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NiDI Technical Series Nº 10 010

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Architecture — A Demanding Market for Stainless Steel

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ABSTRACT

This paper describes the reasons why stainless steels perform well in architectural applications. The evolution of their uses in architecture will be shown, illustrating the changes in the demands on the material.

Normally a combination of properties, such as high strength and corrosion resistance — as well as appearance, prestige and cost — all affect the architect's material selection.

While strength and corrosion resistance are important to the function and durability of architectural applications, appearance is crucial. Major problems for the mill include physical tolerances and surface finish. Material must be dead-flat and mill finishes must have superior uniformity of color from coil to coil.

INTRODUCTION

The first major architectural applications for stainless steel were mainly functional rather than decorative, the best known of which is the Chrysler Building in New York City where the stainless was used for roofing as well as for the finials and decorative trim.

The reason for its selection was the relatively minor expenditure for a roof in relation to the overall cost of the complete building. Therefore, the architects wanted to use a material that would be durable even if it was costly. Because of the configuration of the roof and the height of the building, cost of any repairs would be prohibitive.

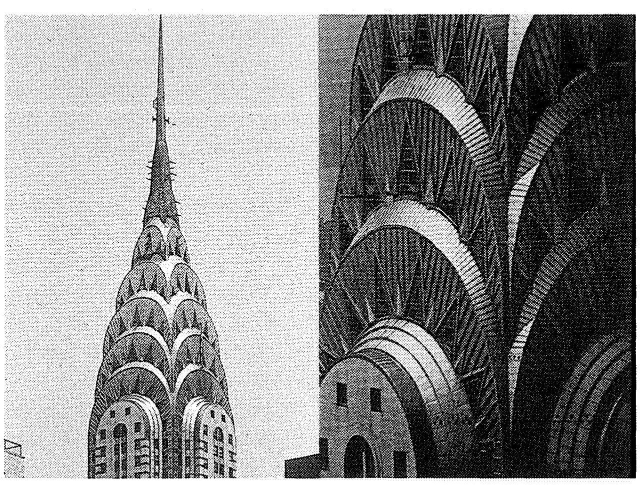

Figure 1
Historic Chrysler Building, New York, a functional use of stainless steel

Of course the appearance did play an important role, in that the material chosen would not cause oxides to run off on to the stonework below and would provide a continuous, glittering appearance.

In the gradual development of the use of stainless steel in architecture it became used more and more in functional as well as aesthetic applications, specifically for entrance work to major buildings, for bank vaults and ornamental trim.

In architecture, as is the case in any other industry, stainless steels are used in applications where function and economics combine to make them a logical choice.

This may be because of any one property or any combination of specific properties — properties such as corrosion resistance, surface density, heat resistance, impact and wear resistance, and high strength.

In *most* architectural applications, however, appearance, prestige, quality image and similar considerations are equally serious reasons for the selection of stainless steel for various building components. These really create the most serious problems for the quality control and production in the mill.

THE PROBLEMS OF ARCHITECTURAL APPLICATIONS

The alloys that are used almost exclusively in architecture do not create any major problems. It is the physical tolerances of these alloys that have to be produced to very close and tight standards. Normally, the regular 18% chrome, 8% nickel AISI Type 304 is used; while occasionally Type 316 would be applied in components that are exposed to more corrosive environments.

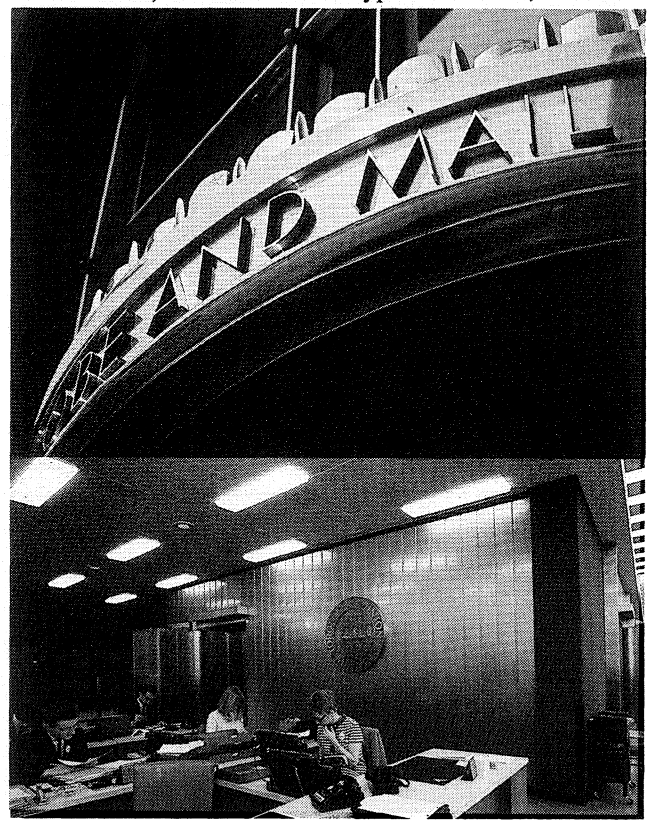

Figure 2
Toronto newspaper building canopy, top, and Toronto-Dominion Bank, Montreal

We all know that Type 304 and Type 316 are routinely produced by all stainless steel producers to the regular AISI tolerances.

This was the case for many years after the first architectural use of stainless steel, until the early fifties when the use of stainless steel started to expand beyond the earlier entrance or trim applications.

When lightweight curtain walls were developed to replace heavy stone and masonry walls, metals were used with ever-increasing frequency on building exteriors. This did not present any immediate problems since the early curtain wall designs used stainless steel only in relatively narrow brake-formed or roll-formed sections, such as you see on many older buildings.

As these formed sections or mullions increased in size, and as other uses presented themselves for stainless steel — such as the panels between the mullions — complaints from the architects started to come in. The two major complaints were that of *oil canning*, which is a term that describes lack of optical flatness on installed metal components.

The other one was color match. These particular complaints became more and more frequent as the trend in design asked for larger areas of metal and used it in flat areas as opposed to formed sections.

One way of correcting that problem, of course, would be to produce finishes that were not quite as reflective or as critical in flatness appearance as the standard N° 4 or N° 8 finishes. The second part of the potential solution to these complaints would be to work to much tighter tolerances than the mills were used to.

Today it is absolutely essential that stainless steel sheet for the architectural market, particularly for curtain wall or ornamental panelling applications, must be dead-flat, and that it must have superior color match from coil to coil.

The second requirement was that as stainless steel became more popular in the architectural field, more fabricators wanted to start producing components from stainless. However, the temper and tensile properties as well as the rapid work hardening characteristics of stainless steel made it very difficult for these fabricators to participate in this market. Therefore, for applications of that type, it became important for the material to be suitable for the fabrication equipment that was already there.

Figure 3
Airport baggage conveyor, where impact resilience, wear resistance and high strength count

Thus, the answer to all these requirements was the development of custom-tailored finishes as well as custom-tailored tolerances.

As a result, two totally different products emerged. First, the area where formability became important. In this case a dead-soft temper of Type 304 sheet enabled the roofer to work the material with standard tin snips, foot shears and handbrakes. And it allowed the roll former to produce proper profiles with the same sets of rolls that he used for carbon steel or even aluminum.

The development of good, bright annealing techniques make the second solution a rather simple and obvious one. The importance on the part of the mill and the marketing people is to identify the actual projects that require this specific property in the stainless and which one of these require good color uniformity as well. For example, while uniformity of color is important for one building, it is not absolutely necessary for another one.

The other two problems, that of good color match plus acceptable optical flatness on large, flat areas were not quite as easy to solve. As a matter of fact, in our efforts to solve the flatness problem we ran into more conditions where color match was more difficult to obtain. The reason for that is simply that producing better apparent flatness in some cases meant using less reflective mill-produced rolled finishes as opposed to mechanically polished finishes.

The directionally polished finishes such as N° 4 and N° 3, as well as the very bright mirrorlike finishes such as N° 8 and buffed bright annealed, tend to emphasize minor deviations from the actual flat condition of the building component.

Therefore, one of the obvious solutions to this problem would be to produce less reflective finishes while maintaining some of the sparkle or brightness that is particular to stainless steel and which the architects would be looking for. That could be, at least partially, the answer to the flatness problem.

A major construction project, where such a finish was developed and where very close cooperation between the mill and the architect made this development possible, was the Canadian Imperial Bank of Commerce project that was built in Toronto on the corner of Bay and King Streets. The architect's specifications called for stainless steel with a finish that expressed a structural, masculine character. Because of this structural character requirement, they would not allow any deviation from optical flatness on the large 4 *4* 56 foot spandrel panels that formed an important part of this curtain wall.

This ruled out the existing mechanically polished finishes, and a considerable number of trial surface treatments were conducted, samples of which were presented to the architects for approval. These treatments included glass bead blasting, sand blasting and shot blasting.

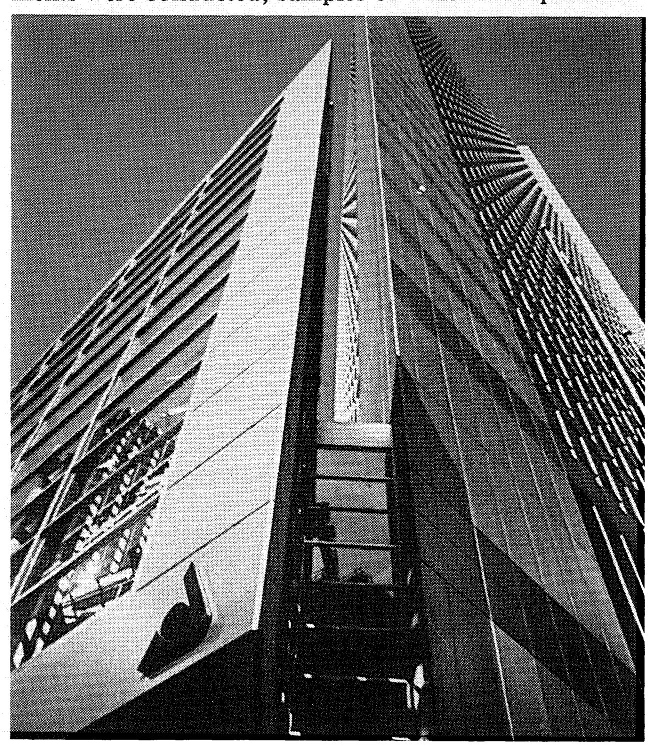

Figure 4
Stainless steel imbues prestige and quality image — Nova Building, Calgary

They finally selected a shot blast finish that did maintain some sparkle in the stainless. However, the work hardening characteristics of stainless steel would not allow the shot blasting of these large sheets. Therefore, rather than shot blasting the sheets, the work rolls on the Sendzimir mill were shot blasted thus creating a reverse shot blast pattern which was acceptable to the architect.

Now, even with such a forgiving finish established, it was realized that the regular AISI tolerances would not be sufficient to ensure the flatness the architect would insist upon. Also, because of the large size of the sheets, 4 feet *4* 52 feet, physical tolerances other than flatness — tolerances such as camber, and squareness — had to be controlled very closely, and standards had to be devised to enable quality control to inspect the material to standards that were tight enough to make the material suitable for the application.

The normal AISI tolerances for flatness, while they state a deviation from the flat plane, do not indicate how long or how short this deviation can be. In other words, a short, steep ripple theoretically would be acceptable under those tolerances, yet would not produce the desired results.

To avoid that possibility, a method of measuring flatness which defines the angle of the slope of the deviation from true flat rather than just the actual height of that deviation, has been developed. The method is illustrated in *Figure 5*.

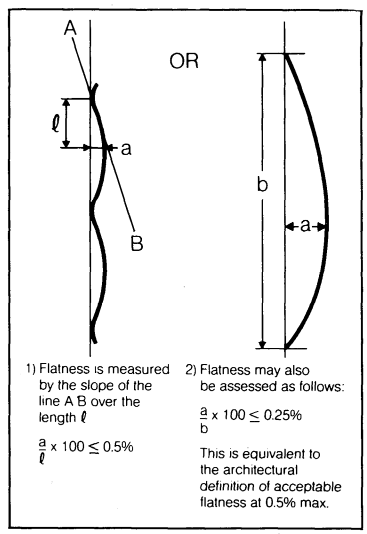

Figure 5
Retractable roof panels — optional

This method is not really new in the construction industry, for example, the NAAMM specifications dating as far back as 1960 list the following criteria:

- ☐ For surfaces having a finish of high reflectivity, 1.0%;
- ☐ For surfaces having a finish of medium reflectivity, 1.25%;
- ☐ For surfaces having a finish of low reflectivity, 1.5%.

This is now generally considered too generous and currently a maximum slope of 0.5% even for medium and low reflectivity panels is considered more realistic.

CARE IN THE MILL

In order to explain what all this really means to an individual specialty steel mill, I would like to take this specific example, which is typical of the industry requirements generally.

The finish that was developed was named after the first project which I described earlier and is called *Imperial*, and has been used on many other projects since. Many lessons were learned on this first project, one of the more important ones being the directionality of this mill-rolled finish.

A great many of the normal steps of the manufacturing process and quality control are different, or more closely controlled, when an architectural order for this finish (as well as other finishes) is produced.

All the manufacturing operations listed in *Table 1* marked with an asterisk, and printed in capital letters, are somehow different from the normal operations.

TABLE 1

1	MELTING
2	Concast
3	Slab grinding
4	HOT PLANETARY ROLLING
5	Anneal and pickle
6	Edge trim
7	Cold rolling .225'' to .180''
8	CONDITIONING
9	Anneal and pickle
10	COLD ROLLING .180'' to .140''; .135''; .125''
11	FINAL ANNEAL AND PICKLE
12	FINAL COLD ROLLING
13	Degreasing or bright anneal
14	SURFACE PROTECTION
15	TENSION LEVELLING
16	APPLY SURFACE PROTECTION
17	CUT TO LENGTH
18	INSPECTION

1 Melting — 8.7% nickel. Higher nickel content to achieve good surface finish in the final cold rolling operation.

4 Hot planetary rolling — Thicker hot bands, .225**, and extra pressure, 585 tons, on the 2 high. The first is to get maximum amount of cold reduction. The second helps to reduce planetary chatter.

8 Conditioning — All material must go through a surface grinding operation to ensure uniformity and absence of inclusions. Only new polishing belts are used. Speed, 20 feet per minute. Two good surfaces are required.

10 Cold Rolling — This cold reduction is done in at least three passes to maximize the working of the steel.

11 Final anneal and pickle — To assure uniformity of final color, all coils for the same project must be annealed and pickled in one single batch.

12 Final cold rolling — Shot blast rolls for Imperial. Minimum reduction in single pass, .015**. Only top quality rolls are used. Very close RMS and hardness tolerances are set for the work rolls. Hardness, 58.62 Rockwell C and 210 to 240 RMS. Rolling direction is engraved on front and back of each coil as well as at the change of each work roll.

14 Surface protection — SPV 202 is applied before tension levelling to protect the surface and avoid leveller streaks.

15 Tension level CTL — Material is tension levelled with SPV protecting its prime surface. Rolling direction and location of sheets on the building is printed continuously on the back, along with heat number, coil number.

16 Re-apply SPV — Between tension level and CTL.

17 & 18 Cut to length & inspection — Two 4 feet square pieces are cut from each coil, one of which is mounted outside to compare the color with the master sample piece. The other one is marked with all appropriate information and held for future reference.

Inspection for physical tolerances such as length, width, squareness and camber are checked on one sheet of each box that is shipped.

Inspection for flatness tolerances is done on each coil until the tension levelling setup is achieved and afterward, on one sheet of each box.

The method shown in *Figure 6* is as follows:

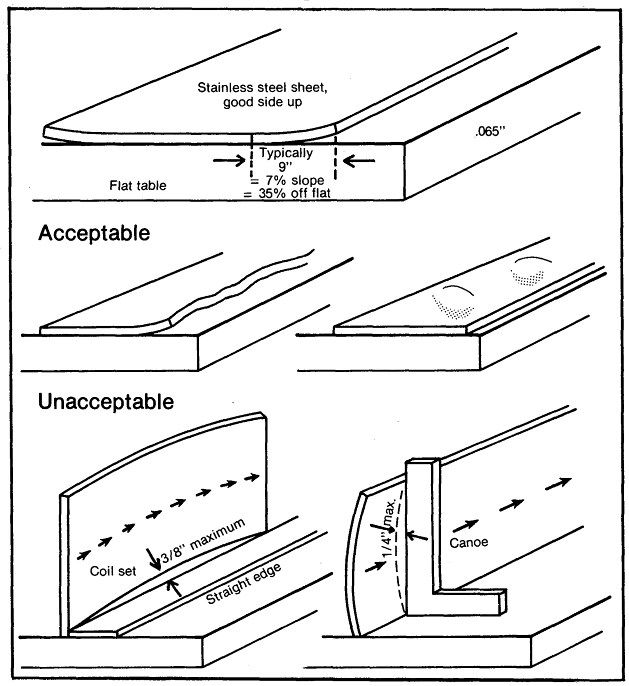

Figure 6
Stainless steel sheet

PROCEDURE	**LIMIT OF ACCEPTANCE**
Lay sheet on flat table good side up. Evaluate deviation of panel from the flat surface at each corner and centre of each side.	.065'' maximum deviation on any corner or side. This would approximate a .35% off-flat condition as depicted in A. Long edges and centre buckle in sheets are unacceptable conditions. See B.
Lay sheet on flat table good side down. Evaluate deviation of panel from the flat surface at each corner and centre of each side.	.090'' maximum deviation on any corner or side. This would approximate a .50% off-flat condition. Long edges and centre buckle on sheets are unacceptable conditions.
Stand sheet on edge (i.e. free standing). Using a straight edge, check coil set and canoe shape.	1/4'' maximum canoe 3/8'' maximum coil set

Coming back now to the color match problem. Even with the care in the A & P and other manufacturing operations, a minor color difference can exist from coil to coil.

To minimize the effect of this on the facade of a building, it is advisable for the producer to sit down with the fabricator and assign coils to building areas.

Where possible, sheets from the same coil should be used on the same facade with sheets from the next coil to be started at a natural break, for instance around a corner, or above a continuous row of windows. These allocations must then be marked on drawings, and the stainless steel sheets are identified by means of line marking with an appropriate location code in addition to the rolling direction arrows and heat numbers.

STAINLESS STEEL'S QUALITY IMAGE

All this extra care is required because of the quality image of the material. Minor faults in appearance or functions that he will live with when other materials and metals are involved are not acceptable to the architect when he specifies stainless steel.

Stainless is used mainly on prestige buildings, and even minor flaws in material and workmanship — that would be forgiven on lesser structures — are not acceptable when corporate headquarters or bank head offices are involved.

There are many examples of Canadian building enclosures that illustrate different physical parameters and tolerances of stainless steel while the purely functional requirements such as corrosion resistance and strength are pretty well identical.

Science North in Sudbury and Atlas Alloys' warehouse in Etobicoke illustrate the requirements of superior formability and good color match. CN Tower is another example.

The CIL building and University Place in Toronto illustrate excellent optical flatness of flat panels, combined with superior color match.

Comparing these newer buildings with older ones using the then popular *stick* designs, which produced the popularly called glass boxes, one can readily see how much the demands on the material have changed over the years.

In most end-use markets, the requirements on stainless steel change for specific technical reasons.

For example, in the pulp and paper industry, many conditions became more corrosive because of the environmental demands for closed systems. As a result, earlier installations of carbon steel switched to stainless, and stainless installations went to higher alloys. Or, sometimes newer, more efficient processes with severe corrosive conditions and higher operating temperatures and pressures replaced older, less efficient operations. The coal gasification methods are an example of that situation.

The architectural market, I believe, is the only end-use market (other than some aspects of the automotive market), where the requirements on stainless change because of design or fashion trends or change in styles started by some well-known influential architects and promptly followed by their architectural disciples or admirers.

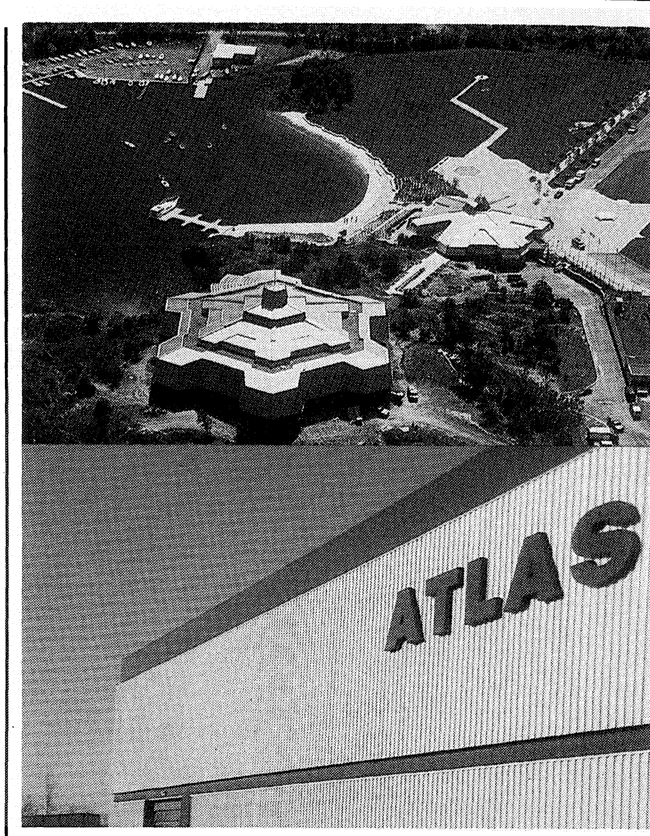

Figure 7
Superior formability and good color match of stainless steel at Science North building, Sudbury, Ontario, top, and Atlas Alloys' warehouse, Etobicoke, Ontario

STAINLESS STEEL FOR STRENGTH AND DURABILITY

Now, having said all that, there are applications where stainless steel is used purely for strength and durability. The very high values of its yield and tensile strength which can be achieved by cold working the material, combined with its excellent atmospheric corrosion resistance, made Type 304 stainless steel the only logical choice for the Ultradome air-supported or air-inflated roof design. See *Figure 8*.

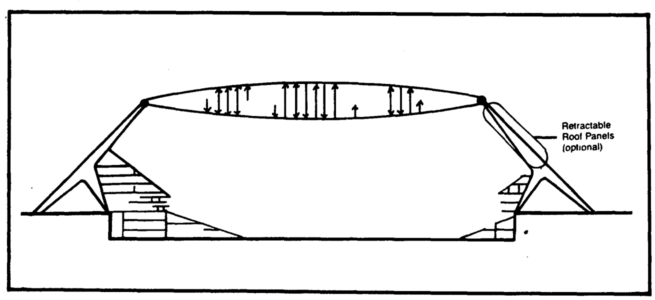

Figure 8

By using a structure that is not subject to bending, buckling or similar forces but that takes full advantage of straight tension forces, a very economical and efficient long span (up to 1000'-0 and more) roof design was developed.

The two, all-seam-welded stainless steel, .062" thick membranes, are put under tension by maintaining .2 PSI (28.8 lbs per sq. ft.) air pressure between them.

This is sufficient to carry all live and dead loads (i.e., snow load) on the roof.

The membranes are welded to a compression ring of structural steel or concrete and are designed to be assembled as a flat circle which can expand to take a spherical shape, both concave and convex, without buckling.

To see how a metal membrane can be made to assume a significant double curvature from a flat sheet, consider a flat circular sheet of stainless steel cut up into pie-shaped segments, *Figure 9*. Now imagine these pieces applied to a hypothetical spherical (dome-shaped) surface with the base diameter the same as the diameter of the original sheet of steel, *Figure 10*.

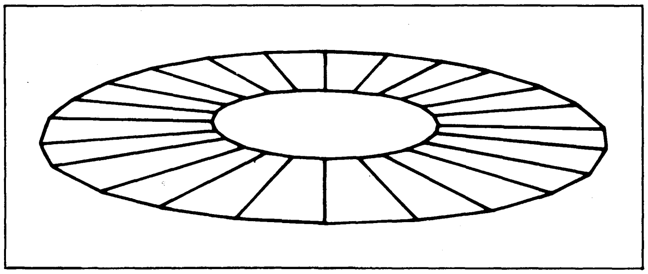

Figure 9

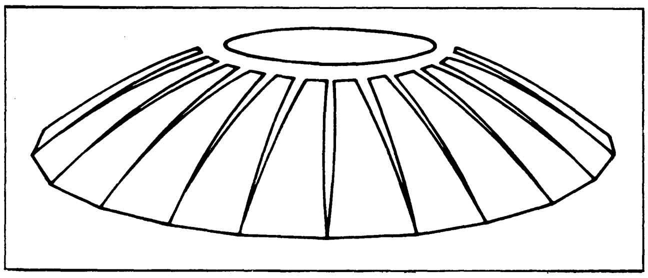

Figure 10

There are spaces between the segments because the spherical surface has a greater area than the flat circle. If there are a sufficient number of segments, they need only go into very slight double curvature to be part of a spherical surface. In reality, the spaces are not large at all. For a 500 foot diameter roof with a 16.5 foot rise, dimension A in *Figure 11* is 8.5 inches and dimension B is 2.25 inches.

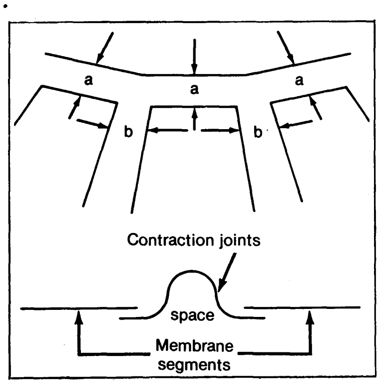

Figure 11

By enlarging the spaces and bridging them with preformed very high temper (135.000 PSI yield) sheet stainless steel, it is possible to make a membrane that will lie flat on the ground for construction and then stretch out to a spherical curvature when it is pushed up by air pressure or when it hangs in suspension.

When the performed contraction joint is put into tension, it flattens out. If the tension is relieved, it springs back to its original shape. Because of the inherent stretchiness that the contraction joints impart to the membrane, the membrane can go from flat to spherical and back, and yet remain in tension at all times, *Figure 12*.

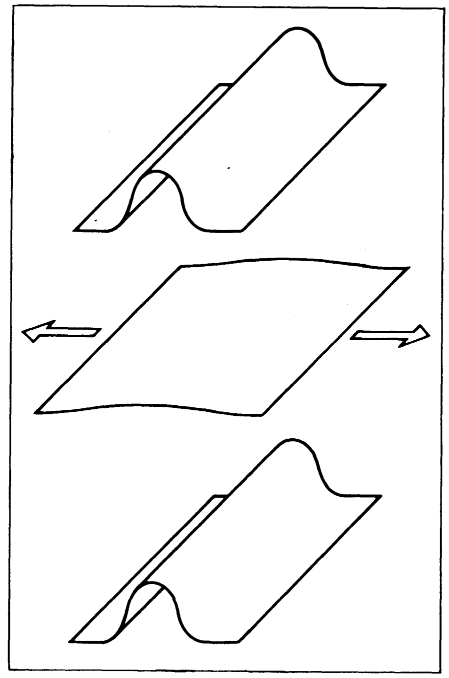

Figure 12

By prestretching the radial contraction joints in graduation from the rim inward, the increased opening required to achieve spherical curvature can be obtained. The circumferential joints around the centre segment are all extended the same amount.

This is what it looks like on the Dalhousie Sportplex in Halifax, Nova Scotia, and this is what a 60 000-seat stadium could look like with this roof design, *Figures 13 and 14*.

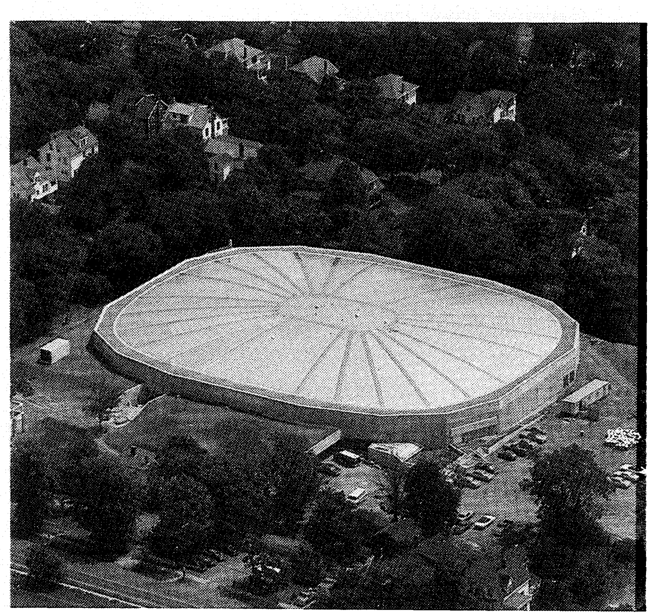

Figure 13
World's first all-stainless steel, long span air-supported roof — Dalhousie University Sportsplex, Halifax, Nova Scotia

Figure 14
Ultradome — with a stainless steel, inflated long-span roof system — a design for a 60 000-seat stadium

In the final analysis, then, while there are a few exceptions, the most critical consideration for the use of stainless steel in the architectural market is performance based on esthetics, prestige and durability.

The Nickel Development Institute is an international nonprofit organization serving the needs of people interested in the application of nickel and nickel-containing materials.

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