# THE NATIONAL ARCHIVES BUILDING ROOF IN GATINEAU, QUEBEC, CANADA

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The government of Canada had the need for a new structure for long-term storage of documents. Planning for the structure was based on a life span of approximately 500 years; therefore, a structural framing system made of 304 stainless steel was specified. In order to protect those documents against water leakage in the long term, a redundantly sealed roof system was desired that would not need any significant maintenance for 50 years. To meet maintenance requirements, exterior panels had to be removable with minimal damage to the panel or adjacent panels. Thermal requirements dictated a panel system that could respond to a broad temperature range without elongating holes around fastener penetrations. To meet architectural requirements, a roof system was needed that could be curved to a 200-meter (656-foot) radius while allowing spans between purlins of 4.2 meters (13.8 feet). As Gatineau, Quebec, is in a seismic zone, the roof system was required to stabilize the structure against earthquake and wind forces. In addition, the roof had to meet budgetary restraints.

The selected roof system consisted of a steel deck, a cementitious board, a double membrane, insulation, topped with outside steel roofing panels. Extensive testing on various aspects of roof performance were conducted. The tests were typically either standard ASTM tests with requirements exceeding the norm or nonstandard set-ups specifically defined for this project.

Construction of the roof system was started in early 1995 and completed in February 1996.

## KEYWORDS

Air leakage, bituminous membrane, cementitious board, curved roof, insulation, National Archives, ponding, roof, roofing panels, roof system, steel, steel deck, water leakage.

## DESIGN REQUIREMENTS

The owner's representatives specified a number of design criteria that were to be considered for the roof system:

| | |
|---|---|
| Live load | 2.3 kPa (48 psf) |
| Dead load | 0.8 kPa (17psf) |
| Wind uplift | 2.0 kPa (42 psf) at corners |
| Diaphragm shear | 17.6 kN/m (1206 lbf/ft) |
| Roof size | 100 m x 200 m (280 ft. x 656 ft.) |
| Roof radius | 200 m(656 ft.) |
| Purlin spacing | 4200 mm (165 in.) |
| Purlin material | 304 stainless · |
| Ambient temperature range | -20°C to 28°C (-4°F to 82°F) |
| Metal skin thermal movement | 35 mm (1.4 in.) |
| Thermal value | 17 ft²·h·°F/Btu (RSI 3.0 (m² °C/W)) |
| Air leakage through retarder | 0.1 l/s/m² (0.15 gallon/ft²·min.) |

Testing requirements included the following:

Air leakage test of roof assembly using modified ASTM E 283.

Water leakage test based on ASTM E 331.

Water ponding test of exterior metal roofing panels.

Strength test of clip system for exterior metal panels.

Corrosion evaluation of aluminum-zinc-alloy-coated steel ("Galvalume") in contact with cementitious board.

Diaphragm capacity.

Testing and evaluation of weld coupons.

## DESIGN PROCESS

In order to meet the broad array of requirements described previously, a composite roof system was chosen. The steel components offered lightness, strength, and economy. The dual membrane provided long-term security for watertightness. Special purpose hold down clips tied the exterior metal skin to the structure while allowing thermal movement. Impregnated polyurethane foam tape sealed the laps of the exterior panels while allowing future removability of individual panels. Let us review the components in more detail. The numbers below are shown in the details in Figure 1.

1. A 76-mm (3-inch) deep steel deck with ribs 152 mm (6 inches) on center and a core thickness of 1.52 mm (0.06 inches) was used to provide diaphragm and gravity strength between purlins. Field curving of the deck was mathematically checked and found to be workable. Please refer to Appendix 3 for calculations. The steel was coated with an aluminum zinc alloy ("Galvalume"). The deck was attached to the stainless purlins with 19-mm (¾-inch) diameter puddle welds in each low rib. E309L-16 electrodes, 4 mm (0.16 inch) in diameter were used to make the connection, using procedures approved by the Canadian Welding Bureau.

2. A cementitious board was used to provide a continuous flat surface for the membranes above and to distribute loading on the steel deck below. In addition, the board acted as a thermal break at clip locations. The boards were 6 mm (¼ inch) thick and measured 1219 mm x 1219 mm (4 feet x 4 feet). Tests were conducted to ensure that there

were no detrimental effects between the aluminum zinc alloy coated steel and the cementitious board.

3. A two-ply bituminous membrane was placed over the cementitious board to act as the main air/vapor/water barrier for the roof system. In this position, it was protected from major thermal variations and weathering. The system was also designed to drain any moisture in the cavity to openings at the roof perimeter. To guard against moisture penetration in areas where fasteners penetrated the membranes (i.e., at clip locations), additional membrane patches were positioned to cover the clip base plates.

4. The rigid mineral wool insulation had two purposes. It provided the main thermal barrier for the roof system. Total insulation thickness was 102 mm (4 inches). Thermal value provided by the insulation was RSI 3.0 $m^2$ $°C/W$ (17 $ft^2·h·°F/Btu$). A dew point calculation is shown in Appendix 2.

As a second requirement, the rigid insulation acted as a load transfer element for the exterior metal skin. In other words, gravity loads applied to the exterior skin and normal to the plane of the roof were transferred to the interior steel roof deck via the insulation. To ensure the insulation's suitability for this second requirement, several tests were carried out:

■ Compressive strength test based on ASTM C 165. Requirement was for 13.4 kPa (280 psf) at 10 percent deformation.

■ Loading test of 14.4 kPa(300 psf ) repeated for 100 cycles. Maximum permanent deformation was not to exceed 8 percent.

■ As a check for longer term resiliency, the insulation was compressed 20 percent and held in position for 8 weeks. After the load was removed, recovery was to be within 3 percent of its original height.

5. The function of the clips was to hold down the exterior metal skin against wind uplift. At the same time, it was desired to minimize the potential for water entry at clip locations. Clips were positioned over each purlin (@ 4200 mm c/c [13.8 ft c/c]) and under each high rib (@ 300 mm c/c [1 ft c/c]). To minimize water entry through fastener holes, the panel was fastened to the clip through the top flange of the profile. To minimize any elongation of the fastener holes due to thermal movement, the clips were designed as a two-component system where the two could move relative to each other in the plane of the roof and in the direction of the exterior metal skin ribs.

6. The exterior metal skin was the architectural element and the first barrier against water entry through the roof of the building. This skin was chosen to be a 100-mm- (4-inch-) deep profile with a core thickness of 1.22 mm (0.05 inches) with ribs 300 mm (1 foot) on center. This profile was sufficiently strong to span the 4200 mm (13.8 feet) between the purlins. As well, the deep ribs allowed the fasteners and side lap to be placed well above normal water drainage paths.

The finish of the exterior skin was an aluminum zinc alloy ("Galvalume"). This was chosen to give a similar finish to the exposed stainless structural steel but with significantly greater economy than a stainless roof skin. To

cover eventual replacement costs for this metal skin, a fund was set aside. Longevity of the metal roof skin is expected to be about 50 years.

Screw down cladding technology was used instead of a field seamed exterior metal skin. This allowed for easier individual panel replacement and easier roof skin replacement without damage to the components underneath.

Complete removal and replacement of the exterior metal skin on this roof has been estimated at 18 working days. This estimate was based on field installation of the original roof.

7. The owner's representatives required that the individual panels be removable with minimal damage to the panel or adjacent panels. The normal means of sealing between adjacent panels is to use caulking that, while very effective, results in high adhesion between adjacent panels. Thus, individual panel removal can easily result in damage.

For this project, the caulking was replaced with a permanently elastic ultra high density polyurethane foam impregnated with neoprene and acrylic-polymer modified water base asphalt. This foam is supplied as a compressed tape that resists water penetration. At the same time, it has only a fraction of the adherence of cured caulking. Use of this tape allowed panel separation without destroying the individual panels.

## TEST PROGRAM

A variety of testing was conducted in order to confirm the quality of the design to the owner's representatives.

### Air Leakage Test

Testing was based on a modified ASTM E 283 using a one square meter test area.[1] Six samples were constructed. Each sample represented different extreme combinations of membrane laps and clips. Acceptable criteria was 0.1 l/s/$m^2$ (0.15 gallons/$ft^2$·min.)at a pressure difference of 75 Pa (1.57 psf). Actual leakage recorded was a maximum of 0.0012 l/s/$m^2$ (0.0018 gallons/$ft^2$·min.)

It may be noted that the test specimens used the maximum fastener penetrations through the membrane. As most of the roof had fewer penetrations per unit area, this test could be considered conservative for the overall roof.

### Water Leakage Test

Testing was based on ASTM E 331 using a sample of 2438 mm x 2438 mm (8 feet x 8 feet) containing the same number of penetrations per unit area as the critical areas in the field.[1] The sample was mounted vertically and subjected to a pressure difference of 285 Pa (6 psf) for a period of 60 minutes while under a spray rate of 3.4 l/$m^2$ (0.28 gallons/$ft^2$). No water leakage resulted.

### Water Ponding Test

A nonstandard water leakage test was required by the owner's representatives to demonstrate the potential watertightness of the exterior metal skin. An assembly was constructed measuring 1920 mm x 5419 mm (6.3 feet x 17.8 feet).[2] This assembly consisted of exterior metal roofing panels complete with end and side laps. A perimeter flashing was sealed against the roofing panels in order to contain the ponding water.

The test requirement was for the entire assembly of metal roof panels to be flooded with water to a total depth of approximately 125 mm (5 inches) from the bottom of the panel. Water was to sit on the panels for a period of 30-minutes. No leakage was permitted. After the water was drained, one metal panel was to be removed and reinstalled. The flooding test would then be repeated for another 30-minute period with a requirement for no leakage.

Testing was carried out to the satisfaction of all involved parties.

### Strength Test of Clip System

Structural testing was carried out to demonstrate the uplift capacity of the hold down clips for the exterior metal roofing panels.[3] Maximum design uplift for the clip was 2.4 kN (540 lbf). Maximum applied load during testing was 17.8 kN (4002 lbf). This maximum load was not controlled by clip failure but by safe test jig capacity.

### Corrosion Evaluation of Aluminum-Zinc-Alloy-Coated Steel in Contact with Cementitious Board

Based on testing that was done,[4] it appears that the aluminum zinc alloy coated steel ("Galvalume") in contact with the cement board will not experience any significant corrosion.

### Diaphragm Capacity

Diaphragm capacity for steel roof deck depends on a number of factors including deck configuration, distance between deck supports, sheet length, deck material thickness and strength, and fastener type and pattern. To confirm that an appropriate diaphragm capacity was available, laboratory testing was performed.[4] A rectangular assembly was built 2.7 m (8.9 feet) wide x 4.2 m (13.8 feet) long, anchored at two corners by pin and roller supports. A racking load was applied at a third corner. Resistance to racking was provided by the installed deck. See Figure 2 for the general arrangement.

Maximum jig capacity of 222 kN (49,910 lbf) was applied to the diaphragm. This resulted in a maximum ultimate shear of 53.0 kN/m (3632 lbf/ft).

## CONCLUSIONS

The custom design of the composite roof system for the National Archives Building presented many design criteria that needed to be satisfied. This was achieved by drawing on many years of experience in roof design. A large number of laboratory tests were conducted to show that the roof met the stringent requirements. As of this writing, the constructed roof has appeared to meet all expectations.

## REFERENCES

1. Ortech Report 95-J53-B0199 (Final), "Testing of VicWest Steel Roof Deck for National Archives of Canada," June 1, 1995.
2. Ortech Report 95-J53-B0295, "Testing of VicWest Steel Roof Deck for National Archives of Canada," August 25, 1995.
3. Ortech Report 95-J53-B0088 (Final), "Testing of Metal Clips for VicWest Steel," March 13, 1995.
4. American Iron and Steel Institute, "Design of Light Gauge Steel Diaphragms," 1969.
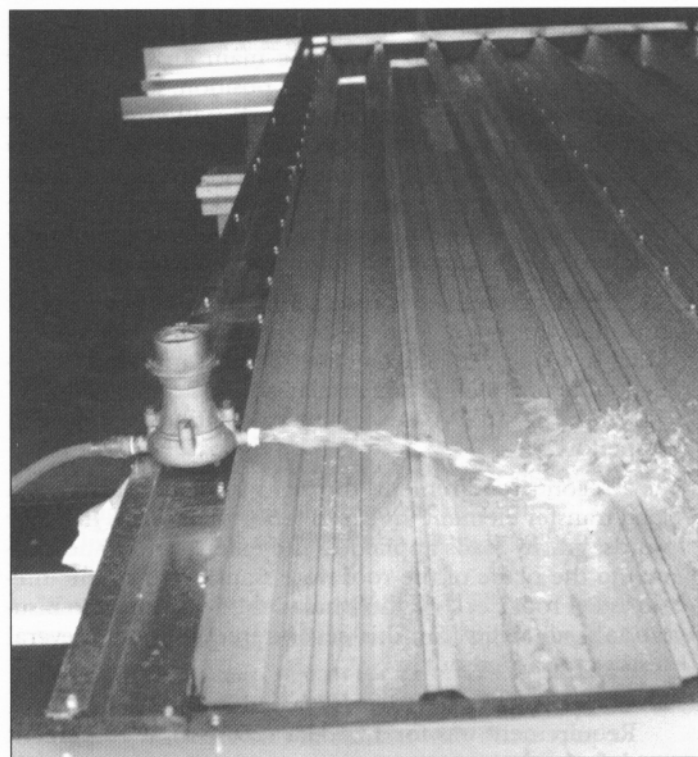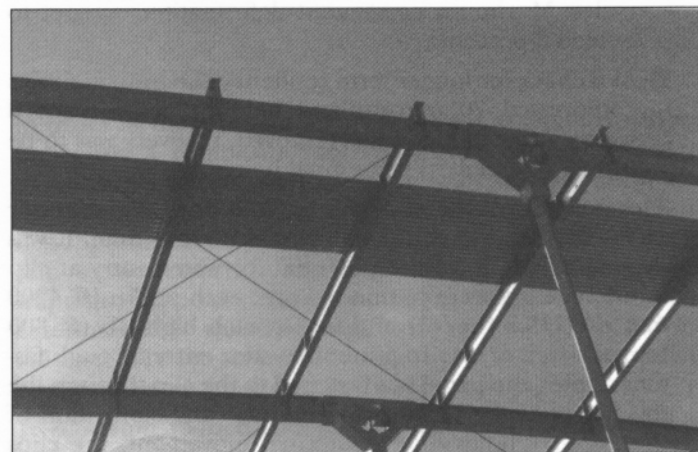
Appendix 1



**Photo 1.** *Waterponding test.*



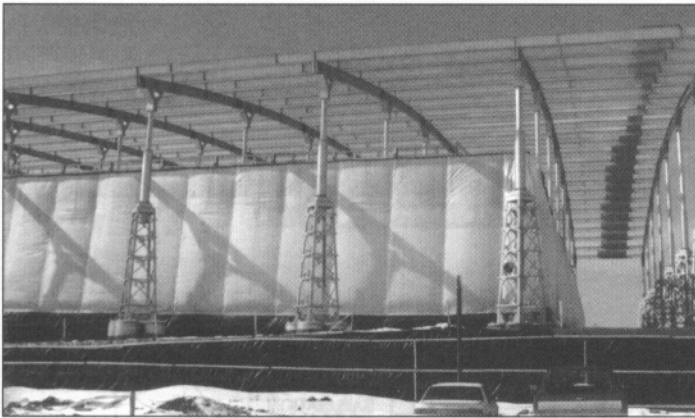**Photo 2.** *Steel roof deck, 1.52 mm (0.06 inch) thick, on stainless structural framing.*
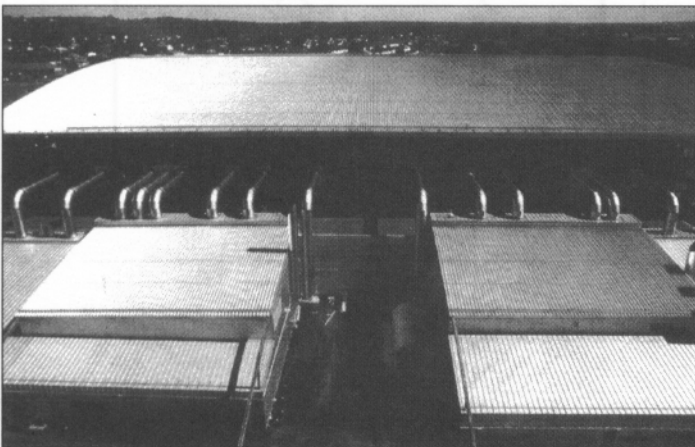
**Photo 3.** *Structural framing of curved roof*



**Photo 4.** *Finished archive building.*

**APPENDIX 2**
**DEW POINT CALCULATION**

**Check Condensation at Screws or Interior Metal Deck**

**(a)    Items**

① #14AB sheet metal screw

② Nylon washer 1.6 mm thick (Thermal break at screw)

③ 1.6 mm thick butyl tape

④ 2 layers modified bitumen

⑤ 6 mm cementitious board

⑥ 1.52 mm interior roof deck

⑦ 3.4 mm ⊥ clip

**(b)    Thermal Condition**
(In Building and Outside)
National Building Code 1990:
    - (-28°C) Winter
    - (+30°C) Summer

Worst Conditions:
Inside Temp.  +20°C
Outside Temp. -28°C
Inside Humidity 40%
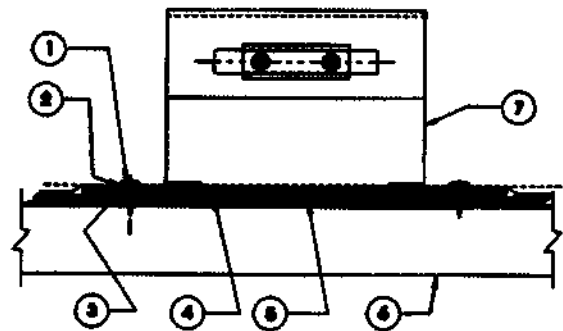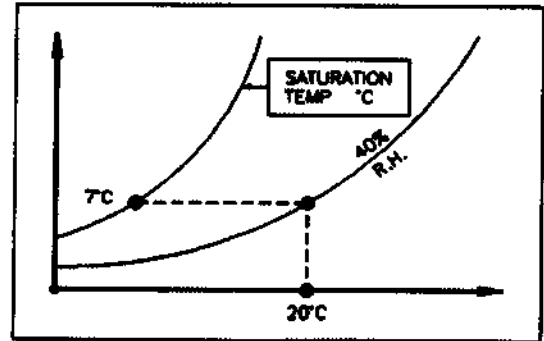
**❋    From Psychrometric Charts**
(See ASHRAE Handbook)
- (6.14) (Fig. 1)

∴ Dew Point is @ 7°C
Temp. at Screw Head
is 14°C > 7°C ∴ O.K.

**❋    Psychrometric Chart**





"T" Clip Layout

**APPENDIX 3**
**INTERIOR STEEL DECK CURVATURE**

**Determine Stress in Deck due to Curvature**

Span = 4200 mm

$$\theta = SIN^{-1} \left| \frac{L}{R} \right|$$
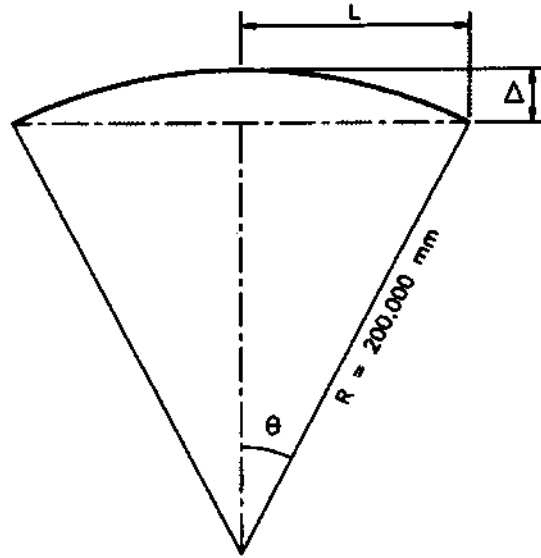
$$= \frac{4200}{200000} = 1.203°$$

$$\Delta = R(1 - COS\,\theta)$$
$$= 44.1 \text{ mm}$$
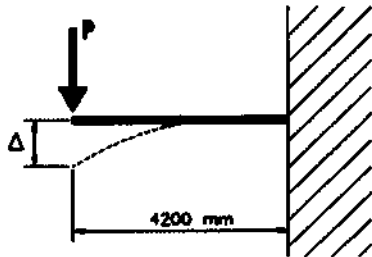
$$\Delta = \frac{P\,L^3}{3\,E\,I} \quad or \quad P = \frac{3\,E\,I\,\Delta}{L^3}$$

**For  76 mm deep deck, 1.52 mm thick**

$$S_x = 60.13 \times 10^3 \text{ mm}^3/\text{m}$$
$$I_x = 2609.9 \times 10^3 \text{ mm}^4/\text{m}$$

$$\therefore P = \frac{(3)(203000)(2609.9 \times 10^3)(44.1)}{4200^3}$$

$$P = 946 \text{ N/m}$$

$$f = \frac{M}{S} = \frac{(946)(4200)}{60.13 \times 10^3} = 66.1 \; MPa$$

66.1 Mpa< Fy = 230 Mpa∴OK

Deck can be curved without damage in field.

APPENDIX 3 (continued)

**Check for Bending Stress:**
(Assume Flat) Limit State Design

D.L. = 0.5 kPa x 1.25 = 0.63 kPa
L.L. = 2.3 kPa x 1.50 = 3.45 kPa

———

T.L. = 4.08 kPa

Deck x 1.52 mm thick

$$\left[ f_{BEND} = \frac{W L^2}{8 S} \right]$$ {Two Span Condition Only}

Depth of Deck = 76 mm
Actual L = 4200 - 200 + 76
∴ L = 4076 mm (See Detail A)

$$\therefore f_{BEND} = \frac{(4.08)(4076^2)}{(8)(60.13 \times 10^3)}$$
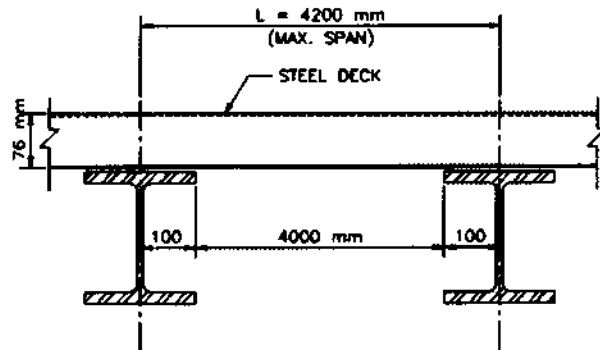
$$\therefore f_{BEND} = 140.9 \; MPa$$

Max. $f$
$_{BEND}$ due to Curving of Roof Sheet
in field is:    66.1 MPa

∴ **Combined Stress:**

$$f_{CURVE} + f_{BEND} = 66.1 + 140.9$$
$$= 207.0 \; MPa$$

$$f_{max \, allow} = \phi Fy = (0.9)(230)$$
$$= \underline{207.0 \; MPa}$$

L = 4200 mm
(MAX. SPAN)
STEEL DECK
76 mm
100    4000 mm    100

**Detail - A**

207.0 MPa ≈ 207.0 MPa
∴ O.K.

**Check Allowance Load for Deflection**
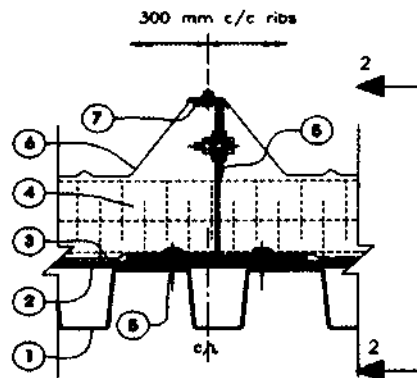L/240 (Live Load only) (Two Span)

$$W_L = \frac{185 \; K E I}{L^3}$$

$$W_L = \frac{(185)(.0042)(203000)(2609 \times 10^3)}{4200^3}$$

$W_L$ = 5.55 kPa > 3.45 kPa ∴ OK

**Check Allowable Load for L/360**
**Deflection** (Two Span)

240/360 x 5.55 = 3.7 kPa

3.7 kPa > 3.45 kPa ∴ OK

300 mm c/c ribs

**DETAIL - 1**
**CROSS SECTION**
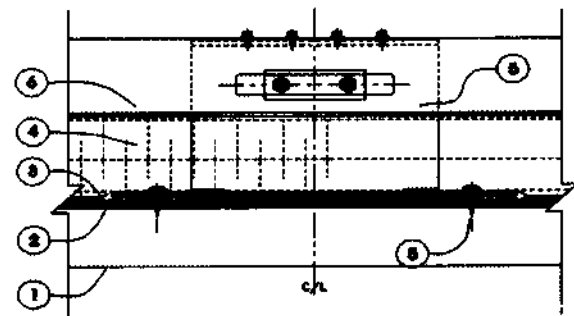
**DETAIL - 2**
**CLIP SIDE VIEW**
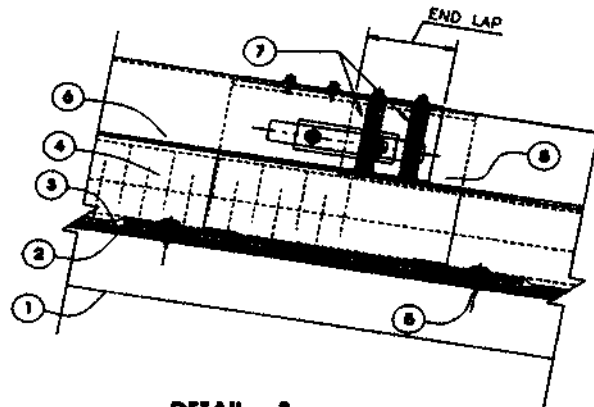
END LAP

**DETAIL - 3**
**TYPICAL END LAP - OUTER METAL ROOF**

SPECIAL ANCHORING
CLIP AT EAVES

WEEP HOLES

INNER ROOF
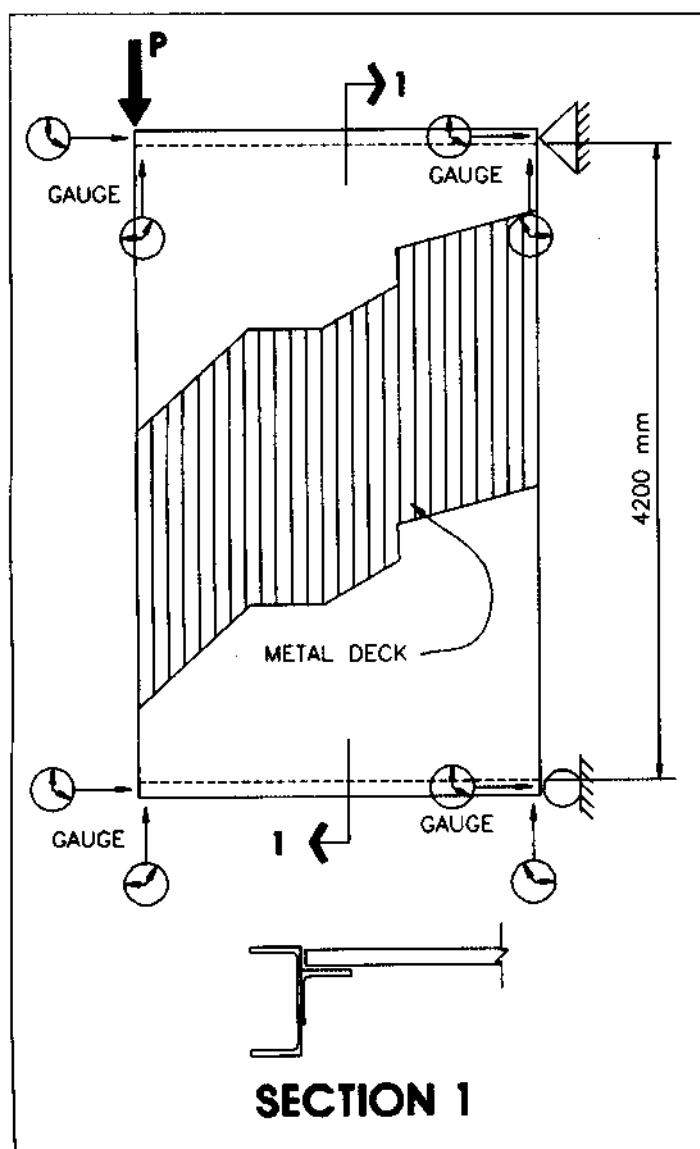DRAINAGE
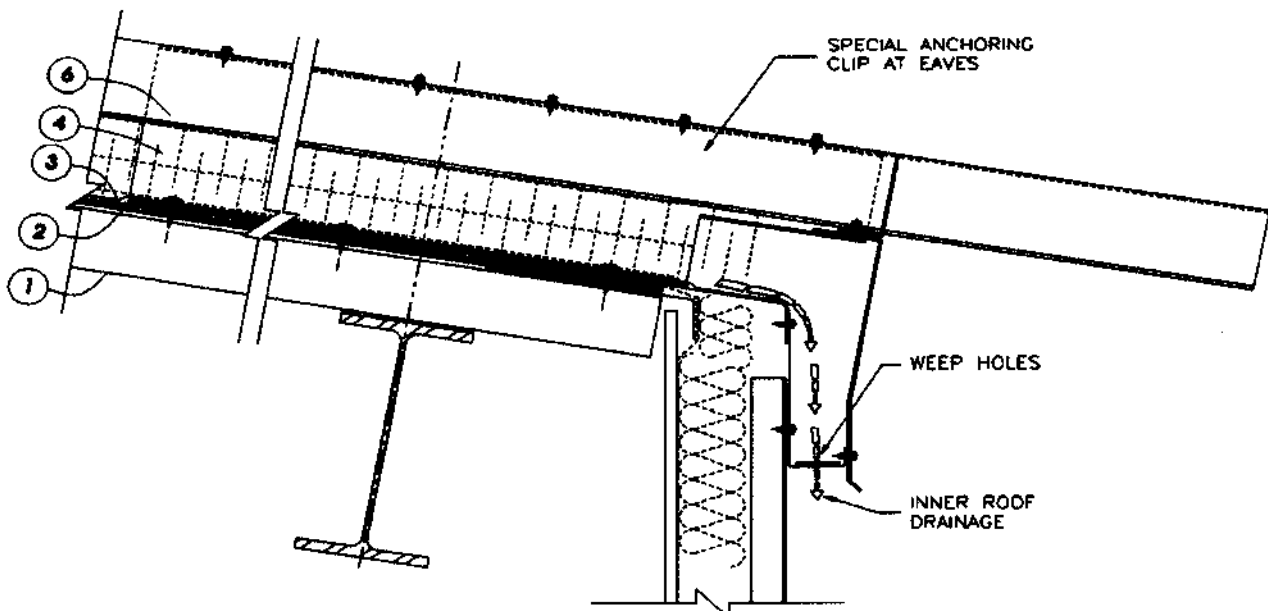
**DETAIL - 4**
**EAVE**

*Figure 1. Typical roof details.*

*Figure 2. Test jig plan showing location of deflection gauges.*