ISSUE 2/2006 ■ VOLUME 23 ■ NUMBER 2

Journal

Hoffmann Architects

Journal of architectural technology published by Hoffmann Architects, Inc., specialists in the rehabilitation of building exteriors.

Concrete Solutions to Concrete Rehabilitation

Steven J. Susca, PE

Shrinking, creeping, cracking. They sound like things that happen in a grade-B horror flick, yet hit the nail on the head when describing problems with concrete.

Concrete's versatility, durability and economy have made it the world's most highly used construction material. Concrete is crush-resistant, fire-resistant and provides insulation against sound and heat. It's also durable, meaning it will last years, even in extreme temperatures. Americans pour about 340 million cubic yards of ready-mixed concrete each year. It is used in highways, streets, parking lots, parking garages, bridges, buildings, dams, homes, floors, sidewalks, driveways and even artwork.

A concrete bridge parapet wall exhibits severe deterioration caused by repeated freezing and thawing cycles.

A Bit of Background

Not only is concrete ubiquitous, it has a long history. In ancient times, the Assyrians and Babylonians used clay as their bonding substance; Egyptians used lime and gypsum. Modern concrete came into play in 1756 when British engineer John Smeaton added pebbles as a coarse aggregate, mixing powdered brick into the cement. Not to be outdone, English inventor Joseph Aspdin invented Portland cement in 1824. This became the dominant cement used in concrete production.

It's been said that concrete is one of the world's most important materials. There's certainly no denying that it's one

(continued on page 2)

Steven J. Susca, PE, is Project Engineer with Hoffmann Architects, Inc. He is specifically experienced in concrete rehabilitation.

(continued from page 1)

of the simplest – a mixture of cement, sand, gravel and water. Typically, concrete comprises 60-70 percent sand and gravel or crushed stone, 15-20 percent water and 10-15 percent cement by volume.

And speaking of cement, many people incorrectly use the words "cement" and "concrete" interchangeably. It's critical to understand the difference between cement and concrete. Think about comparing flour to a chocolate chip cookie; the flour is in the cookie. Cement is only one component of concrete; when mixed with water it forms a paste in a process called hydration. This paste coats the surfaces of the fine aggregate (sand) and coarse aggregate (gravel or crushed stone), binding them together and forming concrete.

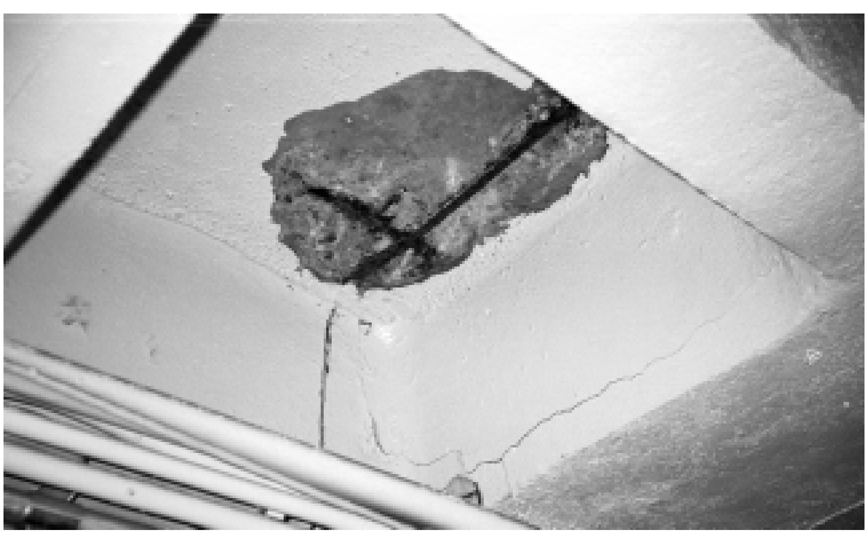
What Causes Deterioration?

Nothing lasts forever, and concrete is no exception. There are many internal and external forces that lead to deterioration and premature failure of cured concrete. Some common causes of concrete failure can include water infiltration, carbonation, corrosion of reinforcing steel, shrinkage, drying, thermal contraction and poor placement practices.

Water – Friend and Foe

Although water is a necessary component of concrete, it's possible to have too much of a good thing. Either directly or indirectly, water is one of the leading causes of concrete deterioration. While the combination of water and favorable temperatures generally can help increase the strength of concrete throughout its life cycle, that combination also can prove fatal, serving as a mechanism for deterioration.

Porous, water-saturated concrete that does not have adequate strength and entrained air is prone to scaling, a form of deterioration caused by freezing of water in concrete. Water expands as it freezes, which can impart great internal pressure into concrete. Over time, as these freeze-thaw cycles continue, the concrete eventually will weaken and fail. This type of deterioration is easy to recognize: concrete subjected to freeze-thaw damage appears to be pulverized or crushed.



A spall at the underside of previously repaired waffle dome.

Water can carry aggressive chemicals such as acids, sulfates or chlorides into the concrete. These chemicals attack concrete and cause corrosion of reinforcing steel in the concrete.

Concrete containing alkali-reactive aggregates is subject to subtle and harmful expansion forces caused by a reaction between the aggregate and the alkali hydroxides that are formed during the hydration process. High moisture content within the concrete while in service facilitates this reaction.

Carbonation

Hardened concrete is a highly alkaline substance, typically with a pH above 12.5. This environment is created by high levels of calcium hydroxide in the concrete and helps to protect embedded steel from corrosive forces. Essentially, a passivating film is created around embedded steel reinforcement. Since steel corrosion needs a neutral or acidic environment to flourish, the steel is effectively protected from corrosive forces.

Rainwater combines with carbon dioxide in the air to form carbonic acid. Over time, this carbonic acid infiltrates the concrete and, through a process called carbonation, combines with the calcium hydroxide to create calcium carbonate. This calcium carbonate has the effect of lowering the pH of the concrete, thereby eliminating the protective passivating layer around the steel. While carbonation itself is not a significant cause of corrosion, it allows a corrosive environment to develop at the surface of the steel. It doesn't take much to encourage corrosion – simply introducing moisture and air and a sprinkling of chlorides from road salts can do the trick.

In situations where concrete has deteriorated, carbonation is one of the

(continued on page 3)

(continued from page 2)

usual culprits. Chemical analysis of damaged concrete helps measure the severity of the carbonation issue.

One way to help combat the effects of carbonation and slow its progress is to apply water repellant to the concrete surface. In more severe situations, an elastomeric waterproofing coating can be applied. These precautions, preferably taken before the deterioration has occurred, limit future carbonation by restricting the entry of carbonic acid into the concrete.

Corrosion

Corrosion of embedded steel items is both a cause and a symptom of deterioration in concrete. There are several different mechanisms that can work alone or together to cause steel corrosion. However, in order for steel corrosion to occur, three ingredients must be present: moisture, oxygen and an electrolyte. Since moisture and oxygen are found nearly everywhere, the only thing missing is an electrolyte. This can come in the form of deicing salts that enter the slab through water infiltration.

As steel corrodes, iron oxide, or rust is formed. This rust occupies a much greater amount of space (up to eight times) than the steel from which it was created. When embedded in concrete, corroding steel imparts great internal pressure into the cement matrix. This eventually results in the formation of a subsurface crack. As the crack grows, it reaches the surface of the concrete and creates a spall.

The result of the spalled concrete is a reduction in the protective cover over the rebar. This allows corrosive elements like moisture and oxygen to easily infiltrate the concrete to the depth of the rebar, further exacerbating the

Figure 1

Figure 2

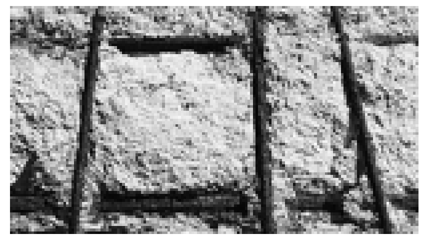


Figure 3

Figure 1 shows a typical piece of undamaged steel rebar, which is often used to reinforce concrete structures. Figures 2 and 3 show concrete that has spalled as a result of embedded rebar that has corroded.

existing corrosion. As this occurs, the cycle repeats itself at a continually increasing rate. Over a period of time, this cumulative process reduces the effective cross-sectional area of the reinforcing steel, which can compromise the structural integrity of the concrete.

Corrosion of embedded reinforcing steel is a serious issue that needs to be addressed in a timely manner to avoid more costly repairs down the road. If it's not caught quickly, corrosion will result in irreparable damage to the concrete. Remember: early detection can mean easier repairs. It just makes sense to take the proper precautions to prevent further problems.

Cracking

All concrete will crack eventually, but problems arise only when it cracks unexpectedly and in unanticipated locations. Cracking can be the result of one or a combination of factors, such as drying, shrinkage, thermal contraction, poor placement, restraint (external or internal) to shortening, subgrade settlement and applied loads. Problems with cracking can be significantly reduced by examining the causes and taking preventative steps.

Crazing is a pattern of fine cracks that do not penetrate much below the surface and generally pose only a cosmetic problem. They are barely visible, except when the concrete is drying after the surface has been wet.

Plastic shrinkage cracking is a result of improper curing, occurring when water evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water (excess water in the mix that works its way to the surface during the initial stages of curing), causing the surface concrete to shrink. Due to the restraint provided by the concrete below

(continued on page 4)

(continued from page 3)

the drying surface layer, tensile stresses develop in the hardening concrete, resulting in shallow cracks of varying depth. These cracks often are fairly wide at the surface. This type of cracking usually appears within two days of placement.

Drying shrinkage is a common issue found in concrete. Because almost all concrete is mixed with more water than needed to hydrate the cement, much of the remaining water evaporates, causing the concrete to shrink. Restraint to shrinkage, provided by the subgrade, reinforcement, or another part of the structure, causes tensile stresses to develop in the cured concrete. In many applications, drying shrinkage cracking is inevitable. Therefore, contraction (control) joints are placed in concrete to predetermine the site of drying shrinkage cracks.

D-cracking is a form of freeze-thaw deterioration that is observed in some pavements after three or more years of service. Due to the natural accumulation of water in the base and sub-base of pavements, the aggregate may eventually become saturated. Then with freezing and thawing cycles, cracking of the concrete starts in the saturated aggregate at the bottom of the slab and progresses upward until it reaches the wearing surface. D-cracking usually starts near pavement joints.

Thermal cracks are formed when the heat of hydration of cementitious materials leads to rising temperatures, or even during normal temperature swings. As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting. This causes tensile stresses that can result in surface thermal cracks if the temperature differential between the surface and center is too great. The width and depth of cracks depend on the temperature differential, physical properties of the concrete and the reinforcing steel.

Loss of support beneath concrete structures, usually caused by settling or washout of soils and sub-base materials, can cause a variety of problems in concrete structures, from cracking and performance problems to structural failure. Loss of support can also occur during construction due to inadequate formwork support or premature removal of forms or shores.

Alkali-aggregate reaction occurs when the active minerals in some aggregates react with the alkali hydroxides in the concrete. Cracks are characterized by crazing – fine cracks that form a pattern similar to that of an alligator skin. These cracks allow more moisture to enter the concrete, further exacerbating the situation. Alkali-aggregate reactivity occurs in two forms: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR).

ASR occurs when certain siliceous aggregates react with the alkali hydroxides to form a silica gel. This gel in turn absorbs water and expands imparting great pressures within the concrete, eventually causing cracks. ACR is a result of a reaction between alkali hydroxides and carbonate rock particles.

Alkali aggregate reaction is very difficult to arrest once it has begun. The best way to guard against this failure is to ensure non-reactive aggregates are used.

An Ounce of Prevention

Concrete failure can be kept at bay by taking proper precautions during the construction phase. If the concrete is correctly placed, consolidated, finished and cured, it has a good start to a prolonged life and delayed deterioration.

Always select the proper materials for the concrete mix. Ensure that the coarse aggregate is properly sized for the particular application. A chemical analysis should be performed to ensure that it's not alkali-reactive. Water for the mix should be potable and free of any chlorides or other deleterious chemicals.

Once it's time to mix the concrete, use the lowest amount of mix water needed for workability; overly wet consistencies can reduce concrete's strength and durability. To minimize the amount of mix water, use the largest size aggregate suitable for the project. Water-reducing agents, or superplasticizers, can be added to the mix to help increase the workability of the fresh concrete without adding water.

The most important aspect of a concrete mix design is the water-to-cement ratio. This is defined as the ratio between the total weight of water in the mix and the total weight of cement. This ratio determines the overall quality of the concrete mixture and to a great extent, its strength. Generally speaking, a lower water-to-cement ratio will result in higher quality concrete, however, one must not sacrifice the workability (the ability to pour, place and finish) of the fresh concrete by making it too dry.

When casting concrete against the earth, it is extremely important to properly prepare and compact the subgrade. Choosing the proper subbase material helps provide uniform support to the slab, reducing the chance of settlement cracks appearing.

To avoid rapid loss of surface moisture, use spray-applied finishing aids or plastic sheets to prevent plastic-shrinkage cracks. Finishing operations should not begin until the water sheen on the surface is gone and excess bleed water on the surface has evaporated. Avoid applying additional "finishing water" at all costs. If any excess water is worked into

(continued on page 5)

(continued from page 4)

the concrete during finishing operations, the concrete paste at the surface will contain too much water, which will likely result in scaling.

In concrete slabs, walls and other large members, it helps to provide contraction or control joints at reasonable intervals. When the concrete cracks, it will do so in a predetermined location, rather than randomly throughout the member.

Take precautions when casting concrete in very high or low temperatures. In areas with freezing temperatures, air-entraining admixtures should be added to the mix to improve freeze-thaw resistance. Some of the mix water can be replaced by ice (on a by-weight basis) to extend the working time of the mix in hot weather. Avoid extreme temperature changes during the curing process.

Once the concrete is in place, it's important to ensure it is cured properly. Curing is the process of maintaining a good balance of temperature and humidity around fresh concrete for a specific amount of time, so the concrete can achieve proper strength and durability.

As concrete cures, it gains strength. The initial curing period generally lasts from seven to 28 days and is when the concrete attains most of its strength. But the actual hardening process continues for years, albeit at a much slower rate, allowing the concrete to get stronger as it gets older.

Keeping on Top of Things

Once the concrete is in place, there are ways to ensure it remains functional and intact for many years. To help extend the life of concrete, it's important to maintain it and keep a watchful eye on any issues that might arise. Regular inspections can reveal problems that are still in the manageable and affordable stages. Other recommendations for dealing with concrete failure include:

· *Control, reduce or prevent cracking.* As noted previously, all concrete will crack eventually. The installation of control joints at regular intervals will cause this to occur in predetermined locations, thereby minimizing unanticipated cracking. When cracks are discovered, an analysis should be done to determine the cause of the crack prior to making any repairs. The crack can then be sealed from moisture infiltration or injected with grout or epoxy.

· *Take steps to prevent corrosion.* When placing new concrete in locations that might experience a high rate of corrosion, such as parking garages, several methods can be used. Sacrificial anodes placed within the concrete formwork and electrically bonded to embedded steel items can provide a form of passive cathodic protection; epoxy coated rebar can be used instead of regular rebar as an additional safeguard; corrosion protection admixtures can be included in the concrete mix; or a migrating corrosion inhibitor can be applied to the surface of cured concrete to help protect embedded reinforcement.

· *Prevent air and water infiltration.* Options to prevent air and water infiltration include removing damaged areas and replacing with relatively non-porous patching material, ensuring proper drainage for concrete floor slabs to avoid pooling water, covering reinforcing steel with a minimum of 1 ½ inches of concrete dense enough to limit chloride, water and air migration, and applying a penetrating concrete sealer to new concrete to limit the amount of moisture entering the member.

· *Prevent any possible chloride contamination.* Sodium chloride has little or no effect on properly air-entrained concrete, but will corrode metal. A weak dose of calcium chloride has little effect on concrete, but strong calcium chloride solutions can be a different story. Effects of magnesium chloride vary, from slight deterioration to aggressive damage, especially in wet-dry and freeze-thaw conditions.

It's a good idea to try to reduce or eliminate chloride use near exposed concrete surfaces. Consider using less damaging alternatives to de-icing salts, such as calcium magnesium acetate. Other options include applying protective coatings to inhibit the intrusion of chlorides, air and water.

Rehabilitation

Even if building owners have been less than diligent in the maintenance and upkeep of their concrete structures, all is not lost when defects and deterioration are discovered. Many products are

(continued on page 8)

Proper curing procedures should be employed to ensure the concrete achieves its intended design strength and durability. Some methods of concrete curing include:

· applying a fog spray or water mist to exposed concrete surfaces;

· covering exposed surfaces with wet burlap or other moisture-retaining cloth;

· spraying a concrete curing compound to the surface; and

· covering the top surface of the concrete with plastic sheeting to retain moisture.

Glossary of Concrete Terms

Admixture – Ingredients that are added to improve the plasticity, workability and finish of concrete.

Aggregate – Hard, inert materials such as sand, gravel or crushed stone that are used with a cementing material to produce concrete.

Air entrainment – Tiny air bubbles intentionally incorporated in concrete while mixing. Improves resistance to freezing and thawing.

Alkali-Silica Reactivity (ASR) – Reaction occurring between some siliceous aggregates and the alkali hydroxides created during the hydration process.

Bond – Adhesion of concrete or mortar to reinforcement, or to other surfaces.

Carbonation – Reaction occurring when carbon dioxide in the air combines with rainwater and permeates concrete to create calcium carbonate.

Cast-in-place concrete – Concrete poured into forms that are erected at the job site. Also known as site-casting.

Cement – A dry binding substance that forms concrete when combined with water and aggregate.

Cementitious – Having cement-like or bonding properties.

Consolidation – Elimination of voids in concrete by vibration, tamping, rolling or other method.

Compressive strength – Ability of a structural material to withstand squeezing forces; the maximum amount of compression that concrete is capable of sustaining.

Concrete – Hardened building material created by combining a mineral and gravel or crushed stone, a binding agent (natural or synthetic cement), chemical additives and water. It is commonly reinforced with steel rods (rebar) or wire screen (mesh).

Consistency – Degree of plasticity of fresh concrete. The normal measure of consistency for concrete is slump.

Construction joint – Point where two adjacent concrete members or successive concrete placements meet.

Control joints – Vertical or horizontal tooled joints built into concrete walls and slabs to control cracking resulting from stresses.

Creep – Time-dependant deformation of a concrete member under load.

Curing – Hardening of concrete after final finishing, when the hydration process continues and the concrete gains strength.

Drying shrinkage – Contraction caused by the loss of moisture.

Efflorescence – White crystalline or powdery deposit on concrete surface, caused by water seeping through and leaching salts from the cement.

Expansion joint – Joint allowing a structure to expand and contract during thermal or other influences without causing excessive tension in or stress to the structure.

Fibrous admixture – Special fibrous substances of glass, steel, or polypropylene that are mixed into concrete to help prevent plastic shrinkage cracking.

Finishing – Leveling, smoothing, compacting and treating surfaces of recently placed concrete or mortar to produce the desired appearance and service.

Hydration – Chemical reaction that occurs when water is added to cement, causing it to harden.

Plasticity – Property of freshly mixed concrete, defined by its workability or resistance to deformation.

Portland cement – Special synthetic blend of limestone and clay, generally stronger, more durable and consistent than natural cement.

Post-tensioning – Method of pre-stressing reinforced concrete in which tendons are tensioned after the concrete has cured.

Precast – Concrete unit, structure or member that is cast and cured in an area or location other than its final position.

Pre-stressed concrete – Concrete that has already been subjected to compression by means of pre-tensioned steel tendons.

Pre-tensioning – Compressing concrete in a structural member by pouring the concrete around stretched high-strength steel strands, curing it, and releasing the external tensioning force on the strands.

Ready-mixed concrete – Concrete mixed before delivery to a construction site.

Rebar – Reinforcing, strengthening steel bars installed in concrete structures. Rebar is short for reinforcing bar.

Reinforced concrete – Concrete that is reinforced by the addition of steel bars, making it more able to tolerate tension and stress.

Set – The process during which concrete cures. Initial set occurs when the concrete has to be broken to change its shapes, generally about one to two hours after it has been placed.

Shrinkage – Volume decrease caused by drying and/or chemical changes.

Slump – Measure of the consistence of freshly mixed concrete upon the removal of a standard slump cone, which provides an indication of the wetness, consistency and workability of the concrete mix.

Spalling – The chipping or flaking of concrete where corrosion of embedded items, improper drainage or venting, or freeze/thaw cycling exists.

Water-cement ratio – Ratio of water to cement in a concrete mixture, which indicates general concrete quality.

Water-reducing agents – Material that either increases workability of freshly mixed concrete without increasing water content, or maintains workability with a reduced amount of water.

Water-repellant coating – Transparent coating or sealer applied to concrete surfaces to help repel water.

Workability – The ease or difficulty of placing and consolidating concrete.

representative projects

Concrete Rehabilitation

Hoffmann Architects has resolved concrete deterioration problems for a variety of facilities, including:

Bishop's Corner
West Hartford, Connecticut
Concrete parking garage repairs and reconstruction

The Bushnell Tower
Hartford, Connecticut
Concrete façade repairs

Cold Spring Harbor Laboratory
Cold Spring Harbor, New York
Concrete parking deck rehabilitation

Embassy Suites
Nashville, Tennessee
Parking garage rehabilitation

Foxwoods Resort Casino
Great Cedar Parking Garage
Mashantucket, Connecticut
Parking garage corrective work

General Electric
Corporate Headquarters
Fairfield, Connecticut
Concrete parking garage repairs

The George Washington University
Ross Hall
Washington, D.C.
Concrete façade, ramp and slab repairs

Hartford Insurance Headquarters
Hartford, Connecticut
Concrete roof runway reconstruction

The Bushnell Tower
Hartford, Connecticut

The George Washington University
Ross Hall
Washington, D.C.

Hartford Square North
Hartford, Connecticut
Parking garage entrance ramp repairs

One Beacon Street
Boston, Massachusetts
Parking garage rehabilitation and reconstruction

One Financial Plaza
Hartford, Connecticut
Concrete parking garage rehabilitation

Southern New England Telephone (AT&T)
340 George Street
New Haven, Connecticut
Concrete parking structure repairs

Town Center Parking Garage
West Hartford, Connecticut
Concrete maintenance rehabilitation

Union Carbide
Corporate Headquarters
Danbury, Connecticut
Parking deck rehabilitation

Xerox Document University
Leesburg, Virginia
Exterior concrete rehabilitation

300 M Street SE
Washington, D.C.
Concrete investigation and emergency structural support

1166 Avenue of the Americas
New York, New York
Concrete roof runway reconstruction

1425 New York Avenue NW
Washington, D.C.
Concrete parking garage investigations

1801 L Street NW
Washington, D.C.
Concrete parking garage repairs

(continued from page 5)

available to rehabilitate a concrete structure that suffers from virtually any combination of issues.

Penetrating concrete sealers – These chemicals are applied to the concrete surface to protect against water infiltration. Due to their low viscosity, they are able to penetrate deep into hardened concrete to form a barrier that prevents liquid water from entering, but allows water vapor to evaporate from the concrete. This can help reduce carbonation, freeze-thaw damage and corrosion of embedded steel items. Typical sealers include silanes and siloxanes.

Epoxies – Numerous products are included in this category and can be used in a wide range of applications. Epoxies with low viscosity and a high modulus of elasticity can be either gravity-fed or injected into cracks to repair them. High-strength epoxy paste adhesives provide a way to structurally bond to concrete.

A new class of epoxies known as healer/sealers can be applied to the surface of a concrete slab to repair cracks and seal pores, protecting the concrete from water infiltration.

Patching mortars – When concrete is spalled or deteriorated and requires repair, many materials are available. Each of these products has advantages and disadvantages based upon the particular application in which it will be used.

The wide variety of patching mortars available today can be overwhelming. Some mortars are best used in vertical or overhead applications, while others are more suitable for underwater repairs. Some have integral migrating corrosion inhibitors to protect the existing rebar from further damage, while others have rapid curing capabilities to allow the structure to be put back into service more quickly.

Conclusion

Concrete is one of the world's most popular construction materials. With proper installation procedures and regular maintenance, this extraordinarily versatile substance can last many years. If addressed in a proper and timely manner, many defects can be repaired and the concrete can be restored to like-new condition.

It is important to realize that faulty concrete repair work actually can worsen structural problems or lead to further damage and even safety hazards. Therefore, when it's time to do repairs, consult a qualified professional. ■

JOURNAL is a publication of Hoffmann Architects, Inc., specialists in the rehabilitation of building exteriors. The firm's work includes investigative and rehabilitative architecture and engineering services for the analysis and resolution of problems within roofs, façades, glazing, and structural systems of existing buildings, plazas, terraces and parking garages.

Please send news, technical information, address changes or requests for free subscriptions to Editor, Hoffmann Architects *JOURNAL*, 2321 Whitney Avenue, Hamden CT 06518.

For information on the services offered by Hoffmann Architects, Inc., contact John Hoffmann, FAIA, President, at 800-239-6665.

2321 Whitney Avenue
Hamden, CT 06518
203-239-6660

500 Fifth Avenue, Suite 830
New York, NY 10110
212-789-9915

1001 Connecticut Avenue NW, Suite 825
Washington, DC 20036
202-530-1100

For more information on the topics discussed in this article, visit us on the web at www.hoffarch.com or contact us at email@hoffarch.com.

Editor: Ruthanne Bell

Hoffmann Architects

2321 Whitney Avenue
Hamden, Connecticut 06518

ADDRESS SERVICE REQUESTED

PRSRT STD
U.S. POSTAGE
PAID
PERMIT NO. 260
BRIDGEPORT, CT