

# ROOFING THE DUBAI INTERNATIONAL AIR TERMINAL CONCOURSE II

Dr. W.T. (Bill) Mansell, Hon DEng, FAIB, FAIM, AAAS



*This article was published originally in the Proceedings of the 2009 RCI Building Envelope Technology Symposium, San Diego, CA.*

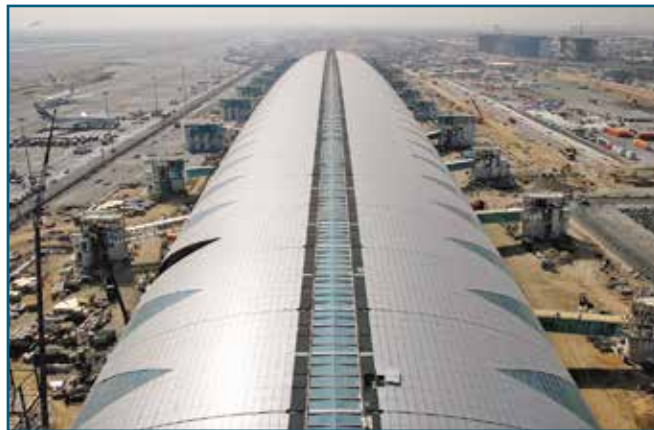
## INTRODUCTION

The Dubai International Air Terminal is an exceptional building, approximately 1 kilometer (0.63 mile) long and has a composite roofing system of approximately 80,000m<sup>2</sup> (860,000 sq. ft.). The geometry of the external cladding is double curvature and includes the requirement for both structural and architectural, elliptical-shaped components. The overall roof/ceiling construction includes 11 individual layers of various materials to achieve structural, thermal, acoustic, and aesthetic performance results. The installation of the roof and ceiling system on this project involved approximately 700 management, technical, supervisory, and working staff for approximately 12 months. The building became operational on schedule in October 2008. With ancillary facilities, the total cost was approximately \$4 billion U.S.

The building provides 26 aircraft loading bridges (with several capable of handling the new A380 Air Bus) and also includes two international hotels, massive lounges, duty-free shopping, immigration, customs, and baggage services.

Complex construction and geometry create a number of challenges, both for the designer and contractor.

The intention of this article is to show that, while we endeavored to use standard products and materials, varying combinations and construction techniques can be used to create unique, long-lasting, and aesthetically



*Figures 1 and 2 – Dubai International Air Terminal, Concourse II.*



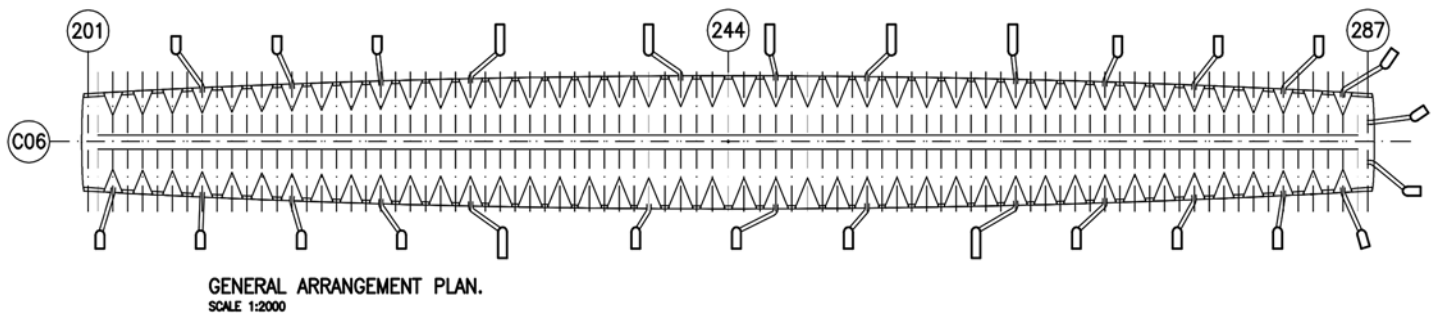


Figure 3 – Dubai International Air Terminal building plan.

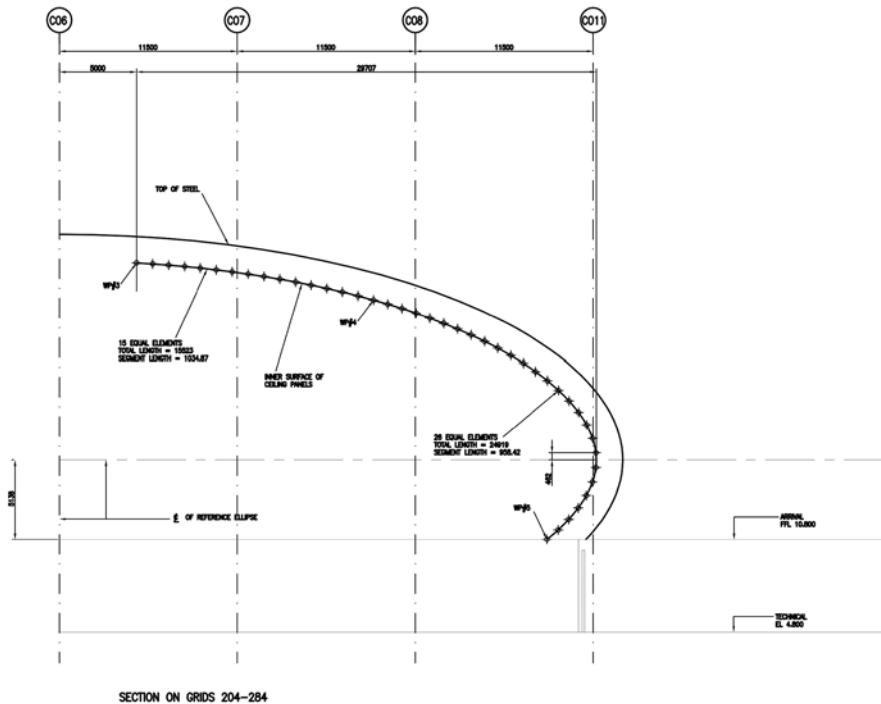


Figure 4 – Dubai International Air Terminal elliptical area cross section.

MATERIAL	PRODUCT
Galvanized steel	Structural deck
Color-coated steel	Metal roof sheeting
EPDM membrane	Vapor barrier/sarking
Rockwool insulation	General insulation
Glass-reinforced plasterboard	Mass layer – acoustics
Extruded aluminum	External tile support
Composite aluminum panels	External cladding tiles
Stainless steel for flashings and trims	Concealed gutters and flashings
Secondary structural steelwork for support items	Skylight supports
Structural stainless steel components	BMU rails

Table 1

pleasing results. The base geometry of this project is outlined in Figures 3 and 4.

The geometry of the building created some challenges in design and construction, which will be discussed herein.

### ASPECTS TO BE REVIEWED

As both a designer and contractor, I shall cover the following items:

- Pricing
- Staffing
- On-site and off-site production
- Building geometry
- Roof construction buildup
- Design development
- Testing
- Building maintenance unit
- Workforce

### Pricing

Pricing, while not a “technical” component, is obviously extremely important to the client (and the contractor, for his survival). Excluding minor fixings and attachment items, there were probably ten major material cost centers involved in the construction. These are shown in Table 1.

Particularly with the metal components, price and supply volatility (together with currency fluctuations) create a major risk factor for the contractor on a fixed-price contract.

The main part of the construction of the concourse took place during a very volatile construction period in Dubai. This also created a shortage of many standard materials, with subsequent price increases.

Fortunately, major suppliers generally can be sympathetic; and if appropriate financial arrangements are made (e.g., establishment of letters of credit for product), then prices can be held firm for the duration of the project.

As with any pricing and contract review, a risk assessment is extremely important; and confirming material costs removes a

substantial risk component from the cost equation.

Labor costs, particularly on such a unique building, are a lot more difficult to calculate. However, this risk, in some geographic areas, is reduced as a result of the low cost of labor.

In addition, management and supervisory staff were a substantial cost. The expense of this staffing included motor vehicles, accommodations, air travel, school fees, and medical insurance.

### Staffing

Our total management structure occupied an on-site office, and the standard working week was 10 hours per day and six days per week (not unusual for major international contracts).

All of the senior staff, including management, engineering, material procurement, supervision, and factory management were very experienced in the roofing industry. A number of the staff also had previous airport experience on similar projects, such as:

- Kuala Lumpur International Air Terminal
- Hong Kong International Air Terminal
- Bangkok International Air Terminal

There were several layers of management/supervision with a formal reporting procedure and with all drafting and external consultants reporting directly to the design-and-engineering director.

The management structure included:

- Safety officer
- Quality assurance officer
- Materials handling supervisor
- Factory manager (on-site production was our selected alternative)

### Project Quality Assurance and Safety Plan

The project documentation required a detailed quality assurance and safety plan be developed, generally in accordance with ISO 9000. The quality assurance plan required an appropriate interface with the client's quality assurance documentation and was required to cover many aspects, including:

- Document preparation
- Sample submission
- Production review
- Installation

Supplementary to the QA plan, every

activity of installation also required a "works method statement." These were progressively prepared prior to the commencement of the various construction activities.

### On-Site/Off-Site Production

Contractors have varying views about the advantage of on-site and off-site production of roofing components. There is generally no substantial cost difference between off-site and on-site production. Convenience and practical considerations are the main determinant. The author believes that on-site production offers several advantages, particularly when many of the components may be of excessive lengths (25 m or 82 ft.), as was the case for the Dubai Concourse II. Advantages were

- Roads in the airport area are crowded, and there is a restriction on the times that trucks may use these roads.
- Length of components requires special permits and escorts. This is avoided.
- Transport damage is eliminated.

On-site production removes all of these difficulties. For the Dubai International Air Terminal, a factory of approximately 3,000m<sup>2</sup> (30,000 sq. ft.) was established to produce these:

- Galvanized steel structural decking
- Secondary structural framing within the roof construction
- Fabricated welded stainless steel gutter system
- Roof profile
- Stainless steel down pipes and sumps

The on-site factory included these items:

- 14-stage structural deck roll former
- 14-stage roof sheet roll former
- Two purpose-built curving machines
- Brake press
- Guillotine
- General sheet metal equipment
- Welding equipment

As mentioned earlier, several of the components were required to be profiled to an elliptical shape, and this included the structural decking (3 in. deep) and the roof sheet profile (2.5-in. rib height).

The curving was achieved by a crimp-curving procedure with a constant angle change. The elliptical profile was developed by a program that allowed vari-

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Figure 5 – Part of the Dubai Terminal on-site temporary factory with stocks of finished product in the foreground.

able spacing of the crimps. This procedure was able to produce a very accurate elliptical profile. The curving machine was purpose-made for the Dubai project. Transportation of the elliptical profiles and long (82-ft.) sections will be covered later in this article.

The factory produced components as required from stocks of raw material being housed within the complex (painted and galvanized coil steel and coil stainless steel).

The major advantages were that product was always available on-site, and with variable length material, sizing could be transferred directly from site to factory in a short time span. During the course of production for the Dubai Terminal, the factory handled in excess of 1,000 tons of coiled material (see Figure 5).

### Plant and Equipment

Apart from the roll forming and curving equipment mentioned previously, special on-site transport vehicles needed to be developed to be able to handle lengthy elliptical-shaped product. Semitrailers were specially modified to have adjustable carrying racks. Also, multilifting point spreader bars were transported with the trailer to allow for ease of lifting.

All roofing products were craned into position using 200-ton extended mobile reach cranes. As with all projects at an active airport, considerable care had to be exercised in relation to the height and location of the jib and also the location of on-site transport equip-



Figure 6 – Crane lifting secondary components to the roof level. Special on-roof support platforms were required.

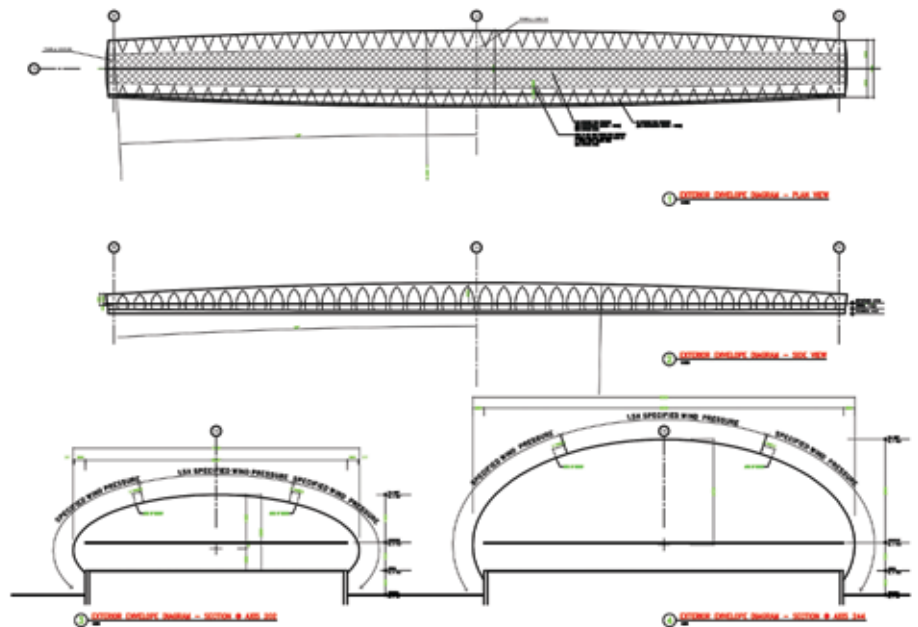


Figure 7 – General details.



Figure 8 – Shows coordination of the cladding and glazing geometry.

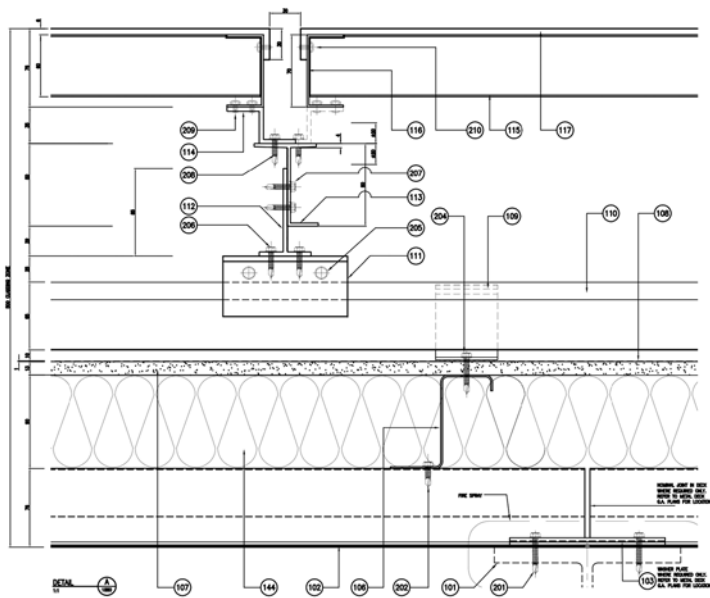


Figure 9 – Section through roof/cladding construction.

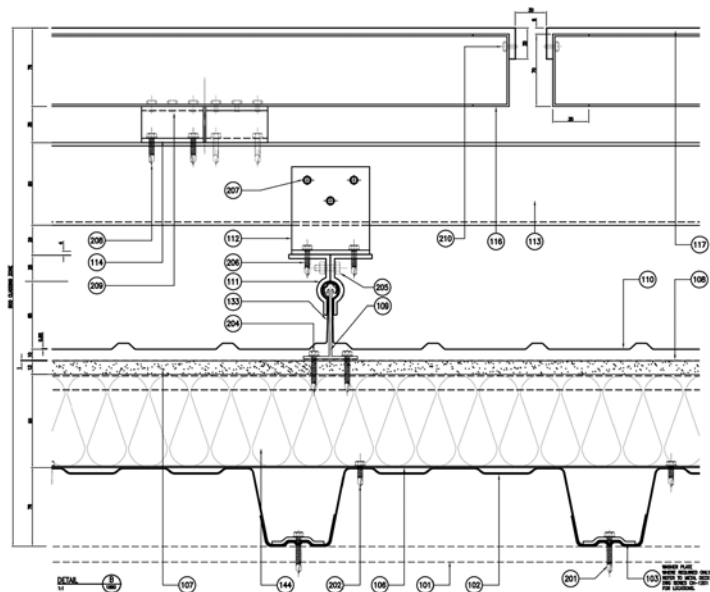


Figure 10 – Section through roof/cladding construction.

ment on the active side of the airport.

Crane lifts were not heavy. Reaching the correct locations was the important requirement. Maximum weight of each lift would be no more than 2 tons (see Figure 6).

### Building Geometry

Please refer to Figure 7, which provides both a plan view and cross section of the building. As will be seen, the geometry is multicurvature with tapers occurring in both plan and elevation, with the cross section being elliptical and with every construction rib a different dimension.

Both in the structural decking and metal waterproofing, and for the outer cladding tiles, tapering suited this difficult geometry. (Theoretically,

every tile is a different shape – approximately 30,000 tiles.) Special programs were developed to determine the production size for these components (see Figure 8).

The overall geometry was made even more difficult as the teardrop-shaped skylight transoms also were required to align with the tapering longitudinal joints in the external cladding system (each “teardrop” is a different size).

The program used for the development of the outer cladding panel size was undertaken by a programmer with previous experience in program development for the tailoring of sailing spinnakers.

### Design Development

A short comment will be made on each of these components in relation to design and/or function. See Figures 9 through 11.

#### 1. Structural Decking

The structural decking was roll-formed in the on-site factory. It was specially developed for the project, as the height limit on the deck was three inches, yet maximum spans were in excess of 19 ft. 6 in. Some of the sheet metal technology to strengthen the profile (added deformation) was developed at Sydney University. As previously mentioned, all of the decks are curved to an elliptical profile by the crimped-curve method. The structural deck was fabricated from 1.2-mm- (18-gauge-) thick (galvanized) material.

In relation to the general design of the structural decking, it has been our experience that this is normally governed by deflection rather than load capacity.

As with most “lightweight” structures, there appear to be differing opinions between architects and engineers as to what acceptable deflections are. A deflection acceptable from an engineering standpoint may be totally unacceptable to the architect on aesthetic grounds. We would normally suggest that the dead load deflection is in the vicinity of

SPAN  
500

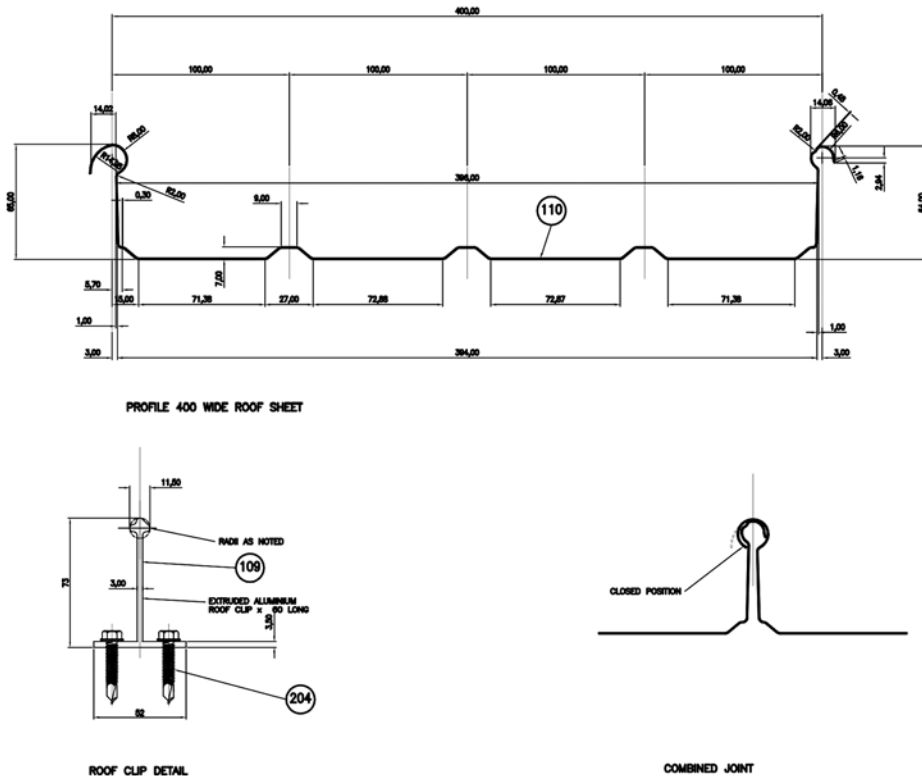


Figure 12 – Drawing of structural deck.

steel [16 gauge], these sections are straight, not curved.) They are secured directly to the structural decking. The purpose of these secondary Z sections is to assist in load distribution to the structural deck and to provide support for the plasterboard mass layer to be subsequently applied.

### 3. Insulation

Insulation is 100-mm- (4-in-) thick Rockwool (45 kilograms/m<sup>3</sup> or 2.8 lbs. per cubic ft.) and was packed tightly between the Z purlin sections.

### 4. Mass Layer

A glass-reinforced, glass-matte-faced plasterboard (underlayment) was then installed. Its primary function is to act as a deck to support the vapor barrier and as a mass layer to assist in achieving the required sound transmission loss (STL). STL is an important feature of cladding systems in an airport terminal and needs to be performance-balanced with the public address systems.

### 5. Vapor Barrier

The vapor barrier was then applied (spot-stuck) to the plasterboard with its laps fully sealed. The 1.2-mm EPDM sheeting acts as both a vapor retardant barrier and also as temporary waterproofing during the construction period (in the very unlikely event that rain occurs).

Depending on how the air conditioning is balanced (positive or negative pressure), a full review of the vapor permeability of the selected material is required.

and dead and live loads at say,

$$\frac{\text{SPAN}}{300}$$

### 2. Secondary Z Spacers

Secondary Z spacers are at 600-mm (2-ft.) centers and are 100 mm (4 in.) deep. (Manufactured from 1.60-mm galvanized

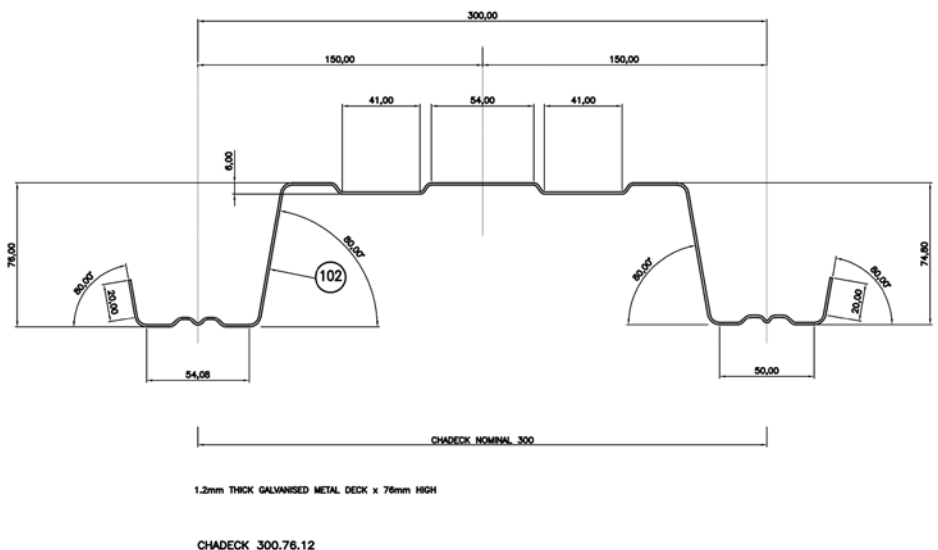


Figure 13 – Profiled metal roof sheet.

## Consulting, Testing and Inspection Services

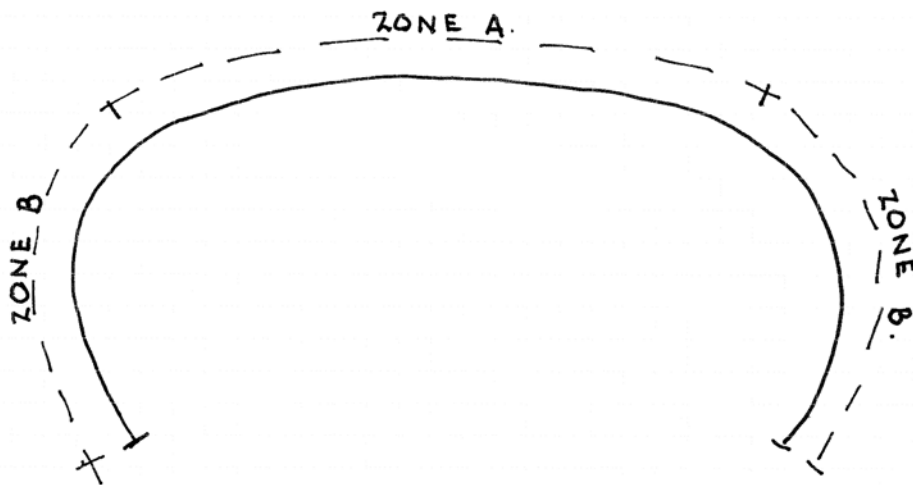
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Notes: Australian Standard AS1170.2:2002 Wind Actions

- For outer cladding, AS1170.2 does not allow a reduction based on pressure equalization; all external components are designed for full pressure.
- Panel deflection is normally considered at  $\frac{\text{SPAN}}{200}$  for maximum live-load condition.

Figure 14.

### 6. Metal Profiled Roofing

The main waterproofing layer is a profiled metal roof sheet (precoated galvanized steel), 0.8 mm thick (22 gauge) with 65-mm-high (2.5 in.) ribs at 400-mm (16-in.) centers. This is secured with extruded aluminum clips, which are secured to the Z sections as mentioned under the Secondary Z Spacer section (Figure 12). The roof sheet-

ing is able to slide over these clips when thermal or building movement occurs.

### 7. Cladding Support Framework

An extruded aluminum frame was then constructed and secured to the bulb of the profiled metal roof sheeting. Spacing and dimensions of these secondary components are shown in Figure 13, and the longitudinal support components are tapered in accordance with the roof geometry.

Metal separation is achieved with an EPDM gasket between the roof sheet and aluminum framework. This was required to prevent corrosion from dissimilar metal contact.



Figure 15 – Dubai International Air Terminal testing for water penetration using aircraft engine.

### 8. Cladding Tiles

The outer tiles are 6-mm “composite” aluminum panels with an external fluoro-carbon coating. These panels are reinforced to allow for foot traffic.

This component acts as a visual screen only and has open joints. There have been some interesting debates in relation to wind pressure on open screen construction (relating to what pressure should be considered).

In this instance, we opted to use the full external pressure that was rationalized from the wind tunnel testing. The design wind pressures considered are shown in Figure 14.

### Testing

The client required substantial testing be undertaken on the external envelope system, and three distinct areas of the project were “mocked-up” and incorporated approximately 1,000 m<sup>2</sup> (approximately 11,000 sq. ft.) of the finished cladding. The system passed all of the tests in Table 2. (See also Figure 15.)



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SUMMARY OF TESTS UNDERTAKEN			
Test	Specified Testing Sequence	Test Standard	Parameter
1.	Static Pressure Air Infiltration	ASTM E283	300 Pa
2.	Static Pressure Water Penetration	ASTM E331	+ 575 Pa for 15 minutes: Water spray rate 204 L/m <sup>2</sup> /hr
3.	Dynamic Water Penetration	AAMA 501.1.94	+ 575 Pa for 15 minutes. Water spray rate 204 L/m <sup>2</sup> /hr.
4.	Structural Loads Testing Serviceability	ASTM E330	Apply +450 Pa and hold for 10s Apply +900 Pa and hold for 10s Apply -450 Pa and hold for 10s Apply -900 Pa and hold for 10s

Table 2.

### Testing Standards

It is an interesting facet of international work that in countries that do not have their own standards (e.g., UAE), the standards normally adopted are those of the country of the primary consultants (architect/engineer). On some international work, it is not uncommon to be required to satisfy BS, DIN, AS, or in some instances, Japanese standards. In some projects (Bangkok International Airport), adherence to BS and ASTM was required.

Secondary testing was also undertaken by Factory Mutual Inc. in the U.S. (Figures 16 and 17), and FM had a joint role of both a testing authority and insurance advisor for the Dubai International Terminal.

All systems used on the structure

required FM approval relating to fire resistance, water penetration, and strength. The required wind uplift classification was to satisfy UL Class 90.

### Building Maintenance Units

The bulk of the roof area is accessible for cleaning from a building maintenance unit (BMU), which runs on stainless steel rails that are incorporated within the roof construction (see Figure 18).

The spacing of the rails is approximately 9 m (30 ft.), and the BMU spans between rails and has both on-board water and power outlets. As can be imagined, the rails also are required to be of an elliptical shape and with a heavy stainless steel box section (150 x 150 x 8 mm), so rolling the appropriate

elliptical shape required considerable innovation in developing a variable program for roller wheel adjustment to achieve the ellipse.

A considerable amount of engineering review was required in relation to the load-carrying capacity of the rail and, in particular, the welding capacity for the attachment of the rail stanchions to the base plate.

### Climatic Conditions

From a contracting/installation viewpoint, it is appreciated that there are substantial geographic areas within the United States where roof installation is not possible during certain times of the year because of severe snow and ice conditions.

In relation to the Dubai International Air Terminal, the major climatic problem was excessively high temperature during the midsummer period.

Maximum summer ambient temperatures can reach the range of 45-50° Celsius (113-122° Fahrenheit). Obviously, it is not possible to undertake external work in these temperatures, and a normal midsummer working day would commence at 4:00 AM and finish at noon.

On government-sponsored projects in Dubai, allowable working hours during sum-



Figure 16 – Fire testing by Factory Mutual, Rhode Island.



Figure 17 – Fire testing by Factory Mutual, Rhode Island.

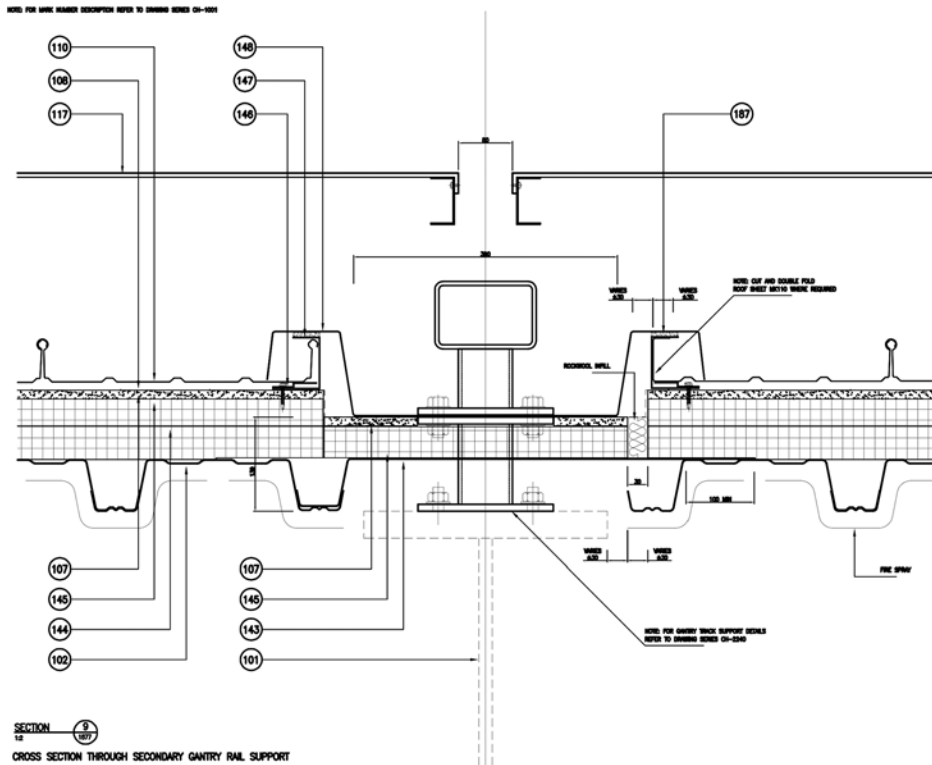


Figure 18 – Integration of BMU rail within the roof construction.

mer are gazetted [editor's note: announced in an official newspaper]. During this extreme temperature period, worker health considerations are foremost, and medication in the form of both tablets and fluids is available to all external workers, who are encouraged to ensure adherence to the required intake.

During the summer months and considering the previously stated ambient temperature, it is possible that exposed components may be 20-30°C hotter than the ambient condition.

Sandstorms are far more frequent than rain, and gutter and drainage systems have to be maintained to ensure that sand build-up does not restrict water flow during the rare occasions when rain occurs.

Rain is normally limited to a two-month period (during winter) and probably averages, for the year, between 50 and 100 mm (2 to 4 in.).

### Contractor's Expertise

In discussions with consultants and major general contractors, it appears that there are a limited number of contractors

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available to undertake projects of this magnitude (over \$50 million U.S.). Apart from the financial considerations (cash flow, working capital, performance bonds, suppliers' payment requirements), the management skills required to run such a project and manage a labor force that may exceed 500 applicators needs to be of an extremely proficient and professional level.

The precontract review of prospective contractors for projects of this magnitude should be extensive and consider all aspects of the operation, not only the technical ability. The review should include a detailed commercial and financial overview.

To ultimately achieve a successful project the size of the Dubai International Air Terminal requires the input of many disciplines, including

- Engineering (structural)
- Engineering (mechanical - condensation)
- Engineering (acoustics)
- Engineering (metallurgical review)
- Manufacturing
- Risk evaluation
- Financial and cash-flow planning
- Documentation preparation, including:
  - Work method statements
  - Quality assurance programs
  - Safety program
  - Product/material submission program
- Construction expertise
- Control of heavy plant and equipment
- Supervision
- Workmen's quality and training

Without acceptance of the importance of the above, major projects can develop very

quickly into a commercial and technical disaster, which certainly will limit achievement of the desired result.

### CONCLUSION

Both from a design and construction viewpoint, the Dubai International Air Terminal was one of the most difficult projects that the author has been involved with in his 50-plus years of experience in the roofing and cladding industry.


Fortunately, the overall final results are self-evident, with the completion of a very successful building.

In relation to the roof construction, this work has now received several awards, including the following:

- NRCA - Gold Circle Award for

Innovation

- NRCA - Safety Award
- Metal Roofing & Cladding Association of Australia
- Royal Australian Institute of Building (National Professional Excellence in Building Award)

With the ever-expanding requirements of architects and designers, the roof designer and consultant have to accept the challenge to develop systems and solutions that satisfy not only the physical requirements but provide an aesthetic conclusion that supports the architect's original intent. We believe that the Dubai International Air Terminal satisfies these requirements. 

Bill Mansell



Bill Mansell has been involved in the roofing and waterproofing/cladding industry in Australia since 1953, commencing as a cadet architectural draftsman. He currently is managing director of the Chadwick Technology Group, international consultants and contractors for complex roofing systems. Although undertaking recent work in both Southeast Asia and India, Chadwick Technology's main operation is currently in the Middle East, with an overall staff in excess of 800 management, supervisory, and installation personnel. Chadwick's innovation has been awarded with seven Gold Circle Innovation Awards from the NRCA, and major works have also been recognized by the Institution of Engineers Australia, Australian Institute of Building, and the Metal Roofing and Cladding Association of New South Wales. Bill Mansell has specialized in the design development of composite systems incorporating unusual materials (e.g., titanium external cladding) and complex geometry (e.g., the torus profile used on the Singapore Expo Railway Station). He has been involved in considerable structural and acoustic testing of composite systems and has been involved in original research in relation to rain noise on metal roofing. His contributions to the construction and roofing industry were recognized with an honorary doctorate from Sydney University in May 2007. He is a member of RCI, a Fellow of the Australian Institute of Building, a Fellow of the Australian Institute of Management, and an Affiliate of the Australian Acoustical Society.

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