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Requirements for WEATHERPROOFING THIN SHELL CONCRETE ROOFS

National Academy of Sciences—
National Research Council

publication 972

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Officers and Board of Governors

Requirements for WEATHERPROOFING THIN SHELL CONCRETE ROOFS

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of the
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Division of Engineering and Industrial Research

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The Building Research Institute gratefully acknowledges the contributions to building science made by the participants in this conference-workshop.

Milton C. Coon Jr.
MILTON C. COON, Jr.
BRI Executive Director

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Abstracts of Conference Papers

REQUIREMENTS FOR WEATHERPROOFING AND SEALANT MATERIALS FOR THIN SHELL CONCRETE ROOFS
By Owen L. Delevante, Harrison and Abramovitz, Architects

Twelve considerations are important in determining the requirements for weatherproofing and sealant materials for use in thin shell concrete roof construction. Definitions are needed for the similarities and differences between this and conventional roof construction, and for the correct finish of the concrete surface to permit successful application of a particular weatherproofing material. Better understanding of the various types of materials and their performance, coupled with quality control by the manufacturer of the basic ingredients is vital to a successful application. There must also be developed a recommended set of formulations for various applications to guide the coating supplier and the specifier, and both formulation and performance specification should be related to reliable, independently certified test data. The author also states that the responsibility for both the manufacture and proper application of weatherproofing and sealant materials should, from the standpoint of the building owner, rest with the manufacturer of the material, and should include a satisfactory guarantee from the same source.

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EFFECT OF PHYSICAL FACTORS ON WEATHERPROOFING OF THIN SHELL CONCRETE ROOFS
By C. E. Lund, University of Minnesota

The variety of configurations and designs in thin shell concrete decks call for detailed study to avoid difficulties with weatherproofing. The factors of inside temperature and humidity, solar radiation, and outside climatic conditions must be evaluated for the specific type of building use. Tables are given showing the maximum permissible relative humidity as related to outside air temperature and thickness of insulation; and temperature variations in insulated concrete decks as related to outside air temperature, the temperature below the deck, and the maximum permissible relative humidity. It is stated that the most favorable location for the insulation is above the concrete deck, and the author suggests that half-inch layers with staggered joints may provide the greater flexibility necessary to conform to contour irregularities. Care must also be taken to protect the insulation against moisture, since any moisture sealed into an insulated deck will expand in volume and create pressures greater than the adhesive strength of the roofing materials.

PROBLEMS AND LIMITATIONS IMPOSED BY THIN SHELL CONCRETE ROOF CONSTRUCTION AND THEIR EFFECT ON WEATHERPROOFING AND SEALANT MATERIALS
By Ralph W. Yeakel, Jr., Eero Saarinen & Associates, Architects

Weatherproofing problems encountered in the construction of a thin shell concrete roof for a terminal building at New York International Airport are described. In this case, it is pointed out that the roof design permits much more of the roof to be visible to the public, and therefore appearance becomes a greater factor. The finish or coating used must complement the concrete. The fact that most thin shell roofs do not have a conventional parapet or curb to allow for flashing turn-up increases the importance of the role of adhesives. It is also noted that coatings must have greater elongation capability than is now standard, because of the type of movement peculiar to the thin shells, and must be amenable to smooth patching with no color variation. Construction joints present a problem since the roofing material must either bridge the joint, or be turned down into it before the sealant is applied.

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PROPERTIES AND USES OF AVAILABLE WEATHERPROOFING AND SEALANT MATERIALS
By Francis Scofield, National Paint, Varnish & Lacquer Association

The requirements for coatings for thin shell concrete roofs are not essentially different from those for painting any other concrete under the same exposure. However, it is noted that the exposure to weathering is much more severe, and the life expectancy of the coating is consequently measurably reduced. Three types of coatings are discussed: asphalt coatings; clear coatings such as silicone or oleoresinous varnishes; and pigmented coatings such as portland cement paints, latex paints, and solvent-thinned elastomeric types of paints. The comparative durability and ease of application of each is noted, and it is stated that most high quality coatings for thin shell concrete are the solvent-thinned paints, often applied as multiple-coat systems. In general, the sealants based on the newer polymers are said to be the most satisfactory, although they may be more difficult to apply. Surface preparation for application of coatings to new concrete is described, as well as steps to be taken in the refinishing of such roofs.

CONFERENCE PAPERS

Conference-Workshop Chairman - Leslie M. Jackson
Head, Architectural Department
The Tremco Manufacturing Company

Requirements for Weatherproofing and Sealant Materials for Thin Shell Concrete Roofs

By Owen L. Delevante,* Project Manager,
Technical Information Department,
Harrison and Abramovitz, Architects

In recent years, those concerned with the design and erection of buildings have become more aware of the increased importance and potential of thin shell concrete roof construction. Initial applications of this concept were primarily in buildings erected for industrial use where long, clear spans and flexibility in plan arrangement were desirable. Continuous improvements in concrete technology and additional experience in this type of construction, coupled with a desire to exploit its inherent sculptural quality, led to its consideration and use in other types of buildings. It affords greater freedom in design of form and detail, and more efficient use of structural materials, the latter often leading to costs competitive with other construction systems. While there are many examples in existence, current interest indicates that these are really considered only forerunners of the possible and probable uses of thin shell concrete roof construction in the future.

As an aside to the subject under discussion, it must be pointed out that the terminology, "thin shell concrete roof construction," is not considered as accurate as "thin concrete shell roof construction." The latter more clearly defines the relationship of material to the shape, considered a "shell," as a covering for or as definition of enclosed space.

To date, concrete technology, including materials, mix designs, various admixtures, and greater familiarity with this construction, does not support recommendations for specifying or attempting to achieve a weatherproof concrete. Regardless of the claims for certain mix designs and admixtures now available, or definite instructions for and supervision of placement of the concrete, the desired quality is rarely, if ever, achieved. Taking into account all factors affecting this quality, it is considered a risk to rely upon the attainment of a weatherproof concrete for a roof.

Of necessity, there have been applications of weatherproofing and sealant materials to these roofs. More importantly, these will be required for examples now under construction as well as those in the planning stage. In many instances, previously used materials and techniques are specified on the assumption that they are also proper and suitable for this construction. Unfortunately, a review of many varied applications to

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date indicates the existence of a serious problem. This concerns the obvious and too often expressed dissatisfaction with certain materials and techniques prematurely labeled successful. There are many elements in those applications which have been and are questionable because of weight, maintenance, cost or appearance. In addition, there are many materials and techniques which have been complete failures. Yet, even when recognized as failures for concrete shell roof construction, they are still specified and used.

Attempts toward solution of the problem seem to be hampered by a lack of understanding of this construction technique. Proper coordination is rarely achieved between the elements and requirements of this construction and the weatherproofing and sealant treatments. There is entirely too much divergence of opinion and purpose in the efforts being made to solve the problem. A mutually satisfactory definition of requirements for weatherproofing and sealant materials for thin concrete shell roof construction can be achieved with:

1) Thorough analysis and understanding of this type of construction.

2) Objective, honest evaluation of past experience and available techniques.

3) Definite indication of purpose and function for the proposed applications of materials.

As the first step towards defining requirements, an example of this roof construction will be analyzed to indicate how and why certain elements affect the selection and application of materials.

The Assembly Hall now under construction at the University of Illinois (Fig. 1) has a tapered folded plate dome with a spring line diameter of 398'-0" and a rise of 60'-0". The exposed surface area to be weatherproofed exceeds 178,000 square feet, or more than four acres. The majority of the dome surface is exposed to view from grade level on the surrounding site. Roof drains are located in a continuous gutter at the perimeter.

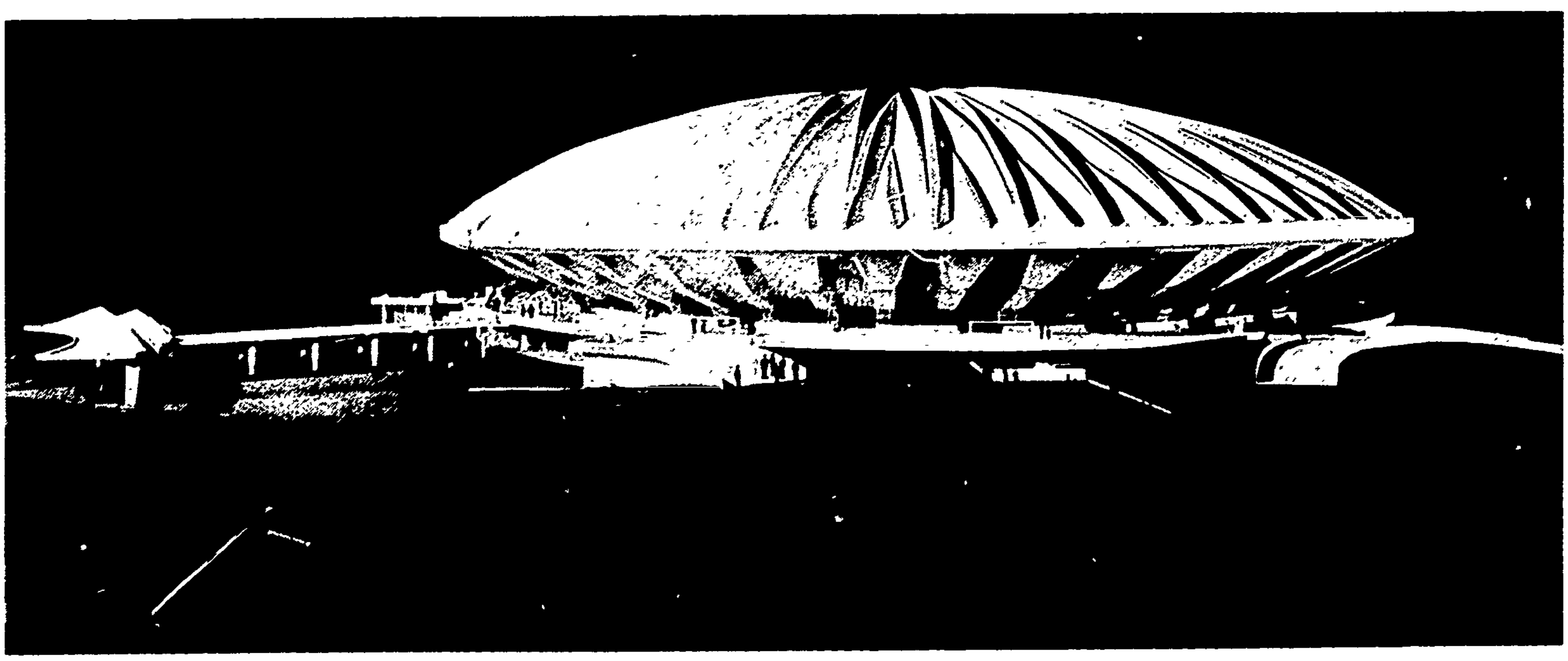

Fig. 1 - Assembly Hall, University of Illinois. Harrison & Abramovitz, Architects; Ammann and Whitney, Structural Engineers.

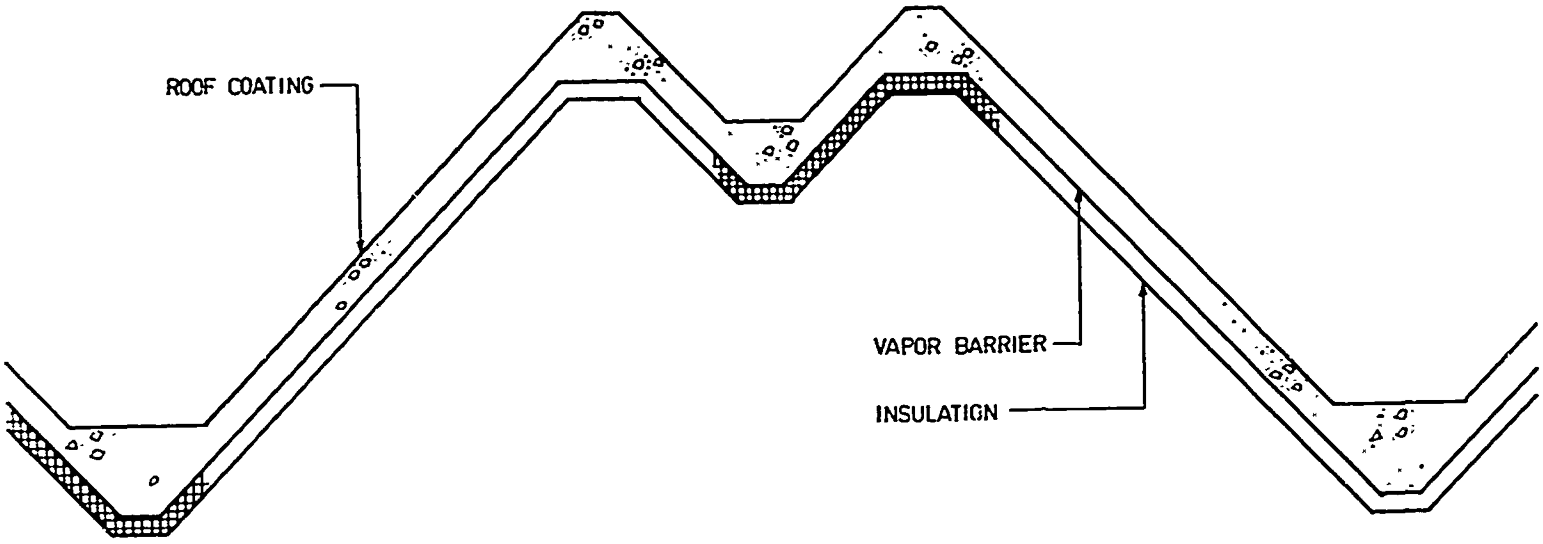

Fig. 2 - Cross-section through the folded plate.

Note how the center surface develops into ridges and valleys, and how one ridge develops into two with a valley between. This valley then becomes another ridge near the perimeter of the dome.

The cross-section through the folded plate (Fig. 2) shows a varying, sawtooth surface which, when related to the surface shown in the photograph, is subject to undulation in the vertical plane of the plate. The treatment on the inside surface is a mechanically anchored 2" thick insulation board with a vapor barrier between it and the concrete. In this example, the location of the vapor barrier is very important because the only possible escape for latent moisture in the concrete is through the top surface.

In this detail, the insulation serves both thermal and acoustical requirements, the latter being a most important consideration. If a vapor barrier was located in the recommended position on the warm side of the insulation, the acoustical properties of the material would be eliminated. As shown, the vapor barrier is primarily intended to prevent transmission of water vapor into the concrete, which could affect the subsequent weatherproofing treatment. In this case, careful analysis of temperature and humidity conditions for the space, including their relation to the ventilation system provided, indicated that the roof construction would be satisfactory for the intended functions.

The geographic location of the building indicates the climatic conditions under which the weatherproofing and sealant materials must perform. In addition, these same climatic conditions dictate to a great extent the circumstances governing the application of materials.

After considering the size, shape and details of the roof construction, the next element to be analyzed is the resultant surface of concrete which is affected by the design mix, placement, finishing and curing. For economy, the engineer designed a concrete mix for this dome using lightweight aggregate with an air-entraining agent. This mix, with ease of placement a major requirement, results in a porous, less dense concrete with good resistance to effects of freezing and thawing. The porosity of surface is an important factor in the selection and application of materials.

To facilitate construction, the dome was designed to be cast in 24 separate pie-shaped segments of about 120 cu. yds. each, with the construction joints so located as to be principally in compression. With such a complex, varying surface, it is easy to visualize the inherent problems in achieving a satisfactory surface for subsequent weatherproofing. Screeding and minimum trowelling will undoubtedly result in a surface with pinholes, hairline cracks, honeycombing, projections and texture.

The contractor is responsible for the proper curing of the concrete, which is generally specified to be accomplished by wet burlap, impermeable film materials or fog sprays. Here, the size of each segment and the complexity of the surface impose a problem in using any of these curing methods. Most contractors prefer and invariably request permission to use an emulsion-type curing compound which is applied directly to the surface after finishing, or a curing compound incorporated in the concrete mix. The former is very questionable because of possible residual effects which may affect the later application of other materials under consideration, and the latter may not be permitted by the structural engineers.

There is another element in this particular example, and possibly in other similar examples relative to the weatherproofing and sealant problem, that receives so little attention it can be considered as ignored. During construction, the dome is supported at the center, slightly more than halfway to the edge, and at the perimeter. These "permanent" supports remain in place until the dome is completely cast and prestressed, the former operation requiring 24 separate pours. Intermediate "temporary" supports are part of the movable formwork, which is moved as required for the casting of individual segments.

The sequence and extent of operations will permit applications of materials to those cured segments before the dome is completely cast. The prestressing operation will require six to eight weeks after completion of the dome. With these time elements, it is a safe assumption that the contractor will want to start weatherproofing and sealant work prior to completion of the prestressing operation, and may even want to start prior to completion of the concrete work on the later segments. If started prior to completion of the concrete work, the application of materials will undoubtedly be virtually complete before the prestressing operation is finished. Under these conditions, there will be introduced the element, as previously noted, that receives so little attention it can be considered ignored.

What happens to the dome, and particularly the concrete, when the "permanent" supports are removed? Does the selection and application of weatherproofing and sealant materials take into account the initial deflection and the plastic flow of the concrete? This combination of movements could easily exceed the later movements caused by thermal change which the materials must withstand.

General practice, and the foregoing, indicate that basically, the selection of weatherproofing and sealant materials and techniques of application for this type of roof construction will be influenced by the following requirements:

1) Materials must be easily applied, relatively economical for the expected or desired life, and require a minimum of simple maintenance for that period.

2) They must adhere securely to the concrete surface and be elastic enough throughout their life to withstand possible initial deflection and plastic flow movements, and later, varying thermal movements.

3) Because of the visibility of the dome, the materials must be as light in color as possible within limits of color stability and cleanliness.

4) Geographic location of the project dictates that the materials must withstand extremes of heat and cold with probable snow and ice on the surface.

5) For purposes of inspection and maintenance, it is necessary that the surface be skid resistant, but this quality must not conflict with the necessary self-removal of snow and ice.

6) Materials will be subject to immersion in water at low points near drains, these same areas also being subject to more traffic.

7) As a minimum requirement, the materials should be fire resistant to the extent that they are self-extinguishing after curing.

It should be borne in mind that a shell roof of this type is considered quite weather-tight because of the steep slopes and monolithic construction designed to function as a single unit principally in compression. This tends to minimize large movement cracks. It has been stated that leaks through the roof construction are generally not as serious a problem as protection of concrete from absorption of moisture. This would cause spalling in freezing and thaw cycles, and eventually attack and weaken structural reinforcing, regardless of the benefits gained from using an air-entraining agent.

The problem is not so much a matter of roofing as it is weatherproofing of the surface. There is general agreement to this, but this agreement does not eliminate the possible use of conventional roofing materials and methods for this weatherproofing. Some of these have been and can be used quite successfully. Some modified conventional roofing methods have also been used successfully, but when the properties of these are analyzed in relation to the listed requirements for selection of materials, and consideration given to weight, maintenance, cost or appearance, it is immediately clear why this approach was and is not completely satisfactory for all examples of this type of construction.

Therefore, it became necessary to indicate one which would meet demands of the industry. Those concerned were quite willing to consider any material or technique available which would provide a solution to the weatherproofing problem. The most suitable approach toward solution seemed to be through the chemical industry with its abundance of protective coatings of many types.

Nearly three years ago, one of the professional periodicals* contained an article on roof construction and roof coatings. It began with this statement: "The chemical industry is assaulting the building field with some startling new concepts of roof construction." The author must be complimented on this terminology, for our present situation is indeed the result of such assault. Its nature, cause and effect prompted my earlier statements, "...dissatisfaction with certain materials and techniques prematurely labeled 'successful'," and "...many materials and techniques which have been complete failures."

*Age of the Plastic Roof by David Allison, Architectural Forum, October, 1958.

Unfortunately, others concerned with the weatherproofing and sealant problem did little to stop the assault and, in many cases, actually aided and abetted it. Therefore, the present situation cannot be entirely blamed on the chemical industry. All concerned with the problem are in some way responsible.

What are the properties and requirements of sealants and those weatherproofing materials now commonly referred to as roof coatings? How is our selection of each further influenced by its inherent advantages and disadvantages? Generally, the next step in selection of materials is reference to the trade literature, which includes descriptive data and suggested specifications to guide those intending to use the material.

The literature distributed on coatings describes a particular coating as easily applied by brush, spray or roller, durable, thin, elastic, lightweight, resilient, reflective, brightly colored and attractive. It is said to be resistant to sunlight, weather, ozone, abrasion, flexing, flame, water and a wide variety of chemicals and solvents. It is claimed to be the only practical solution to the problem of weatherproofing thin shell concrete roof construction.

Generally, it is intended that this coating be specified by the proprietary term used by the subcontractor, applicator or supplier to denote his particular formulation, which uses a basic vehicle or resin purchased from a chemical manufacturer. (For clarity the term "subcontractor" will be used to cover any one of these three providing such coatings). The chemical manufacturer has been responsible for the basic research, continuing research, evaluation, testing, production, advertising and marketing of these vehicles. The extensive research and testing enables recommending formulations to purchasers. Often the chemical manufacturer maintains lists of suppliers of these formulated coatings for distribution to anyone interested.

Superficially, this arrangement appears satisfactory, since there seems to be a measure of control to offer some guidance and protection to those specifying or buying the coatings, but closer analysis proves otherwise. The measure of control is minor, the exact guidance difficult to obtain, and the protection for those specifying and accepting these coatings is virtually nonexistent, because there are no satisfactory answers to the following questions:

1) Is there one recommended formulation which possesses all the advertised qualities?

2) If not, are there other recommended formulations which possess specifically desired qualities?

3) The manufacturer publishes test data on the coatings, but are or were the tests performed on one or all of the recommended formulations?

4) How does the chemical manufacturer, architect, or owner determine that formulations used by a subcontractor agree with those recommended?

5) If formulations used by a subcontractor are found not to agree with those recommended by the chemical manufacturer, who is responsible? Who pays for any required corrective work?

6) If a subcontractor uses a recommended formulation, supposedly suitable for a specific requirement, and the formulation fails, who is responsible? Who pays for any corrective work?

7) If for any reason a formulation should fail, what corrective work is possible on a thin concrete shell roof?

As mentioned previously, these subcontractors purchase basic vehicles or resins from chemical manufacturers. Assumedly following manufacturers' recommendations, they formulate coatings denoted by a proprietary term. This coating is then advertised, produced, marketed and applied under the assumption that it has qualities similar to those recommended or tested by the chemical manufacturer. The description invariably places emphasis on the apparently proven qualities of an unknown formulation tested and recommended by the manufacturer of the basic vehicle or resin, not on the subcontractor's particular formulation.

Under these circumstances, the answers to some of the previous questions are obvious. Others have been answered by experience which has all too often proven unfortunate for those concerned with the problem.

A subcontractor should not commence or recommend commencing work on a thin concrete shell roof without satisfactory resolution of the following items described by his specifications, since these specifications are intended as guidance for those specifying or using the material:

1) Curing of concrete—Completely disregarding the contractor's construction schedule or procedure, one subcontractor may require that the concrete be cured at least 28 days. Another may adopt a more realistic attitude and specify minimum curing periods for various concrete mixes using different types of cement. This is not fully applicable, all-inclusive or correct. Most recognize the problems that may be met in the subsequent application of a coating with a spray-on emulsion type of cure, and prohibit its use. While questionable to the general contractors in some cases, this requirement is generally followed.

2) Surface of concrete—Such phrases as these are found in the specifications: Finish on concrete should be equivalent to that resulting from one light steel troweling; concrete shall have a wood float finish; substrates must be smooth, dry and free of loose materials; honeycombing and voids should be trowel grouted and sharp projections removed. These requirements will certainly lead to comment from contractors, particularly the contractor placing concrete for this dome.

3) Cracks—Some specifications require that any crack larger than a hairline be properly filled, but they do not specify how. Others have the same requirement and specify that such cracks are to be filled with a sealant material, which they consider compatible with the coating. Others go further and specify a treatment consisting of mesh in the coating applied over those cracks previously treated with sealant material. In bidding a job there must be an extensive amount of clairvoyance employed to determine the amount of time, material and labor that will be required for such work.

If this matter is thought unimportant, consider the fact that a subcontractor prepares his specifications for the guidance of those intending to use the materials. An architect may specify that all cracks larger than a hairline shall be filled with a compatible, approved sealant material, and all joints so treated shall have a covering strip of mesh thoroughly imbedded in the coating. Who has the authority to define a hairline crack? Who decides which cracks should be filled and covered with mesh? Who pays for this work?

4) Joints—Whether due to construction, expansion, or change in materials, joints must be treated in a manner the subcontractor considers satisfactory. This may involve recommended compatible sealant compounds, mesh, flashings or combinations of each. This is a responsibility of, and must be given serious consideration by, the architect and engineer since proper detailing and specifications for these joints are very important to the solution of satisfactory weatherproofing of the roof surface.

There is often encountered a most paradoxical and annoying element in the trade literature. In reading the advertising literature and suggested specification, it is obvious that something is missing. There is an abundance of pictures and prose describing a wonderful coating, and test data provided by the manufacturer of the important basic vehicle or resin. The material supposedly will function in every way advertised for a period of time, this period being estimated from performance in relatively recent installations and from the performance of the coating under accelerated or normal weather tests. This is a case of having faith in the printed word, and belief that because the subcontractor so asserts, the material will function as claimed. The manufacturer of the basic vehicle or resin makes similar assertions. However, the certain something missing from the advertising literature and specifications is any mention of a guarantee.

Many subcontractors disclaim any responsibility for the material, even if used according to their recommendations. The chemical manufacturer will not guarantee the results to be obtained. Some subcontractors will reluctantly offer a guarantee, depending upon the scope of the job, the client, or if the owner pays a premium for the work. The coating will not be covered by a conventional roofing bond. This will probably prove beneficial in the over-all picture, because there is a definite advantage in requiring a guarantee.

Obviously, the requirements of one portion of the industry conflict with those of others involved. There is little mutual appreciation of the procedures and purposes, the techniques of construction or the use of materials under consideration by the several different groups involved in the work. If this situation continues, our problems will become more severe, with, of course, most undesirable repercussions.

In summation, a unified approach to the solution of the problem suggests that the following comments and questions be considered relative to thin concrete shell roof construction and requirements for both weatherproofing and sealant materials:

1) The similarities and differences in conventional and thin concrete shell roof construction must be defined to eliminate the air of mystery which so often surrounds the latter.

2) We should define and provide the correct finish on a concrete surface for application of a particular weatherproofing material. We may not always be correct

in requiring a steel trowel or wood float finish. The former may be too smooth and the latter too rough. An intermediate finish similar to that achieved by a magnesium or aluminum float may prove most appropriate.

3) Application procedures for weatherproofing and sealant materials should recognize the contractor's methods of forming, placing and finishing concrete, and consider the contractor's construction schedule and contingent work. In many cases it would be advantageous to use materials that breathe, which would permit the escape of latent moisture from the concrete without damage to the weatherproofing.

4) Weatherproofing and sealant materials cannot be expected to perform a structural function. This requires understanding and defining the function of a particular joint, and detailing it for correct performance, as well as careful selection and use of proper materials, including joint primers, sealants and flashings.

5) Quality control in the manufacture of materials is most important. Insistence on competition, and our search for economy, have often led to complete failure. In such cases, all concerned suffer.

6) Where there have been failures, they should be examined very carefully. This evaluation should then be incorporated in continuing research programs.

7) The use of conventional and modified conventional roofing materials and methods should be fully explored. In some cases, these have a great deal of merit and their merits should be exploited.

8) Until there is more experience with the new materials, their use must be observed closely to avoid the common shifting of responsibility when trouble arises. All concerned must police the early jobs. If time for inspection is not available, the materials should not be specified, purchased or applied.

9) In the foregoing, the term "subcontractor" has been used to denote subcontractor, applicator or supplier of coatings. Often an architect specifies a certain weatherproofing treatment and, if the material or application proves faulty, the general contractor claims to know nothing about the weatherproofing work, since it is a special field. The subcontractor, as the applicator, may blame the concrete surface or may blame the coating material. Since the applicator purchased the material, the supplier, in turn, either blames the concrete surface, application method or the basic vehicle or resin used. If the formulation, and the manufacture of the coating material are assumed to be perfect, there remains only the manufacturer of the all-important basic vehicle or resin. His recommendations are based on tests, supposedly reliable, but which do not guarantee the results to be attained. The circle is nearly complete. The next question—easily the most difficult to answer—is directed by the owner to the architect: Why did you specify this material and what has been received for the expenditure involved? There should be a way of answering this question.

10) The chemical manufacturer will sell the vehicle or resin to anyone. It is not even necessary that the purchaser be on his distributed list of suppliers. With this condition, there are many formulated coatings none of which are specifically related to available test data. Furthermore, are those test data unbiased?

11) There must be established a set of recommended formulations for various applications. These should be general in nature and include generic ingredients. For each formulation recommended, there should be a related performance specification, which will be of little value if it is so broad that it permits inclusion of all available manufactured coatings. Both the formulation and performance specification should be related to reliable, independent test data.

Talk of "secret ingredients" in the formulations of coatings and sealants should be omitted or at least minimized. In practice, there is little possibility that they can or actually do exist. There have been cases where these unknown ingredients proved to be the cause of failure. Competition should result from quality control and methods of production, not from cheaper and less suitable materials. Given a recommended formulation, adequate performance specification, and reliable test data for guidance and control, it can then be required that any material used by an applicator be certified for conformity. The materials can then be tested for conformity during the work, in much the same way as other materials on a job.

12) There must be a definition of responsibility covering both the manufacture and application of materials in question. From the owner's viewpoint, this must be a single responsibility, most suitably lodged with the manufacturer of the coating or sealant material. In turn, this single responsibility should include a satisfactory guarantee from the same source. At present, the required degree of satisfaction is difficult to define, but it cannot be neglected; it must be established.

There is absolutely no justification for continuing to introduce any element of risk in the investment of the owner's building dollar—either in capital investment or maintenance costs. To eliminate this risk, all involved in this matter must direct their combined efforts towards a mutually beneficial solution to the problem. Neglect or compromise of any one element will undoubtedly result in an unsatisfactory solution.

Effect of Physical Factors on Weatherproofing of Thin Shell Concrete Roofs

By C. E. Lund,*
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Many of the factors affecting the weatherproofing of thin shell concrete roof construction are similar to those which affect the more common types of concrete decks. Due to the variety of configurations and designs in thin shell concrete decks, the problems introduced require more detailed study to avoid difficulties. The factors of inside temperature and humidity, solar radiation, and outside climatic conditions must be evaluated for the specific type of building use.

Cold climates require special precautions in roof design to avoid condensation on the interior surfaces as well as within the roofing and deck structure itself. Interior surface condensation is dependent upon the interior room air temperature and relative humidity, which must be maintained at appropriate levels, and upon the outside air temperature. These variables are usually fixed by requirements and location. To avoid interior surface condensation, the temperature of the interior surface of the ceiling must be higher than the dew point temperature of the inside air. Roofing materials and concrete are both high conductors of heat. To increase the inside ceiling surface temperature, insulation must be added either above or below the concrete deck. In either location, the insulation requires special consideration to avoid moisture difficulties.

Industrial requirements may add moisture to the interior of the building, or special processes may require a certain humidity level. Where a high occupancy load is encountered, the moisture given off by the occupants may raise the humidity of the inside air above the critical dew point of the interior ceiling surface temperatures. A person gives off on the average 1/6 lb. of water per hour, and when engaged in greater activity, such as dancing, etc., the rate of moisture given off is increased 50% or more.

Table I illustrates the maximum permissible relative humidity to avoid interior surface condensation at an inside air temperature of 75°F for different outside air temperatures, using noninsulated concrete decks and decks with 1" and 2" insulation.

For a noninsulated deck, the maximum relative humidity which can be maintained varies from 24% at -10°F outside air to 39% at 20°F. With the addition of 1" or 2" insulation,

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TABLE I

Maximum Permissible Relative Humidity
(Inside air temperature, 75°F)

Outside Air Temperature °F	Thickness of Insulation None	1"	2"
-10	24%	61%	73%
0	27	63	76
10	33	68	79
20	39	70	82

the relative humidity can be increased from 61% to 70% or from 73% to 82% respectively within the temperature range -10°F to 20°F without danger of surface moisture dripping.

Another type of moisture problem may be encountered within the deck itself, depending upon the type of insulated deck. With the roofing applied directly to a 3" concrete deck, the residual moisture within the concrete is evaporated only from the exposed interior surface. During the winter months, the residual moisture will migrate in two directions: 1) to the air below; and 2) to the under side of the built-up roofing. However, if the vapor pressure within the building is higher than the vapor pressure within the concrete, the moisture migration will be toward the low vapor pressure area which is below the roofing. Roofing applied according to specifications is, for all practical purposes, impermeable to vapor and may be considered a vapor barrier. Roofing is a poor insulator; the temperature drop across the roofing is negligible which results in a negligible vapor pressure drop during cold weather. Since the rate of vapor movement across a material is dependent upon the resistance and the vapor pressure drop across the material, it is apparent that the moisture or vapor movement across the built-up roofing is negligible. Where the mopping between layers of felt is spotty or does not provide a solid homogeneous mass, the vapor will continue to seek the lowest vapor pressure areas between the plies of felt, and condense at these points. Although the pressure gradient between plies is small, it is sufficient to induce the vapor to travel toward the outside during the cold weather. The top pour or mopping of bitumen prevents the vapor from continuing on to the outside, and thus it condenses between plies either as a liquid (water) or as a solid (ice). To avoid this type of vapor movement, the top surface of the concrete should be given a continuous coating of primer to seal its surface.

During the summer, the temperature of the deck is considerably higher than during the winter, due to the additional heat from solar radiation. Under these conditions, the vapor pressure in the concrete deck may be 10 times greater than the vapor pressure within the interior of the building. Because of the high vapor pressure in the concrete, the moisture movement during the summer is accelerated toward the interior of the building. More moisture difficulties occur during the spring, following the pouring of concrete decks during the winter months, than when the decks are poured in the spring or early summer. The latter conditions permit the accelerated drying of the concrete deck prior to the coming of the cold weather.

There have been many instances throughout the United States where moisture problems have arisen within buildings due to the season when construction took place. When a building is enclosed during the early part of the winter, without adequate heat or ventilation during the completion of the interior, moisture from curing of concrete floors, partition walls, plastering, etc., contributes to high interior humidity conditions. The result is surface condensation upon interior surfaces of walls, windows, and roof decks. In addition, the moisture, because of its high vapor pressure, may be transmitted into the improperly designed roof deck, causing "ghost leaks."

With the addition of insulation below the deck either as a form board, for aesthetic purposes, or for reasons of economy and comfort, the problem becomes more complicated. Most types of insulating form boards have a low resistance to the passage of water vapor, which permits moisture to accumulate between the interior insulation and the adjacent surface of the concrete deck. This moisture may be in a liquid or in a solid state, such as frost or ice, depending upon the outside air temperature. For example, a 3" concrete deck with 1" of insulation as the interior surface will have the temperatures shown in Table II between the concrete deck and the insulation:

TABLE II

Temperature Variations in Insulated Concrete Deck
(3" concrete deck, 1" insulation below)

Outside Air Temperature °F	Temperature below Concrete Deck °F	Maximum Permissible Relative Humidity %
-10	3	5
0	11	7
10	20	11
20	28	18

Due to the low temperatures below the deck, the inside relative humidity at an air temperature of 75°F cannot exceed 5% for an outside temperature of -10°F or 18% for an outside temperature of 20°F. Such low relative humidities rarely exist within a building, so the condensation of moisture may be anticipated below the concrete deck. The rate of moisture or frost accumulation is dependent upon the vapor pressure drop from the inside air to the under side of the deck, the resistance of the insulation board to vapor migration, and the length of time the condition exists. The vapor pressure drop is dependent upon the inside air temperature and humidity, and the outside air temperature. Recognizing that insulation is permeable to vapor movement, this type of design should be avoided.

The resistance of the insulation may be increased by treating the surface exposed to the interior air with some type of vapor-resistant material or paint. Essentially, this is similar to applying a vapor barrier over the interior surface of the insulation. However, this is not practical in many cases, as it affects the interior design requirements. Another problem is introduced if an interior vapor barrier is applied. Usually, the roofing is applied as soon as the deck surface is satisfactory. As roofing is highly impermeable to vapor movement, the uncured concrete does not have an opportunity to dissipate the trapped moisture. The insulation, which may absorb some moisture during the pouring of the concrete, is also unable to dry out. Eventually, due to the combination of heat from solar radiation and the higher heat transfer of the moist concrete, deterioration of the insulation may take place. Sprayed-on types of interior insulation are usually highly permeable to vapor and would be subjected to the same difficulties. Inorganic, foamed types of insulation may be used between the form board and the concrete decks, providing that all joints are positively sealed throughout its thickness. These types of insulating materials are impermeable to vapor migration, except that the joints permit a high rate of vapor migration if not positively sealed.

The most favorable location for the insulation is above the concrete deck. Contour irregularities introduce problems regarding the type of insulation which will readily lend itself to the contour of the deck. One-half inch layers with staggered joints may provide the greater flexibility necessary to conform to contours. The concrete deck should first be primed, followed by a vapor seal course. A single-ply felt, solidly mopped to the deck, followed by solid mopping of the first layer of insulation to the felt will provide a satisfactory vapor seal. Only a two-ply vapor seal course guarantees that a good seal will be obtained when there is a question of workmanship and quality control. There are several proprietary types of vapor barriers which provide excellent protection against moisture when applied according to the manufacturer's recommendations. These types are not dependent upon the mopping to obtain a good vapor seal.

Economy of operation during the heating season must be considered in determining the insulation requirements. Solar radiation under summer conditions and reradiation from the underside of uninsulated roofs will add discomfort to the occupants below.

The most common types of thin shell decks consist of 3" reinforced concrete. The overall transmittance value for an uninsulated concrete deck is 0.712 Btu per hour per square foot of area. Adding 1" of insulation above or below the deck reduces the transmittance coefficient to 0.237, or a reduction of 67% in the heat loss through the roof. Two inches of insulation have a transmittance value of 0.14, or a reduction of 82%. The law of diminishing returns governs the most economical thickness of insulation to be used. The saving in fuel costs for a particular area may be accurately calculated to determine the quantity of insulation to be used.

Reradiation from the under side of a roof may cause discomfort to the occupants, as it increases the discomfort index. To compensate for this increase in radiation loss from the human body to the under side of an uninsulated roof, the inside air temperature must be increased approximately 5°F to re-establish the comfort index. For example, at an outside temperature of -10°F and an inside temperature of 75°F, the inside surface temperature of uninsulated 3" concrete deck is 38°F; for 1" of insulation added, 63°F, and for 2" of insulation, 68°F.

Solar radiation will produce roof surface temperatures in excess of 160°F for dark colored roofs, and in excess of 130°F for light colored roofs, depending upon the outside air temperature. The inside surface temperatures of a noninsulated deck will be 119°F for the dark roof, and 102°F for the light colored roof, when exposed to solar radiation. With the addition of 1" of insulation, the inside surface temperature will be 88°F and 83°F, for the dark and light colored roofs respectively. For 2" of insulation, the inside surface temperatures will be 83°F and 80°F, respectively, based upon an inside air temperature of 75°F. The reradiation to the human body during the hot summer months from an uninsulated 3" concrete deck because of the hot surfaces underneath the deck is an important factor upon summer comfort. Capital investment in cooling equipment and the attendant maintenance cost would be prohibitive and inadvisable, unless the roof was properly insulated.

To avoid roof blisters, alligators and similar failures, the insulation must be protected against moisture, and applied during dry weather to a dry deck. Any moisture sealed into an insulated deck will expand in volume and create pressures which are greater than the adhesive strength of the roofing materials. This condition is produced by the radiant heat from the sun and high outside air temperatures, and also occurs when the built-up roofing materials have the lowest bonding strength because higher temperatures cause them to become less viscous. When water changes to a vapor state, the volume change is 1500 times. Air and vapor pressure changes will attain 5 psi, or 720 psf or more. The weight of a graveled roof is approximately 600 lbs. per square, or 6 psf. Contrary to some opinions, the weight of a roof is too insignificant to overcome blistering.

When felts are applied to a deck, the first ply should be solidly mopped and broomed to the deck, with successive plies similarly applied. Every attempt should be exercised to obtain a monolithic type of a built-up roof to avoid any interstices or voids between plies where air and vapor may be trapped. When sprayed-on types of roofs, sealants and other similar materials are used, a monolithic roof is more easily obtained, and the roof is less vulnerable to blistering. However, the manufacturer's specification must be rigidly followed to avoid roof failures. Most of the failures of roofs of this type which have been investigated have been attributed to poor workmanship, and to not using the required quantities of bitumen.

Expansion and contraction of the deck and the roof must be given special attention. Insulation below the deck increases the temperature range to which the concrete deck is exposed. The insulation retards the heat in the summer from the outside and in the winter from the inside. In severe climates, a range of 200°F should be used for design purposes for dark colored roofs. The temperature range may be slightly less for light colored roofs. Expansion joints should be specified for both the deck and the roofing.

When the insulation is applied above the deck, the temperature range for the concrete deck is negligible, as it is insulated from outside climatic changes. This reduces to a minimum the movement of the concrete deck due to expansion or contraction. However, the roofing remains exposed to the higher temperatures which will necessitate expansion joints. With insulation between the roofing and the concrete deck, the roofing is subject to a wide range of temperature change, approximately 200°F. As a result, the roofing becomes more brittle in the winter and more fluid in the summer.

Racking of roof decks has caused many roof failures due to splitting of the roof. Continuity of structural steel from a heated area to an unheated area produces abnormal expansion and contraction, with excessive deck movement. This may cause serious roof problems, especially where concrete decks are continuous from heated to unheated areas, such as overhangs, etc.

The responsibilities for obtaining a satisfactory roof and deck rest with the architect, general contractor, deck applicator, roofer and materials manufacturer. They must adhere to good design practices, rigid specifications, good workmanship and quality control. The architect should advise his client of the pitfalls created by false economy. Such economy should not be practiced at the expense of downgrading the exterior components of a building which are exposed to extreme climatic conditions. A building's primary purpose is protection against the elements, followed by its utility and esthetic value.

The general contractor must coordinate the work of all the trades and assist the subcontractors, wherever possible, to exercise quality control. Protection against roof damage, adequate heating, and ventilating of an uncompleted structure are necessary. The roof deck applicator and the roofer must adhere to the specifications and insist on quality control. Roofing is no longer a job for the inexperienced, but is becoming more and more a specialized art.

Problems and Limitations Imposed by Thin Shell Concrete Roofs and Their Effect on Weatherproofing and Sealant Materials

By Ralph W. Yeakel, Jr.,* Supervising Resident Architect for TWA Unit Terminal, Eero Saarinen & Associates, Architects

Comments on sealants and roofing materials in this paper are limited to the particular problems and limitations presented by those shell structures in which appearance is the determining factor in the selection of the roofing or sealant material. For purposes of practical illustration, I shall use as an example the most recent structure in the general category of shell construction, the construction of which I supervised, and then touch briefly on some of the points which are broadly applicable to this structural type.

The building, designed by Eero Saarinen and Associates, is the Trans-World Airlines Terminal at the New York International Airport at Idlewild. While it is not, technically speaking, a shell, and is certainly far from thin, the problems of protecting the roof surfaces against penetration of moisture are essentially those faced in most shell structures. It has a series of sloped surfaces intersecting at a center point and at eight low drainage points (Fig. 1). The thickness of the bent cantilevers, which we call shells, varies from 7" to 2'6". The center plate at which the four shells join is 44" thick.

The thin shell problems are still present, however. For, regardless of thickness, a crack is still a crack, porosity is porosity, and the general characteristics of junctures between concrete and aluminum or steel remain the same in terms of detailing and physical behavior. Parenthetically, I might point out that one cannot think in terms of "thin" shells alone. This particular structure represents a solution to a problem, a prototype which may well appear in the future with as much frequency as those of thinner section, partially because of the variations possible, and partially because thin shells do not find ready acceptance with all building authorities in the United States.

In this construction, water can gather at two places on the surfaces—in the valleys surrounding the center plate, and at the drainage points. Further, we had to stop our coating on a watershed surface in a manner both effective and unobtrusive. This called for either a caulked reglet or an almost mystic faith in adhesives. Unfortunately, there has been no firm decision made concerning the final method of covering the shells, or even the final material, although a bulletin has been issued and prices taken for two types of chlorosulforated polyethylene and neoprene-chlorosulforated polyethylene applications.

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(Photographs by George Adams Jones, Philadelphia, Pa.)

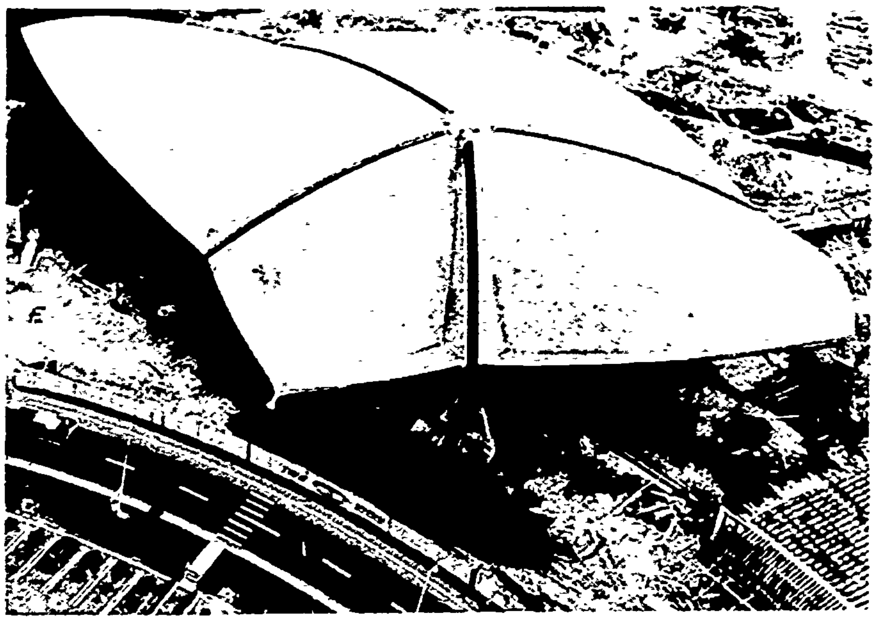

Fig. 1 - Aerial view of 55,000 sq. ft. structure. Note low points at junctures of edge beams and shells.

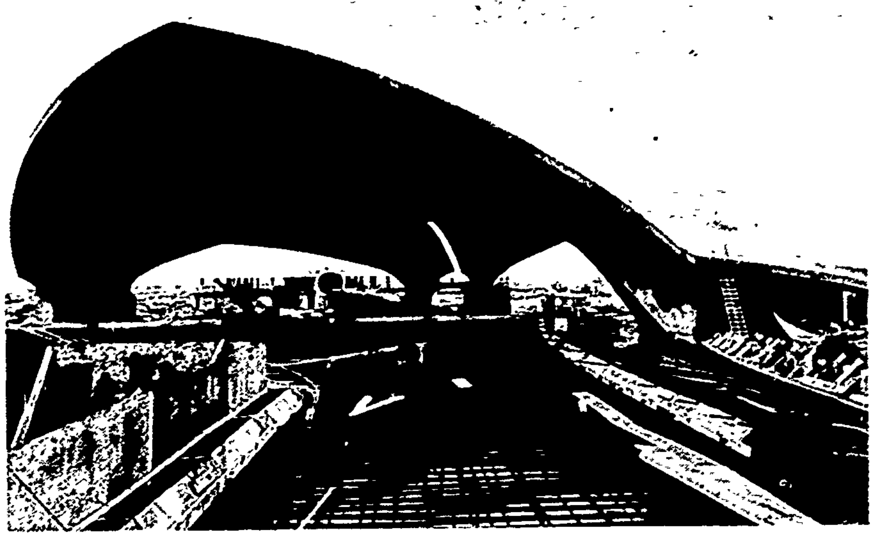

Fig. 2 - Cantilevers thrust 2 million-lb. loads 110' from supporting buttresses. Roofing material must bridge normal shrinkage or deflection cracks.

Fig. 4 - One of 4 sculptured concrete buttresses which support the 11-million-lb. total weight of shells.

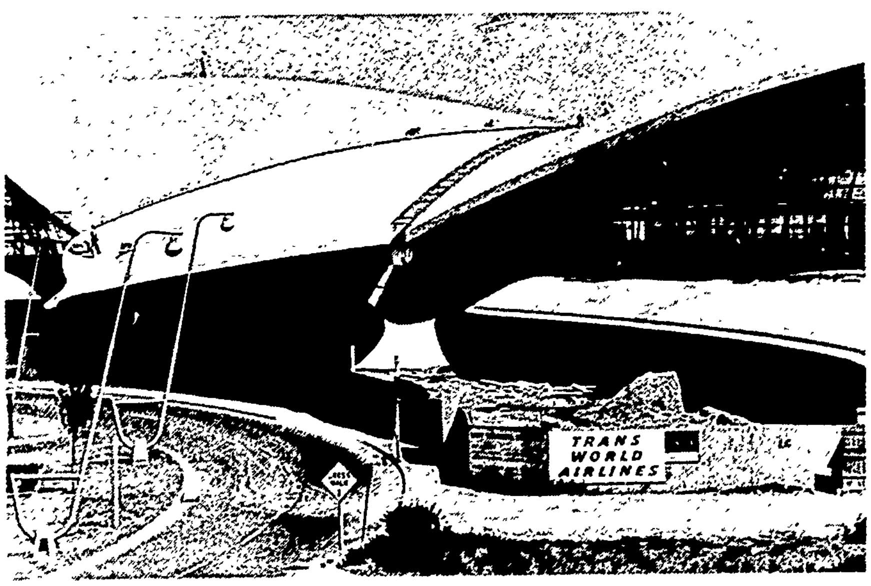

Fig. 3 - Front shell dips to within 12' of roadway.

The intention of the designers was to finish the shell surfaces, while retaining the appearance and texture of normal concrete. This created the first problem in the selection of a coating. Then, the shells, cantilevering 110' from their buttress supports (Fig. 2), are subject to deflection and creep, hence cracking. Here arose the second problem. The shells, by reason of their shape and angle of surfaces, are subject to more than a normal amount of wind uplift. Thus, the third problem.

Finally, the shell on the front elevation dips almost to the roadway (Fig. 3), bringing a large portion of the roof surface into immediate public view, thus posing the fourth problem. Even if the first problem, that of maintaining the appearance of concrete, were ignored, the architect would still be presented with a problem of general appearance, of selecting a roofing of uniform texture and color, free from laps and seams, etc. Obviously, a question arises immediately as to whether a coating or a sealant is wanted. There are very few areas of retained water, and the concrete is quite thick. It was conjectured that a sealant of a clear or water-white appearance might be the best solution.

To date, there have been no measurable cracks in the surfaces, and the under side of the shells indicates no leaking-through, after a particularly snowy winter and normal spring rains. Suppose that the surface was simply sealed and the contractor told to proceed with sprayed-on acoustic plaster beneath? What could be done if the shell then deflected during the second summer or the next freezing winter? The first sign of leaking would be a ruined plaster surface, which would be hard to replace due to the interior design of the building, and a top surface would then have to be coated. If the leak were to occur during the winter or spring, it would be necessary to wait until warm weather dried the concrete before it could be coated, thus subjecting the building to a season of leaks about which nothing could be done. Also, it might be found that the sealant we had applied earlier interfered with the bond of the subsequent coating.

Prudence, therefore, dictates a coating to start with, but there does not appear to be a transparent or water-white coating flexible enough to follow deflection, capable of sufficient elongation to bridge potential cracks and joints, and having the capacity of bonding to a surface which may have already been sealed. This problem has yet to be solved.

Turning to the general problems of coating shell structures, where appearance is the most important factor in determining the choice of a material or a technique, let us first consider concrete as we use it in shell construction. To begin with, it is safe to assume that the concrete will be of a lightweight type, that is, the coarse aggregate being expanded shale or slag instead of stone. The use of these aggregates produces a concrete of approximately one-third less weight but the same compressive strength as stone concrete. The placement, finishing and curing of this concrete in shells, however, differs sharply from ordinary slab concrete treatment. Dealing as we do in the TWA Terminal at Idlewild with curved, inclined surfaces of formwork, we are immediately faced with a problem of placement. We cannot simply pour the concrete in the forms and trowel it. Unless one is willing to pour a shell such as this in a series of narrow, concentric bands, with all the delays of setting time and the resulting joints and planes, it is necessary to pour a fairly large section of a shell at a time, and preferable to pour the entire shell at once.

A major problem becomes immediately apparent: how are the upper sections poured while the sections below are still plastic? Obviously, a 'mold' or counterform is required, but the mold cannot be placed all in one, or we shall have no way of getting concrete into the lower areas from above. Also, we would not be able to finish the lower concrete, since a pour like this takes from 24 to 36 hours to complete, and the concrete at the bottom is thoroughly hardened by the time the top has been finally placed and the form removed. Further, in order to properly vibrate the mass to ensure uniformity and density, we must have access to the entire area being poured, while it is being poured.

What evolved, finally, was a series of removable and reusable counterform panels which allowed the pouring of lifts of 4' or 5' at a time. Only enough panels to cover about a third of the pour are required, since, by the time the pour has risen to the one-third point, the bottom concrete has hardened sufficiently to permit removing the panels and reusing them above, while still remaining workable enough at the surface to be tooled.

We chose, in this circumstance, to utilize a ligno-sulfonate admixture which fulfilled three functions: first, it acted as a wetting agent, permitting reduction of water; second, it acted as a plasticizer, which enabled uniform and easy flow of the concrete within the counterform; and third, it acted as a retarder, which delayed initial setting so that finishing could follow normally.

The finishing of the concrete was largely a matter of compromise between esthetics and what we hoped would be a good bonding finish for a future roofing material. We selected a lightly floated finish as the ideal compromise. In this we were guided somewhat by the unfortunate experience of our own contractor: an acrylic material applied a year earlier on a hangar roof at the same airport had lifted within six weeks of application, and never could be made to stay tight. That surface had been steel-trowelled to a ringing finish.

Curing was done by water-soaked burlap, with each shell being soaked for seven contionous days and nights after pouring, then being kept sprinkler-wet during sunlight hours for an additional two weeks. We were unwilling to use a chemical cure for fear of discoloration and of possible future interference with bonding of a roofing material. One further step became part of the curing process, although it arose from structural necessity. The supporting falsework beneath the forms was not removed until all of the concrete in all four shells developed a minimum compressive strength of 4000 psi, tested by laboratory breaking of cylinders. The immediate effect of this was to reduce the possibility of creep and deflection in the shells upon decentering of the forms.

Before turning to other facets of the problem, it would be well to add some comments on concrete mixing and composition. Both of these things have a bearing on the uniformity and density of concrete, and hence affect whatever roofing material is placed on the surfaces. A controlled mixing operation of almost process-plant precision is an absolute requirement. Our own operation developed after many meetings between architect, engineer, contractor, admixture manufacturer and concrete producer. We developed a precise mixing time; a uniform, supervised method of introducing batch water and admixtures into the truck body; and set a time limit on unloading any given truck. Slump tests and air-content tests were taken from batch to batch, as well as a running record of mix-water temperature and batch temperature. The result of this care was almost perfectly uniform concrete, with no cracking caused by varying densities.

In summary, then, here are some general problems imposed by shell construction:

1) The roof is not just a roof; it is also, in the case of most shell structures, a wall. This means that the public sees a great deal more of it than they usually

see of a roof on a conventional structure. There is a trend in our architecture to emphasize the natural appearance, texture and finish of materials as design elements. In the case of shells, it is concrete, and we want it to look like concrete. Whatever finish or coating is applied to the surface should complement the texture and appearance of the concrete, not compete with it. Our needs would best be satisfied in this case by a transparent material.

2) Most shells do not have a conventional parapet or curb, hence the roofing applicator cannot count on having a convenient flashing turn-up as a boundary for his roof.

   Frequently the coating will have to end on an upward incline, so there is more than a normal chance of water working its way beneath the edge of the roof and posing an adhesive problem.

3) Shells are more subject to movement than conventionally framed structures, and the coating material must have greater elongation than standard roofing materials.

4) The under side is frequently exposed and made a decorative element in the space below, hence the roof should also be effectively vapor-sealed to avoid condensation on plaster surfaces.

5) The presence of construction joints presents a dual problem: suitable caulking or sealing materials are needed; and the roofing material must be capable either of bridging the joint or of being effectively turned down into the joint, before the caulking is applied. This, also, can pose an adhesive problem.

6) Concrete being the material that it is, there is always the possibility of spalling. The coating material, then, must be adaptable to quick,smooth patching with no color differentiation.

No consideration has been given herein to wearing qualities, for several reasons. First, aside from normal weathering and atmospheric effects, shells are not generally subject to foot traffic or superimposed live loads, other than snow. Normally, they are not pierced for ventilator fans or other mechanical devices which require maintenance traffic. While specific local atmospheric conditions, such as factory- or refinery-produced smokes and gases, may have harmful effects on coating materials, these are general, and are probably not complicated by any factors found uniquely in shell construction.

Surface sealing materials have not been discussed because they are not generally applicable to shell construction. A sealer can be effective only so long as the surface remains completely intact. All concrete is subject to shrinking, and a shrinkage crack which may have no structural significance whatsoever will break a sealed surface and permit the entry of water.

Properties and Uses of Available Weatherproofing and Sealant Materials

By Francis Scofield,* Director, Scientific Section,
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The requirements for coatings for thin shell concrete roof construction are not essentially different from the requirements for painting any other concrete under the same exposure. Good practice for painting a concrete wall generally gives excellent performance on these structures. A satisfactory coating must resist the alkali in the concrete, must adhere well, and must in itself be resistant to the weather and other factors that it encounters.

Coatings for concrete are designed for protection or decoration or both. Although concrete will last a long time, its performance is greatly improved by covering it with a film that may be renewed fairly readily, to take the wear and prevent the absorption of moisture. For many purposes, some other color or gloss than that obtainable with natural concrete is required, and a coating is the easiest way to do this.

In some respects, roofs represent one of the easiest surfaces to paint. The surfaces are smooth, with few sharp edges, little trim, and not much to interfere with cleaning and application by the most modern techniques. Unless there is a flat or re-entrant area, we do not have the problem of standing water. Since roofs are rarely inspected at close range, our standards for appearance and appearance retention are not as high as they are on areas that are more closely examined. The very rigidity of concrete permits the use of coatings of less flexibility than is demanded for most other surfaces.

On the other hand, the exposure on roofs is much more severe than it is on most other surfaces. It is generally agreed that the life of a coating exposed at 45° facing South is only about three-fifths that of a coating exposed vertically facing South. Roofs of the kind discussed here rarely have any shade or other protection from the sun and rain. Further, the very fact that roofs are not closely inspected at frequent intervals may allow a coating to deteriorate farther than it should before being recoated, with resulting problems of removal of the old coating. Roofs are rarely designed with the convenience of the applicator in mind, and are often very inaccessible.

A number of coatings are available for the weatherproofing and decoration of roofs. Where appearance is not to be considered, asphalt coatings are usually the lowest in cost and

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most satisfactory in terms of resistance to sun and rain, simply because they can be applied in very thick layers. Where the original appearance of the concrete is desired, colorless coatings are available, and there is a wide variety of pigmented materials, where a change in appearance is desired.

Asphalt Coatings

The simplest and the oldest of the asphalt coatings is simply a solution of asphalt in a petroleum derivative, or alternatively, a melted asphalt applied hot. Very thick coatings with good resistance to weather and water can be built up easily in this fashion. Asphalt to which asbestos fiber or other filler is added is also used for this purpose. Recently, emulsions with the advantages of reduced fire hazard and ease of application have been introduced. They may also be applied to surfaces that are not completely dry.

All these coatings suffer from the disadvantage of their black color, which is often objectionable, and also from their tendency to bleed into succeeding coats of oil paint, if some other color is desired. Recently, asphalt coatings containing substantial amounts of aluminum have been introduced. Usually these give a metallic appearance, but a limited range of colors is also available. Aluminum-asphalt coatings show less tendency to bleed into succeeding coats of paint.

Clear Coatings

Clear coatings are required where the original appearance of the concrete must be preserved, but absorption of moisture and dirt should be reduced. These are usually silicone or oleoresinous varnishes. By applying fairly heavy layers of a material formulated to give good penetration into the concrete, an excellent water-repellant surface may be obtained. However, since the coating is colorless, it is difficult to be sure that an adequate amount has been applied.

These coatings are not successful in preventing the penetration of moisture into cracks and larger holes. These must be filled with a suitable caulking material or sealant. Further, clear coatings do not have the inherent durability of pigmented materials, so unless good penetration into the concrete is obtained, their life is likely to be short.

Pigmented Coatings

Where colored effects are desired, particularly white, a pigmented coating is indicated. Several types of these are available: portland cement paints, latex paints, and solvent-thinned paints. Each has the alkali resistance required for application to fresh concrete, and a history of successful use in the painting of concrete surfaces.

Portland cement paint is widely used on concrete and masonry walls, but the fact that it requires moisture to cure, and that most such paints chalk very freely, makes this generally the least desirable of the three types for roof construction.

Latex paints, formulated for use on exterior masonry, have excellent durability. The fact that they can be applied to damp surfaces is often helpful, particularly in those climates and during those seasons when heavy dews are encountered. They are porous to some degree, which allows moisture trapped in the concrete to escape without blistering. Latex paints are usually flat, and collect and retain dirt a little more readily than do glossy paints. This is not very important except for areas with only a little slope, and for roofs in heavily industrialized areas.

Solvent-thinned paints, designed for application to concrete, are practically all based on elastomeric types of materials which, if properly designed to retain the elastomeric characteristics, give the flexibility needed to accommodate dimensional changes. They appear to be the answer to many problems where flexibility is needed. These paints have excellent durability and are relatively impermeable to moisture, thus sealing the surface well. Solvent-thinned paints are somewhat more difficult to apply than are the water-thinned coatings, and must be applied to dry surfaces. Instructions for surface preparation and priming must be strictly adhered to. If moisture gains access to the concrete, blistering is likely to occur.

Since most of these coatings are rubbery in nature, they have and retain a flexibility which enables them to adjust to changes in the roof without cracking. Most high quality weatherproofing treatments for thin shell concrete roofs are based on coatings of this kind, often applied as multiple-coat systems.

Most of these coatings are so new that their expected performance is not reliably known. There is a need for accelerated tests to determine performance. Some have been proposed, but they have limited usefulness. People in paint technology generally agree that reliable predictions of the performance of exterior coatings can only be based on exposure tests for the period under discussion. Without such data, realistic guarantees cannot be made for materials only out of the laboratory a short time.

Sealants

Wherever there are cracks in the roof, these should be sealed with a caulking compound or sealant designed for this use. Since these sealants must allow for some expansion and contraction, or other movement of one area with respect to another, they must be designed to retain their flexibility for prolonged periods of time. If they crack or pull away, opportunity is afforded for moisture to enter, often with disastrous results. Compounds based on asphalt, natural oils, or synthetic polymers have all been used with success. Asphalt compounds are rarely indicated unless an asphalt coating is to be used, since bleeding into the top coat will usually occur. In general, sealants based on some of the newer polymers are the most satisfactory, but may be more difficult to apply.

Surface Preparation

The preparation of new concrete surfaces for painting is usually fairly simple. Any contamination on the surface of the concrete, either resulting from fabrication or other causes, should be removed by washing with a suitable solution or by mechanical scrubbing. If the surface is extremely smooth and hard, it should be roughened mechanically or by acid etching, and if a solvent-thinned material is to be used, the surface should be allowed to dry thoroughly. When refinishing a roof, the problem depends upon the condition of the surface and the type of coating to be applied. All dirt, loose paint and similar material should of course, be removed.

If the previous coating is in good shape, vigorous brushing may be all that is required, but if it is peeling and coming loose, stronger measures such as wire-brushing or sandblasting may be necessary. There is no future in painting over a coat of paint that is not adhering well to the surface. If water-thinned paints are to be used, all chalk should be removed, or else the loose chalk should be taken off and a coat of surface-conditioner (usually a suitably treated oil) should be applied. Any areas from which the previous paint has been removed should be spot primed before application of the finish coat.

Interior Paints

The finishing of the interiors of thin shell concrete roofs does not differ significantly from the problem of finishing the interior of any concrete wall above grade. Unless there are some reasons to the contrary, a permeable coating is usually desirable to allow moisture to escape but, if the concrete is dry, an impermeable paint may be a satisfactory vapor barrier to prevent moisture getting into the concrete from inside the building.

When applying paint as a vapor barrier, the same rules apply as for any other application: the paint must be thick and continuous. A great point is made of the different permeabilities of various materials, but it is my opinion that within the limits of usual, practical paints, a coating with a high gloss indicating a continuous vehicle phase, applied thickly enough, will act as an effective vapor barrier regardless of the material. "Holidays," gaps and hard-to-coat interior surfaces determine the efficiency much more than the actual material used.

WORKSHOP REPORT

Conference-Workshop Chairman - Leslie M. Jackson
Head, Architectural Department
The Tremco Manufacturing Company

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REQUIREMENTS FOR WEATHERPROOFING THIN SHELL CONCRETE ROOFS

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Report of the Workshop on Weatherproofing of Thin Shell Concrete Roofs

Presented by Nembhard N. Culin,* Associate,
Frederick G. Frost, Jr. & Associates

EXTERIOR CONCRETE SURFACES

Concrete Mixes

Concrete mixtures for shell structures are: normal weight concrete with variable proportions of cement, sand, coarse aggregate and water; or lightweight aggregate concrete in which natural or manufactured lightweight aggregates are used to reduce the dead load. Insulating, nonstructural concretes are not considered in this report as they are not used for shell structures.

Admixtures

The use of admixtures in concrete is permissible, provided there is no detrimental effect on the bond between the weatherproofing coating and the concrete surface. The view was also expressed by some participants in the workshop that no admixture is known to improve the bond. The characteristics of commonly used coatings should be considered when admixtures are formulated.

Size of Pour

The sizes of pours will vary with the area to be covered, configuration, mix, etc. For example, the roof of the Assembly Hall at the University of Illinois was placed in 120-yd. sections, whereas on the TWA Terminal at Idlewild concreting was carried on continuously for 36 hours during one operation.

Finishes

The finish must not be too rough or too smooth. A suitable condition can usually be obtained with one or two passes of a magnesium or aluminum float.

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*Mr. Culin was assisted in the preparation of this report based on the deliberations of the workshop group by Messrs. Kenneth Cummins, Owen Delevante, Leslie M. Jackson, Norman Kruchkow, Julian Panek and Warren B. Warden.

Curing

Curing a thin shell is an important consideration and is usually accomplished by keeping the surface of standard concrete mixes wet for a period of seven days. Sprayed-on, membrane types of curing compounds are to be avoided, due to their possible adverse effect on the weatherproofing coating bond. Polyethylene film or other kinds of sheeting may be practical at times. Care should be used with water sprays, or curing films and sheet, on structures of lightweight aggregate concrete, since there is a possibility of saturation of the aggregate. It is recommended that sprayed-on, membrane-type curing compounds be studied to determine their effect on the bond when used with various weatherproofing coating materials.

Moisture Content

There are several methods of testing water content on the site, none of which are considered satisfactory. It is recommended that additional industry research be conducted on the matter of providing accurate field test methods.

Surface Irregularities

Undesirable concrete surface irregularities should be eliminated. Cracks and depressions should be filled using a material which will bond satisfactorily to the weatherproofing coating, be durable, and feather-edge to the desired thickness. Epoxy and latex-base compounds are two of the materials suggested for this purpose. High points on the concrete surface should be removed by rubbing or other approved method.

Hairline Cracks

To be certified for coating, a surface must be reasonably free of cracks. Any crack larger than a hairline is not permissible and must be properly treated before application of finish materials. A hairline crack is defined as any visible crack less than .005" in width.

EXPANSION AND CONSTRUCTION JOINTS

The workshop discussed expansion and construction joints and agreed on the relative importance of the two types. An expansion joint completely separates two adjacent segments of a shell roof and provides for the accumulative movement of each segment. Considerable movement may take place in such joints, which may affect the coating.

Expansion joint location and design is of critical importance to the success of shell construction. In particular, problems at re-entrant corners should be given careful consideration. Expansion joints should never be located in valleys or low areas where water, snow, or ice might accumulate, since normal construction practices will stop coatings at expansion joints. Should the coating be carried over expansion joints for some design reason, it must be remembered that the coating material will be subjected to additional bending and other stresses leading to possible failure.

A construction joint is considered an integral part of the shell and, therefore, should not affect the application of a weatherproofing coating.

CRACKS

Two kinds of cracks can be expected in concrete shell construction, surface cracks, and those of a structural nature. There was general agreement that the coating supplier or applicator should in no way be held responsible for cracks that develop in the substrate. When cracks do occur, either before or after weatherproof coating application, it was agreed that complete instructions should be obtained, either from the architect or the engineer, before corrective measures are undertaken. The nature of the crack must be determined before a satisfactory corrective measure can be taken. This applies more particularly to shell construction than to conventional types.

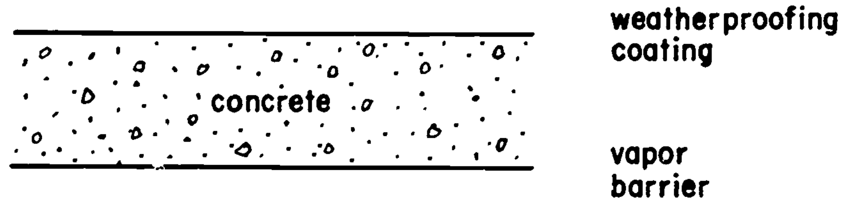
VAPOR BARRIERS AND INSULATION

The handling of the vapor barrier and insulation is an important and integral part of the roofing system, and further, both the type and positioning of these elements with respect to the concrete deck and the overlying coating can have marked influence on the serviceability of the roof. Time did not permit a full coverage of this subject, and the solutions given below represent only a start toward recognition and definition of some of the more important variables. Full coverage of all the ramifications of the handling and placement of vapor barriers and roof insulation is a lengthy and complicated subject.

As used herein, "impermeable, nonabsorbing insulation" applies to foamed polystyrene, foamed glass and similar types, wherein the internal cells are closed and sealed from each other. These types of insulation are vapor barriers in themselves, or at least highly vapor resistant. The term "impermeable" as applied either to the coating or the vapor barrier is relative, since technically these coatings, including normal built-up bituminous roofing membranes, are semipermeable to both water vapor and air. The order of magnitude, however, is low enough to be negligible for most practical considerations of moisture condensation problems.

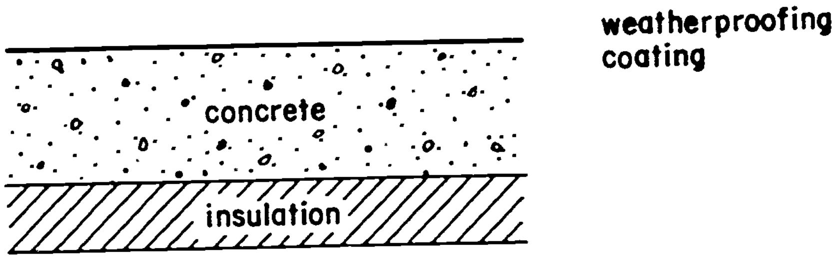
The effect of the positioning of the vapor barrier and the insulation was discussed in terms of average environmental and construction conditions. It is recognized that there are environments (humidity and temperature conditions) wherein certain combinations which are not recommended below would perform satisfactorily with little or no calculated risk, as long as the given environment was maintained. In fact, there are climate and building use conditions wherein the vapor barrier can be eliminated entirely by maintaining condensation control. (Recognition and discussion of some of these factors has been previously presented in BRI Monograph No. 1, "A Study to Improve Bituminous Built-up Roofs"). Such calculated risks, however, are only feasible if both the internal and external humidity and temperature conditions can be predicted. For unknown environments, or for building use conditions subject to change, the following generalizations represent accepted conservative practice:

1) Vapor barrier only on interior surface of the concrete deck with no insulation.



Normal winter environment over much of the U. S. would probably result in condensation of moisture against the cold interior vapor barrier surface. If the concrete is moist or not completely cured, high vapor pressures, approaching 5 psi, can occur during summer exposure which may result in blistering, ballooning, etc. Vapor barriers are not required or recommended in hot, dry climate regions for this type of construction.

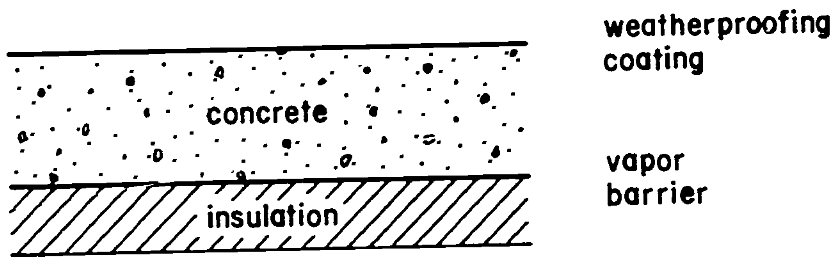
2) Insulation only on interior surface of concrete with no vapor barrier.



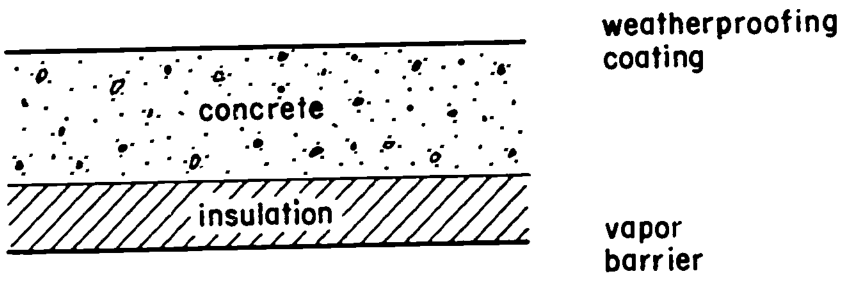
This construction is generally not recommended since there is danger of frost or ice condensation on the lower side of the concrete, and saturation of the insulation during the winter months. However, this method of placement can be used where environmental requirements are favorable and predictable. The use of impermeable, nonabsorbing insulation presents no problem in this positioning, provided all of the insulation joints are well sealed.

3) Both vapor barrier and insulation on the interior surfaces of the concrete. Two positions of the barrier are possible here:

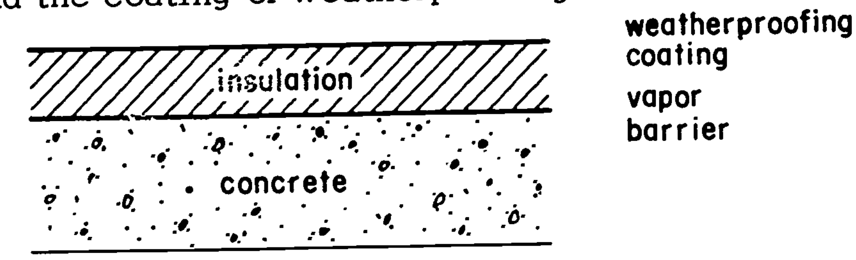
   a) Placing the vapor barrier between the concrete deck and the underlying insulation is pointless since this has all the disadvantages of both (1) and (2) above.



   b) Placing the vapor barrier on the interior face of the insulation is normal construction practice for those conditions wherein it is not feasible to have the insulation on the external side of the concrete deck. If properly constructed, this placement should give satisfactory service.

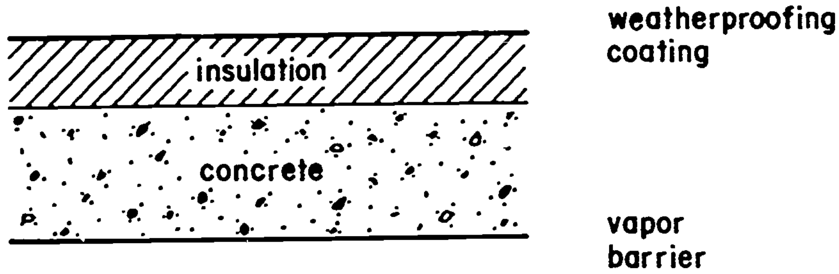


4) Positioning the insulation on top of the concrete deck with the vapor barrier in between, and the coating or weatherproofing surface on top.



This is the normal and customary construction practice. When the impermeable, nonabsorbing insulations are used, the vapor barrier may be omitted, if the joints are properly sealed. The vapor barrier may also be omitted in certain environmental conditions subject to the calculated risk conditions previously noted.

5) Placing the vapor barrier below the deck.



This has no particular merit. It puts the concrete within the sandwich, thereby increasing the danger of blistering, particularly if the concrete is not thoroughly dried.

The paper, "Effect of Physical Factors on the Weatherproofing of Thin Shell Concrete Roof Construction" by Professor C. E. Lund (Page 11) further covers some of the mechanisms involved, and the difficulties to be anticipated from moisture condensation in roofing systems subject to various environments. These considerations were not repeated generally in the workshop session. One exception was the stress laid on the danger of retained moisture in inadequately dried ed concrete decks placed during late fall or winter construction. Decks placed in the late spring or summer normally have adequate time and opportunity to dry out properly. It was pointed out that concrete itself is a fairly good vapor barrier, if dry, but will transmit liquid water rapidly through capillarity. The importance of good workmanship combined with proper materials and design was also stressed.

WEATHERPROOFING COATING AND SEALANT MATERIALS

Standards and Specifications

The workshop reviewed present standards and specifications which appear to be useful in the preparation of performance specifications for weatherproofing coating and sealant materials used on thin shell concrete roofs. With respect to joint sealant materials, the workshop participants felt that the American Standards Association Specification A116.1-1960, Polysulfide-Base Sealing Compounds for the Building Trade, might be used in specifications for thin shell concrete roofs, with the addition of performance requirements applicable to the specific case under consideration. The members of the workshop pointed out that the ASA specification is presently limited to only four types of materials, but as its format is that of a performance specification, it becomes a useful starting point for modification.

With respect to weatherproofing coating materials, the members of the workshop felt that there are, at present, no fully acceptable specifications or test methods that properly evaluate the performance characteristics of coatings. It was agreed that the establishment of testing procedures and specifications is a basic need for the industry, and it was, therefore, the recommendation of the group that the American Society for Testing and Materials' procedure be used for the development of performance test methods for coatings. Most urgently needed tests are for the laboratory evaluation of performance characteristics and for accelerated aging. Studies should also be conducted of the correlation of the results of accelerated aging tests with actual performance of weatherproofing coatings. The workshop participants pointed out that present ASTM tests for bitumens used for waterproofing coatings evaluate material properties, and that tests for the evaluation of performance characteristics are required for thin shell construction.

Temperature Ranges for Weatherproofing Coatings

After considerable discussion, it was agreed that the design surface temperature range for materials under consideration should be -40°F to + 180°F. Extreme temperatures above or below these might be encountered, but should be considered special cases. The important parameters affecting thin coatings, as far as temperatures are concerned, are the length of time the temperature occurs, the rate of change, and the extreme lows. Fast rates of temperature change are more critical than slow rates. Weatherproofing coatings designed to perform satisfactorily at rates of change as great as 60° per hour or 1° per minute may tentatively be regarded as safe. However, the workshop felt that this subject requires more research.

Another significant factor is that the temperature at which the rate of change occurs is just as important as the rate of change itself. It is also necessary to realize that the coating must adjust itself to the effect of temperature change in the concrete shell, as well as to the ambient air temperature and solar radiation influences. In addition to the temperature range, consideration should be given specifically to the low temperature as it affects the safe rate of movement and flexibility of coatings, and the high temperature range as it affects accelerated aging.

It was recommended that manufacturers state on their product containers and in their literature the minimum and maximum temperatures at which their materials can be applied, and also the minimum and maximum temperatures at which their materials will perform satisfactorily under service conditions.

Effect of Ultraviolet Rays

Ultraviolet rays are of special concern, and must be considered as a factor in the deterioration of coatings.

Adhesion

Weatherproofing coatings and joint sealants can be formulated to have satisfactory adhesion to concrete and other materials used in concrete shell construction. However, it is essential that the conditions that will exist for specific applications be properly evaluated and the correct performance characteristics specified.

Application Temperatures for Weatherproofing Coatings

The minimum and maximum temperatures for application depend on the type of material. Materials used for weatherproofing coverings on concrete shell roofs may be grouped as follows with respect to application temperatures: the emulsion materials which must not be subjected to freezing during application; the bituminous materials made to be applied hot; and the solvent-thinned or cut-back types of materials which vary in their temperature application limits.

When deck temperatures are below freezing, the moisture content of the slab will be very difficult to determine, and this would affect the application of most coatings. At the opposite end of the temperature range, problems involving viscosity, and also the personal discomfort of application workmen, are limiting factors.

Thickness of Weatherproofing Coatings

The thickness of the coating is not important to the appearance of the roofing, except in cases where translucent or textured coatings are involved. Thickness of coating was discussed as it relates to cost. In general, the thicker the application the greater the cost. For a given life, the thickness of the weatherproofing coating applied will vary with the durability of the particular formulation. To obtain 100% coverage, eliminate "holidays," cover surface defects, and obtain uniform thickness, multiple coats are recommended. The rate of erosion of the coating is also a factor related to thickness. In some materials the erosion rate is constant; in others, erosion proceeds at an accelerating rate.

There is a very definite relation between the roughness of the finished concrete substrate and the recommended thickness of film to be applied. The amount of weatherproofing coating required will depend on the amount needed to achieve the required thickness over the high points. The minimum thickness resulting from a single application of a weatherproofing coating depends on the properties of each material.

Texture of Weatherproofing Coatings

The choice between a textured or a smooth surface is the prerogative of the designer. A smooth roof surface is washed clean more easily than a textured roof, and is more resistant to traffic damage. Textured surfaces are advantageous in covering imperfections in the substrate, and also reduce the spectral effect of finished surface.

Mechanical Damage to Weatherproofing Coatings

The workshop agreed that both coatings and built-up roof coverings used for weatherproofing concrete shells should be protected where heavy traffic is anticipated. Erosion of weatherproofing coatings by water, ice and snow is also a matter of concern. Caution must be used in snow and ice removal so that tools do not damage the weatherproofing coating.

Chemical Damage to Weatherproofing Coatings

Most of the materials discussed in the workshop are chemically resistant to fumes from air conditioning or other types of equipment, except with respect to colorfastness. When discoloration or fading does occur, the finish and life of coatings may also be affected. Most weatherproofing coating materials can stand prolonged immersion in water. However, shell roof configurations that produce low areas without positive drainage should be avoided.

Fire Resistance of Weatherproofing Coatings

The workshop participants agreed that coatings under 10 mils thick over concrete present no fire resistance problem. Above 10 mils, materials used should meet the Class C rating of the Underwriters' Laboratories, Inc., dealing with propagation of fire. Materials should be formulated to be self-extinguishing and have negligible fuel contribution.

It was suggested that the National Fire Protection Association be requested to develop data and classification information for rating weatherproofing coating materials.

Color Stability of Weatherproofing Coatings

In general, dark pigments are more stable than light ones, with the exception of white. The best colors, from a nonfading and nonchalking standpoint, are those produced by the iron oxide pigments (red) and the chromium oxide pigments (green). The use of extenders, rather than pigments alone, is usually detrimental to the stability of the color within extremely short periods of service. Tinted whites are not generally stable. It was felt that the neutral colors such as white, gray and black should be given preference, until more permanent colors are developed.

There is no known, commercially available, transparent, penetrating type of weatherproofing coating which has the property of bridging the cracks that occur in concrete shell roofs. Therefore, the workshop participants do not recommend the use of transparent coatings at this time.

Need for Priming Concrete Shell Roof Surfaces

Priming of concrete surfaces is recommended to reduce porosity and increase the bond of the waterproofing material.

The Problem of Air-Borne Particulate Matter

It was recommended that research be undertaken on the problem of air-borne foreign matter settling on uncured weatherproofing coating materials. When coatings are applied in an environment with considerable air-borne dust, quick-drying materials may be used to reduce this problem.

Expected Service Life of Weatherproofing Coatings

The workshop participants felt that a service life expectancy of five years would be sufficient for waterproofing and sealant materials, since in most instances the surface would require renewal after this period of time to maintain appearance. The cost of providing for greater service life than five years might also exceed the cost of periodic recoating. In lieu of setting a life expectancy for a given material, it was proposed that the coating system selected be the one providing the lowest cost per square foot per year of operation, including all amortization and maintenance costs.

The workshop recommended that applicators and suppliers consider entering into installation and service agreements for the application, inspection and maintenance of coatings on a per square foot per year basis over a specified period of time, say five to 10 years, with renewal options.

Responsibility for Performance

The supplier of the formulated weatherproofing coating material should be responsible for the performance of the material. Guarantees by suppliers are often of questionable significance. The materials manufacturers among the workshop participants were in agreement that they could guarantee the basic materials to meet specified performance requirements. Therefore, specification of the coating system should require that the applicator be approved and/or franchised by the manufacturers of the constituents of the coating system.

It is also strongly recommended that mock-up sections of shell structures be constructed at the job-site to determine performance characteristics and provide opportunity for prior approval of color and texture.

SUMMARY

The demonstrated interest in the subject of weatherproofing thin shell concrete roofs indicates two things: 1) that the use of this type of construction is expanding rapidly, and 2) that there are technical problems still unsolved. Members of the workshop do not claim to have answered all the questions; in fact, they were not convinced that the problem is fully understood. It was the consensus that another round-table conference in the near future would be highly productive.

In general, the group was in agreement that interested organizations and industries should push their research programs and accelerate the development of both field and laboratory testing procedures.

There is no doubt that the advent of the thin shell roof, with the attendant design and appearance problems, has sparked the development of a new roofing technology which may in time give conventional methods serious competition. Already there are signs that presently accepted methods are being modified to meet this competition.

This workshop demonstrates that representatives of diverse groups in the building field can get together, discuss their problems, arrive at conclusions and make recommendations that will in the long run, be of benefit to all. It is only through an organization such as the Building Research Institute, operating in a free society, that this type of progress is possible.

Open Forum Discussion

Moderator—Leslie M. Jackson, Head, Architectural Department
The Tremco Manufacturing Company

Panel Members—Messrs. Culin, Delevante and Scofield

Joseph Poindexter, Roofing Siding Insulation Magazine: Are the effects of insulation on or under the vaulted surfaces common to thin shell construction different from a comparable application in a flat roof, i.e., is there an appreciable difference in the ventilating characteristics of the flat ceiling area and the curved ceiling area? Does the exterior curve of the thin shell roof cause substantial deflection of radiant heat, resulting in a lowering of the insulation requirement?

Mr. Lund:* Insulation effects are comparable for both thin shell and flat roof construction. The question about ventilating is not clear. However, if you are concerned about false or suspended ceilings, below the deck, the curved deck is more easily vented due to stack effect. Reflection of radiant heat from thin shell decks is for all practical purposes approximately the same as from flat decks. Color is important but insulation requirements are not changed, as surface dirt and degradation will increase the absorption of radiant heat even for coatings that are highly reflective to begin with.

J. A. Rorick, I. B. M.: Do you have any information concerning the insulating value of ponded roofs, or any data on temperatures of the water and the under side of the roof deck where roofs are ponded?

Mr. Lund:* The water temperature of ponded roofs is dependent upon the wet bulb temperature of the outside air and the wind velocity as they affect the rate of evaporation, as well as upon the depth of water. A good approximation is that the water will be at the outside dry bulb temperature which is higher than the wet bulb temperature as a result of solar radiant heat! Depending upon its color, the roof will be 40^{o} to 70^{o} cooler than an unponded roof.

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*EDITOR'S NOTE: Many of the questions considered in the discussion period were submitted prior to the workshop and answers given by the Messrs. Culin and Delevante represent the thinking of the workshop participants. The answers to questions directed to Prof. C. E. Lund were written by him and presented by Mr. Delevante, since Prof. Lund could not be present for the discussion.

Ben H. Evans, Texas A & M College: Could the concrete used in a thin shell be of such composition as to provide sufficient insulation for normal purposes, through the use of expanded aggregate, high air content, low strength concretes?

Mr. Lund: No. In southern areas the heat transfer into a building will be high, and in northern areas the heat loss from the building will be high. Insulation is recommended.

Mr. Culin: Would you comment on the advantages of double shell construction with a ventilated air space for hot climate locations?

Mr. Lund: There are definite advantages, provided positive ventilation is obtained through outlets at the highest roof elevation. Solar radiation, which raises the roof temperature 40^{o} to 70^{o} above the outside air temperature, will be intercepted by the top shell and the absorbed heat in the top shell will be removed by the ventilated air. The temperature of the top surface of the bottom shell will approach the outside air temperature if there is sufficient ventilating air.

John McEvoy, E. I. DuPont de Nemours & Co.: One item which should be considered by the workshop is labor. Unfortunately, the roofing trade is regarded as the least skilled craft on a construction job. The roofing contractor is criticized for sloppiness and short-cut economies which sacrifice quality. Actually, the responsibility for this unhappy situation must be shared by owner, architect and roofing manufacturer alike since the guiding principle in conventional roofing has been: "How little can I get away with spending for my roof?" What can BRI do to upgrade the roofing industry to a level commensurate with rigid requirements of thin shell waterproofing?

Mr. Delevante: I feel that BRI has, as one of its objectives, the definition of satisfactory criteria for evaluating quality of materials, the performance of those materials, and methods of application, as we've seen in this workshop. It also permits and encourages discussion of respective purposes and problems between the various groups involved.

Carl J. Ebert, Construction Specifications Institute: In view of the present uncertainty concerning the effectiveness of many proprietary, "secret formula" roof coatings, is it not more logical to attempt to improve the quality of the concrete deck to the extent of making it weatherproof? This is being done successfully in the Caribbean area.

Mr. Delevante: There has already been much research done to achieve this quality in concrete. Our principal problem seems to occur in the field application of this knowledge. The desired quality may be, and too often is, affected by the design mix, batching, placement, finishes and curing. I doubt that these problems are going to be solved as quickly as we can improve our weatherproofing coatings.

C. T. Grimm, Zonolite: What type of insulating materials are most suited to application on the exterior of thin shell concrete structures?

Mr. Delevante: To date, board type materials have been considered more satisfactory than insulating concrete or soft, flexible materials. They are more easily placed on the shells, and generally provide a better surface for application of the coating material. However, they are not completely satisfactory because of the problems of instability, anchorage, and the appearance at the joint.

Mr. Grimm: Are exterior insulations generally more desirable than those applied to the interior?

Mr. Delevante: Generally, yes, but we found in the workshop that each specific project requires a careful evaluation.

S. B. Twiss, Cycleweld Chemical Products: Has any attempt been made through the Portland Cement Assn. or other groups to supply panels or blocks of the constant composition cured concrete for coating test purposes? This would appear to be basic to development of specifications for satisfactory coatings.

Mr. Delevante: It is correct that this procedure is basic to proper specifications for, and the development of, satisfactory coatings. To my knowledge, there is no organization that makes a general practice of supplying such blocks or panels for testing purposes. It is recommended that these be provided by an independent testing laboratory doing work on the coating, to relate the various concrete mixtures in use to the performance of the coating being tested. I think each job has its own specific requirements, and a generalization such as testing a standard concrete block might prove dangerous. The workshop report, of course, contains recommendations regarding the finish of the concrete surface to receive coatings.

G. M. LaFave, Coast Pro-Seal & Mfg. Co.: Along positive lines, what tests, in your opinion, are necessary to be consistent with performance guarantees? Functional and permanence properties are obvious goals, but, in the technological development race we are running, there is necessarily a great dependence upon accelerated testing. Consequently, all of us are caught in something of a dilemma.

Mr. Delevante: Suggested tests for a specific film thickness are: tensile strength in psi; elongation at 0°F, 20°F and 75°F; permanent set at break; adhesion strength in shear; and adhesion strength in tension. Following ASTM recommended test methods, (with the understanding that these are a guide only and have never been considered acceptable for this material)—tests can be made on laboratory-cured films to simulate outdoor exposure. In a long-range program they cannot be considered a completely satisfactory substitute for tests made on materials weathered under normal exposure.

R. Boyd, Hollingshead Corp.: In view of Prof. Lund's statement that roof design and efficiency are the responsibility of the architect, general contractor, deck and roofing contractors, how would you place a single responsibility or guarantee?

Mr. Delevante: I would recommend placing a single responsibility for satisfactory guarantee on the manufacturer of the coating material. This recommendation is made on the basis that the material will be applied by properly supervised and approved or franchised applicators, if the manufacturer does not do the application work.

E. S. Wormser, Gibson-Homans Co.: Since the subcontractor is dealing with coatings developed possibly two years earlier, and the building owner wants a 20-year guarantee on a surface which the subcontractor often does not see until application begins, what is the best compromise solution for performance responsibility?

Mr. Delevante: The owner should have a satisfactory guarantee but it has not and will not be suggested that this be a 20-year guarantee. My recommendation follows what I said previously, and what was in the workshop report, and this is not to be considered a compromise solution. We feel that such a guarantee will have enough in it to protect the owners.

Unsigned Question: What do you feel the applied cost of the roof coating should be—20¢, 30¢, 50¢, or $1.00 a sq. ft?

Mr. Delevante: 30¢ per sq. ft. applied may be considered a reasonable working figure.

John F. Leary, Jr., B. B. Chemical Co.: What problems have been encountered in using polyurethane coatings for concrete surfaces? What sealers have been found most effective for use with polyurethane coatings? Are polyurethane sealant compounds giving good performance in concrete structures?

Mr. Delavante: While possessing fairly good weathering characteristics, the use of polyurethanes in coatings for concrete surfaces or sealant compounds is not recommended. The flexibility of the material in question is satisfactory, but the elongation is not sufficient to recommend that it be used on thin shell concrete roof construction. Consequently, it is unnecessary to define the proper sealant for such a coating.

R. C. Surtees, Canadian Industries, Ltd.: You mention that resinous coatings, polymers, often give best results. Can the workshop rate the available polymers, or list those that give outstanding results? I am thinking of generic names, of course, rather than specific trade names for coatings.

Mr. Scofield: The polymer is only part of the formula. The rating of a coating depends on all of the components, the substrate, the exposure conditions, etc. The best polymer for one formulation and use may be entirely unsuitable for another set of conditions.

APPENDIX

WORKSHOP AGENDA

1.0) Exterior Concrete Surfaces

1.1) What are the different types of concrete mixes used at present time in thin shell construction?

1.2) Is it recommended that admixtures be used in concrete mixes, and if so, is there any objection to this because of possible effects on bond of weather-proofing and sealant materials?

1.3) What are the sizes of concrete pours usually made in this type of construction?

1.4) What are the different methods of finishing concrete and the effect of each on the subsequent application of materials?

1.5) What are the recommended ways of curing this concrete and their effects, if any, on the bonding of the materials?

1.6) What are the recommended lengths of time necessary for proper curing of the concrete?

1.7) What amount of moisture would be left in a slab, assuming no rain or water is applied to the surface: At the end of one week? two weeks? three weeks? four weeks?

1.8) What testing method, if any, should be used to determine the amount of moisture in concrete prior to application of materials?

1.9) Will there be low spots or flat areas requiring repair, and what methods of repair are recommended?

1.10) Define a hairline crack.

1.11) Define a crack that extends through the concrete slab.

1.12) Is the resultant color of cured concrete important?

2.0) Expansion and Construction Joints

2.1) In this type of construction what are the recommended locations of expansion and construction joints?

2.2) Will the locations of joints in convex or concave surfaces have any effect on the selection of weatherproofing and sealant materials?

2.3) How much and what kind of movement can be expected between joints in the sizes of pours previously discussed?

2.4) What effect will movement at joints have on adhesion and elongation of weatherproofing material applied over joints?

2.5) If cracks form due to movement, what is the recommended procedure for repairs before application and after application of weatherproofing materials? Who is responsible for corrective work?

3.0) Vapor Barriers and Insulation

3.1) What is effect on selection and application of weatherproofing materials of the use of:

a) Vapor barrier only on interior surface of concrete with no insulation?

b) Insulation only on interior surface of concrete with no vapor barrier?

c) Both vapor barrier and insulation on interior surface of concrete?

3.2) What is effect on selection and application of weatherproofing materials of the use of:

a) Vapor barrier on interior surface and insulation on exterior surface of concrete?

b) Vapor barrier and insulation on exterior surface of concrete?

c) Insulation only on the exterior surface of concrete with no vapor barrier?

3.3) If no vapor barrier is used, what is the effect of moisture transmission from the interior through the concrete and insulation, if used?

3.4) Does any of the foregoing indicate a definite need for a weatherproofing material which is permeable?

4.0) Weatherproofing and Sealant Materials

4.1) Is there at the present time any kind of performance specification for materials?

4.2) What temperature range should materials be expected to meet?

4.3) Are satisfactory adhesion to concrete and satisfactory flexibility possible in one material?

4.4) What are maximum and minimum temperatures at which materials should be applied and the effect of application at other temperatures on the performance of materials?

4.5) Is thickness of coating a factor from the standpoint of design?

4.6) Is thickness of coating a factor from the standpoint of application?

4.7) Should materials be textured or smooth?

4.8) Can a weatherproofed surface be used for traffic beyond normal inspections of the coating?

4.9) Should materials be chemically resistant to fumes from industry and air conditioning equipment?

4.10) Can the materials withstand prolonged immersion in water at low points or drains?

4.11) What effect will snow and ice have on the materials?

4.12) To what extent does material have to be fire resistant?

4.13) What can be done to achieve stability in colors other than black?

4.14) If material is a transparent liquid type, will it bridge cracks?

4.15) Should concrete surface be primed to reduce the porosity of concrete and increase the bond of weatherproofing material?

4.16) Should the weatherproofing material be applied over expansion or construction joints?

4.17) If so, how should these joints be treated with fillers and sealant materials?

4.18) If not, when should these joints be treated as recommended?

4.19) What should be the desired life of the material?

4.20) What cost per square foot applied should be the goal of the manufacturers and applicators?

4.21) What are the possible methods of application and the advantages and disadvantages of each?

4.22) How do labor union requirements affect the possible methods of application?

4.23) What guarantee should the owner expect to receive from the material manufacturer and/or the applicator?

4.24) How much maintenance should an owner reasonably expect on these materials?

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