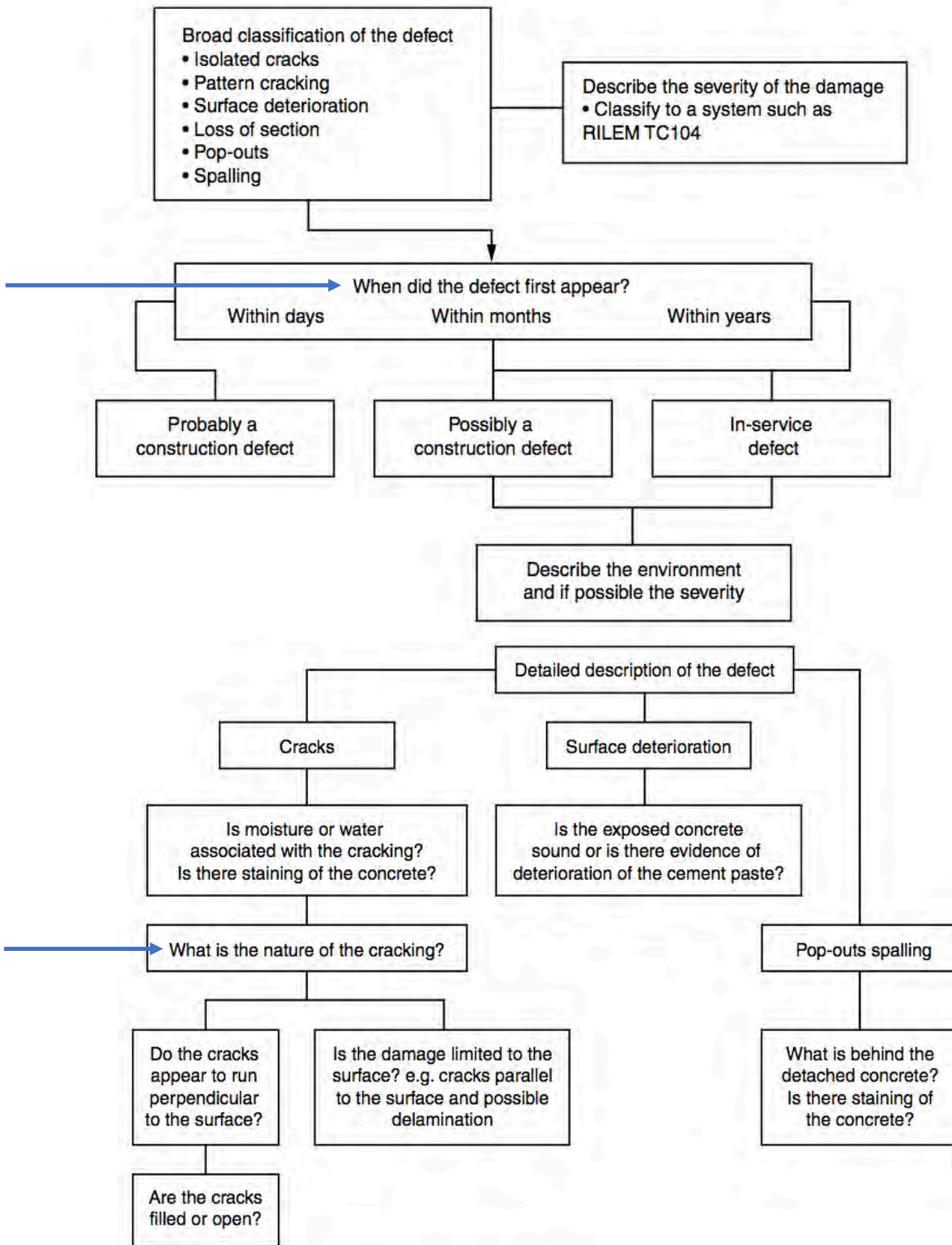


Figure 5: Describing defects from RILEM TC104: Suggested flow diagram for visual inspection. Arrows indicate the importance of two questions: “when did the defect first appear?”, which leads to the differentiation between crack-cause (construction or in-service) and the second question, “what is the nature of the cracking?”

## A. Visual assessment of cracks

Modern understanding of concrete cracking recognizes that all concrete will crack, for various reasons. In his 1983 *Concrete International* article, Ed Abdun-Nur wrote, “Cracking seems to be a universal characteristic of concrete. Large sums of money have been expended in an effort to find a cure, but concrete seems to go on its own way and crack anyway”.<sup>30</sup>

Cracks in concrete can indicate a structural or a non-structural problem. Structural cracking affects the integrity of the building, and is a primary concern, but is not discussed in this thesis. Non-structural cracking can compromise the material integrity of the concrete and lead to further deterioration. Non-structural cracks include cracks caused by carbonation-related cracking and the associated carbonation-related corrosion of steel reinforcement, plastic shrinkage, freeze-thaw and thermal effects, and alkali-silica reaction (ASR). This thesis focuses on carbonation-related cracking and corrosion of steel reinforcement.

Cracks reduce the protection provided by concrete cover over steel reinforcement, which accelerates the deterioration of the steel rebar and can cause further deterioration through issues such as freeze-thaw, ASR, and chemical attack. Cracks may impact the long-term performance of the structure, and crack mitigation methods, according to ACI 562M-13, should consider causes, movement, size, orientation, width, and complexity of the cracks. The document also recognizes that not all cracks need to be repaired, and that “the cause and repair of cracking shall be assessed and considered in repair design”.<sup>31,32</sup>

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<sup>30</sup> Jeffrey W. Coleman. “Cracking...Defect or Normal?”. *Concrete International* (September 2013), 35-41.

<sup>31</sup> ACI 562M-13.

<sup>32</sup> See ACI 546.3R-14 Guide to Materials selection for concrete repair.

i. Immediate

A record of when the crack occurred will provide useful information pertaining to the cause of the crack. *Reunion Internationale des Laboratoires et Experts des Matériaux, Systèmes de Construction et Ouvrages* (RILEM) TC-104-DCC provides a useful flowchart for defining crack inception (Figure 5).<sup>33</sup> The RILEM flowchart guides the analysis from broad classification (such as isolated cracks, pattern cracking, surface deterioration, loss of section, pop-outs, and spalling) directly to the question, “When did the defect first appear?”<sup>34</sup> Defining the timeframe when the crack occurred to days, months, or years, can determine if the crack was a construction defect or an in-service defect. Construction defects and in-service defects indicate two different types of problems. The flowchart helps define a clear visual survey of crack damage, which can include crack width and crack monitoring, to describe the damage that has occurred and the possible options for treatment.<sup>35</sup>

Construction defects lead to cracks which appear within months of construction; these may include fine or hairline cracks, which occur as the mix cures. Early cracking (months-to-years following construction) is due to shrinkage during curing, when there is a reduction of volume in the paste, which occurs as excess water evaporates. During the hydration and curing processes, the volume of the concrete decreases slightly, possibly leading to cracking of the concrete. Volume change is referred to as plastic shrinkage. Some degree of plastic shrinkage

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<sup>33</sup> RILEM TC104. “Draft recommendation for damage classification of concrete structures”. *Materials and Structures* 27.170 (1994): 362–369.

<sup>34</sup> RILEM TC-104-DCC. “State-of-the-art report: The use of damage classification systems for concrete structures”, Javor, T. *Materials and Structures* 24 (1991): 253.

<sup>35</sup> Frank Rendell, et. al. Deteriorated concrete: Inspection and physicochemical analysis, *Chapter 4 "In situ investigation of concrete deterioration"*. (ICE Construction Materials Collection, 2011), 57-86.

should always be accounted for in the mix design, although most shrinkage takes place over long periods. Shrinkage can be further diminished by prolonged moist curing. Contradictory results on shrinkage are commonly reported. In some cases, well-cured concrete will shrink more rapidly. Rapid shrinkage can result in more cracking to the interior of the concrete.

Other immediate construction defects are autogenous shrinkage, the dimensional change of the paste caused by chemical shrinkage, and self-desiccation of the paste. Shrinkage and self-desiccation create tensile stress in the paste and lead to the development of cracks (Figure 6).

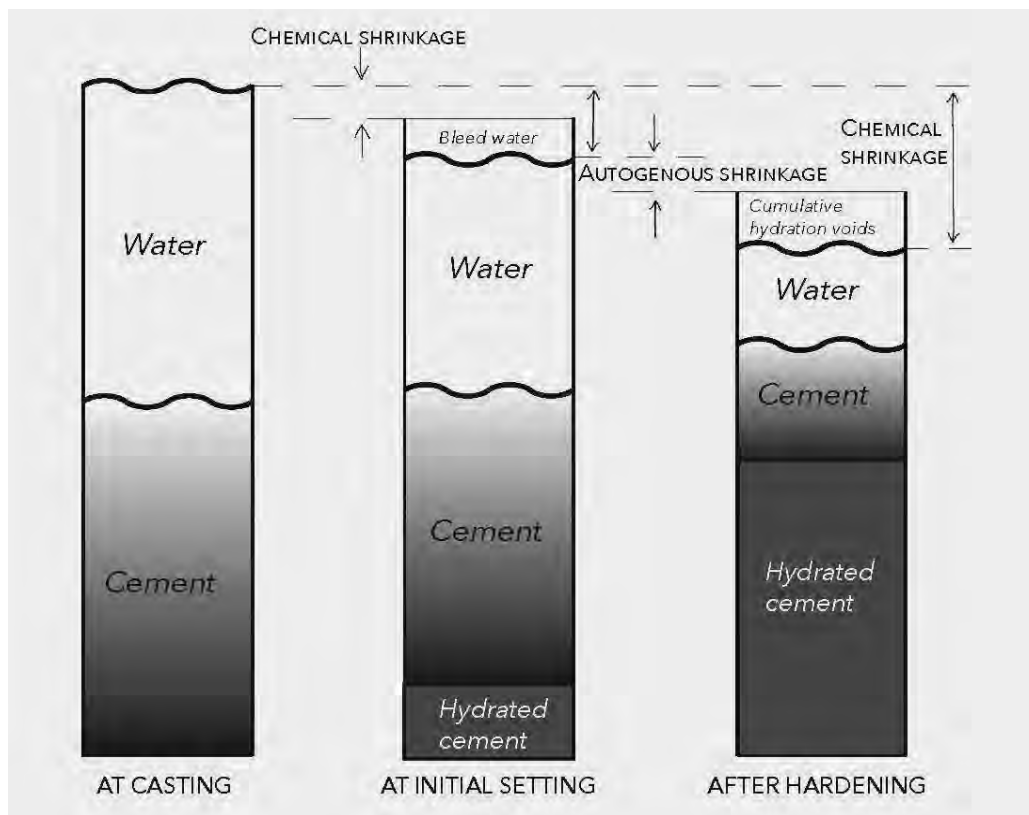


Figure 6: Schematic drawing showing various stages of shrinkage and the correlation to the volume of the concrete.



## ii. Short-term

In-service defects include a broader range of problems including external contamination or surface deposits, moist or wet conditions, surface texture, cracks or crazing, corrosion of steel and rust staining.<sup>36</sup> The severity of a crack can be visually characterized by crack direction—longitudinal, transverse, vertical, diagonal, or random—and width. Crack widths can easily be measured with a crack gauge or ruler. Cracks as small as 0.05mm can be seen on the dry surface of concrete. Table 7 is a useful reference for type of cracking, location, causes, and time of appearance. Table 7 corresponds with Figure 8, which is a diagrammatic representation of common crack locations.

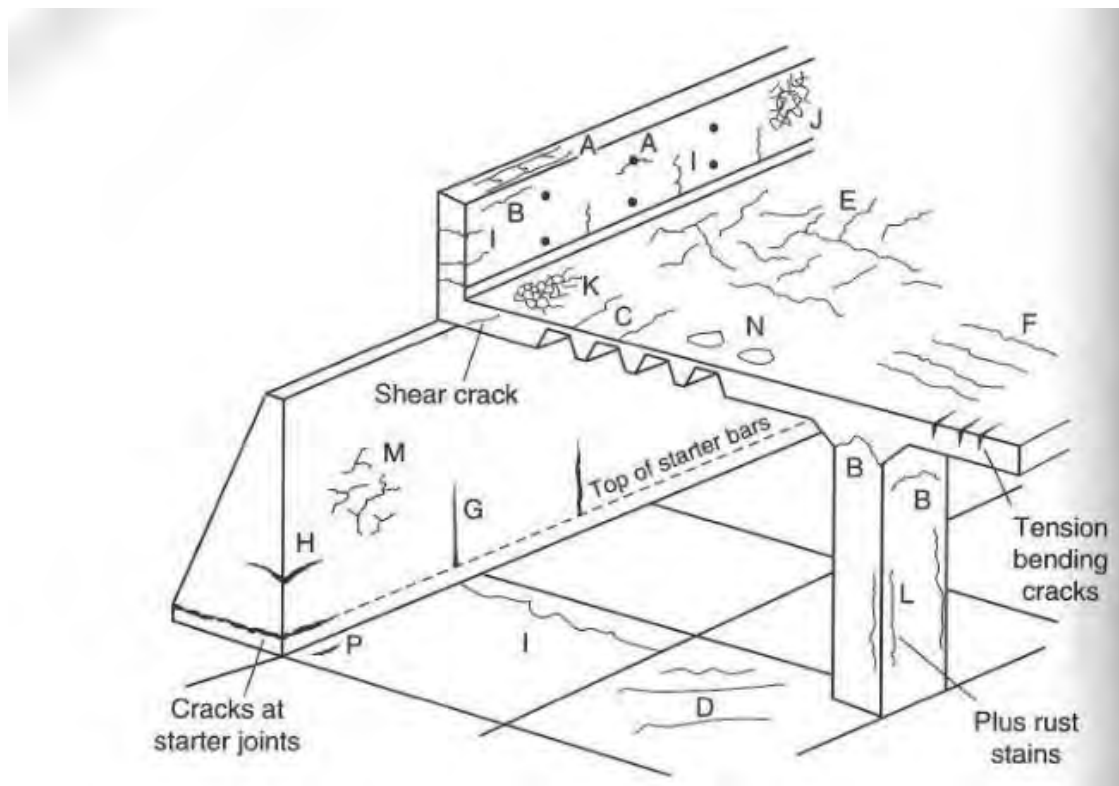


Figure 8: Schematic representation of the various types of cracking which can occur in concrete (See table ). From Concrete Society Report, *Non-structural Cracks in Concrete*, Technical Report 22.3. (Concrete Society, London, 1992), 48.

### Classification of Intrinsic Cracks

<sup>36</sup> Rendell, 57-86.

TYPE OF CRACKING	Symbol in Fig.	Subdivision	Most common location	Primary cause (excluding restraint)	Secondary causes/factors	Remedy (assuming basic redesign is impossible)	Time of appearance
Plastic settlement	A	Over reinforcement	Deep sections	Excess bleeding	Rapid early drying conditions	Reduce bleeding or revibrate	10 min to 3 h
	B	Arching	Top of Columns				
	C	Change of depth	Trough and waffle slabs				
Plastic shrinkage	D	Diagonal	Pavement and slabs	Rapid early drying	Low rate of bleeding	Improve early curing	30 min to 6 h
	E	Random	Reinforced concrete slabs				
	F	Over reinforcement	Reinforced concrete slabs	Rapid early drying or steel near surface			
Early thermal contraction	G	External restraint	Thick walls	Excess heat generation	Rapid cooling	Reduce heat and/or insulate	1 day to 2 or 3 weeks
	H	Internal restraint	Thick slabs	Excess temperature gradients			
Long-term drying shrinkage	I		Thin slabs and walls	Inefficient joints	Excess shrinkage Inefficient curing	Reduce water content Improve curing	Several weeks or months
Crazing	J	Against formwork	Walls	Impermeable formwork	Rich mixes Poor curing	Improve curing and finishing	1 to 7 days, sometimes much later
	K	Floated concrete	Slabs	Over-trowelling			
Corrosion of reinforcement	L	Carbonation Chloride	Columns and beams	Inadequate cover	Poor quality concrete	Eliminate causes listed	More than 2 years
Alkali-aggregate reaction	M		Damp locations	Reactive aggregate plus high-alkali cement		Eliminate causes listed	More than 5 years
Blister	N		Slabs	Trapped bleed water	Use of metal float	Eliminate causes listed	Upon touching
D-cracking	P		Free edges of slabs	Frost-damaged aggregate		Reduce aggregate size	More than 10 years

Table 7: Concrete Society Report, Non-structural Cracks in Concrete, Technical Report 22.3. (Concrete Society, London, 1992), 48.

### iii. Long-term

Long-term cracks can be structural or non-structural and provide visual indications of the cause of cracking. Once concrete cracks, it is likely that the cracks will grow, branch, or deepen. The plane of a crack is parallel to the tension force causing the crack to open. Force can be direct tension, tension induced by bending, tension in a diagonal crack caused by shear in a beam or, alternatively, indirect tension induced by compressive force.<sup>37</sup> The crack path of tensile strain is a longitudinal crack.<sup>38</sup>

What all these cracks have in common is that as the stress field increases in intensity, the cracks will widen, deepen, and extend in length, otherwise known as progressive cracking. Progressive cracking forms approximately in the same plane or, two-dimensionally, in the same line.<sup>39</sup> “In the same line” describes the path the crack takes through the heterogeneous material—be it through or around the coarse aggregate particles. Figure 9 shows that in young concrete the cracks develop around the aggregate, but, conversely in old concrete cracks will fracture the aggregate particles. Thus the age of the crack can be discerned from the path the crack develops.<sup>40</sup> Crack monitoring can provide useful information to understand the reason for cracking, and a record of crack development can aid in differentiating deterioration causes.

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<sup>37</sup> Adam Neville, “Which way do cracks run?”, *Concrete: Neville’s Insights and Issues*, (London: Thomas Telford, 2015), 181-201.

<sup>38</sup> F.O. Slate and K.C. Hoover. “Microcracking in concrete”, *Engineering Application of Fracture Mechanics* 3 (1984).

<sup>39</sup> Neville, *Concrete: Neville’s Insights and Issues*, 181-201.

<sup>40</sup> Neville, *Concrete: Neville’s Insights and Issues*, 181-201.

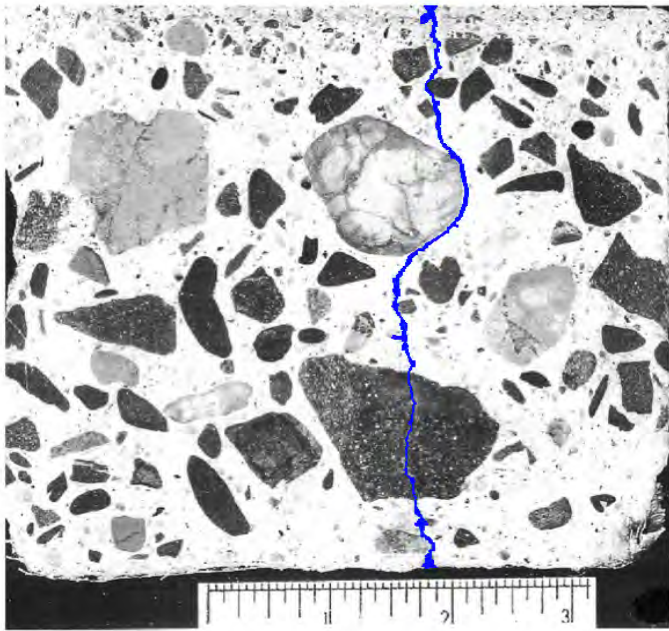


Figure 9.1

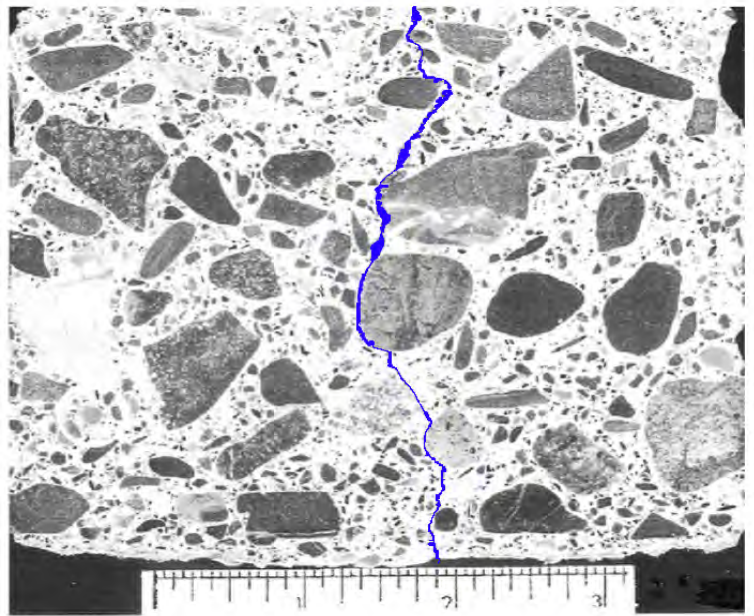


Figure 9.2

*Figure 9: Examples of crack paths; scale in inches. Adam Neville, "Which way do cracks run?", 183. Showing that when the hydrated cement paste is much weaker than the aggregate particles, cracks travel around the particles (Example 9.2). When the aggregate particles are weak, they cannot act as crack arresters, and the crack develops in a straight line fracturing the aggregate particles in its path (Example 9.1).*



# Carbonation-induced corrosion

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Carbonation typically does not directly cause cracking of concrete, but it has an important effect. Carbonation is the reaction of carbonic acid with hydrated cement. Carbon dioxide penetrates the concrete surface and dissolves in pore water to form carbonic acid. During carbonation, calcium hydroxide in the cement paste reacts with carbonic acid to form calcium carbonate.<sup>41</sup> As calcium carbonate is formed at the expense of the calcium hydroxide, the pH of the concrete is lowered.

When carbonation depth reaches the steel rebar, the steel is no longer protected from corrosion. The primary factor controlling the rate of carbonation is the diffusivity of the hydrated cement paste.<sup>42</sup> The structure of the pore system depends on the cement-fine aggregate mixture, the water-cement-ratio (w/c), and the curing process.

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<sup>41</sup> Kayla Hanson, 20 July 2015. “Understanding Carbonation”. *National Precast Concrete Association online*, 24 April 2017. <http://precast.org/2015/07/understanding-carbonation/>.

<sup>42</sup> A.M. Neville, *Properties of concrete*, 181-201.

Rebar embedded in the hydrated cement paste forms a passivating oxide layer, protecting the steel from the reaction with oxygen and water. To maintain the passivated oxide layer, the pH of the cement paste must remain high. During carbonation, when calcium hydroxide reacts with carbonic acid, partial neutralization of the pH of paste (from about 13 to 8) results, destroying the passivating layer on the steel. Subsequent corrosion causes a net expansion of steel and corrosion (Figure 10). If the rebar is too close to the surface, or if the concrete is too porous, carbonation will reach the reinforcement in a shorter amount of time, and the concrete will crack (Figure 11).

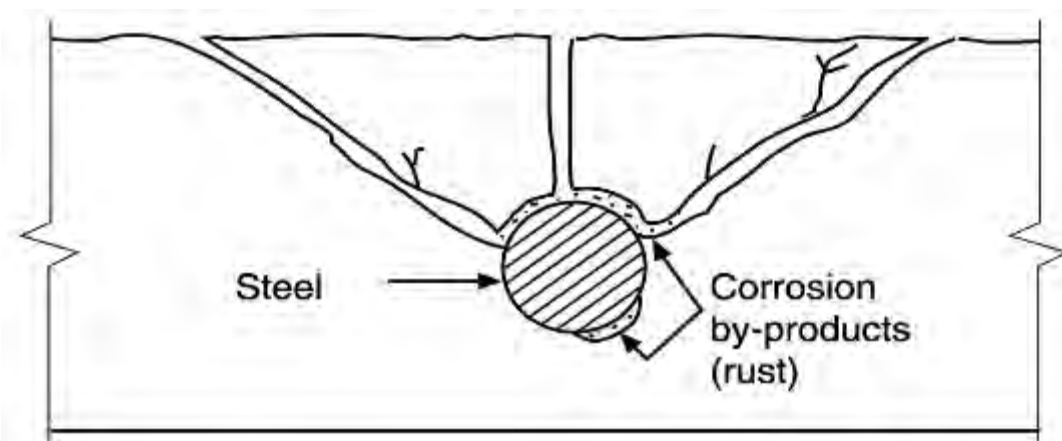
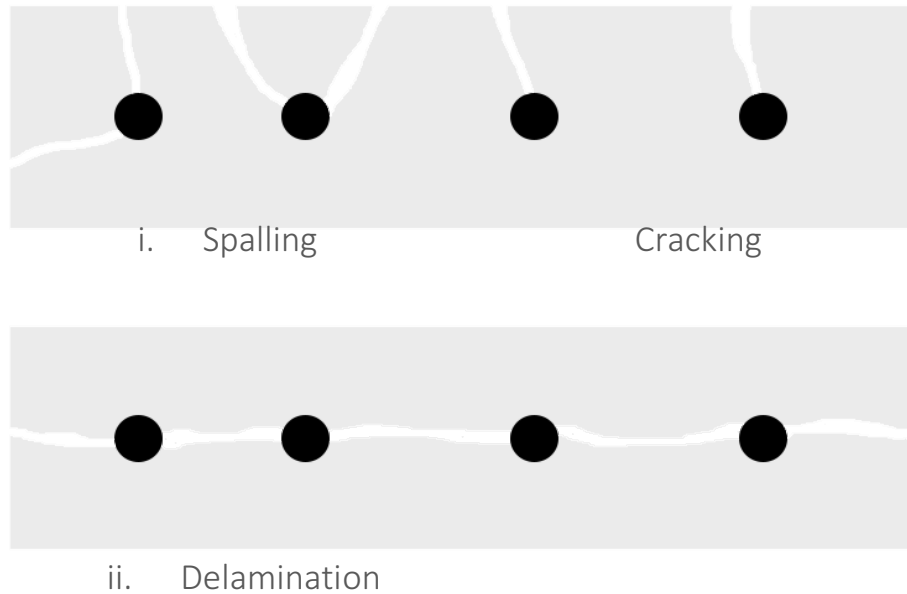


Figure 10: The expansion of corroding steel creates tensile stresses in the concrete, which result in cracking, delamination and spalling. Source, "Types and Causes of Concrete Deterioration", PCA Portland Cement Association 2002.

Carbonation will also occur in newly formed cracks exposed to oxygen and moisture. Carbon dioxide can ingress through cracks so that the 'front' advances locally from the penetrated cracks. In many cases, corrosion can take place even when the full carbonation front is still a few millimeters away from the surface of the steel if localized carbonation has taken place."<sup>43</sup>

<sup>43</sup> A.M. Neville, *Properties of concrete*, 459-497.

### *Cracking associated with corrosion of reinforcement*



*Figure 11: Description of Defects, Source: Rendell. Spalling and delamination are considered types of cracks in this schematic. Spalling describes small pop-outs of concrete due to corrosion of the reinforcement, and delamination describes total loss due to what we can describe as internal cracking.*

## A. Mix design

Mix design dictates proportions of cement, water, fine and coarse aggregates, and admixtures.<sup>44</sup> For this reason, mix design is fundamental. Most modern applications of concrete assume that the engineer has properly defined the mix design. For existing concrete structures, proper mix design was not always specified. American Concrete Institute (ACI) Committee 211 provides techniques for estimating mix proportions for desired placability, consistency, strength,

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<sup>44</sup> Admixtures are not discussed in this thesis as they are not relevant to post-construction treatment.



water-cement ratio, density, and generation of heat.<sup>45</sup> Figure 12 is a representation of the principal properties considered to establish the mix design for "good concrete".

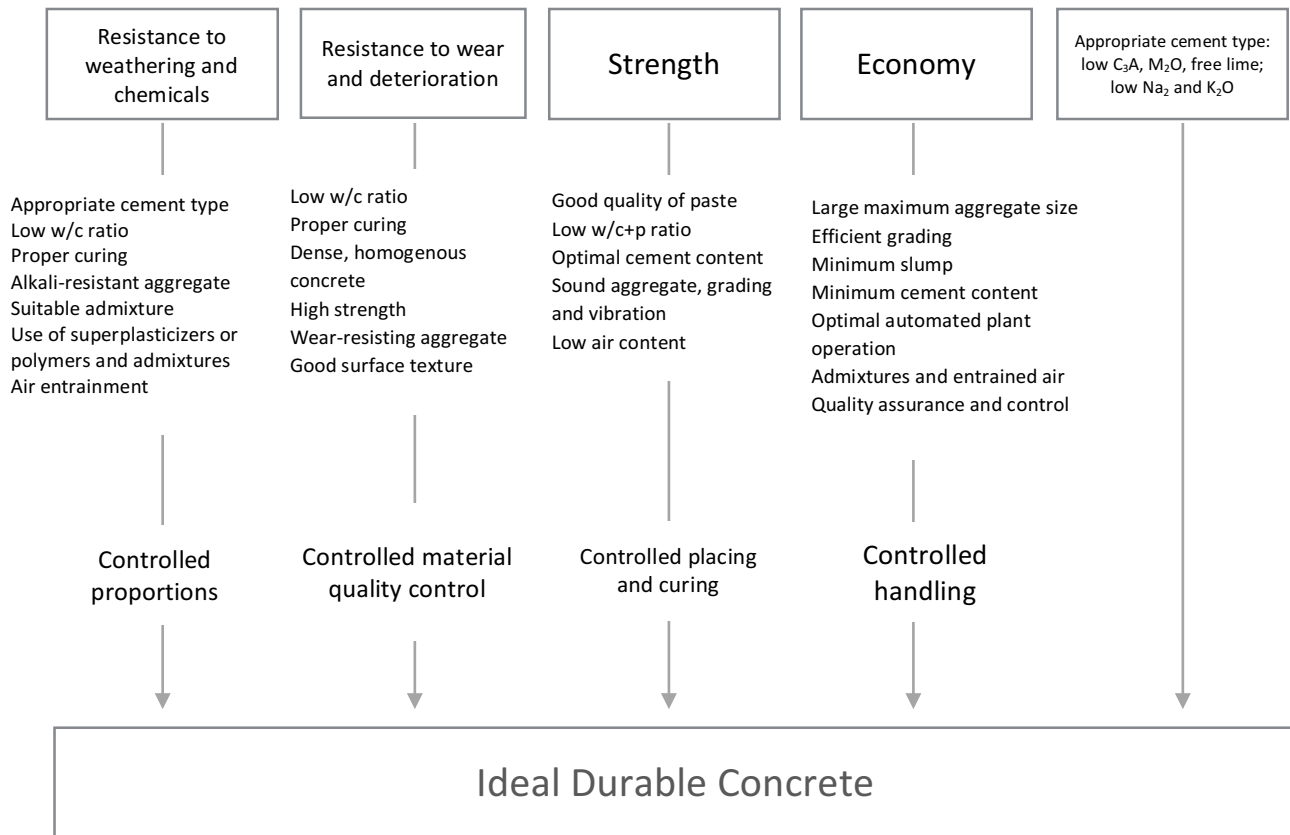


Figure 12: ACI 211.1 "Ideal Durable Concrete", representation of the principle properties considered during the mix design for "good concrete".

#### i. Water-cement ratio

One of the most important issues is the water-cement ratio (w/c). The strength of in-service concrete at a given age depends on the water-cement ratio: the lower the w/c ratio, the higher the concrete strength. ACI associates w/c ratio with durability requirements, such as

<sup>45</sup> "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass concrete", (American Concrete Institute Committee Report 211.1-91, 2002).

exposure to freezing and thawing, seawater, or sulfates. Neville explains w/c ratio as one of the oldest parameters used in concrete technology. As explained by Neville, "Compressive strength at a specified age, usually 28 days, measured on standard test specimens, has traditionally been the criterion of acceptance of concrete"<sup>46</sup> (Table 9). Strength is determined by the net quantity of water used per unit quantity of cement or total cementitious materials, excluding water absorbed by the aggregates.<sup>47</sup>

**RELATIONSHIP BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH OF CONCRETE\***

<b>28-DAY COMPRESSIVE STRENGTH (PSI)</b>	<b>NON-AE</b>	<b>AE</b>
<b>2,000</b>	0.82	0.74
<b>3,000</b>	0.68	0.59
<b>4,000</b>	0.57	0.48
<b>5,000</b>	0.48	0.40
<b>6,000</b>	0.41	0.32

Table 9: ACI Committee Report 211.1-91, *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass concrete*. 2002.

\* Table illustrates a general relationship between w/c and compressive strength.

The first formulation of a relationship between strength and the non-solid ingredients of concrete is attributed to Rene Feret in France in 1892 and Duff Abrams in the United States circa 1919.<sup>48</sup> At the time, Feret was the Chief of the Laboratory of Bridges and Roads at Boulogne-sur-Mer, France, and dedicated his study to testing the strength of mortars.<sup>49</sup> He understood that

<sup>46</sup> Neville, *Concrete: Neville's Insights and Issues*, 181-201.

<sup>47</sup> ACI Committee Report 211.1-91.

<sup>48</sup> Neville, *Concrete: Neville's Insights and Issues*, 181-201.

<sup>49</sup> F. Winslow Taylor. *A treatise on concrete, plain and reinforced: materials, construction, and design of concrete and reinforced concrete*. 2d ed.( New York: J. Wiley & Sons. 1909).

the presence of water-and air-filled space in mortar had a negative influence on the strength of the mortar. He drafted an equation to determine the volumetric proportions of w/c. Around the same time, Abrams also discovered the relationship between strength and w/c, and drafted the equation known as Abrams' law.<sup>50</sup> Both laws are still used by engineers today, even though the cements used in the early twentieth-century were very different from modern cements and most modern concrete which usually contain water reducers and other constituents.

Once the water-cement ratio is determined, the amount of cement per unit volume of the concrete is found by using the following equation:

$$\text{weight of cement} = \frac{\text{weight of water}}{\text{water-cement}}$$

The value of w/c, a mass ratio, considers water available for hydration. The water available for hydration will later be replaced by the products of hydration or the space it occupies will remain a void.<sup>51</sup> The water requirement for hydration was established by Henri Le Chatelier in 1887 during a fifteen year study for his doctorate thesis *Study of the Constitution of Hydraulic Mortars*<sup>52,53</sup> (Figure 13).

It was not until the 1958 that T.C. Powers of the Research and Development Division of the Portland Cement Association established quantitative data about water involved in the

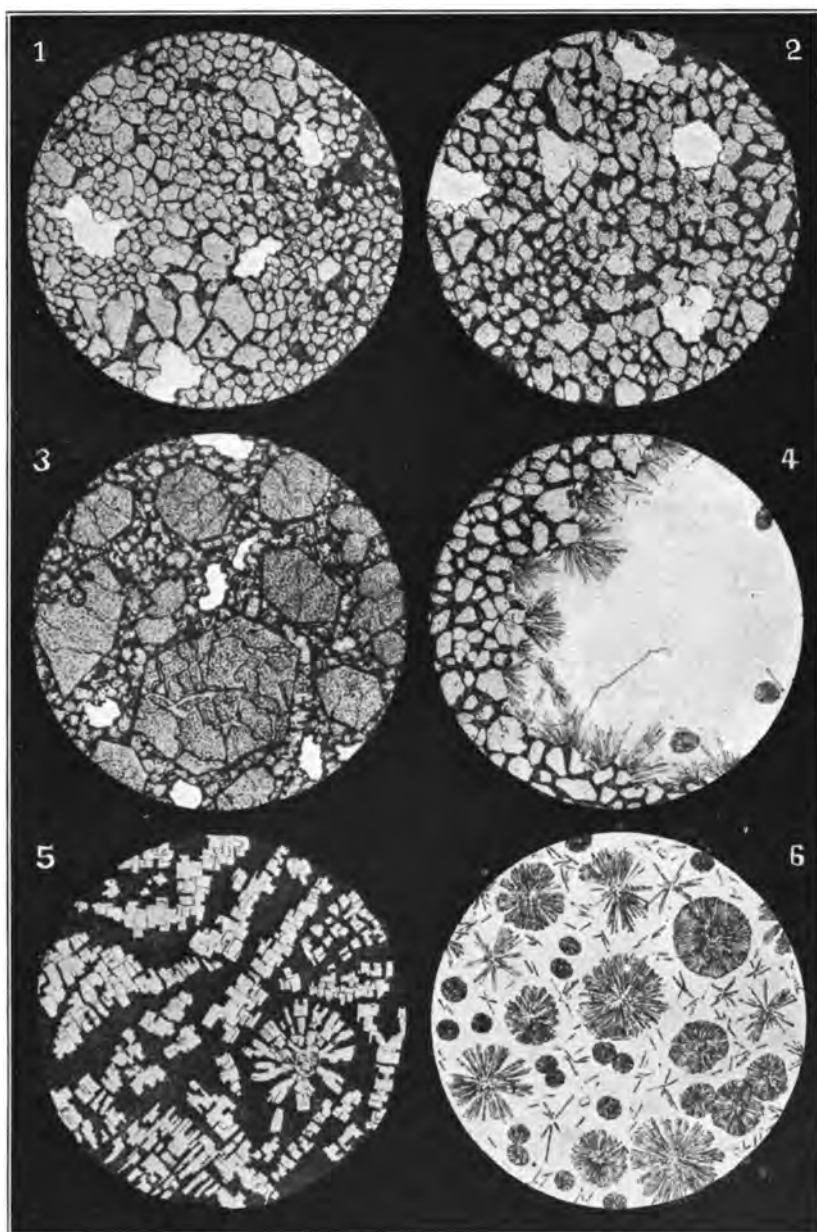
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<sup>50</sup> Winslow.

<sup>51</sup> Neville, *Concrete: Neville's Insights and Issues*, 181-201.

<sup>52</sup> ACI requires the original mixing water equal to 1.2 times the solid volume of the cement. The ACI requirement is based on the hydration product, which requires enough water to fill 30% pore space. With less water, not all of the cement can hydrate. From Bryant Mather and William G. Hime. "Amount of Water Required for Complete Hydration of Portland Cement", *Concrete International* 24.6 (2002), 56-58.

<sup>53</sup> Henri Le Chatelier. *Experimental researches on the constitution of hydraulic mortars*. (New York: MCGraw Publishing Company, 1887, Translated to English by J.L.Mack, 1905).



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*Figure 13: Crystallized silicates and aluminates, which are formed during the calcination or during the set of cements; the figures show the structures observed in their sections: Figure 2 — A thin section of Portland cement from Boulange showing the same crystals as the grey grappier from Teil, and a much more abundant ferruginous matrix. Figure 3 — A cement similar to Figure 2 in which some crystals have developed in an exceptional degree. Figure 4 — The beginning of hydration of a Portland cement, showing the elongated crystals of the hydrated silicate.*

*From Henri Le Chatelier. Experimental researches on the constitution of hydraulic mortars.*

hydration of cement and about the volumes of cement, water, and products of hydration.<sup>54,55</sup>

Powers concluded that the formation of pores can be attributed to an excess of water during hydration. Powers' findings are still valid when studying modern cement and concrete.<sup>56</sup>

#### HYDRATION OF A CEMENT PASTE

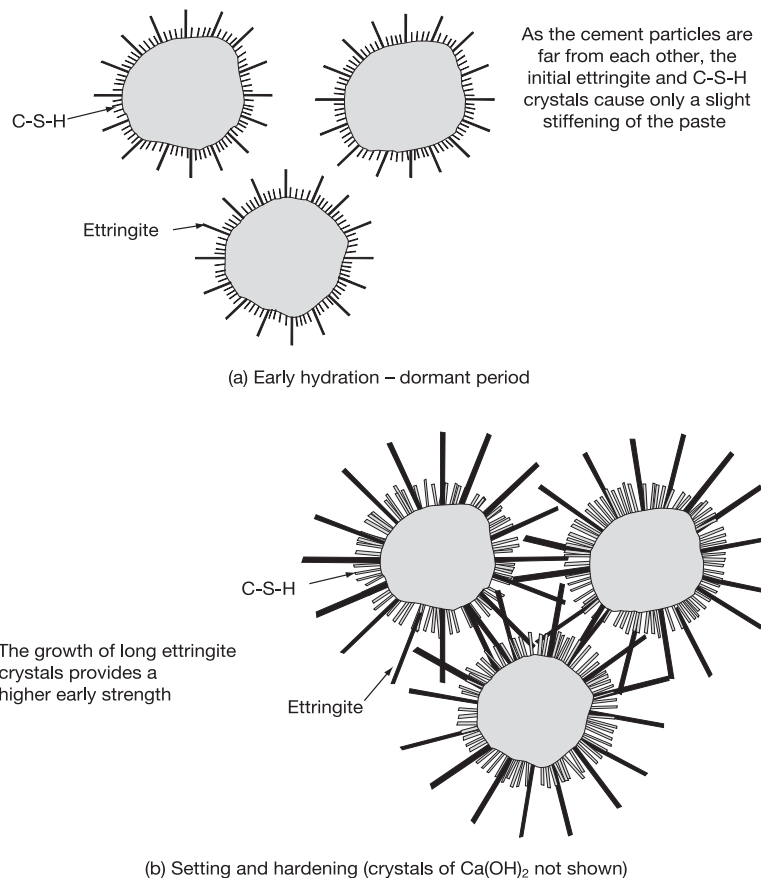


Figure 14: Schematic representation of the hydration of a paste with high w/c made with Portland cement with a high content of C3A. Schematic source: A.M. Neville, *Properties of concrete*, John Wiley & Sons, Inc., Malaysia, 1997.

<sup>54</sup> Work began in 1939, but was delayed on account of World War II and resumed following the wartime hiatus.

<sup>55</sup> T.C. Powers. "Structure and physical properties of hardened portland cement paste". *Journal of the American Ceramic Society* 41:1. (January 1, 1958).

<sup>56</sup> More information can be found in Adam Neville "How closely can we determine the water-cement ratio of hardened concrete?"

Hydration is the reaction of water with Portland cement mixed with sand, gravel and water to produce concrete. In the anhydrous state, or un-hydrated state, four primary types of minerals are present in cement as alite, belite, aluminate ( $C_3A$ ) and ferrite ( $C_4AF$ ), with small amounts of sulfate from gypsum. When water is added to the cement, a complex set of chemical reactions starts, generating heat (an exothermic reaction). The physical effect is seen in Figure 14. During the dormant, or induction, period when concrete can be placed – alite and belite react to form calcium silicate hydrate (C-S-H) and calcium hydroxide (CH), the two main products of hydration.<sup>57</sup>

During hydration, the rapid formation of hydration products (C-S-H and CH) occurs in the space occupied by the mix water (Figure 15). This results in a decrease in total pore volume and an increase in strength. Several early studies connect porosity to strength of the concrete. Moncmanová wrote, “Strength of concrete, whether compressive or bending, is also indirectly proportional to w/c ratio as porosity severely diminishes the strength of all materials.”<sup>58</sup>

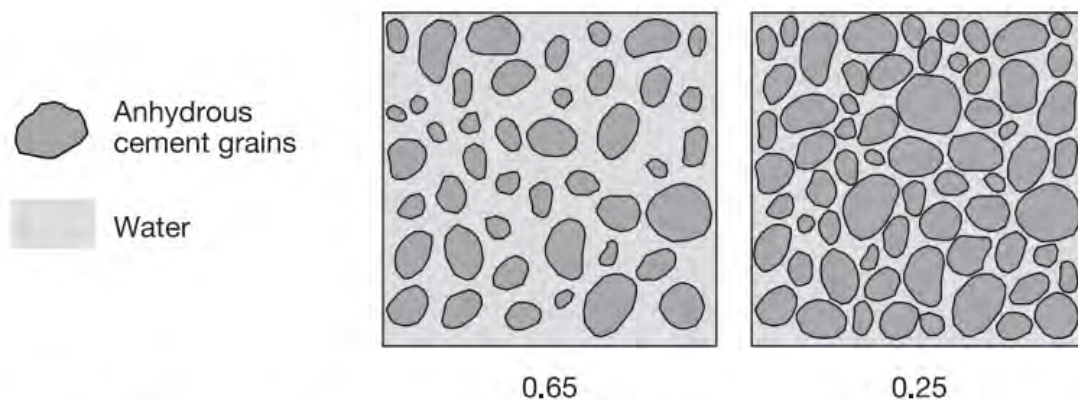


Figure 15: Diagrammatic representation of fresh cement paste with a w/c of 0.65 and 0.25. The ratio of the areas of water and cement is equal to the W/C by volume. from Adam Neville, *Concrete: Neville's Insights and Issues*, Thomas Telford, 2006.

<sup>57</sup> A.M. Neville, *Properties of concrete*, 280-284.

<sup>58</sup> Moncmanová, A., *Environmental Deterioration of Materials*, (Boston: WIT Press, 2007).

Most concretes with low overall porosity have a closed pore structure with pores that are not interconnected. In high porosity concrete, the pores are interconnected, and the concrete is said to have an “open pore structure”. Open or closed pore structures influence the permeability of the concrete. The diffusivity of the pore system is a fundamental factor affecting carbonation of the hardened cement paste.

## ii. Aggregate

Aggregate can affect cracking in two ways, water requirement and overall strength. The size, shape and surface texture of the aggregate affects the amount of water required for reasonable fluidity. For water-cement ratios below 0.4, crushed aggregate will result in strengths up to 38 percent higher than when gravel was used. When the water-cement ratio increases, the influence of aggregate is not as important.<sup>59</sup>

Surface texture particularly affects the bond of the aggregate to the cement paste. Aggregate type is selected during the process of mix design. Aggregate surface texture is classified by polished or dull; smooth or rough. Examples of the texture and some specific aggregates are shown in Table 16.

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<sup>59</sup> A.M. Neville, *Properties of concrete*, 280-284.

### ***SURFACE TEXTURE OF AGGREGATES (BS 812: PART 1) WITH EXAMPLES***

<b>GROUP</b>	<b>SURFACE TEXTURE</b>	<b>CHARACTERISTICS</b>	<b>EXAMPLES</b>
<b>1</b>	Glassy	Conchoidal fracture	Black flint, vitreous slag
<b>2</b>	Smooth	Water-worn, or smooth due to fracture of laminated or fine-grained rock	Gravels, chert, slate, marble, some rhyolites
<b>3</b>	Granular	Fracture showing more or less uniform rounded grains	Sandstone, oolite
<b>4</b>	Rough	Rough fracture of fine- or medium-grained rock containing no easily visible crystalline constituents	Basalt, felsite, porphyry, limestone
<b>5</b>	Crystalline	Containing easily visible crystalline constituents	Granite, gabbro, gneiss
<b>6</b>	Honeycombed	With visible pores and cavities	Brick, pumice, foamed slag, clinker, expanded clay

*Table 16: BS 812: Testing aggregates, Methods for sampling. 2012.*

The stress at which cracks develop can depend on the size and texture of the aggregate. Smooth aggregate (gravel) leads to cracking at lower stresses than rough/angular aggregate (crushed rock).<sup>60</sup> The properties of the aggregate significantly influence the strength of concrete in compression.

<sup>60</sup> Ibid.



### iii. Curing procedures

Curing influences the manner in which the cement hardens, and the quality of the concrete microstructure. Proper curing is evaluated by considering time, temperature, and ambient humidity. Curing must start after placing to avoid autogenous shrinkage and cracking within the body of the concrete mass. Its influence on strength is directly related to w/c ratios, inadequate curing affects strength at high w/c ratios, and high w/c ratios also show a lower rate of development of strength<sup>61</sup> (Figure 17).

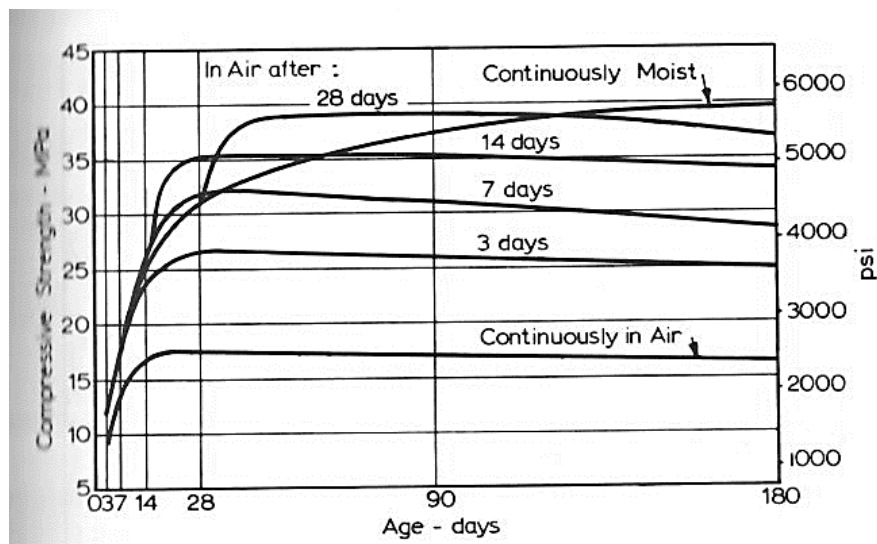


Figure 17: Influence of moist curing on the strength of concrete with a water-cement ratio of 0.50.

There is an approximate difference in w/c ratio between curing needs in situations where loss of water needs to be prevented and where water from the outside is necessary for hydration to continue.<sup>62</sup> This is particularly significant for concrete on the outer-zone of the structure and

<sup>61</sup> P. Nischer, "Gerneal report: effects of early overloading and insufficient curing on the properties of concrete after complete hardening", in *Proceedings of RILEM International Conference on Concrete of Early Ages 2* (1982), 117-26.

<sup>62</sup> "The dividing line is approximately at a water-cement ratio of 0.5: A.M. Neville, *Properties of concrete*, 280-284.

near reinforcement. The outer zone of the concrete structure is subject to weathering, carbonation, and abrasion, and its permeability will have an influence on the protection of steel reinforcement against corrosion.

The ambient relative humidity is another factor influencing carbonation. In humid environments, the natural curing process of the concrete is delayed. The delay of the initial curing on carbonation influences the outer zone to diffuse CO<sub>2</sub>. Figure 18 shows the progress of carbonation over a period of 16 years where the sample exposed to the highest relative humidity shows the largest depth of carbonation.

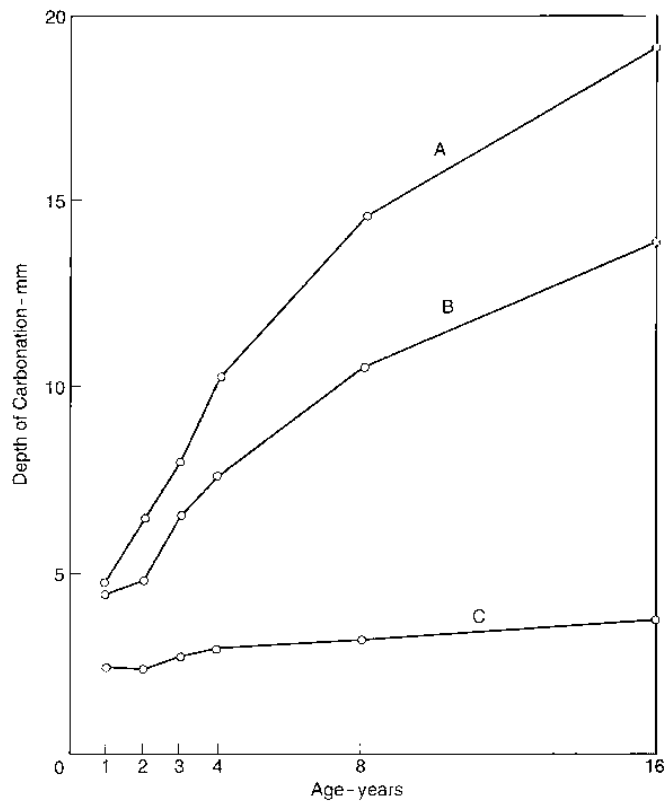
Wet or moist environments, and urban environments with acidic rain, and microclimates with high relative humidity potentially accelerate cracking and carbonation. Carbonation is dependent on RH, it occurs only at an RH of 40-90 percent.

When the RH in the pores is higher than 90 percent, carbon dioxide is not able to enter the pore, and when the RH is lower than 40 percent the carbon dioxide cannot dissolve in the water. This dependence on environmental conditions for the development of corrosion may cause problems for assessment of the material condition because the measurements are also highly dependent on the temperature and humidity at the time of investigation.<sup>63</sup>

There is considerable influence of relative humidity and moisture content on the carbonation of concrete, made from the same mix proportions, on multiple areas of a concrete structure. The age of concrete will also influence carbonation depth. Walls exposed to rain and sloping surfaces washed by rain will have a lower depth of carbonation. Over a whole structure, the depth of carbonation can be 50 percent more than the smallest depth.<sup>64</sup> Small variations in relative humidity, and temperature have little effect on carbonation, but large variations can foreshadow considerable differences in the depth of carbonation.

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<sup>63</sup> Breyse, Chapter 4.



*relative humidity; (B) outdoors, protected by a roof; (C) horizontal surface outdoors. The values are averages for concretes*

## B. Placement of reinforcement

Steel reinforcement is used in concrete because concrete has a low tensile strength and cannot resist tensile loads. The first use in construction was in 1853 when Francois Coignet used rebar in a four-story home in Paris. Mild steel was widely available at the beginning of the 20th century, and was used to form reinforcement cages of straight or bent metal. Steel and concrete have similar coefficients of thermal expansion, and proper placement of the steel rebar will allow the two materials to expand and contract without undue stress and cracking.<sup>65</sup>

<sup>64</sup> A.M. Neville, *Properties of concrete*, 283.

Placement of bars must be carefully designed before construction. The National Precast Concrete Association (NPCA) requires that the structural integrity of precast panels is dependent on the grade of the steel, the size and spacing of the steel reinforcing, and the location of the steel within the product. The location of the steel is particularly important in relationship to concrete cover. *Cover* describes the least distance between the surface of the reinforcement and the outer surface of the concrete.<sup>66</sup> Cover is the most important factor in protecting the steel reinforcement from corrosion.<sup>67</sup> The minimum concrete cover is specified in the ACI 318.

Insufficient concrete cover allows carbonation to reach the rebar more quickly than it would in concrete with properly designed cover. Increasing the rebar cover increases the time before carbonation and chloride ingress reaches the rebar and begins to corrode the metal.<sup>68</sup> Neville found that under steady conditions, “the depth of carbonation increases in proportion to the square root of time of exposure”. Oxygen availability also affects the concrete system, because corrosion can only develop when the rebar is exposed to oxygen.

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<sup>65</sup> Angus Stocking, 11 December 2015. “Precast concrete reinforcement: an ever-evolving technology”, National Precast Concrete Association online, 24 April 2017. <http://precast.org/precast-magazines/precast-solutions/2016-winter/precast-concrete-reinforcement-an-ever-evolving-technology/>.

<sup>66</sup> International Concrete Repair Institute, *Concrete Repair Terminology*, (2010).

<sup>67</sup> Concrete Construction Staff, 13 March 2005. “Placing Reinforcing Steel”, ConcreteConstruction.net. 24 April 2017. [http://www.concreteconstruction.net/how-to/construction/placing-reinforcing-steel\\_o](http://www.concreteconstruction.net/how-to/construction/placing-reinforcing-steel_o).

## C. Environment

Table 19 is a list of environmental influences and results. Concrete can also be damaged from chemical attacks, due to the in-service environment. Alkali soils and groundwater containing calcium sulfates, and chlorides can cause extensive damages to the concrete system, reacting with the hydrated lime and aluminate in the cement paste.<sup>69</sup> Sulfuric acid weakens the concrete and compromises steel reinforcement if it is able to reach the rebar.<sup>70</sup> Acid attack present in the atmosphere also include nitrogen oxides (NO<sub>x</sub>).

### **ENVIRONMENTAL INFLUENCES**

Carbon dioxide and acidic gases	Lower pH around the steel that enables corrosion to progress
Water	Can introduce depassivating chloride ions into concrete
Freeze thaw in colder zones	Breakdown of surface, progressive cracking, water penetration to reinforcement that enables corrosion to progress
Salt ingress	Marine salt introduces depassivating chloride ions into the surface of the concrete
Chemical attack	Chemical attack by chlorides can cause corrosion of steel or sulphates that can cause degradation of the cementitious matrix
Vibration	Causes cracking, spalling, and delamination
Impact damage	Causes physical weakening of structural components, exposure of steel reinforcement, cracking etc

Table 19: *The Investigation and Repair of Historic Concrete*, NSW Heritage Office

<sup>68</sup> D. Breyse. *Deterioration processes in reinforced concrete: an overview*, (Bordeaux University: Woodhead Publishing Limited, 2010), 1-23.

<sup>69</sup> R. Dodge Woodson, *Concrete Structures - Protection, Repair and Rehabilitation*. (Amsterdam: Elsevier, 1997), 31-39.

<sup>70</sup> Woodson, 31-39.

“Clean air” is composed of nitrogen (N<sub>2</sub>), oxygen (O<sub>2</sub>), CO<sub>2</sub>, water vapor (H<sub>2</sub>O) and inert gases from natural sources. Following the industrial revolution, the atmosphere has experienced an increase in CO<sub>2</sub>, in the pollutants sulfur dioxide (SO<sub>2</sub>), ozone, and nitrogen oxide (NO<sub>x</sub>), as well as “secondary pollutants” formed from the primary pollutants: sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), nitric acid (HNO<sub>3</sub>).<sup>71</sup> Since 1950, atmospheric levels of CO<sub>2</sub> levels (a heat-trapping greenhouse gas) have been on the rise.<sup>72</sup> (Figure 20-21)

*Proxy (indirect) measurements*

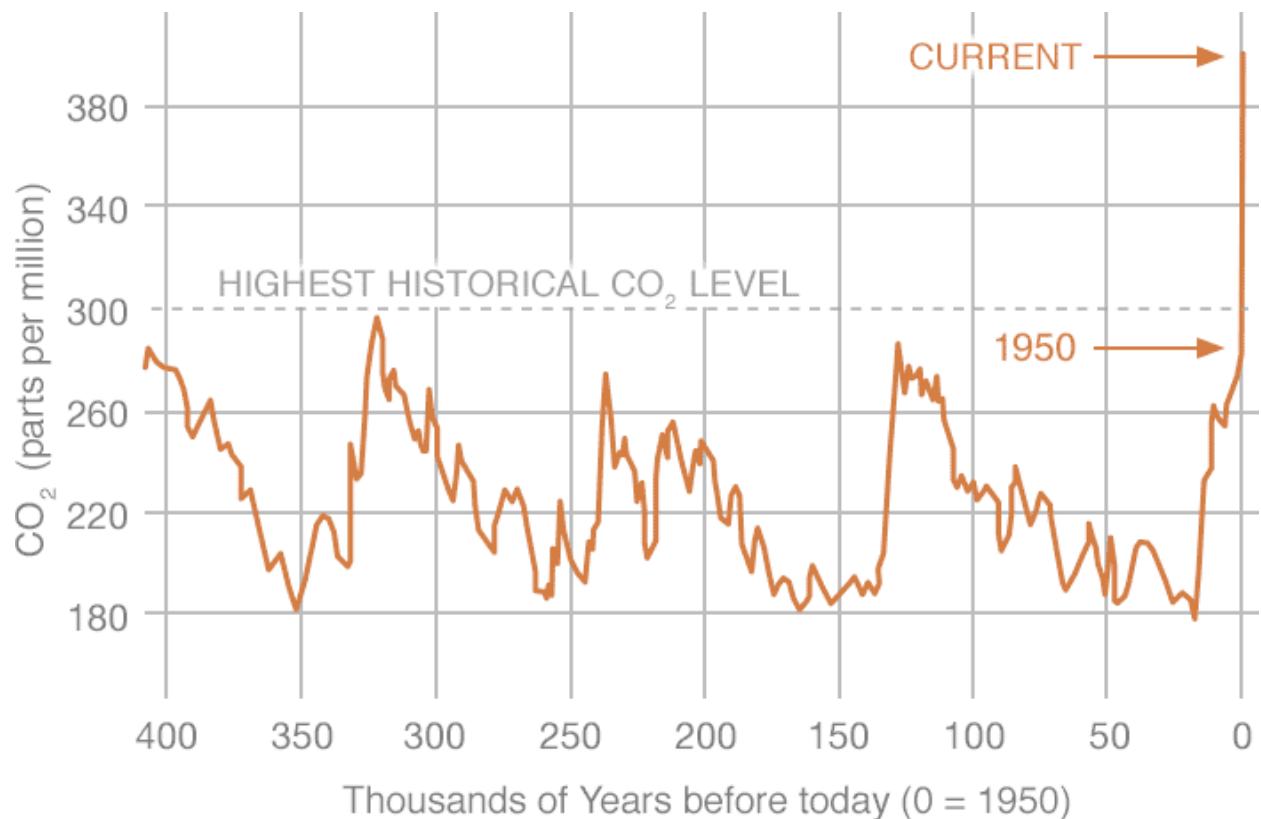
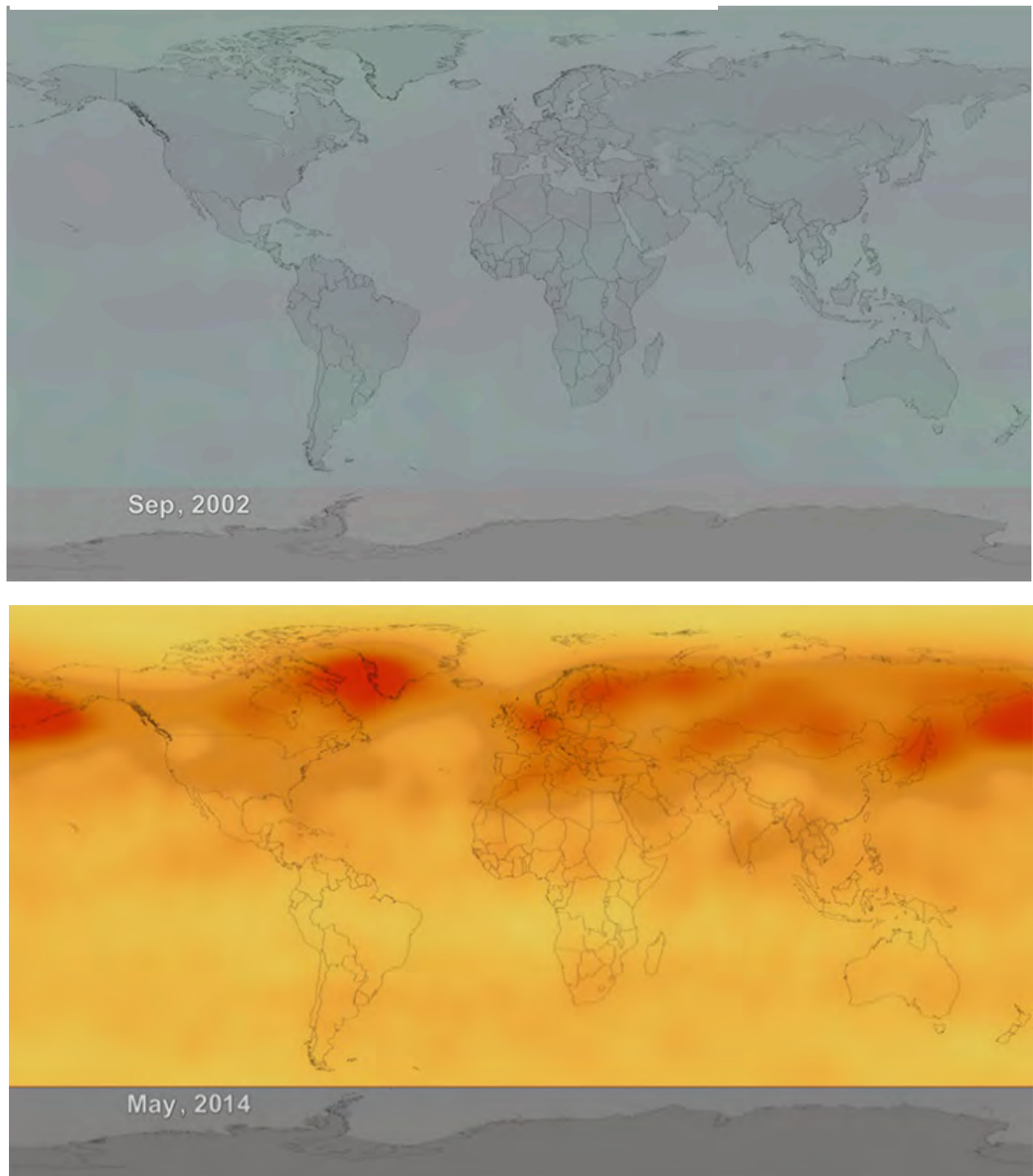


Figure 20: The second chart shows CO<sub>2</sub> levels during the last three glacial cycles, as reconstructed from ice cores. Source: Reconstruction from ice cores. Credit: NOAA.

<sup>71</sup> Jan Rosvall and Stig Aleby, editors, *Air Pollution and Conservation, Safeguarding our Architectural Heritage*, (Amsterdam: Elsevier, 1988), 37-63.

<sup>72</sup> “Carbon Dioxide”, NASA Global Climate Change, Climate.NASA.gov. (March 2017). <https://climate.nasa.gov/vital-signs/carbon-dioxide/>

*Time series: 2002-2014*



*Figure 21: The time series shows global distribution and variation of the concentration of mid-tropospheric carbon dioxide in parts per million (ppm) . The overall color of the map shifts toward the red with advancing time due to the annual increase of CO<sub>2</sub>. Top: September 2002, Bottom: May 2014. Data source: Atmospheric Infrared Sounder (AIRS) . Credit: NASA.*

The observations of pollution damage of the built environment increased during the first half of the twentieth century, especially in urban centers powered by coal. Population increases resulted in an increase in the energy consumption of the industrialized world following World War II and a drastic increase in the combustion of oil and coal causing SO<sub>2</sub>, NO, NO<sub>2</sub>, and other pollutants to be emitted into earth's atmosphere.

The many primary and secondary pollutants are a complex mixture of reactive compounds. Since the early 1980s until present day, particulate matter from vehicle-derived sources has been the dominant source of pollution, particularly in dense urban areas.<sup>73</sup> Diesel particulates consist of spherical particles which agglomerate on the surface of building materials. The conglomerates of diesel particulate have a soiling factor three times greater than the particulate of coal combustion.<sup>74</sup>

Environmental deterioration is known to increase substantially under the influence of pollutant gases, temperature, and humidity. Pollutant gases and higher levels of CO<sub>2</sub> are detrimental to the service-life of Portland cement based concrete. The acids formed will attack concrete, lowering alkalinity.<sup>75</sup> They also acids weaken the concrete and can increase permeability.

As with building stone, each concrete surface comprises a unique composite system, as noted by the 1988 Air Pollution and Conservation conference:

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<sup>73</sup> Trudie Mansfield, et al., "Diesel Particulate Emissions and the Implications for the Soiling of Buildings", *The Environmentalist* Volume 11.4, (1991).

<sup>74</sup> Mansfield.

<sup>75</sup> Satish Chandra, "D6:1990 Influence of pollution on mortar and concrete", *Swedish Council for Building Research*, (Solna, Sweden: Byggeforskningsrådet, 1990).



As an example of the extreme complexity involved in the evaluation of deterioration rates with this type of materials we note that a single stone may have quite different specific surfaces depending on its history, because many climatic (e.g. temperature shock, frost, salt crystallization) or anthropogenic factors (e.g. carving, mechanical cleaning, structural loading) cause the formation of microscopic fractures and so increase the specific surface. Also the salts transported by capillary water or fired by acid attack remain active throughout innumerable microclimatic cycles causing deterioration independent of other decay factors.<sup>76</sup>

Several researches have emphasized the importance of *transport process* when studying primary and secondary pollutant attack on building materials, especially Yates in the article “Mechanisms of Air Pollution damage to brick, concrete, and mortar”:

In considering air pollutant attack, we must first consider transport processes, concentrations and chemical type of pollutants. The length of time pollutants remain in the atmosphere, the distance they travel, and the atmospheric concentrations they attain will depend on the meteorological conditions and deposition processes. The processes for transportation from the atmosphere to a surface are usually considered under two main headings — dry and wet deposition.<sup>77</sup>

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<sup>76</sup> Rosvall and Aleby, 37-63.

<sup>77</sup> T. Yates, “Mechanisms of Air Pollution damage to brick, concrete, and mortar”, *Air Pollution Reviews: Effects of Air Pollution on the Built Environment*, (London, US: ICP, 2003), 107-130.

# Treating historic concrete

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## A. History of treatment

During the early twentieth century, concrete was considered, as noted earlier in this thesis, a durable and permanent material. Concrete had not been in use long enough for cracks and patterns of cracking to become recognized as a flaw inherent to the material, and early criticism only touched on the use of concrete for specialized in-service environments. Beginning in the 1910s, structural engineers began to study mechanisms of deterioration leading to cracking, and options for repair. Repair materials became available as early as the 1930s, but were not mass-manufactured until the post-WWII period.

Early repairs were limited to cementitious patching. Following WWII, a number of treatments were developed to control concrete cracking through infill and crack bridges. In 1956, the National Bureau of Standards reported positive test results for small reinforcing bars to control the cracks in reinforced concrete. The bars were meant to control spacing and width of cracks when used in the design of new concrete structures. The test results indicated that width

Samples of improved reinforcing bar used in the investigation at NBS.

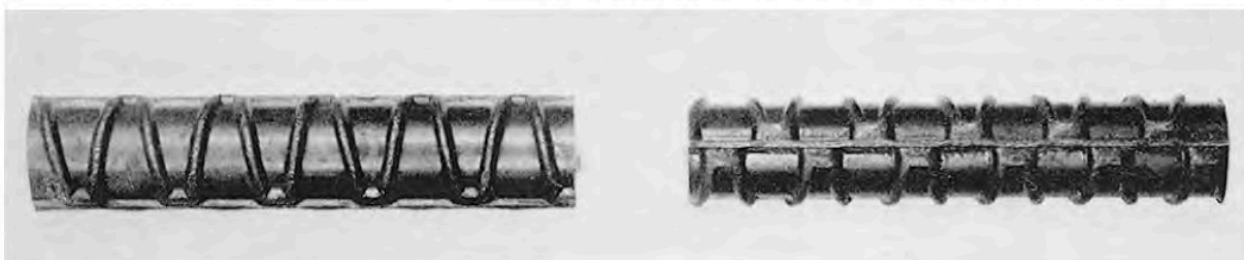


Figure 22: Deformed bars used to better bond the steel to the concrete, distribute strain and limit crack width. National Bureau of Standards, "Control of cracks in reinforced concrete", Publication #C561010, The Aberdeen Group, 1956.

of cracks can best be controlled by using a large number of small bars and by increasing the reinforcement with enhanced bars.<sup>78</sup> (Figure 22)

In 1961, S.Champion wrote *Failure and Repair of Concrete Structures*. The text critically analyzed concrete failure as either chemical or mechanical deterioration, and detailed several methods for repairing concrete, notably crack stitching. (Figure 23)

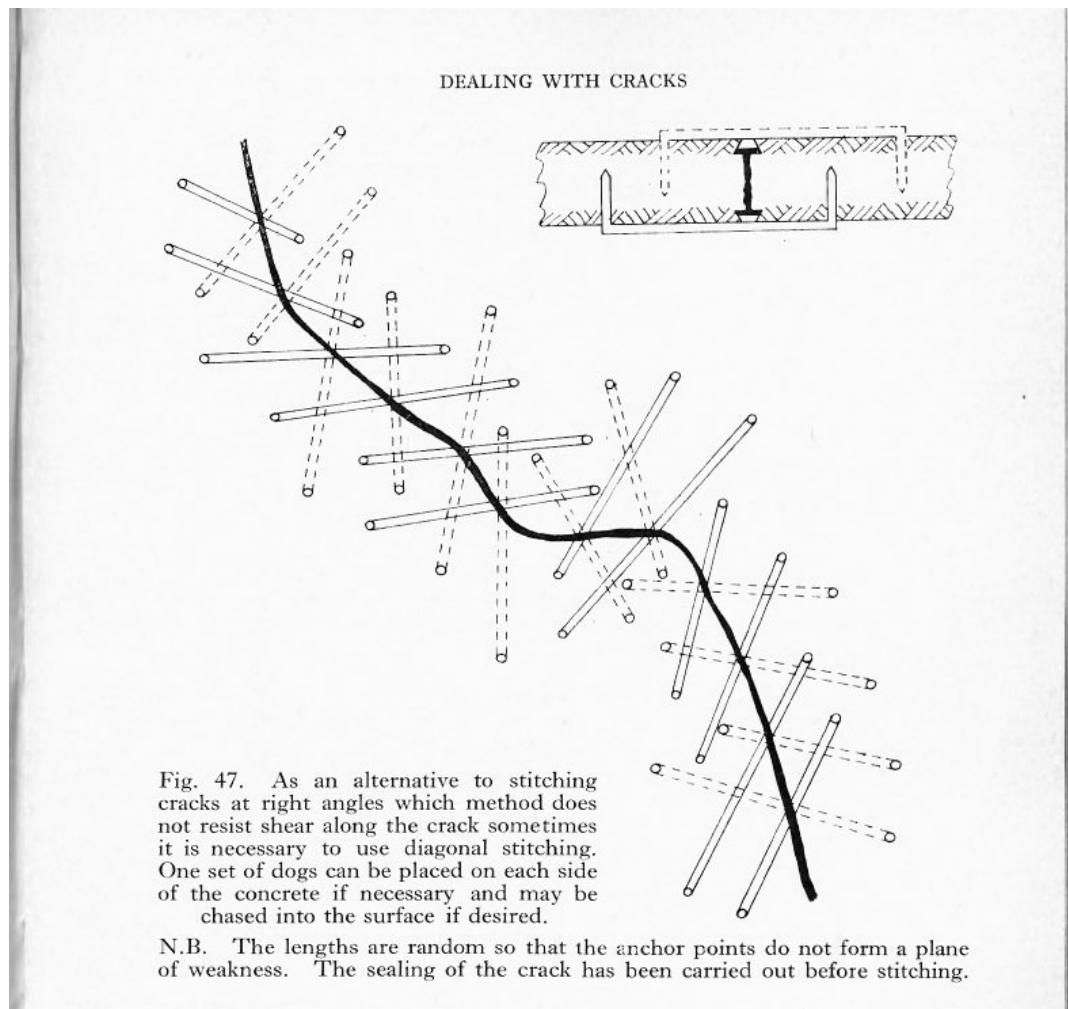


Figure 23: Crack Stitching, S. Champion, *Failure and Repair of Concrete Structures*. Contractors Record Limited, London. 1961.

<sup>78</sup> National Bureau of Standards. (1956).

In 1969 the National Bureau of Standards published “Concrete repair problems: Causes and Cures”, making the assertion that for good results in repairing, it is essential to determine the causes of deterioration.<sup>79</sup> This opinion strengthened Champion’s commitment to the cause-symptom-treatment methodology.

In this report, the Bureau stresses that it is critical to understand the underlying cause or causes of deterioration (readily apparent or not) with conditions surveys and material testing. The report also recognizes the potential for deterioration caused by a continuing phenomenon, and suggests a difference in treatment for the two: “If the deterioration is caused by a continuing phenomenon, steps must be taken either to deal with the phenomenon or to protect the concrete. When deterioration results from an isolated cause or a series of occurrences, repair work usually starts immediately.”<sup>80</sup> Common causes of deterioration and recommendations for repair were demonstrated through several tables included in the text (Figure 24). It is important to note that this report defined coatings as materials of liquid or plastic consistency applied directly over concrete to protect it or to add characteristics not attainable with the existing concrete. Coatings described materials such as epoxy resins, bituminous compounds, linseed oil, fluorsilicate compounds and silicones, as well as paints used to hide discolorations or provide added resistance to hostile environments and weathering. Coatings were recommended for protection of stained exposed concrete, and treatment of honeycombing, or other surface features that were considered architecturally unacceptable.<sup>81</sup>

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<sup>79</sup> National Bureau of Standards. “Control of cracks in reinforced concrete”. (The Aberdeen Group, 1969).

<sup>80</sup> National Bureau of Standards. (1969).

<sup>81</sup> Ibid.

In 1979, the National Bureau of Standards released tests results on epoxies used for concrete repair and restoration.<sup>82</sup> NBS recommended epoxy resins, which were meant as a cheap and easy material in the context of the then rising costs of concrete restoration (materials and labor). Several research initiatives prior to 1957 created a market for epoxy resins as adhesives and coatings. The main advancement in epoxy technology was the introduction of amine cross-linking agents, explored by Castan in U.S. Patent 2444333.<sup>83</sup> Epoxy resins comprise reactive epoxide groups. Greenlee Laboratories led experimentation in this early period in the utilization of polyalcohols for use in coatings because of their resistance to chemicals and solvents (noted as “super-phenolic”).<sup>84</sup> Researchers at Shell Development Corporation further investigated the super-phenolic discoveries for raw propylene derivatives (converted to resins) and epoxides (derived from the raw material epichlorohydrin). Shell Chemical Corp. marketed epichlorohydrin for epoxy coatings and vinyl chloride resins—a major contribution to the continued experimentation in commercial chemical product development. By the late-1950s, epoxy coatings were a market item desirable for their ability to be modified with the use of moderately priced solvents and for their easy application and relatively quick curing. NBS’s 1979 manual “Control of cracks in reinforced concrete” stated the epoxy coatings made the greatest advances in the market where resistance to acids, alkalies, or organic chemicals was a requirement of their use, and they were used experimentally on concrete for the first time in the late 1960s.<sup>85</sup>

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<sup>82</sup> National Bureau of Standards. “Control of cracks in reinforced concrete”. (The Aberdeen Group, 1979).

<sup>83</sup> Irving Skeist, assisted by George R. Somerville, *Epoxy resins*. (New York: Reinhold, 1958).

<sup>84</sup> Ibid.

<sup>85</sup> National Bureau of Standards. “Control of cracks in reinforced concrete”. (The Aberdeen Group, 1979).

The National Bureau of Standards 1979 report is considerably less detailed than the report from 1969, and the emphasis on “Causes and Cures” is reduced to a brief note: “The cause of any cracking of a concrete surface should be determined before undertaking repairs. Structural defects should be remedied before filling cracks to prevent recurrence of cracking.”<sup>86</sup> The report instructs large cracks to be filled with epoxiess or epoxy-based mortars in the same manner as patching. Smaller cracks (0.002 or 0.003 inch up to 0.25 inch) should be closed using injection equipment by drilling holes at close intervals along the crack and using a syringe to inject the crack with an epoxy resin.<sup>87</sup>

The United States Department of the Interior also provided a guide for the repair of concrete. The Bureau of Reclamation published the first Concrete Manual in July 1938, and in November 1970 the first edition was updated to *Standard Specifications for Repair of Concrete, M-47*.<sup>88</sup> The revised edition is a reflection of a more modern attitude to crack treatment and concrete repair, which is defined by a wide availability of products and manufacturers which cater to individual treatments for specific conditions. The Bureau of Reclamation further revised these two documents in 1975 and 1996 as guidelines for all concrete repair projects undertaken by that agency. In 2007 the National Park Service, also part of the Department of the Interior, published Preservation Brief 15: Historic Concrete, highlighting the value of early concrete structures as significant cultural artifacts.

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<sup>86</sup> Ibid.

<sup>87</sup> Ibid.

<sup>88</sup> United States Department of the Interior Bureau of Reclamation Technical Service Center, *Guide to Concrete Repair*, April 1997.

Table I—Classification of Concrete Damage		
Concrete Damage	Repair Technique	Repair Materials
Alkali-Aggregate Expansion	Coatings	Bituminous coatings
	Concrete replacement	Epoxies
	Jacketing	Jacketing materials
	Total replacement	Latex-modified concrete
	Linseed oil Portland cement concrete	
Cavitation	Coatings	Bituminous coatings
	Concrete replacement	Epoxies
	Jacketing	Jacketing materials
	Pneumatically applied mortar	Latex-modified concrete Portland cement concrete
	Prepacked concrete	Portland cement mortar
Cracks—Active	Caulking	Elastic sealants
	Jacketing	Jacketing materials
	Stitching	
	Stressing	
Cracks—Dormant	Acid etching	Bituminous coatings
	Caulking	Dry pack
	Coatings	Elastic sealants
	Concrete replacement	Epoxies
	Dry pack	Expanding mortars
	Grinding	High-speed-setting materials
	Grouting	
	Jacketing	Jacketing materials
	Pneumatically applied mortar	Latex-modified concrete Portland cement concrete
	Thin bonded or unbonded resurfacing	Portland cement grout Portland cement mortar
	Sandblasting	
	Stressing	
Crazing	Coatings	Epoxies
	Grinding	High-speed setting materials
	Pneumatically applied mortar	Latex-modified concrete
	Thin bonded or unbonded resurfacing	Linseed oil Portland cement concrete
	Sack rub	Portland cement grout
	Sandblasting	Portland cement mortar
Dusting	Acid etching	Bituminous coatings
	Coatings	Epoxies
	Grinding	High-speed setting materials
	Jacketing	Jacketing materials
	Sandblasting	Latex-modified concrete
	Thin bonded or unbonded resurfacing	Linseed oil
	Total replacement	Special floor aggregates
Efflorescence	Surface hardeners	
	Acid etching	Portland cement concrete
	Total replacement	Portland cement grout
	Portland cement mortar	

Figure 24.1: National Bureau of Standards, “Control of cracks in reinforced concrete”, Publication, The Aberdeen Group, 1969

Table I—Classification of Concrete Damage cont.		
Concrete Damage	Repair Technique	Repair Materials
Fire damage	Acid etching	Dry pack
	Caulking	Elastic sealants
	Coatings	Epoxies
	Concrete replacement	Expanding mortars
	Dry pack	Latex-modified concrete
	Grinding	Portland cement concrete
	Jacketing	Portland cement grout
	Mortar replacement	Portland cement mortar
	Pneumatically applied mortar	
	Prepacked concrete	
	Thin bonded or unbonded resurfacing	
	Sack rub	
	Sandblasting	
	Stitching	
	Stressing	
	Total replacement	
Form Scabbing	Coatings	Dry pack
	Concrete replacement	Epoxies
	Dry pack	Expanding mortars
	Mortar replacement	High-speed setting materials
	Pneumatically applied mortar	Latex-modified concrete
	Thin bonded or unbonded resurfacing	Portland cement concrete
	Total replacement	Portland cement grout Portland cement mortar
Holes—Small	Acid etching	Dry pack
	Coatings	Epoxies
	Dry pack	High-speed setting materials
	Grinding	
	Mortar replacement	Latex-modified concrete
	Thin bonded or unbonded resurfacing	Portland cement grout Portland cement mortar
Holes—Large	Coatings	Epoxies
	Concrete replacement	Expanding mortars
	Pneumatically applied mortar	High-speed setting materials
	Prepacked concrete	Latex-modified concrete
	Total replacement	Portland cement concrete
	Portland cement mortar	
Honeycombing	Concrete replacement	Epoxies
	Dry pack	Dry pack
	Mortar replacement	Expanding mortars
	Prepacked concrete	Portland cement concrete
	Total replacement	Portland cement mortar
Permeability	Autogenous healing	Bentonite
	Coatings	Bituminous coatings
	Jacketing	Epoxies
	Pneumatically applied mortar	Expanding mortars
	Prepacked concrete	Jacketing materials
	Total replacement	Latex-modified concrete
		Linseed oil Portland cement concrete Portland cement mortar

Figure 24.2: National Bureau of Standards, “Control of cracks in reinforced concrete”, Publication, The Aberdeen Group, 1969



Table I—Classification of Concrete Damage cont.		
Concrete Damage	Repair Technique	Repair Materials
Popouts	Coatings	Bituminous coatings
	Thin bonded or unbonded resurfacing	Epoxies
	Total replacement	Expanding mortars
	Linseed oil	Latex-modified concrete
	Portland cement grout	
	Portland cement mortar	
	Special floor aggregates	
Sandstreaking	Concrete replacement	Expanding mortars
	Mortar replacement	Portland cement concrete
	Prepacked concrete	Portland cement grout
	Total replacement	Portland cement mortar
Scaling	Coatings	Bentonite
	Grinding	Bituminous coatings
	Jacketing	Epoxies
	Pneumatically applied mortar	High-speed setting materials
	Thin bonded or unbonded resurfacing	Latex-modified concrete
	Total replacement	Linseed oil
	Sandblasting	Portland cement concrete
	Silicones	Portland cement mortar
	Special floor aggregates	
Spalling	Coatings	Bituminous coatings
	Concrete replacement	Epoxies
	Grinding	Expanding mortars
	Jacketing	High-speed setting materials
	Mortar replacement	Latex-modified concrete
	Pneumatically applied mortar	Linseed oil
	Prepacked concrete	Portland cement concrete
	Thin bonded or unbonded resurfacing	Portland cement mortar
	Total replacement	Silicones
	Sandblasting	Special floor aggregates
Stains and Uneven Color	Acid etching	Epoxies
	Coatings	Latex-modified concrete
	Grinding	Portland cement concrete
	Pneumatically applied mortar	Portland cement grout
	Thin bonded or unbonded resurfacing	Portland cement mortar
	Sack rub	Silicones
	Sandblasting	

Figure 24.3: National Bureau of Standards, "Control of cracks in reinforced concrete", Publication, The Aberdeen Group, 1969

## B. Modern guidelines and standards

A primary concern for conservation is the cracking of concrete, although a thorough understanding of the reasons for cracking, limited in this thesis to carbonation and corrosion of reinforcement, is critical prior to treatment selection. Once an understanding of the reasons for cracking is gained, the conservator needs to navigate the maze of products sold by the concrete repair industry. Concrete repair products are often sold with marketing propaganda. The marketing literature is plentiful, yet technical information is not always readily available.

Industrial products on the market are suitable for use on modern concrete, but may provide undesirable effects on historic structures in the eyes of the conservator. Nearly all treatments claim to provide water resistance; most claim to bridge cracks and provide chemical protection from deterioration. But there is often ambiguity in how these materials will affect the concrete over the life-cycle of the structure, i.e. how will the treatment age, and how will its deterioration will affect the concrete. There are currently many misunderstandings concerning compatibility considerations in concrete repair.

Data from the concrete repair industry indicate failure of some well-designed conservation treatments. The increasing need for conservation treatments was addressed at the Getty's Conserving Concrete Heritage Experts Meeting. Some of the conference attendees recognized that most repair solutions are not permanent, and claimed that "repair work is undertaken with the understanding that with minimal further intervention the service life of the structure will be extended for a reasonable period of time".<sup>89</sup>

To address this issue, Breysse and Abraham identified critical information in their book

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<sup>89</sup> Custance-Baker and Macdonald.

*Deterioration processes in reinforced concrete: an overview.* They suggested a thorough selection of useful data before application of treatments. Useful data can be classified as (i) “providing information about the current material conditions, such as porosity, internal damage, and rebar cover depth”; (ii) “providing information about the deterioration rate, such as diffusion coefficient and corrosion current”; and (iii) “providing information about the environment, such as temperature or humidity”, some of which were discussed in Chapter III.<sup>90</sup>

The durability of a conservation treatment depends the compatibility of the repair with the concrete substrate. Unfortunately, there is a dearth of information on the fundamentals of compatibility issues in the product literature. According to Vaysburd, “The opinions and recommendations issued on the subject are in some cases confusing, misleading or incorrect, regrettably leading to fallacies about compatibility in the practicing community.”<sup>91</sup>

Today the growing community Vaysburd addressed includes conservators and heritage professionals. Considerable progress in this field has been achieved in the past twenty-five years through research on concrete conservation and the behavior of modern materials. This has been the result of a growing recognition of recent and modern architecture as heritage places. Seminal texts produced by organizations involved in cultural heritage are included in the next section.

#### i. Requirements for the conservator

The Madrid Document of 2011 addresses “Approaches for the Conservation of

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<sup>90</sup> Breysse, Chapter 4.

<sup>91</sup> Vaysburd, 717-721.

Twentieth-Century Architectural Heritage”.<sup>92</sup> The document works to develop guidelines to support the conservation and management of change to twentieth-century heritage places. Article 3 emphasized the research on technical problems related to modern materials, promoting the development of specific repair methods appropriate to the unique building materials and construction techniques of the twentieth century.<sup>93</sup> The Madrid Document stresses the need for the conservation of a typology—modern and twentieth-century architectural heritage—a typology that largely encompasses historic concrete structures.

The American Institute for Conservation of Historic and Artistic Works (AIC) *Code of Ethics and Guidelines for Practice* (1994) outlines specific objectives for the conservation professional when designing a treatment. It stated:

The conservation professional should recognize the critical importance of preventative conservation as the most effective means of promoting the long-term preservation of cultural property. The conservation professional should provide guidelines for continuing use and care, recommend appropriate environmental conditions for storage and exhibition, and encourage proper procedures for handling, packing, and transport.<sup>94</sup>

The conditions for treatment, defined by AIC, also require the conservator to consider the continuum of care dedicated to each treatment, which is “judged suitable to the preservation of the aesthetic, conceptual, and physical characteristics of the property.”<sup>95</sup> AIC states that the conservator is responsible for “choosing materials and methods appropriate to the objectives of each specific treatment and consistent with currently accepted practice.”<sup>96</sup> AIC does not discuss

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<sup>92</sup> ICOMOS. “Approaches for the Conservation of Twentieth-Century Architectural Heritage: Madrid Document”. (Charter from International Scientific Committee on Twentieth Century Heritage, 2014).

<sup>93</sup> Madrid Document.

<sup>94</sup> American Institute for Conservation of Historic and Artistic Works (AIC), *Code of Ethics and Guidelines for Practice*, (Revised August 1994).

<sup>95</sup> AIC.

<sup>96</sup> Ibid.

conservation of concrete specifically, but makes important recommendations for the conservation of any historic material. Regarding treatment selection, AIC states, “The advantages of the materials and methods chosen must be balanced against their potential adverse effects on future examination, scientific investigation, treatment, and function.” Finally, AIC suggests a full documentation of the treatment plan:

Following examination and before treatment, the conservation professional should prepare a plan describing the course of treatment. This plan should also include the justification for and the objectives of treatment, alternative approaches, if feasible, and the potential risks. When appropriate, this plan should be submitted as a proposal to the owner, custodian, or authorized agent.<sup>97</sup>

Documentation is an AIC requirement should the treatment have a negative impact on the original fabric. The Getty defined the fundamental requirement of conservation as “minimum intervention and retention of original fabric”. This is not always possible in the repair of advanced cracking, when retention of the original fabric may result in what the Getty described as “significant impact on the appearance and materiality of the concrete, which in many cases is core to architectural expression.”<sup>98</sup>

## ii. ACI Codes

ACI 562-16: Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings provides information on material and design requirements for repair of damaged, deteriorated, or deficient structural concrete members. ACI 562 was developed as a reference to the International Existing Building Code. The code serves as a supplement to existing codes

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<sup>97</sup> AIC.

<sup>98</sup> Custance-Baker and Macdonald.

when repairing structural defects of in-service concrete.

Before treatment, the guide recommends research into the material properties available from drawings, specifications, and other documents, or if not available, obtained from historical data charts. These charts provides default compressive strength of existing structural concrete based on historic building code requirements. The ACI document discusses a design report, which outlines the engineer’s reasoning, assumptions, and judgments used in the design documents (construction drawings and specifications). The design report concept is useful to the conservator as well, as it begins with a description of the existing structure and identifies the structural system, age of construction, and original building code. The background section should also include alterations and additions to the structure. ACI recognizes that “the design of repairs shall consider the effects of cracks on the expected durability, performance, and design service life of the repair.” The commentary elaborates that “protection of repaired concrete may be as vital as the repair itself. Consideration should be given to post-repair cracking and the need for protection of the existing concrete and repair material from the ingress of deleterious materials”.<sup>99</sup> ACI 562-16 also requires documentation of future maintenance and inspection procedures. That documentation should be provided to the owner, and is meant to inform the owner of the steps that are required to maintain the structure after completion of repairs.<sup>100</sup>

ACI 318 and ACI 562 are both applicable to the evaluation of an existing building prior to treatment. ACI 318 was developed to provide minimum design requirements for new concrete structures. ACI 562 specifically addresses a performance-based approach for evaluation of

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<sup>99</sup> American Concrete Institute, ACI 562M-13: “Code requirements for evaluation, repair and rehabilitation of concrete buildings” (ACI 562M-13) and commentary. (ACI Committee 562, 2016).

<sup>100</sup> Marjorie M. Lynch. “Evolution of ACI 562 Code—Part 8” *Concrete International* (October 2016), 64-69.

existing structures.

Proper surface preparation is critical to the lifetime of a conservation treatment. Coating durability depends on adequate surface preparation of the concrete. Each surface coating and concrete surface can require a different types of surface preparation to extend the service life of the coating. The 2015 TNEMEC Surface Preparation and Application Guide outlines a step-by-step process of surface preparation, which incorporates standard methods from NACE International, the Society for Protective Coatings, the International Concrete Repair Institute and the American Society for Testing and Materials. NACE No. 6/SSPC-13 is an excellent source for further information on surface preparation, and contaminant identification. ICRI Guideline No. 310.2 details the necessary tools for preparing concrete surfaces, and SSPC-SP13/NACE 6 Surface Preparation of Concrete gives requirements for surface preparation using mechanical, chemical or thermal methods.<sup>101</sup>

Application should conform with the instructions of the manufacturer for specific products. Improper application and general misuse of coatings are potential causes of failure for the concrete in service. The dry film thickness required for the surface coating depends on the intended use. Many sealers are applied in a thin film (1.5mils or less). The thin film technique can also be used as a bonding coat under a topcoat. Epoxies, polyesters, and vinyl esters are usually applied as a thick film, especially in immersive or harsh environments. Multiple coats are generally required in systems used to resist hydrostatic pressure, and also for paints and pigmented coatings. There is a need for research on the effects of multiple coats on the concrete substrate, with respect to vapor transmissivity, and issues of future re-coating, and surface preparation.

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<sup>101</sup> TNEMEC. “Surface Preparation and Application Guide”, (TNEMEC Company: 2015).

## C. Performance criteria

Concrete can certainly be treated to reduce moisture intrusion that will lead to rebar corrosion. The primary sources for treatment discussion in this thesis were the ACI Guide to Selecting Protective Treatments for Concrete, and product literature from several major manufacturers.

The unique internal environment of existing concrete, caused by ageing and chemical change, creates a challenging environment for some treatments. Vaysburd also identified a problem with the conservation process itself:

The application of a repair alters the internal environment. The exterior environment depends largely on the structure's geographical location (e.g. temperature, relative humidity, rainfall levels and soil types) and the human activity nearby (e.g. prevailing winds and industrial—or traffic generated pollution). The internal environment exists within the structure and, in addition, is created by the engineered repair design.<sup>102</sup>

The internal environment of the concrete changes constantly after treatment, as water, sometimes with dissolved salts, moves in and out of the material, based on temperature gradients.

Surface-applied treatments for historic concrete require a holistic approach to the diagnosis of concrete structures and the long-term behavior of treated surfaces. Coatings applied to the substrate, for example, must be able to bond well; adhesion testing can be executed before large-scale coating application.

Some treatments need to penetrate the surface.<sup>103</sup> Problematically, much of the product literature is written for application of treatment on fresh concrete, and does not necessarily apply to historic structures.

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<sup>102</sup> Vaysburd, 717-721.

<sup>103</sup> Louis D. Vincent. (2010).





# Treatments available to the conservator

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## A. Classes of treatments

The jargon of concrete treatments and repair options is difficult to interpret. In this thesis, the term “repair” has been used to differentiate cementitious patching (to compensate for losses) from treatments (used to mitigate symptoms of deterioration). Terminology for treatment options can be even more confusing. Manufacturers often use the terms “sealers” and “coatings” incorrectly, and typically do not differentiate between penetrating and non-penetrating treatments. There is a great need for interdisciplinary collaboration to clarify meaning within the industry.

The ACI selection guide (2013) defines terminology for the manufacture, construction, and maintenance of concrete.<sup>104</sup> Two of these definitions are:

film - typically coatings, a layer of paint or plaster applied in a single operation

coating - (on architectural concrete) — material used to protect a concrete surface from atmospheric contaminants and those that penetrate slightly and leave a visible clear or pigmented film on the surface. (See also sealer .)<sup>105</sup>

The ACI 2013 guide was compared to widely available marketing materials from the following companies: Mapei, Sika, FOSROC, Edison Coatings, Cathedral Stone, and Flexcrete. The guide provides recommendations for protective treatments based on the physical or chemical attacks that concrete is subjected to, including water, acids, alkalis, salt solutions, and organic chemicals.

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<sup>104</sup> “Guide to Selecting Protective Treatments for Concrete”

<sup>105</sup> Ibid.

It offers an exhaustive list of protective treatments and systems descriptions. These include vinyls and latex-based materials; bituminous paints, mastics and enamels; epoxies; and silanes and siloxanes.

NACE No. 6/SSPC-SP 13 Surface Preparation of Concrete, jointly published by NACE International and The Society for Protective Coatings, was also an important source for understanding the preparation of surfaces prior to the application of protective coating or lining systems.<sup>106</sup> The manual covers the following definitions, but it is more useful as a guideline to surface preparation than to coating selection:

Coatings - Protective Coating or Lining System (Coating): For the purposes of this standard, protective coating or lining systems (also called protective barrier systems) are bonded thermoset, thermoplastic, inorganic, organic/inorganic hybrids, or metallic materials applied in one or more layers by various methods such as brush, roller, trowel, spray and thermal spray. They are used to protect concrete from degradation by chemicals, abrasion, physical damage, and the subsequent loss of structural integrity. Other potential functions include containing chemicals, preventing staining of concrete, and preventing liquids from being contaminated by concrete

Sealer (Sealing Compound): A liquid that is applied as a coating to a concrete surface to prevent or decrease the penetration of liquid or gaseous media during exposure. Some curing compounds also function as sealers. Adhesives form a barrier through the physical properties of the sealant itself and by adhesion to the substrate.<sup>107</sup>

The National Center for Preservation Technology and Training (NCPTT), a research, technology and training center of the National Park Service, defines consolidants, water repellents, and pollution deterrents as:

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<sup>106</sup> “NACE No. 6/SSPC-SP 13 Surface Preparation of Concrete”, (Joint Surface Preparation Standard, NACE International, 2003).

<sup>107</sup> Ibid.

Consolidants are coating systems that are used to restore some strength to the stone that is severely weakened by decay.

Water repellents are surface coatings to prevent the ingress of water into the stone.

Pollution deterrents are chemical treatments that inhibit the sulfating of calcium carbonate by pollution.<sup>108</sup>

NCPTT comments that water repellency is provided by alkylsilanes, silicones, and fluoropolymers. It should be noted, however, that water repellents (and consolidants) are not “coatings”. The NCPTT article “Air pollution, coatings and cultural resources” studied how pollutants interact with the material fabric of cultural resources and what we can do to minimize damage from air pollution using organic coatings and treatments.

The treatments that were researched for this thesis are divided between “surficial” treatments (using a geological term to characterize treatments that function at the surface), and penetrants, which “penetrate cracks, pores, and other surface defects”.<sup>109</sup>

The concrete repair industry represents an enormous product market. Repair materials are particularly specialized. Research for this portion of the thesis focused on treatments used to prevent carbonation and corrosion, applied to prolong the service life of concrete. These treatments do not include admixtures, modifications to mix design, or rebar placement, as the discussion is limited to work on existing buildings. The discussion includes the basic properties of surface-applied treatments and briefly examines the use of siloxanes, sealers, anti-carbonation coatings, penetrating water repellents, crack fillers and injectable grouts.

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<sup>108</sup> Striegel, et.al., “Air pollution, coatings, and cultural resources”, in *Progress in Organic Coatings* 48 (2003), 281-288.

<sup>109</sup> Definition from Oxford Dictionaries, copyright Oxford University Press.

## B. Surficial treatments

Surficial treatments as a category include sealers, crack fillers, and some water repellents. This category can also include paints, but the focus of this thesis is on transparent, colorless products. Surficial treatments can be an effective way of protecting in-service concrete, when applied as part of a thorough maintenance routine.

### i. Sealers

According to ACI terminology, sealers are surface-applied liquids that are colorless, absorbed by the concrete, and leave little or nothing visible on the surface. Sealers are used to prevent or decrease the penetration of liquid or gaseous media below the surface of the concrete. The term “coating” is used synonymously, presumably because both function at or very near to the surface. ACI defines coatings as materials used to protect concrete surfaces. Coatings, which are actually film-formers, can be used to preserve, protect, seal or smooth the surface of the concrete.

Colorless, transparent coatings and sealers can thus be considered as a single type of treatment, differing in appearance but not function.<sup>110</sup> Both impede the movement of liquid water and water vapor, and can therefore be problematic with respect to freeze-thaw performance. Coatings can blister and peel; non film-forming sealers cannot. With both types, there can be some penetration into the concrete at fine cracks, depending on the application procedure.

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<sup>110</sup> “Guide to Selecting Protective Treatments for Concrete”

Waterborne acrylics seem to be the most widely available sealers on the market. Of the six manufacturers investigated, five produce a waterborne acrylic coating; the major international corporations sell more than one with several specifications available. Acrylic polymer sealers are used to reduce water, and are said to reduce chloride-ion ingress.<sup>111</sup>

Epoxy-based coatings are used in severe conditions, as are some polyesters and urethanes. Surface preparation is particularly critical with these materials. For most of them, the concrete must be quite dry at the time of application. Their use on historic concrete structures has been limited, largely because of issues of reversibility and color stability. A number of these polymers will yellow or brown when exposed to the UV radiation in bright sunlight; some will cloud in the presence of relatively small amounts of moisture.<sup>112</sup>

## ii. Crack fillers

Crack fillers are formulations that fill surface cracks as a protection against water penetration. They are paste-consistency materials that can be trowel applied, wiping the excess with a cloth or sponge. Most will seal cracks up to ½ inch in width in a single application with little or no shrinkage.<sup>113</sup> Products on the market are typically cement- or cement/lime-based, although there are also a number of thixotropic epoxies that are used as crack fillers. There is also some utility to elastomeric sealants, in those situations where significant movement at the cracks can be verified by engineering monitoring. ACI 562-13 states that: “For cracks that are essentially acting as a joint or are active, one type of effective repair is to seal the crack with an

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<sup>111</sup> “Guide to Selecting Protective Treatments for Concrete”

<sup>112</sup> “Guide to Selecting Protective Treatments for Concrete”

<sup>113</sup> “Sakrete Concrete Crack Filler”, SGC Horizon Building & Construction Group, 2013.

elastomeric sealant.”<sup>114</sup> Color matching can be a visual issue if the cracks are wide, but with the cementitious products, it is possible to custom color them (in the factory or in the field) with dry alkali-stable pigments.

### iii. Water repellants

Siloxane water repellents are commonly used to impart hydrophobicity to concrete surfaces. The beading of water prevents most of it from penetrating into surface pores. The term “siloxane” is an updated (and more correct) name for what were originally called silicones. Both words continue to be in use in some product literature.

Applied at low concentrations, siloxanes are not film-formers. They do not significantly decrease the movement of water vapor, and are sometimes called “breathable sealers”. This characteristic may or not be useful in treating concrete. There has been surprisingly little research on this. One problem with siloxanes is that they can gradually be lost from weathering, as they have no film integrity and do not adhere well to carbonated concrete.

## C. Penetrants

Penetrating treatments or penetrants may refer to products that are applied to the surface but function well beneath it. Penetrants can include anti-carbonation “coatings”, penetrating water repellents, migrating corrosion inhibitors, and crack injection materials.

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<sup>114</sup> ACI 562-16.

## i. Anti-carbonation coatings

Anti-carbonation “coatings” are applied to stop carbon dioxide ingress, essentially acting as deeply penetrating sealers. They protect concrete by filling pores to form a complex barrier within the concrete pore structure. Several of the major manufacturers, including Flexcrete, FOSROC, KEIM, and Sika, sell anti-carbonation coatings in addition to their more conventional products such as paints and other pigmented coatings.

## ii. Penetrating water repellants

Silane treatments are the most broadly used penetrating water repellents. Alkylsilanes are small molecules that can penetrate concrete when applied thoroughly to the surface. They are effective at reducing moisture ingress and chloride-ion attack, and as a result can reduce the corrosion of rebar. To enhance surface hydrophobicity, they are often blended with some siloxanes. Theoretically, as the siloxanes are lost by weathering, the alkylsilanes will continue to keep the zone around the near-surface rebars dry.

As with ordinary siloxane (silicone) treatments, there is good vapor transmissivity. According to the American Concrete Institute, “Because these water repellants do not form films, they provide limited protection to... cracks that form after application. Cracks formed after the water repellant is applied allow water to penetrate through the treated substrate”.<sup>115</sup>

Many researchers have studied the use of surface-applied materials to improve the durability of concrete and concrete structures. Ibrahim Al-Gahtani evaluated silanes and siloxanes and found that the treatments particularly enhance performance when used with a top

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<sup>115</sup> ACI Committee 515, *Guide to Selecting Protective Treatments for Concrete*. (July 2013).



coat.<sup>116</sup> Researchers have also been testing silane (and silane-siloxanes blends) materials as protective treatments for concrete when exposed to sulfate ion.<sup>117</sup>

A recent experimental treatment involves imparting water repellency with a hydrophobic consolidant that is a low viscosity blend of ethyl silicate (also known as TEOS) and an alkylsilane. Used as a penetrating water repellent, rather than for strengthening, it seems to work more effectively after application of a hydroxylating conversion treatment that modifies the chemistry of the carbonated zone.

### iii. Grouts

Deep introduction of flowable grout into cracks is done either by gravity feeding, or injection under pressure. Product selection is dependent on a number of factors, including ease of mixing, and the range of crack widths to be filled. As with crack fillers, the concept is seal the cracks, but in this instance considerably beyond the surface.

Most commercial grouts are cement-based, often polymer-modified, to be field mixed with water immediately prior to use. Water reducers are standardly utilized, to keep the water/cement ratio low, enhance flow, and minimize shrinkage. An additional benefit to the use of cement-based grouts is the alkalinity that it can create at the bars, if the grout reaches well into the cracks, and those cracks give direct access to the steel.<sup>118</sup>

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<sup>116</sup> M.Ibrahim, et al. "Use of surface treatment materials to improve concrete durability". *ACI Mater J* II.1.(1999); 36-40.

<sup>117</sup> D.C.Stark. "Continuing Studies of Concrete in Sulfate Soils," *PL972: Concrete Technology Today*, (Portland Cement Association: Skokie, IL, July 2002), 3.

<sup>118</sup> M.M. Al-Zahrani, M. Maslehuddin, S.U. Al-Dualaijan, M. Ibrahim. "Mechanical properties and durability characteristics of polymer- and cement-based repair materials". in *Cement & Concrete Composites* 25 (2003).

Epoxy-based injection grouts require more pressure for adequately deep injection, although this technology has been available for decades. The equipment is more complex, as turbulent mixing of the two components is accomplished as injection takes place. The principal use of this technique is structural repair, for bridges, highways and dams. The commentary in ACI 562-13 is interesting, as it fully supports the concept presented in this thesis that solving the underlying problems (carbonation and corrosion) is essential: “For repair by crack injection, the process and material should be appropriate to the site conditions. Crack injection should not be used to repair cracks caused by corrosion of steel reinforcement... unless supplemental means are employed to mitigate the cause of the cracks.”<sup>119</sup>

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<sup>119</sup> ACI 562-16.



# Conclusions

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Today cracks are recognized as an inevitable symptom of the deterioration of concrete structures. This thesis has explored just a few factors causing cracking and historical approaches to treatment. It is hoped that this thesis can assist in the selection of treatments of reinforced concrete structures.

One issue faced at the beginning of the research for this thesis was the much-debated question of whether conserving modern heritage should follow existing philosophical approaches or instead demands a new paradigm. The technical complexities of conserving historic concrete are still a fundamental challenge in the field. The early stages of concrete cracking are often ignored, without consideration of the long-term progression of the cracks. More and more concrete buildings are demolished for faulty construction, costly maintenance, and unsustainable repairs—Victor Lundy’s Church of the Resurrection, formerly in Harlem, New York; Paul Rudolph’s Riverview High School and Micheels House in Westport, Connecticut are just a few examples of lost concrete buildings. Rudolph’s Orange County Government and Philip Johnson and Richard Forster’s New York State Pavilion are two examples of concrete structures whose fate is under constant scrutiny

In 2014, The Getty Conservation Initiative convened the *Conserving Concrete Heritage Experts Meeting*. It confronted key issues in the conservation of modern concrete architecture, particularly the apparent friction between concrete industry practices and the dictums of conservation management. However, products sold by the concrete repair industry can often assist the conservation of concrete structures when properly selected and applied. Proper

selection may be difficult, given the thousands of sealers, water repellents, MCI's, and crack fillers/grouts available, but given the scale of modern concrete architecture, it has become impossible for conservators to conceive specially catered mixes.

More and more historic buildings are being conserved properly through the dissemination of interdisciplinary knowledge on successful treatments already undertaken; such as those at Fallingwater, Guggenheim, and Eero Saarinen's TWA Flight Center. Early concrete conservation projects faced technical challenges that necessitated judicious, case-by-case judgment. Today, many case studies on specific cracking and concrete deterioration are available to aid in the development of conservation treatments, including those illustrating how others have arrived at balanced philosophical decisions, such as those in modern and contemporary sculptures and monuments including Peter Eisenmann's Memorial to the Murdered Jews of Europe; international conservation treatments of the Berlin Wall; Simon Rodia's Watts Towers and Donald Judd's Untitled Sculpture in New Canaan, Connecticut.

Conservators can also find useful information through articles published in the Concrete Repair Bulletin, a journal produced by the International Concrete Repair Institute. These case studies and others document the implementation of conservation strategies for the preservation of both architectural and engineering structures.

The importance of preserving twentieth-century places has grown since the late 1980s, with an increase in local, national, and international organizations (such as Docomomo International and World Monuments Fund's Modernism at Risk campaign) dedicated to the conservation modern heritage. International charters and guidelines have aided in the conservation recent and modern heritage. So have interdisciplinary partnerships between conservators, architects, and engineers. The American Concrete Institute especially connects

these professional communities on the subject of the repair and maintenance of concrete structures, and provides guidance on diagnosing problems and systematically working through treatment options.

Today there are preventative measures available for upgrading the performance of concrete structures that will be tomorrow's landmarks. These can include modifications to the mix, stabilization of rebar placement, and more effective curing procedures. Measures taken during construction of modern concrete can mitigate damage or stall progressive cracking. A conservation approach has the potential to begin during construction.

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# Appendix A

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## BERLIN WALL

The Berlin Wall case study was written to support the thesis on carbonation-induced cracking of reinforced concrete structures. The research is ongoing, but illustrates many of the problems discussed in this thesis, and acts as a final commentary on the conservation of significant concrete monuments.





*Figure 1: Section of the Berlin Wall at the Berlin Wall Memorial, Photo Number P1040262. Image Prof.Dr.phil. Leo Schmidt FSA , Anja Merbach MA, Sophia Hoermannsdorfer MSc. Concrete is has been chipped by relic-scavengers.*

The Berlin Wall Foundation was established in 2008 as part of a citizens' effort to preserve the segments of the wall remaining in Berlin, and "commemorate the victims of the Wall in a dignified form".<sup>128</sup> The section of the Wall on Bernauer Strasse was secured in 1990, and a conservation plan for the site was developed. The group of citizens worked closely with the Berlin Senate under the association "Berliner Mauer - Gedenkstaette und Dokumentationszentrum" and in 2008 the sponsorship was transferred to the "Berlin Wall Foundation". In 1993, the group founded the Marienfelde Refugee Centre Museum Association to research the history of inner-German movement of peoples between 1949 and 1990, and to make this history broadly accessible by the public. The Association was legally recognized in 1994, and the Association entered negotiations to establish the Berlin Wall Foundation:

The Berlin Wall Foundation was established as a foundation under public law by legislation passed on September 17, 2008. The foundation encompasses two institutions:

<sup>128</sup> <http://www.stiftung-berliner-mauer.de/en/berlin-wall-memorial-47.html>



the Berlin Wall Memorial on Bernauer Strasse and the Marienfelde Refugee Centre Memorial, both of which retained their names.

The purpose of the foundation is to document and provide information about the history of the Berlin Wall and the mass migration from the German Democratic Republic as a part and contributory factor of the German division and the East–West conflict. It also aims to preserve historical sites and authentic remains and to provide for a dignified commemoration of the victims of Communist tyranny.

The founding of the Berlin Wall Foundation and the expansion of the memorial are important steps to realizing the memorial concept of the Berlin Senate and the federal government.<sup>129</sup>



Figure 2: Section of the Berlin Wall, Photo Number P1050279. Image Prof.Dr.phil. Leo Schmidt FSA , Anja Merbach MA, Sophia Hoermannsdorfer MSc.

<sup>129</sup> <sup>129</sup> <http://www.stiftung-berliner-mauer.de/en/berlin-wall-memorial-47.html>

The Berlin Wall Memorial represents the central memorial site of the German division. In its historic location on Bernauer Strasse, the Memorial extends 1.4 kilometers along the former border strip. The memorial contains the last piece of the Berlin Wall and local remnants of the border obstacles. Bernauer Strasse was the focal point of the German division; it is the location where the wall was originally constructed, and the first fatalities of the division occurred on this street. In 1989, the first segments of the Wall were knocked down between Bernauer Strasse and Eberswalder Strasse to create the crossing between East and West Berlin.

The Memorial comprises an open-air exhibition along the border strip, including the Monument in Memory of the Divided City and the Victims of Communist Tyranny as well as the Window of Remembrance and the Chapel of Reconciliation.

The East Side Gallery, located on Muehlenstrasse along the River Spree in the Friedrichshain neighborhood of former East Berlin, invited 118 international artists to create 106 wall paintings on the original segments of the Berlin Wall to proclaim the joy of the fall of the Wall in 1989. From February to September 1990, artists painted 1315 meters of the Berlin wall in East Berlin's Muelenstrasse. In November 1991, these murals and remnants of the wall were placed under monument protection. Since 1991, the walls have been exposed to weather and visitors, graffiti, overpainting, concrete deterioration, and total loss in the ay of development.<sup>130</sup> In 1996 (2 paintings) and 2000 (40 paintings) segments of the gallery were restored under the initiative of the artists. The entire wall was renovated in 2009, when all surviving artists were invited to copy their paintings from the original wall to the renovated Wall, in preparation for the 20th anniversary of the Fall of the Wall.<sup>131</sup>

<sup>130</sup> <https://www.google.com/culturalinstitute/beta/exhibit/east-side-gallery/qQAJocMp?hl=de>

<sup>131</sup> Mueller Kroll, Monika, "Famed East Side Gallery Under COstruction", East Side Gallery, Berlin, NPR special series, 1 June 2009.





*Figure 4: Section of the Berlin Wall, Photo Number P1050229. Image Prof.Dr.phil. Leo Schmidt FSA , Anja Merbach MA, Sophia Hoermannsdorfer MSc.*



## *CONDITIONS*

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Remaining sections of the wall Berlin are severely deteriorated due to corrosion of the reinforcement, which was placed close to the surface during construction of the prefabricated panels. In 2015 Dr. Leo Schmidt led a project to document the remaining sections of the wall. The documentation report will aid in conservation of the Wall, already begun at the Berlin Wall Memorial.



*Figure 3: Figure 3: Section of the Berlin Wall, Photo Number P1040890. Image Prof.Dr.phil. Leo Schmidt FSA , Anja Merbach MA, Sophia Hoermannsdorfer MSc.*

### iv. Fragments of the Berlin Wall in New York

Jerry I. Speyer, chairman of Tishman Speyer real estate, purchased a section of the Berlin Wall in 1989 as the wall was being dismantled for new construction or sold as artifacts. Speyer and business partners arranged the sale with a Berlin local in a parking lot where hundreds of pieces of the wall had been relocated. Speyer pieced together a continuous five-segment section

and paid \$50,000. The section was moved to its location at 520 Madison Avenue, and placed inside a water feature in an adjacent courtyard.

Speyer intentionally placed the panels in a publicly accessible location. In 2013, after 12 years of exposure to weather and water spray, the concrete was severely deteriorated. The water feature induced wetting and drying cycles, sprayed the concrete, and created a humid atmosphere around the base of the segments. Contributing factors to advanced deterioration of the segment include: Manhattan's harsh winters of the 1990s, atmospheric pollutants, and public vandalism, resulting in cracking and delamination of the concrete support, corrosion of the internal rebar, and flaking and loss of the paint layers.<sup>132</sup> Tishman Speyer had been monitoring the condition of the wall, but the impetus for conservation followed the loss of large chunks of painted substrate from the base in 2013. Concurrently, the monument had been vandalized with the words "IT'S LIKE TALKIN TO A WALL", spray painted through a stencil in English, Arabic, and Hebrew.

During conservation the vandalism was removed with an organic solvent and the asbestos piping at the top of the wall was removed and replaced with a replica of the material. The conservators noted that Manhattan, as compared to Berlin, has "more extreme diurnal fluctuations of relative humidity, higher temperatures in summer, and between two and three times greater annual precipitation".<sup>133</sup> Further:

"Water migration and associated salt activity, in combination with the fluctuating ambient environment, caused widespread tenting, lifting, flaking, and loss of the paint layers.

<sup>132</sup> Graves, Kiernan, and Katey Corda. "Conserving a boundary: The conservation and management of a Berlin Wall mural", Getty Conservation Institute, Los Angeles, CA, *Studies in Conservation* Vol. 61.2, 2016.

<sup>133</sup> Graves, Kiernan and Katey Corda. Climatic data were compiled from data found at National Oceanic and Atmospher Administration ([noaa.org](http://noaa.org)) and Royal Netherlands Meterological Insitute ([eca.knmi.nl](http://eca.knmi.nl)); averages were taken from data spanning 1981-2011 from weather stations in Manhattan, NY, USA and Berlin, Germany.

Years of dirt, pollution, and other urban grime were accumulating on the surface of the painting. Finally the public's unmediated interaction with the mural was resulting in vandalism and mechanical damage, particularly towards its base where tourists often sat to be photographed with the wall."

Research of Kiernan Graves and Katey Corda found the five panels were part of the "fourth generation" Berlin Wall construction, fabricated between 1975 and 1980, originally located along Waldemarstrasse. The West side of the wall was painted in the early 1980s by artists expressing outrage and as a public rejection of the structure. This section was part of a long span of wall painted by Thierry Noir and Kiddy Citny using aerosol spray paint sometime between 1984 and 1986.

v. Conservation treatment

The section was moved to an off-site warehouse in New Jersey for the duration of remedial treatment. Wall painting conservators stabilized the wall's paint layers and removed graffiti with an organic solvent. The painting was also given a light surface cleaning to removed dirt and pollution.

Separately, the concrete conservators cleaned areas of unpainted concrete and removed corrosion from exposed metal surfaces. However the concrete substrate was not restored to the point of full restoration. Conservators noted: "Deterioration that occurred since the mural's purchase was stabilized but not disguised, while detached fragments and incidences vandalism that occurred after its arrival in Manhattan were restored where possible."<sup>134</sup>

<sup>134</sup> Graves, Kiernan, and Katey Corda. "Conserving a boundary: The conservation and management of a Berlin Wall mural", Getty Conservation Institute, Los Angeles, CA, *Studies in Conservation* Vol. 61.2, 2016.

Following remedial treatment, the panels were restored to 520 Madison. It was decided that the panels would be relocated to the interior corridor of the apartment building's lobby. The Wall, at the insistence of Jerry Speyer and Tishman Speyer executives, is still on public view, and is easy to access through the 53rd street entrance, as well as visible from the exterior and former courtyard.

# Appendix B

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## DENKMAL FÜR DIE ERMORDETEN JUDEN EUROPAS

The Holocaust Memorial in Berlin was the impetus for this thesis. At the time of writing, the Foundation to the Memorial, the architect Peter Eisenmann, and the engineering firm Buro Happold were in a legal dispute concerning the deterioration of the concrete blocks. This brief case study was the written for Carolina Castellanos' class "Comparative Heritage Management" in the Spring of 2016, and was meant to inform the thesis researching early-age cracking of reinforced concrete structures.





# DENKMAL FÜR DIE ERMORDETEN JUDEN EUROPAS



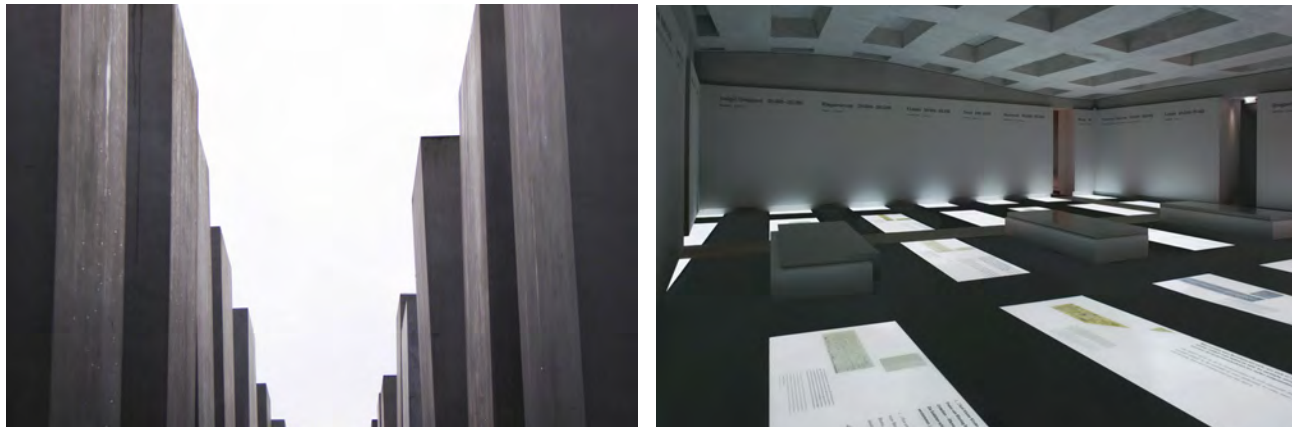
*Image: Foundation for the Memorial for the Murdered Jews in Europe*

## **1. Introduction to the heritage place, the memorial and Berlin**

Peter Eisenman's Memorial to the Murdered Jews of Europe is a five-acre field of 2711 concrete slabs arranged in a grid: the specific number is a reference to the number of pages in the Talmud. The Field of Stelae, the site of the monument, and the subterranean Information Centre honor and remember up to six million Jewish victims of the Holocaust.

The Field of Stelae is arranged in a grid and allows visitors to navigate the narrow aisles, and the concrete slabs - 0.95 m deep and 2.38 m wide - vary in height to allow moments of total immersion and solitude at different points in the field. This sense of solitude is increased by the width of the aisles, which allow only enough room for one visitor. The field is accessible from any side, at any time of day. This accessibility facilitates a create-your-own-experience atmosphere, and visitors leave this new form of memorial with a variety of reactions ranging from playful exuberance to concentrated solitude. Several visitors have even gotten lost inside the field of stelae, which is built on an undulating ground surface in a busy tourist center of Berlin.

The sense of loss is in direct correlation with the artistic intent of American architect Peter Eisenman, who designed the memorial as a way to present "a new idea of memory as distinct from nostalgia". Eisenman's new idea of memory, and its varied worldwide reception, is what makes the site significant: inside the Field of Stelae visitors are encouraged to experience the isolation and to question their sense of loss, both in remembrance of the Holocaust and its catastrophic effects on the heritage of



*image: Foundation for Monument, photo: Marko Priske*

the Jewish culture, commemorating both the event and the renowned suffering of the survivors, in addition to the Jewish memory.

The climatic history of the design process indicates a radical deviation for the form of the monument, as it was proposed to create a new inauthentic site of memory, which commemorates the introspection of the visitors.<sup>1</sup> The new memorial form continues to be debated through worldwide reactions to the media's representation of visitors. Seen from any of the outer rows of stelae, the field appears in a wave-like formation, and every direction outward displays Berlin's heritage and monuments.

Berlin was the city that was affected by the events of the 20th century unlike any other. After the war, the built environment of the Nazi regime was a burdensome reminder of the nation's crimes, and the divided German nation undertook several projects to destroy relics and monuments central to the rise of the Nazi regime. During the postwar years in Berlin, both the East and West Germans struggled to confront the Nazi legacy in the urban fabric of their divided cities. World War II's destruction of Berlin, and the city's postwar political division by the Western Allies and the Soviet Union, also left a burdensome legacy that was difficult to reconstruct in a positive light on either side of the iron curtain. In West Berlin, the Allies demolished Spandau Prison, and in East Germany, the *Führerbunker* was partially



*image: Topography des Terrors as examples of Nazi Architecture, photo by Scott m. Baker*

<sup>1</sup> Dekel, Irit, "Ways of looking: Observation and transformation at the Holocaust Memorial, Berlin", The Hebrew University of Jerusalem Mount Scopus, Jerusalem, 2009.

demolished by the Soviets, buried after the reunification, and only recently was the site recognized with a plaque, warning of the bunker's involvement in WWII crimes. This struggle is referred to as *Vergangenheitsbewältigung*, translated literally it means overcome the repressed/ negative or intimidating past.<sup>2</sup> And, as Germans confronted their *vergangenheitsbewältigung*, they found both attempts and denials of historic preservation brought uncomfortable reminders of a constantly resurfacing Nazi past.

As we have seen, the use of Nazi architecture and historic sites involved in the events of the Holocaust varied greatly – such as the immediate occupation of the former Nazi Air Ministry at Tempelhof by US troops, the destruction and later preservation of the military SS and the Reich Security-Gestapo Main Office at the *Topographie des Terrors*, and the creation of Peter Eisenman's *Denkmal für die ermordeten Juden Europas* on the former "Death Strip".

The memorial opened on the chosen site in 2005: sixteen years after the fall of the Berlin Wall, marking the unification of the city and the proposal for the memorial by the German public. The field's location in the historic center city enhances Berlin's rich cultural and specifically commemorative heritage, which includes Norman Foster's 1992 restoration of the Reichstag, the Brandenburg Gate, Tiergarten Park, and the Topography of Terror - a museum built on the former headquarters of the Gestapo and the SS. The German heritage is also commemorated in the memorial's specific site, as it was built on Pariserplatz: the Berlin Wall's death field and, before 1945, the site of the minister gardens, and not far from Hitler's former Chancellery and bunker.<sup>3</sup> The site remained an empty space after the fall of the wall, and history was reactivated when the memorial opened to the public in May 2005, as the German government's first official memorial to the events of the Holocaust, on a site of significant importance to the history of contemporary German society.<sup>4</sup>

## 2. Synthesis of conditions currently affecting conservation and management

### a. Physical Conditions



images: deterioration of concrete slabs/ Physical Conditions affecting the site, photos from Getty images

The memorial opened to the public in 2005, but today 80% of the concrete slabs are severely deteriorating. The hairline cracks, the largest 4.7 meters long, began after the field had been open to the public for just seven months. The cracks caused lime run and further deterioration in the stones, which the German media described as "undulating gravestones".<sup>5</sup> The aesthetic appearance of the stones is central to Eisenman's design concept, but their deterioration makes it additionally unsafe for visitors, who enjoy

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<sup>2</sup> author's translation

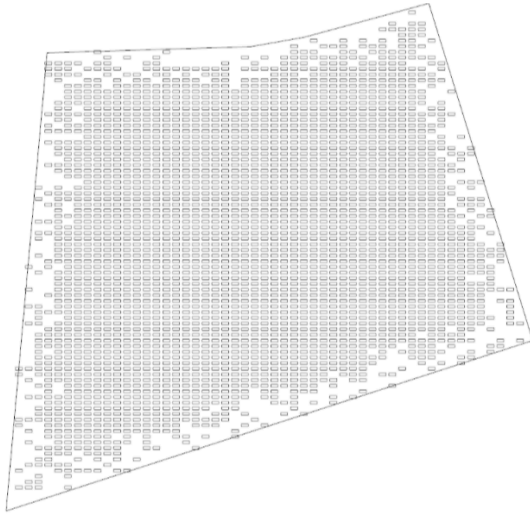
<sup>3</sup> Stevens, Quentin. "Visitor Resonances at Berlin's Holocaust Memorial: Contrary to conventions, expectations, and rules", *Public Art Dialogue*, Vol 2, Issue 1, March 2012, 34-59.

<sup>4</sup> Dekel, Irit, "Ways of looking: Observation and transformation at the Holocaust Memorial, Berlin", The Hebrew University of Jerusalem Mount Scopus, Jerusalem, 2009.

<sup>5</sup> Kate Connolly in Berlin, "Cracks appear at Berlin's Holocaust memorial", *the guardian*, 8 August 2007.



the interaction with the monument. By 2014, 44 of the slabs, the worst cases, had been secured with steel ties to prevent total degradation.<sup>6</sup> Stones are assessed every six months for deterioration, in addition to a study undertaken by the Aachen Institute for Building Research, which is currently examining one of the slabs, and which in 2014 had ordered an additional 380 steel collars for other reinforcements.<sup>7</sup>



*images: map of the concrete filed as physically boundless, by Generative Landscapes*



The reason for the deterioration of the stones is not known, and there is an inconclusive battle of blame between the Foundation, the architect, and the Firma Geithner (Wilhelmshaven/Joachimsthal plant), who developed the specific mixture of “the best concrete Berlin has ever seen”.<sup>8</sup> The concrete stelae were developed by the Firma Geithner to meet particularly high requirements for color and durability as set by the architect Peter Eisenman and the German Senate prior to construction in 2003. Each stone had to be meticulously checked against one of ten reference stones individually approved by Eisenman, and the process only saw the creation of 16 stelae per day, 60 per week. But, in 2014, Eisenman accused the Firma Geithner of changing the material composition of the concrete to cut costs.

And in further controversy, the concrete slabs were also treated with the substance "Protectosil" by Degussa, a chemical company responsible for the Zyklon B which fueled the gas chambers during the NS regime.<sup>9</sup> The treatment of the concrete is described on Stiftung Denkmal für die ermordeten Juden Europas' website:

The stelae contain a steel reinforcement and are manufactured by pouring an extra-hard concrete mixture into specially-produced steel forms at the Joachimsthal plant of the Firma Geithner.

<sup>6</sup> "Cracks Plague '05 Holocaust Memorial". Durability and Design. 29 May 2014.

<sup>7</sup> "Cracks Plague '05 Holocaust Memorial". Durability and Design. 29 May 2014.

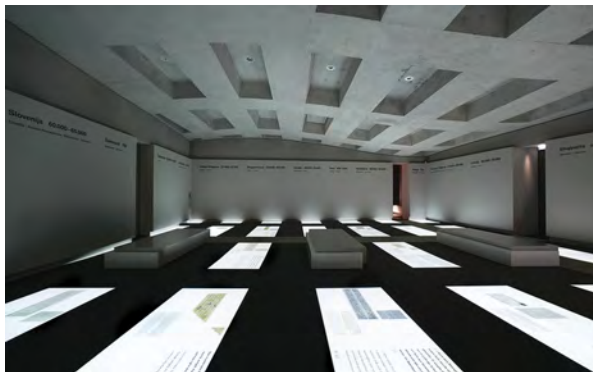
<sup>8</sup> "Cracks Plague '05 Holocaust Memorial". Durability and Design. 29 May 2014.

<sup>9</sup> "Degussa to Continue Work on Holocaust Memorial", Deutsche Welle. 14 November 2003.

Having sought advice from renowned concrete experts (Professor Müller, Karlsruhe; Professor Hillemeier, Berlin) already known to the company or recommended by the Senate Department of Urban Development, the Firma Geithner developed a concrete formula and a production procedure which ensured that the constructions particularly high quality requirements were fulfilled. At the factory, the surface of the stelae were also treated with the substance »Protectosil« by Degussa which provides considerable protection against weather factors and leaching and at the same time serves as graffiti protection.<sup>10</sup>

The Foundation speculates that Eisenman was not capable of designing a concrete to withstand the extreme weather fluctuations in the city of Berlin. However it is more likely that the substance Prostectosil created an impermeable barrier against the demands of freeze thaw conditions below the concrete's surface. This reaction would cause the water to become trapped under the surface of the substance, and it would cause cracks to deteriorate the concrete.

Additionally, the memorial field's location in a busy tourist center could also be a cause for the deterioration of the stelae. The German media speculated in 2007 "that the cracks are due to tremors caused by construction projects adjacent to the site, including the new US Embassy, or even vibration caused by commuter trains that pass beneath the memorial".<sup>11</sup> The vibrations of the busy tourist center are a likely cause for the deterioration of the concrete, and in addition to the vast scale of activity caused by construction and commuter trains, the site is also located on a busy bus route and it commonly abused by visitors to the memorial, detailed later in the paper.



*images: interior, subterranean information center, photos from Stiftung Denkmal für die ermordeten Juden Europas*

## **b. Commemoration of negative, tragic or shameful events**

The memorial creates a new experience for those lost during the tragic events of the Holocaust as well as for those left behind. As essentially an artist's installation on historical ground, the form of the commemoration is highly debated, as well as the actions of the visitors. The memorial was proposed in 1989 by the journalist Lea Rosh and launched on citizens' initiative after the journalist had returned from a trip to Yad Vashem in Israel. Lea Rosh called for a the memorial as a "visible affirmation of action" to be built on the grounds of the former Gestapo headquarters in Berlin's central Kreuzberg neighborhood, and opened a debate on the outrage against the German government's failure to dedicate a memorial similar to Yad Vashem and the Vietnam Veterans Memorial in Washington, D.C. The citizens' initiative that followed, Perspective for Berlin, was able to gather petition signatures and donations for the memorial, in addition to public forums and wide discussions about the topic in the media. The group was

<sup>10</sup> Geschichte des Denkmals für die ermordeten Juden Europas, Stiftung Denkmal für die ermordeten Juden Europas.

<sup>11</sup> Josh Ward in Berlin, "Monument in Danger? Widespread Cracking Found at the Holocaust Memorial", 8 August 2007. Spiegel Online International.

considered to be politically left and opposed to postwar German denial, and called for the Gestapo Terrain as the site of their monument as an important symbol of the German repression of the NS past.

In the months before unification, Perspectives for Berlin used the site of the Gestapo Terrain as a rallying point for their memorial and created a two-fold narrative of Nazi evil alongside German guilt. Establishing a monument at this location, the group vocalized, would “acknowledge German guilt to an international public by mourning for the suffering of those who had died,” and “such mourning work in the present might begin to make amends for crimes of the past and indicate how Germany as a society had changed”. Additionally, the group felt “by admitting guilt to the international community in this way, Germany would make clear its commitment to the Western ‘civilized world’ and its cosmopolitan humanitarian values”.<sup>12</sup>

### **c. The design competition**

*The artistic competition [for the Holocaust Memorial] makes clear that today’s Germany is assuming it’s obligation:*

- *not to avoid the truth, or to give in to forgetfulness*
- *to honor the murdered Jews of Europe*
- *to remember them in sorrow and shame*
- *to accept the burden of German history*
- *to give the signal for a new chapter of human cohabitation in which*
- *injustice to minorities will no longer be possible*
- *City of Berlin guidelines to first public art competition for the Memorial to Murdered Jews of Europe, 1994*

The selected area for the memorial was marked in 1990, after the fall of the Berlin Wall, and after several heated debates, multiple design competitions followed over the course of the next seven years. Two rounds of competitions produced designs that were widely debated in the Jewish community and international media: both the Jakob-Marks design and the Burning Rachel design from the second competition were eventually rejected. The design by the Berlin-based artist Christine Jakob-Marks proposed a tilted metal plate with broken stones from Massada National Park on which the names of 4.5 million murdered Jews would be engraved, and was eventually rejected, among a long list of other concerns, for its Christian aesthetic.

James E. Young, a professor at the University of Massachusetts at Amherst, spoke about his experience as an expert juror for the memorial competition in 2000 and 2001 and the difficulty of being asked to join a council of experts both without native Jewish representation, and with the burden of German consciousness of the event: “The problem was that in voiding itself of Jews, Germany had forever voided itself of the capacity for a normal, healthy response to Jews and their ideas ... Without a Jewish eye to save it from egregiously misguided judgments, anything was possible.”<sup>13</sup>

Young used his perspective as an American scholar to lead the decision on the design process, which by 2000 was in its third round. And Young argued that the site of memory wasn’t meant to preserve history, rather it had to create history for a nation of Germans who had been raised without the symbols and stories of the Jewish people. Young was able to lead in the debates for the design of the memorial with the argument that the preservation of sites of the Nazi regime would only remember the history as

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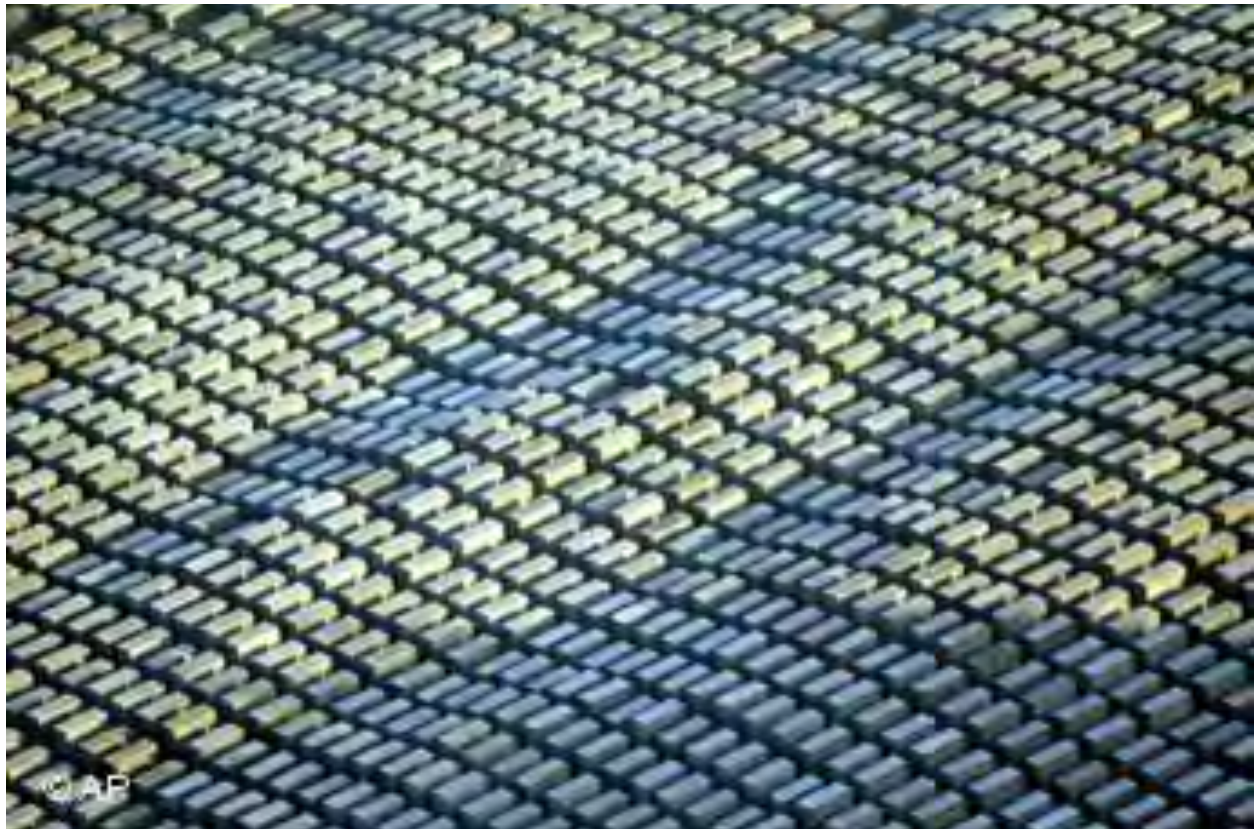
<sup>12</sup> Karen E Till, “The New Berlin: Memory, Politics, Place”, University of Minnesota Press, 2005.

<sup>13</sup> Karen E Till, “The New Berlin: Memory, Politics, Place”, University of Minnesota Press, 2005.



defined by the Nazi plan: “A centrally located memorial at a symbolic site, in contrast, might offer a contemporary interpretation of the violent legacy of the German nation”.<sup>14</sup>

Lea Rosh continued to speak for the Memorial Association, but during over ten years of debates, became frustrated that Germany was not able to create an interactive memory space similar to the one she experienced at Yad Vashem. And other judges of the design competitions became troubled by the effect a memorial would have on this historic district of Berlin, and the representation through a conceptual memory. The most profound connection that was made between the memorial’s design and places of memory, was made by the artists Renata Stih and Frieder Schnock when visiting a cemetery where they realized “that all places are cemeteries; through the artistic process, they make connections with the past occupants of a place and question why people tear down old structures to forget”.<sup>15</sup>



*Image: DW.com, Aerial view of the Memorial for the Murdered Jews in Europe*

#### **d. The winning design**

Peter Eisenman and Richard Serra's submission was chosen in 1997, however Serra soon after dropped out of the design team. Serra told the New York Times that he quit for personal reasons, and that it had nothing to do with the project. It is still unclear why Serra withdrew from the competition, however his withdrawal orchestrated the height of the debates, when the writer Gunter Grass was demanding the memorial be abandoned, and public argued against an abstract artistic monument as “neither a witness to the past nor a sign to the future”, and further indignation that the murdered Jews of Europe should be

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<sup>14</sup> Karen E Till, “The New Berlin: Memory, Politics, Place”, University of Minnesota Press, 2005.

<sup>15</sup> Karen E Till, “The New Berlin: Memory, Politics, Place”, University of Minnesota Press, 2005.



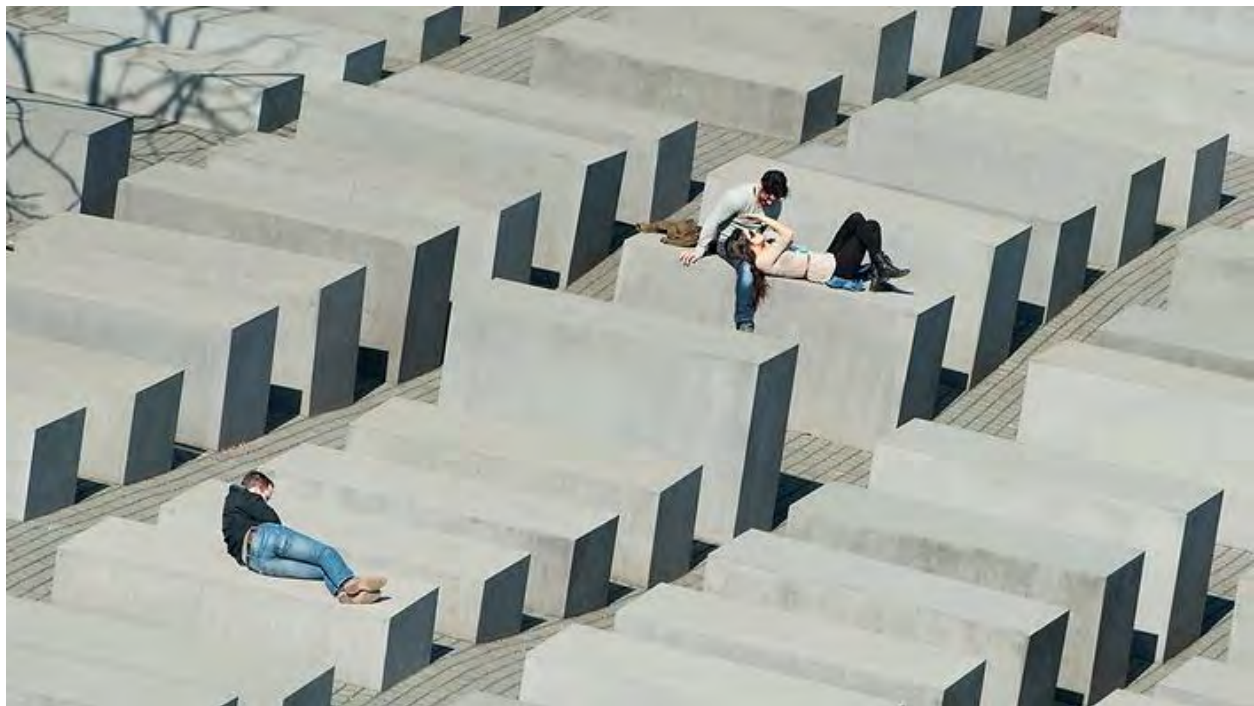
commemorated alongside other groups persecuted during the Holocaust, including the Gypsies, homosexuals, the disabled, and the Soviet prisoners of war.<sup>16</sup>

Eisenman's modified design was chosen in the summer of 1998 without the sculptor Richard Serra, and in 1999 the design was revised again to include the subterranean information center, at the request of Michael Naumann, the State Minister for Culture and the Media. In January 2000, construction began, ten years after the vocalized inception of the need for a monument, and five years before any monument would be open to the public.<sup>17</sup>

The design concept presented a rigid grid of concrete blocks, allowing the potential of the outer stelae to grow or confine over time. The grid is a connection to human reason, but the spatial awareness of causal relationships is thrown into question at the site, as visitors become unable to understand the memorial in its entirety, and only their experience on an undefined path through the field. Eisenman describes the memorial as showing innate disturbances and chaotic potential in systems that are otherwise orderly.<sup>18</sup> There is no conclusive understanding to be derived from the memorial, and Eisenman has stated that the memorial is not meant to express nostalgia or memory of the past, and it is only meant to convey the events of the Holocaust as visitors experience the monument in present-day.

#### **e. Activities outlying the site: Nostalgia bus and Visitor's Terrace**

The site is built inside a busy historic and tourist district and the meaning of the memorial has been hindered by development and kitsch-tourism infringing on the site. The Visitor Terrace, which borders the eastern boundary of the park, contains several restaurants with outdoor tables overlooking the



*image: visitors lounging, photo: REUTERS/FABRIZIO BENSCH*

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<sup>16</sup> Edmund L. Andres, "Serra Quits Berlin's Holocaust Memorial Project", The New York Times, 4 June 1998.

<sup>17</sup> Geschichte des Denkmals für die ermordeten Juden Europas, Stiftung Denkmal für die ermordeten Juden Europas.

<sup>18</sup> Christine Gale, "The Memorial to the Murdered Jews of Europe", University of Massachusetts.

memorial. Some see this commercial center as a threat to the memory of the Holocaust that mocks the efforts of the memorial and create a cyclorama of the visitors.<sup>19</sup> And still others are outraged by the recreational nature of the site itself.

The field of stelae has no entrance or exits, and visitors are encouraged to make their own path through the field, but this also facilitates a playful atmosphere that disgraces the commemorative intention of the site. This is a failure on the intention of the site as planned by the German government, which assumed that because of the memorial's central location in the historic city center and its widespread international media coverage, the memorial would be entered with the intention of feeling sad or moved. Further, the intention of the site as stated by the Bundestag was to "maintain the memory of this unthinkable occurrence in German history" and "admonish all future generations to never again violate human rights, to defend the democratic constitutional state at all times, to secure equality before the law for all people and to resist all forms of dictatorship and regimes based on violence".<sup>20</sup> These goals have not been met in present day, as demonstrated by countless acts of vandalism, recreation, and an overall attitude of disrespect on the part of the visitors and reported in international media.

In contrast to the reports of the media, the workers at the site, including educators, tour guides, and security, continually discuss the site's evolving roles of etiquette. One host reported: "It is okay to eat a sandwich, people get hungry, but not to have a picnic", and, while no official guidelines have been set for the use of the memorial, means of improper behavior are constantly open for discussion.<sup>21</sup> Play is not directly encouraged, but interpretive use is, and the design of the memorial forces visitors to build their own metaphor or meaning after experiencing the site. And, inquisitive visitors are encouraged to think about the meaning of the memorial as the evolution of a graveyard. This is commonly excised by way of "getting lost" either in the memorial or in thought while inside the memorial. Visitor use will be discussed the final part of this case study: the proposed management system.



*Images: [DW.com](https://www.dw.com), children at play in the monument*

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<sup>19</sup> Mangos, Simone. "A Monumental Mockery", unpublished personal opinion.

<sup>20</sup> German Bundestag, "Resolution concerning the Memorial to the Murdered Jews of Europe," June 25, 1999, cited in Stiftung Denkmal, memorial brochure

<sup>21</sup> Dekel, Irit, "Ways of looking: Observation and transformation at the Holocaust Memorial, Berlin", The Hebrew University of Jerusalem Mount Scopus, Jerusalem, 2009.

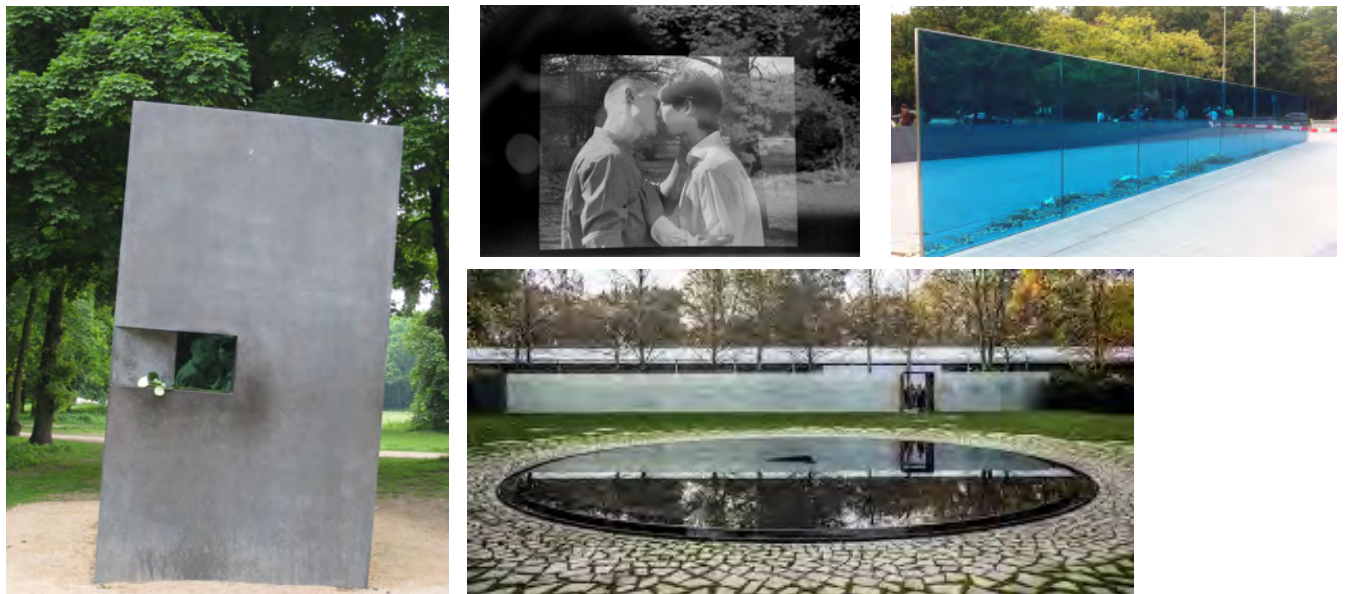
#### 4. Proposed management system

"To admonish all future generations to never again violate human rights, to defend the democratic constitutional state at all times, to secure equality before the law for all people and to resist all forms of dictatorship and regimes based on violence."

- German Bundestag

##### a. General policies

The general policies of my proposed management system are in direct correlation with the Foundation's mission statement, as it was derived from the aims of the artistic competition set forth by the City of Berlin (and stated in section 2.c). Additionally, the Foundation pledges to commemorate the Nazi genocide of European Judaism "by maintaining and running the memorial for the Murdered Jews of Europe", including both the Field of Stelae and the Information Center, as well as the Memorial to the Homosexuals Persecuted under the Nationalist Socialist Regime, the Memorial to Sinti and Roma Murdered During the Nazi Regime, and the Memorial to the Euthanized Victims of the Nazi Regime.<sup>22</sup>



*Images: Other memorials owned by the Foundation for the Murdered Jews of Europe in Berlin, photo: Stiftung Denkmal*

Additionally, it is my vision for the site to maintain its impressive and international touristic value, and to improve the educational objectives of the subterranean information center. The site is one of the most visited Holocaust memorials in the world, and I would not like to put a management plan in place that would take away from its large visitation rights, or the characteristics intrinsic to Peter Eisenman's design, which allows for total access without restriction or boundary.

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<sup>22</sup> Geschichte des Denkmals für die ermordeten Juden Europas, Stiftung Denkmal für die ermordeten Juden Europas.

## **b. Governance framework**

The memorial was proposed in 1989 by the journalist Lea Rosh after she had returned from a trip to Yad Vashem in Israel. She organized a group of advocates for the memorial called Perspectives for Berlin, the group felt “by admitting guilt to the international community in this way, Germany would make clear its commitment to the Western ‘civilized world’ and its cosmopolitan humanitarian values” as well as “to indicate how Germany as a society had changed”. The design process was drawn out over the next fifteen years, but the site that was built is managed by The Foundation to the Murdered Jews of Europe, with board members active in the German Bundestag, the Federal State of Berlin, the Central Council of Jews in Germany, among others.

The Foundation is the main core of the memorial's governmental framework, but the memorial is also affiliated with hundreds of other Holocaust memorials, museums and documentary and research centers. In addition, the interactive and exploratory nature of the memorial makes it essentially governed by the visitors, who chose to use the space reflectively or not, and the civically engaged people of Berlin, who immediately characterized the memorial as their own.

### **I. Foundation**

Executive Director - Uwe Neumaerker

Deputy Director - Dr. Ulrich Baumann

Secretary - Barbara Hoven

### **II. Foundation - Board of Trustees**

"The Board of Trustees consists of 22 members. It decides all basic issues within the Foundation's remit. It is responsible for the legal and judicial representation of the Foundation. The Board of Trustees appoints the Director and the Advisory Board. All parliamentary parties of the German Bundestag, the German Government, the Federal State of Berlin, the Association Memorial to the Murdered Jews of Europe, the Central Council of Jews in Germany, the Jewish Community of Berlin, the Jewish Museum Berlin, the Topography of Terror Foundation and the Working Group of Concentration Camp Memorials in Germany are represented on the Board of Trustees." - *Geschichte des Denkmals für die ermordeten Juden Europas*, Stiftung Denkmal für die ermordeten Juden Europas

### **III. Advisory Board**

"The Advisory Board of the Foundation for the Memorial to the Murdered Jews of Europe consists of representatives of 15 different institutions and social groupings, including survivors' associations, historical research institutes, museums, memorial centres and youth groups. The commission's spokesperson is Professor Wolfgang Benz, former Director of the Centre for Research into Anti-Semitism at the Technical University in Berlin. The main focus of the Board's work is on ensuring that all victims of Nazi persecution are included in the Foundation's programme and that the discrimination, persecution, deportation and extermination of fellow human beings is kept alive in public memory." - *Geschichte des Denkmals für die ermordeten Juden Europas*, Stiftung Denkmal für die ermordeten Juden Europas

### **IV. Foundation - Partners<sup>23</sup>**

#### **a. Memorial Sites**

Anne Frank House Amsterdam, Netherlands

Auschwitz-Birkenau memorial site, Poland

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<sup>23</sup> lists copied directly from the Foundation's website: *Geschichte des Denkmals für die ermordeten Juden Europas*, Stiftung Denkmal für die ermordeten Juden Europas

Bergen-Belsen memorial site  
Buchenwald memorial site  
Dachau memorial site  
Drancy memorial site, France  
Falstad memorial site, Norway  
Flossenbürg memorial site  
German Resistance Memorial Center, Berlin  
House of the Wannsee Conference, Berlin  
Majdanek memorial site, Poland  
Mauthausen memorial site, Austria  
Neuengamme memorial site  
Ravensbrück memorial site  
Sachsenhausen memorial site  
Stutthof memorial site, Poland  
Westerbork memorial site, Netherlands

**b. Museums**

Budapest Holocaust Museum and Documentation Centre  
Danish Jewish Museum  
German-Russian Museum, Berlin-Karlshorst  
German Historical Museum, Berlin  
Holocaust and Jewish Resistance Heritage Museum, Israel  
Imperial War Museum, London  
Museum of Jewish Heritage, New York  
Jewish Holocaust Museum, Melbourne  
Jewish Museum, Berlin  
Jewish Museum, Frankfurt/M.  
Jewish Museum Franken, Fürth  
Jewish Museum, Munich  
Jewish Museum, Prague  
Jewish Museum, Warsaw  
Jewish Museum, Vienna  
Kazerne Dossin: Memorial, Museum and Documentation Centre on Holocaust and Human Rights  
US-Holocaust Museum, Washington  
The Jewish Museum of Greece  
The Jewish Museum of Thessaloniki

**c. Documentation and Research Institutes**

Arbeitsstelle Holocaustliteratur, University of Gießen  
Center for Jewish Culture, Cracow  
Mémorial de la Shoa / Centre de documentation juive contemporaine, Paris  
Centre de la mémoire Oradour-sur-Glane  
Centrum Judaicum, Berlin  
Documentation Centre of Austrian Resistance, Vienna  
Documentation and Culture Centre of German Sinti & Roma, Heidelberg  
Documentation Centre Nazi Party Rally Grounds, Nuremberg  
Drew University, Madison  
Fritz Bauer Institut, Frankfurt/M.

FRONTIER-Projekt »Schreiben im Holocaust«  
 Hamburg Institute for Social Research  
 Institute of National Remembrance, Warsaw  
 Institut für die Geschichte der deutschen Juden, Hamburg  
 Institute of Contemporary History, Munich  
 ITS - International Tracing Service, Bad Arolsen  
 Jewish Historical Research Institute, Warsaw  
 Leo Baeck Institute, Jerusalem  
 Leo Baeck Institute, London  
 Leo Baeck Institute, New York  
 Moses Mendelssohn Center for European-Jewish Studies, Potsdam  
 Obersalzberg Documentation  
 Simon Dubnow Institute, Leipzig  
 Simon Wiesenthal Center, Los Angeles  
 Terezin Initiative Institute, Czech Republic  
 Topography of Terror, Berlin  
 Ukrainian Center For Holocaust Studies, Kiev  
 Wiener Library  
 Yad Vashem - The Holocaust Martyrs and Heroes Remembrance Authority, Jerusalem  
 YIVO Institute for Jewish Research, New York  
 Center for Research on Antisemitism, Berlin  
 Zentrum für Zeithistorische Forschung, Potsdam

#### **d. Associations, Institutions, and Advocacy Groups**

Action Alliance against Violence, Right-Wing Extremism and Xenophobia  
 Association for the Memorial to the Murdered Jews of Europe  
 Berlin History Workshop  
 Bundeszentrale für politische Bildung » Was tun gegen Rechtsextremismus?«  
 Bündnis für Demokratie und Toleranz, Berlin  
 Bundesstiftung Magnus Hirschfeld  
 Deutsch-Israelische Gesellschaft e.V., Hamburg  
 Facing History and Ourselves, Boston  
 Fondation pour la Mémoire de la Shoah, Paris  
 Foundation »Remembrance, Responsibility and Future«, Berlin  
 Gardens of the Righteous Worldwide, Milano  
 Goethe-Institut »Places of Remembrance«  
 International Tracing Service Bad Arolsen  
 Kleinmann Family Foundation  
 Haus der Bayerischen Geschichte, Augsburg »Tracks - The Jewish Pupils and the Era of National Socialism at the Maria-Theresia-School«  
 Lesbian and Gay Federation in Germany (LSVD)  
 STEP 21 - Youth Initiative for Tolerance and Responsibility with Project [Weiße Flecken]  
 Stiftung Sächsische Gedenkstätten  
 The American Jewish Committee, New York

#### **e. Visual Exhibitions and Art Projects**

Alex Deutsch »Ich habe Auschwitz überlebt«  
 Auschwitz - Final Station Extermination  
 Birobidzhan - Stalins Forgotten Zion



Familie Turteltaub  
gewissenlos - gewissenhaft ; Menschenversuche im Konzentrationslager  
Learning about the Holocaust through Art  
Sobibor - The Forgotten Revolt  
Synagogues in Germany - Internet Archive  
Tracing the past - German-jewish cultural heritage, [DW.de](http://DW.de)  
Museumsportal Berlin - Berlin's online platform for museums exhibitions, memorials and palace

## **V. Major Stakeholders**

Gedenkstättenübersicht der Topographie des Terrors  
NS-Gedenkstätten und Dokumentationszentren  
Verband der Geschichtslehrer Deutschlands e. V.

### **d. Specific objectives**

The intention of the site as stated by the Bundestag was to “maintain the memory of this unthinkable occurrence in German history” and “admonish all future generations to never again violate human rights, to defend the democratic constitutional state at all times, to secure equality before the law for all people and to resist all forms of dictatorship and regimes based on violence”<sup>24</sup> These goals have been contested in present day, as demonstrated by countless acts of vandalism, recreation, and an overall attitude of disrespect on the part of the visitors and reported in international media. The specific objective of this management plan is in direct correlation with this statement of the Bundestag, to return the site as a memorial through the expansion of the subterranean information center and to increase the educational resources of the Foundation by hiring more tour guides, interpreters and support for educational programming.

Further, I propose for the original design of the memorial to be kept in place - this is in reference to the countless proposals to alter the monument, including the proposal to engrave the slabs with the names of millions of known victims of the Holocaust, and the proposal to border the park with a perimeter fence, or to limit in any way the visitation rights inherent to the design of the site.



*Images: Luca Onniboni*

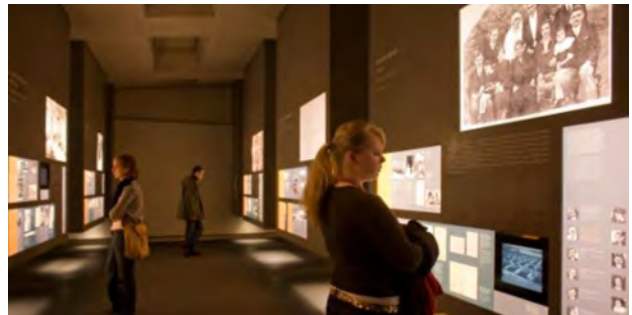
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<sup>24</sup> German Bundestag, “Resolution concerning the Memorial to the Murdered Jews of Europe,” June 25, 1999, cited in Stiftung Denkmal, memorial brochure



*Images: the subterranean information center, Foundation for the Murdered Jews of Europe*

The contested use of the site creates continuity with the original design of the architect, and the experience of the memorial as a site to get lost and a site of reflection, specifically pertaining to the evolution of our perspective on Holocaust memory. But, the most significant aspect of the site as it is a memorial, is the information center below the concrete field. The center exposes the structure below the concrete slabs. The information center contains the room of dimensions, the room of families, the room of names, the room of sites as well as exhibition space, video archives, and a portal to Yad Vashem's collection of names and the Federal archive. I propose an expansion to the subterranean information center, as well as access to the center to be expanded to all corners of the park. If the educational objective of the Foundation and exposure to the rich resources accessible in the center were to be expanded, the site would be a success to both the design competition of 1989 and the statement from the German Bundestag: the memorial would remain a living reminder of those who were lost and those who lost during the tragic events of the European Holocaust.





## **I. Conditions affecting the site / conditions to be resolved**

The memorial creates a new experience for those lost during the tragic events of the Holocaust as well as for those left behind. As essentially an artist's installation on historical ground, the form of the commemoration is highly debated, as well as the actions of the visitors, and the site has been subject to physical deterioration. These are the five key issues to be addressed in the management plan.

### **i. Commemoration of negative, tragic or shameful events**

The memorial as it was proposed in 1989 launched a political initiative in the city of Berlin and the entirety of Germany to deal with the scars of the 20th century. The citizen's initiative for the memorial, then known as Perspectives for Berlin, used the site of the Gestapo Terrain as a rallying point for their memorial and created a two-fold narrative of Nazi evil alongside German guilt. Establishing a monument at this location, the group vocalized, would “acknowledge German guilt to an international public by mourning for the suffering of those who had died,” and “such mourning work in the present might begin to make amends for crimes of the past and indicate how Germany as a society had changed”. Additionally, the group felt “by admitting guilt to the international community in this way, Germany would make clear its commitment to the Western ‘civilized world’ and its cosmopolitan humanitarian values”.<sup>25</sup>

### **ii. Physically boundless**

The memorial field's location in a busy tourist center could be a cause for the deterioration of the stelae. The German media speculated in 2007 “that the cracks are due to tremors caused by construction projects adjacent to the site, including the new US Embassy, or even vibration caused by commuter trains that pass beneath the memorial”.<sup>26</sup> The location is additionally problematic because of the tourist center that it was in. This popular historic neighborhood attracts tourism and recreation, but also creates a transient atmosphere of recreation. Visitors to the site are often on holiday, and many stumble into the concrete field from the Tiergarten border, and do not encounter the vast educational resources of the Information Center.

### **iii. Material Conditions**

Today 80% of the concrete slabs are severely deteriorating. The hairline cracks began after the field had been open to the public for just seven months. The cracks caused lime run and further deterioration in the stones. The aesthetic appearance of the stones is central to Eisenman's design concept, but their deterioration makes it additionally unsafe for visitors, who enjoy the interaction with the monument.

### **iv. Social and public use as a park**

The use of the site has been the major conflict since its opening in 2005. Etiquette for the memorial remains largely unknown, and needs to be written and accessible to visitors. Workers at the site, who include educators, tour guides, and security, continually discuss the site's evolving roles of etiquette. One host reported: “It is okay to eat a sandwich, people get hungry, but not to have a picnic”, and, while no official guidelines have been set for the use of the memorial, means of improper behavior are constantly open for discussion.<sup>27</sup> Play is not directly encouraged, but interpretive use is, and the design of the

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<sup>25</sup> Karen E Till, “The New Berlin: Memory, Politics, Place”, University of Minnesota Press, 2005.

<sup>26</sup> Josh Ward in Berlin, “Monument in Danger? Widespread Cracking Found at the Holocaust Memorial”, 8 August 2007. Spiegel Online International.

<sup>27</sup> Dekel, Irit, “Ways of looking: Observation and transformation at the Holocaust Memorial, Berlin”, The Hebrew University of Jerusalem Mount Scopus, Jerusalem, 2009.

memorial forces visitors to build their own metaphor or meaning after experiencing the site. And, inquisitive visitors are encouraged to think about the meaning of the memorial as the evolution of a graveyard. This is commonly exercised by way of “getting lost” either in the memorial or in thought while inside the memorial.

#### **v. Representations of the memorial in the media**

The use of the site is also contested constantly in international media. This conflict of use could be easily resolved by a closer examination of the architectural intention of the memorial. Eisenman describes the memorial as showing innate disturbances and chaotic potential in systems that are otherwise orderly.<sup>28</sup> There is no conclusive understanding to be derived from the memorial, and Eisenman has stated that the memorial is not meant to express nostalgia or memory of the past, and it is only meant to convey the events of the Holocaust as visitors experience the monument in present-day.



*Image: Entrance to the Information Center with portraits from Yad Vashem and major Holocaust archives*

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<sup>28</sup> Christine Gale, “The Memorial to the Murdered Jews of Europe”, University of Massachusetts.

## **e. Operational framework**

### **Management Plan promotes three main program areas:**

1. Architectural Conservation of the Memorial Site as it was designed by the Architect Peter Eisenman
2. Promotional and Education Material detailing site etiquette and memorial values
3. Expansion of the Subterranean Information Center, educational programming and interaction with tour guides and memorial staff, and construction of entrances from all corners of the memorial site

### **f. Monitoring and evaluation mechanisms**

The memorial has a diverse network of affiliations and partner organizations, all geared toward the commemoration of the tragic events of the Holocaust. This management plan does not mean to question the hundreds of partners for the Memorial or the Foundation, but it does hope to expand the Educational department at the Memorial, add more tour guides, and inseminate a manual for etiquette to be distributed at the site. The expansion of entrances to the site will solve many of the conflicts and debates regarding use of the park, and will work to constantly remind visitors where they are, so that there is no chance of getting access from any point without first realizing where you are.

- The etiquette manual requires training sessions for all current and incoming staff
- The conservation plan will involve an extensive checklist for all tour guides, to be completed by iPad submissions at the end of every shift
- These brief surveys will monitor the condition of the concrete, and the safety of the visitors, and they will be reviewed on a quarterly basis for the meeting of the Board of Trustees
- This survey process will be an expansion of the current management plan, which only assesses the condition of the concrete every six months
- As to implementation, a budget will be supplied for the conservation of the stones on a quarterly basis

